Assessment of the Albemarle Sound-Roanoke River Striped Bass (*Morone saxatilis*) in North Carolina, 1991–2017

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EXECUTIVE SUMMARY

The North Carolina Fisheries Reform Act requires that fishery management plans be developed for the state's commercially and recreationally important species to achieve sustainable levels of harvest. Stock assessments are the primary tools used by managers to assist in determining the status of stocks and developing appropriate management measures to ensure the long-term viability of stocks.

The Albemarle Sound-Roanoke River (A-R) striped bass stock is managed jointly by the North Carolina Division of Marine Fisheries (NCDMF), the North Carolina Wildlife Resources Commission (NCWRC), and the South Atlantic Fisheries Coordination Office (SAFCO) of the U.S. Fish and Wildlife Service (USFWS) under guidelines established in the Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan (FMP) for Atlantic Striped Bass and the North Carolina Estuarine Striped Bass FMP. The Albemarle Sound Management Area (ASMA) includes Albemarle Sound and all of its joint and inland water tributaries, (except for the Roanoke, Middle, Eastmost, and Cashie rivers), Currituck Sound, Roanoke and Croatan sounds and all of their joint and inland water tributaries, including Oregon Inlet, north of a line from Roanoke Marshes Point to the north point of Eagle Nest Bay. The Roanoke River Management Area (RRMA) includes the Roanoke River and its joint and inland water tributaries, including Middle, Eastmost, and Cashie rivers, up to the Roanoke Rapids Lake Dam.

A forward-projecting statistical catch-at-age model was applied to data characterizing landings/harvest, discards, fisheries-independent indices, and biological data collected from the 1991 through 2017 time period. Both observed recruitment and model-predicted recruitment have been relatively low and declining in recent years. Fisheries-dependent and fisheries-independent data indicate a truncation of both length and age structure in recent years.

Reference point thresholds for the A-R striped bass stock were based on 35% spawner potential ratio (SPR). The estimated threshold for female spawning stock biomass (SSB; $SSB_{Threshold}$ or $SSB_{35\%}$) was 121 metric tons. Terminal year (2017) female SSB was 35.6 metric tons, which is less than the threshold value and suggests the stock is currently overfished ($SSB_{2017} < SSB_{Threshold}$). The female SSB target (SSB_{Target} or $SSB_{45\%}$) was 159 metric tons. The assessment model estimated a value of 0.18 for the threshold fishing mortality ($F_{Threshold}$ or $F_{35\%}$). The estimated value of fishing mortality in the terminal year (2017) of the model was 0.27, which is greater than the threshold value and suggests that overfishing is currently occurring in the stock ($F_{2017} > F_{Threshold}$). The fishing mortality target (F_{Target} or $F_{45\%}$) was estimated at a value of 0.13.

An independent, external peer review of this stock assessment approved the stock assessment for use in management for at least the next five years.

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1 INTRODUCTION

1.1 The Resource

The common and scientific names for the species are striped bass, *Morone saxatilis* (Artedi et al. 1792). In North Carolina it is also known as striper, rockfish, or rock. Striped bass naturally occur in fresh, brackish, and marine waters along the western Atlantic coast from Canada to Florida, and through the U.S. coast of the Gulf of Mexico. Striped bass are anadromous, conducting annual spawning migrations in the spring of each year up to the fall line in freshwater tributaries. In addition, after spawning portions of the stocks from the Albemarle Sound-Roanoke River, Chesapeake Bay, Delaware Bay, and the Hudson River migrate along the Atlantic coast north in the summer and south in the winter. The stocks from the Chesapeake Bay constitute the majority of this migrating population. Due to these facts, striped bass have been the focus of fisheries from North Carolina to New England for several centuries and have played an integral role in the development of numerous coastal communities (ASMFC 1998). Striped bass regulations in the United States date to colonial times; in 1639 the Massachusetts Bay colony passed a law that prohibited striped bass from being used as fertilizer to promote fishery commerce with Europe (Hutchinson, T. [1764] 1936; McFarland 1911).

1.2 Life History

1.2.1 Stock Definitions

There are two geographic management units and four striped bass stocks inhabiting the estuarine and inland waters of North Carolina. The northern management unit is comprised of two harvest management areas: the Albemarle Sound Management Area (ASMA) and the Roanoke River Management Area (RRMA; Figure 1.1). The striped bass stock in the two harvest management areas is referred to as the Albemarle-Roanoke (A-R) stock, and its spawning grounds are located in the Roanoke River in the vicinity of Weldon, NC. The ASMA includes the Albemarle Sound and all its tributaries, (except for the Roanoke, Middle, East-most, and Cashie rivers), Currituck, Roanoke and Croatan sounds and all their tributaries, including Oregon Inlet, north of a line from Roanoke Marshes Point across to the north point of Eagle Nest Bay in Dare county. The RRMA includes the Roanoke River and its tributaries, including Middle, East-most, and Cashie rivers, up to the Roanoke Rapids Lake Dam. Management of recreational and commercial striped bass regulations within the ASMA is the responsibility of the NCDMF. Within the RRMA, commercial regulations are the responsibility of the NCDMF while recreational regulations are the responsibility of the North Carolina Wildlife Resources Commission (NCWRC). The A-R stock is also included in the management unit of Amendment 6 to the Atlantic States Marine Fisheries Commission (ASMFC) Interstate Fishery Management Plan (FMP) for Atlantic Striped Bass (ASMFC 2003).

1.2.2 Movements & Migration

Numerous tagging studies have been conducted on striped bass in North Carolina and along the Atlantic Coast since the 1930s. Several older studies suggest the A-R stock is at least partially migratory, with primarily older adults participating in offshore migrations. Tag-recapture studies (Merriman 1941; Vladykov and Wallace 1952; Davis and Sykes 1960; Chapoton and Sykes 1961; Nichols and Cheek 1966; Holland and Yelverton 1973; Street et al. 1975; Hassler et al. 1981; Boreman and Lewis 1987; Benton, unpublished) indicated that a small amount of offshore migration occurs; however, these studies occurred when the stock was experiencing very high exploitation rates and the age structure was truncated. Most of the fish tagged during these early studies were young and male. Recent research on the A-R stock demonstrates that as A-R striped bass get older they migrate out of the ASMA into North Carolina's near shore ocean waters, and then as they continue to age they participate in summertime coastal migrations to northern areas including Chesapeake Bay, Delaware Bay, Hudson Bay, and coastal areas of New Jersey, New York, Rhode Island, and Massachusetts (Callihan et al. 2014). The probability of a six-year-old striped bass (average size 584 mm or 23 inches total length, TL) migrating out of the ASMA is 7.5%. This probability increases with age, and by age 11 (average size 940 mm or 37 inches TL) the probability of migrating outside North Carolina's waters is 72.5%. (Callihan et al. 2014). Callihan et al. (2014) also found that when the total A-R stock abundance is higher there is a greater likelihood that smaller striped bass utilize habitat in the Pungo, Tar-Pamlico, and Neuse rivers and northwestern Pamlico Sound.

1.2.3 Age & Size

Striped bass have been aged using scales for more than 70 years (Merriman 1941). Scales of striped bass collected in North Carolina show annulus formation taking place between late April through May in the Albemarle Sound and Roanoke River (Trent and Hassler 1968; Humphries and Kornegay 1985). Annuli form on scales of striped bass caught in Virginia between April and June during the spawning season (Grant 1974).

Age data have been a fundamental part of assessing A-R striped bass since the first A-R assessment (Gibson 1995). The oldest observed striped bass in the A-R stock to date (in 2017) was 23 years old from the 1994 year class. The fish was originally collected and tagged on the spawning grounds during the 2007 season by the NCWRC, aged to 13 years old and was then recaptured by an angler on June 10, 2017 near Sandy Hook, New Jersey. The fish was 40 inches long and weighed 35 pounds when originally tagged. Historically, Smith (1907) reported several striped bass captured in pound nets in Edenton in 1891 that weighed 125 pounds each. Worth (1904) reported the largest female striped bass taken at Weldon that year for strip spawning weighed 70 pounds. The oldest striped bass observed in the data used for this assessment was 17 years old.

1.2.4 Growth

As a relatively long-lived species, striped bass can attain a moderately large size. Females grow to a considerably larger size than males; striped bass over 30 pounds are almost exclusively female (Bigelow and Schroeder 1953; NCDMF and NCWRC, unpublished data).

Growth rates for the A-R stock are rapid during the first three years of life and then decrease to a slower rate as the fish reach sexual maturity (Olsen and Rulifson 1991). Growth occurs between April and October. Striped bass stop feeding for a brief period just before and during spawning but feeding continues during the upriver spawning migration and begins again soon after spawning (Trent and Hassler 1966). From November through March growth is negligible.

Available annual age data (scales) were fit with the von Bertalanffy age-length model to estimate growth parameters for both female and male striped bass. This model was weighted by the number of data points and applied to fractional ages. Unsexed age-0 fish were included in the fits for both the males and females. Estimated parameters of the age-length model are shown in Table 1.1. Fits to the available data performed well for both females (Figure 1.2) and males (Figure 1.3).

Parameters of the length-weight relationship were also estimated in this study. The relation of total length in centimeters to weight in kilograms was modeled for males and females separately. Parameter estimates of the length-weight model are shown in Table 1.2. Predicted weight at length performed well based on both the female (Figure 1.4) and male (Figure 1.5) striped bass data.

1.2.5 Reproduction

Striped bass spawn in freshwater or nearly freshwater portions of North Carolina’s coastal rivers from late March to June depending on water temperatures (Hill et al. 1989). Peak spawning activity occurs when water temperatures reach 16.7°–19.4°C (62.0°–67.0°F) on the Roanoke River (Rulifson 1990, 1991). Spawning behavior is characterized by brief peaks of surface activity when a mature female is surrounded by up to 50 males as eggs are broadcast into the surrounding water, and males release sperm, termed “rock fights” by locals (Worth 1904; Setzler et al. 1980). Spawning by a given female is probably completed within a few hours (Lewis and Bonner 1966).

1.2.5.1 Eggs

Mature eggs are 1.0–1.5 mm (0.039 to 0.059 inch) in diameter when spawned and remain viable for about one hour before fertilization (Stevens 1966). Fertilized eggs are spherical, non-adhesive, semi-buoyant, and nearly transparent. The incubation period at peak spawning temperatures ranges from 42 to 55 hours. At 20.0°C (68.0°F), fertilized eggs need to drift downstream with currents to hatch into larvae. If the egg sinks to the bottom, its chances of hatching are reduced because the sediments reduce oxygen exchange between the egg and the surrounding water. Hassler et al. (1981) found that eggs hatch in 38 hours. After hatching, larvae are carried by the current to the downstream nursery areas located in the western Albemarle Sound (see section 1.3.3; Hassler et al. 1981).

1.2.5.2 Larvae

Larval development is dependent upon water temperature and is usually regarded as having three stages: (1) yolk-sac larvae are 5–8 mm (0.20 to 0.31 inch) in total length (TL) and depend on yolk material as an energy source for 7 to 14 days; (2) fin-fold larvae (8–12 mm; 0.31–0.47 inch TL) having fully developed mouth parts and persist about 10 to 13 days; and (3) post fin-fold larvae attain lengths up to 30 mm (1.18 inches) TL in 20 to 30 days (Hill et al. 1989). Researchers of North Carolina stocks of striped bass (primarily the A-R stock) divide larval development into yolk-sac and post yolk-sac larvae (Hill et al. 1989; Rulifson 1990). Growth occurs generally within the same rates described above depending upon temperature. At temperatures ≥ 20°C (68°F) larvae develop into juveniles in approximately 42 days (Hassler et al. 1981).

1.2.5.3 Juveniles

Most striped bass enter the juvenile stage at about 30 mm (1.18 inches) TL; the fins are then fully formed, and the external morphology of the young is like the adults. Juveniles are often found in schools and associate with clean sandy bottoms (Hill et al. 1989). Juveniles spend the first year of life in western Albemarle Sound and lower Chowan River nursery areas (Hassler et al. 1981). There is evidence of density-dependent habitat utilization; when large year classes are produced juveniles are collected in early June as far away from the western Albemarle Sound as the lower Alligator River (63 water miles) and Stumpy Point, Pamlico Sound (75 water miles; NCDMF, unpublished data).

1.2.5.4 Maturation & Fecundity

Early research conducted on the A-R stock indicated that females began reaching sexual maturity in approximately three years, at sizes of about 45.7 cm (18 inches) TL (Trent and Hassler 1968; Harris and Burns 1983; Harris et al. 1984). In the most recent maturation study conducted on a recovered stock with expanded age structure, Boyd (2011) found that 29% of A-R females reached sexual maturity by age 3, while 97% were mature by age 4, and 100% were mature at age 5 (Table 1.3). In general, there is a strong positive correlation between the length, weight, and age of a female striped bass and the number of eggs produced. Boyd (2011) estimated fecundity ranging from 176,873 eggs for an age-3 fish to 3,163,130 eggs for an age-16 fish.

1.2.6 Mortality

1.2.6.1 Natural Mortality

Striped bass are a long-lived species with a maximum age of at least 31 years (Atlantic coastal stock) based on otoliths (Secor 2000), suggesting overall natural mortality is relatively low. Previous assessments have assumed a constant natural mortality (M) of 0.15 across all ages, consistent with Hoenig's (1983) regression on maximum age (ASMFC 2009; NCDMF 2010).

Harris and Hightower (2017) estimated annual total instantaneous natural mortality for striped bass using both an integrated model and a multi-state only model based on VEMCO acoustic, Passive Integrated Transponder, and traditional external anchor tagging data. The integrated model produced a study-wide natural mortality rate of 0.70 while the multi-state only model produced an estimate of 0.74 (average of 0.72 over the two methods). The estimates apply to striped bass ranging in length from 45.8 cm to 89.9 cm (18 inches to 35 inches, approximately 3 to 9 years old).

There are a number of methods available to estimate natural mortality based on life history characteristics. These include approaches based on parameters of the von Bertalanffy age-length relationship (Alverson and Carney 1975; Ralston 1987; Jensen 1996; Cubillos 2003) as well as approaches based on maximum age (Alverson and Carney 1975; Hoenig 1983; Hewitt and Hoenig 2005; Then et al. 2015). Several of these methods were applied to A-R striped bass to produce estimates of age-constant natural mortality for females and males. Values for the life history parameters required by some of these approaches were those estimated in this stock assessment (see section 1.2.4). For approaches that depend on maximum age, a maximum age of 17 was assumed for females and a maximum age of 15 was assumed for males. These maximum ages are based on the maximum ages observed in the available data within the ASMA and RRMA over the assessment time series (1991–2017). Life history-based empirical estimates of age-constant natural mortality ranged from 0.099 to 0.37 for females and from 0.090 to 0.44 for males (Table 1.4).

Natural mortality of long-lived fish species is commonly considered to decline with age, as larger fish escape predation. Several approaches are available to derive estimates of age-varying natural mortality (e.g., Lorenzen 1996, 2005). Here, the Lorenzen (1996) approach was used to produce estimates of M at age. As expected, estimates of M decrease with increasing age (Table 1.5; Figure 1.6).

1.2.6.2 Discard Mortality

Discards from the commercial gill-net fishery are broken into two categories, live and dead discards as recorded by the observer. Live discards are multiplied by a discard mortality rate, which for gill-net fisheries is estimated at 43% (ASMFC 2007).

Nelson (1998) estimated short-term mortality for striped bass caught and released by recreational anglers in the Roanoke River, North Carolina as 6.4%. Nelson found that water temperature and hooking location were important factors affecting catch-and-release mortality, consistent with previous studies (Harrell 1988; Diodati 1991).

1.2.7 Food & Feeding Habits

Several food habit studies have been conducted for juvenile and adult striped bass since 1955 in the Roanoke River and Albemarle Sound. Studies of juvenile striped bass diets in Albemarle Sound found zooplankton and mysid shrimp as primary prey items in the summer, with small fish (most likely bay anchovies) entering the diet later in the season (Rulifson and Bass 1991; Cooper et al. 1998). Adults feed extensively on blueback herring and alewives in the river during the spawning migration (Trent and Hassler 1968). Manooch (1973) conducted a seasonal food habit study in Albemarle Sound and found primarily fish in the Clupeidae (Atlantic menhaden, blueback herring, alewife, and gizzard shad) and Engraulidae (anchovies) families dominated the diet in the summer and fall. Atlantic menhaden (54%) was the most frequently eaten species and comprised a relatively large percentage of the volume (50%). In the winter and spring months, invertebrates occurred more frequently in the diet (primarily amphipods during the winter and blue crabs in the spring). Similarly, Rudershausen et al. (2005) found a diverse array of fish in the diets of age-1 striped bass whereas the diets of age-2 and age-3+ striped bass were primarily comprised of menhaden in 2002 and 2003 in the Albemarle Sound. Tuomikoski et al. (2008) investigated age-1 striped bass diets in Albemarle Sound where American shad comprised most of their diet in 2002, but yellow perch dominated the diet in 2003. The 2003 year class for yellow perch was one of the highest on record in NCDMF sampling programs, so the high occurrence of yellow perch in striped bass stomachs may not be typical (NCDMF 2010). However, it also supports other research that striped bass exhibit an opportunistic feeding behavior (Rulifson et al. 1982).

From the fall of 1995 through the spring of 2001, stomach contents from 1,796 striped bass collected from the NCDMF Striped Bass Independent Gill-Net Survey were analyzed. Unidentifiable fish parts were the dominant stomach content from western Albemarle Sound samples (35.9%), followed by river herring (33.2%) and Atlantic menhaden (16.5%). The dominance of river herring during the spawning migration supports results reported by Trent and Hassler (1968) and Manooch (1973). Blue crab accounted for 0.2% of the total stomach contents from the western sound. In eastern Albemarle Sound samples, unidentifiable fish parts accounted for 34.0%, followed by Atlantic menhaden (31.5%), Atlantic croaker (12.1%), anchovy spp. (11.1%) and spot (6.5%). Blue crab comprised 2.1% of the stomach contents from the eastern sound.

From the fall of 2001 through the spring 2010, the NCDMF analyzed 4,448 striped bass stomachs having food contents. In western Albemarle Sound samples unidentifiable fish parts accounted for 61.2% of stomach contents, followed by Atlantic menhaden (23.1%), anchovy spp. (4.0%), invertebrates (3.0%), Atlantic croaker (2.5%), and river herring (2.0%). Blue crab accounted for less than 1.0% of stomach contents in western sound samples. It is interesting to note the decline in the prevalence of river herring in striped bass diets in the western sound since 2001. In eastern

Albemarle Sound samples, unidentifiable fish parts accounted for 41.2% of the stomach contents, followed by Atlantic menhaden (40.8%), anchovy spp. (6.4%), spot (6.4%), and Atlantic croaker (2.9%). Blue crab accounted for less than 1.0% of stomach contents in the eastern sound samples as well.

From 2011 through 2017, the NCDMF analyzed 1,918 striped bass stomachs having contents. In western Albemarle Sound samples, unidentifiable fish parts accounted for 35.9% of stomach contents, followed by Atlantic menhaden (12.6%), Atlantic croaker (10.0%), and Clupeidae species (1.8%). Blue crab accounted for less than 1.0% of stomach contents in western sound samples. In eastern Albemarle Sound samples, unidentifiable fish parts accounted for 19.3% of the stomach contents, followed by Atlantic menhaden (2.4%) and invertebrates (1.7%). Blue crab accounted for less than 1.0% of stomach contents in the eastern sound samples.

1.3 Habitat

1.3.1 Overview

Habitat loss has contributed to the decline in anadromous fish stocks throughout the world (Limburg and Waldman 2009). Striped bass use a variety of habitats as described in the life history section with variations in habitat preference due to location, season, and ontogenetic stage. Although primarily estuarine, striped bass use habitats throughout estuaries and the coastal ocean. Striped bass are found in most habitats identified by the North Carolina Coastal Habitat Protection Plan (CHPP) including: water column, wetlands, submerged aquatic vegetation (SAV), soft bottom, hard bottom, and shell bottom (NCDEQ 2016). Each habitat is part of a larger habitat mosaic, which plays a vital role in the overall productivity and health of the coastal ecosystem. Although striped bass are found in all of these habitats, usage varies by habitat. Additionally, these habitats provide the appropriate physicochemical and biological conditions necessary to maintain and enhance the striped bass population. Therefore, the protection of each habitat type is critical to the sustainability of the striped bass stock.

1.3.2 Spawning Habitat

The main spawning habitat for A-R striped bass is in the Roanoke River in the vicinity of Weldon, NC, around river mile (RM) 130. This is the location of the first set of rapids at the fall line transition between the Coastal Plain and the Piedmont. Historic accounts indicate major spawning activity centered at Weldon (Worth 1904), but striped bass were known to migrate up the mainstem Roanoke River to Clarksville, VA (RM 200; Moseley et al. 1877) and possibly as far as Leesville, VA (RM 290; NMFS and USFWS 2016). Striped bass spawning migrations have been impeded since construction of the initial dam on the mainstem of the Roanoke River at Roanoke Rapids, NC (RM 137) around 1900 (NMFS and USFWS 2016). The dam was approximately 12-feet high (Hightower et al. 1996) and impeded striped bass migrations especially during low flow years. Completion of the John H. Kerr Dam, 42 river miles upstream of Roanoke Rapids Dam, by the U.S. Army Corps of Engineers in 1953 completely blocked access to upriver habitats, and construction of the current Roanoke Rapids Dam by Virginia Electric and Power Company in 1955 and Gaston Dam in 1964 eliminated striped bass usage of the 42 river miles below Kerr Dam (NMFS and USFWS 2016). Spawning activity now ranges from RM 78 to RM 137 with most of the activity occurring between RM 120 and RM 137, still centered around Weldon.

1.3.3 Nursery & Juvenile Habitat

Juveniles are found in schools; the location of the schools varies considerably with the age of the fish and apparently prefer clean sandy bottoms but have been found over gravel beaches, rock bottoms, and soft mud (Hill et al. 1989). The Roanoke River delta area does not seem to be an important nursery area for YOY striped bass. They appear to spend the first year of life (age-0) growing in and around the western Albemarle Sound and lower Chowan River (Hassler et al. 1981).

As they enter their second and third year, striped bass are found throughout Albemarle Sound and its tributaries. The presence of age-1 and -2 striped bass in the Albemarle Sound Independent Gill-Net Survey confirms this, as well as reports of discarded undersized fish from the striped bass recreational creel survey conducted throughout the Albemarle Sound and its tributaries (NCDMF, unpublished data).

1.3.4 Adult Habitat

Analysis of tagging data indicate younger, smaller adult A-R striped bass (from 35.0–60.0 cm TL) remain in inshore estuarine habitats, while older, larger adults (>60.0 cm TL) are much more likely to emigrate to ocean habitats after spawning; (Callihan et al. 2014). Further, smaller adults show evidence of density-dependent movements and habitat utilization, as the likelihood of recapture outside the ASMA in adjacent systems (i.e., northwestern Pamlico Sound, Tar-Pamlico, Pungo, and Neuse rivers, lower Chesapeake Bay, and the Blackwater and Nottoway rivers in Virginia) increases during periods of higher stock abundance (Callihan et al. 2014).

1.3.5 Habitat Issues & Concerns

Numerous documents have been devoted entirely to habitat issues and concerns, including the North Carolina Coastal Habitat Protection Plan (Street et al. 2005; NCDEQ 2016) and ASMFC's "Atlantic Coast Diadromous Fish Habitat: A review of Utilization, Threats, Recommendations for Conservation, and Research Needs" (Greene et al. 2009). Many contaminants are known to adversely affect striped bass at numerous life stages and can be detrimental to eggs and larvae (Buckler et al. 1987; Hall et al. 1993; Ostrach et al. 2008). Adequate river flows during the spawning season are also needed to keep eggs suspended for proper development (N.C. Striped Bass Study Management Board 1991).

Hassler et al. (1981) indicated that adequate river flow during the pre-spawn and post-spawn periods was the most important factor contributing to survival of fish larvae and the subsequent production of strong or poor year classes.

1.4 Description of Fisheries

Since 2015, the current total allowable landings (TAL) has been set at 124.7 metric tons (275,000 lb) and is split evenly between the commercial and recreational fisheries in the ASMA and RRMA (Table 1.6). In the ASMA, the commercial fishery has a TAL of 62.37 metric tons (137,500 lb) while the ASMA and RRMA recreational fisheries each have a TAL of 31.18 metric tons (68,750 lb). The TAL has changed throughout the previous two decades in response to changes in stock abundance and has ranged from for a low of 71.12 metric tons (156,800 lb) in the early 1990s to 249.5 metric tons (550,000 lb) from 2003 to 2014.

1.4.1 Commercial Fishery

Striped bass are landed commercially in the ASMA primarily with anchored gill nets and to a lesser degree by pound nets. Insignificant landings occur in fyke nets and crab pots. Since 1991, landings in the commercial fishery have ranged from a low of 31.03 metric tons (68,409 lb) in 2013 to a high of 124.2 metric tons (273,814 lb) in 2004 (Table 1.7). Total catch has shown an overall decline since 2004.

1.4.1.1 Historical

The Albemarle Sound area commercial striped bass fishery has been documented in numerous reports for over 100 years. Worth (1884) suggests an industry origin of 1872. During the early 1880s, a large fishery developed on Roanoke Island catching striped bass in the spring and fall (Taylor and White 1992). Gears included haul seines, drag nets, purse seines, fish traps, and gill nets. In 1869, pound nets were first used in the Albemarle Sound and became a more prominent aspect of the fishery in the early 1900s (Taylor and White 1992). The commercial fishery for striped bass has principally occurred from November through April in the Albemarle Sound, whereas, Roanoke River commercial effort was concentrated during the spring spawning run. During the summer months, landings from all areas were much lower (Hassler et al. 1981). Anchored and drift gill nets were the most productive gear types in the spring spawning run portion of the Roanoke River fishery. In 1981, anchored gill nets were prohibited in the Roanoke River, and the mesh size of drift gill nets was restricted, resulting in sharply curtailed landings during the spawning run (Hassler and Taylor 1984). Bow and dip netting was a productive method of harvesting spawning fish in the Roanoke River until it was prohibited in 1981. Prior to this rule, fishermen using bow nets in the upper Roanoke River could retain 25 striped bass per day when taken incidentally during shad and river herring fishing. A local law allowing the commercial sale of striped bass in Halifax and Northampton counties was enacted by the North Carolina General Assembly and created a prominent commercial fishery for striped bass in its principal spawning area (Hassler et al. 1981). This law was repealed in 1981 and commercial fishing for striped bass was eliminated in the inland portions of the Roanoke River. Limited commercial fishing seasons were implemented in Albemarle Sound in 1984 (October–May; Henry et al. 1992). State regulations enacted in 1985 prohibited the sale of hook-and-line-caught striped bass.

1.4.1.2 Current

The ASMA commercial striped bass fishery from 1990 through 1997 operated on a 44.45-metric ton (98,000-lb) TAL (Table 1.6). The TAL was split to have a spring and fall season. The commercial fishery operated with net yardage restrictions, mesh size restrictions, size limit restrictions, and daily landing limits. The A-R stock was declared recovered in 1997 by the ASMFC. In 1998, the commercial TAL was increased to 56.88 metric tons (125,400 lb) and additional increases in poundage occurred in 1999 and 2000. From 2000 through 2002, the commercial TAL remained at 102.1 metric tons (225,000 lb). In 2015, the TAL was adjusted to a total of 124.7 metric tons (275,000 lb) for all sectors, based on projections from the 2014 benchmark stock assessment (NCDMF 2014). Since the initial TAL was set in 1990, seasons, yardage, mesh size restrictions, and daily landing limits have been used to control harvest and maintain the fishery as a bycatch fishery.

1.4.2 Recreational Fishery

Striped bass are landed recreationally in the ASMA and RRMA by hook and line, primarily by trolling or casting artificial lures and using live or cut bait. In recent years, the catch-and-release fly fishery in the RRMA has seen an increase in angler effort. Combined recreational harvest from both management areas has ranged from 5.9 metric tons (13,095 lb) in 1985 to 106.9 metric tons (235,747 lb) in 2000 (Table 1.7). Since 1997, harvest steadily increased from 25.2 metric tons (55,653 lb) to 106.9 metric tons (235,747 lb) in 2000. Since 2000, harvest has shown an overall decline, except for a slight increase in 2011–2012 for the ASMA, 2012 for the RRMA, 2015 for the ASMA, and 2015–2016 for the RRMA. The harvest estimate for 2017 in the ASMA stands as the third lowest on record since 1982.

1.5 Fisheries Management

1.5.1 Management Authority

Fisheries management includes all activities associated with maintenance, improvement, and utilization of the fisheries resources of the coastal area, including research, development, regulation, enhancement, and enforcement.

North Carolina's existing fisheries management system for striped bass is adaptive, with rulemaking authority vested in the North Carolina Marine Fisheries Commission (NCMFC) and the North Carolina Wildlife Resources Commission (NCWRC) within their respective jurisdictions. The NCMFC also has the authority to delegate to the fisheries director the ability to issue public notices, called proclamations, suspending or implementing particular commission rules that may be affected by variable conditions.

Fisheries management includes all activities associated with maintenance, improvement, and utilization of the fisheries resources of the coastal area, including research, development, regulation, enhancement, and enforcement. North Carolina's existing fisheries management system is powerful and flexible, with rulemaking (and proclamation) authority vested in the NCMFC and the NCWRC within their respective jurisdictions.

The North Carolina Department of Environmental Quality (NCDEQ) is the parent agency of the NCMFC and the NCDMF. The NCMFC is responsible for managing, protecting, preserving and enhancing the marine and estuarine resources under its jurisdiction, which include all state coastal fishing waters extending to three miles offshore. In support of these responsibilities, the NCDMF conducts management, enforcement, research, monitoring statistics, and licensing programs to provide information on which to base these decisions. The NCDMF presents information to the NCMFC and NCDEQ in the form of fisheries management and coastal habitat protections plans and proposed rules. The NCDMF also administers and enforces the NCMFC's adopted rules.

The NCWRC is a state government agency authorized by the General Assembly to conserve and sustain the state's fish and wildlife resources through research, scientific management, wise use and public input. The Commission is the regulatory agency responsible for the creation and enforcement of hunting, trapping and boating laws statewide and fishing laws within its jurisdictional boundaries including all designated inland fishing waters. The NCWRC and NCDMF share authority for regulating recreational fishing activity in joint fishing waters.

1.5.2 Management Unit Definition

There are two geographic management units defined in the estuarine striped bass FMP and include the fisheries throughout the coastal systems of North Carolina (NCDMF 2004). The management unit for this assessment is the ASMA and RRMA and is defined as:

Albemarle Sound Management Area (ASMA) includes the Albemarle Sound and all its joint and inland water tributaries, (except for the Roanoke, Middle, Eastmost and Cashie rivers), Currituck, Roanoke and Croatan sounds and all their joint and inland water tributaries, including Oregon Inlet, north of a line from Roanoke Marshes Point across to the north point of Eagle Nest Bay in Dare county. The Roanoke River Management Area (RRMA) includes the Roanoke River and its joint and inland water tributaries, including Middle, Eastmost and Cashie rivers, up to the Roanoke Rapids Dam. The striped bass stock in these two harvest management areas is referred to as the Albemarle Sound-Roanoke River (A-R) stock, and its spawning grounds are located in the Roanoke River in the vicinity of Weldon, NC. Management of recreational and commercial striped bass regulations within the ASMA is the responsibility of the North Carolina Marine Fisheries Commission (NCMFC). Within the RRMA commercial regulations are the responsibility of the NCMFC while recreational regulations are the responsibility of the North Carolina Wildlife Resources Commission (NCWRC). The A-R stock is also included in the management unit of the Atlantic States Marine Fisheries Commission (ASMFC) Amendment #6 to the Interstate Fishery Management plan (FMP) for Atlantic Striped Bass and includes Albemarle Sound and all its joint and Inland Water tributaries, (except for the Roanoke, Middle, Eastmost and Cashie rivers), Currituck, Roanoke, and Croatan sounds and all their Joint and Inland Water tributaries, including Oregon Inlet, north of a line from Roanoke Marshes Point 35 48'.5015' N – 75 44'.1228' W across to the north point of Eagle Nest Bay 35 44'.1710' N - 75 31'.0520' W (Figure 1.1).

1.5.3 Regulatory History

The ASMA commercial striped bass fishery from 1991 through 1997 operated on a 44.45-metric ton TAL (Table 1.6). The TAL was split to have a spring and fall season. The commercial fishery operated with net yardage restrictions, mesh size restrictions, size limit restrictions, and daily landing limits. The A-R stock was declared recovered in 1997 by the ASMFC. In 1998, the commercial TAL was increased to 56.88 metric tons and additional increases in the TAL occurred in 1999 and 2000. From 2000 through 2002, the commercial TAL remained at 102.1 metric tons. The ASMFC Striped Bass Management Board approved another TAL increase in 2003. From 2003 to 2014, the TAL remained at 249.5 metric tons. Based on a stock assessment benchmark, the TAL was reduced to 124.7 metric tons in 2015. Since the initial TAL was set in 1990, seasons, yardage, mesh size restrictions, and daily landing limits have been used to control harvest and maintain the fishery as a bycatch fishery.

Striped bass have been managed as a bycatch of the multi-species commercial fishery in the ASMA since 1991. Since 1991, when the striped bass season was open, commercial fishermen were allowed to land from seven to 15 fish per day, not to exceed 50% by weight of the total catch and fish had to meet the 18-inch TL minimum size limit. Gill nets continue to account for the highest percentage of the commercial harvest, followed by pound nets.

1.5.4 Current Regulations

Striped bass from the A-R stock are harvested commercially within the ASMA and recreationally in both the RRMA and the ASMA. Commercial harvest is currently limited to the ASMA although there was a small commercial fishery operating in the Roanoke River during the early 1980s. The commercial fishery is regulated as a bycatch fishery with a TAL, size limits, daily possession limits, seasonal (closed May 1 through September 30) and gear restrictions, net attendance requirements, and permitting and reporting requirements all imposed to prevent TAL overages and limit discard losses. Finfish dealers who purchase striped bass are required to obtain a striped bass dealer permit from NCDMF. The dealers are required to report their landings daily to NCDMF for the quota to be monitored. Dealers are also required to affix striped bass sale tags, provided by NCDMF, to the fish when purchased from the fishermen.

The recreational fishery within the RRMA is regulated through a creel limit, minimum size limit including a protective slot, and a fixed length spring season, while the ASMA recreational fishery is regulated through a creel limit, minimum size, and the variable spring and fall seasons that close once harvest targets are reached or set season closure dates are reached (closed May 1 through September 30). The A-R striped bass stock is managed by the NCDMF, the NCWRC, and the South Atlantic Fisheries Coordination Office (SAFCO) of the U.S. Fish and Wildlife Service (USFWS) under guidelines established in the ASMFC Interstate FMP for Atlantic Striped Bass and the North Carolina Estuarine Striped Bass FMP.

1.5.5 Management Performance

Management strategies for the A-R striped bass stock have met with variable success over the last several decades. Unrestricted harvest and poor habitat conditions led to a stock collapse in the 1980s; however, severe harvest restrictions and Roanoke River streamflow improvements led to population recovery spurred by increases in recruitment, spawning stock biomass growth, and age structure expansion in the late 1990s and 2000s. Consequently, commercial and recreational harvest restrictions were eased, and the TAL was increased throughout the 2000s. From 1990 through 2002, harvest reached the TAL easily, with the season often having to close after only weeks or months to prevent harvest from exceeding the TAL. Starting in 2003, with the increase in TAL to 249 metric tons, harvest started to consistently decline through 2008, even with extended commercial and recreational seasons in the ASMA. From 2009 through 2014, harvest was still well below the TAL (Figure 1.7). The reason for the decline in harvest even with extended seasons is likely due to declining stock abundance due to several poor year classes produced from 2001 to present. Even with a reduction in the TAL in 2015 to 125 metric tons, harvest has not reached the TAL, although a reduced American shad season starting in 2014 could have contributed to the commercial quota not being reached as the majority of commercial harvest historically came during the American shad commercial season in the ASMA. Recent survey data and stock assessments have supported managers' concerns about declining landings, poor recruitment, reductions in population abundance, and a truncation of age structure (NCDMF 2014, 2018).

1.6 Assessment History

1.6.1 Review of Previous Methods & Results

The A-R stock has an extensive assessment history. Dorazio (1995) and Gibson (1995) prepared the first comprehensive assessment of the A-R striped bass stock based on a Virtual Population Analysis (VPA using CAGEAN, Deriso et al. 1985) and a Brownie tag-return model analysis (Brownie et al. 1985). Schaaf (1997) later provided CAGEAN-based VPA results through 1996 based on the methodology established in Gibson (1995). Smith (1996) used the MARK software program to estimate survival of striped bass in Albemarle Sound through analysis of release and recovery data. Carmichael (1998) updated the CAGEAN assessment through 1997 and later developed an ADAPT VPA assessment of the A-R stock using age-specific indices from the Albemarle Sound Independent Gill-Net surveys, the Roanoke River Electrofishing Survey, and juvenile and yearling abundance indices from Albemarle Sound (Carmichael 1999). The 1999 assessment also included an analysis of tag-return data based on the MARK program. The ADAPT catch-at-age and MARK tag-return assessment framework was updated in 2000 (Carmichael 2000). Analysis of tag-return data for estimation of mortality was discontinued after 2000 as the results were deemed similar to those from the VPA and was duplicative work; subsequent assessments focused on the catch-at-age data. The VPA stock assessment was conducted annually until 2006 to determine stock status and to evaluate potential changes to the TAL (Carmichael 2001, 2002, 2003; Grist 2004, 2005; Takade 2006). The assessment shifted to an ASAP2 model for the 2010 assessment and a yield-per-recruit (YPR) model was used to calculate the benchmarks externally (Takade 2010). The 2014 assessment was performed similarly using an ASAP3 model and benchmarks were calculated with a YPR model. Projections were made using the Age Structured Projection Model (AGEPRO). The most recent stock assessments indicated that the stock was not overfished and overfishing was not occurring (Mroch and Godwin 2014; Flowers et al. 2016).

1.6.2 Progress on Research Recommendations

- Incorporate high reward tagging into the current tagging program to provide estimates of tag return rates for each sector; this will allow for more precise estimates of natural mortality and fishing mortality from tag-based analyses.

  There is an ongoing multi-species tagging study that was initiated in 2014 and funded through the NCDMF Coastal Recreational Fishing Fund. The study employs both high reward and double tags to estimate tag loss and angler reporting rates.

- Improve estimates of discard losses from the Albemarle Sound Management Area (ASMA) commercial gill-net fisheries.

  NCDMF's Programs 466 and 467 monitor commercial gill-net fisheries and record bycatch (see also section 2.1.2). These programs are continually expanding and should lead to improved estimates of commercial discards over time.

- Re-evaluate hook-and-release mortality rates from the ASMA and RRMA recreational fisheries incorporating different hook types and angling methods at various water temperatures (e.g., live bait, artificial bait, and fly fishing).

  No progress.

- Improve estimates of hook-and-release discard losses in the recreational fishery during the closed harvest season

  There is a plan in place starting in May 2021 to provide additional funding to the existing striped bass creel survey in the ASMA that will extend intercepts during the closed harvest season (May–September).

2 DATA

2.1 Fisheries-Dependent

2.1.1 Commercial Landings

2.1.1.1 Survey Design & Methods

Prior to 1978, North Carolina's commercial landings data were collected by the National Marine Fisheries Service (NMFS). Between 1978 and 1993, landings information was gathered through the NMFS/North Carolina Cooperative Statistics program. Reporting was voluntary during this period, with North Carolina and NMFS port agents sampling the state's major dealers (Lupton and Phalen 1996). Beginning in 1994, the NCDMF instituted a mandatory dealer-based trip-ticket system to track commercial landings.

On January 1, 1994, the NCDMF initiated a Trip Ticket Program (NCTTP) to obtain more complete and accurate trip-level commercial landings statistics (Lupton and Phalen 1996). Trip ticket forms are used by state-licensed fish dealers to document all transfers of fish sold from coastal fishing waters from the fishermen to the dealer. The data reported on these forms include transaction date, area fished, gear used, and landed species as well as fishermen and dealer information.

The majority of trips reported to the NCTTP only record one gear per trip; however, as many as three gears can be reported on a trip ticket and are entered by the program's data clerks in no particular order. When multiple gears are listed on a trip ticket, the first gear may not be the gear used to catch a specific species if multiple species were listed on the same ticket but caught with different gears. In 2004, electronic reporting of trip tickets became available to commercial dealers and made it possible to associate a specific gear for each species reported. This increased the likelihood of documenting the correct relationship between gear and species.

2.1.1.2 Sampling Intensity

North Carolina dealers are required to record the transaction at the time of the transactions and report trip-level data to the NCDMF on a monthly basis. For further information on the sampling methodology for the NCTTP, see NCDMF 2019.

2.1.1.3 Biological Sampling

Biological sampling occurs during the spring and fall fishery. NCDMF personnel have a target of 600 samples from the spring fishery and 300 samples from the fall fishery. Fish are sampled monthly from various fish houses throughout the ASMA, throughout each season. Fish are measured to the nearest mm for fork length (FL) and TL and weighed to the nearest 0.01 kg. Sex is determined using the Sykes (1957) method and scales are removed from the left side of the fish, above the lateral line and between the posterior of the first dorsal fin and the insertion of the second dorsal fin. Scales are cleaned and pressed on acetate sheets using a Carver heated hydraulic press. NCDMF employees read scales using a microfiche reader set on 24x or 33x magnification. For each sex, a minimum of 15 scales per 25-mm size class is read and subsequently used to assign ages to the remainder of the sample.

2.1.1.4 Potential Biases & Uncertainties

All fish that are caught are not required to be landed (discards) or sold so some fish may be taken home for personal consumption and are not reported in the landings. The reporting of multiple gears on a single trip ticket could also be a source of bias since the order in which gears are reported are not indicative of the primary method of capture.

2.1.1.5 Development of Estimates

Commercial landings were summarized by year using the NCTTP data. Length data collected from the commercial fish house sampling program were used to compute annual length-frequency distributions by sex.

2.1.1.6 Estimates of Commercial Landings Statistics

The NCTTP is considered a census of North Carolina commercial landings, though reliability of the data decreases as one moves back in time. Commercial landings were highest in the late 1960s and have substantially decreased through recent years (Figure 2.1). Landings have been constrained with a TAL since 1991.

The minimum lengths and ages observed in the commercial fisheries landings are strongly tied to the minimum length regulations at the time fish are collected, measured, and aged. The most noticeable impact is the implementation of the 18-inch minimum TL length limit in 1991; striped bass less than 45 cm TL (~18 inches; Figures 2.2, 2.3) and younger than age 3 (Figures 2.4, 2.5) have been rarely observed since 1991. The length and age compositions show that fewer larger and older fish have been observed in recent years (Figures 2.2–2.5).

2.1.2 Commercial Gill-Net Discards

2.1.2.1 Survey Design & Methods

NCDMF's Program 466 (Onboard Observer Monitoring) was designed to monitor fisheries for protected species interactions in the gill-net fishery by providing onboard observations. Additionally, this program monitors finfish bycatch and characterizes effort in the fishery. The onboard observer program requires the observer to ride onboard the commercial fishermen's vessel and record detailed gill-net catch, bycatch, and discard information for all species encountered. Observers contact licensed commercial gill-net fishermen holding an Estuarine Gill-Net Permit (EGNP) throughout the state to coordinate observed fishing trips. Observers may also observe fishing trips from NCDMF vessels under Program 467 (Alternative Platform Observer Program), but these data were not used in this stock assessment due to the lack of biological data collected through the program.

2.1.2.2 Sampling Intensity

Fishing trips targeting striped bass are observed throughout the year; however, most observed trips occur during the fall when landings are the greatest in the Albemarle and the spring for the Pamlico Sound, both areas of which have a history of Atlantic sturgeon and sea turtle interactions.

2.1.2.3 Biological Sampling

Data recorded includes species, weight, length, and fate (landed, live discard, or dead discard).

2.1.2.4 Potential Biases & Uncertainties

Program 466 began sampling statewide in May 2010. To provide optimal coverage throughout the state, management units were created to maintain proper coverage of the fisheries. Management units were delineated based on four primary factors: (1) similarity of fisheries and management, (2) extent of known protected species interactions in commercial gill-net fisheries, (3) unit size, and (4) the ability of the NCDMF to monitor fishing effort. Total effort for each management unit can vary annually based on fishery closures due to protected species interactions or other regulatory actions. Therefore, the number of trips and effort sampled each year by management unit varies both spatially and temporally.

Program 466 data do not span the entire time series for the assessment (no data are available for 1991–2000) and statewide sampling began in May 2010 decreasing the variability of observed trips with better spatial and temporal sampling beginning in 2012.

Striped bass discard data were not available in sufficient quantities to estimate discards or post-release mortality from commercial pound net or gig fisheries; however, these fisheries and others are known to have discards of striped bass. Additionally, commercial discards likely occur in other states, so the estimates presented here likely underestimate the total number of striped bass commercial discards removed from the A-R stock.

It is also important to note that this survey was designed to target trips that occur in times and areas where protected species interactions are highest; the program does not target striped bass trips. For this reason, a high number of zero-catch trips relative to striped bass occur in the data.

2.1.2.5 Development of Estimates

A generalized linear model (GLM) framework was used to predict striped bass discards in the A-R gill-net fishery based on data collected during 2012 through 2017. Only those variables available in all data sources were considered as potential covariates in the model. Available variables were year, season, mesh category (small: <5 inches and large: ≥5 inches) and management area (Figure 2.6), which were all treated as categorical variables in the model. Effort was measured as soak time (days) multiplied by net length (yards). Live and dead discards were modeled separately.

All available covariates were included in the initial model and assessed for significance using the appropriate statistical test. Non-significant covariates were removed using backwards selection to find the best-fitting predictive model. The offset term was included in the model to account for differences in fishing effort among observations (Zuur et al. 2009, 2012). Using effort as an offset term in the model assumes the number of striped bass discards is proportional to fishing effort (A. Zuur, Highland Statistics Ltd., personal communication).

Examination of the data indicated they were significantly zero inflated for both the live and dead discards. There are two types of models commonly used for count data that contain excess zeros. Those models are zero-altered (two-part or hurdle models) and zero-inflated (mixture) models (see Minami et al. 2007 and Zuur et al. 2009 for detailed information regarding the differences of these models). Minami et al. (2007) suggests that zero-inflated models may be more appropriate for catches of rarely encountered species; therefore, zero-inflated models were initially considered though were unable to converge. For this reason, zero-altered models were pursued.

The best-fitting model for live discards and for dead discards was applied to available effort data from the NCTTP to estimate the total number of live discards and dead discards for the A-R gill-net fishery.

In order to develop estimates of commercial discards for years prior to 2012, a hindcasting approach was used. The ratio of live or dead discards in numbers to A-R gill-net landings was computed by year for 2012 to 2017. As these ratios were variable among years (Figure 2.7), the working group decided to apply the median ratio over 2012 to 2017 separately for live and dead discards. The median ratio for either live or dead discards was multiplied by the commercial gill-net landings in 1991 to 2011 to estimate the live and dead commercial gill-net discards for those years.

Because only dead discards were input into the assessment model, the estimates of live commercial gill-net discards were multiplied by 43%, an estimate of post-release mortality described in section 1.2.6.2. These estimates of live discards that did not survive were added to the estimates of commercial dead discards to produce an estimate of total dead discards for the commercial gill-net fishery for 2012 to 2017.

The available length samples from the NCDMF's Program 466 were summarized by year and used to characterize the length distribution of striped bass commercial discards by year.

2.1.2.6 Estimates of Commercial Gill-Net Discard Statistics

The best-fitting GLM for the commercial gill-net live discards assumed a zero-altered Poisson distribution (dispersion=2.9). The significant covariates for both the count and binary part of the model were year, season, mesh, and area. The best-fitting GLM for the dead discards assumed a zero-altered Poisson (dispersion=2.7). The significant covariates for the count part of the model were year, season, mesh, and area and the significant covariates for the binary part of the model were season and mesh.

Estimates of annual commercial dead discards ranged from a low of 2,500 striped bass in 2008 to a high of just over 11,600 striped bass in 2001 between 1991 and 2017 (Table 2.1; Figure 2.8). Total lengths of commercial discards have ranged from 10 cm to 85 cm (Figure 2.9). The majority of discards have been less than 60 cm TL.

2.1.3 Albemarle Sound Recreational Fishery Monitoring

From the 1950s through the late 1980s, various researchers conducted creel surveys in the Albemarle Sound and Roanoke River, although the Roanoke River has the most complete historical time series of catch and effort data (Hassler et al. 1981). Starting in 1988 and 1990 respectively, the NCWRC and NCDMF initiated annual creel surveys in the RRMA and ASMA that have continued to date.

2.1.3.1 Survey Design & Methods

The NCDMF collects catch and effort data through on-site interviews at boat ramps during allowed harvest days for each of four ASMA sampling zones (Figure 2.10). Statistics were calculated through a non-uniform probability access-point creel survey (Pollock et al. 1994). Site probabilities were set in proportion to the likely use of a site according to time of day, day of week, and season. Probabilities for this survey were assigned based on seasonal striped bass fishing pressure observed during past surveys, in addition to anecdotal information (S. Winslow and K. Rawls, NCDMF, personal communication). Probabilities can be adjusted during the survey period according to angler counts to provide more accurate estimates. Morning and afternoon periods were assigned unequal probabilities of conducting interviews, with each period representing half a fishing day. A fishing day was defined as one and a half hours after sunrise until one hour after sunset. These values varied among sites within zones due to differing fishing pressure.

2.1.3.2 Sampling Intensity

The ASMA striped bass creel survey data series includes estimates of effort, catch, and discards for years 1990–2017. The survey does not operate during the closed harvest season, so estimates of catch and release during this time are not available. In the early years of the survey when the

TAL was very low, the seasons may have only lasted a few days to a few weeks. In recent years as the TAL has increased, the harvest season occurs from October 1 through April 30. Creel clerks work all three weekend days (Friday–Sunday) and two weekdays. Interview sessions are approximately five hours and 45 minutes long, either in the morning or afternoon.

2.1.3.3 Biological Sampling

In the ASMA creel survey, all striped bass are sampled during the surveys and measured for TL (mm) and weighed to the nearest 0.1 kg by NCDMF personnel. No scales are collected for ageing purposes. Striped bass are not sexed during the creel survey.

2.1.3.4 Potential Biases & Uncertainties

One bias that has increased over time in the ASMA creel survey is the number of private access sites that are not included in the pool of public access points available to the survey. The increase in private sites is due to increased development of single-family dwellings and developments on the Albemarle Sound and tributaries in the last 20 years.

Another bias inherent in any non-uniform probability access-point creel survey is accurately matching the site probabilities to actual fishing pressure throughout the harvest season. Determining accurate probabilities is made more difficult when the harvest area is a large, open system such as a coastal estuary, and the species of interest is migratory in nature and movement (and hence fishing pressure) varies throughout the harvest area seasonally.

The bias associated with the increase in the number of private access points not included in the survey serves to systematically underestimate harvest and effort statistics, while the bias associated with varying probabilities throughout the season is not systematic and can produce under or over estimates of harvest and effort on an annual basis.

2.1.3.5 Development of Estimates

In the ASMA from 1990 to the spring season of 2005, a non-uniform probability roving access-point creel survey was used to estimate recreational hook-and-line effort and catch and release of striped bass during the allowed harvest seasons. Catch and effort data are collected daily for each of four ASMA sampling zones. Fishing effort was estimated by counting empty boat trailers at public and private boating access sites and using interview data to remove trailer counts for other users, including recreational fishermen targeting other species, hunters, recreational boaters, and commercial fishermen. Harvest was estimated as the product of catch rates and total fishing effort stratified by day and zone (Pollock et al. 1994).

In the ASMA from the fall of 2005 to present, angler catch statistics were calculated through a non-uniform probability access-point creel survey (Pollock et al. 1994). Site probabilities were set in proportion to the likely use of a site according to time of day, day of week, and season. Probabilities for this survey were assigned based on seasonal striped bass fishing pressure observed during past surveys, in addition to anecdotal information (S. Winslow and K. Rawls, NCDMF, personal communication). Probabilities can be adjusted during the survey period according to angler counts to provide more accurate estimates. Morning and afternoon periods were assigned unequal probabilities of conducting interviews, with each period representing half a fishing day. A fishing day was defined as one and a half hours after sunrise until one hour after sunset. These values varied among sites within zones due to differing fishing pressure. Harvest was estimated by applying the sample unit probabilities to interview data stratified by day and zone (Pollock et al. 1994).

Dead discards (no live) were input into the assessment model, so the estimates of Albemarle Sound recreational discards were multiplied by 6.4%, an estimate of post-release mortality described in section 1.2.6.2.

Lengths sampled from the Albemarle Sound recreational creel survey were used to characterize the length distribution of striped bass harvested by the Albemarle Sound recreational fishery by year.

In the absence of length samples from the recreational fisheries characterizing the releases, tagging data of striped bass recaptured by recreational anglers was used to develop length frequencies for the recreational releases. The composition of the total catch was derived first and then the length composition of the harvested fish was subtracted to estimate the length composition of the recreational releases. Due to the very low numbers of recaptured fish in some years, the recaptured fish length data were pooled across all years. For recaptures without lengths associated with them, if they were caught within three months of initial release, negligible growth was assumed and they were assigned a recapture length equal to the initial tagging length. The number of recaptures with associated lengths per year for the Albemarle Sound ranged from 3 to 127 with a mean of 39. Effective sample size was determined as the average number of unique locations and dates per year for recaptures in the associated management area. The proportion of fish recaptured per 2-cm length bin, t_l, was calculated from these pooled data such that:

$$t_l = \frac{\sum_{y=1997}^{y=2017} T_{y,l}}{\sum_{y=1997}^{y=2017} T_y}$$

where $T_{y,l}$ is the number of fish tagged in year y and length bin l. A smoother was applied across the resulting proportion data using the following centrally-weighted five-point moving average:

$$Smoothed[t_l] = \frac{[t_{l-2} + t_{l-1} + 3t_l + 2t_{l+1} + t_{l+2}]}{9}$$

The length composition of the total catch per year and length bin, $C_{y,l}$, was then estimated as:

$$Smoothed\left[C_{y,l}\right] = Smoothed[t_l]C_y$$

where C_y is the total catch numbers of striped bass per year.

A smoother was applied to recreational harvest length frequencies, $H_{y,l}$, and the numbers of recreational releases per year and length bin, $D_{y,l}$, were then estimated as:

$$D_{y,l} = Smoothed\left[C_{y,l}\right] - [H_{y,l}]$$

In some instances, this produced length bins with negative discard values. The negative values were truncated to zero, and the data set for each year was then rescaled to match the original total number of releases per year.

2.1.3.6 Estimates of Albemarle Sound Recreational Fishery Statistics

Annual recreational harvest of striped bass in the Albemarle Sound has ranged from a low of 3,500 fish in 2010 to a high of just over 40,000 fish in 2001 (Table 2.2; Figure 2.11). No overall trend is apparent in the recreational harvest time series, but estimates in the most recent two years (2016 and 2017) are among the lowest observed since 1991.

Estimates of recreational dead discards in the Albemarle Sound have been variable from 1991 through 2017 (Table 2.2; Figure 2.12). Recreational dead discards have ranged from a low of 605 striped bass in 2006 to a high of over 5,800 striped bass in 1998.

The length distribution of recreational harvested striped bass has remained relatively consistent from 1996 through 2017 (Figure 2.13). The majority of lengths fall between 45 and 60 cm TL. Lengths of striped bass observed in the Albemarle Sound recreational discards have also demonstrated consistency over the years in which lengths are available (1997–2017; Figure 2.14); the majority of these recreational discards range between 40 and 60 cm TL.

2.1.4 Roanoke River Recreational Fishery Monitoring

2.1.4.1 Survey Design & Methods

The NCWRC conducts the RRMA striped bass creel survey to estimate angler effort, catch, and harvest during the spring harvest season. In some years, estimates of angler effort and catch and release of striped bass after the harvest season closes are also made (depending on available funding). The creel survey employs a non-uniform probability, stratified access-point creel survey design (Pollock et al. 1994) to estimate recreational fishing effort (angler hours, and angler trips), harvest of striped bass, and numbers of striped bass caught and released. The creel survey is stratified by area (upper zone or lower zone), time (AM or PM), and type of day (weekdays and weekend days). The upper zone includes the river segment from Roanoke Rapids Lake dam downstream to the U.S. Highway 258 Bridge near Scotland Neck (Figure 2.15). The lower zone extends from U.S. Highway 258 Bridge downstream to Albemarle Sound. Because past analyses depict differential catch rates through progression of the open harvest season, the survey was stratified into two-week sample periods. Within periods, samples and estimates are further stratified by type of day because fishing effort and catch is also known to vary as a function of day type. Selection of access points where interviews occurred was based on probability of boat trailer counts generated from prior RRMA creel surveys as well as expert opinion by biological and enforcement staff. Probabilities of fishing activity for time of day (0.4 for AM and 0.6 for PM during periods one and two and equal probabilities during all other periods) are estimated based upon prior experience with the RRMA striped bass fishery.

2.1.4.2 Sampling Intensity

The RRMA striped bass creel survey data series includes 1988–2017 for harvest season estimates and 1995–1999, 2005–2008, and 2010–2017 for closed season catch and effort estimates. The creel survey is conducted during March, April, and May of each year. Creel clerks typically work two weekdays and both weekend days each week. Interview sessions last three hours and one session is conducted in each zone each sample day.

2.1.4.3 Biological Sampling

RRMA striped bass creel clerks record the total number of striped bass caught and the number of striped bass harvested. Creel clerks measure TL (mm), weight (kg), and determine sex of each striped bass harvested when possible. Counts and total weights of harvested striped bass (i.e., no individual data) are recorded for angling parties when interview sessions are busy. In some years, creel clerks also record the number of striped bass released within length limit categories (e.g., short, legal, slot, over-slot), type of bait used, angler residency, and trip expenditures.

2.1.4.4 Potential Biases & Uncertainties

In the RRMA creel survey, sample unit probabilities are adjusted each year depending on current conditions and expected trends in angler effort. Additionally, construction of new boating access areas has necessitated addition and deletion of creel locations. The NCWRC Jamesville-Astoria Rd. boating access area was added to the survey in 2011, and the two private ramps in Jamesville were subsequently removed from the survey. In 2016, a new boating access area in Lewiston-Woodville was added to the survey. Calculation of fishing effort was made using expansions of trailer count data from 1988–2001, but from 2002–2017, fishing effort was calculated by expanding interview data by the sample unit probability.

2.1.4.5 Development of Estimates

From 1988–2001, total fishing effort was estimated from counts of empty boat trailers at boating access areas along the entire river. Trailer counts were conducted each day of the open season. Total numbers of anglers were estimated by expanding trailer counts by the mean number of anglers per party as determined from interviews at access areas. The starting point for effort counts was randomly selected. Counts were made during mid-morning, or mid-afternoon periods. Based on interview data, trailer counts were adjusted to eliminate commercial fishermen, hunters, and recreational boaters. Data were adjusted based on the proportion of recreational anglers interviewed by creel clerks within each zone by period and kind of day. Harvest was estimated as the product of catch rates and total fishing effort stratified by period, zone, and kind of day (weekday or weekend day).

From 2002–2017, a specifically designed creel survey program was used to provide estimates of catch, harvest, and effort using formulas derived from Pollock et al. (1994). Estimates of striped bass catch, harvest, and effort for each sample day were made by expanding interview data by the sample unit probability (product of the access point probability and time of day probability). Within sample periods, catch, harvest, and effort estimates for weekdays and weekend days are separately averaged. The averages are then expanded to the total number of days of each type for that sample period. Separate estimates of total catch, harvest, and effort are made for each zone. Finally, sample period and zone totals are added to calculate the annual estimates.

Only dead discards were input into the assessment model, so the estimates of Roanoke River recreational discards were multiplied by 6.4%, an estimate of post-release mortality described in section 1.2.6.2.

As discard estimates were only available starting in 1995, a hindcasting approach was used to develop estimates back to 1991. The ratio of dead discards to harvest in numbers was calculated for 1995 through 2017 (Figure 2.16). The median ratio over those years was multiplied by the Roanoke River recreational harvest in 1991 to 1994 to estimate the dead discards for these earlier years.

Lengths sampled from the Roanoke River recreational creel survey were used to characterize the length distribution of striped bass harvested by the Roanoke River recreational fishery by year.

Roanoke River discard length compositions were derived using the same methodology as the Albemarle Sound discard length compositions described in section 2.1.3.5. The number of recaptures with associated lengths per year for the Roanoke River ranged from 18 to 191 with a mean of 88.

2.1.4.6 Estimates of Roanoke River Recreational Fishery Statistics

Estimates of recreational harvest in the Roanoke River have ranged from a low of about 3,100 fish in 1985 to a high of just over 38,000 fish in 2000 (Table 2.3; Figure 2.17). Recreational harvest increased from the beginning of the time series in 1982 to the early 2000s. Since then, recreational harvest in the Roanoke River has shown an overall slight decline.

Discards from the Roanoke River recreational fishery have been variable (Table 2.3; Figure 2.18). Estimates have ranged from a low of 4,215 striped bass in 2017 to a high of over 18,600 striped bass in 1997. There is no clearly discernable trend in these discard estimates over time.

As was observed with the Albemarle Sound recreational harvest and discard lengths, there was consistency in the total lengths observed in the Roanoke River recreational harvest (Figure 2.19) and discards (Figure 2.20) observed over time. The majority of striped bass collected from the Roanoke River recreational fishery were between 40 cm and 55 cm TL for both the harvest and discards.

2.2 Fisheries-Independent

2.2.1 Juvenile Abundance Survey (Program 100)

2.2.1.1 Survey Design & Methods

The NCDMF Juvenile Anadromous Survey, also known as Program 100 (P100), targets young-of-year (YOY) striped bass using a bottom trawl in Albemarle Sound. The survey was taken over by the NCDMF in 1984 and continues to sample the same seven fixed stations in western Albemarle Sound initiated in 1955 by Dr. William Hassler of N.C. State University, making it one of the longest continuous time series of striped bass fisheries-independent abundance data on the east coast (Figure 2.21). The sampled habitats are preferred nursery habitat for YOY striped bass in the Albemarle Sound as they increase in size and move from near-shore nursery areas to more open water habitats (Hassler et. al 1981).

The survey uses an 18-foot semi-balloon trawl with a body mesh size of 0.75-inch bar mesh and a 0.125-inch bar mesh tail bag. Tow duration is 15 minutes. Temperature, salinity, and dissolved oxygen are recorded.

2.2.1.2 Sampling Intensity

Trawl sampling is conducted bi-weekly for eight weeks starting in mid-July at seven established locations in the western Albemarle Sound area for a total of 56 samples. Trawl sites are located at the edge of breaks and contours, usually within the 2.4 m–3.7 m (8 feet–12 feet) depth profile.

2.2.1.3 Biological Sampling

All striped bass captured are counted and a subsample (maximum of 30) is measured (mm; TL and FL). In the event a striped bass is captured that may overlap with the size range of a YOY and a 1-year old striped bass, the specimen is brought back to the lab for examination of otoliths and/or scale samples to determine its age. In recent years, a subsample of YOY and age-1 striped bass has been weighed to the nearest gram for improved length at age relationships.

2.2.1.4 Potential Biases & Uncertainties

The Juvenile Abundance Survey is a fixed survey that the division appropriated from another source, so the fixed stations were retained for the continuity of data. A fixed-station survey can run the risk of bias if the sites selected do not adequately represent the sampling frame.

Additionally, even if the sites adequately cover the sampling frame, the increased variation that would come about from sampling randomly is not accounted for and is therefore at risk of being neglected.

Indices derived from fixed-station surveys such as P100 may not accurately reflect changes in population abundance (Warren 1994, 1995). The accuracy of the estimates is tied to the degree of spatial persistence in catch data of the species (Lee and Rock 2018). The persistence of the P100 data were evaluated following the approach of Lee and Rock (2018) and results suggested a lack of year*station interaction, which indicates the presence of spatial persistence and so suggests the survey is likely tracking trends in relative abundance.

2.2.1.5 Development of Estimates

A nominal index was calculated by year using a standard arithmetic mean (numbers per tow). A generalized linear model (GLM) framework was also used to model the relative abundance of YOY striped bass. Potential covariates were evaluated for collinearity by calculating variance inflation factors. Collinearity exists when there is correlation between covariates and its presence causes inflated p-values. The Poisson distribution is commonly used for modeling count data; however, the Poisson distribution assumes equidispersion; that is, the variance is equal to the mean. Count data are more often characterized by a variance larger than the mean, known as overdispersion. Some causes of overdispersion include missing covariates, missing interactions, outliers, modeling non-linear effects as linear, ignoring hierarchical data structure, ignoring temporal or spatial correlation, excessive number of zeros, and noisy data (Zuur et al. 2009, 2012). A less common situation is underdispersion in which the variance is less than the mean. Underdispersion may be due to the model fitting several outliers too well or inclusion of too many covariates or interactions (Zuur et al. 2009).

Data were first fit with a standard Poisson GLM and the degree of dispersion was then evaluated. If over- or underdispersion was detected, an attempt was made to identify and eliminate the cause of the over- or underdispersion (to the extent allowed by the data) before considering alternative models, as suggested by Zuur et al. (2012). For example, the negative binomial distribution allows for overdispersion relative to the Poisson distribution whereas a quasi-Poisson GLM can be used to correct the standard errors for overdispersion. If the overdispersion is the result of an excessive number of zeros (more than expected for a Poisson or negative binomial), then a model designed to account for these excess zeros can be applied. There are two types of models that are commonly used for count data that contain excess zeros: zero-altered (two-part or hurdle models) and zero-inflated (mixture) models (see Minami et al. 2007 and Zuur et al. 2009 for detailed information regarding the differences of these models). Minami et al. (2007) suggests that zero-inflated models may be more appropriate for catches of rarely encountered species; therefore, zero-inflated models were considered here when appropriate.

All available covariates were included in the initial model and assessed for significance using the appropriate statistical test. Non-significant covariates were removed using backwards selection to find the best-fitting predictive model.

2.2.1.6 Estimates of Survey Statistics

Available covariates were year, depth, surface and bottom temperature, and surface and bottom salinity. The best-fitting GLM model assumed a negative binomial distribution (dispersion=1.4) and the significant covariates were year and bottom temperature.

The nominal and GLM-standardized indices were similar throughout the time series (Figure 2.22). Both exhibit substantial inter-annual variability over time.

2.2.2 Independent Gill-Net Survey

2.2.2.1 Survey Design & Methods

In October 1990, the NCDMF initiated the Striped Bass Independent Gill-Net Survey, also known as Program 135 (P135). The survey was designed to monitor the striped bass population in the Albemarle and Croatan sounds.

The survey follows a random stratified design, stratified by geographic area. This survey divides the water bodies comprising the Albemarle region into six sample zones that are further subdivided into one-mile square quadrants with an average of 22 quadrants per zone (Figure 2.23). Albemarle Sound, Croatan Sound, and Alligator River sample zones (Zones 2–7) were selected for this survey, based on previous sampling and historical abundance information (Street and Johnson 1977). Sampling in Zone 1 was discontinued shortly after the survey began in favor of sampling Zone 7, to allow for tagging to produce estimates of mixing of the Albemarle-Roanoke striped bass stock and the migratory portion of the Atlantic migratory stock which may utilize the eastern portion of the Albemarle Sound during the winter months while overwintering. The survey gear is a multi-mesh monofilament gill net. Four gangs of twelve meshes (2.5-, 3.0-, 3.5-, 4.0-, 4.5-, 5.0-, 5.5-, 6.0-, 6.5-, 7.0-, 8.0-, 10.0-inch stretched mesh, ISM) of gill nets are set in each quadrant by the fishing crew. One two-gang set is weighted to fish at the bottom (sink net), and the other is floating unless the area is unsuitable for gill-net sampling (marked waterways and areas with excessive submerged obstructions). The use of 12 different mesh sizes allowed for the capture of fish age one and older. Alternate zones and quadrants are randomly selected if the primary selection cannot be fished. A fishing day is defined as the two crews fishing the described full complement of nets for that segment for one day. One unit of effort is defined as each 40-yard net fished for 24 hours.

The fishing year is divided into two segments: (1) fall/winter survey period, 1 November through 28 February; and (2) spring survey period, 1 March through late May. The sampling methods remain the same during each sampling season. Areas fished, sampling frequency, and sampling effort is altered seasonally.

For the fall/winter segment, two survey crews fish replicate 40-yard anchored, floating, and sinking monofilament gill nets from 2.5- to 4.0- ISM in one-half inch increments with a twine size of 0.33 mm (#104), 5.0- to 7.0-ISM with a twine size of 0.40 mm (#139), and 8.0-ISM and 10.0-ISM, with a twine size of 0.57 mm (#277). Heavier twine sizes in the larger mesh nets are intended to improve retention of larger, heavier fish. Gill nets were constructed with a hanging coefficient of 0.5. Gear soak time is 48 hours for each selected quadrant.

In the spring segment, gill-net effort is concentrated in western Albemarle Sound (Zone 2) near the mouth of the Roanoke River (Figure 2.23). The shift to Zone 2 was designed to increase the chance of intercepting mature striped bass congregated in this area during their migration to the Roanoke River spawning grounds. Effort is concentrated in this zone to determine differences in the size, age, and sex composition of the spring spawning migration relative to the fall/winter resident population. Zone 2 is sub-divided into southern and northern areas.

2.2.2.2 Sampling Intensity

The NCDMF monitors the adult striped bass population in Albemarle Sound through spring (March–May) and fall (November–February). The fishing year is divided into two segments: (1) fall/winter survey period, 1 November through 28 February; and (2) spring survey period, 1 March through late May. All zones are sampled equally, except in the spring when effort is shifted to Zone 2. Each crew samples each of the six zones, providing 24 fishing days per month and a total of 96 fishing days for the season. A fishing day is defined as one crew, fishing the full complement of nets specified, for that segment for one day (24 hours).

The southern area, adjacent to the Roanoke River, received increased effort at a 2:1 ratio south to north, based on the historical seasonal abundance of mature striped bass (Harris et al. 1985). Quadrants sampled are randomly selected as previously noted. Fishing effort is conducted continuously, seven days a week weather permitting, until the end of late May.

2.2.2.3 Biological Sampling

All striped bass are counted and measured and healthy striped bass that survived entanglement are tagged with internal anchor tags and then measured to the nearest mm for FL and TL. Scales are removed from the left side of the fish, above the lateral line and between the posterior of the first dorsal fin and the insertion of the second dorsal fin. When possible, sex is determined by applying directional pressure to the abdomen towards the vent and observing the presence of milt or eggs.

For both the fall/winter and spring segment, fish that did not survive entanglement are processed at the NCDMF laboratory. Fish are measured to the nearest mm for FL and TL and weighed to the nearest 0.01 kg. Sex is determined by visual inspection and scales are removed as previously described. Scales are cleaned and pressed on acetate sheets using a Carver heated hydraulic press. Scales are read using a microfiche reader set on 24x or 33x magnification. For each sex, a minimum of 15 scales per 25 mm size class is read and subsequently used to assign ages to the remainder of the sample.

2.2.2.4 Potential Biases & Uncertainties

The P135 Survey deploys a passive gear of an array of nets with varying mesh size over a variety of randomly selected locations. The effort expended on survey design should result in estimates with relatively low bias. The survey design was informed by previous abundance and sampling data. It is possible that changes in the stock (habitat use, migration corridors, etc.) since the implementation of the sampling program may cause estimates to vary.

Many factors affect gill-net catch efficiency including net visibility and turbidity (Berst 1961; Hansson and Rudstam 1995), though setting nets overnight may offset some concerns of net visibility. Efficiency can also decrease if nets become tangled or fouled with debris. In the P135 Survey, performance of individual net panels is evaluated and recorded and catch is evaluated at the sample level (catch from a gang of nets is a sample), so performance of individual net panels may not have a large impact on catch from a sample.

2.2.2.5 Development of Estimates

Nominal indices of abundance were developed for both the fall/winter and spring components of the P135 Survey and were calculated using stratified average estimator (numbers per gang of net, 480 yards of 12 mesh sizes). For both the fall/winter and spring segments, only catches observed during the first 24 hours of the soak were included in the development of the index. Standardized indices were also calculated using the GLM approach described in section 2.2.1.5.

Biological data collected during the survey were summarized to characterize both the length and age frequencies of striped bass observed by sex and survey component.

2.2.2.6 Estimates of Survey Statistics

Available covariates for the GLM standardization included year, quad (fall/winter only), depth, and surface temperature. The best-fitting GLM for the fall/winter index assumed a negative binomial distribution (dispersion=1.6) and the significant covariates were year, quad, and surface temperature. The best-fitting GLM for the spring index assumed a negative binomial distribution (dispersion=1.5) and the significant covariates were year, depth, and surface temperature.

The GLM-standardized indices tracked well with the nominal indices for both the fall/winter (Figure 2.24) and spring (Figure 2.25) components of the P135 Survey. Indices from both components of the survey indicate decreasing trends in the most recent years of the time series (Figures 2.24, 2.25).

Females observed during the fall/winter component of the P135 Survey have ranged from 15 cm to 95 cm TL and males have ranged from 15 cm to 80 cm TL (Figure 2.26). Striped bass observed during the spring component of this survey were generally larger; females have ranged from 20 cm to 115 cm TL and males have ranged from 15 cm to 90 cm TL (Figure 2.27).

Females ranging from ages 1 to 10 have been collected during the fall/winter component of the P135 Survey (Figure 2.28). Males collected during the fall/winter have ranged in age from 1 to 7. Older striped bass tend to be observed during the spring component of this survey (Figure 2.29). Female striped bass as old as 15 and males as old as 10 have been observed in the spring. The modal age has varied over time for both females and males in both the fall/winter and spring components of the P135 Survey.

2.2.3 Roanoke River Electrofishing Survey

2.2.3.1 Survey Design & Methods

The NCWRC Electrofishing Survey on the Roanoke River spawning grounds began in 1991 to meet the ASMFC FMP requirements to monitor spawning stock abundance (Figure 2.30). A boat-mounted electrofishing unit (Smith-Root 7.5 GPP) is used (1 dip netter) to capture fish during daylight hours. Sampling is conducted at stations within strata. Sampling stations are located on main and secondary river channel habitats. Three strata are sampled each day, and strata selection is dependent on flow conditions. Flows of approximately 7,000 cubic feet per second (cfs) or less restrict access to strata above the rapids in proximity to the Weldon boating access area. To minimize size selection during sampling, striped bass were netted as they were encountered regardless of size. Water temperature (°C) is recorded each sample day.

2.2.3.2 Sampling Intensity

NCWRC personnel collect striped bass weekly between mid-April and May, on the historic spawning grounds of the Roanoke River near Weldon (RM 130) and Roanoke Rapids (RM 137), North Carolina. Sampling begins as the water temperature approaches 15.0°C (59.0°F) and continues through the range of optimal spawning temperatures until water temperatures surpass 22°C or until striped bass spawning is complete; optimum spawning temperatures range from 18.0° to 22.0°C (64.4° to 71.6°F) for striped bass in the Roanoke River.

2.2.3.3 Biological Sampling

Information on sex, age, and size composition of the spawning stock is also collected. Each fish is measured to the nearest mm for TL and sex is determined by assessing the presence of eggs or milt when pressure is applied to the fish's abdomen. Weight (kg) and scales are obtained from a subsample (target maximum of five fish of each 25-mm size group and sex per sample day) of fish. Weight and scales are collected from all fish greater than 700 mm. Scales are removed from the left side of the fish, above the lateral line and between the posterior of the first dorsal fin and the insertion of the second dorsal fin. Scales are aged using an EyeCom 3000 microfiche reader at 24x or 36x magnification. A primary reader ages up to 15 individuals per 25-mm length group per sex, and a subsample (20% of aged scales) is aged by a secondary reader for age verification. Age discrepancies between the readers are reconciled in concert.

2.2.3.4 Potential Biases & Uncertainties

The electrofishing survey spans a seven-mile section of the Roanoke River, determined to be the spatial extent of the spawning grounds. Site selection in early years of the survey was opportunistic to some degree, but multiple strata were always sampled so that sites were spread out within the spawning habitat/survey area each sample day. In more recent years, sites have been randomly selected within each of the three strata and the strata selections are based on flow conditions; however, some sample sites cannot be sampled due to flow conditions or angling activity. Inability to access sampling sites due to flow conditions or angler presence could bias the abundance estimates either by concentrating striped bass in the accessible areas or allowing striped bass to go undetected. Additionally, it is possible that fish may be missed by the dip netter. If striped bass are not universally available to the dip netter at all population densities, it could bias abundance estimates.

Other biases could be due to the gear itself; striped bass of abnormal size may not be as vulnerable to the stunning effects of the electrofishing gear and could escape capture. Electrofishing tends to select for larger fish as they are more visible to the dip netters and have a lower immobilization threshold (Sullivan 1956; Reynolds 1996; Dolan and Miranda 2003; Ruetz et al. 2007). For this reason, the relative abundance of smaller fish is likely biased too low (Reynolds 1996). Collection of fish by netting may be associated with bias. Daugherty and Sutton (2005) demonstrated that capture efficiency was affected by moderate flow rates due to movement of fish out of range of the netters. Schoenebeck and Hansen (2005) indicated how gear saturation caused electrofishing catch rate to be non-linearly related to abundance. Some fish may be less likely to be immobilized by electrofishing gear. Dolan and Miranda (2003) demonstrated how immobilization thresholds were inversely proportional to body size. Conductivity, water temperature, water transparency, dissolved oxygen, depth, flow, and electric current are some of the factors that can impact the efficiency of electrofishing gear (Reynolds 1996; McInerny and Cross 2000; Speas et al. 2004; Buckmeier and Schlechte 2009).

2.2.3.5 Development of Estimates

A nominal index was calculated using a ratio estimator (numbers per minute; Pollock et al. 1994). A standardized index was also calculated using the GLM approach described in section 2.2.1.5. An offset term was included in the model to account for differences in survey effort (measured in minutes) among sampling events (Zuur et al. 2009, 2012).

Biological data collected during the survey were summarized to characterize both the length and age frequencies of striped bass observed by sex.

2.2.3.6 Estimates of Survey Statistics

Available covariates for the GLM were year, stratum, discharge, and temperature. The final best-fitting model assumed a negative binomial distribution (dispersion=1.3) and the significant covariates were year, stratum, and temperature. The nominal and GLM-standardized indices were similar throughout the time series (Figure 2.31). Both series exhibit inter-annual variation and both demonstrate a general declining trend since the early 2000s.

The total lengths of females observed in the Roanoke River Electrofishing Survey have ranged from 20 cm to 120 cm TL (Figure 2.32). Males have ranged in length from 10 cm to 110 cm TL. Some truncation of the length distributions is apparent in the most recent years of the survey.

A broad range of ages have been collected during this survey (Figure 2.33). Females have ranged in age from 1 to 17 years while males have ranged in age from 1 to 15 years. The age distributions have shown a truncation in the last few years of the survey.

3 ASSESSMENT

3.1 Method—Stock Synthesis

3.1.1 Scope

The unit stock was defined as all striped bass within the ASMA and RRMA.

3.1.2 Description

This assessment is based on a forward-projecting length-based, age-structured model. A two-sex model is assumed. The stock was modeled using Stock Synthesis (SS) text version 3.30.14 software (Methot 2000; Methot and Wetzel 2013; Methot et al. 2019). Stock Synthesis is an integrated statistical catch-at-age model that is widely used for stock assessments throughout the world. SS was also used to estimate reference point values. All input files are available upon request.

3.1.3 Dimensions

The assessment model was applied to data collected from within the range of the assumed biological stock unit (ASMA-RRMA; section 1.2.1).

The time period modeled was 1991 through 2017 using an annual time step based on the calendar year. The year 1991 was selected as the start year because it was the earliest year for which landings from the Albemarle Sound recreational fleet were available (section 2.1.3). The terminal year, 2017, was selected because it was the most recent year from which data were available at the start of the assessment process.

3.1.4 Structure / Configuration

3.1.4.1 Catch

The model initially incorporated three fishing fleets: ASMA commercial fishery (ARcomm), ASMA recreational fishery (ASrec), and the RRMA recreational fishery (RRrec). Landings (i.e., “retained” catch) were entered for each of these fleets (ARcomm: weight; ASrec: numbers; RRrec: numbers; Table 3.1; Figure 3.1). Dead discards (in numbers) were also included for each of the three fleets (Table 3.2; Figure 3.2). After evaluation of initial model runs, it was decided to treat the RRrec discards as a separate fleet (see section 3.1.4.8).

3.1.4.2 Survey Indices

Four indices of relative abundance were selected for input into the model. All indices were derived from fisheries-independent surveys (Table 3.3; Figure 3.3). The index derived from the Program 100 Juvenile Trawl Survey (P100juv) was input as an index of age-0 recruitment and so associated biological data (lengths or ages) were not required as inputs into the model. Indices derived from the fall/winter component of the Program 135 Independent Gill-Net Survey (P135fw), the spring component of the Program 135 Independent Gill-Net Survey (P135spr), and the Roanoke River Electrofishing Survey (RRef) were also used.

Changes in indices over time can occur due to factors other than changes in abundance; the fisheries-independent indices were standardized using a GLM approach to attempt to remove the impact of some of these factors (Maunder and Punt 2004; see sections 2.2.1–2.2.3). Catchability (q) was assumed to be time-invariant for each survey and all survey indices were assumed to have a linear relation to abundance.

3.1.4.3 Length Composition

Annual length frequencies were input for each fleet's landings and discards for the years in which lengths were available for the particular fleet (see sections 2.1.1–2.1.3). Annual length frequencies characterizing the P135fw, P135spr, and RRef surveys were also input (see sections 2.2.2 and 2.2.3). Where possible, sex-specific length frequencies were used. Length frequencies were input by 2-cm length bins ranging from 10 cm to 130 cm TL.

3.1.4.4 Age Composition

Annual sex-specific age data were input for the AScomm landings as well as the P135fw, P135spr, and RRef surveys. The age data were input as raw age-at-length data, rather than age compositions generated from applying age-length keys to the catch-at-length compositions. The input compositions are therefore the distribution of ages obtained from samples in each length bin (conditional age-at-length). This approach is considered a superior approach because it avoids double use of fish for both age and length information, it contains more detailed information about the age-length relationship and so improves the estimation of growth parameters, and the approach can match the protocols of sampling programs where age data are collected in a length-stratified program (Methot et al. 2019).

Age 15 was treated as a plus group that included ages 15 through 17, the maximum age within the data input into the stock assessment model. Ages were assumed to be associated with small bias and negligible imprecision.

3.1.4.5 Biological Parameters

Natural Mortality

Natural mortality is one of the most important parameters in a stock assessment and one of the most difficult to estimate. The availability of an empirical estimate is rare. The empirical estimate of natural mortality from the Harris and Hightower (2017) study (0.72, see section 1.2.6.1) was assumed for both females and males in the model presented to the peer reviewers (see section 5) and treated as an age-invariant, fixed input. While the peer reviewers were pleased with the working group's attempt to incorporate an empirical estimate of natural mortality, they felt the value was too high given the species maximum age (see section 1.2.6.1).

Given the uncertainty in the assumed rate of natural mortality, a series of sensitivity runs were performed at the second peer review workshop in which the assumption regarding natural mortality was varied (see section 3.1.7.2). The values assumed for natural mortality in these runs were selected from the range estimated based on the species life history (Table 1.4; section 1.2.6.1). After discussion between the working group and the peer review panel, a value of 0.40 was settled on for use in the final base run. This value was assumed for both sexes and treated as an age-invariant, fixed input. Both the working group and the peer review panel felt this value was more appropriate given the species' life history and maximum age and was closer to the empirical estimate of natural mortality estimated in the Harris and Hightower (2017) study than other values explored.

Growth

Growth (age-length) was assumed to be sex specific and was modeled using the von Bertalanffy growth curve. In the SS model, when fish recruit at the real age of 0.0, their length is set equal to the lower edge of the first population length bin (here, 10 cm; Methot et al. 2019). Fish then grow linearly until they reach a real age equal to a user-specified age (here, age 1). As the fish continue to age, they grow according to the von Bertalanffy growth equation.

Allowing SS to estimate the growth curve ensures that the assumptions about selectivity are consistent with other parts of the model and that uncertainty in the growth estimates is incorporated into the estimates of spawning stock biomass, fishing mortality, and reference points (Hall 2013). All age-length growth parameters were estimated for both sexes. The estimated growth parameters for each sex were L_∞, K, coefficient of variation (CV) for length at age 1, and CV for L_∞. Initial values for L_∞ and K were derived by fitting the von Bertalanffy model to the available age-length data by sex (see also section 1.2.4; Table 1.1). Initial values for the CVs for length at age 1 and L_∞ were derived empirically for each sex. The initial values for the growth parameters were treated as informative priors (prior standard deviation=0.05 for L_∞ and K; prior standard deviation=0.8 for CV1 and CV2) assuming a normal distribution. Examination of the observed data was used to set reasonable bounds on all growth parameters for males and females.

Parameters of the length-weight relationship were fixed (i.e., not estimated) for both males and females. The assumed values were those estimated in this report as described in section 1.2.4 (Table 1.2).

Maturity & Reproduction

Female maturity at age as estimated by Boyd (2011; section 1.2.5.4) was treated as a fixed input in the model. Reproduction was assumed to occur on January 1 each year.

Fecundity

The selected fecundity option in SS was such that causes eggs to be equivalent to spawning biomass.

3.1.4.6 Stock-Recruitment

A Beverton-Holt stock-recruitment relationship was assumed. Virgin recruitment, R_0, was estimated within the model. Steepness, h, was fixed at 0.9 and the standard deviation of log(recruitment), σ_R, was fixed at 0.6. Recruitment deviations were estimated from 1980 to 2015. The deviations are assumed to sum to zero over this time period. Setting the first year in which to estimate recruitment deviations (1974) earlier than the model start year (1991) allows for a non-equilibrium age structure at the start of the assessment time series (Methot et al. 2019).

3.1.4.7 Fishing Mortality

SS allows several options for reporting fishing mortality (*F*). The *F* values reported here represent a real annual *F* calculated as a numbers-weighted *F* (see Methot et al. 2019) for ages 3–5. This age range was selected based on the high selectivity for this age range by the fleets and the large percentage of the total catch this age range comprises. Note the last NCDMF stock assessment for striped bass reported apical *F* values (*F* at age 4) and so are not directlycomparable to the results of this assessment (Flowers et al. 2016).

3.1.4.8 Selectivity

In SS, selectivity can be a function of length and/or age. In the current assessment, selectivity was assumed to be a function of length for all fleets and surveys due to the high confidence in the length data for characterizing these data sources. Retention for the fleets was also assumed to be a function of length (the only option for retention parameters).

In initial runs, all selectivity patterns were modeled using the recommended double normal curve. The double normal curve is extremely flexible and can take on shapes ranging from asymptotic to dome shaped. Evaluation of the initial model fits to the length composition data indicated some potential issues with the predicted selectivity patterns (i.e., strong patterns in the length residuals). Fits to the RRrec harvest lengths were especially poor so the decision was made to fix the selectivity to match the protective slot (section 1.5.4) and treat the discard portion of this fishery as a separate fleet. The presence of strong residual patterns in the fits to the length composition data prompted consideration of an even more flexible selectivity function, the cubic spline. Use of the cubic spline for the ARcomm fleet (six nodes) and the P135fw survey (three nodes) provided improvements in fits to the length composition data associated with these fleets and so was assumed in the final base model.

Early model runs suggested difficulty in predicting the female and male length composition data from the RRef survey. Investigation of the data and discussion with the model developer suggested this was due to the highly skewed sex ratio and different length frequency patterns between female and male striped bass observed in the survey. The SS model allows for selectivity for male fish to differ from selectivity for female fish and this option was selected for the RRef survey. The male selectivity parameters were modeled as an offset of the female selectivity parameters.

3.1.4.9 Equilibrium Catch

The SS model needs to assume an initial condition of the population dynamics for the period prior to the estimation period. Typically, two approaches are used to meet this assumption. The first approach starts the model as far back as necessary to satisfy the notion that the period prior to the estimation of dynamics was in an unfished or near unfished state. For striped bass, reliable catch records back to the start of the fishery are not available. For this reason, the model developer recommended use of the second approach, which is to estimate (where possible) initial conditions assuming equilibrium catch (R.D. Methot Jr., NOAA Fisheries, personal communication). The equilibrium catch is the catch taken from a fish stock when it is in equilibrium with removals and natural mortality balanced by stable recruitment and growth.

3.1.5 Optimization

The SS model assumes an error distribution for each data component and assigns a variance to each observation. The ARcomm landings, ASrec and RRrec harvests, and RRrec discards were fit in the model assuming a lognormal error structure. These data were assumed precise and assigned a minimal observation error. The standard errors (SEs) of the annual ARcomm landings were assumed equal to 0.02 prior to the start of the Trip Ticket program (1994; section 2.1.1) and were assumed equal to 0.01 for the remainder of the time series. As the commercial landings data are derived from a census and recreational data are derived from a survey, a slightly higher standard error was assumed for the annual ASrec and RRrec harvest estimates (SE=0.02). The RRrec discard estimates were based on a hindcast method in earlier years (1991–1994) of the time series and were assumed to have a CV equal to 0.06. Discard estimates from this fleet in subsequent years were assumed to have a CV equal to 0.04.

As dead discards are part of the overall total removals, they were also assumed to be precise, though were assumed to have higher variance than the landings and harvest due to the increased uncertainty in the estimation methods. The coefficient of variation (CV) assumed for the ARcomm discards was derived from the GLM standardization (see section 2.1.2.5). The CVs for discards from the ASrec fleet were derived empirically. A normal distribution was assumed for the error structure of the discards for each fleet.

Survey indices were fit assuming a lognormal error distribution with variance estimated from the GLM standardization.

Composition information was fit assuming a multinomial error structure with variance described by the effective sample size. For each fleet and survey, the effective sample size was the number of sampled trips and a maximum of 200 was imposed.

The objective function for the base model included likelihood contributions from the landings and harvest, discards, survey indices, length compositions, age data, and recruitment deviations. The total likelihood is the weighted sum of the individual components. All likelihood components with the exception of the age data, were initially assigned a lambda weight equal to 1.0. Based on a recommendation from the model developer, the likelihood components for the age data were reduced to 0.25 (R.D. Methot Jr., NOAA Fisheries, personal communication).

The model results are dependent, sometimes highly, on the weighting of each data set (Francis 2011). Francis (2011) points out that there is wide agreement on the importance of weighting, but there is lack of consensus as to how it should be addressed. In integrated models that use multiple data sets, it is not uncommon for the composition data to drive the estimation of absolute abundance when inappropriate data weightings are applied or the selectivity process is miss-specified (Lee et al. 2014). Francis (2011) argues that abundance information should primarily come from indices of abundance and not from composition data. Following the recommendation of Francis (2011), the model was weighted in two stages. Stage 1 weights were largely empirically derived (standard errors, CVs, and effective sample sizes described earlier in this section) and applied to individual data observations. Stage 2 weights were applied to reweight the length and age composition data by adjusting the input effective sample sizes. The stage 2 weights were estimated based on method TA1.8 (Appendix A in Francis 2011) using the SSMethod.TA1.8 function within the r4ss package (Taylor et al. 2019) in R (R Core Team 2019).

3.1.6 Diagnostics

Several approaches were used to assess model convergence. The first diagnostic was to check whether the Hessian matrix (i.e., matrix of second derivatives of the likelihood with respect to the parameters) inverted. Next, the model convergence level was compared to the convergence criteria (0.0001, common default value). Ideally, the model convergence level will be less than the criteria.

Model stability was further evaluated using a "jitter" analysis. This analysis is a built-in feature of SS in which the initial parameter values are varied by a user-specified fraction. This allows evaluation of varying input parameter values on model results to ensure the model has converged on a global solution. A model that is well behaved should converge on a global solution across a reasonable range of initial parameter estimates (Cass-Calay et al. 2014). Initial parameters were randomly jittered by 10% for a series of 50 random trials. The final model total likelihood value, annual estimates of spawning stock biomass (SSB), annual *F* values, and associated thresholds (see section 4) from the jitter runs were compared to the base run results.

Additional diagnostics included evaluation of fits to landings and harvest, discards, indices, and length compositions and comparison of predicted growth parameters to empirical values. The evaluation of fits to the various data components included a visual comparison of observed and predicted values and calculation of standardized residuals for the fits to the fisheries-independent survey indices and length composition data. The standardized residuals were first visually inspected to evaluate whether any obvious patterns were present. In a model that is fit well, there should be no apparent pattern in the standardized residuals. If most of the residuals are within one standard deviation of the observed value, there is evidence of under-dispersion. This is indicative of a good predictive model for the data. That is, the model is fitting the data much better than expected, given the assumed sample size.

Checking for patterns in standardized residuals over time can be done via the runs test, which was applied to the standardized residuals of the fits to the fisheries-independent survey indices. The runs test was applied using the RunsTest function in the DescTools package (Signorell et al. 2019) in R (R Core Team 2019). In a perfectly fit model, the standardized residuals have a normal distribution with mean equal to 0 and standard deviation equal to 1. The Shapiro-Wilk distribution test was applied to determine whether the standardized residuals of the fits to the fisheries-independent survey indices were normally distributed. This test was conducted using the shapiro.test function within the stats package in R (R Core Team 2019). An alpha level of 0.05 was used for both the runs test and Shapiro-Wilk distribution test to determine significance.

3.1.7 Uncertainty & Sensitivity Analyses

3.1.7.1 Evaluate Data Sources

Uncertainty can also be explored by assessing the contribution of each source of information (Methot 1990). The contribution of a data source or other parameter(s) can be manipulated by changing the weight, or emphasis, of the associated likelihood component.

The contribution of different fisheries-independent surveys was explored by removing the data from each survey one at a time in a series of model runs. In each of these runs, the survey under evaluation was effectively removed by assigning a lambda weight of 0.0 to the likelihood component for that survey's index and associated biological data (if present).

Annual estimates of female spawning stock biomass and *F* were compared to those from the base run.

3.1.7.2 Alternative Natural Mortality

Natural mortality was assumed to be constant across sexes and ages in the final base run (M=0.40; section 3.1.4.5); however, natural mortality that varies by sex and age may be more realistic. In one sensitivity run, natural mortality was assumed equal to the values derived using the modified Lorenzen approach described in section 1.2.6.1 (assumed sex-specific and age-variable).

Additionally, a run was performed in which natural mortality was assumed equal to the empirical estimate of 0.72 derived from the Harris and Hightower (2017) study (assumed sex- and age-constant). Finally, a run was performed in which natural mortality was assumed equal to 0.30 to provide a run that used a lower range value for natural mortality (assumed sex- and age-constant).

3.1.8 Results

A summary of the input data used in the base run of the striped bass stock assessment model is shown in Figure 3.4.

3.1.8.1 Base Run—Diagnostics

The final base run resulted in an inverted Hessian matrix, but the model's final convergence level was 0.00673183. This value is higher than the convergence criteria, which was set at 0.0001. It is not unusual for models with hundreds of parameters to produce higher convergence levels and so values less than 1.0 for such models are typically deemed acceptable (R.D. Methot Jr., NOAA Fisheries, personal communication). Four out of 111 estimated parameters were estimated near their bounds (Table 3.4). These are the CV for female age at L_∞, CV for male age at L_∞, initial equilibrium F for the RRrec discard fleet, and one of the selectivity parameters for the ARcomm fleet.

Twenty one of the 50 jitter runs successfully converged (Table 3.5). None of the converged jitter runs resulted in a likelihood value that was lower than the base run (Figure 3.5). The majority of the converged runs produced similar trends in female SSB and F to the base run (Figure 3.6). The results of one of the converged runs (run 46) was not included in these plots as it estimated female SSB to be an order of magnitude higher and F an order of magnitude lower than the other converged runs. Overall, the jitter analysis gives evidence that the base model converged to the global solution.

There is near identical agreement between observed and predicted landings and harvest for the ARcomm, ASrec, and RRrec fleets (Figure 3.7). This is not unexpected given the small amount of error assumed for these data (section 3.1.5). The SS model tended to underestimate discards for the ARcomm fleet (Figure 3.8A). For the ASrec discards, the model overestimated in some years and underestimated in others (Figure 3.8B). The RRrec discards were fit well by the model (Figure 3.8C).

Model fits to the fisheries-independent survey indices are reasonable (Figures 3.9–3.12). The model-predicted indices tended to capture the overall trend in the observed values for the P100juv (Figure 3.9), P135fw (Figure 3.10), and RRef (Figure 3.12) survey indices but did a poor job of predicting the trend for the P135spr survey index (Figure 3.11). The model did not capture the same degree of inter-annual variability seen in the observed index. Visual inspection of the standardized residuals indicates no clear temporal patterns for any of the survey indices and this was confirmed by the results of the runs tests, which produced non-significant (α=0.05) P-values (Table 3.6). None of the standardized residuals for the fisheries-independent survey indices were found to be significantly different from a normal distribution based on the results of the Shapiro-Wilk test for normality.

The fits to the length compositions aggregated across time appear reasonable for most of the fleets and surveys with the exception of the fit to the ARcomm discard lengths (Figure 3.13). This poor fit is likely due, in part, to the small effective sample sizes associated with the ARcomm discard length compositions. Examination of the fits to the length composition data by individual year indicates fits ranging from good to poor (Figures 3.14–3.28). Again, the poor fit to the ARcomm discard lengths is evident (Figure 3.16). The presence of bimodality in the P135fw survey lengths provided some difficulty in model fitting (Figures 3.23, 3.24). This was also true for the P135spr survey lengths (Figures 3.25, 3.26). Residuals from the fits to the length composition data for the different data sources are shown in Figures 3.29–3.37. The fits to the length composition data from the P135fw survey (Figures 3.35), P135spr survey (Figure 3.36), and RRef survey (Figure 3.37) show residual patterns which suggest the periodic presence of strong year classes. The strongest length composition residual patterns are evident in the ASrec harvest (Figure 3.31) and ASrec discard (Figure 3.32) fits. Fits to the ASrec harvest lengths suggest underestimation at mid-range lengths and overestimation at the smallest and largest lengths (Figure 3.31). The opposite pattern is seen in the fits to the ASrec discard lengths, which shows overestimation at mid-range lengths and underestimation at the smallest and largest lengths (Figure 3.32).

The growth curves estimated by the model are similar to the curves derived empirically (Figure 3.38). The predicted growth curves for both females and males suggest a small degree of underestimation of length at age.

3.1.8.2 Base Run—Selectivity & Population Estimates

The predicted selectivity curves are shown in Figures 3.39–3.41 and are considered reasonable.

Annual predicted recruitment is variable among years and demonstrates a general decrease over the time series (Table 3.7; Figure 3.42). Predicted recruitment deviations are shown in Figure 3.43 and show no obvious concerning pattern.

There is less inter-annual variability in predicted female spawning stock biomass (SSB; Table 3.7; Figure 3.44) than that exhibited in the predicted recruitment values (Figure 3.42). Female SSB values were highest in the late 1990s through the mid-2000s and have generally decreased since. The predicted stock-recruitment relationship indicates the relation is not particularly strong (Figure 3.45). This is not unexpected given the model assumed a fixed value of 0.9 for the steepness parameter. Predicted values of spawner potential ratio (SPR) show a slightly decreasing trend over the time series (Table 3.7; Figure 3.46).

Predicted population numbers at age suggest 60–65% of the population has been dominated by age-0 and age-1 fish (Tables 3.8–3.9). These predicted numbers at age show an increase in the numbers of older fish through the mid-2000s, followed by a possible truncation of age structure in recent years. The predictions of landings at age for the ARcomm fleet indicate that most (~82%) of the fish captured are ages 3 through 5 (Table 3.10). The majority (84%) of the discards for the ARcomm fleet are ages 2 through 5 (Table 3.11). The harvest for the ASrec fleet is dominated (nearly 81%) by ages 3 through 6 (Table 3.12). Approximately 74% of the discards for the ASrec fleet are ages 3 and 4 (Table 3.13). The RRrec fleet captures mostly (93%) age-3 to age-5 striped bass in the harvest (Table 3.14) while most (67%) of the RRrec discards are age 3 and 4 (Table 3.15).

Model predictions of annual *F* (numbers-weighted, ages 3–5) exhibit moderate inter-annual variability throughout the assessment time series and peaks are observed in 2012 and 2016 (Table 3.16; Figure 3.47). Predicted *F* values range from a low of 0.15 in 1997, 1999, and 2003 to a high of 1.3 in 2012. There a decline in *F* in the last year of the time series.

3.1.8.3 Evaluate Data Sources

The removal of the different survey data sets had minimal impact on estimates of female SSB and *F* (Figure 3.48).

3.1.8.4 Alternative Natural Mortality

Assuming age-varying natural mortality (Lorenzen *M*) and a lower value of natural mortality (*M*=0.30) produced estimates of female SSB that were lower than those in the base run while the overall trends were similar (Figure 3.49A). Using the higher empirically-derived value of natural mortality (*M*=0.72) resulted in higher estimates of female SSB than those predicted in the base run. The model that assumed the empirical estimate of natural mortality resulted in lower estimates of *F* relative to the base run as did the run that assumed natural mortality varied with age and sex (Figure 3.49B). Predicted *F* values were slightly higher when the lower value of natural mortality was assumed (*M*=0.30). estimates of recruitment increased by an order of magnitude when using the empirically-derived natural mortality and when using the Lorenzen natural mortality (Figure 3.50).

3.2 Discussion of Results

The current stock assessment for striped bass indicates some concerning trends. Observed recruitment in recent years of the assessment time series (Figures 2.22, 3.3A) has been relatively low and predicted recruitment has been showing a general decline recently (Figure 3.42). Overall, recruitment is highly variable and has been generally lower in recent years relative to that observed and predicted from 1991 through 2000. From 1993 through 2000, the stock produced seven of the top nine year classes in terms of age-0 abundance. The 2000 cohort is the largest produced in the entire time series. Since then, from 2001 through 2006, five out of the six cohorts produced were below-average in terms of numbers and only the 2005-year class is considered a strong year class (Table 3.7; Figure 3.42). These observations suggest there is another factor besides simply the size of SSB that has an influence on producing strong year classes. Much research from the 1950s through the 1980s supports the importance of flow in the Roanoke River during the spawning period and subsequent weeks while eggs and larvae are being transported down the Roanoke River to the nursery habitat in the western Albemarle Sound and the importance of flow in supporting abundant striped bass year-class production (Hassler et al. 1981; Rulifson and Manooch 1990; Zincone and Rulifson 1991).

The length (Figures 2.2, 2.3) and age (Figures 2.4, 2.5) compositions of striped bass sampled from the commercial landings show that fewer larger and older fish have been observed in recent years. A truncation of the length (Figure 2.32) and age (Figure 2.33) structure is also evident in the observations from the Roanoke River Electrofishing Survey. Recent observations from the Roanoke River Electrofishing Survey of abundance are the lowest in the time series (Figure 2.31). The abundance of age 9+ fish in the survey has also been declining in recent years. Predicted population numbers at age show a truncation in the most recent years of the time series and an overall decline in total population abundance (Tables 3.8, 3.9). Predicted female SSB (Figure 3.44) has also shown a declining trend in recent years and, estimates in recent years have been the lowest in the entire time series. The 2016 estimate of fishing mortality was the second highest in the time series and declined in 2017 (Figure 3.47).

Performance of the stock assessment model was considered good in terms of predicting the observed data. The quality of the fits is strongly tied to the input variance and effective sample sizes. Fits to the observed landings, harvest, and discard were reasonable and this was expected given the low variance assumed for these data sources. Of the fisheries-independent survey indices, all but the P135spr index were fit well and no issues were detected among the residuals for any of the survey indices. The model was insensitive to the removal of the various sources of fisheries-independent survey data suggesting the different surveys share similar signals in the data with regard to population trends.

Striped bass commonly migrate outside the bounds of the A-R management unit, either to other internal waters of North Carolina such as western Pamlico Sound and the Tar-Pamlico, Pungo, and Neuse rivers or by joining the migratory ocean stock. The probability of migration increases with age and has increased over time (Callihan et al. 2014). In the most recent years examined in Callihan et al. (2014), the probability has been most significant for fish age 6 and older (20% or greater). In addition, smaller adults show evidence of density-dependent movements and habitat utilization, as the likelihood of recapture outside the ASMA in adjacent systems increases during periods of higher stock abundance. When a striped bass migrates, it may not return to its natal waterbody; this could be due to harvest outside of the ASMA and RRMA and is not accounted for in the harvest losses here. This loss of fish from the system will likely be interpreted by the model as losses due to natural and/or fishing mortality. The most recent assessments of the A-R striped bass stocks attempted to account for these migration losses by adjusting the natural mortality rate by the probability of migration and fishing mortality occurring in the Atlantic Ocean, thereby creating an estimate of total unobserved mortality that accounted for both natural mortality and losses not attributable to North Carolina fisheries (Mroch and Godwin 2014; Flowers et al. 2016). In this assessment, migration losses were not specifically modeled; this total unobserved mortality was treated as fixed in the modeling process.

The ages in this assessment were derived from scales and were assumed to be associated with small bias and negligible imprecision; however, Welch et al. (1993) found that scales tend to underage striped bass for fish that are older than age ten. This suggests that the maximum age assumed for this assessment, age 17, may be an underestimate of the true maximum age. Assuming maximum age that is too young can positively bias the estimates of SPR (Goodyear 1993) and the derived reference points.

There is additional recent evidence that age 17 may not be the maximum age for the A-R stock. In 2017, an angler returned a striped bass tag from a fish that had been tagged on the spawning grounds in 2007, which was aged at the time to 13 years old, increasing the oldest know age fish in the A-R stock to 23. In April 2020, an angler caught and cut the tag off a striped bass in the Roanoke River that was originally tagged in 1995 and estimated to be age 6, which suggests the oldest known fish in the stock is now at 31 years old, likely from the 1989 year class. Note that these instances are of single tag returns and it is not known how reflective they are of the relative abundance of these older fish in the stock. The available observed data suggested few fish older than age 9 are present in the stock, especially in recent years.

4 STATUS DETERMINATION CRITERIA

The General Statutes of North Carolina define overfished as “the condition of a fishery that occurs when the spawning stock biomass of the fishery is below the level that is adequate for the recruitment class of a fishery to replace the spawning class of the fishery” (NCGS § 113-129). The General Statues define overfishing as “fishing that causes a level of mortality that prevents a fishery from producing a sustainable harvest.”

The working group decided that the spawner potential ratio (SPR) was an appropriate proxy for developing reference points. Levels of SPR ranging from 20% to 50% have been found to be appropriate for various stocks, but historical analysis of SPR shows increased risk of recruitment overfishing levels if SPR falls below 30% (Walters and Martell 2004). For this assessment, threshold values were based on 35% SPR and targets were based on 45% SPR.

The fishing mortality reference points and the values of *F* that are compared to them represent numbers-weighted values for ages 3 to 5 (section 3.1.4.7). The SS model estimated a value of 0.13 for F_{Target} ($F_{45\%}$). The estimate of $F_{\text{Threshold}}$ ($F_{35\%}$) from the SS model was 0.18. The estimated value of fishing mortality in the terminal year (2017) of the model was 0.27, which is greater than the threshold value and suggests that overfishing is currently occurring in the stock ($F_{2017} > F_{\text{Threshold}}$; Figure 4.1).

The target level for female spawning stock biomass (SSB_{Target} or $SSB_{45\%}$) was estimated at 159 metric tons by the SS model. The estimated threshold for SSB ($SSB_{\text{Threshold}}$ or $SSB_{35\%}$) was 121 metric tons. Terminal year (2017) female SSB was 35.6 metric tons, which is less than the threshold value and suggests the stock is currently overfished ($SSB_{2017} < SSB_{\text{Threshold}}$; Figure 4.2).

The estimates in the most recent years are often associated with large uncertainty in stock assessment models. Approaching the ending year of the time series, the estimates of the most recent years lack data support from subsequent years during calibration. Nevertheless, stock status is often based on the terminal year estimates of fishing mortality and population size (or a proxy) to address the management needs and interests.

5 SUITABILITY FOR MANAGEMENT

Stocks assessments performed by the NCDMF in support of management plans are subject to an extensive review process, including a review by an external panel of experts. External reviews are designed to provide an independent peer review and are conducted by experts in stock assessment science and experts in the biology and ecology of the species. The goal of the external review is to ensure the results are based on the best science available and provide a valid basis for management.

The review workshop allows for discussion between the working group and review panel, enabling the reviewers to ask for and receive timely updates to the models as they evaluate the sensitivity of the results to different model assumptions. The workshop also allows the public to observe the peer review process and better understand the development of stock assessments.

The external peer review panel first met with the working group in person in December 2019. The reviewers were concerned with the external fit of the von Bertalanffy growth model to the observed age-length data; model predicted size was consistently smaller than empirical size for larger, older fish. The reviewers were also concerned with residual patterns in the fits to the length composition data indicative of model misspecification. Another major concern was failure of the model to capture trends observed in the empirical data. The peer reviewers did not support the presented model for management use but agreed to a second review after the working group addressed their concerns. In preparing the updated model, the working group noted an error in the input data that invalidated the first model. The working group corrected the data issue and also addressed the peer reviewer concerns regarding model fitting. A second assessment was presented to the peer review panel via webinar in June 2020.

The external peer reviewers worked with the working group to develop a model (presented in section 3) that the peer review endorsed for management use for at least the next five years and agreed the determination of stock status (overfished and overfishing) for the North Carolina Albemarle Sound-Roanoke River striped bass in the terminal year concurs with professional opinion and observations. The reviewers also agreed that: (1) the justification of inclusion and exclusion of data sources are appropriate; (2) the data sources used in this assessment are appropriate; (3) determination of stock status for the terminal year is robust to model assumptions on natural mortality and growth; (4) the extensive exploration of sensitivities to model assumptions and configurations, especially the sensitivity analysis regarding the natural mortality and growth assumptions, resolves the reviewers' primary areas of concerns such as the concerns over the fitting to growth data and length composition data and the concern regarding the overestimation of abundance for the last three years of the time series; (5) reviewers recommend future assessments consider key abiotic drivers of poor recruitment such as river flow and key biotic drivers such as catfish predation and competition; (6) reviewers also recommend collection of sex-specific growth data from juveniles and old fish to better inform growth estimates and length- or age-specific natural mortality estimates, and to resolve the concern on growth estimates showing little difference between males and females. Detailed comments from the external peer reviewers are provided in the Appendix.

While the peer reviewers did approve the model for management use and were confident in the declining trend in recruitment based on assessment results and results from the Juvenile Abundance Survey (P100; Figure 5.1), there was a great deal of uncertainty in the potential causes of the decline in recruitment (Appendix). One key uncertainty was related to the impacts of changes in river flow on YOY abundance. The review panel recognized the declining recruitment in the time series did not appear to result solely from reduced stock abundance due to harvest (i.e., overfishing). The review panel suggested future assessments consider formally incorporating the flow-recruitment relationship into the stock assessment as spring flow conditions are believed to influence recruitment and ultimately stock abundance. Another area of potential influence on the striped bass stock is the prevalence of the non-native blue catfish (*Ictalurus furcatus*). The population of blue catfish in the Roanoke River and western Albemarle Sound and tributaries has increased dramatically in recent years (Darsee et al. 2019; NCDMF 2019). The reviewers felt predation by blue catfishes could potentially impact recruitment of striped bass directly or could influence food resources for striped bass through competition for prey (e.g., Pine et al. 2005). The review panel recognized the degree to which this occurs is not known, but future assessments should consider this as a factor that may influence abundance but is not tied to striped bass harvest.

6 RESEARCH RECOMMENDATIONS

The research recommendations listed below are offered by the working group to improve future stock assessments of the A-R striped bass stock.

<u>High</u>

- Improve estimates of discard mortality rates and discard losses from the ASMA commercial gill-net fisheries (ongoing through observer program)
- Collect data to estimate catch-and-release discard losses in the ASMA recreational fishery during the closed harvest season
- Investigate relationship between river flow and striped bass recruitment for consideration of input into future stock assessment models

Medium

- Transition to an assessment that is based on ages derived from otoliths
- Improve estimates of catch-and-release discard losses in the RRMA recreational fishery during the closed harvest season
- Incorporate tagging data directly into the statistical catch-at-age model
- Improve the collection of length and age data to characterize commercial and recreational discards
- Explore the direct input of empirical weight-at-age data into the stock assessment model in lieu of depending on the estimated growth relationships

Low

- Re-evaluate catch-and-release mortality rates from the ASMA and RRMA recreational fisheries incorporating different hook types and angling methods at various water temperatures (e.g., live bait, artificial bait, and fly fishing)
- Investigate the potential impact of blue catfish on the A-R striped bass population (e.g., habitat, predation, forage)

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8 TABLES

Table 1.1. Parameter estimates and associated standard errors (in parentheses) of the von Bertalanffy age-length growth curve by sex. The function was fit to total length in centimeters.

Sex	**n**	L_∞	K	t_0
Female	29,991	160 (0.81)	0.071 (0.00063)	-0.62 (0.014)
Male	29,691	161 (1.3)	0.064 (0.00082)	-0.87 (0.017)

Table 1.2. Parameter estimates and associated standard errors (in parentheses) of the length-weight function by sex. The function was fit to total length in centimeters and weight in kilograms.

Sex	**n**	a	b
Female	28,814	2.8E-06 (4.4E-08)	3.2 (2.3E-03)
Male	33,411	5.9E-06 (1.0E-07)	3.1 (2.7E-03)

Table 1.3. Percent maturity of female striped bass as estimated by Boyd (2011).

Age	**% Maturity**
0	0
1	0
2	0
3	28.6
4	96.8
5	100
6	100
7	100
8	100
9	100
10	100
11	100
12	100
13	100
14	100
15	100
16	100
17	100

Table 1.4. Age-constant estimates of natural mortality derived from life history characteristics.

Method	Female	Male	Average
Alverson and Carney 1975	0.37	0.44	0.40
Hoenig 1983 (regression)	0.26	0.30	0.28
Hoenig 1983 (rule-of-thumb)	0.25	0.28	0.26
Ralston 1987 (linear regression)	0.16	0.15	0.16
Jensen 1996 (theoretical)	0.11	0.095	0.10
Jensen 1996 (derived from Pauly 1980)	0.11	0.10	0.11
Cubillos 2003	0.099	0.090	0.094
Hewitt and Hoenig 2005	0.25	0.28	0.26
Hoenig (nls; from Then et al. 2015)	0.37	0.41	0.39
Then et al. 2015	0.30	0.34	0.32
Average	0.23	0.25	0.24

Table 1.5. Estimates of natural mortality at age by sex based on the method of Lorenzen (1996).

Age	Female	Male
0	2.8	2.2
1	1.4	1.3
2	1.0	1.0
3	0.88	0.88
4	0.79	0.80
5	0.73	0.74
6	0.69	0.70
7	0.66	0.67
8	0.64	0.65
9	0.62	0.63
10	0.60	0.62
11	0.59	0.60
12	0.58	0.59
13	0.57	0.58
14	0.56	0.57
15	0.56	0.57
16	0.55	0.56
17	0.55	0.56

Table 1.6. Changes in the total allowable landings (TAL) in metric tons and pounds (in parentheses) for the ASMA-RRMA, 1991–2017.

Regulatory Period	ASMA Commercial	ASMA Recreational	RRMA Recreational	Combined TAL
1991–1997	44.45 (98,000)	13.34 (29,400)	13.34 (29,400)	71.12 (156,800)
1998	56.88 (125,400)	28.44 (62,700)	28.44 (62,700)	113.8 (250,800)
1999	62.57 (137,940)	31.28 (68,970)	31.28 (68,970)	125.2 (275,968)
2000–2002	102.1 (225,000)	51.03 (112,500)	51.03 (112,500)	204.1 (450,000)
2003–2014	124.7 (275,000)	62.37 (137,500)	62.37 (137,500)	249.5 (550,000)
2015–2017	62.37 (137,500)	31.18 (68,750)	31.18 (68,750)	124.7 (275,000)

Table 1.7. Striped bass commercial landings and discards and recreational harvest and discards from the ASMA-RRMA, 1991–2017.

	Commercial Landings	Commercial Discards	Recreational Harvest		Recreational Discards	
	ASMA	ASMA	ASMA	RRMA	ASMA	RRMA
Year	metric tons	numbers	numbers	numbers	numbers	numbers
1991	49.24	10,267	14,395	26,934	1,507	9,516
1992	45.65	8,434	10,542	13,372	1,279	4,725
1993	49.70	8,952	11,404	14,325	847.4	5,061
1994	46.48	4,302	8,591	8,284		2,927
1995	39.88	4,938	7,343	7,471		3,373
1996	40.92	4,150	7,433	8,367		10,461
1997	43.64	3,967	6,901	9,364	1,969	18,673
1998	56.26	5,817	19,566	23,109	5,881	12,159
1999	73.94	7,401	16,967	22,479	2,581	10,468
2000	97.17	10,500	38,085	38,206	5,052	5,961
2001	100.0	11,630	40,127	35,231	3,931	4,544
2002	101.2	6,633	27,896	36,422	3,300	3,570
2003	120.9	10,394	15,124	11,157	1,618	2,448
2004	124.2	4,475	28,004	26,506	2,627	11,989
2005	105.6	9,566	17,954	34,122	1,358	10,093
2006	84.62	6,715	10,711	25,355	605.1	4,194
2007	77.94	4,803	7,143	19,305	870.3	3,360
2008	34.01	2,538	10,048	10,541	2,366	12,137
2009	43.49	3,294	12,069	23,248	2,596	8,702
2010	90.72	10,017	3,504	22,445	1,037	7,930
2011	61.86	6,646	13,341	22,102	1,381	6,894
2012	52.48	4,256	22,345	28,847	1,598	4,033
2013	31.03	6,706	4,299	7,718	1,048	4,750
2014	32.23	2,794	5,529	11,058	1,478	10,594
2015	51.98	3,539	23,240	20,031	3,170	6,927
2016	55.89	3,989	4,794	21,260	662.5	3,369
2017	34.50	2,762	4,215	9,899	1,578	5,021

Table 2.1. Annual estimates of commercial gill-net discards (numbers of fish), 1991–2017. Note that values prior to 2012 were estimated using a hindcasting approach.

Year	Discards
1991	10,267
1992	8,434
1993	8,952
1994	4,302
1995	4,938
1996	4,150
1997	3,967
1998	5,817
1999	7,401
2000	10,500
2001	11,630
2002	6,633
2003	10,394
2004	4,475
2005	9,566
2006	6,715
2007	4,803
2008	2,538
2009	3,294
2010	10,017
2011	6,646
2012	4,256
2013	6,706
2014	2,794
2015	3,539
2016	3,989
2017	2,762

Table 2.2. Annual estimates of recreational harvest and dead discards (numbers of fish) for the ASMA, 1991–2017.

Year	Harvest	Discards
1991	14,395	1,507
1992	10,542	1,279
1993	11,404	847
1994	8,591	
1995	7,343	
1996	7,433	
1997	6,901	1,969
1998	19,566	5,881
1999	16,967	2,581
2000	38,085	5,052
2001	40,127	3,931
2002	27,896	3,300
2003	15,124	1,618
2004	28,004	2,627
2005	17,954	1,358
2006	10,711	605
2007	7,143	870
2008	10,048	2,366
2009	12,069	2,596
2010	3,504	1,037
2011	13,341	1,381
2012	22,345	1,598
2013	4,299	1,048
2014	5,529	1,478
2015	23,240	3,170
2016	4,794	663
2017	4,215	1,578

Table 2.3. Annual estimates of recreational harvest and dead discards (numbers of fish) for the RRMA, 1991–2017. Note that discard values prior to 1995 were estimated using a hindcasting approach.

Year	Harvest	Discards
1991	26,934	9,516
1992	13,372	4,725
1993	14,325	5,061
1994	8,284	2,927
1995	7,471	3,373
1996	8,367	10,461
1997	9,364	18,673
1998	23,109	12,159
1999	22,479	10,468
2000	38,206	5,961
2001	35,231	4,544
2002	36,422	3,570
2003	11,157	2,448
2004	26,506	11,989
2005	34,122	10,093
2006	25,355	4,194
2007	19,305	3,360
2008	10,541	12,137
2009	23,248	8,702
2010	22,445	7,930
2011	22,102	6,894
2012	28,847	4,033
2013	7,718	4,750
2014	11,058	10,594
2015	20,031	6,927
2016	21,260	3,369
2017	4,215	5,021

Table 3.1. Annual estimates of commercial landings and recreational harvest that were input into the SS model, 1991–2017. Values assumed for the coefficients of variation (CVs) are also provided.

Year	ASMA Commercial		ASMA Recreational		RRMA Recreational	
	metric tons	CV	numbers	CV	numbers	CV
1991	49.24	0.02	14,395	0.02	26,934	0.02
1992	45.65	0.02	10,542	0.02	13,372	0.02
1993	49.70	0.02	11,404	0.02	14,325	0.02
1994	46.48	0.01	8,591	0.02	8,284	0.02
1995	39.88	0.01	7,343	0.02	7,471	0.02
1996	40.92	0.01	7,433	0.02	8,367	0.02
1997	43.64	0.01	6,901	0.02	9,364	0.02
1998	56.26	0.01	19,566	0.02	23,109	0.02
1999	73.94	0.01	16,967	0.02	22,479	0.02
2000	97.17	0.01	38,085	0.02	38,206	0.02
2001	99.99	0.01	40,127	0.02	35,231	0.02
2002	101.18	0.01	27,896	0.02	36,422	0.02
2003	120.91	0.01	15,124	0.02	11,157	0.02
2004	124.20	0.01	28,004	0.02	26,506	0.02
2005	105.64	0.01	17,954	0.02	34,122	0.02
2006	84.62	0.01	10,711	0.02	25,355	0.02
2007	77.94	0.01	7,143	0.02	19,305	0.02
2008	34.01	0.01	10,048	0.02	10,541	0.02
2009	43.49	0.01	12,069	0.02	23,248	0.02
2010	90.72	0.01	3,504	0.02	22,445	0.02
2011	61.86	0.01	13,341	0.02	22,102	0.02
2012	52.48	0.01	22,345	0.02	28,847	0.02
2013	31.03	0.01	4,299	0.02	7,718	0.02
2014	32.23	0.01	5,529	0.02	11,058	0.02
2015	51.98	0.01	23,240	0.02	20,031	0.02
2016	55.89	0.01	4,794	0.02	21,260	0.02
2017	34.50	0.01	4,215	0.02	9,899	0.02

Table 3.2. Annual estimates of dead discards that were input into the SS model, 1991–2017. Values assumed for the coefficients of variation (CVs) are also provided.

	Albemarle/Roanoke Commercial		Albemarle Sound Recreational		Roanoke River Recreational	
Year	**numbers**	**CV**	**numbers**	**CV**	**numbers**	**CV**
1991	10,267	0.82	1,507	0.060	9,516	0.06
1992	8,434	0.67	1,279	0.051	4,725	0.06
1993	8,952	0.72	847	0.034	5,061	0.06
1994	4,302	0.34			2,927	0.06
1995	4,938	0.40			3,373	0.04
1996	4,150	0.33			10,461	0.04
1997	3,967	0.32	1,969	0.079	18,673	0.04
1998	5,817	0.47	5,881	0.24	12,159	0.04
1999	7,401	0.59	2,581	0.10	10,468	0.04
2000	10,500	0.84	5,052	0.20	5,961	0.04
2001	11,630	0.93	3,931	0.16	4,544	0.04
2002	6,633	0.53	3,300	0.13	3,570	0.04
2003	10,394	0.83	1,618	0.065	2,448	0.04
2004	4,475	0.36	2,627	0.11	11,989	0.04
2005	9,566	0.77	1,358	0.054	10,093	0.04
2006	6,715	0.54	605	0.024	4,194	0.04
2007	4,803	0.38	870	0.035	3,360	0.04
2008	2,538	0.20	2,366	0.095	12,137	0.04
2009	3,294	0.26	2,596	0.10	8,702	0.04
2010	10,017	0.80	1,037	0.041	7,930	0.04
2011	6,646	0.53	1,381	0.055	6,894	0.04
2012	4,256	0.17	1,598	0.064	4,033	0.04
2013	6,706	0.27	1,048	0.042	4,750	0.04
2014	2,794	0.11	1,478	0.059	10,594	0.04
2015	3,539	0.14	3,170	0.13	6,927	0.04
2016	3,989	0.16	663	0.027	3,369	0.04
2017	2,762	0.11	1,578	0.063	5,021	0.04

Table 3.3. GLM-standardized indices of relative abundance derived from fisheries-independent surveys that were input into the SS model, 1991–2017. The empirically-derived standard errors (SEs) are also provided.

	Program 100 Juvenile		Program 135 Fall/Winter		Program 135 Spring		Roanoke River Electrofishing	
Year	**Index**	**SE**	**Index**	**SE**	**Index**	**SE**	**Index**	**SE**
1991	0.709	0.19	0.44	0.043				
1992	2.12	0.51	0.44	0.037	0.48	0.034		
1993	42.4	8.8	0.42	0.039	0.28	0.021		
1994	59.4	12	0.79	0.071	0.18	0.017	125	21
1995	8.54	1.8	0.31	0.024	0.94	0.063	42.1	7.0
1996	35.0	7.2	0.59	0.051	0.67	0.048	29.0	5.0
1997	5.12	1.1	0.54	0.031	0.84	0.057	75.7	12
1998	5.24	1.3	0.94	0.066	1.1	0.074	102	16
1999	0.968	0.26	0.49	0.034	1.1	0.069	92.1	15
2000	55.9	12	0.37	0.042	0.92	0.061	72.1	12
2001	3.52	0.82	0.50	0.053	1.1	0.072	210	35
2002	5.68	1.2	0.31	0.028	0.83	0.057	110	24
2003	0.253	0.095	0.80	0.060	0.38	0.029	221	39
2004	1.72	0.43	0.47	0.036	0.86	0.064	57.1	11
2005	23.0	4.8	0.65	0.057	0.71	0.051	104	17
2006	2.87	0.64	0.20	0.016	1.0	0.072	120	20
2007	4.94	1.1	0.83	0.085	0.41	0.031	53.0	8.8
2008	5.35	1.2	0.55	0.058	1.2	0.089	77.2	12
2009	0.363	0.11	0.54	0.048	0.71	0.057	76.5	13
2010	6.75	1.4	0.60	0.081	0.99	0.081	106	19
2011	15.3	3.2	0.20	0.018	1.1	0.094	46.3	7.7
2012	3.42	0.79	0.23	0.020	1.2	0.11	58.2	9.1
2013	0.369	0.11	0.37	0.032	1.4	0.12	39.6	7.6
2014	17.0	3.6	0.32	0.037	0.93	0.081	66.7	13
2015	18.4	3.8	0.17	0.017	0.51	0.039	46.4	9.1
2016	5.39	1.1	0.12	0.018	0.31	0.026	20.1	3.7
2017	1.29	0.30			0.36	0.030	14.5	2.5

Table 3.4. Parameter values, standard deviations (SD), phase of estimation, and status from the base run of the stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD[Value]	Phase	Status
1	NatM_p_1_Fem_GP_1	0.40		-2	fixed
2	L_at_Amin_Fem_GP_1	17	0.050	3	estimated
3	L_at_Amax_Fem_GP_1	160	0.050	3	estimated
4	VonBert_K_Fem_GP_1	0.065	0.0010	3	estimated
5	CV_young_Fem_GP_1	0.19	0.0053	3	estimated
6	CV_old_Fem_GP_1	0.0010	8.4E-07	3	LO
7	Wtlen_1_Fem_GP_1	4.6E-06		-3	fixed
8	Wtlen_2_Fem_GP_1	3.2		-3	fixed
9	Mat50%_Fem_GP_1	1		-3	fixed
10	Mat_slope_Fem_GP_1	0		-3	fixed
11	Eggs/kg_inter_Fem_GP_1	1		-3	fixed
12	Eggs/kg_slope_wt_Fem_GP_1	0		-3	fixed
13	NatM_p_1_Mal_GP_1	0.40		-2	fixed
14	L_at_Amin_Mal_GP_1	18	0.050	4	estimated
15	L_at_Amax_Mal_GP_1	161	0.050	4	estimated
16	VonBert_K_Mal_GP_1	0.060	0.0011	4	estimated
17	CV_young_Mal_GP_1	0.19	0.0060	4	estimated
18	CV_old_Mal_GP_1	0.0010	8.0E-07	4	LO
19	Wtlen_1_Mal_GP_1	7.5E-06		-3	fixed
20	Wtlen_2_Mal_GP_1	3.1		-3	fixed
21	CohortGrowDev	1.0		-1	fixed
22	FracFemale_GP_1	0.50		-99	fixed
23	SR_LN(R0)	6.2	0.039	1	estimated
24	SR_BH_steep	0.90		-4	fixed
25	SR_sigmaR	0.60		-4	fixed
26	SR_regime	0		-4	fixed
27	SR_autocorr	0		-99	fixed
28	Main_InitAge_17	-0.37	0.52	4	estimated
29	Main_InitAge_16	-0.20	0.55	4	estimated
30	Main_InitAge_15	-0.23	0.55	4	estimated

Table 3.4. **(*continued*)** Parameter values, standard deviations (SD), phase of estimation, and status from the base run of the stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD[Value]	Phase	Status
31	Main_InitAge_14	-0.30	0.53	4	estimated
32	Main_InitAge_13	-0.36	0.52	4	estimated
33	Main_InitAge_12	-0.38	0.50	4	estimated
34	Main_InitAge_11	-0.53	0.48	4	estimated
35	Main_InitAge_10	-0.75	0.45	4	estimated
36	Main_InitAge_9	-0.77	0.39	4	estimated
37	Main_InitAge_8	-0.76	0.34	4	estimated
38	Main_InitAge_7	-0.79	0.31	4	estimated
39	Main_InitAge_6	-0.88	0.30	4	estimated
40	Main_InitAge_5	-0.70	0.28	4	estimated
41	Main_InitAge_4	-0.23	0.22	4	estimated
42	Main_InitAge_3	0.65	0.091	4	estimated
43	Main_InitAge_2	0.037	0.11	4	estimated
44	Main_InitAge_1	-0.48	0.12	4	estimated
45	Main_RecrDev_1991	-0.54	0.12	4	estimated
46	Main_RecrDev_1992	-0.25	0.11	4	estimated
47	Main_RecrDev_1993	0.72	0.081	4	estimated
48	Main_RecrDev_1994	1.2	0.076	4	estimated
49	Main_RecrDev_1995	0.89	0.099	4	estimated
50	Main_RecrDev_1996	1.6	0.074	4	estimated
51	Main_RecrDev_1997	0.81	0.11	4	estimated
52	Main_RecrDev_1998	1.2	0.086	4	estimated
53	Main_RecrDev_1999	0.36	0.14	4	estimated
54	Main_RecrDev_2000	1.5	0.062	4	estimated
55	Main_RecrDev_2001	0.38	0.098	4	estimated
56	Main_RecrDev_2002	0.00039	0.085	4	estimated
57	Main_RecrDev_2003	-0.92	0.13	4	estimated
58	Main_RecrDev_2004	-0.12	0.088	4	estimated
59	Main_RecrDev_2005	0.81	0.077	4	estimated
60	Main_RecrDev_2006	0.47	0.098	4	estimated

Table 3.4. **(*continued*)** Parameter values, standard deviations (SD), phase of estimation, and status from the base run of the stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD[Value]	Phase	Status
61	Main_RecrDev_2007	0.56	0.083	4	estimated
62	Main_RecrDev_2008	-0.24	0.082	4	estimated
63	Main_RecrDev_2009	-1.6	0.12	4	estimated
64	Main_RecrDev_2010	0.065	0.077	4	estimated
65	Main_RecrDev_2011	0.77	0.059	4	estimated
66	Main_RecrDev_2012	-0.0074	0.089	4	estimated
67	Main_RecrDev_2013	-0.91	0.16	4	estimated
68	Main_RecrDev_2014	0.43	0.095	4	estimated
69	Main_RecrDev_2015	0.39	0.11	4	estimated
70	Main_RecrDev_2016	0.020	0.13	4	estimated
71	Main_RecrDev_2017	-0.47	0.15	4	estimated
72	InitF_seas_1_flt_1ARcomm	0.085	0.0064	1	estimated
73	InitF_seas_1_flt_2ASrec	0.011	0.00055	1	estimated
74	InitF_seas_1_flt_3RRrecharv	0.019	0.00089	1	estimated
75	InitF_seas_1_flt_8RRecdisc	0.0057	0.00031	1	LO
76	LnQ_base_P100juv(4)	-8.2	0.56	5	estimated
77	Q_power_P100juv(4)	0.60	0.086	6	estimated
78	LnQ_base_P135fw(5)	-3.0	0.17	5	estimated
79	Q_power_P135fw(5)	-0.54	0.033	6	estimated
80	LnQ_base_P135spr(6)	-1.7	0.19	5	estimated
81	Q_power_P135spr(6)	-0.74	0.033	6	estimated
82	LnQ_base_RRef(7)	1.8	0.22	5	estimated
83	Q_power_RRef(7)	-0.37	0.056	6	estimated
84	SizeSpline_Code_ARcomm(1)	2.0		-99	fixed
85	SizeSpline_GradLo_ARcomm(1)	0.060	0.046	3	estimated
86	SizeSpline_GradHi_ARcomm(1)	0.0010	9.0E-05	3	HI
87	SizeSpline_Knot_1_ARcomm(1)	29		-99	fixed
88	SizeSpline_Knot_2_ARcomm(1)	45		-99	fixed
89	SizeSpline_Knot_3_ARcomm(1)	49		-99	fixed
90	SizeSpline_Knot_4_ARcomm(1)	52		-99	fixed

Table 3.4. (***continued***) Parameter values, standard deviations (SD), phase of estimation, and status from the base run of the stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD[Value]	Phase	Status
91	SizeSpline_Knot_5_ARcomm(1)	55		-99	fixed
92	SizeSpline_Knot_6_ARcomm(1)	88		-99	fixed
93	SizeSpline_Val_1_ARcomm(1)	-6.1	0.29	2	estimated
94	SizeSpline_Val_2_ARcomm(1)	-4.4	0.23	2	estimated
95	SizeSpline_Val_3_ARcomm(1)	-2.1	0.13	2	estimated
96	SizeSpline_Val_4_ARcomm(1)	-1.0		-99	fixed
97	SizeSpline_Val_5_ARcomm(1)	-1.1	0.072	2	estimated
98	SizeSpline_Val_6_ARcomm(1)	-2.6	0.30	2	estimated
99	Retain_L_infl_ARcomm(1)	30	3.6	1	estimated
100	Retain_L_width_ARcomm(1)	9.6	1.7	2	estimated
101	Retain_L_asymptote_logit_ARcomm(1)	999		-4	fixed
102	Retain_L_maleoffset_ARcomm(1)	0		-4	fixed
103	Size_DblN_peak_ASrec(2)	53	0.28	1	estimated
104	Size_DblN_top_logit_ASrec(2)	0.13	209	1	estimated
105	Size_DblN_ascend_se_ASrec(2)	3.7	0.057	2	estimated
106	Size_DblN_descend_se_ASrec(2)	3.5	123	2	estimated
107	Size_DblN_start_logit_ASrec(2)	-999		-4	fixed
108	Size_DblN_end_logit_ASrec(2)	15		-5	fixed
109	Retain_L_infl_ASrec(2)	40	0.38	1	estimated
110	Retain_L_width_ASrec(2)	5.1	0.19	2	estimated
111	Retain_L_asymptote_logit_ASrec(2)	999		-4	fixed
112	Retain_L_maleoffset_ASrec(2)	0		-4	fixed
113	Size_DblN_peak_RRrecharv(3)	46		-3	fixed
114	Size_DblN_top_logit_RRrecharv(3)	-2.2		-3	fixed
115	Size_DblN_ascend_se_RRrecharv(3)	-4.0		-4	fixed
116	Size_DblN_descend_se_RRrecharv(3)	-2.0		-4	fixed
117	Size_DblN_start_logit_RRrecharv(3)	-999		-4	fixed
118	Size_DblN_end_logit_RRrecharv(3)	-999		-5	fixed
119	SizeSpline_Code_P135fw(5)	2.0		-99	fixed
120	SizeSpline_GradLo_P135fw(5)	0.56	0.11	3	estimated

Table 3.4. (***continued***) Parameter values, standard deviations (SD), phase of estimation, and status from the base run of the stock assessment model. LO or HI indicates parameter values estimated near their bounds.

ID	Label	Value	SD[Value]	Phase	Status
121	SizeSpline_GradHi_P135fw(5)	-0.41	0.091	3	estimated
122	SizeSpline_Knot_1_P135fw(5)	25		-99	fixed
123	SizeSpline_Knot_2_P135fw(5)	42		-99	fixed
124	SizeSpline_Knot_3_P135fw(5)	57		-99	fixed
125	SizeSpline_Val_1_P135fw(5)	-4.6	0.38	2	estimated
126	SizeSpline_Val_2_P135fw(5)	-1.0		-99	fixed
127	SizeSpline_Val_3_P135fw(5)	-1.4	0.26	2	estimated
128	Size_DblN_peak_P135spr(6)	47	2.2	1	estimated
129	Size_DblN_top_logit_P135spr(6)	-0.018	222	1	estimated
130	Size_DblN_ascend_se_P135spr(6)	5.1	0.22	2	estimated
131	Size_DblN_descend_se_P135spr(6)	3.5	123	2	estimated
132	Size_DblN_start_logit_P135spr(6)	-999		-4	fixed
133	Size_DblN_end_logit_P135spr(6)	15		-5	fixed
134	Size_DblN_peak_RRef(7)	57	1.1	1	estimated
135	Size_DblN_top_logit_RRef(7)	0.014	219	1	estimated
136	Size_DblN_ascend_se_RRef(7)	4.4	0.099	2	estimated
137	Size_DblN_descend_se_RRef(7)	3.5	123	2	estimated
138	Size_DblN_start_logit_RRef(7)	-999		-4	fixed
139	Size_DblN_end_logit_RRef(7)	15		-5	fixed
140	SzSel_MaleDogleg_RRef(7)	59	1.8	1	estimated
141	SzSel_MaleatZero_RRef(7)	7.9	1.1	1	estimated
142	SzSel_MaleatDogleg_RRef(7)	0		-4	fixed
143	SzSel_MaleatMaxage_RRef(7)	-6.2	5.6	2	estimated
144	Size_DblN_peak_RRecdisc(8)	51	0.69	3	estimated
145	Size_DblN_top_logit_RRecdisc(8)	0.052	222	3	estimated
146	Size_DblN_ascend_se_RRecdisc(8)	4.4	0.095	4	estimated
147	Size_DblN_descend_se_RRecdisc(8)	3.5	123	4	estimated
148	Size_DblN_start_logit_RRecdisc(8)	-999		-4	fixed
149	Size_DblN_end_logit_RRecdisc(8)	15		-5	fixed

Table 3.5. Results of the base run compared to the results of 50 jitter trials in which initial parameter values were jittered by 10%. A single asterisk (*) indicates that the Hessian matrix did not invert. Two asteriskes (**) indicate that the convergence level was greater than 1.

Run	Total LL	SSB_{2017}	$SSB_{Threshold}$	F_{2017}	$F_{Threshold}$
base	4,879	35.6	121	0.266	0.18
1	*				
2	**				
3	**				
4	*				
5	*				
6	*				
7	5,061	41.7	115	0.22	0.18
8	4,879	35.3	121	0.27	0.18
9	*				
10	4,956	35.5	115	0.26	0.18
11	*				
12	6,138	51.3	29.7	0.05	0.30
13	*				
14	4,879	35.3	121	0.27	0.18
15	4,879	35.6	121	0.27	0.18
16	4,879	35.6	121	0.27	0.18
17	5,298	45.5	40.2	0.07	0.20
18	**				
19	**				
20	4,879	35.6	121	0.27	0.18
21	*				
22	**				
23	4,879	35.3	121	0.27	0.18
24	*				
25	*				

Table 3.5. **(*continued*)** Results of the base run compared to the results of 50 jitter trials in which initial parameter values were jittered by 10%. A single asterisk (*) indicates that the Hessian matrix did not invert. Two asteriskes (**) indicate that the convergence level was greater than 1.

Run	Total LL	SSB_{2017}	$SSB_{Threshold}$	F_{2017}	$F_{Threshold}$
26	4,879	35.3	121	0.27	0.18
27	4,879	35.3	121	0.27	0.18
28	*				
29	4,886	35.6	122	0.27	0.19
30	*				
31	4,879	35.3	121	0.27	0.18
32	**				
33	**				
34	**				
35	4,879	35.3	121	0.27	0.18
36	*				
37	*				
38	7,009	50.4	42	0.087	0.19
39	4,956	35.5	115	0.26	0.18
40	**				
41	*				
42	*				
43	4,879	35.6	121	0.27	0.18
44	4,879	35.6	121	0.27	0.18
45	**				
46	7,390	1,667	739	0.026	0.27
47	*				
48	**				
49	*				
50	4,879	35.6	121	0.27	0.18

Table 3.6. Results of the runs test for temporal patterns and results of the Shapiro-Wilk test for normality applied to the standardized residuals of the fits to the fisheries-independent survey indices from the base run of the assessment model. *P*-values were considered significant at $\alpha = 0.05$.

	Runs Test		Shapiro-Wilk	
Survey	**median**	***P*-value**	**W**	***P*-value**
P100juv	-0.029	0.70	0.98	0.80
P135fw	0.016	1.0	0.98	0.81
P135spr	0.017	0.31	0.97	0.70
RRef	0.019	0.30	0.97	0.67

Table 3.7. Annual estimates of recruitment (thousands of fish), female spawning stock biomass (SSB; metric tons), and spawner potential ratio (SPR) and associated standard deviations (SDs) from the base run of the stock assessment model, 1991–2017.

Year	Recruitment		SSB		SPR	
	Value	SD	Value	SD	Value	SD
1991	227	27	148	10	0.22	0.012
1992	299	30	129	8.0	0.30	0.011
1993	780	57	116	7.0	0.26	0.011
1994	1,211	83	87	6.1	0.25	0.013
1995	876	82	67	4.9	0.23	0.011
1996	1,720	110	66	4.0	0.23	0.0096
1997	850	88	105	5.5	0.31	0.012
1998	1,284	98	165	8.2	0.31	0.012
1999	564	79	203	10	0.35	0.012
2000	1,736	87	266	12	0.29	0.010
2001	583	53	255	12	0.28	0.010
2002	398	31	243	11	0.28	0.010
2003	157	20	220	10	0.32	0.010
2004	356	29	259	8.1	0.27	0.0062
2005	889	60	209	5.7	0.24	0.0061
2006	618	57	140	4.2	0.20	0.0065
2007	643	46	81	3.3	0.14	0.0061
2008	277	20	60	3.1	0.21	0.0078
2009	75	9	94	4.6	0.24	0.0096
2010	404	28	108	4.6	0.22	0.0082
2011	810	40	100	2.7	0.21	0.0054
2012	357	29	68	1.7	0.11	0.0044
2013	111	17	21	1.0	0.13	0.0053
2014	510	49	41	1.9	0.20	0.0065
2015	541	62	76	2.7	0.17	0.0058
2016	359	49	58	2.3	0.16	0.0076
2017	202	31	36	2.7	0.18	0.012

Table 3.8. Predicted population numbers (numbers of fish) at age at the beginning of the year from the base run of the stock assessment model, 1991–2017.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1991	226,690	168,260	188,106	233,819	63,912	25,981	13,654	9,380	6,190	3,942	2,602	2,091	1,583	1,047	721	502	336	528
1992	298,814	151,951	112,634	125,023	136,282	24,395	7,538	4,169	3,328	2,451	1,652	1,118	908	690	457	315	219	378
1993	779,868	200,297	101,736	75,069	77,339	64,844	9,498	2,946	1,778	1,527	1,172	806	550	448	341	226	156	295
1994	1,211,036	522,750	134,083	67,734	45,664	34,408	22,844	3,376	1,163	766	690	542	376	258	210	160	106	212
1995	875,700	811,762	349,814	89,216	41,084	19,718	11,354	7,542	1,252	478	333	309	246	171	118	96	73	146
1996	1,720,200	586,983	543,056	232,456	53,319	16,624	5,845	3,361	2,552	476	195	140	132	106	74	51	41	94
1997	850,404	1,153,053	392,701	360,342	138,727	21,982	5,069	1,757	1,136	961	191	81	59	56	45	31	22	58
1998	1,283,700	570,034	771,993	261,187	222,840	67,949	8,925	2,033	754	520	457	93	39	29	27	22	15	39
1999	564,216	860,478	381,751	514,639	162,098	108,982	27,753	3,635	887	349	249	222	45	19	14	13	11	27
2000	1,736,040	378,201	576,252	254,690	323,729	83,014	47,650	12,152	1,702	440	179	130	116	24	10	7	7	20
2001	582,912	1,163,685	253,259	384,410	157,504	153,276	32,110	18,429	5,091	762	205	85	62	56	11	5	4	13
2002	398,252	390,732	779,193	168,910	236,515	72,748	56,893	11,898	7,437	2,208	344	94	39	29	26	5	2	8
2003	157,198	266,953	261,601	519,606	103,739	108,157	26,827	21,318	4,941	3,354	1,042	166	46	19	14	13	3	5
2004	355,698	105,371	178,669	174,420	326,834	51,302	43,366	10,649	9,240	2,326	1,659	528	85	24	10	7	7	4
2005	889,434	238,426	70,529	118,948	106,898	148,739	18,382	15,420	4,162	3,930	1,039	759	244	40	11	5	3	5
2006	617,552	596,193	159,578	46,919	71,316	44,860	48,553	6,191	5,931	1,778	1,777	483	357	115	19	5	2	4
2007	642,528	413,945	398,816	106,011	27,249	25,795	11,768	13,588	2,106	2,341	760	788	217	162	52	8	2	3
2008	277,352	430,673	276,335	263,098	56,240	6,450	3,405	1,699	2,766	562	726	253	271	76	56	18	3	2
2009	75,442	185,910	288,136	183,127	153,665	21,566	1,767	911	513	931	202	268	95	102	29	21	7	2
2010	404,054	50,569	124,449	191,666	109,788	65,088	7,117	592	343	212	404	90	121	43	46	13	10	4
2011	809,868	270,836	33,815	82,579	113,573	42,732	18,416	2,083	207	139	94	186	42	57	20	22	6	6
2012	357,286	542,855	181,202	22,451	48,267	42,752	11,647	5,122	675	76	55	38	77	17	24	8	9	5
2013	110,836	239,483	362,573	119,121	10,411	6,946	2,761	821	530	93	12	9	7	14	3	4	2	3
2014	509,662	74,290	159,688	237,869	61,499	2,172	691	274	115	100	21	3	2	2	4	1	1	1
2015	541,110	341,625	49,683	105,708	137,920	22,681	561	177	82	39	37	8	1	1	1	1	0	1
2016	358,590	362,706	228,496	32,914	59,484	44,092	4,617	110	40	21	11	11	2	0	0	0	0	0
2017	201,758	240,360	242,368	151,168	18,131	16,999	7,995	913	29	13	8	4	4	1	0	0	0	0

Table 3.9. Predicted population numbers (numbers of fish) at age at mid-year from the base run of the stock assessment model, 1991–2017.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1991	185,596	137,665	153,355	178,506	39,479	13,994	7,544	5,587	3,895	2,551	1,706	1,378	1,046	692	477	332	222	349
1992	244,646	124,334	91,953	98,331	93,998	15,222	4,712	2,722	2,255	1,695	1,154	784	638	486	322	222	154	266
1993	638,495	163,879	83,012	58,548	51,580	38,486	5,662	1,851	1,167	1,027	797	551	377	307	234	155	107	202
1994	991,500	427,629	109,372	52,752	30,003	19,764	13,126	2,056	745	505	462	365	254	174	142	108	72	143
1995	716,952	663,952	285,161	68,969	26,130	10,735	6,177	4,387	772	305	216	202	161	113	77	63	48	96
1996	1,408,361	480,113	442,364	179,575	34,230	9,179	3,204	1,954	1,566	302	125	91	86	69	48	33	27	61
1997	696,247	943,477	320,264	283,368	97,083	14,007	3,210	1,151	768	662	133	56	41	39	31	22	15	40
1998	1,050,997	466,488	630,316	205,761	155,829	43,425	5,696	1,342	513	359	318	65	28	20	19	15	11	27
1999	461,938	704,168	311,814	408,170	115,996	72,061	18,364	2,487	624	250	179	161	33	14	10	10	8	19
2000	1,421,338	309,488	470,656	200,285	222,738	51,628	29,633	7,865	1,139	300	123	89	80	16	7	5	5	14
2001	477,245	952,227	206,828	301,525	107,033	93,380	19,546	11,707	3,352	512	139	58	42	38	8	3	2	9
2002	326,059	319,712	636,296	132,372	159,925	44,176	34,825	7,667	4,994	1,517	239	66	27	20	18	4	2	5
2003	128,701	218,394	213,608	412,096	72,947	68,484	16,902	14,035	3,390	2,359	742	119	33	14	10	9	2	3
2004	291,217	86,208	145,782	136,546	220,461	30,708	25,859	6,657	6,026	1,554	1,123	359	58	16	7	5	4	3
2005	728,199	195,058	57,526	92,102	69,239	84,979	10,668	9,562	2,720	2,643	708	520	168	27	8	3	2	3
2006	505,602	487,618	130,066	35,756	42,880	22,975	25,683	3,610	3,726	1,162	1,183	324	240	78	13	4	1	3
2007	526,041	338,213	323,925	77,210	13,248	9,370	4,470	6,127	1,088	1,303	438	462	128	96	31	5	1	2
2008	227,074	352,268	224,954	201,066	34,819	3,376	1,762	933	1,604	337	441	155	166	46	35	11	2	1
2009	61,766	152,106	235,001	141,791	99,996	12,389	1,023	559	329	614	134	180	64	68	19	14	5	1
2010	330,805	41,352	101,375	147,538	68,481	34,620	3,850	350	218	141	274	61	83	29	32	9	7	3
2011	663,054	221,530	27,553	63,132	69,667	22,308	9,712	1,185	125	87	60	120	27	37	13	14	4	4
2012	292,513	443,650	146,918	15,287	18,284	10,862	3,091	1,646	251	30	23	16	32	7	10	4	4	2
2013	90,741	195,557	293,675	85,586	4,751	2,190	870	306	230	44	6	5	3	7	2	2	1	1
2014	417,269	60,753	129,924	181,124	37,339	1,104	350	150	67	61	13	2	1	1	2	1	1	1
2015	443,017	279,392	40,438	79,294	77,954	10,232	249	84	42	21	20	4	1	1	0	1	0	0
2016	293,582	296,493	185,853	24,428	31,785	18,774	2,053	56	23	13	7	7	1	0	0	0	0	0
2017	165,182	196,503	197,152	114,032	10,402	7,901	3,755	476	16	8	5	3	3	1	0	0	0	0

Table 3.10. Predicted landings at age (numbers of fish) for the ARcomm fleet from the base run of the stock assessment model, 1991–2017.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1991	1	71	343	5,471	6,939	4,564	2,537	1,507	802	424	249	188	139	91	62	43	29	46
1992	1	56	180	2,626	14,205	4,219	1,355	632	401	244	146	93	73	55	36	25	17	30
1993	3	84	185	1,781	8,912	12,240	1,869	492	237	168	115	74	49	40	30	20	14	26
1994	6	280	310	2,048	6,627	8,068	5,564	702	194	106	85	63	43	29	24	18	12	24
1995	5	509	948	3,137	6,788	5,182	3,098	1,768	237	75	47	41	32	22	15	12	9	19
1996	9	353	1,410	7,831	8,514	4,236	1,538	755	461	72	26	18	16	13	9	6	5	11
1997	3	414	609	7,365	14,253	3,764	897	261	133	93	16	6	5	4	3	2	2	4
1998	3	163	953	4,251	18,195	9,279	1,264	242	71	40	31	6	2	2	2	1	1	2
1999	2	253	485	8,674	13,903	15,772	4,171	458	88	29	18	15	3	1	1	1	1	2
2000	5	121	796	4,627	29,136	12,388	7,379	1,585	176	37	13	9	8	2	1	1	0	1
2001	2	401	377	7,519	15,131	24,258	5,271	2,552	560	69	16	6	5	4	1	0	0	1
2002	1	149	1,284	3,653	25,030	12,703	10,383	1,845	920	226	31	8	3	2	2	0	0	1
2003	1	130	553	14,578	14,580	25,101	6,437	4,322	799	449	124	19	5	2	2	1	0	1
2004	1	48	351	4,496	41,186	10,561	9,239	1,921	1,330	277	175	53	8	2	1	1	1	0
2005	4	113	145	3,178	13,613	30,847	4,009	2,893	628	492	116	80	25	4	1	0	0	0
2006	4	388	448	1,689	11,656	11,653	13,435	1,508	1,183	297	265	68	49	16	3	1	0	1
2007	8	540	2,241	7,346	7,529	10,445	5,107	5,422	717	686	201	198	53	39	13	2	1	1
2008	1	252	698	8,544	8,469	1,531	834	354	463	78	90	30	31	9	6	2	0	0
2009	0	79	527	4,351	17,469	3,992	342	151	68	102	20	25	8	9	3	2	1	0
2010	3	39	413	8,231	21,876	20,587	2,371	173	82	42	72	15	20	7	8	2	2	1
2011	4	160	86	2,714	17,182	10,254	4,629	453	37	20	12	23	5	7	2	3	1	1
2012	4	616	885	1,276	9,669	12,003	3,488	1,407	157	15	10	6	13	3	4	1	1	1
2013	2	396	2,580	10,352	3,474	3,242	1,343	363	200	31	4	3	2	4	1	1	0	1
2014	3	53	492	9,393	11,112	614	203	70	24	17	3	0	0	0	0	0	0	0
2015	3	234	147	3,949	22,544	5,624	143	39	15	6	5	1	0	0	0	0	0	0
2016	3	358	974	1,758	13,414	15,131	1,701	37	11	5	2	2	0	0	0	0	0	0
2017	2	220	955	7,576	4,002	5,752	2,837	286	7	3	2	1	1	0	0	0	0	0

Table 3.11. Predicted dead discards at age (numbers of fish) for the ARcomm fleet from the base run of the stock assessment model, 1991–2017.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1991	3	112	257	856	714	376	163	70	24	7	2	1	0	0	0	0	0	0
1992	3	88	135	411	1,462	348	87	29	12	4	1	0	0	0	0	0	0	0
1993	9	133	138	279	917	1,008	121	23	7	3	1	0	0	0	0	0	0	0
1994	19	442	232	321	682	665	359	33	6	2	1	0	0	0	0	0	0	0
1995	16	804	710	491	699	427	200	82	7	1	0	0	0	0	0	0	0	0
1996	30	557	1,055	1,226	876	349	99	35	14	1	0	0	0	0	0	0	0	0
1997	9	653	456	1,153	1,467	310	58	12	4	2	0	0	0	0	0	0	0	0
1998	11	257	713	665	1,872	764	82	11	2	1	0	0	0	0	0	0	0	0
1999	5	399	363	1,358	1,431	1,299	269	21	3	0	0	0	0	0	0	0	0	0
2000	16	190	596	724	2,998	1,020	476	74	5	1	0	0	0	0	0	0	0	0
2001	6	633	282	1,177	1,557	1,998	340	119	17	1	0	0	0	0	0	0	0	0
2002	4	235	961	572	2,576	1,047	670	86	27	4	0	0	0	0	0	0	0	0
2003	2	206	414	2,282	1,500	2,068	415	201	24	8	1	0	0	0	0	0	0	0
2004	5	76	263	704	4,238	870	596	89	40	5	2	0	0	0	0	0	0	0
2005	12	179	109	497	1,401	2,541	259	135	19	8	1	0	0	0	0	0	0	0
2006	12	612	336	264	1,200	960	866	70	35	5	2	0	0	0	0	0	0	0
2007	24	852	1,678	1,150	775	861	329	252	21	12	2	1	0	0	0	0	0	0
2008	5	398	522	1,337	872	126	54	16	14	1	1	0	0	0	0	0	0	0
2009	1	124	395	681	1,798	329	22	7	2	2	0	0	0	0	0	0	0	0
2010	9	61	309	1,288	2,252	1,696	153	8	2	1	1	0	0	0	0	0	0	0
2011	14	253	65	425	1,768	845	299	21	1	0	0	0	0	0	0	0	0	0
2012	12	973	663	200	996	990	225	65	5	0	0	0	0	0	0	0	0	0
2013	5	625	1,931	1,620	358	268	87	17	6	1	0	0	0	0	0	0	0	0
2014	11	84	368	1,470	1,144	51	13	3	1	0	0	0	0	0	0	0	0	0
2015	11	369	110	618	2,321	464	9	2	0	0	0	0	0	0	0	0	0	0
2016	10	566	729	275	1,381	1,248	110	2	0	0	0	0	0	0	0	0	0	0
2017	5	347	715	1,186	412	474	183	13	0	0	0	0	0	0	0	0	0	0

Table 3.12. Predicted harvest at age (numbers of fish) for the ASrec fleet from the base run of the stock assessment model, 1991–2017.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1991	0	0	76	3,143	3,292	2,256	1,548	1,232	876	576	385	311	236	156	108	75	50	79
1992	0	0	31	1,198	5,351	1,656	656	411	348	263	179	122	99	76	50	34	24	41
1993	0	0	33	834	3,448	4,933	928	328	211	187	145	100	69	56	43	28	19	37
1994	0	0	45	767	2,049	2,598	2,207	373	138	94	86	68	47	32	27	20	13	27
1995	0	0	130	1,120	2,002	1,592	1,172	897	161	64	45	42	34	24	16	13	10	20
1996	0	0	174	2,520	2,263	1,172	524	345	282	55	23	16	16	12	9	6	5	11
1997	0	0	66	2,072	3,312	911	267	104	71	62	12	5	4	4	3	2	1	4
1998	0	0	241	2,804	9,911	5,266	883	226	89	62	55	11	5	4	3	3	2	5
1999	0	0	80	3,742	4,953	5,854	1,908	281	72	29	21	19	4	2	1	1	1	2
2000	0	0	232	3,507	18,238	8,080	5,931	1,707	253	67	28	20	18	4	2	1	1	3
2001	0	0	113	5,851	9,724	16,241	4,349	2,823	827	127	34	14	10	9	2	1	1	2
2002	0	0	266	1,968	11,135	5,888	5,929	1,413	941	287	45	12	5	4	3	1	0	1
2003	0	0	50	3,423	2,827	5,071	1,602	1,442	356	249	79	13	3	1	1	1	0	0
2004	0	0	59	1,964	14,858	3,969	4,278	1,192	1,103	286	207	66	11	3	1	1	1	0
2005	0	0	19	1,089	3,854	9,097	1,457	1,409	409	399	107	79	25	4	1	0	0	1
2006	0	0	44	431	2,457	2,558	3,635	547	574	179	183	50	37	12	2	1	0	0
2007	0	0	150	1,281	1,084	1,566	944	1,346	238	283	95	100	28	21	7	1	0	0
2008	0	0	134	4,283	3,506	660	442	253	442	93	122	43	46	13	10	3	1	0
2009	0	0	104	2,230	7,394	1,759	186	110	66	124	27	36	13	14	4	3	1	0
2010	0	0	12	607	1,332	1,306	185	18	11	7	14	3	4	2	2	0	0	0
2011	0	0	14	1,147	5,995	3,726	2,072	272	29	20	14	28	6	9	3	3	1	1
2012	0	0	290	1,088	6,812	8,805	3,152	1,706	255	30	23	16	32	7	10	4	4	2
2013	0	0	219	2,285	633	615	314	114	84	16	2	2	1	2	1	1	0	0
2014	0	0	53	2,636	2,576	148	60	28	13	11	2	0	0	0	0	0	0	0
2015	0	0	47	3,310	15,606	4,053	127	46	23	11	11	2	0	0	0	0	0	0
2016	0	0	64	300	1,889	2,219	307	9	4	2	1	1	0	0	0	0	0	0
2017	0	0	79	1,627	710	1,062	645	87	3	1	1	0	0	0	0	0	0	0

Table 3.13. Predicted dead discards at age (numbers of fish) for the ASrec fleet from the base run of the stock assessment model, 1991–2017.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1991	0	0	42	789	457	175	63	23	7	2	1	0	0	0	0	0	0	0
1992	0	0	17	301	743	129	27	8	3	1	0	0	0	0	0	0	0	0
1993	0	0	18	210	479	384	38	6	2	1	0	0	0	0	0	0	0	0
1994	0	0	25	193	284	202	90	7	1	0	0	0	0	0	0	0	0	0
1995	0	0	72	281	278	124	48	17	1	0	0	0	0	0	0	0	0	0
1996	0	0	96	633	314	91	21	7	2	0	0	0	0	0	0	0	0	0
1997	0	0	36	521	460	71	11	2	1	0	0	0	0	0	0	0	0	0
1998	0	0	133	704	1,376	410	36	4	1	0	0	0	0	0	0	0	0	0
1999	0	0	44	940	687	455	77	5	1	0	0	0	0	0	0	0	0	0
2000	0	0	128	881	2,531	628	241	33	2	0	0	0	0	0	0	0	0	0
2001	0	0	62	1,470	1,350	1,263	176	54	7	0	0	0	0	0	0	0	0	0
2002	0	0	147	494	1,546	458	241	27	8	1	0	0	0	0	0	0	0	0
2003	0	0	28	860	392	395	65	28	3	1	0	0	0	0	0	0	0	0
2004	0	0	32	493	2,062	309	174	23	9	1	0	0	0	0	0	0	0	0
2005	0	0	11	274	535	708	59	27	3	1	0	0	0	0	0	0	0	0
2006	0	0	24	108	341	199	148	10	5	1	0	0	0	0	0	0	0	0
2007	0	0	83	322	151	122	38	26	2	1	0	0	0	0	0	0	0	0
2008	0	0	74	1,076	487	52	18	5	4	0	0	0	0	0	0	0	0	0
2009	0	0	57	560	1,027	137	8	2	1	0	0	0	0	0	0	0	0	0
2010	0	0	6	152	185	102	8	0	0	0	0	0	0	0	0	0	0	0
2011	0	0	8	288	832	290	84	5	0	0	0	0	0	0	0	0	0	0
2012	0	0	160	273	947	686	128	33	2	0	0	0	0	0	0	0	0	0
2013	0	0	121	574	88	48	13	2	1	0	0	0	0	0	0	0	0	0
2014	0	0	29	662	358	12	2	1	0	0	0	0	0	0	0	0	0	0
2015	0	0	26	832	2,167	316	5	1	0	0	0	0	0	0	0	0	0	0
2016	0	0	35	75	262	173	13	0	0	0	0	0	0	0	0	0	0	0
2017	0	0	43	409	99	83	26	2	0	0	0	0	0	0	0	0	0	0

Table 3.14. Predicted harvest at age (numbers of fish) for the RRrec fleet from the base run of the stock assessment model, 1991–2017.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1991	0	0	150	11,196	9,646	4,067	1,353	413	90	14	2	0	0	0	0	0	0	0
1992	0	0	35	2,402	8,825	1,683	323	77	20	4	0	0	0	0	0	0	0	0
1993	0	0	41	1,851	6,293	5,551	509	69	13	3	0	0	0	0	0	0	0	0
1994	0	0	47	1,449	3,186	2,491	1,031	67	7	1	0	0	0	0	0	0	0	0
1995	0	0	134	2,078	3,055	1,498	537	158	9	1	0	0	0	0	0	0	0	0
1996	0	0	154	4,022	2,971	950	207	52	13	1	0	0	0	0	0	0	0	0
1997	0	0	64	3,609	4,745	805	115	17	4	1	0	0	0	0	0	0	0	0
1998	0	0	221	4,628	13,454	4,405	361	36	4	1	0	0	0	0	0	0	0	0
1999	0	0	89	7,427	8,085	5,888	934	53	4	0	0	0	0	0	0	0	0	0
2000	0	0	202	5,501	23,526	6,421	2,294	254	12	1	0	0	0	0	0	0	0	0
2001	0	0	94	8,769	11,985	12,336	1,607	401	36	1	0	0	0	0	0	0	0	0
2002	0	0	338	4,512	20,998	6,843	3,355	307	62	5	0	0	0	0	0	0	0	0
2003	0	0	35	4,297	2,919	3,227	496	172	13	2	0	0	0	0	0	0	0	0
2004	0	0	50	2,987	18,583	3,060	1,607	172	48	3	0	0	0	0	0	0	0	0
2005	0	0	39	3,958	11,518	16,758	1,306	486	43	10	1	0	0	0	0	0	0	0
2006	0	0	131	2,306	10,811	6,941	4,797	277	88	7	1	0	0	0	0	0	0	0
2007	0	0	470	7,232	5,037	4,490	1,315	716	38	11	1	0	0	0	0	0	0	0
2008	0	0	102	5,843	3,936	458	150	33	17	1	0	0	0	0	0	0	0	0
2009	0	0	144	5,561	15,168	2,229	115	26	5	2	0	0	0	0	0	0	0	0
2010	0	0	60	5,631	10,168	6,147	425	16	3	0	0	0	0	0	0	0	0	0
2011	0	0	20	2,975	12,797	4,907	1,329	67	2	0	0	0	0	0	0	0	0	0
2012	0	0	376	2,545	13,113	10,458	1,823	378	17	1	0	0	0	0	0	0	0	0
2013	0	0	281	5,284	1,206	725	180	25	6	0	0	0	0	0	0	0	0	0
2014	0	0	67	5,976	4,805	171	34	6	1	0	0	0	0	0	0	0	0	0
2015	0	0	29	3,628	14,074	2,258	35	5	1	0	0	0	0	0	0	0	0	0
2016	0	0	244	2,061	10,685	7,749	524	6	1	0	0	0	0	0	0	0	0	0
2017	0	0	146	5,436	1,952	1,804	535	28	0	0	0	0	0	0	0	0	0	0

Table 3.15. Predicted dead discards at age (numbers of fish) for the RRrec fleet from the base run of the stock assessment model, 1991–2017.

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1991	0	7	446	3,809	2,058	1,043	624	470	327	214	143	115	87	58	40	28	19	29
1992	0	3	132	1,034	2,383	546	189	112	93	69	47	32	26	20	13	9	6	11
1993	0	5	153	789	1,683	1,782	292	98	62	54	42	29	20	16	12	8	6	11
1994	0	11	156	551	760	713	529	85	31	21	19	15	10	7	6	4	3	6
1995	0	20	505	895	825	486	312	226	40	16	11	10	8	6	4	3	2	5
1996	0	31	1,636	4,868	2,255	865	338	210	168	32	13	10	9	7	5	4	3	7
1997	0	65	1,288	8,341	6,878	1,400	359	132	88	76	15	6	5	4	4	3	2	5
1998	0	16	1,235	2,951	5,381	2,116	310	75	29	20	18	4	2	1	1	1	1	2
1999	0	16	421	4,036	2,756	2,410	685	95	24	10	7	6	1	1	0	0	0	1
2000	0	4	339	1,057	2,836	930	596	162	24	6	3	2	2	0	0	0	0	0
2001	0	10	123	1,309	1,122	1,387	324	199	57	9	2	1	1	1	0	0	0	0
2002	0	3	327	499	1,456	570	501	113	74	22	4	1	0	0	0	0	0	0
2003	0	1	72	1,013	432	573	158	134	33	23	7	1	0	0	0	0	0	0
2004	0	3	250	1,713	6,684	1,321	1,243	327	296	76	55	18	3	1	0	0	0	0
2005	0	7	119	1,393	2,542	4,440	620	567	161	156	42	31	10	2	0	0	0	0
2006	0	13	195	393	1,155	890	1,103	157	161	50	51	14	10	3	1	0	0	0
2007	0	11	590	1,036	453	484	254	342	59	70	23	25	7	5	2	0	0	0
2008	0	29	1,060	6,951	2,937	409	239	129	221	46	60	21	23	6	5	2	0	0
2009	0	7	592	2,618	4,480	789	73	41	24	44	10	13	5	5	1	1	0	0
2010	0	2	234	2,492	2,823	2,047	253	23	14	9	18	4	5	2	2	1	0	0
2011	0	10	72	1,206	3,255	1,497	726	90	9	7	4	9	2	3	1	1	0	0
2012	0	26	507	392	1,266	1,211	378	193	28	3	2	2	4	1	1	0	0	0
2013	0	14	1,231	2,646	379	272	121	42	30	6	1	1	0	1	0	0	0	0
2014	0	5	632	6,463	3,260	139	49	21	10	9	2	0	0	0	0	0	0	0
2015	0	14	120	1,731	4,213	810	22	8	4	2	2	0	0	0	0	0	0	0
2016	0	11	410	396	1,289	1,121	135	4	1	1	0	0	0	0	0	0	0	0
2017	0	11	634	2,693	607	672	356	45	2	1	0	0	0	0	0	0	0	0

Table 3.16. Annual estimates of fishing mortality (numbers-weighted, ages 3–5) and associated standard deviations (SDs) from the base run of the stock assessment model, 1991–2017.

	Fishing Mortality	
Year	**Value**	**SD**
1991	0.25	0.015
1992	0.23	0.012
1993	0.35	0.021
1994	0.32	0.020
1995	0.28	0.019
1996	0.20	0.012
1997	0.15	0.0082
1998	0.21	0.012
1999	0.15	0.0071
2000	0.26	0.013
2001	0.24	0.012
2002	0.29	0.017
2003	0.15	0.0066
2004	0.30	0.0099
2005	0.42	0.011
2006	0.52	0.026
2007	0.48	0.030
2008	0.21	0.013
2009	0.28	0.015
2010	0.34	0.0094
2011	0.44	0.010
2012	1.3	0.057
2013	0.35	0.023
2014	0.23	0.0091
2015	0.50	0.017
2016	0.75	0.045
2017	0.27	0.025

9 FIGURES

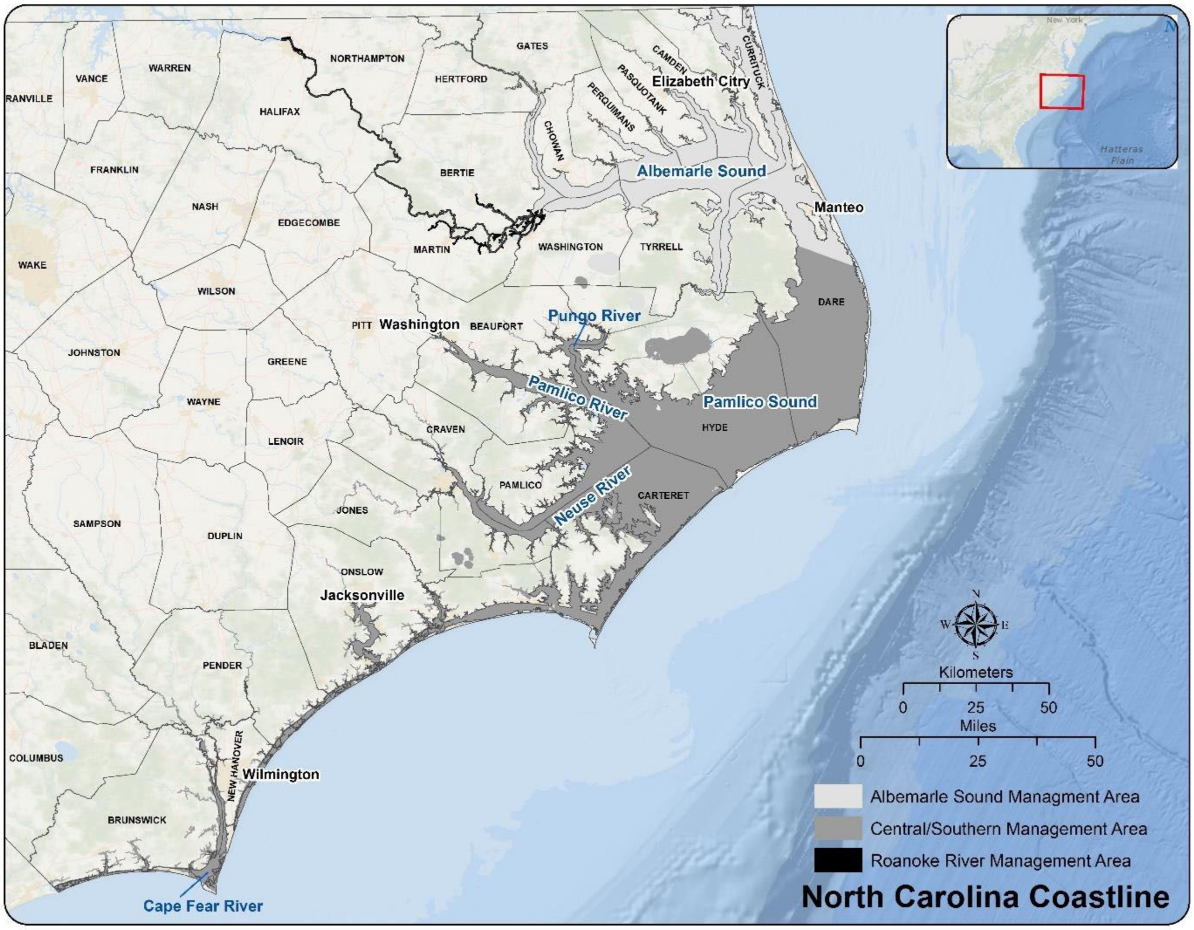

Figure 1.1. Boundary lines defining the Albemarle Sound Management Area, Central-Southern Management Area, and the Roanoke River Management Area.

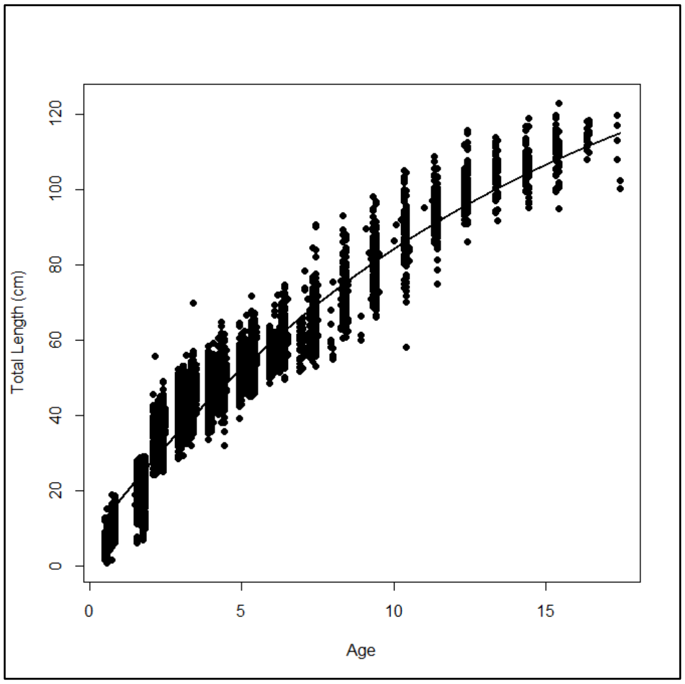

Figure 1.2. Fit of the age-length function to available age data for female striped bass.

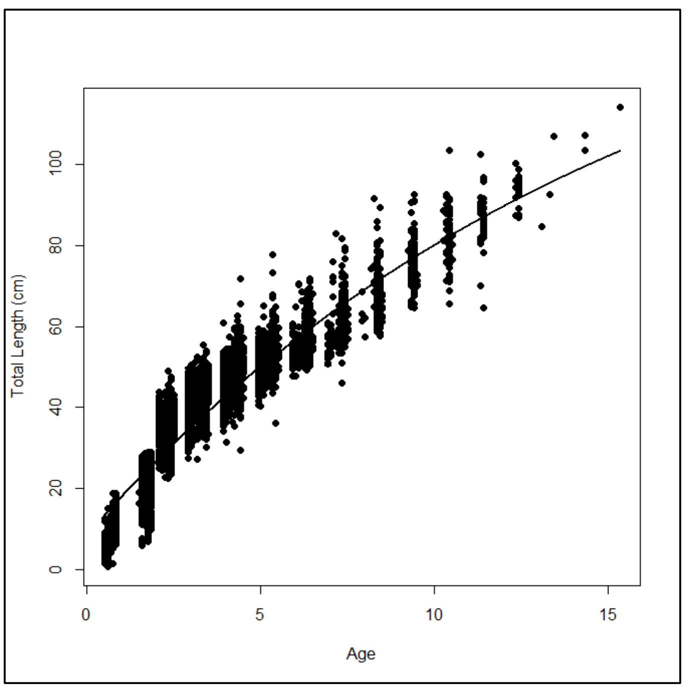

Figure 1.3. Fit of the age-length function to available age data for male striped bass.

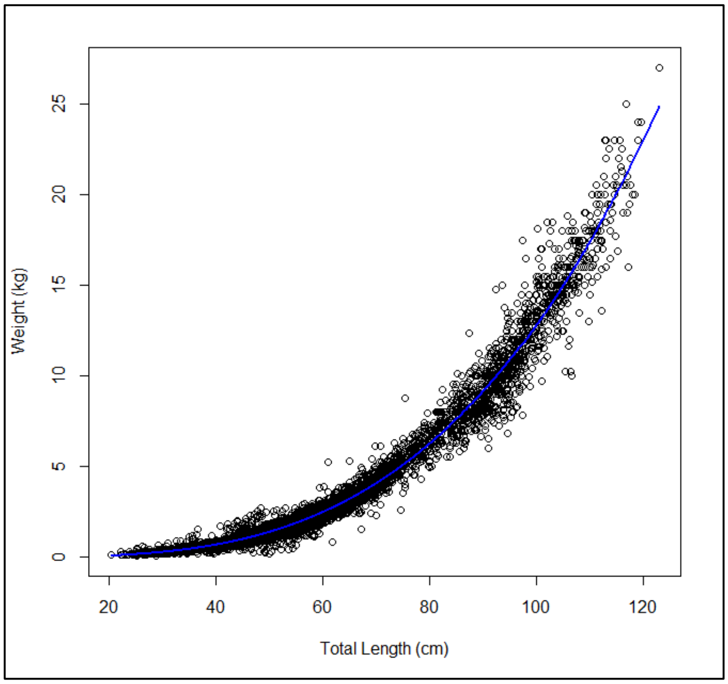

Figure 1.4. Fit of the length-weight function to available biological data for female striped bass.

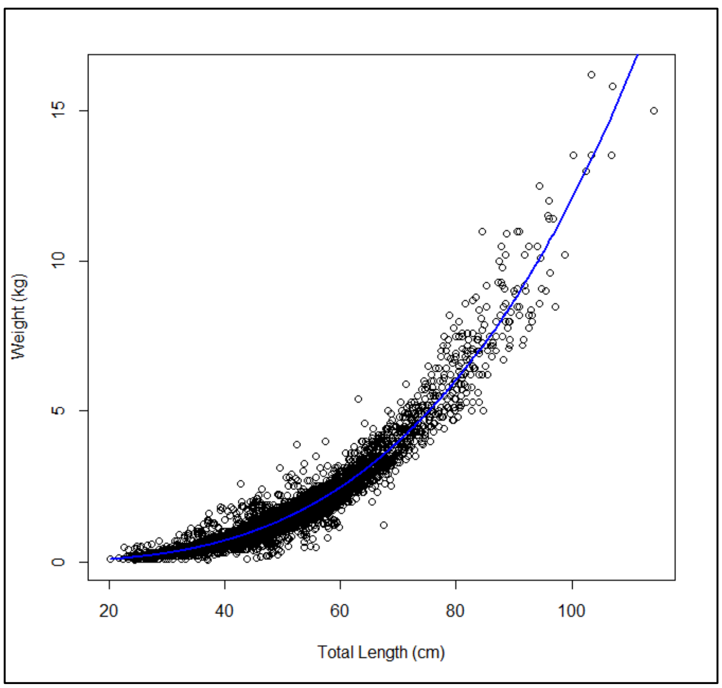

Figure 1.5. Fit of the length-weight function to available biological data for male striped bass.

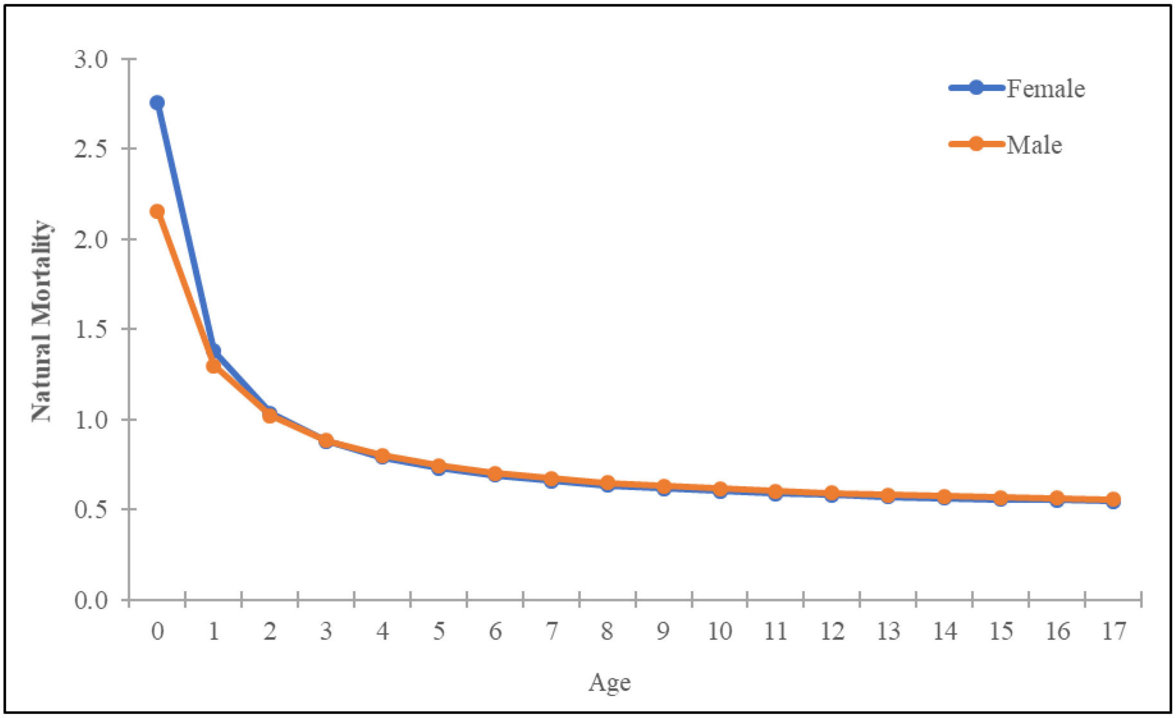

Figure 1.6. Estimates of natural mortality at age based on the method of Lorenzen (1996).

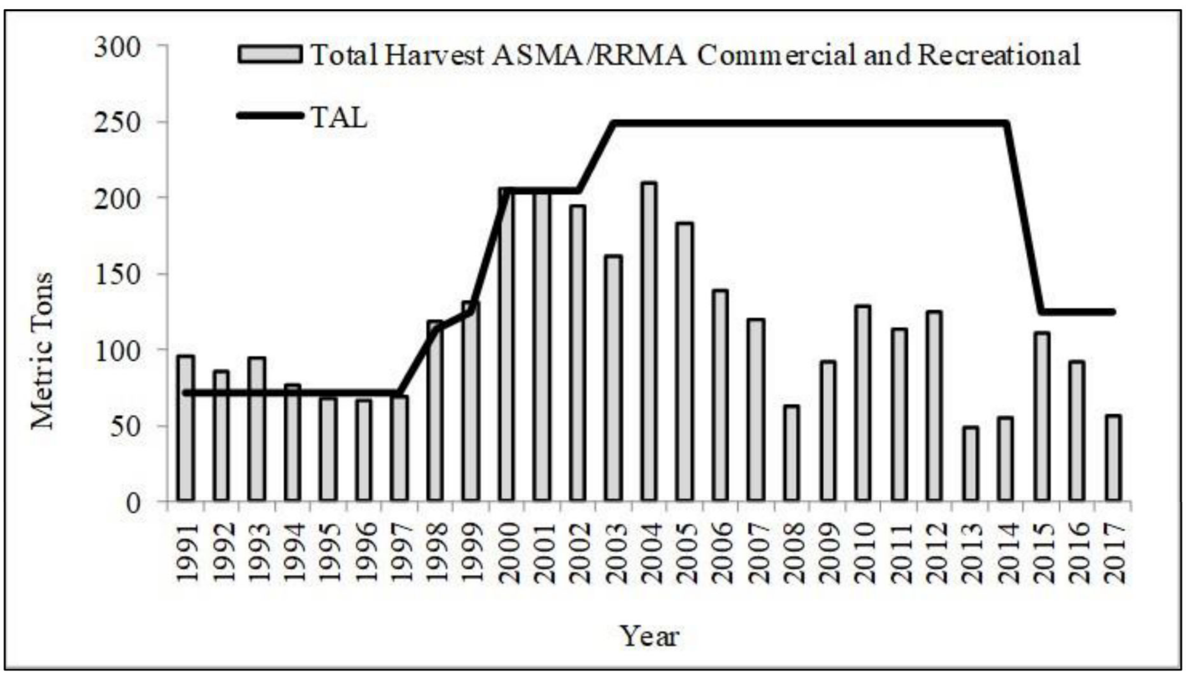

Figure 1.7. Annual total landings/harvest in metric tons of striped bass from the ASMA and RRMA commercial and recreational sectors combined compared to the TAL, 1991–2017.

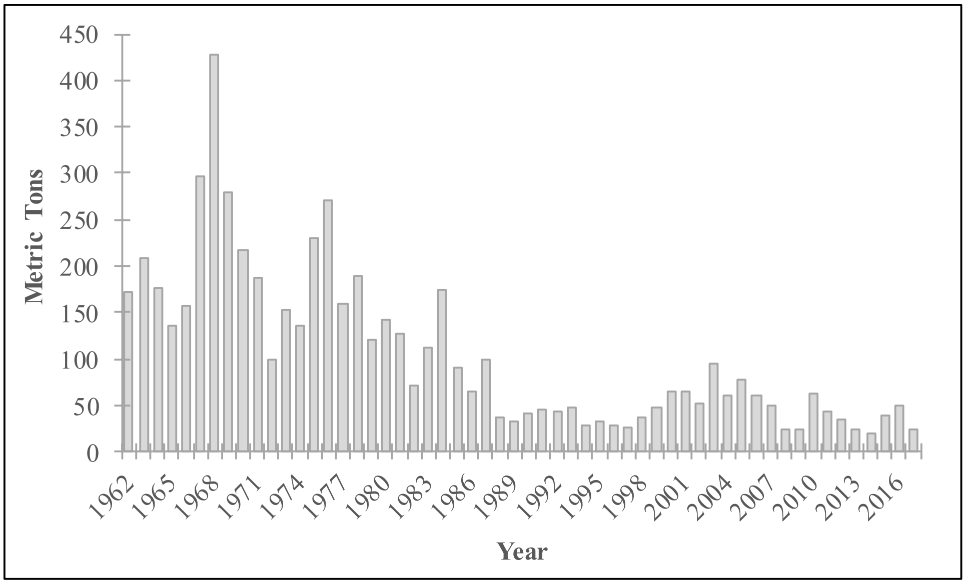

Figure 2.1. Annual commercial landings of striped bass in the ASMA-RRMA, 1962–2017.

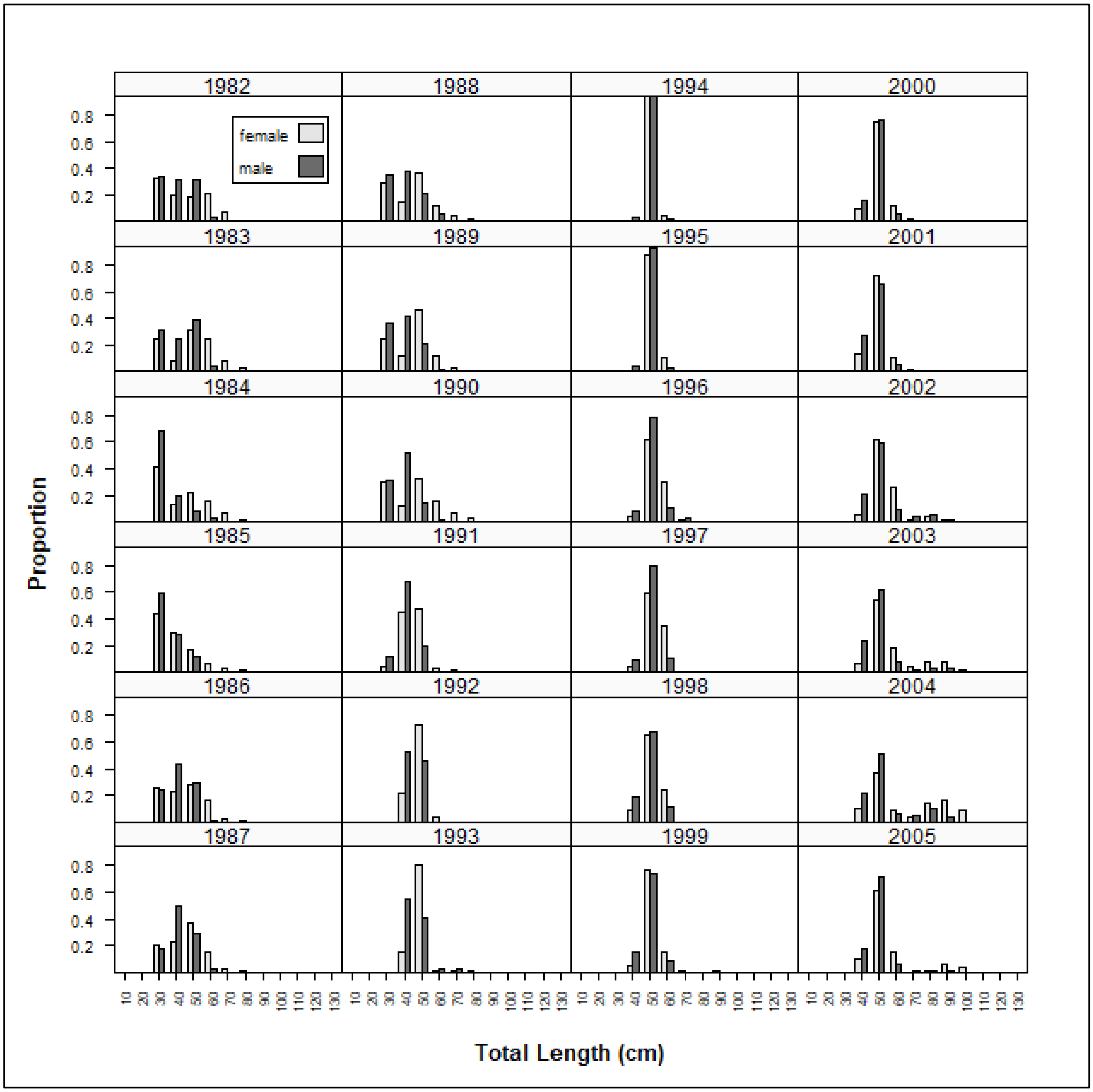

Figure 2.2. Annual length frequencies of striped bass commercial landings, 1982–2005.

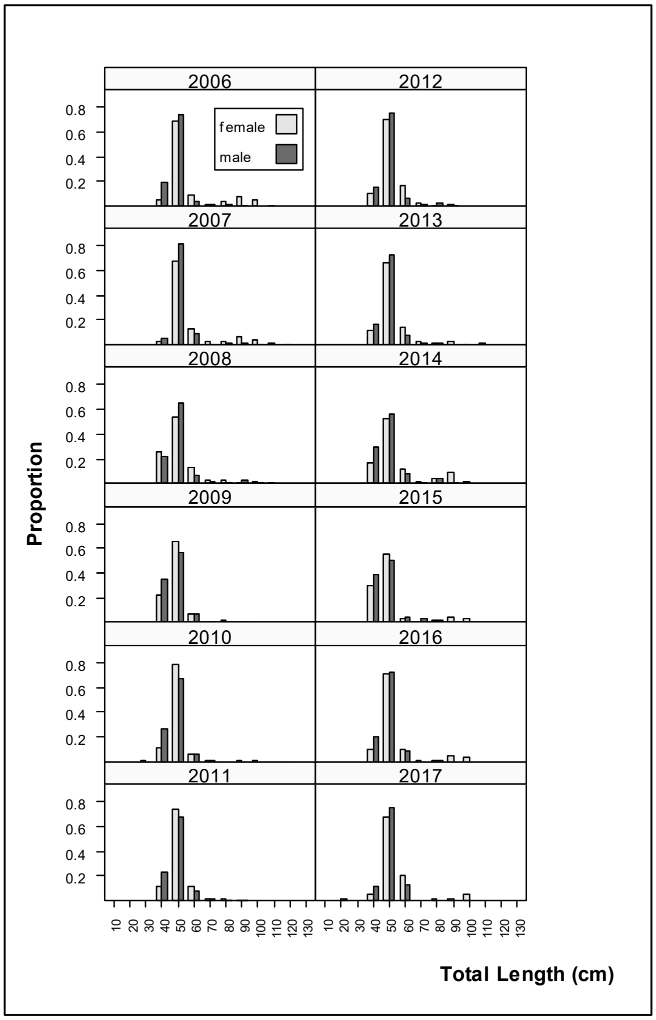

Figure 2.3. Annual length frequencies of striped bass commercial landings, 2006–2017.

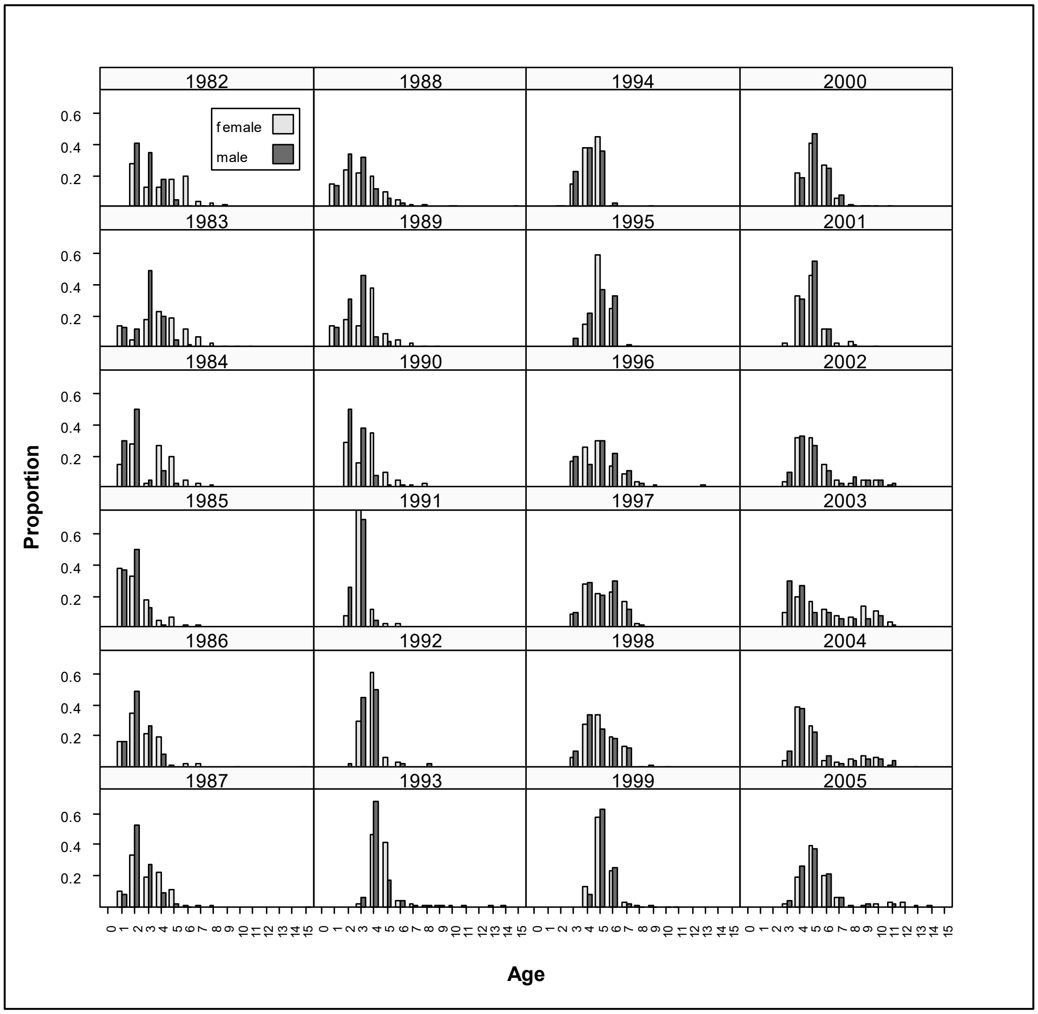

Figure 2.4. Annual age frequencies of striped bass commercial landings, 1982–2005. The age-15 bin represents a plus group.

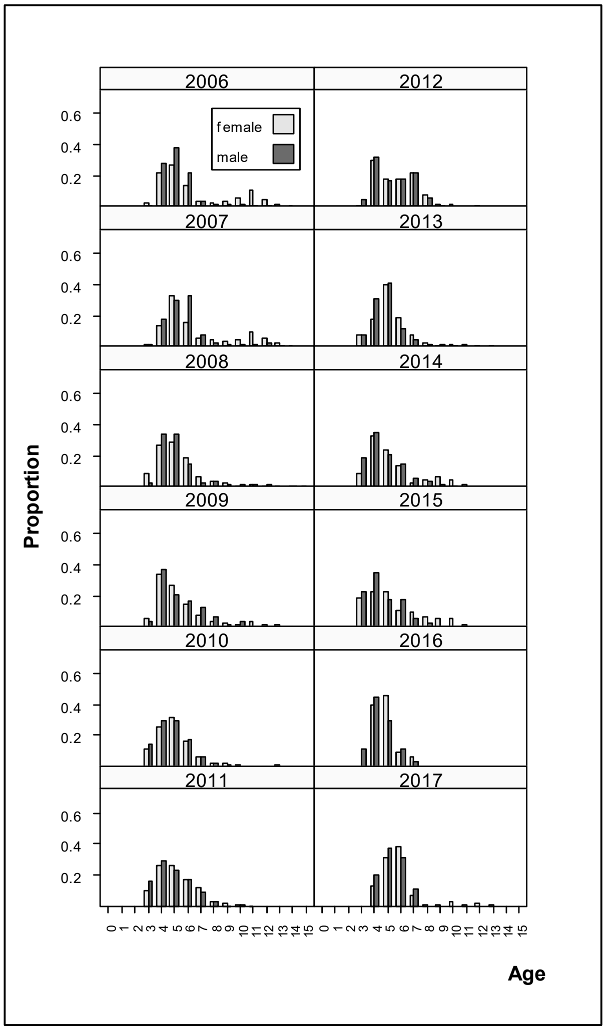

Figure 2.5. Annual age frequencies of striped bass commercial landings, 2006–2017. The age-15 bin represents a plus group.

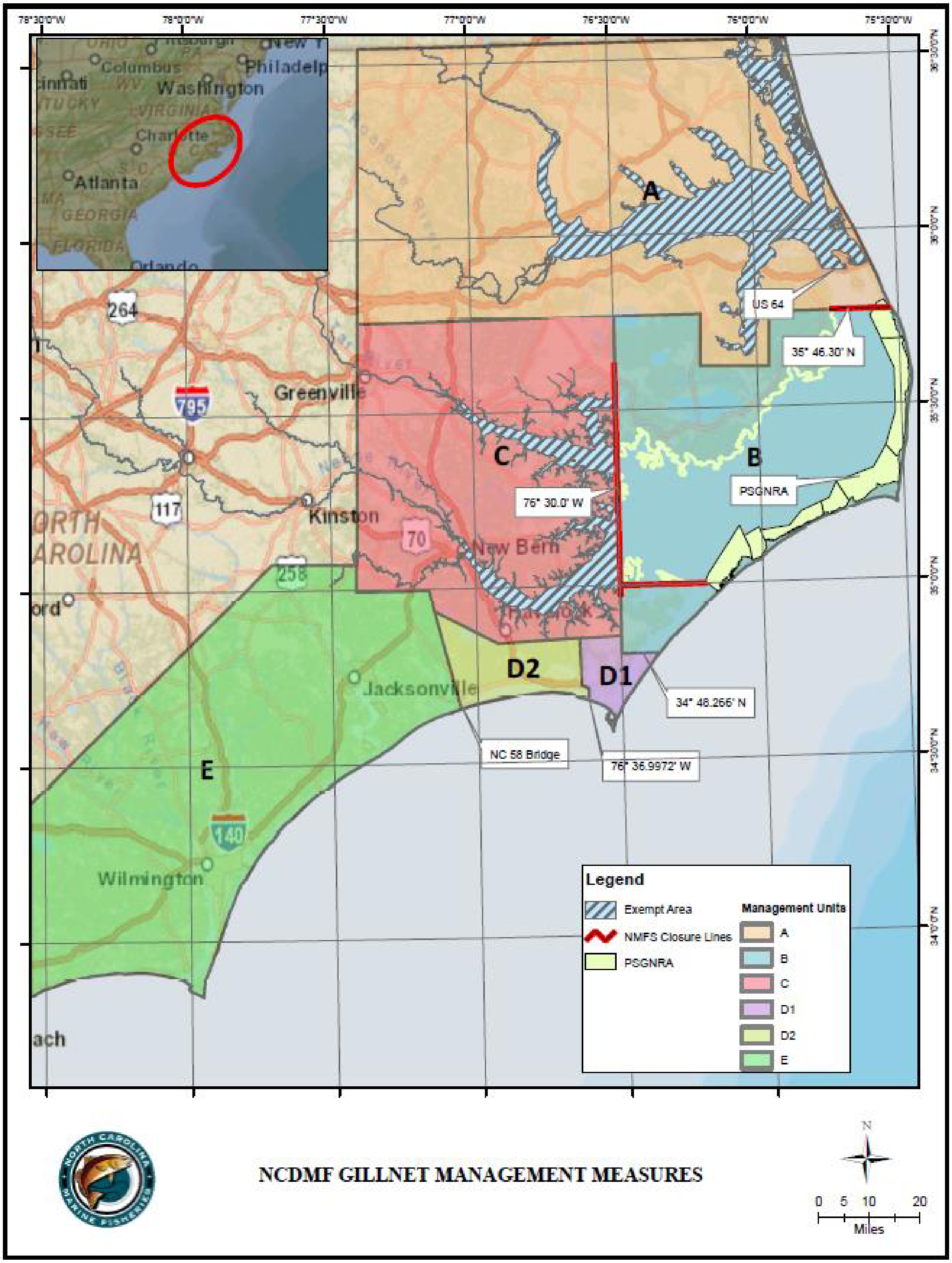

Figure 2.6. Management areas used in development of GLM for commercial gill-net discards.

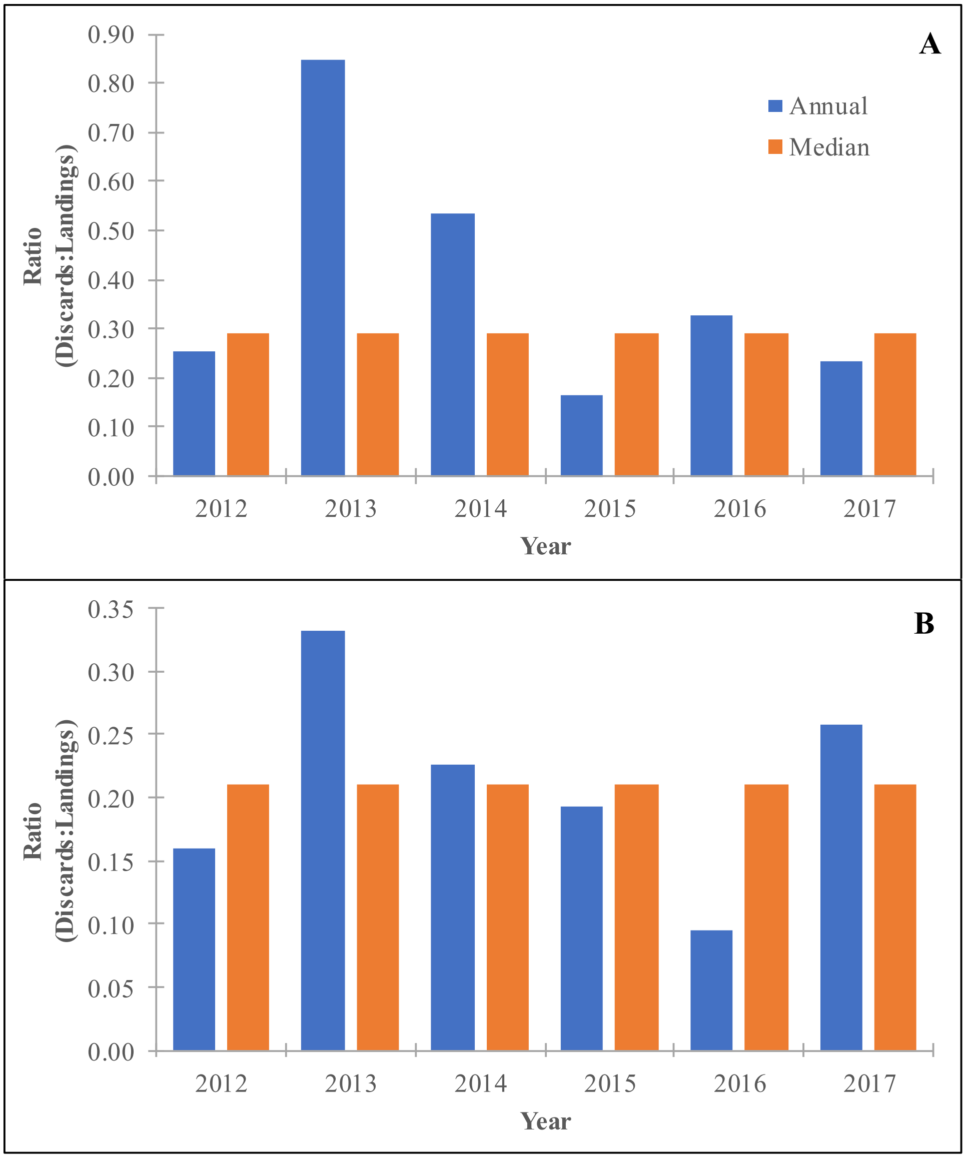

Figure 2.7. Ratio of commercial (A) live and (B) dead discards to commercial landings, 2012–2017.

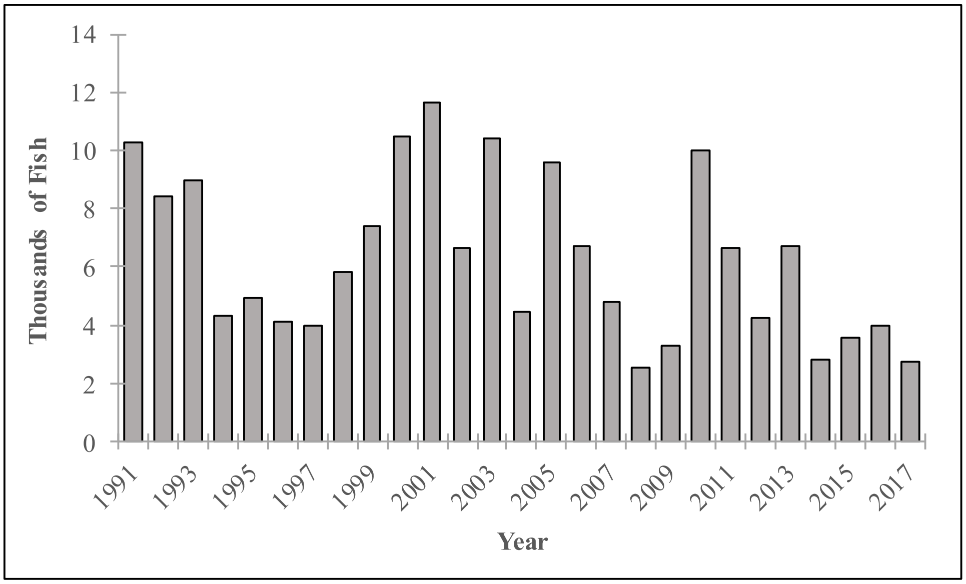

Figure 2.8. Annual estimates of commercial gill-net discards, 1991–2017. Note that values prior to 2012 were estimated using a hindcasting approach.

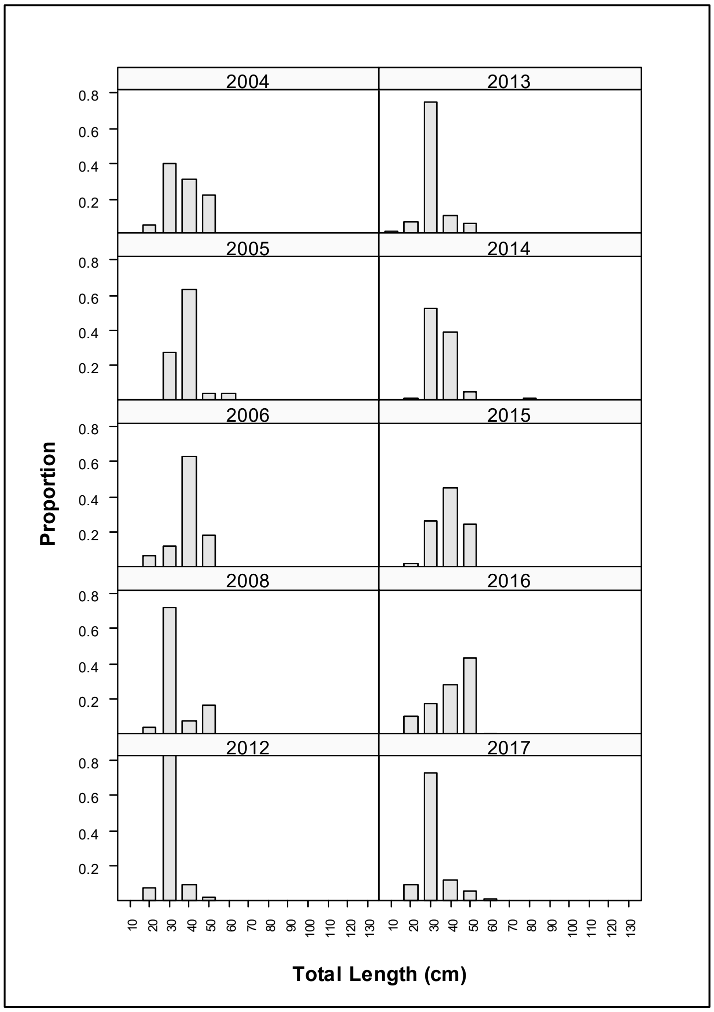

Figure 2.9. Annual length frequencies of striped bass commercial gill-net discards, 2004–2017.

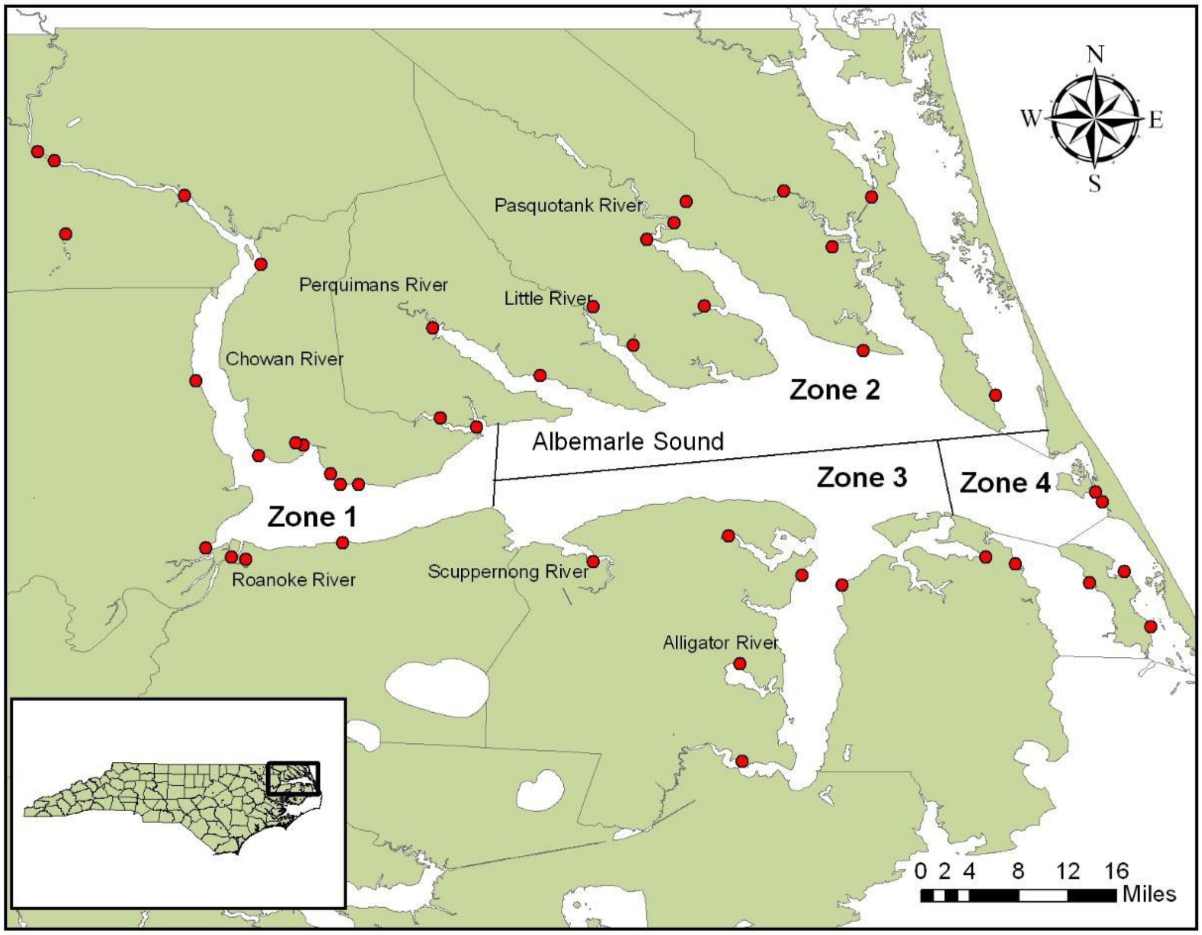

Figure 2.10. Sampling zones and access sites of the striped bass recreational creel survey in the ASMA.

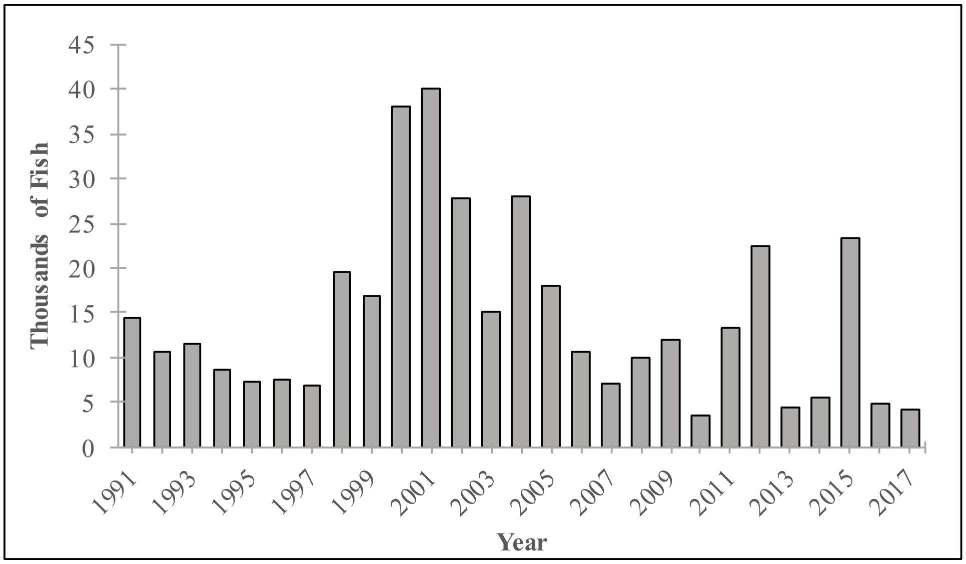

Figure 2.11. Annual estimates of recreational harvest for the Albemarle Sound, 1991–2017.

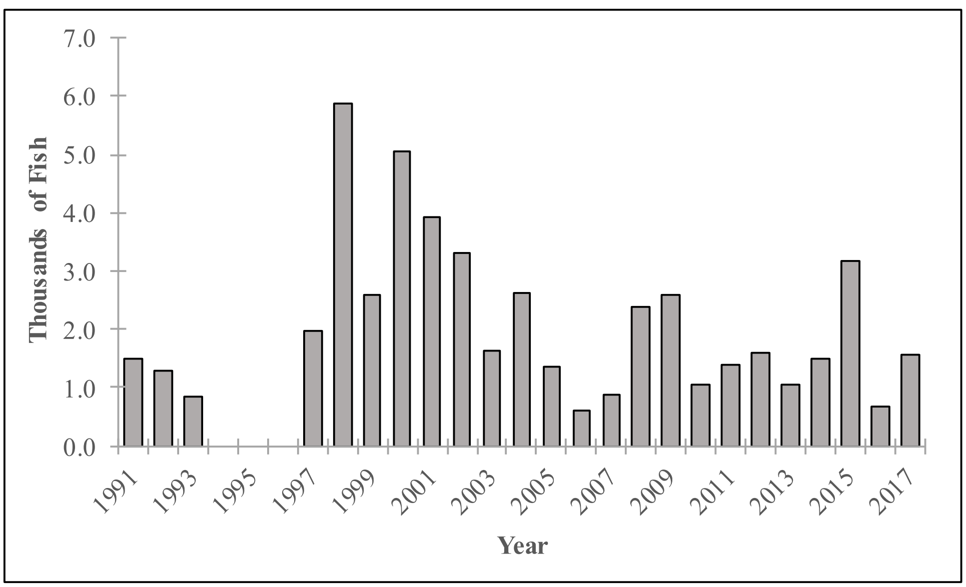

Figure 2.12. Annual estimates of recreational dead discards for the Albemarle Sound, 1991–2017.

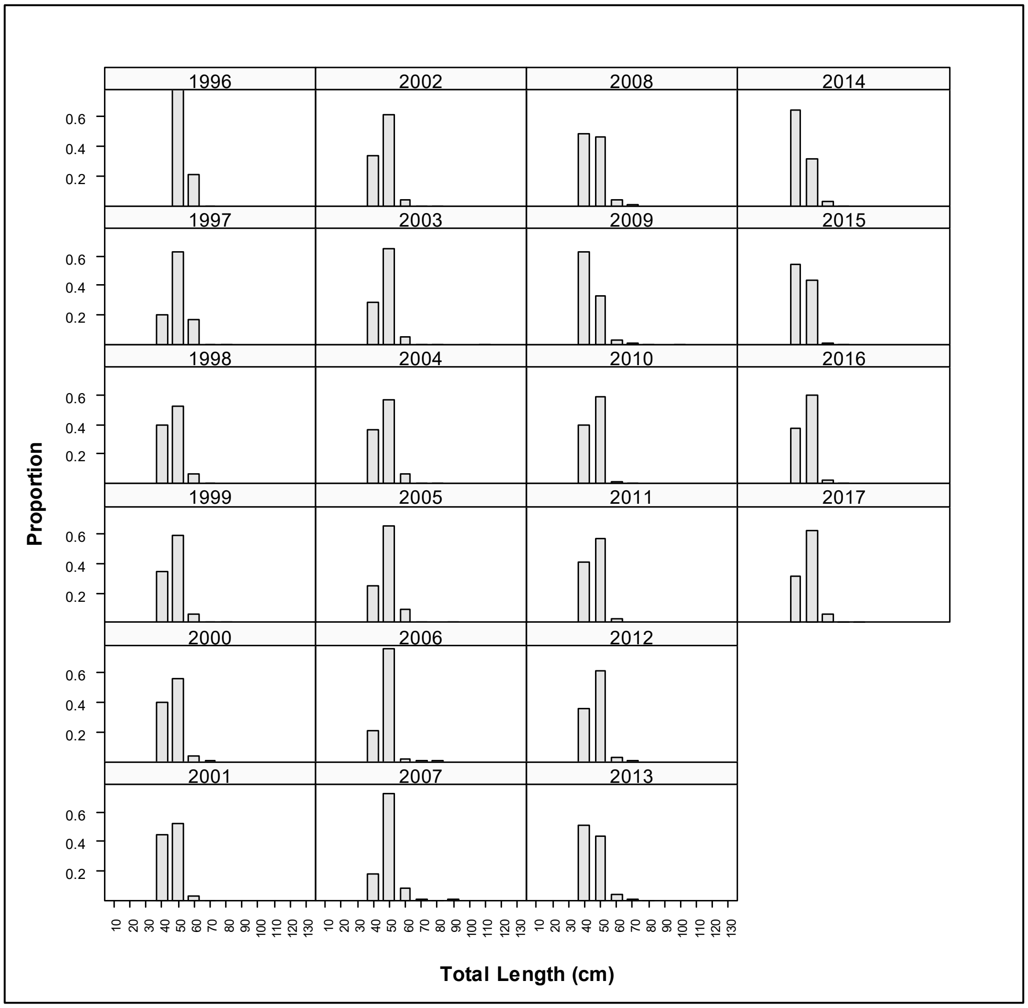

Figure 2.13. Annual length frequencies of striped bass recreational harvest in the Albemarle Sound, 1996–2017.

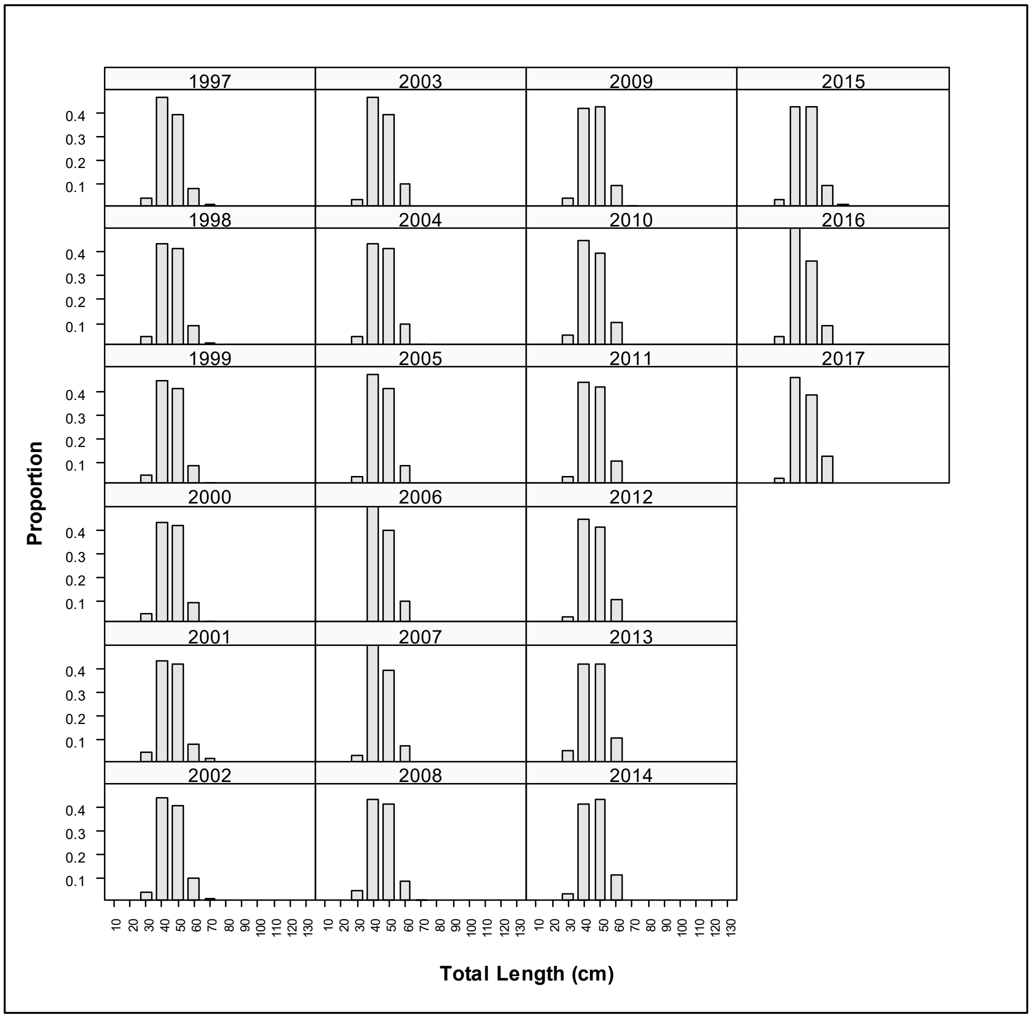

Figure 2.14. Annual length frequencies of striped bass recreational discards in the Albemarle Sound, 1997–2017.

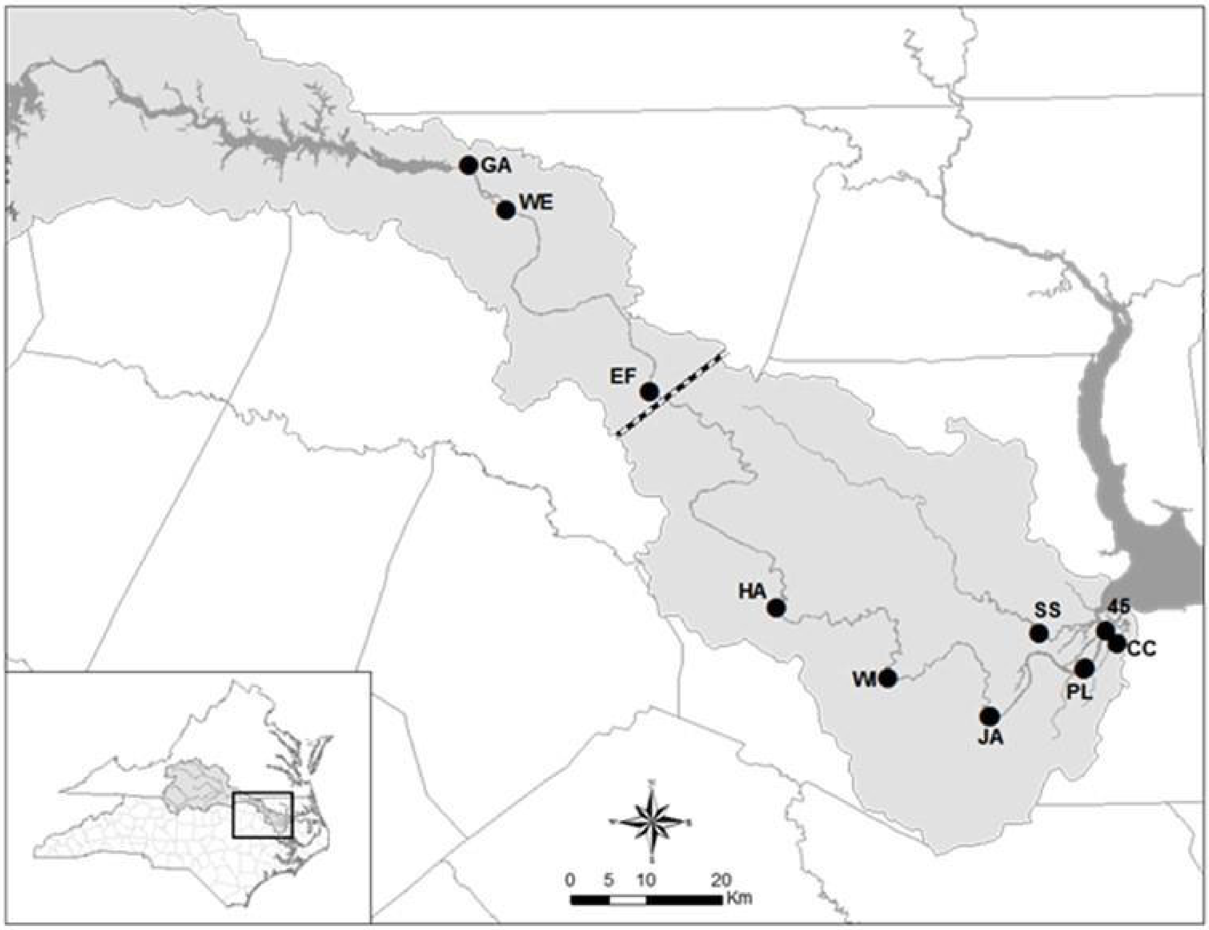

Figure 2.15. Map of angler creel survey interview locations in the RRMA, NC. The dashed line indicates the demarcation point between the upper and lower zones. Zone 1 access areas include (GA) Gaston (US HWY 48), (WE) Weldon, and (EF) Scotland Neck (Edwards Ferry US HWY 258). Zone 2 access areas include (HA) Hamilton, (WI) Williamston, (JA) Jamesville, (PL) Plymouth, (45) US HWY 45, (CC) Conaby Creek, and (SS) Sans Souci (Cashie River).

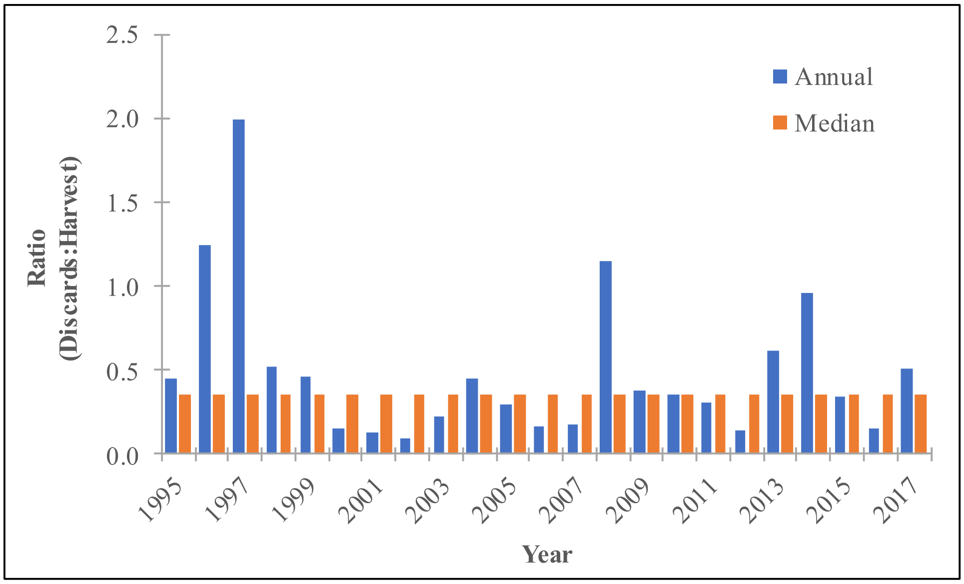

Figure 2.16. Ratio of recreational dead discards to recreational harvest in the Roanoke River, 1995–2017.

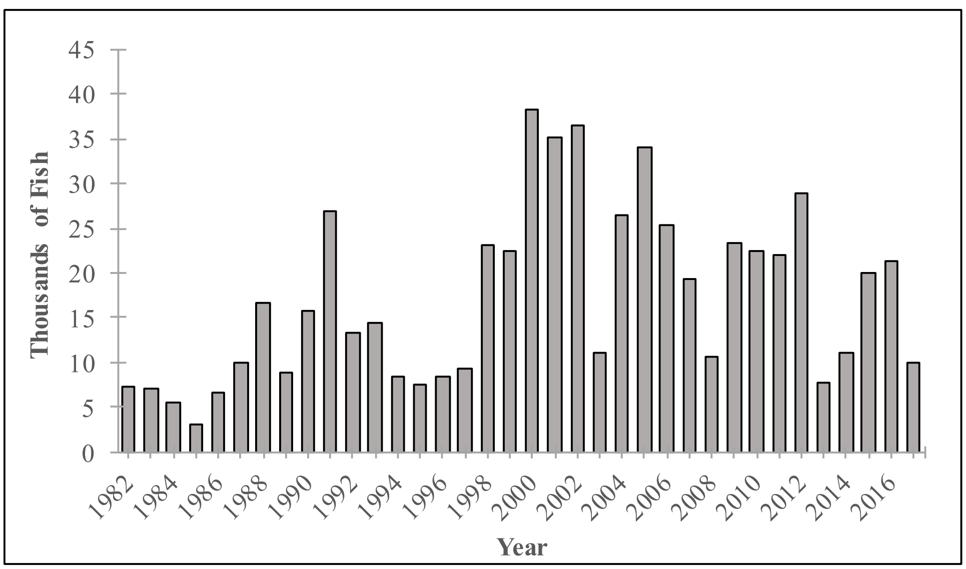

Figure 2.17. Annual estimates of recreational harvest for the Roanoke River, 1982–2017.

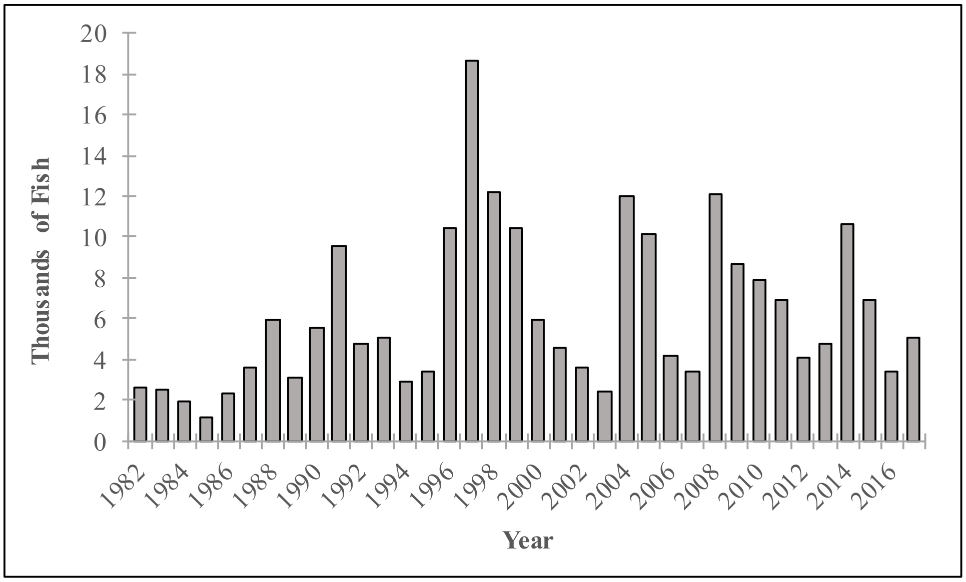

Figure 2.18. Annual estimates of recreational dead discards for the Roanoke River, 1982–2017. Note that discard values prior to 1995 were estimated using a hindcasting approach.

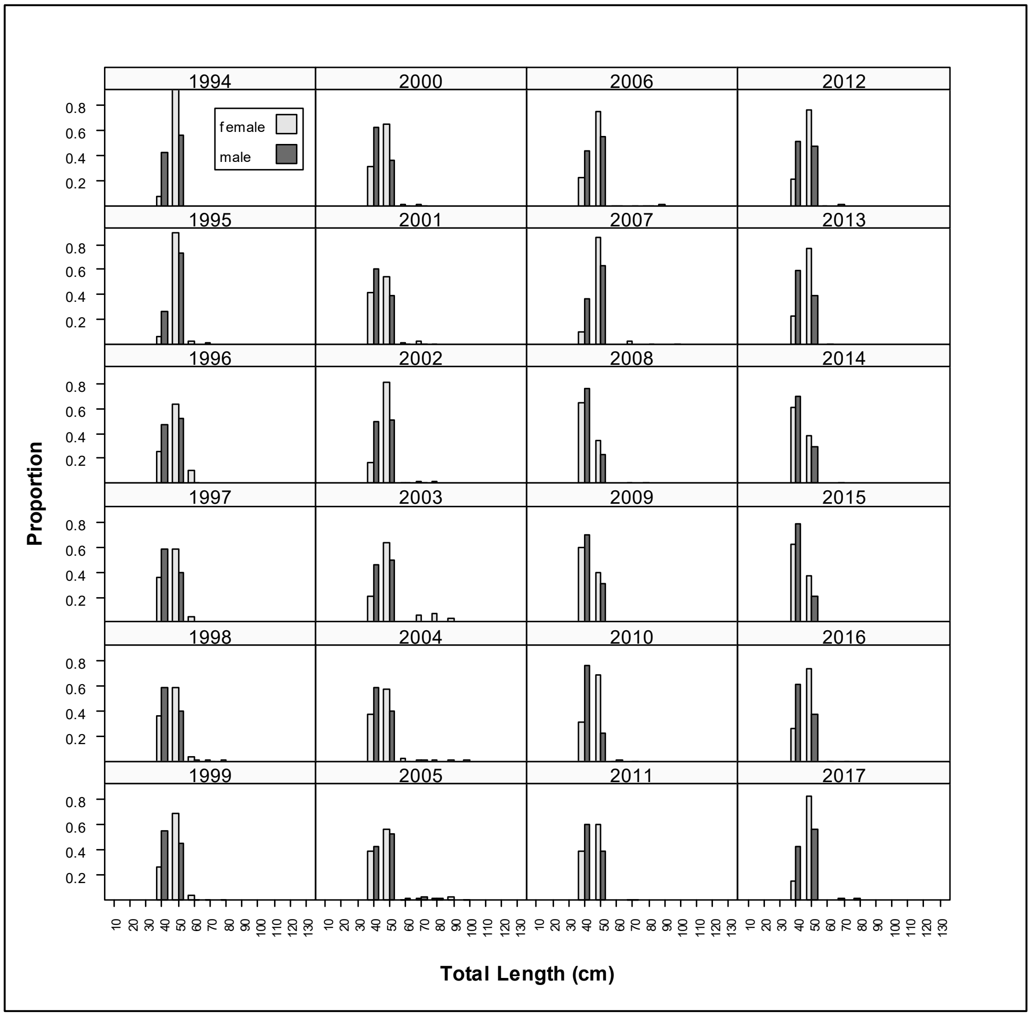

Figure 2.19. Annual length frequencies of striped bass recreational harvest in the Roanoke River, 1994–2017.

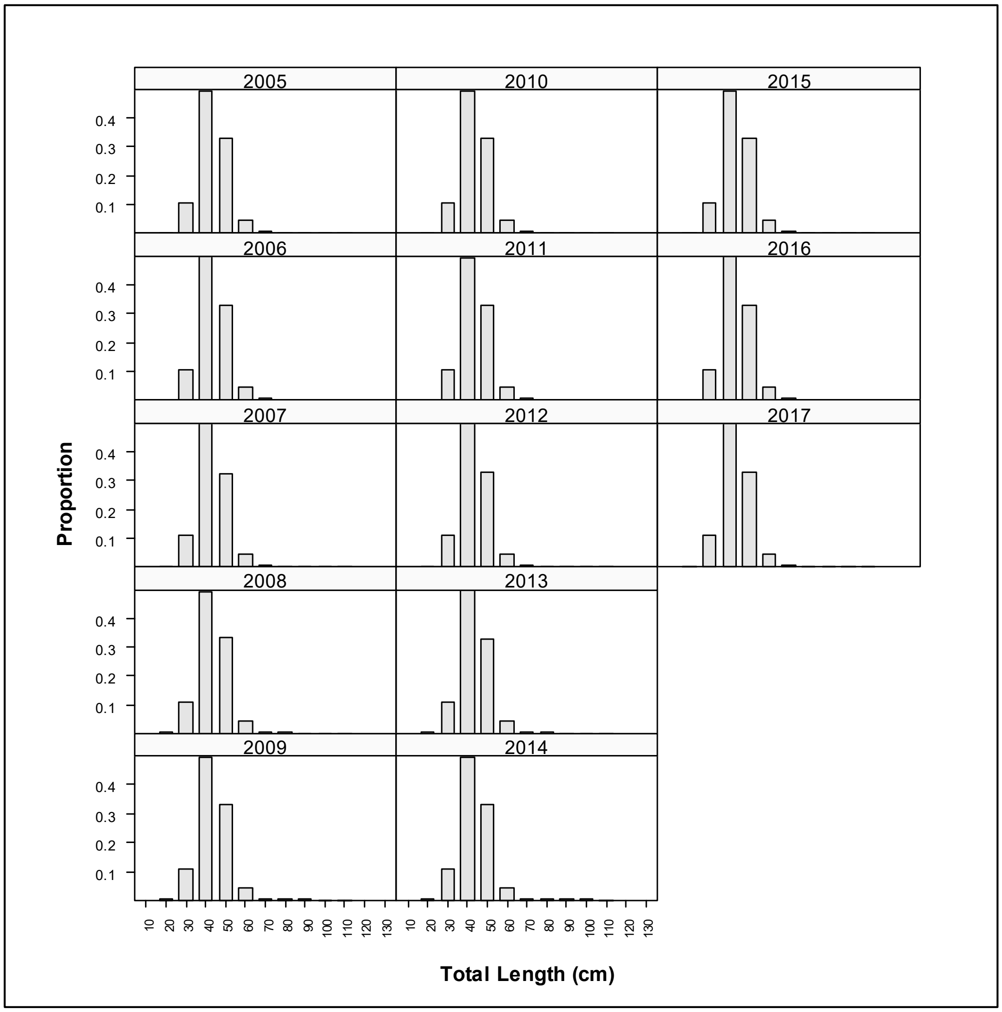

Figure 2.20. Annual length frequencies of striped bass recreational discards in the Roanoke River, 2005–2017.

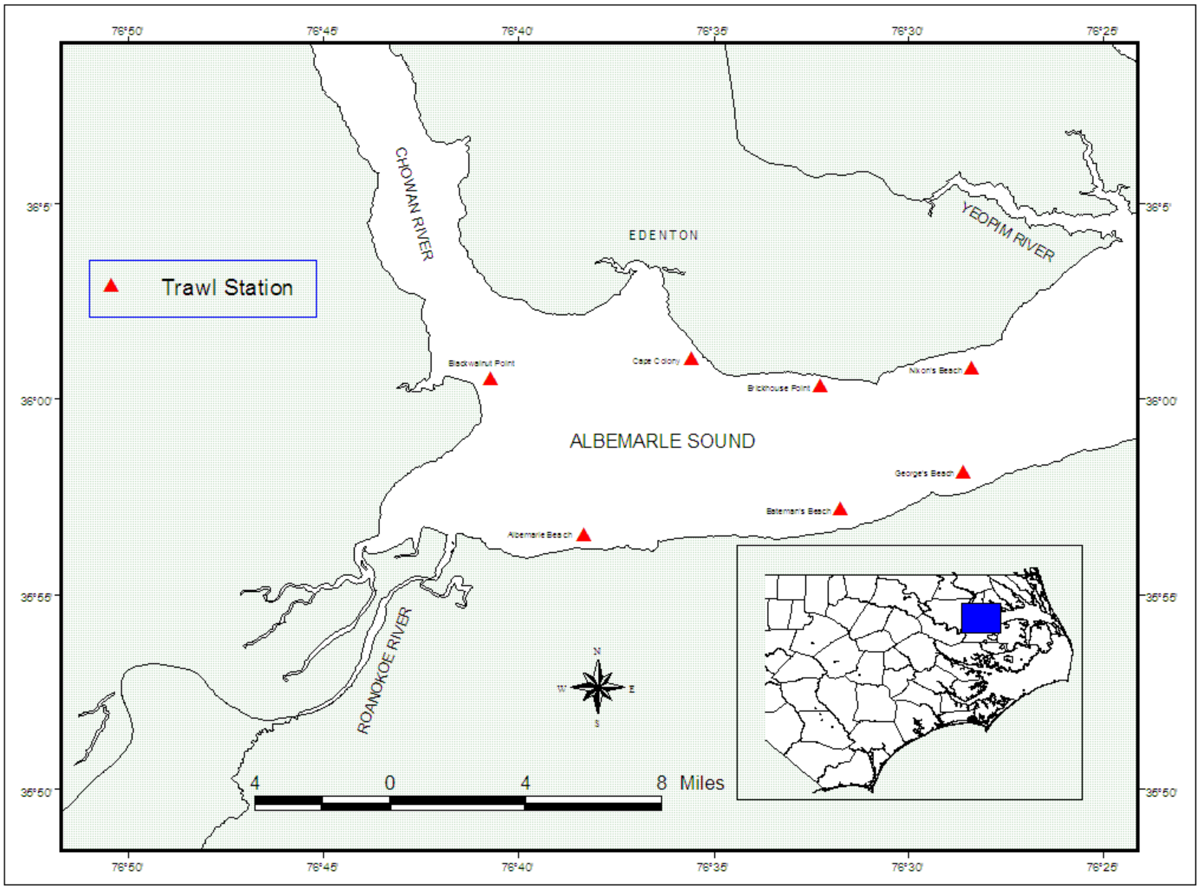

Figure 2.21. Map of NCDMF Juvenile Abundance Survey (Program 100) sampling sites.

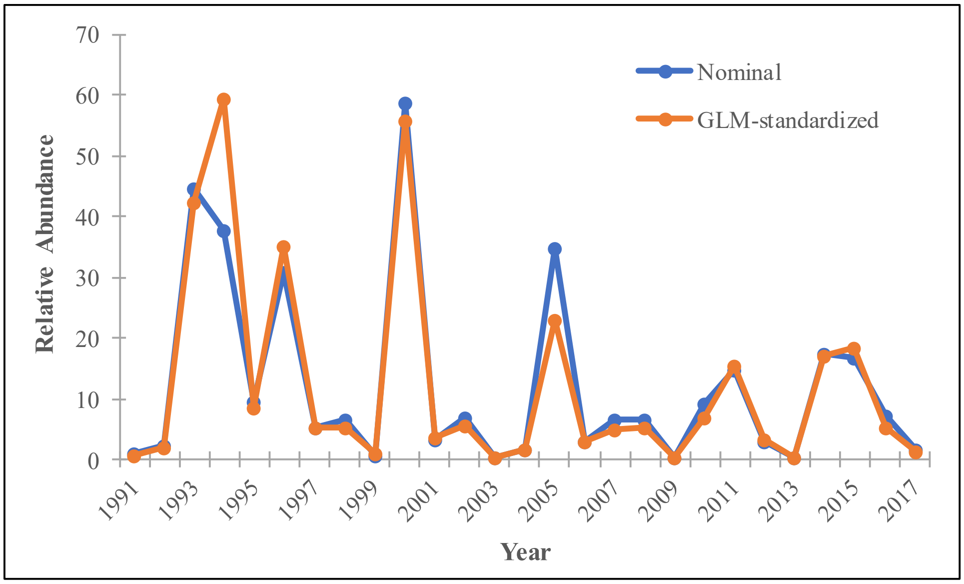

Figure 2.22. Nominal and GLM-standardized indices of relative age-0 abundance derived from the Juvenile Abundance Survey (P100), 1991–2017.

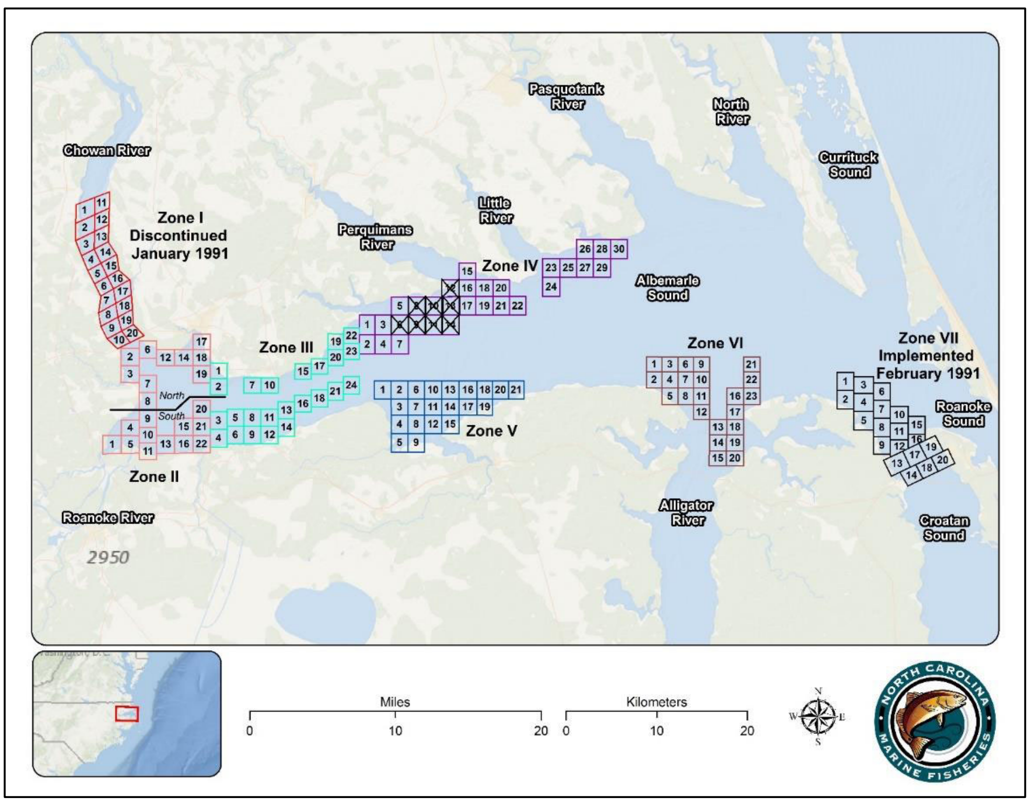

Figure 2.23. Map of sampling grids and zones for the NCDMF Independent Gill-Net Survey (Program 135).

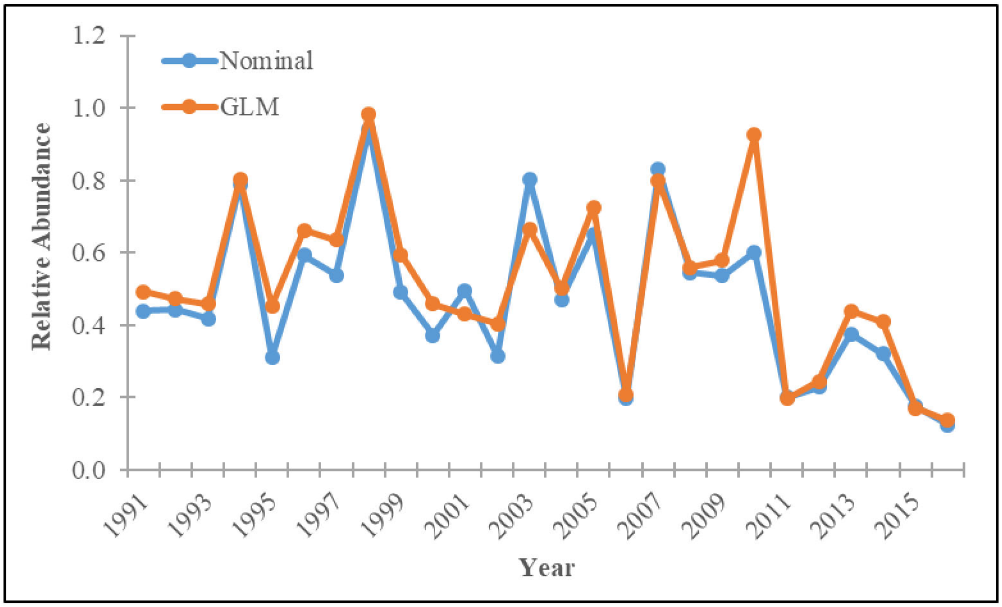

Figure 2.24. Nominal and GLM-standardized indices of relative abundance derived from the fall/winter component of the NCDMF Independent Gill-Net Survey (P135), 1991–2016.

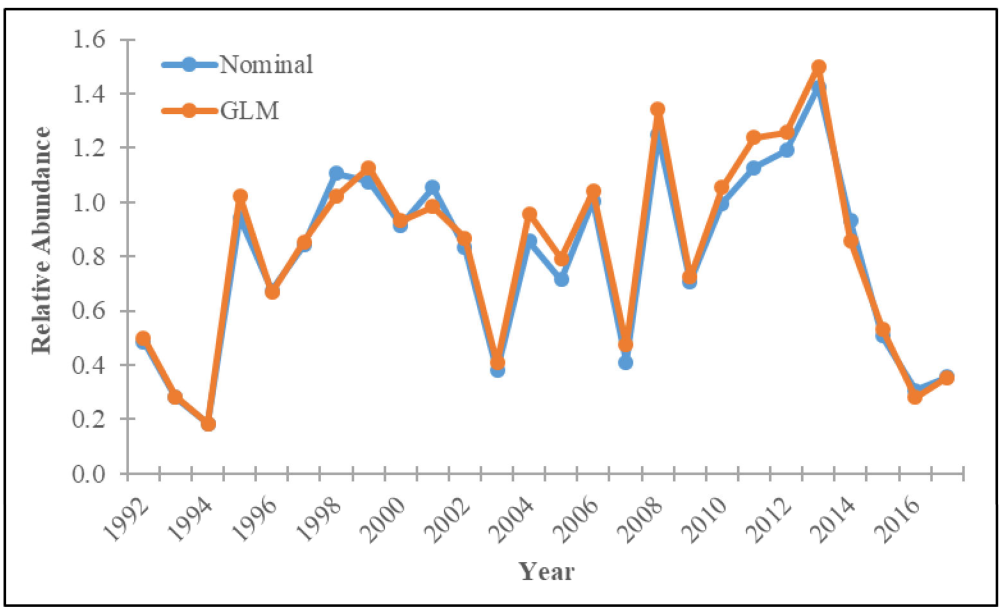

Figure 2.25. Nominal and GLM-standardized indices of relative abundance derived from the spring component of the NCDMF Independent Gill-Net Survey (P135), 1992–2017.

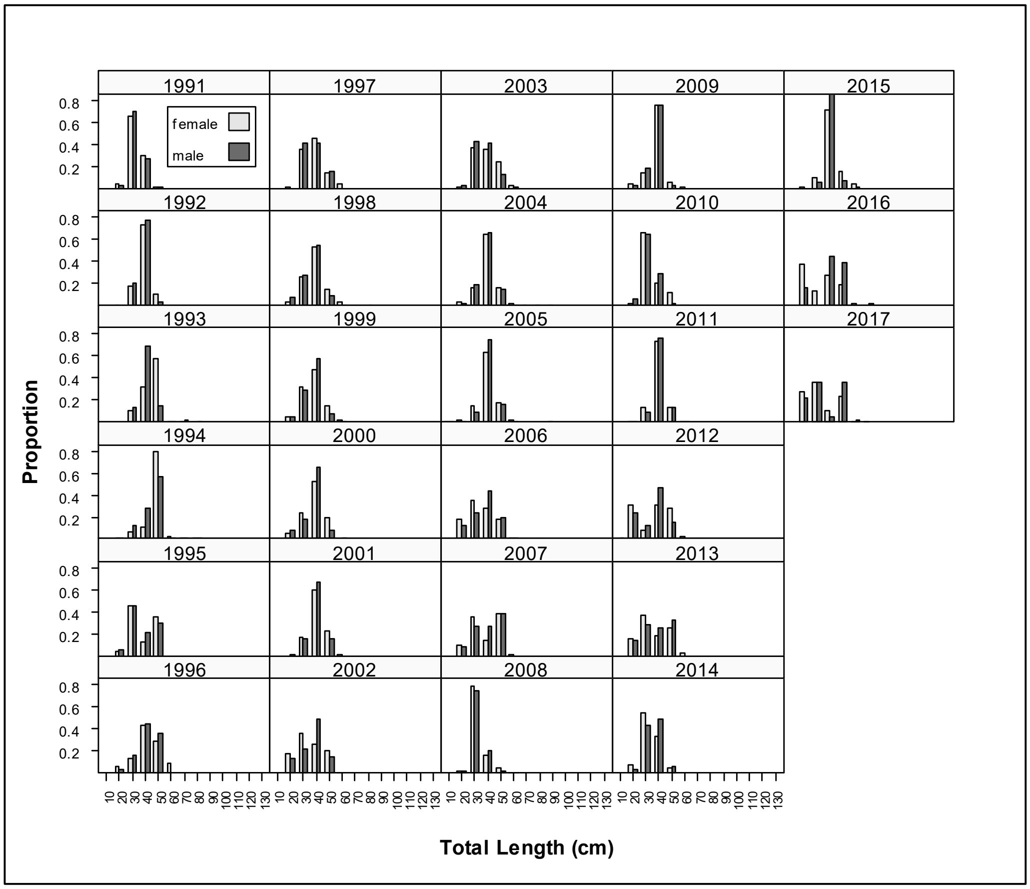

Figure 2.26. Annual length frequencies of striped bass sampled from the fall/winter component of the NCDMF Independent Gill-Net Survey (P135), 1991–2017.

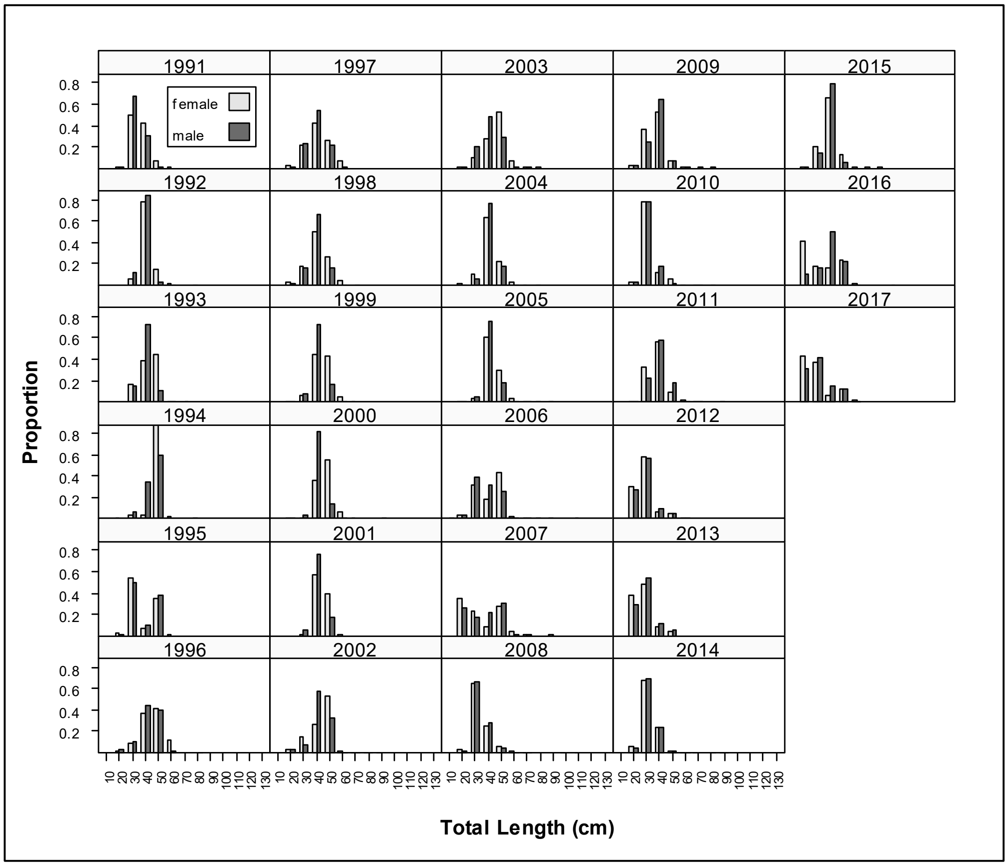

Figure 2.27. Annual length frequencies of striped bass sampled from the spring component of the NCDMF Independent Gill-Net Survey (P135), 1991–2017.

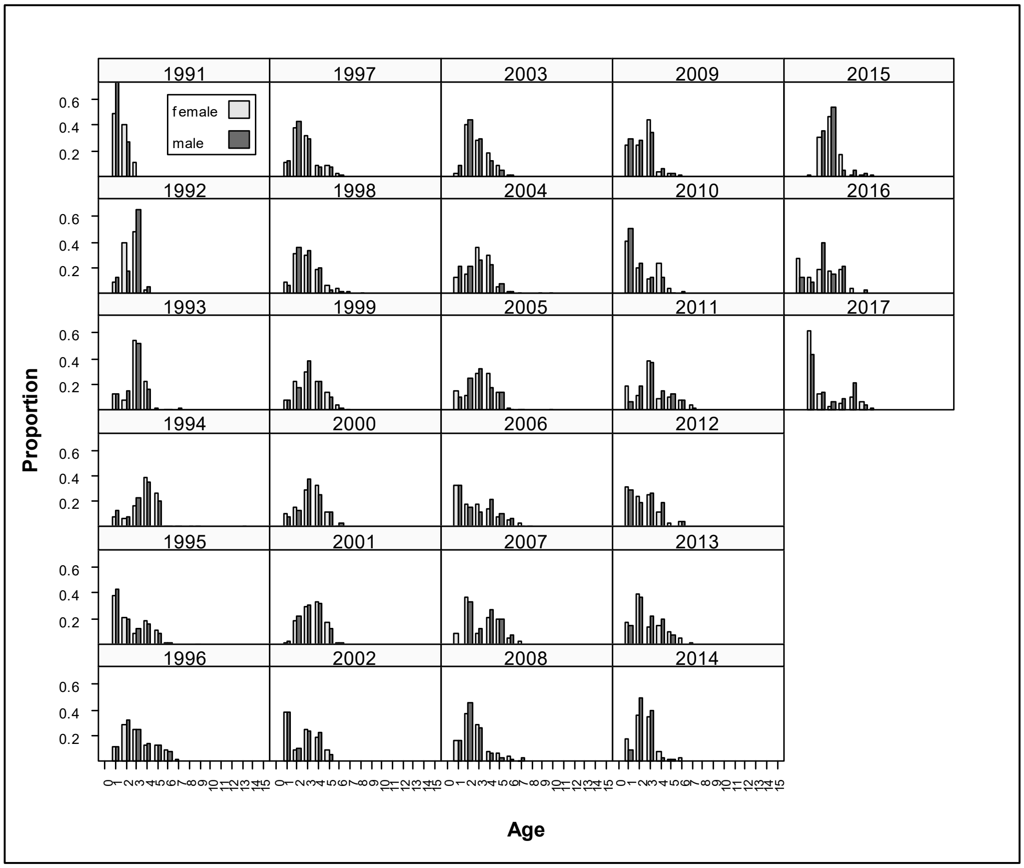

Figure 2.28. Annual age frequencies of striped bass sampled from the fall/winter component of the NCDMF Independent Gill-Net Survey (P135), 1991–2017. Thea age-15 bin represents a plus group.

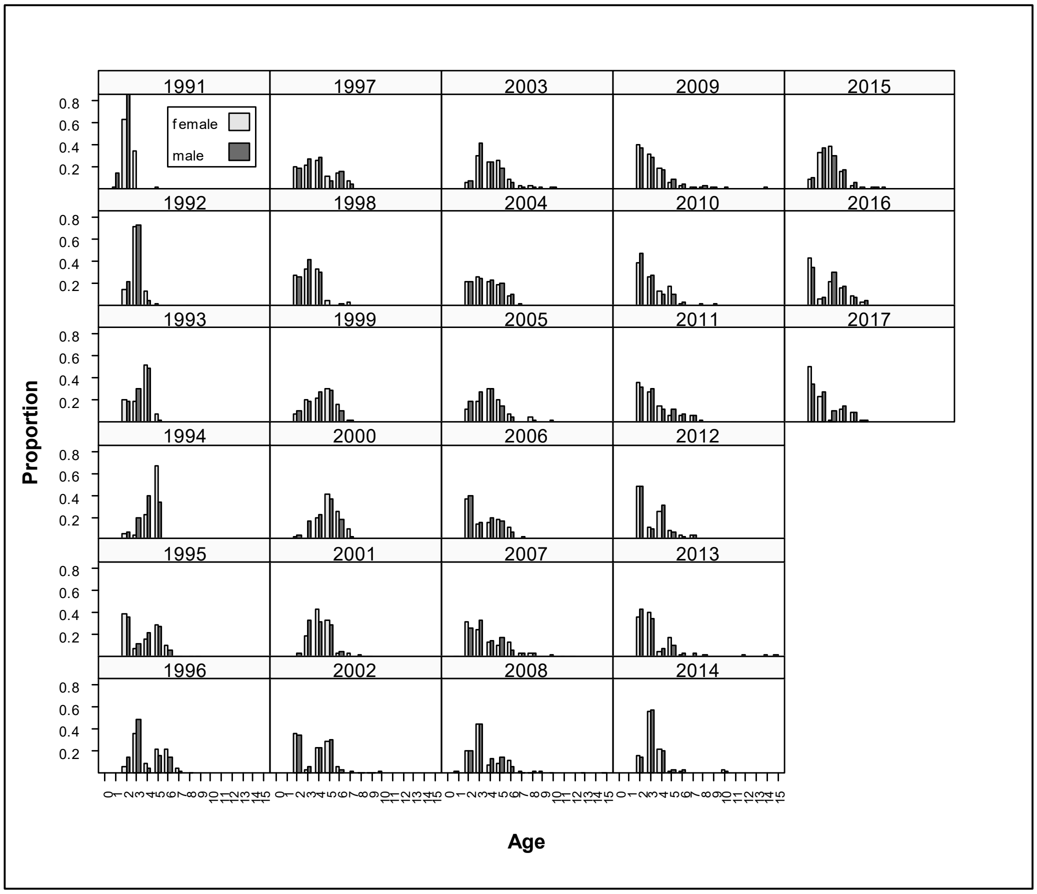

Figure 2.29. Annual age frequencies of striped bass sampled from the spring component of the NCDMF Independent Gill-Net Survey (P135), 1991–2017. The age-15 bin represents a plus group.

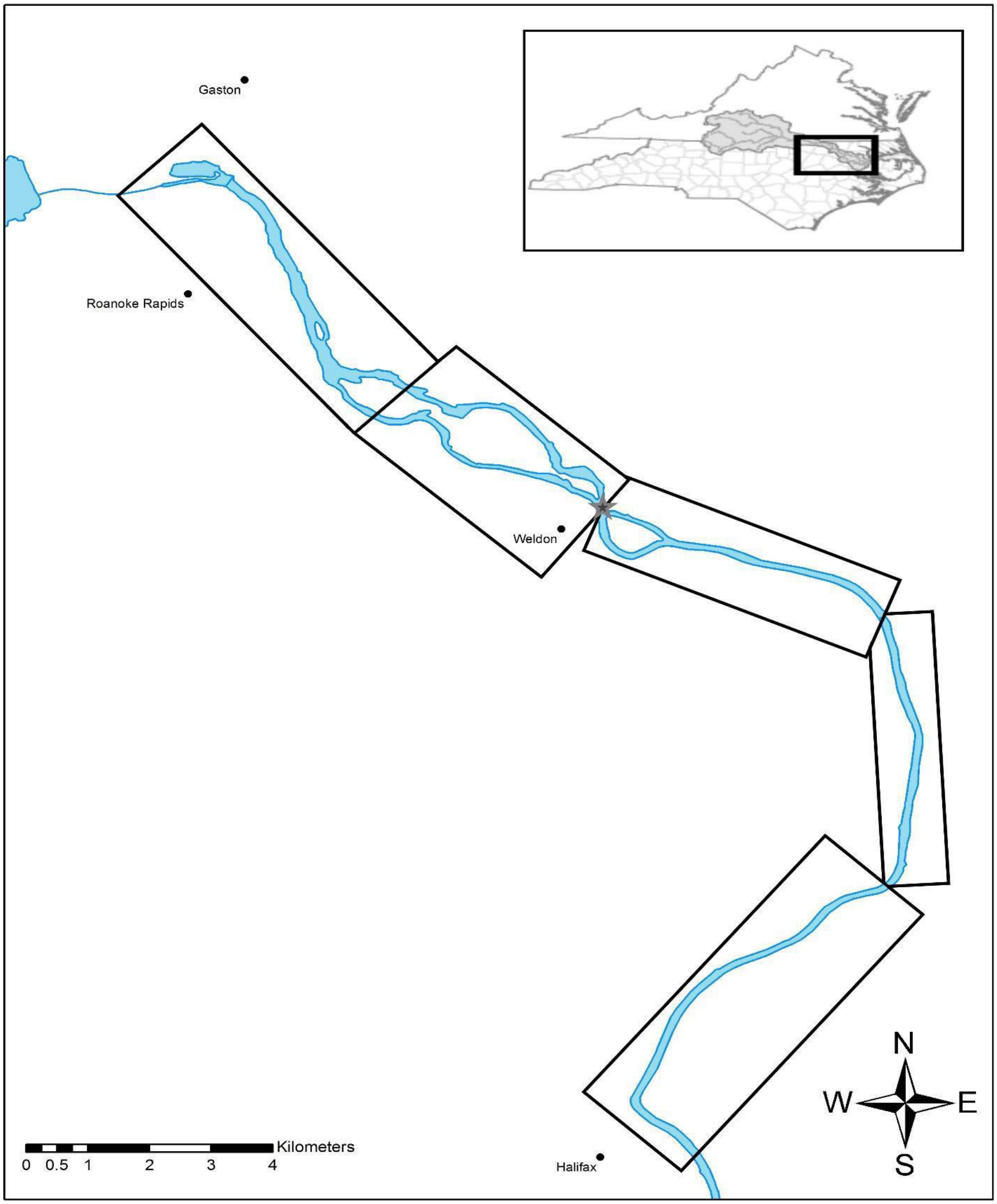

Figure 2.30. Striped Bass spawning grounds on the Roanoke River, near the vicinity of Weldon, North Carolina. Black boxes represent relative locations of river strata. The gray star indicates location of rapids near the Weldon boating access area; flows less than 7,000 cfs restrict access to the strata above this location.

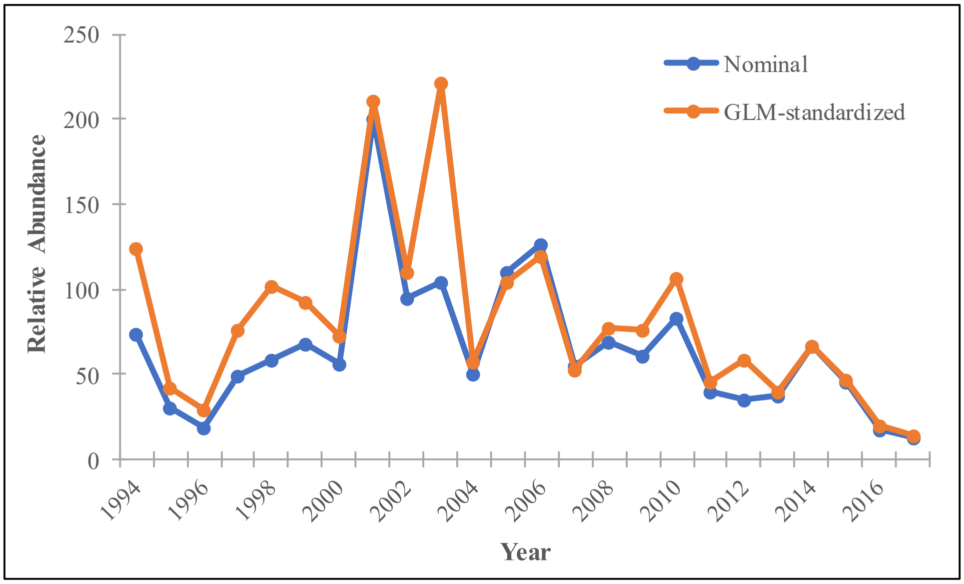

Figure 2.31. Nominal and GLM-standardized indices of relative abundance derived from the NCWRC Roanoke River Electrofishing Survey, 1994–2017.

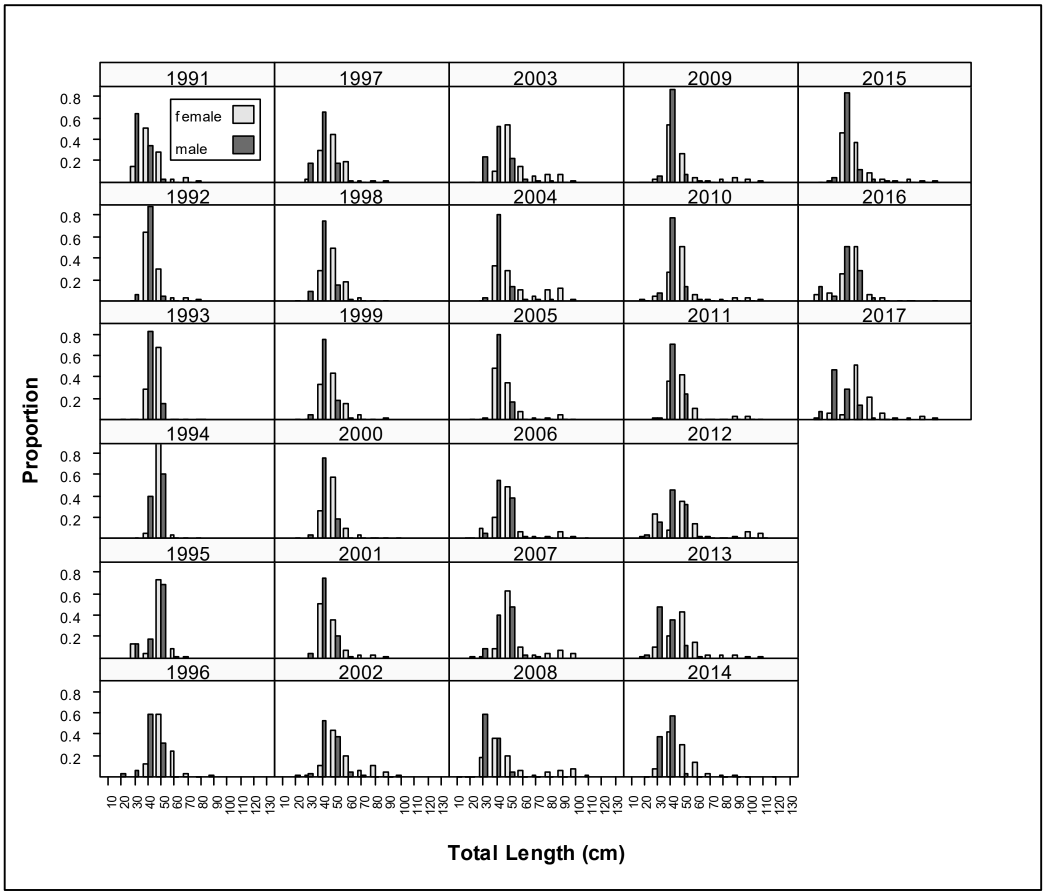

Figure 2.32. Annual length frequencies of striped bass sampled from the NCWRC Roanoke River Electrofishing Survey, 1991–2017.

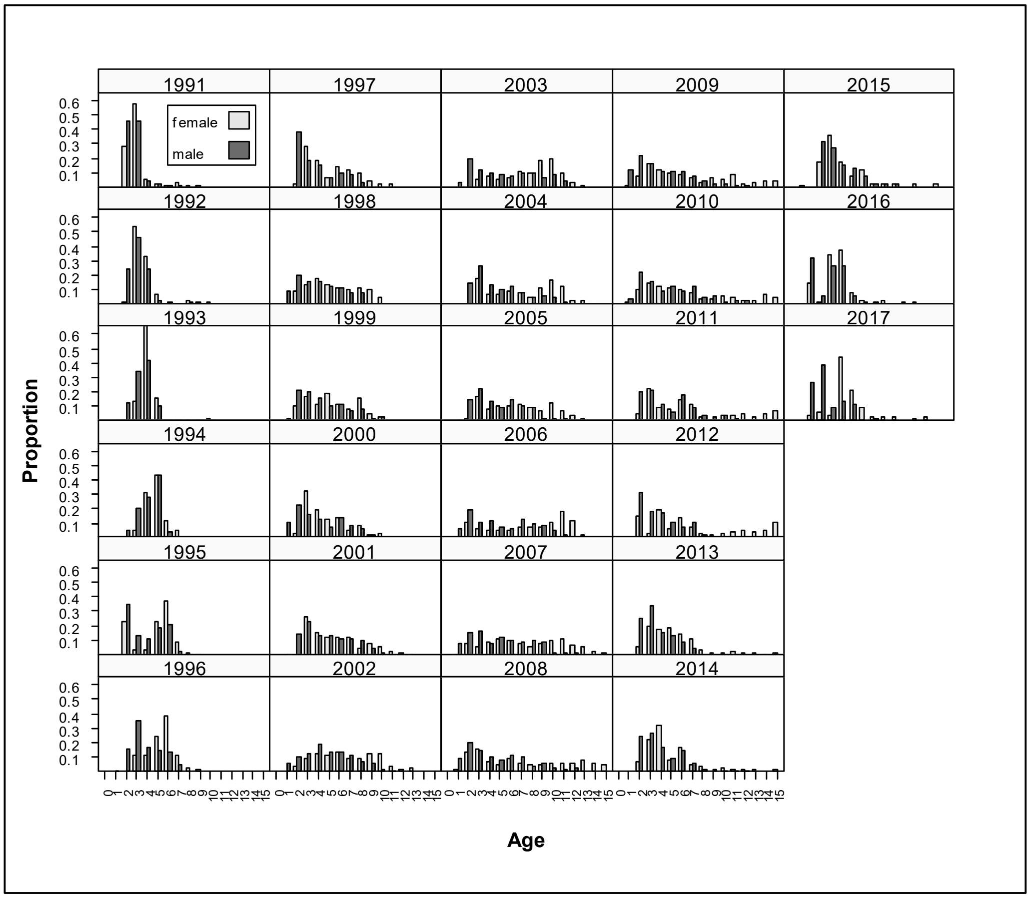

Figure 2.33. Annual age frequencies of striped bass sampled from the NCWRC Roanoke River Electrofishing Survey, 1991–2017. The age-15 bin represents a plus group.

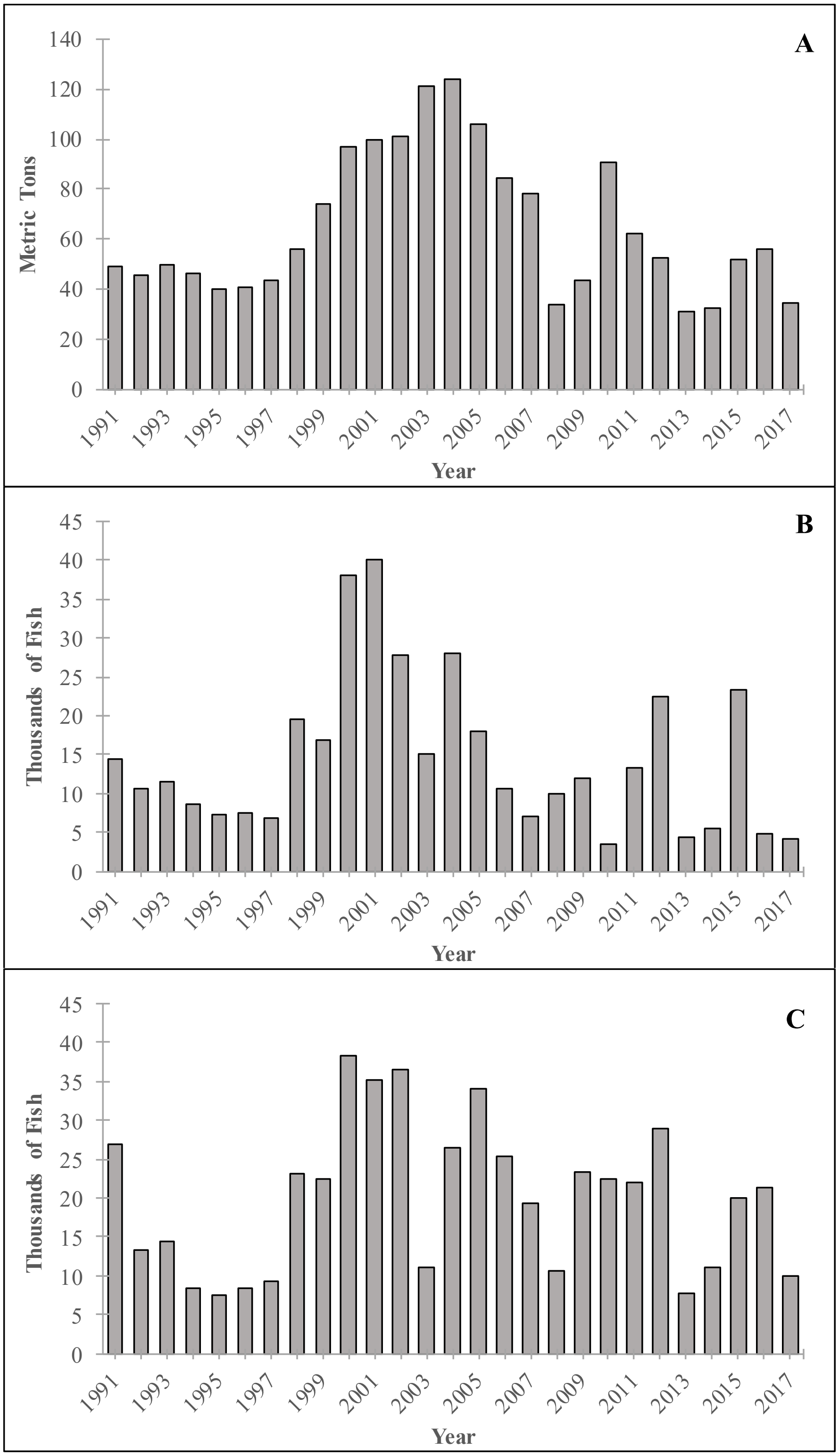

Figure 3.1. Annual (A) ARcomm landings, (B) ASrec harvest, and (C) RRrec harvest values that were input into the SS model, 1991–2017.

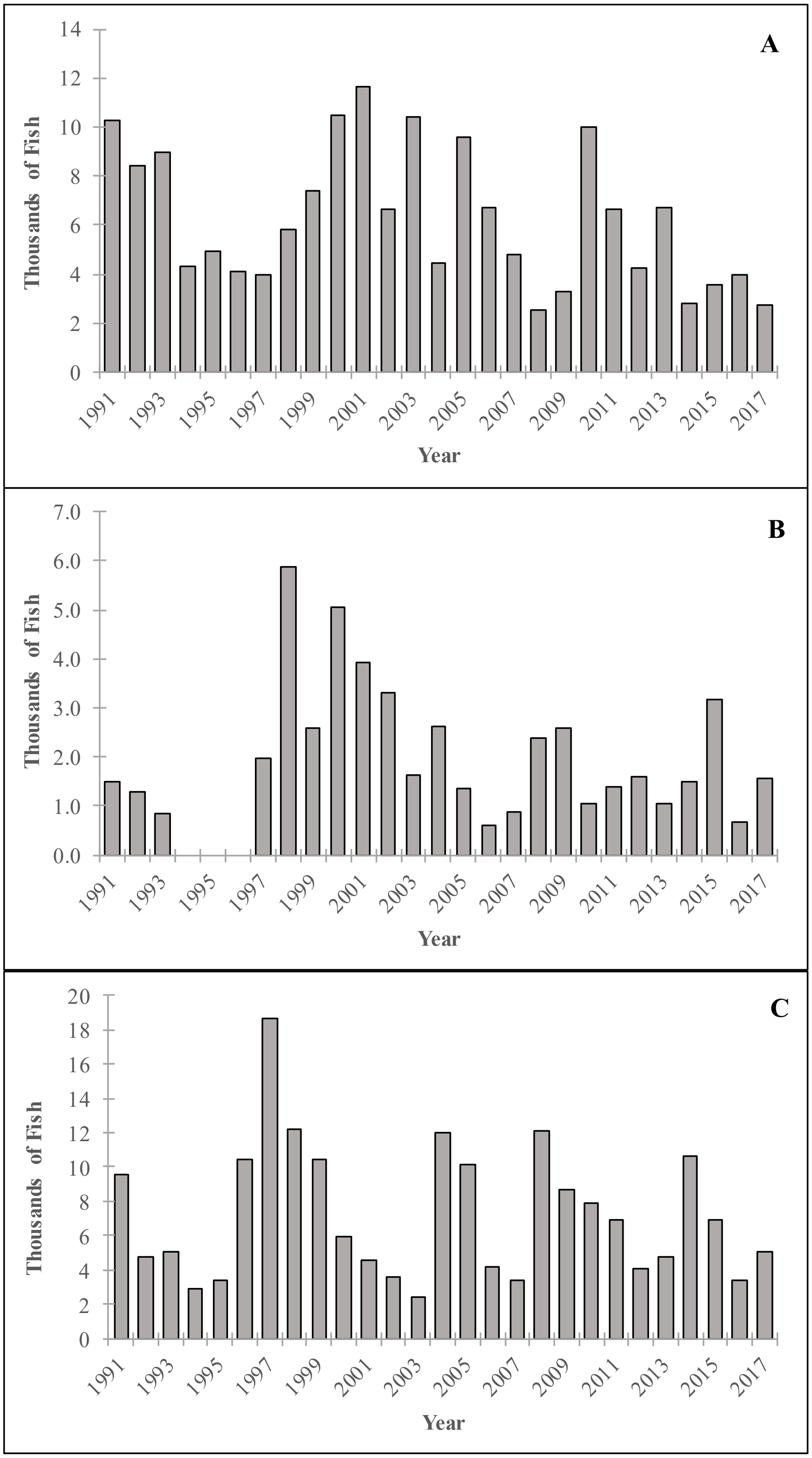

Figure 3.2. Annual (A) ARcomm, (B) ASrec, and (C) RRrec dead discards that were input into the SS model, 1991–2017.

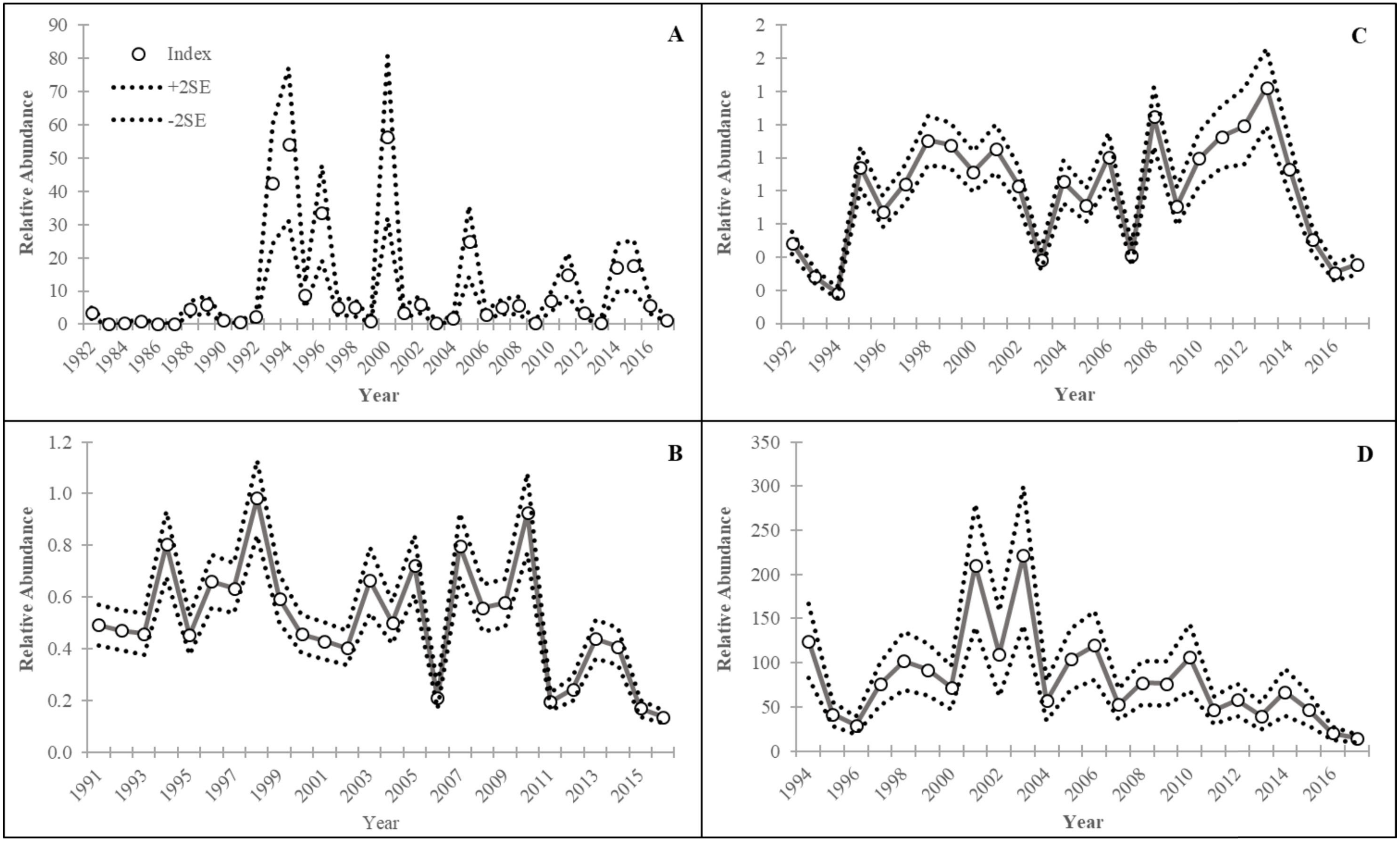

Figure 3.3. GLM-standardized indices of abundance derived from the (A) P100juv, (B) P135fw, (C) P135spr, and (D) RRef surveys that were input into the SS model, 1991–2017.

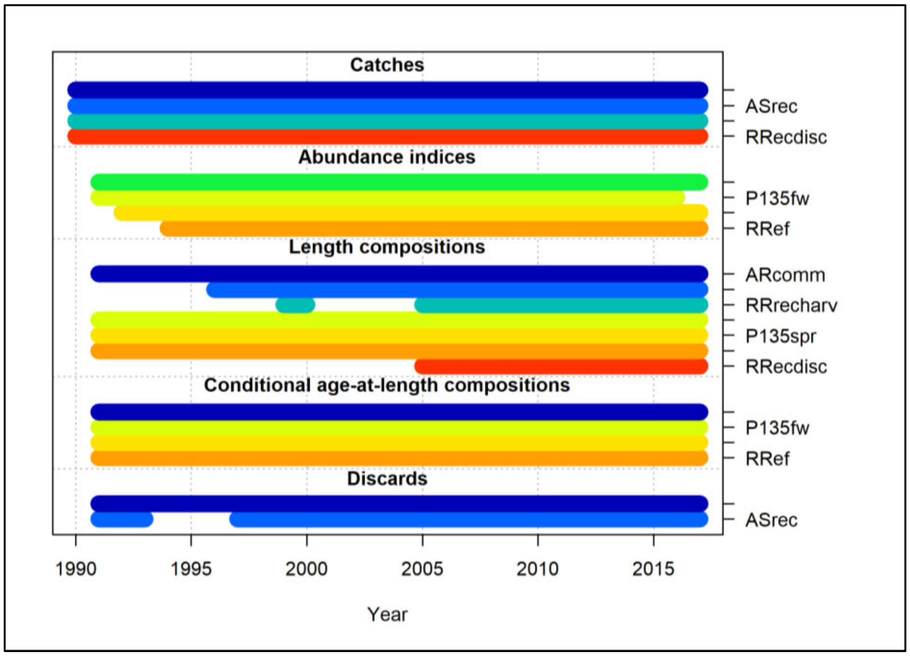

Figure 3.4. Summary of the data sources and types used in the stock assessment model for striped bass.

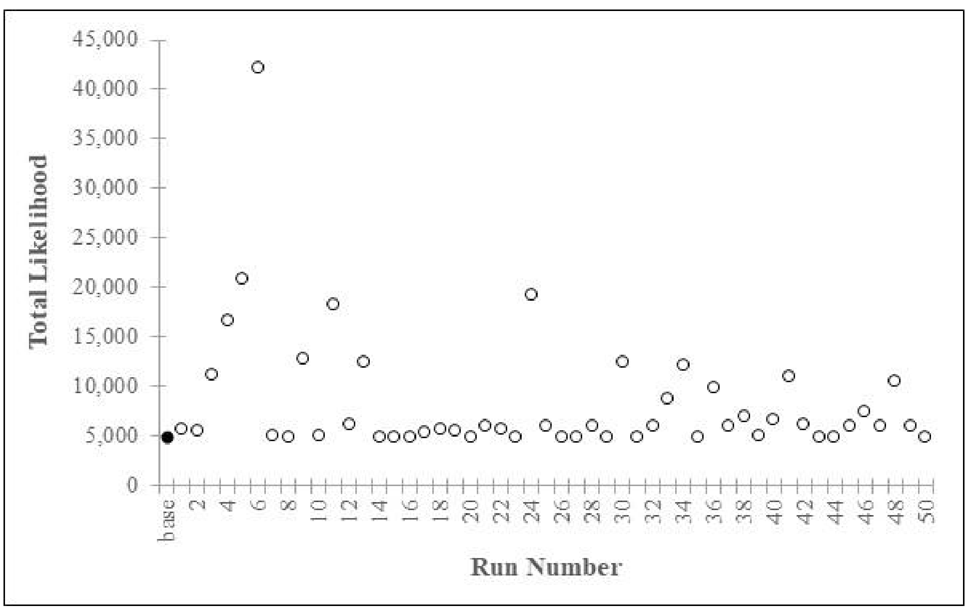

Figure 3.5. Negative log-likelihood values produced from the 50 jitter trials in which initial parameter values were jittered by 10%. The solid black circle is the value from the base run.

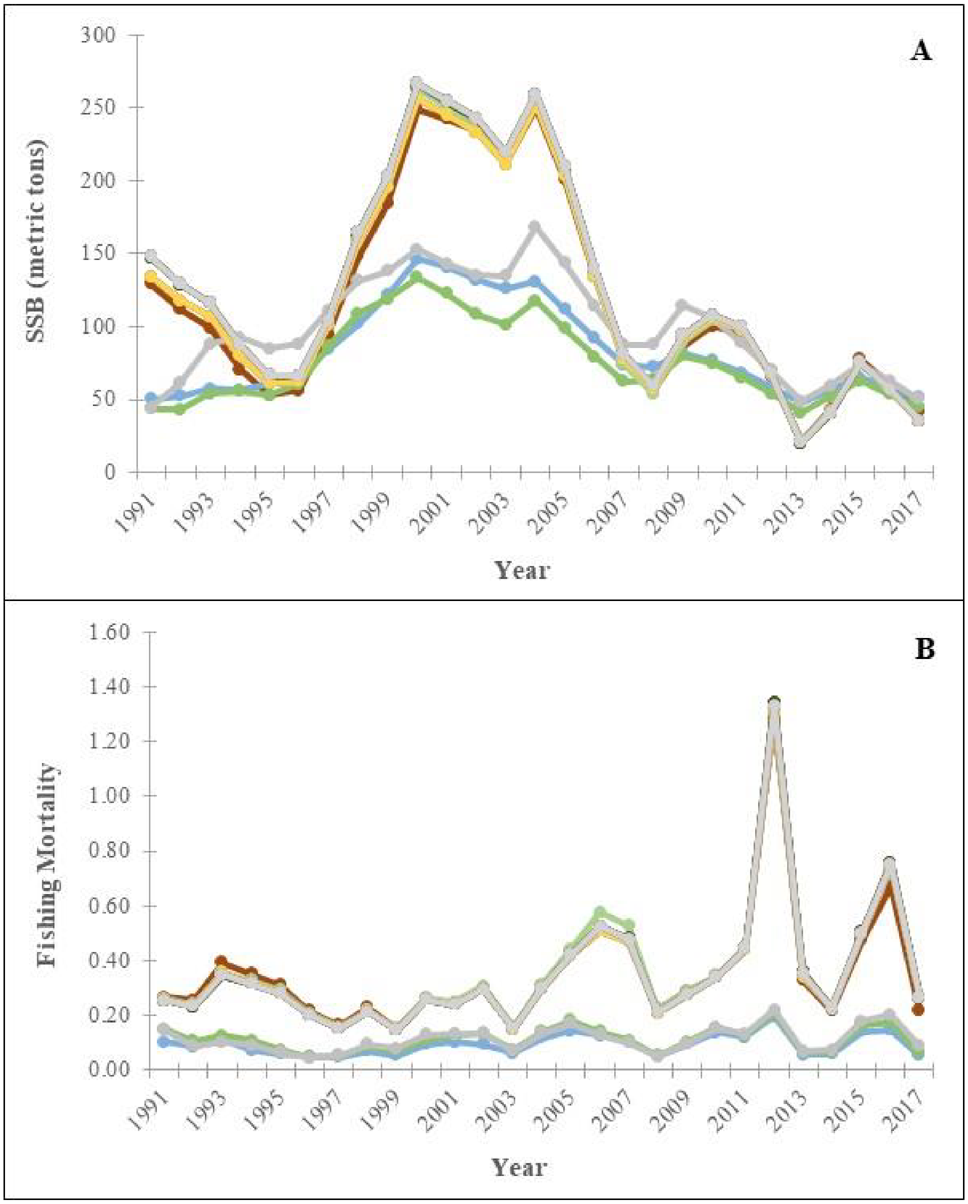

Figure 3.6. Predicted (A) female SSB and (B) *F* (numbers-weighted, ages 3–5) from the converged jitter trials (run 46 removed) in which initial parameter values were jittered by 10%, 1991–2017.

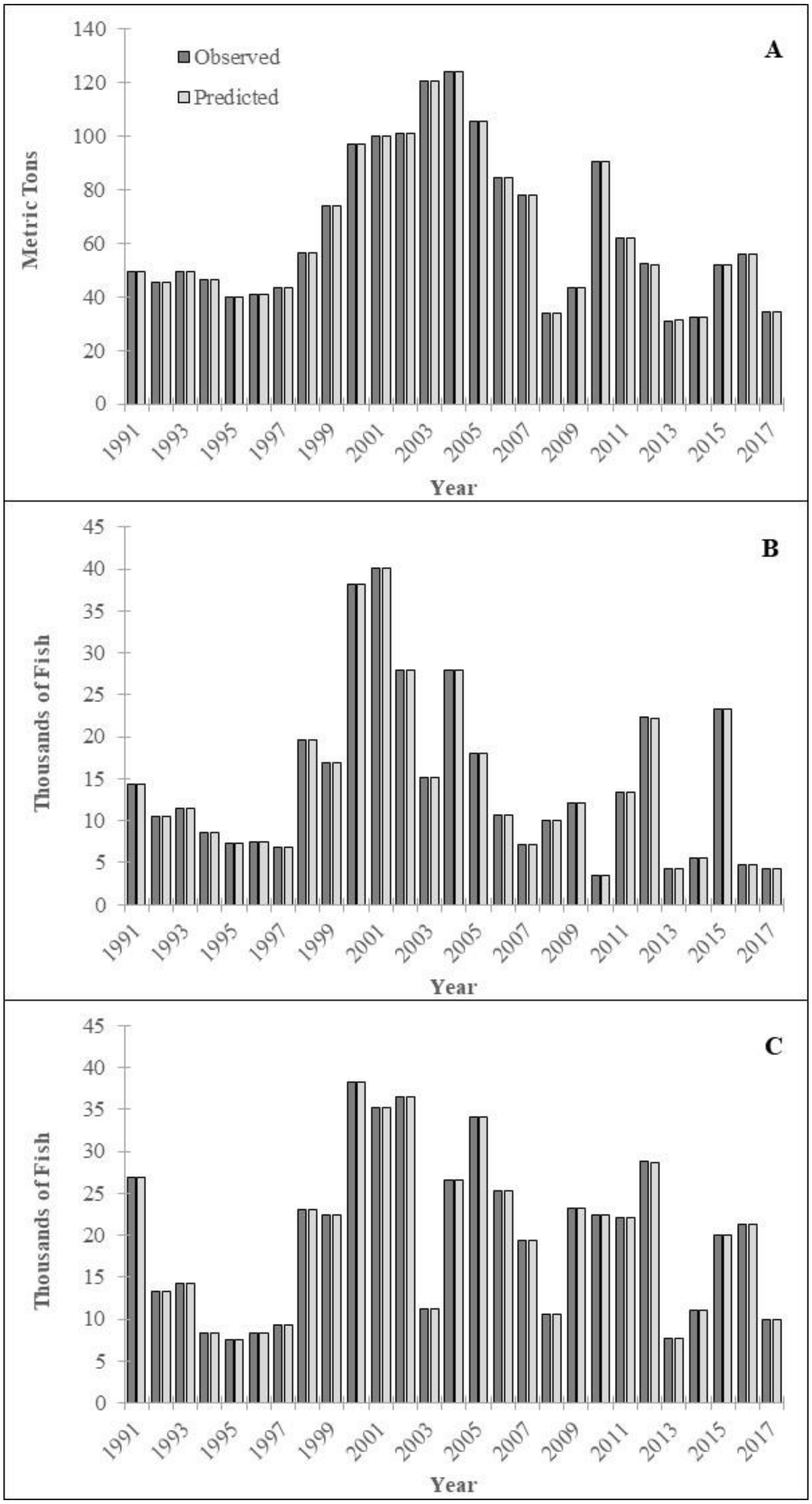

Figure 3.7. Observed and predicted (A) ARcomm landings, (B) ASrec harvest, and (C) RRrec harvest from the base run of the stock assessment model, 1991–2017.

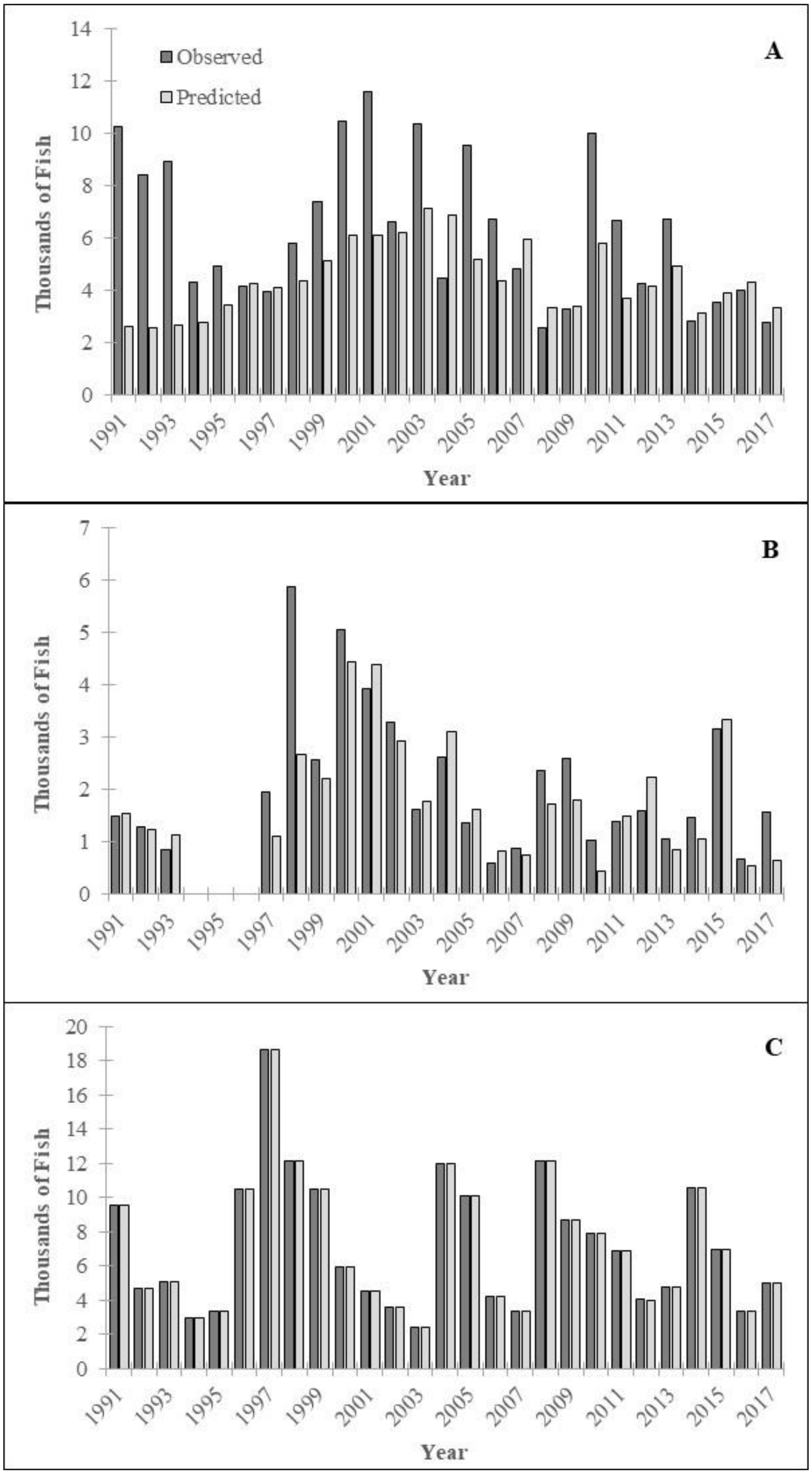

Figure 3.8. Observed and predicted (A) ARcomm, (B) ASrec, and (C) RRrec dead discards from the base run of the stock assessment model, 1991–2017.

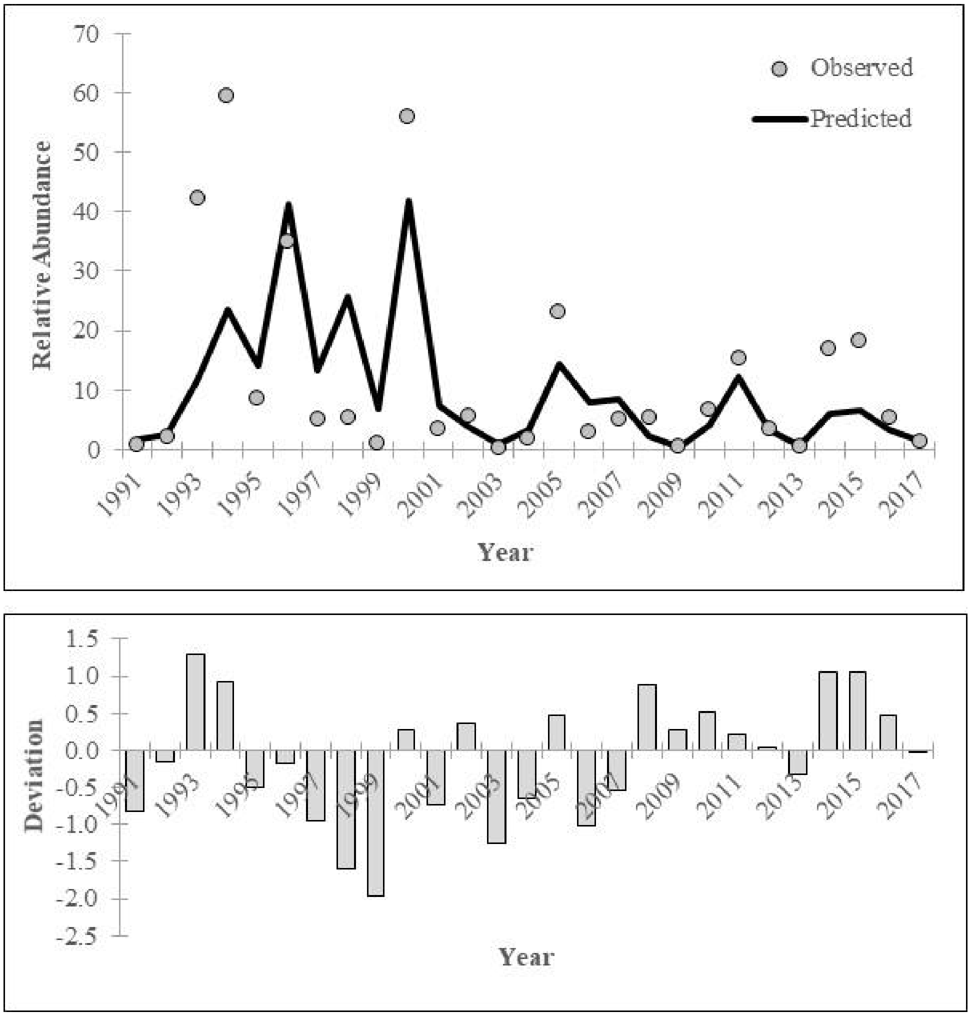

Figure 3.9. Observed and predicted relative abundance (top graph) and standardized residuals (bottom graph) for the P100juv survey from the base run of the stock assessment model, 1991–2017.

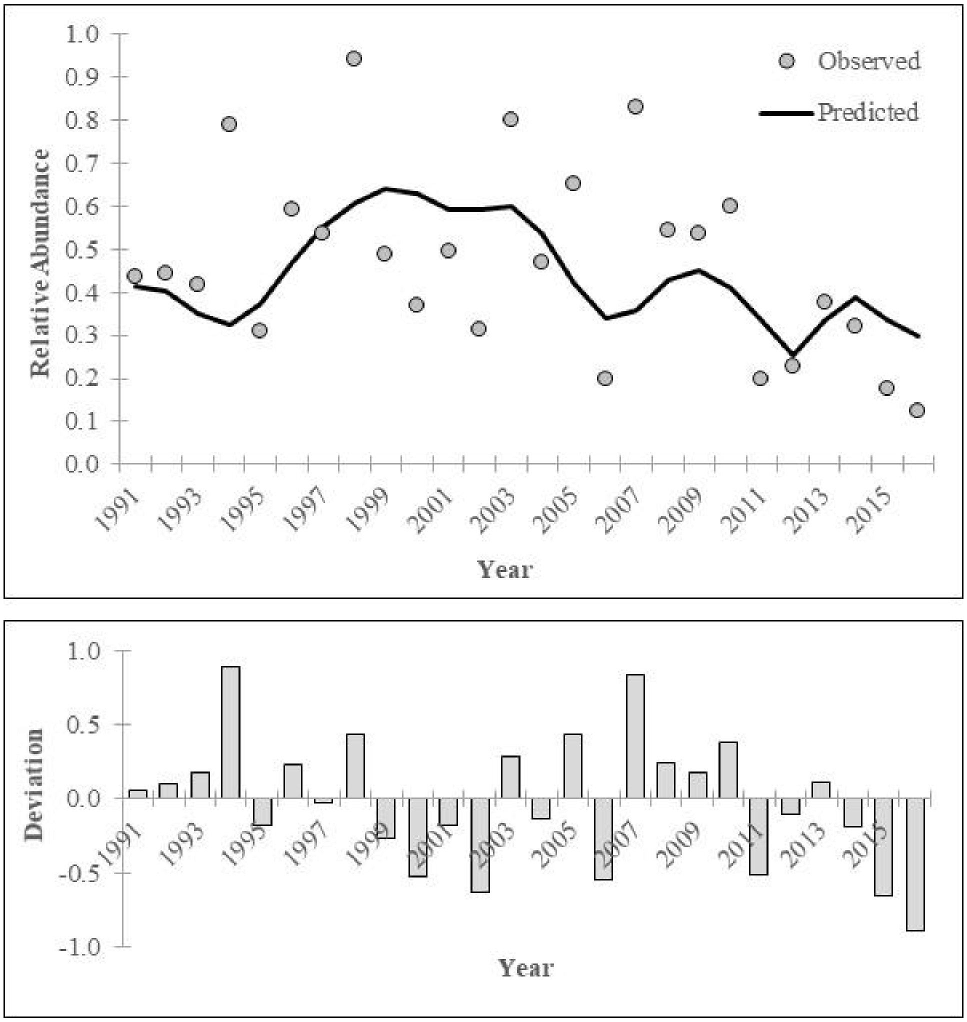

Figure 3.10. Observed and predicted relative abundance (top graph) and standardized residuals (bottom graph) for the P135fw survey from the base run of the stock assessment model, 1991–2017.

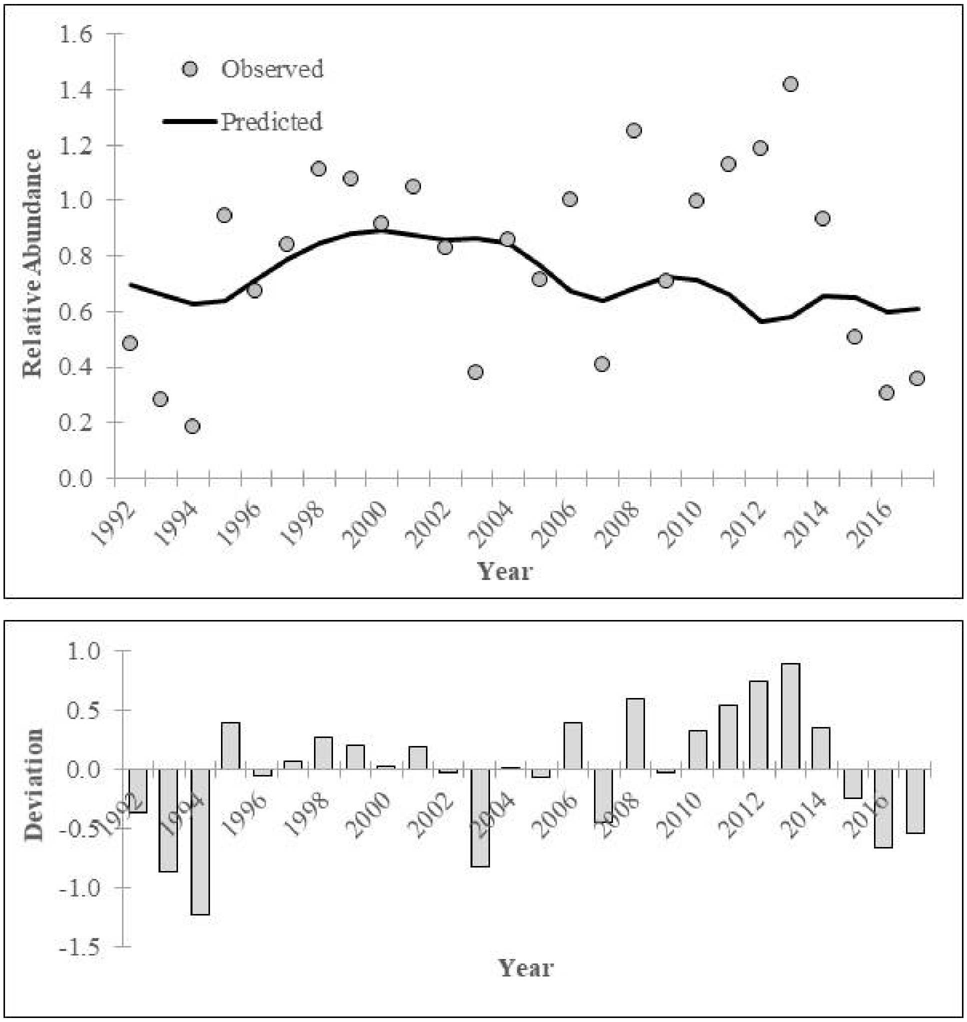

Figure 3.11. Observed and predicted relative abundance (top graph) and standardized residuals (bottom graph) for the P135spr survey from the base run of the stock assessment model, 1992–2017.

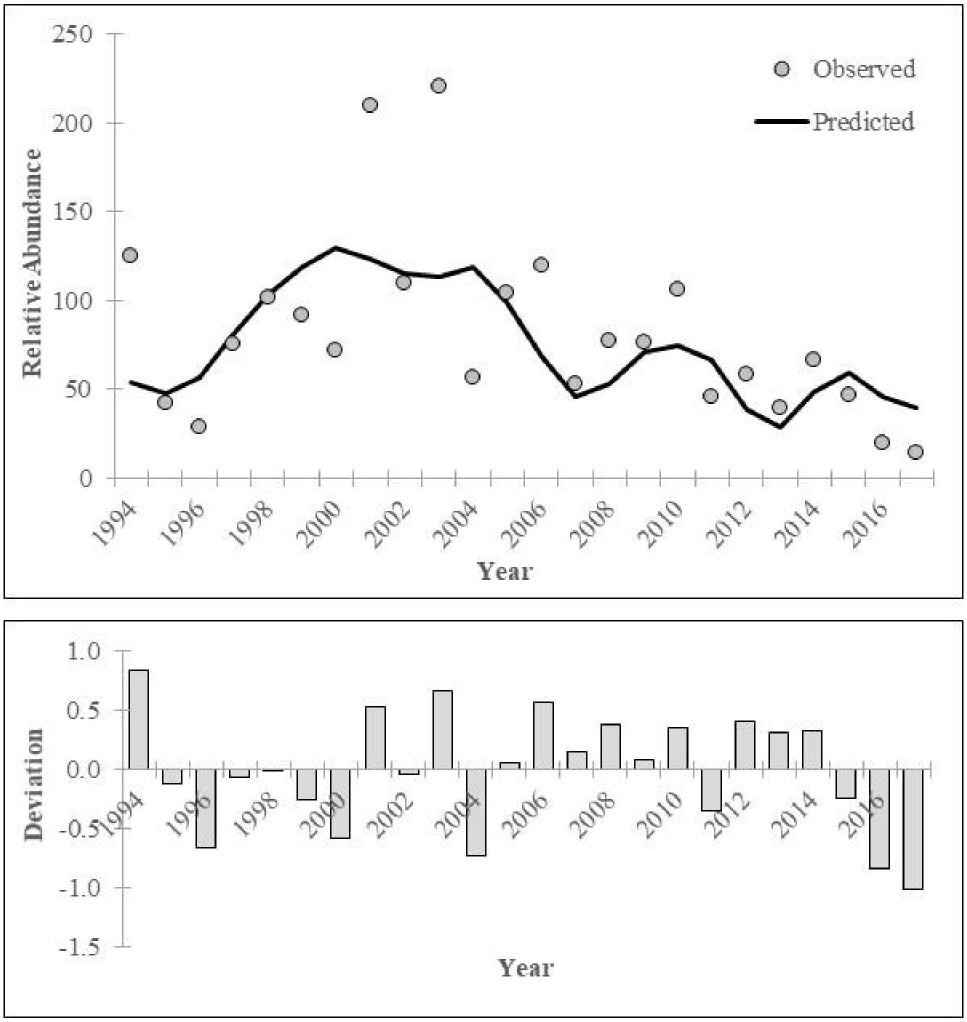

Figure 3.12. Observed and predicted relative abundance (top graph) and standardized residuals (bottom graph) for the RRef survey from the base run of the stock assessment model, 1994–2017.

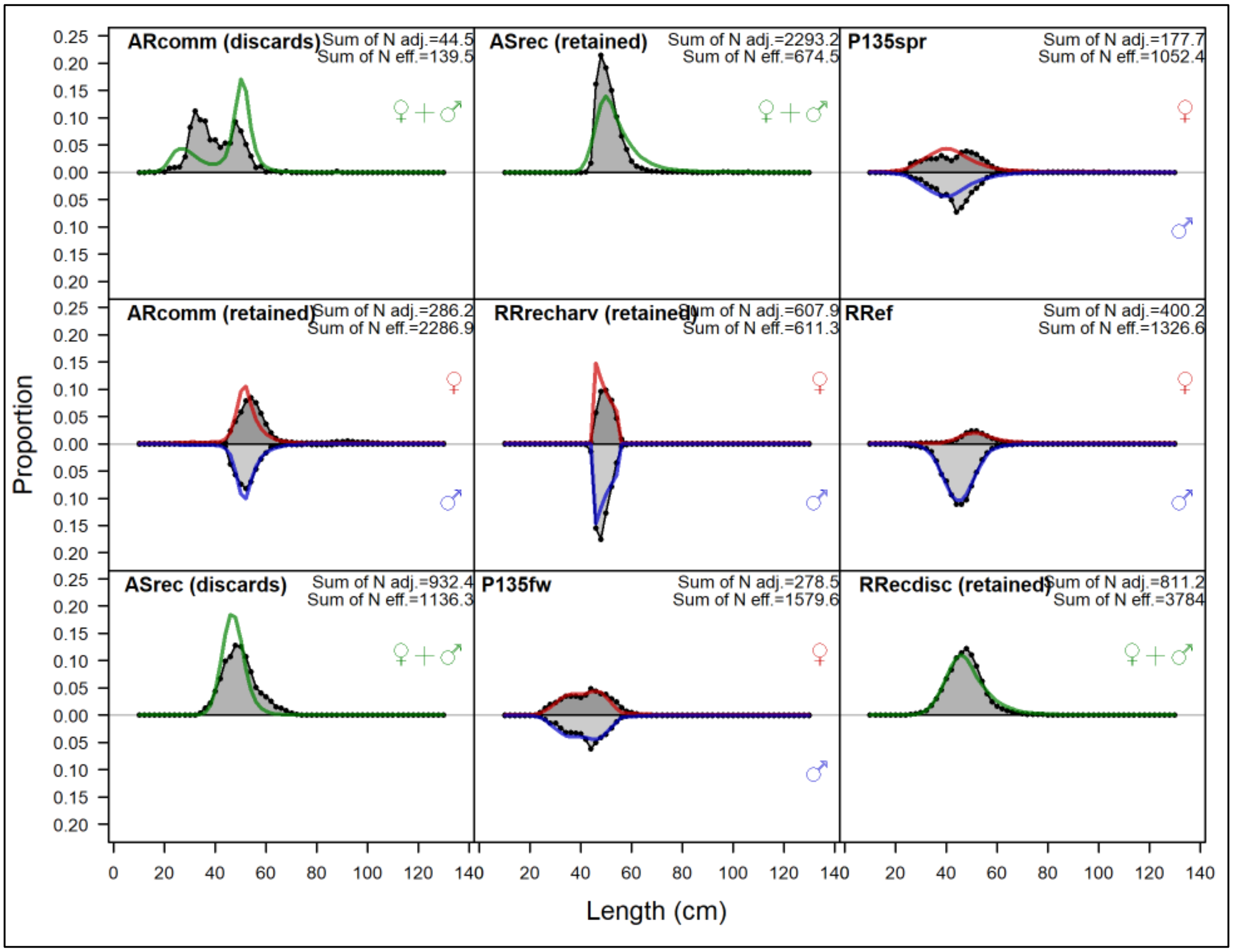

Figure 3.13. Observed and predicted length compositions for each data source from the base run of the stock assessment model aggregated across time. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

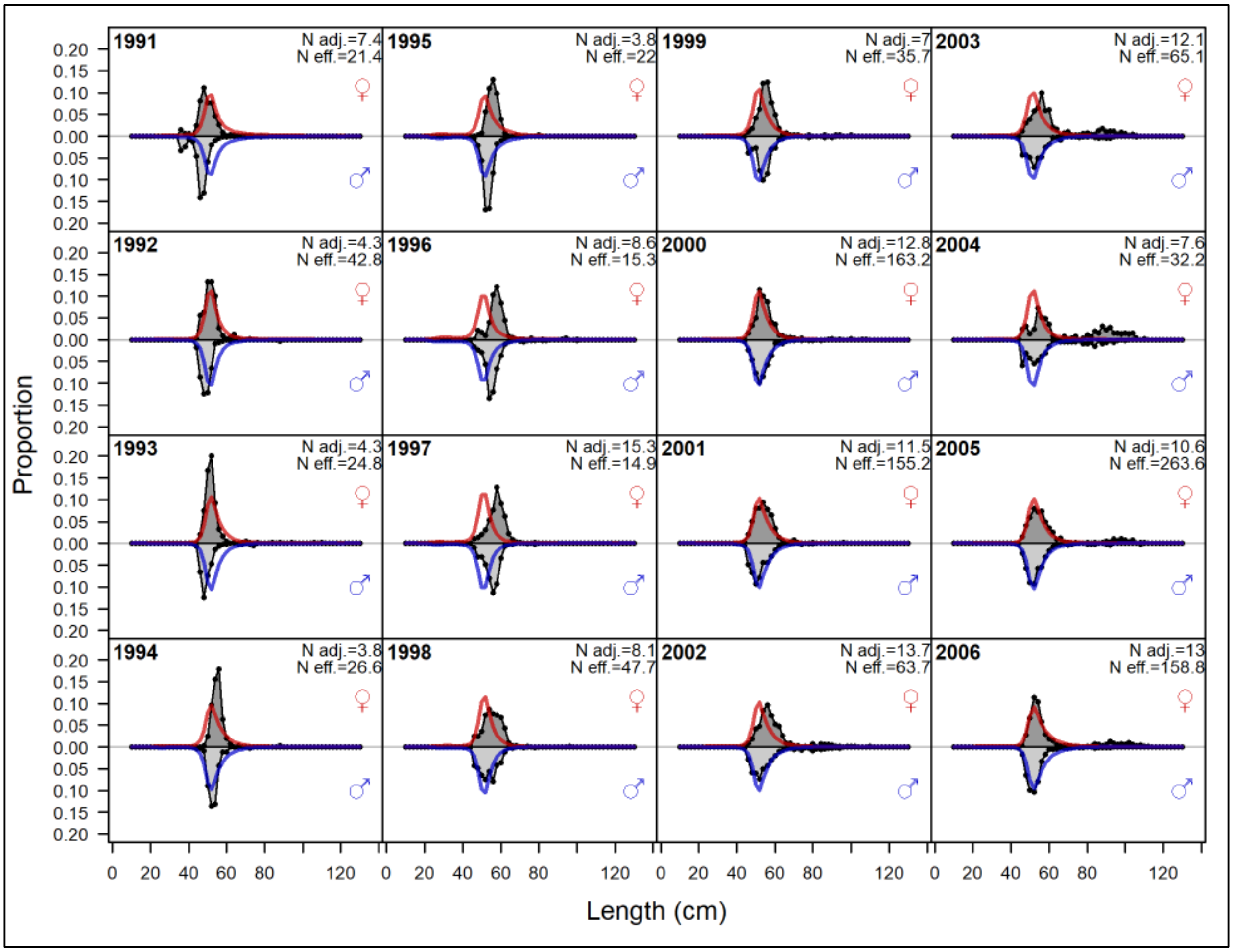

Figure 3.14. Observed and predicted length compositions for the ARcomm landings from the base run of the stock assessment model, 1991–2006. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

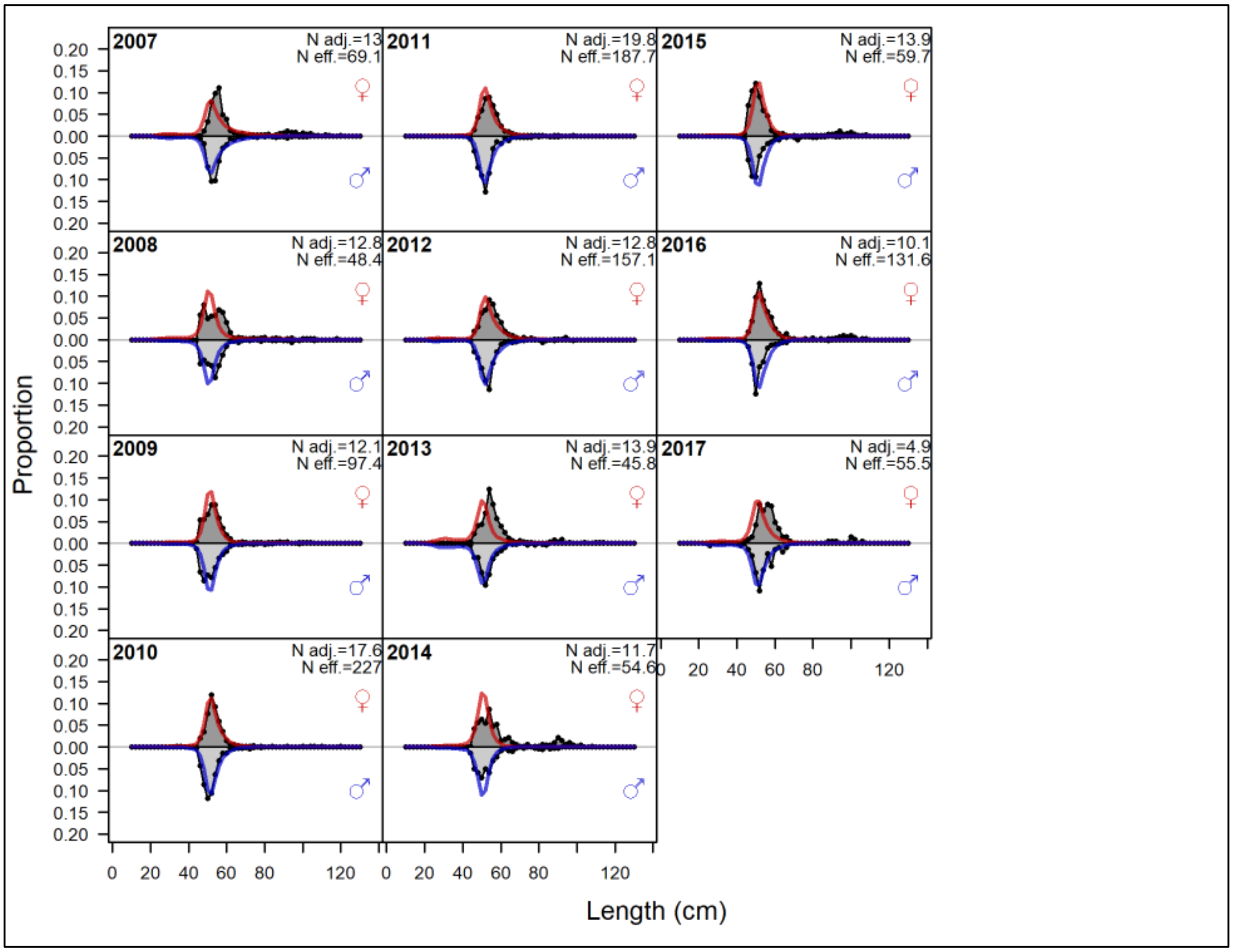

Figure 3.15. Observed and predicted length compositions for the ARcomm landings from the base run of the stock assessment model, 2007–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

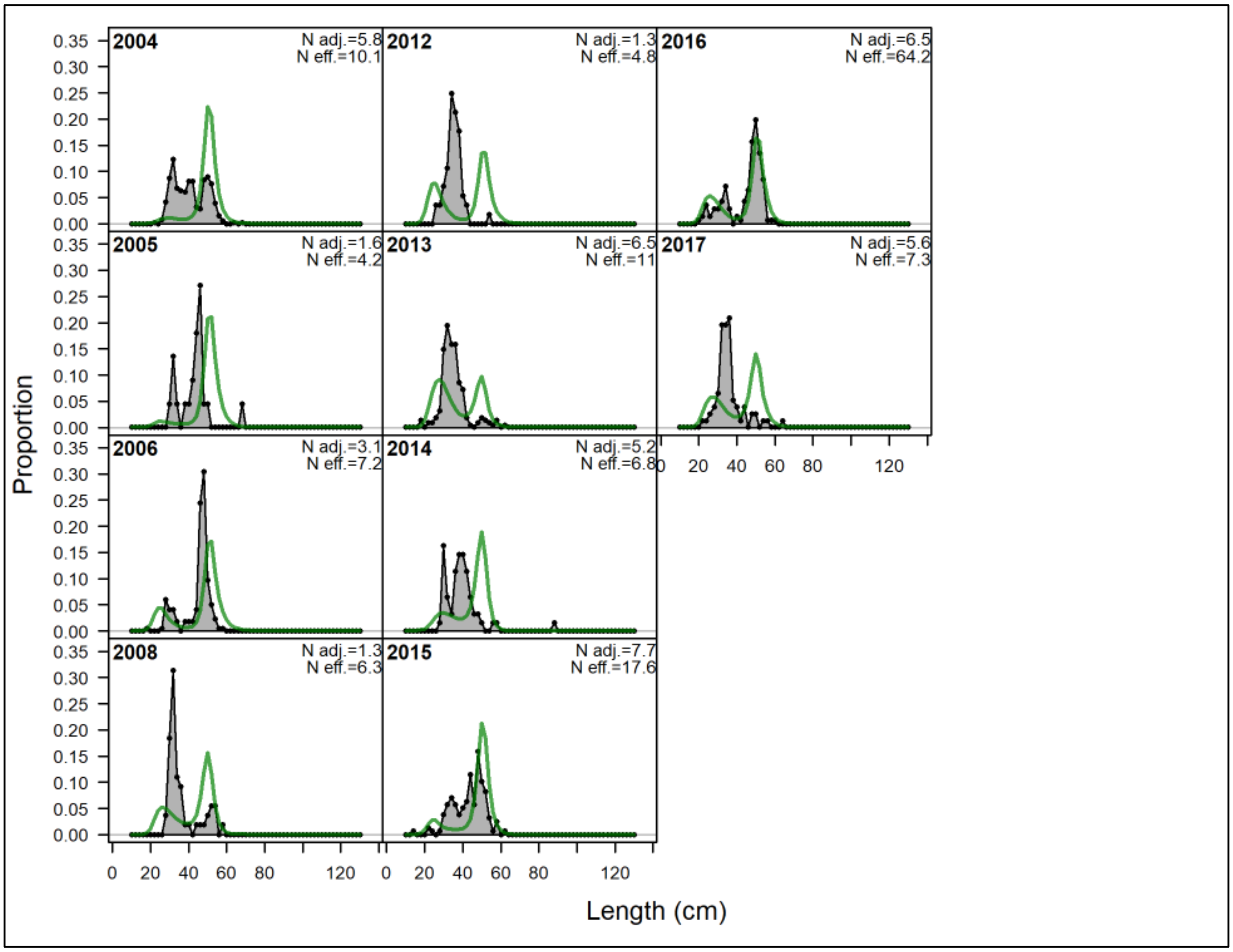

Figure 3.16. Observed and predicted length compositions for the ARcomm discards from the base run of the stock assessment model, 2004–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

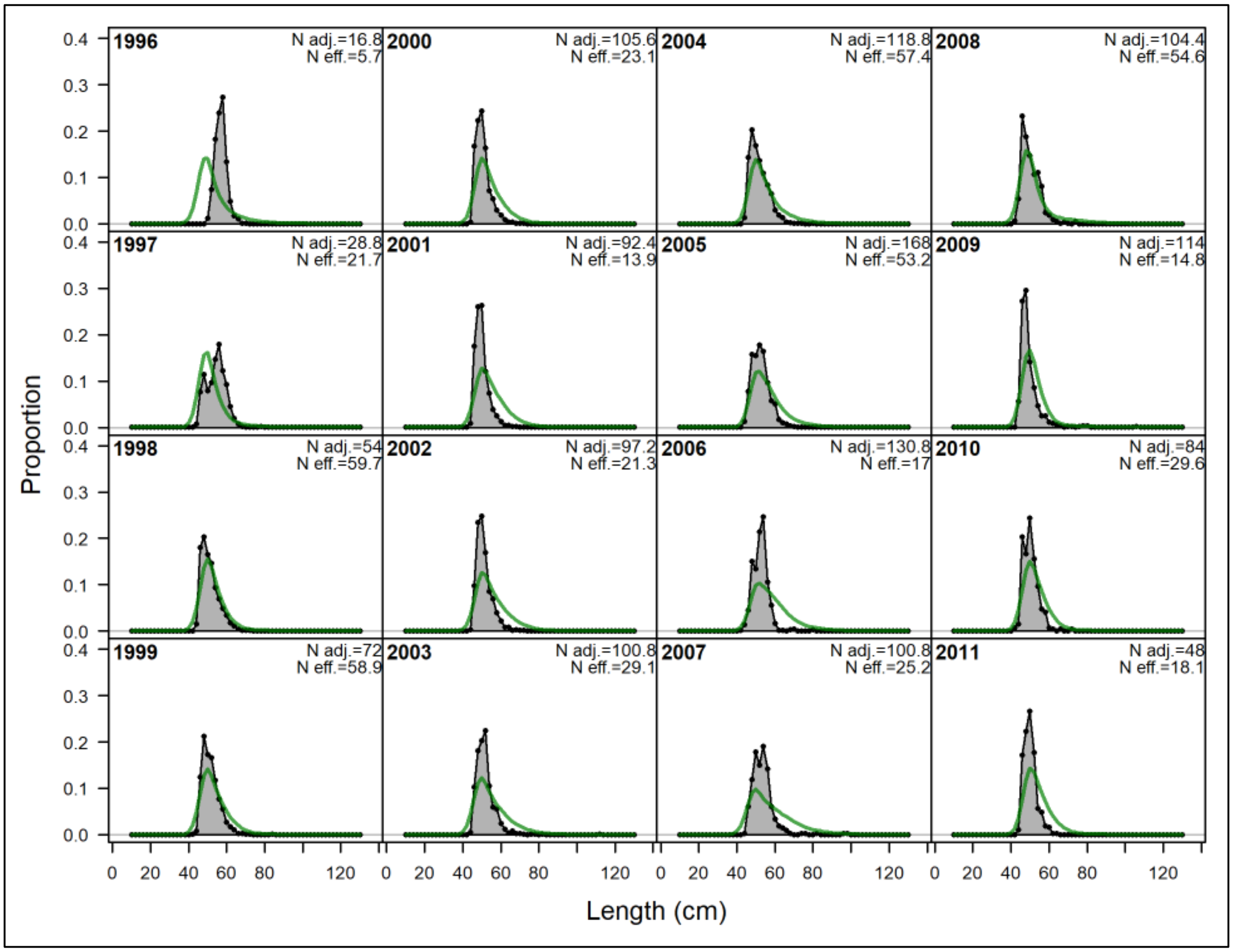

Figure 3.17. Observed and predicted length compositions for the ASrec harvest from the base run of the stock assessment model, 1996–2011. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

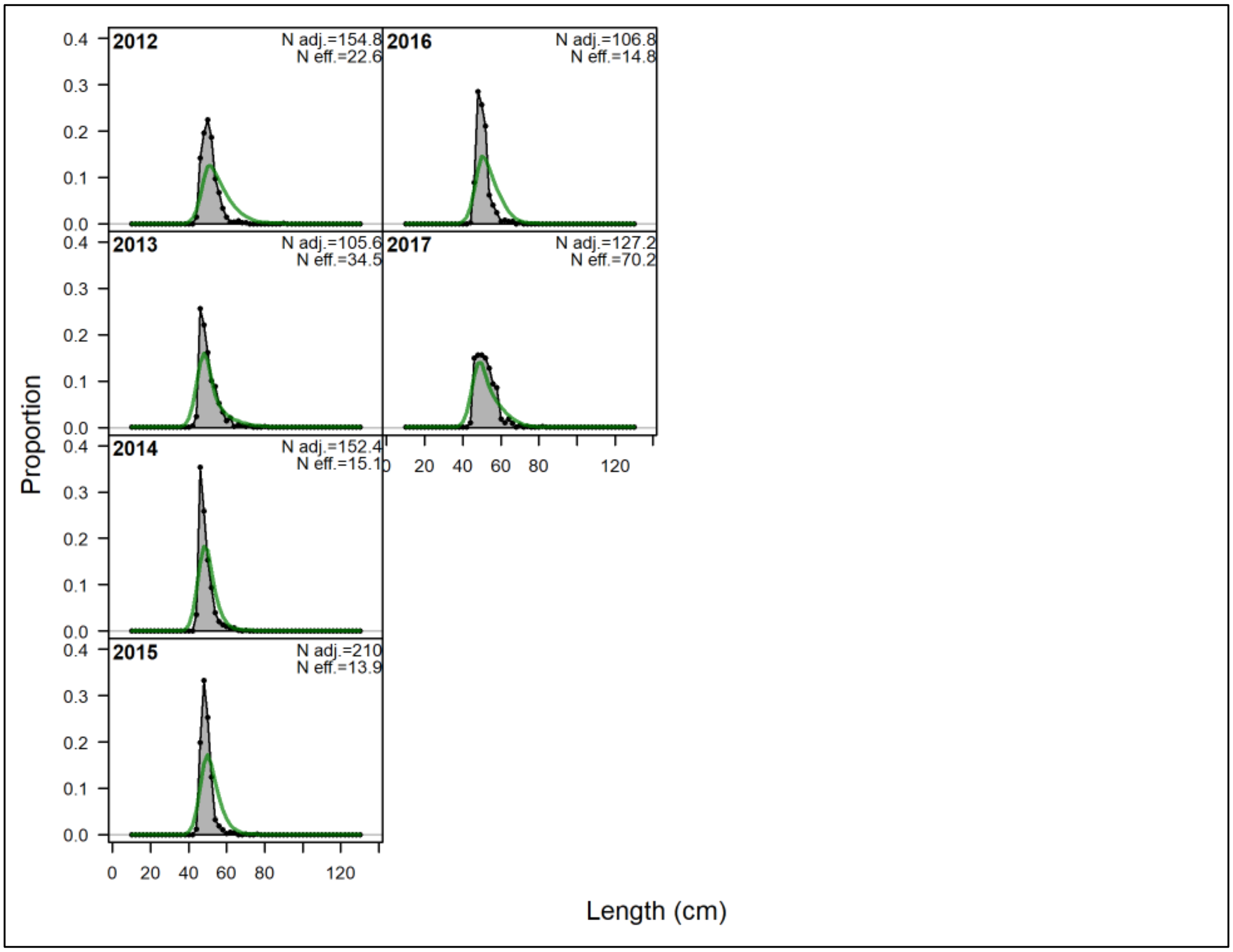

Figure 3.18. Observed and predicted length compositions for the ASrec harvest from the base run of the stock assessment model, 2012–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

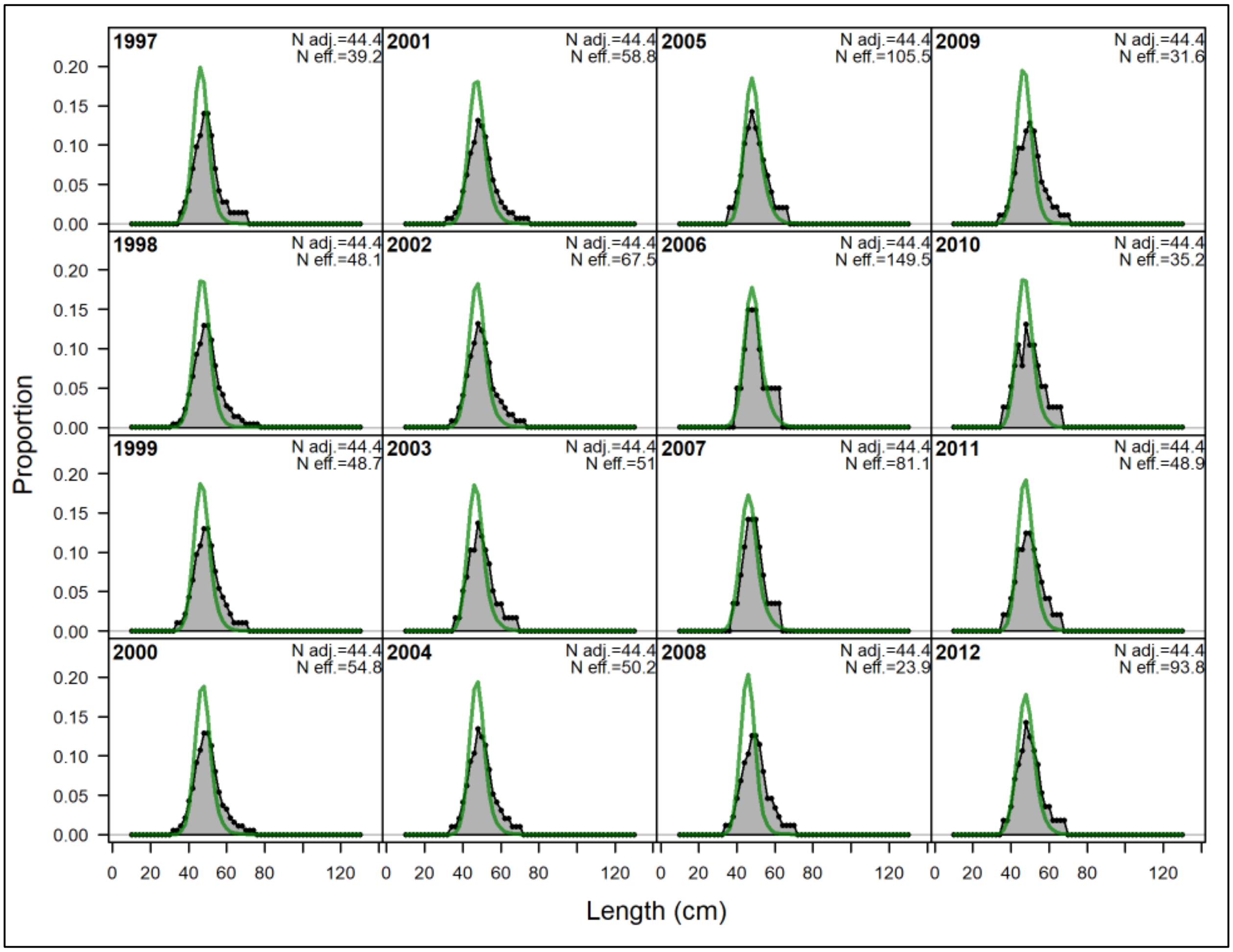

Figure 3.19. Observed and predicted length compositions for the ASrec discards from the base run of the stock assessment model, 1997–2012. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

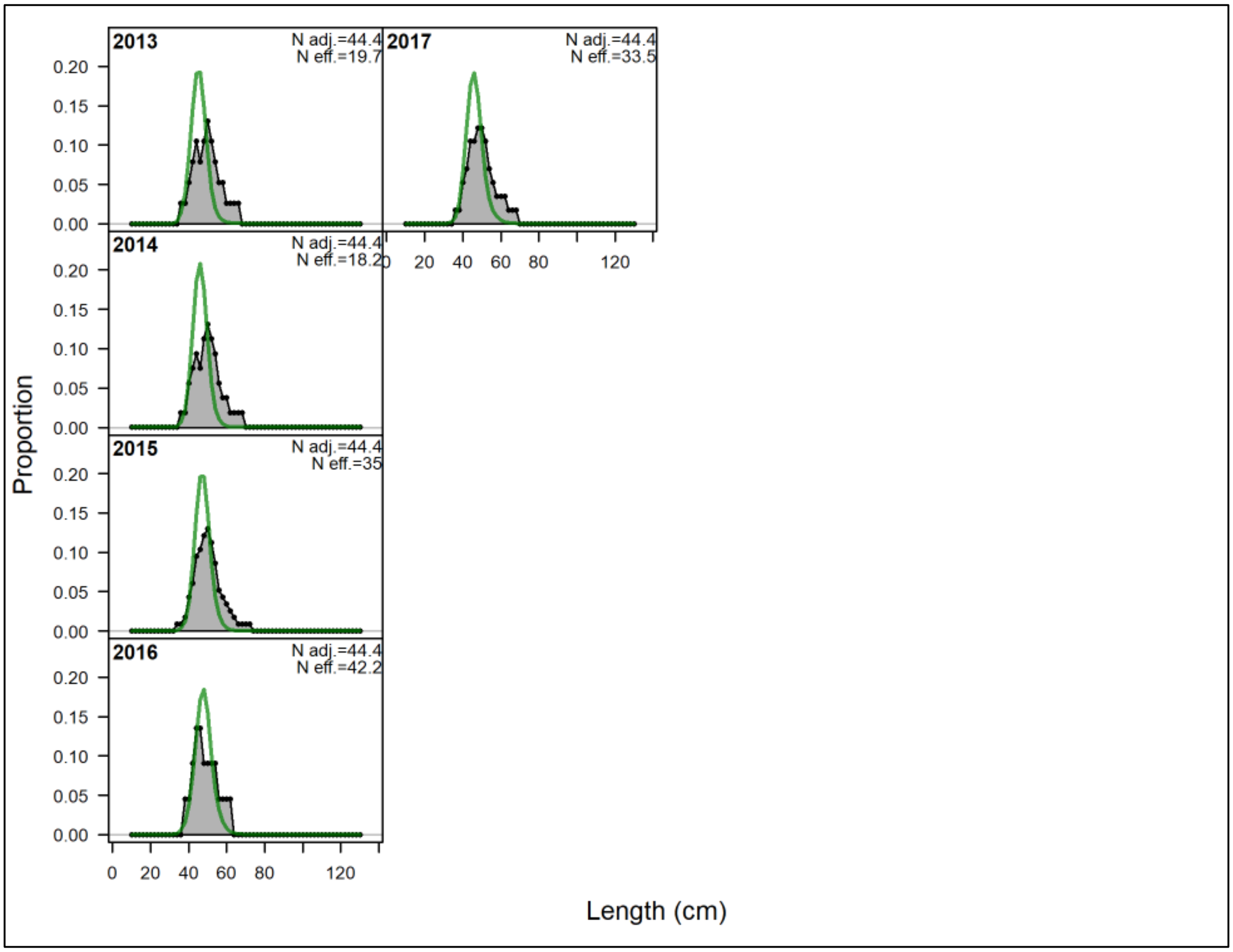

Figure 3.20. Observed and predicted length compositions for the ASrec discards from the base run of the stock assessment model, 2013–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

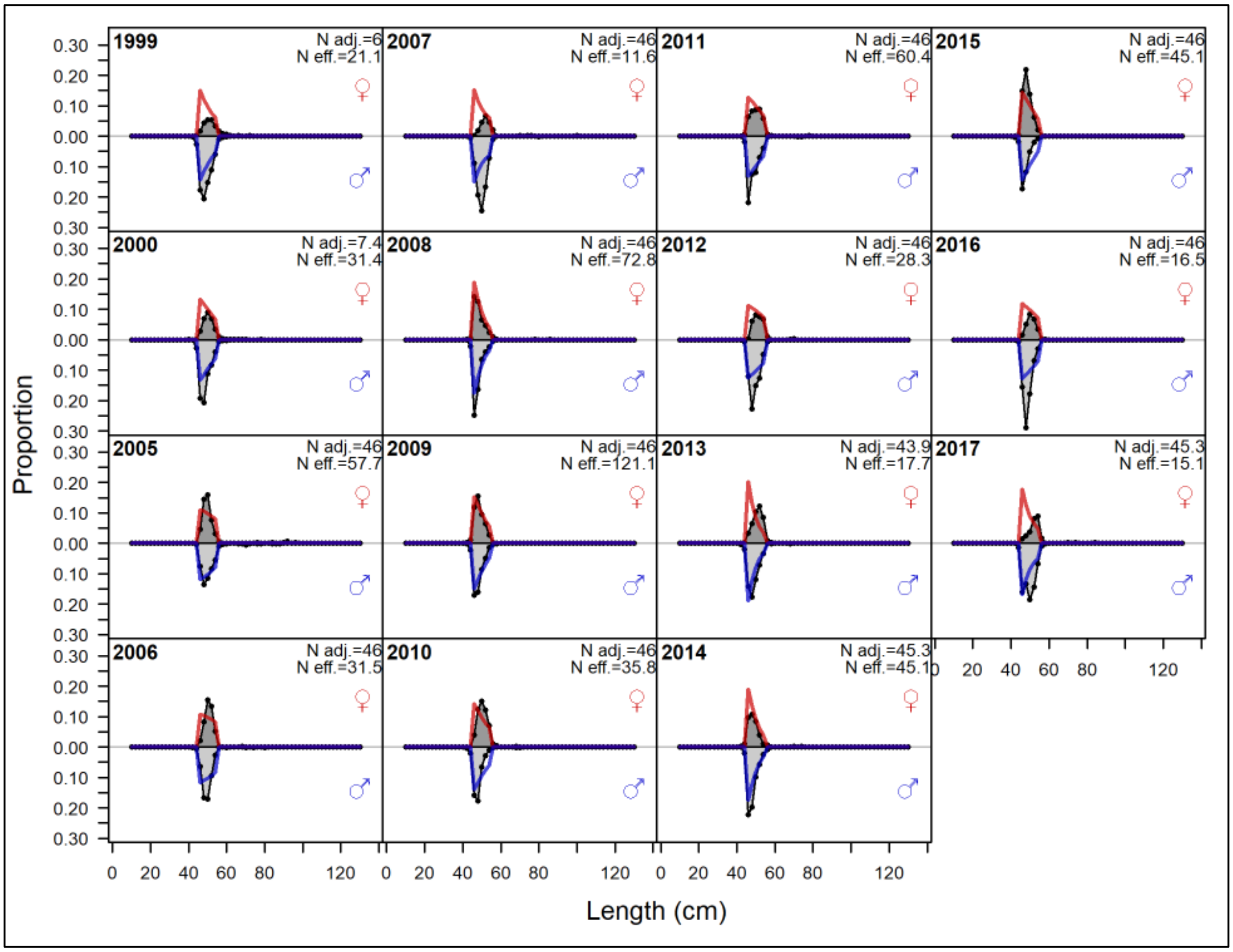

Figure 3.21. Observed and predicted length compositions for the RRrec harvest from the base run of the stock assessment model, 1999–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

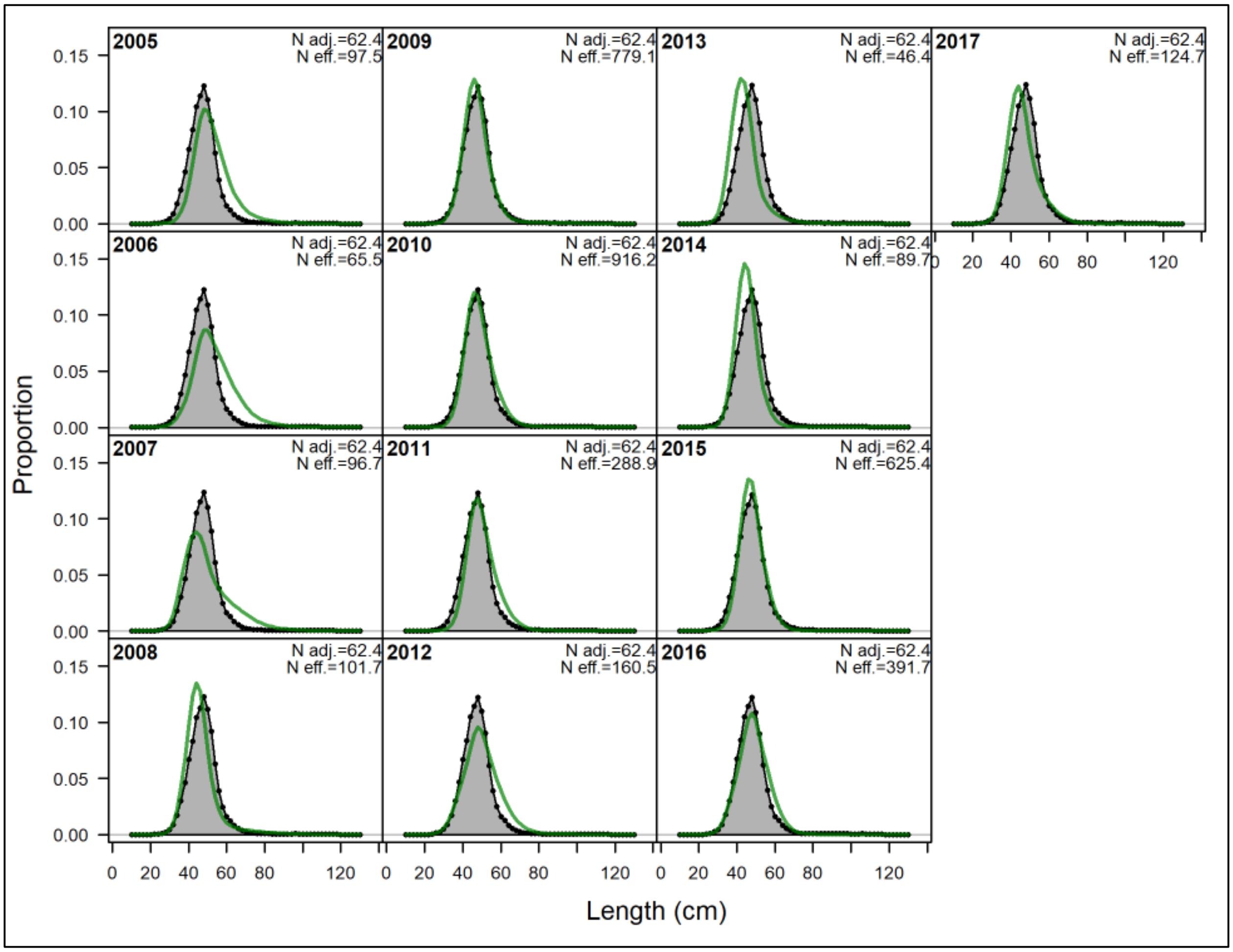

Figure 3.22. Observed and predicted length compositions for the RRrec discards from the base run of the stock assessment model, 2005–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

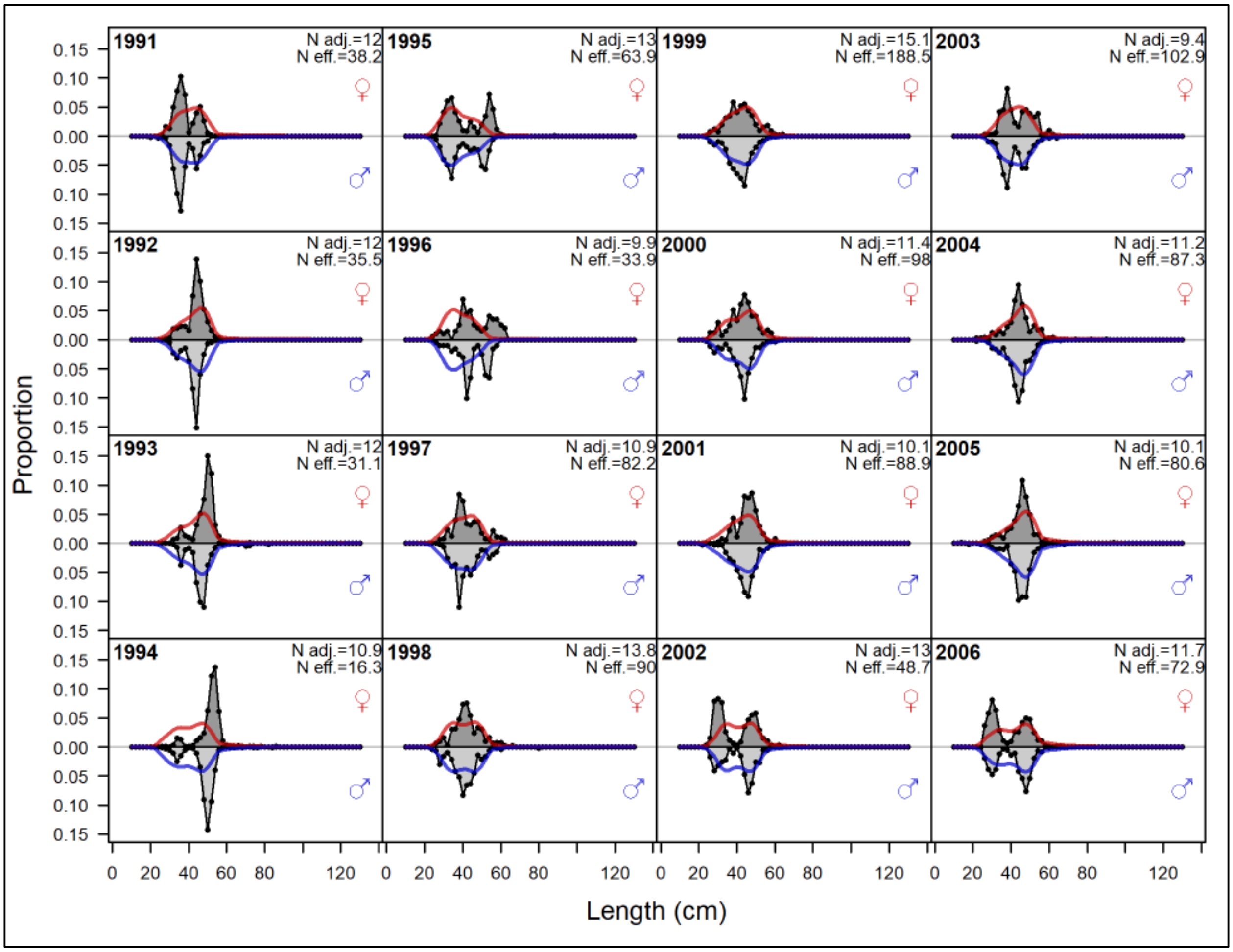

Figure 3.23. Observed and predicted length compositions for the P135fw survey from the base run of the stock assessment model, 1991–2006. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

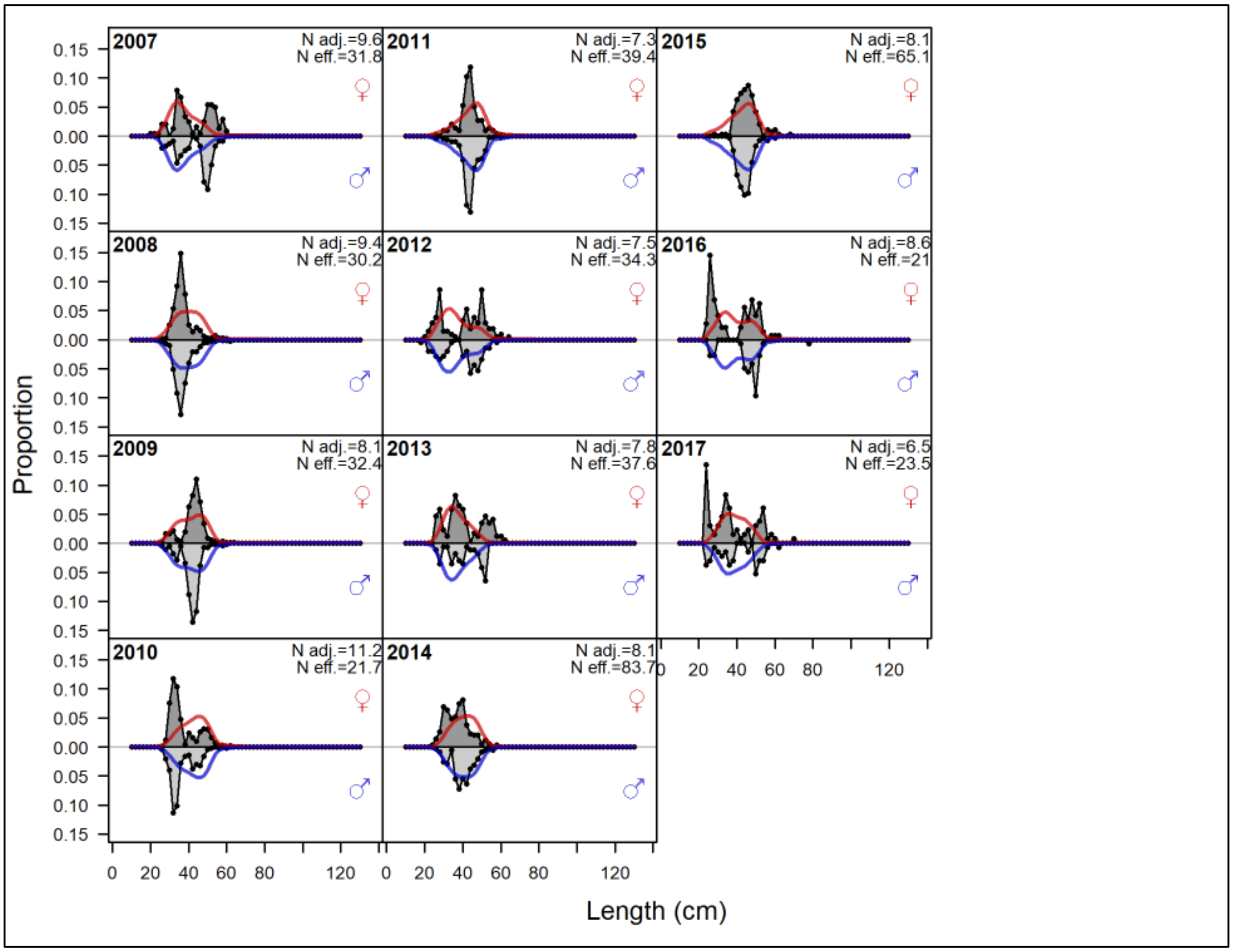

Figure 3.24. Observed and predicted length compositions for the P135fw survey from the base run of the stock assessment model, 2007–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

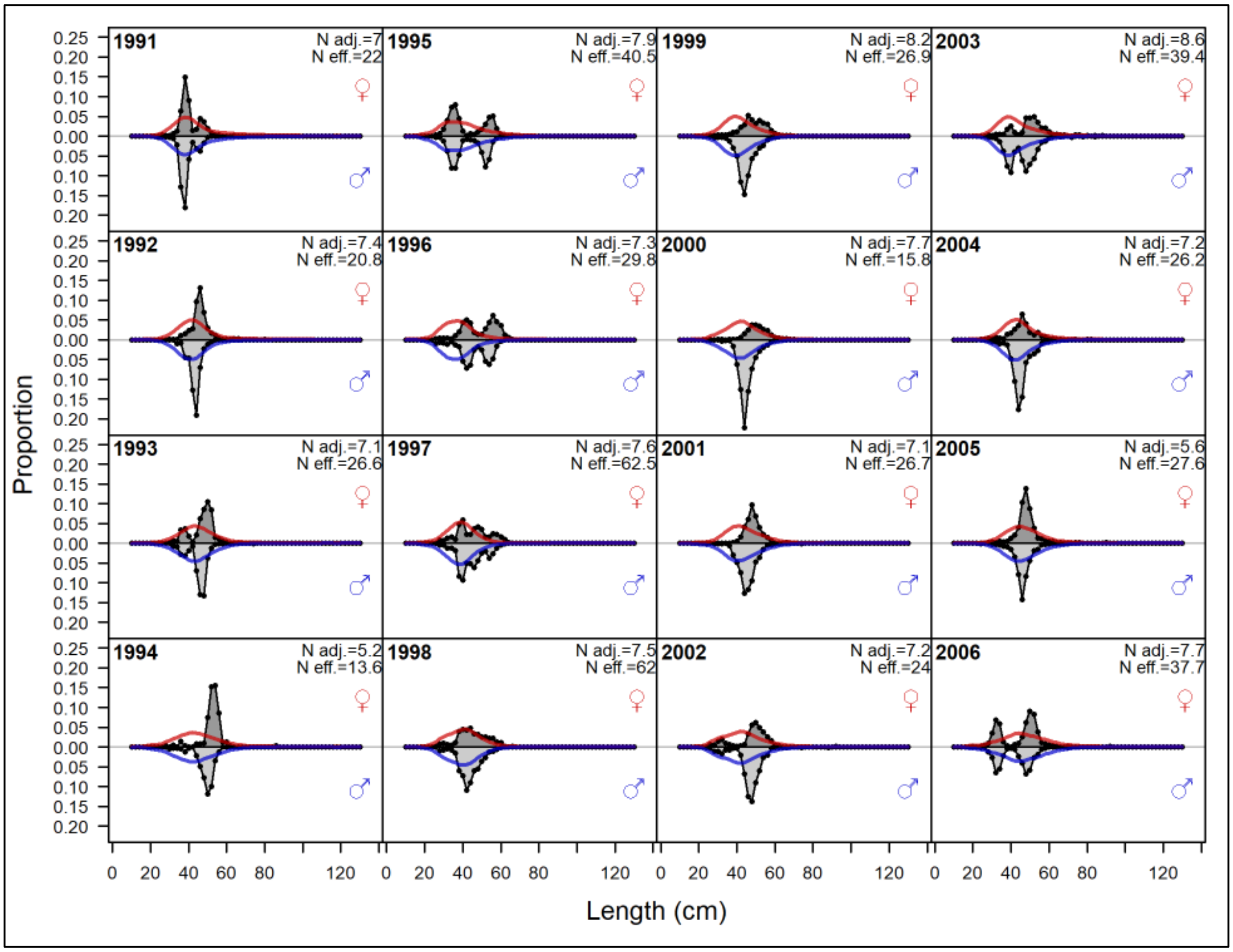

Figure 3.25. Observed and predicted length compositions for the P135spr survey from the base run of the stock assessment model, 1991–2006. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

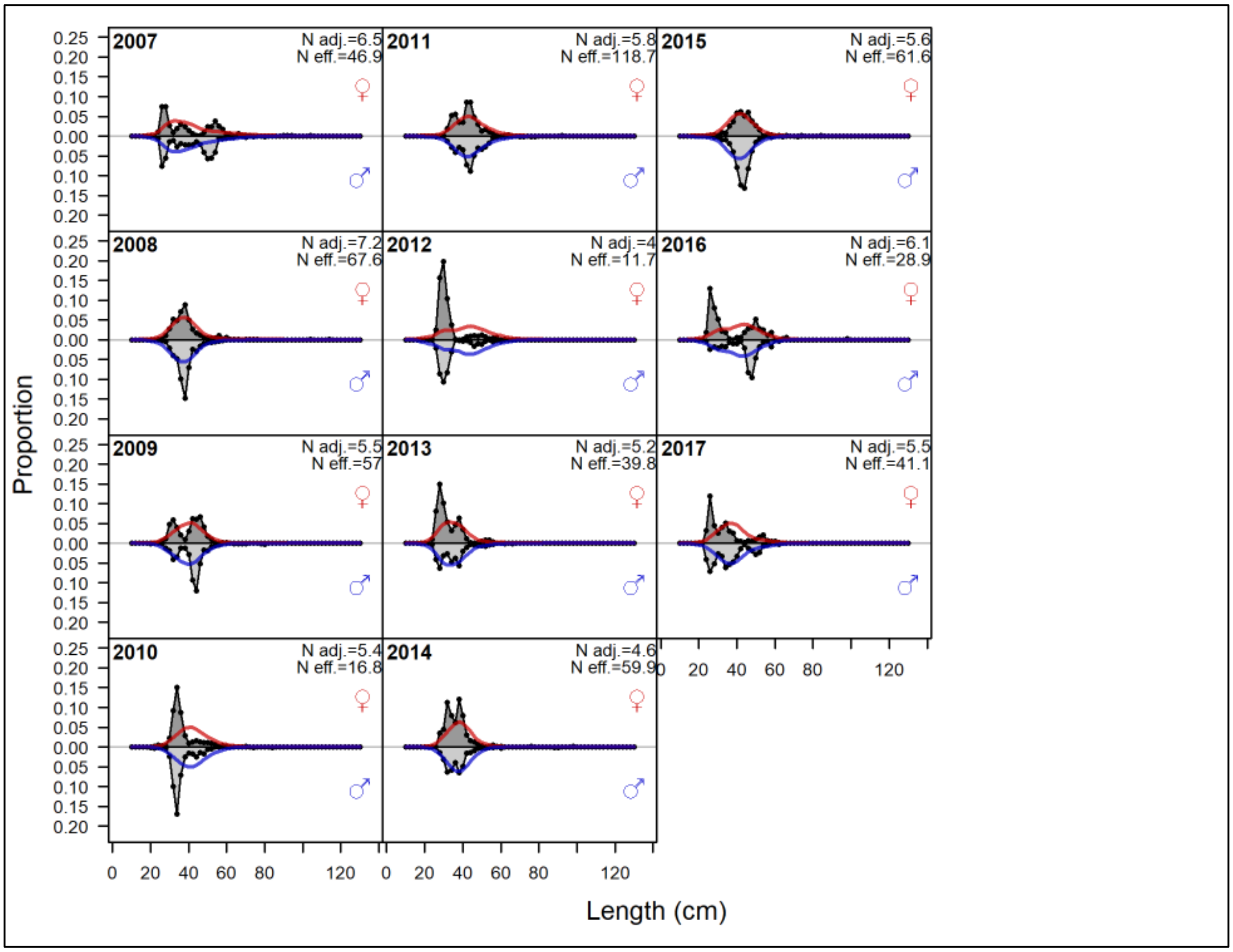

Figure 3.26. Observed and predicted length compositions for the P135spr survey from the base run of the stock assessment model, 2007–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

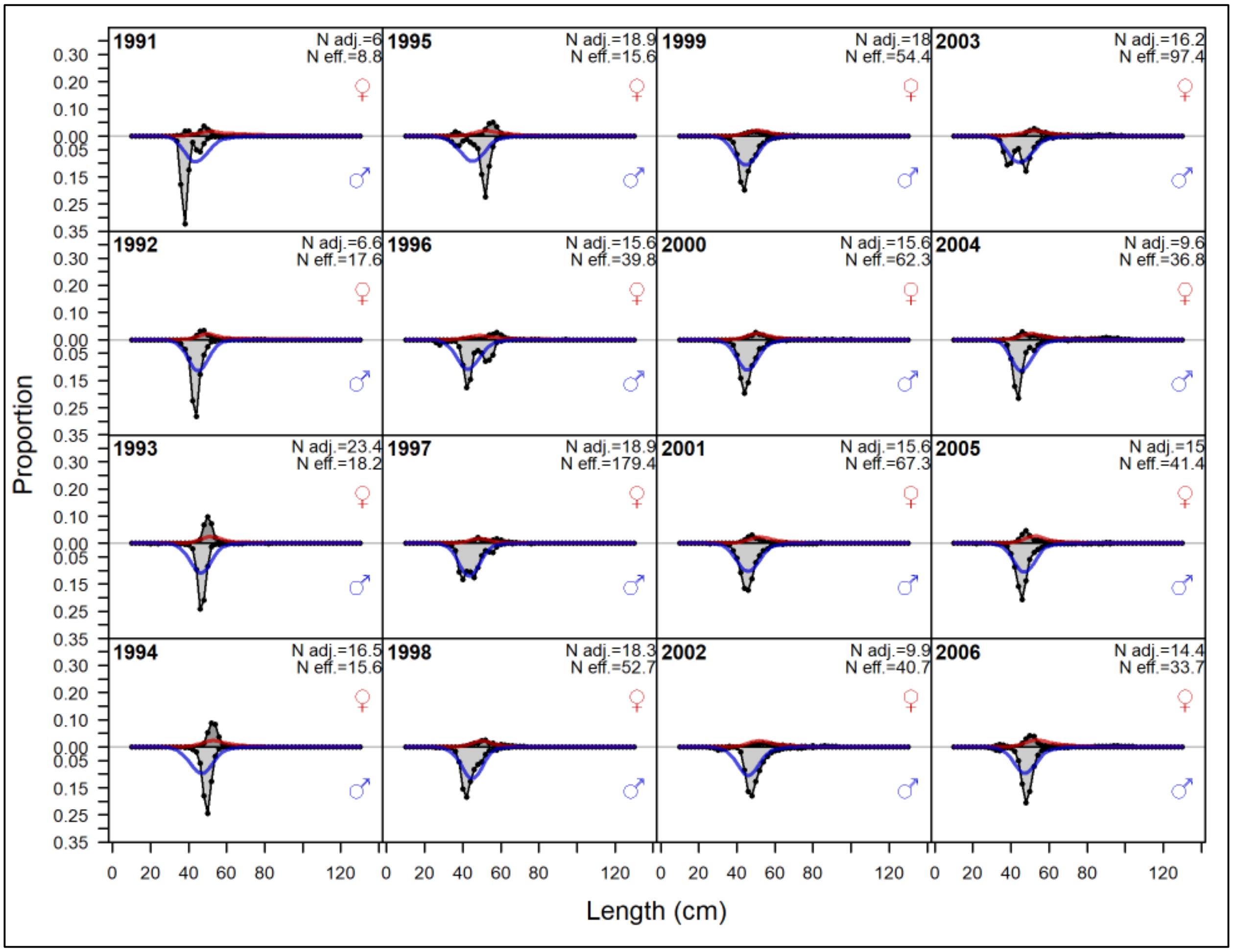

Figure 3.27. Observed and predicted length compositions for the RRef survey from the base run of the stock assessment model, 1991–2006. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

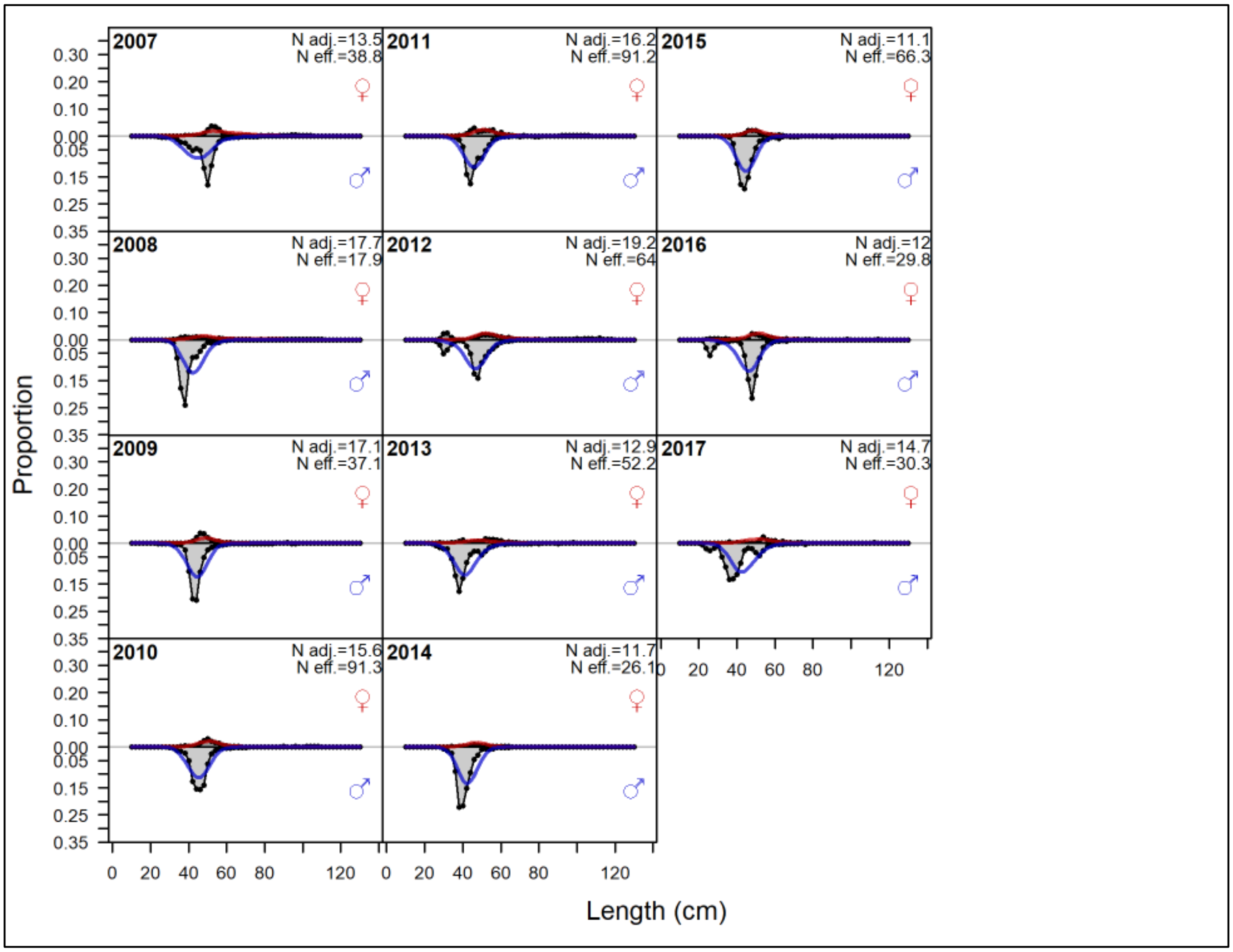

Figure 3.28. Observed and predicted length compositions for the RRef survey from the base run of the stock assessment model, 2007–2017. N adj. represents the input effective sample size (number of trips sampled) and N eff. represents the model estimate of effective sample size.

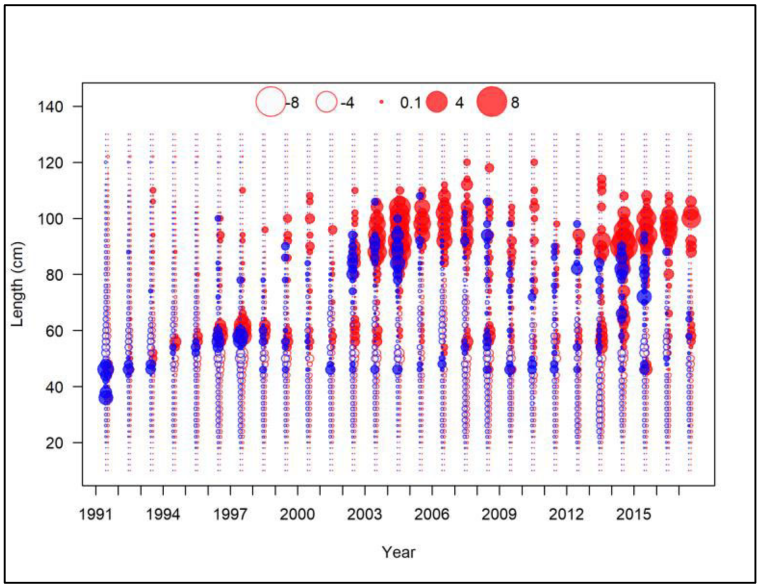

Figure 3.29. Pearson residuals (red: female; blue: male) from the fit of the base model run to the ARcomm landings length composition data, 1991–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

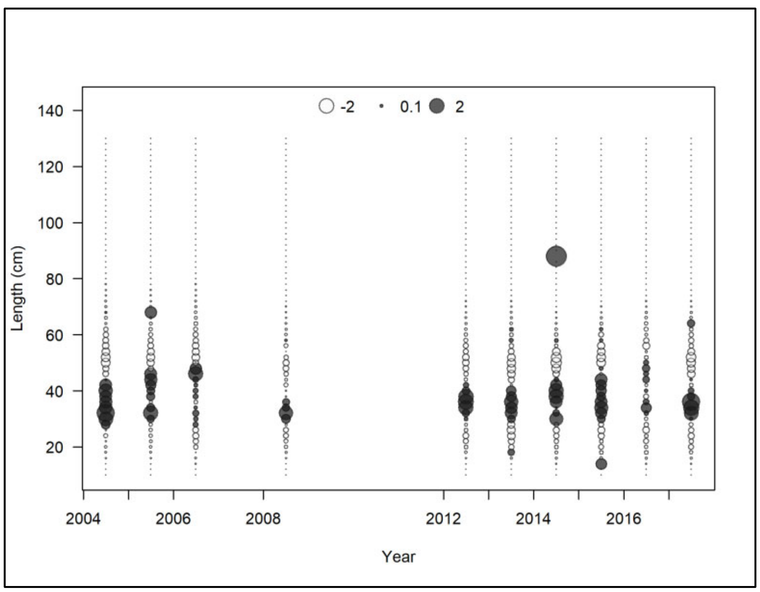

Figure 3.30. Pearson residuals from the fit of the base model run to the ARcomm discards length composition data, 1991–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

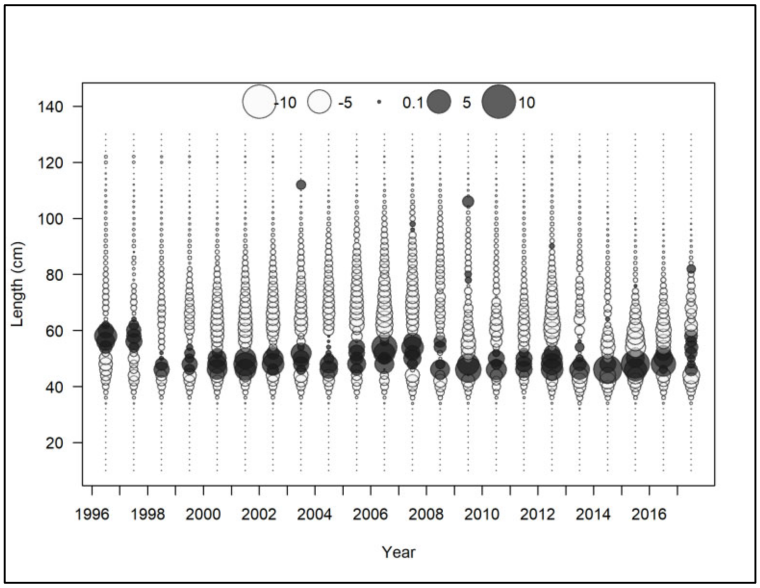

Figure 3.31. Pearson residuals from the fit of the base model run to the ASrec harvest length composition data, 1996–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

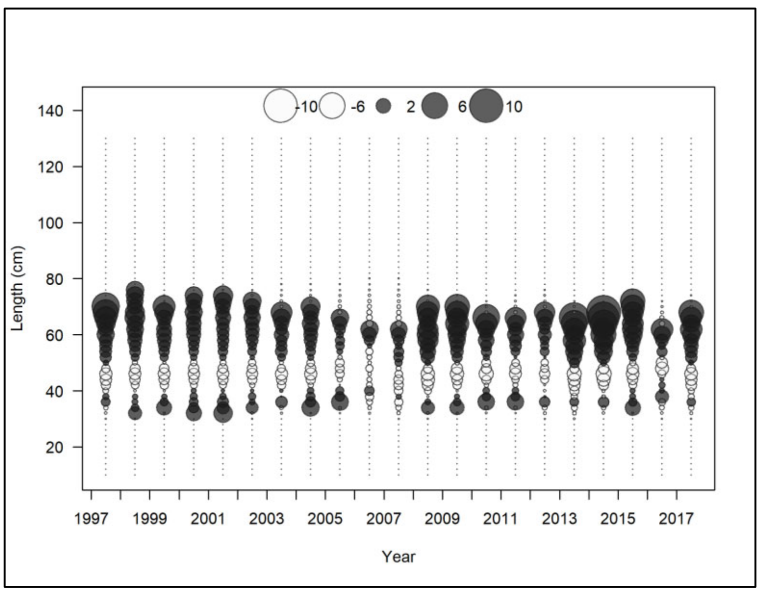

Figure 3.32. Pearson residuals from the fit of the base model run to the ASrec discard length composition data, 1997–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

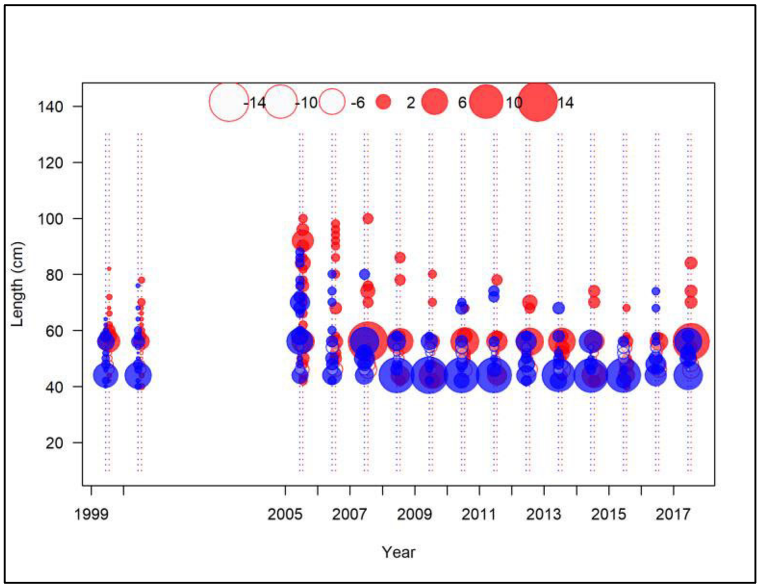

Figure 3.33. Pearson residuals (red: female; blue: male) from the fit of the base model run to the RRrec harvest length composition data, 1999–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

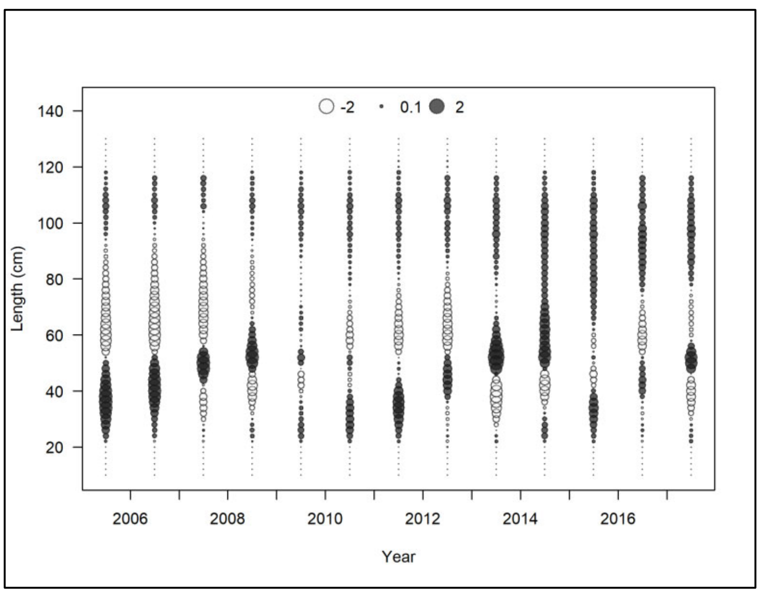

Figure 3.34. Pearson residuals from the fit of the base model run to the RRrec discard length composition data, 2005–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

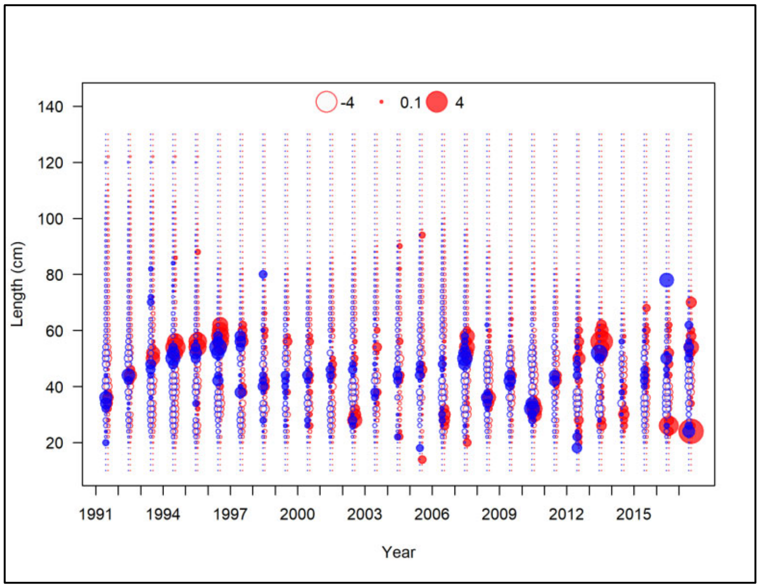

Figure 3.35. Pearson residuals (red: female; blue: male) from the fit of the base model run to the P135fw survey length composition data, 1991–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

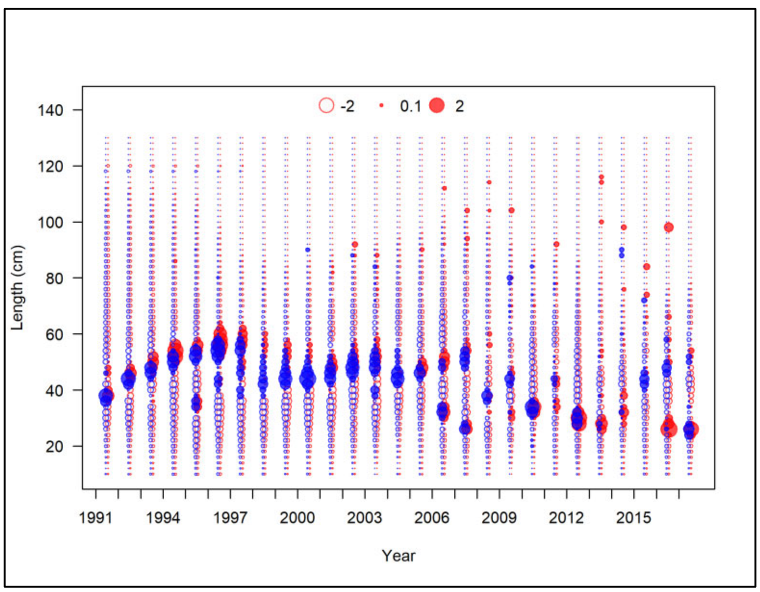

Figure 3.36. Pearson residuals (red: female; blue: male) from the fit of the base model run to the P135spr survey length composition data, 1991–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

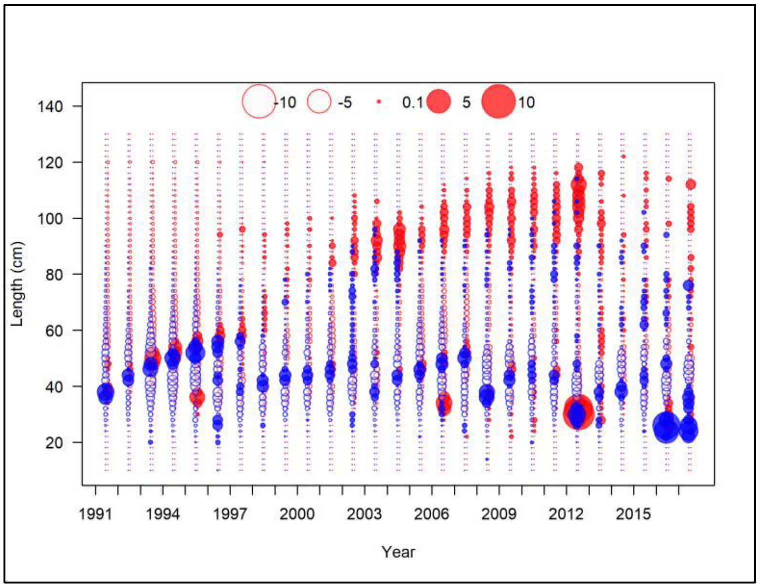

Figure 3.37. Pearson residuals (red: female; blue: male) from the fit of the base model run to the RRef survey length composition data, 1991–2017. Closed bubbles represent positive residuals (observed > expected) and open bubbles represent negative residuals (observed < expected).

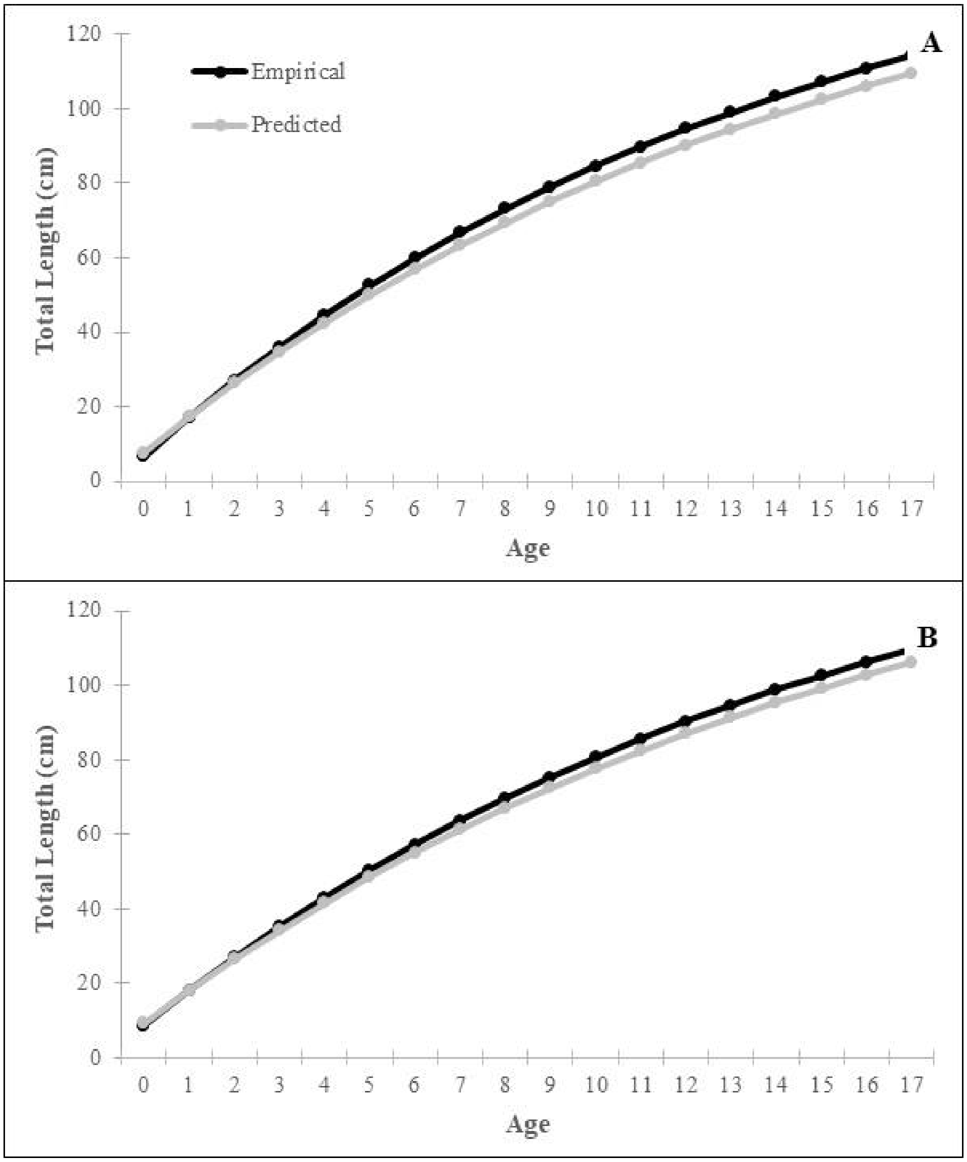

Figure 3.38. Comparison of empirical and model-predicted age-length growth curves for (A) female and (B) male striped bass from the base run of the stock assessment model.

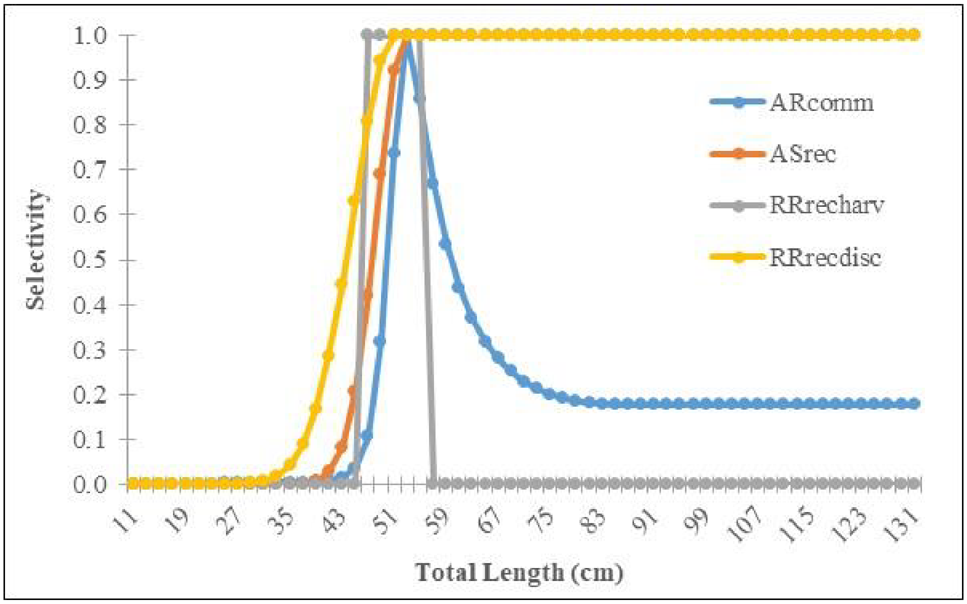

Figure 3.39. Predicted length-based selectivity for the fleets from the base run of the stock assessment model.

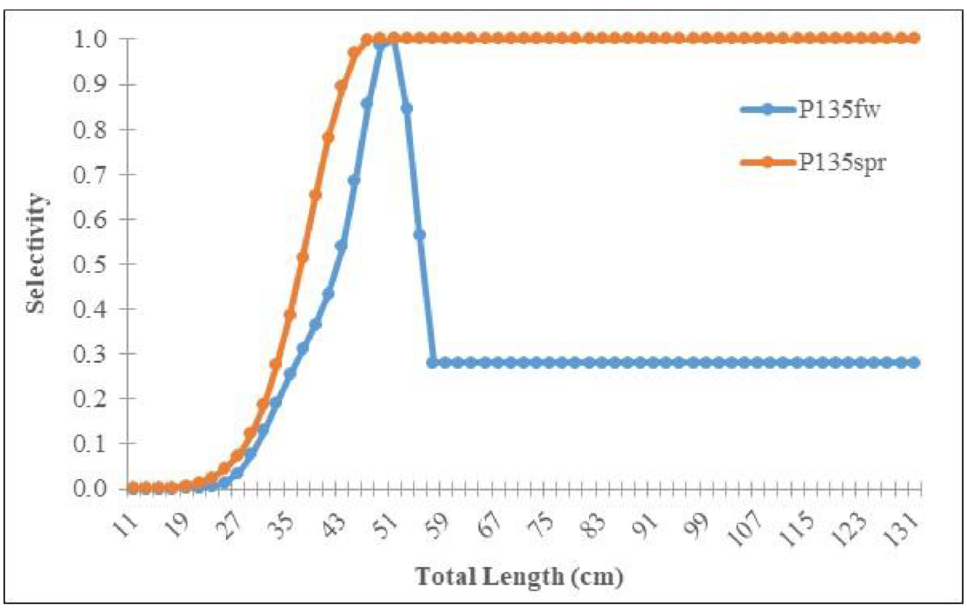

Figure 3.40. Predicted length-based selectivity for the P135fw and P135spr surveys from the base run of the stock assessment model.

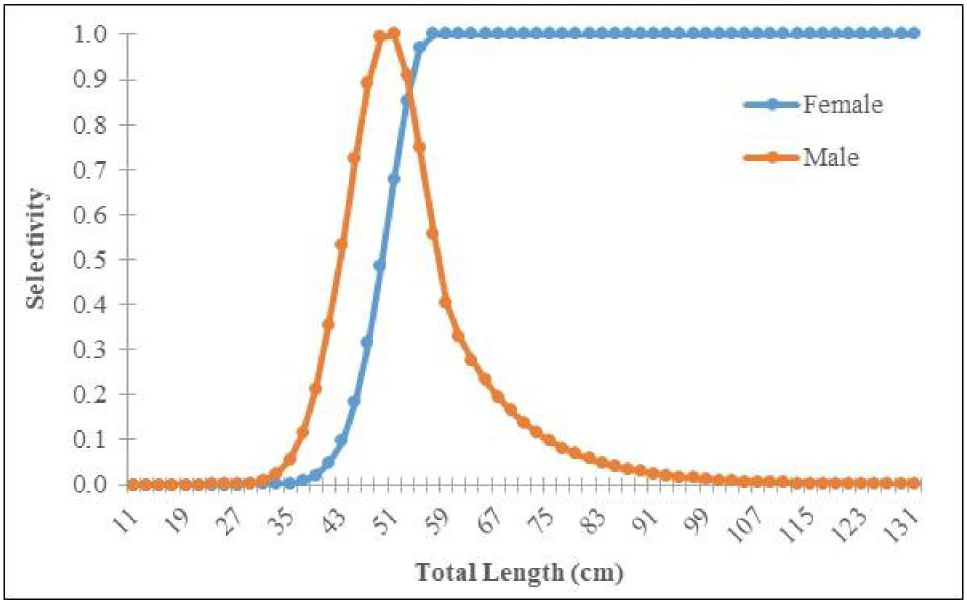

Figure 3.41. Predicted length-based selectivity for the RRef survey from the base run of the stock assessment model.

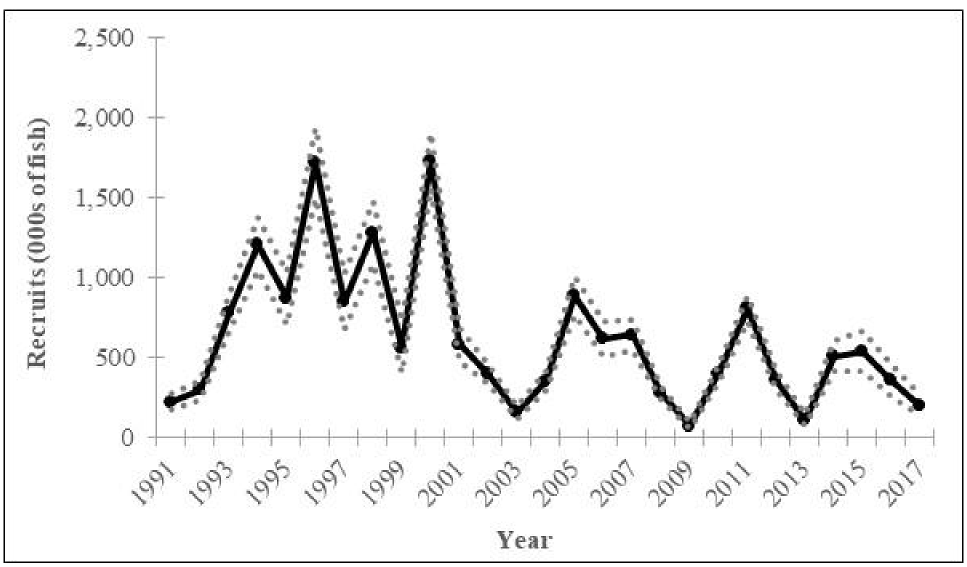

Figure 3.42. Predicted recruitment of age-0 fish from the base run of the stock assessment model, 1991–2017. Dotted lines represent ± 2 standard deviations of the predicted values.

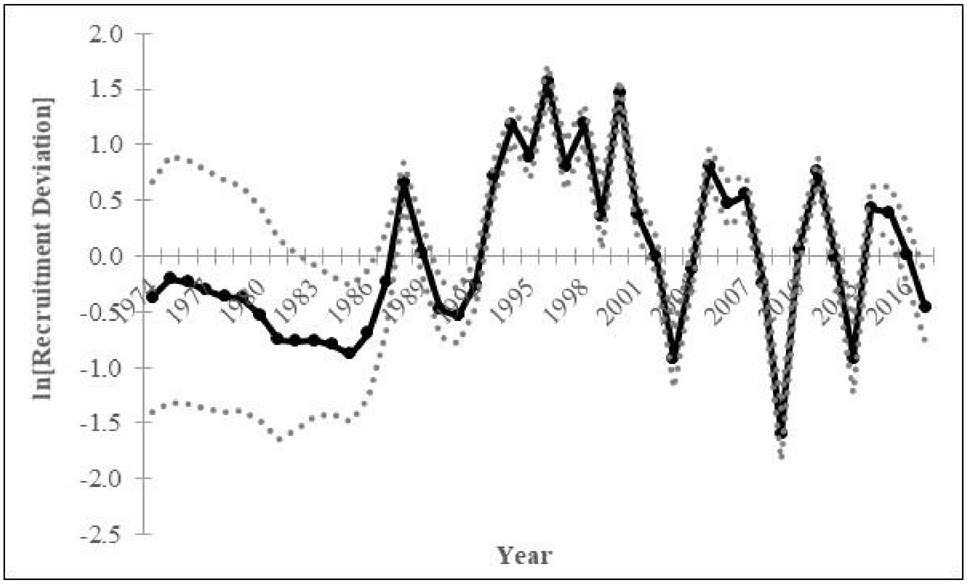

Figure 3.43. Predicted recruitment deviations from the base run of the stock assessment model, 1991–2017. Dotted lines represent ± 2 standard deviations of the predicted values.

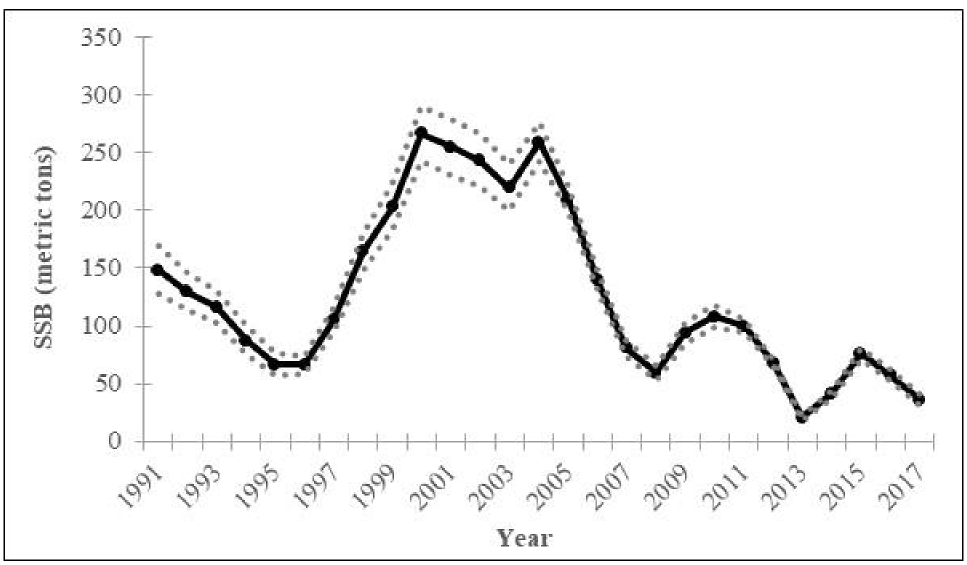

Figure 3.44. Predicted female spawning stock biomass from the base run of the stock assessment model, 1991–2017. Dotted lines represent ± 2 standard deviations of the predicted values.

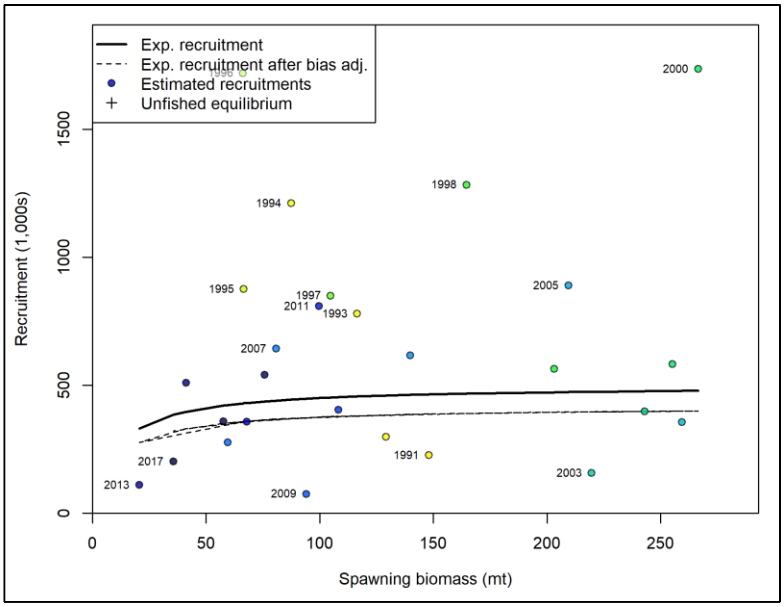

Figure 3.45. Predicted Beverton-Holt stock-recruitment relationship from the base run of the stock assessment model with labels on first (1991), last (2017), and years with (log) deviations > 0.5.

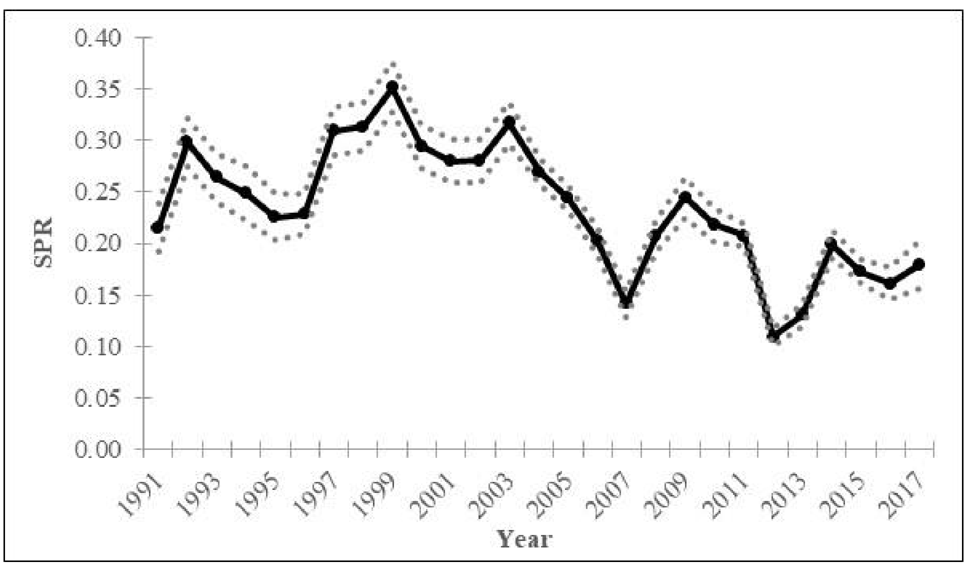

Figure 3.46. Predicted spawner potential ratio (SPR) from the base run of the stock assessment model, 1991–2017. Dotted lines represent ± 2 standard deviations of the predicted values.

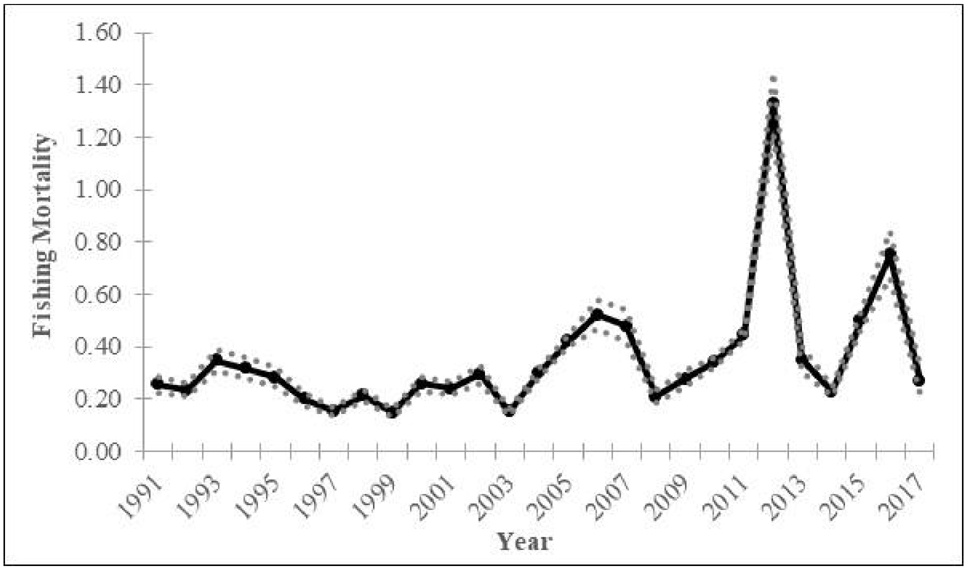

Figure 3.47. Predicted fishing mortality (numbers-weighted, ages 3–5) from the base run of the stock assessment model, 1991–2017. Dotted lines represent ± 2 standard deviations of the predicted values.

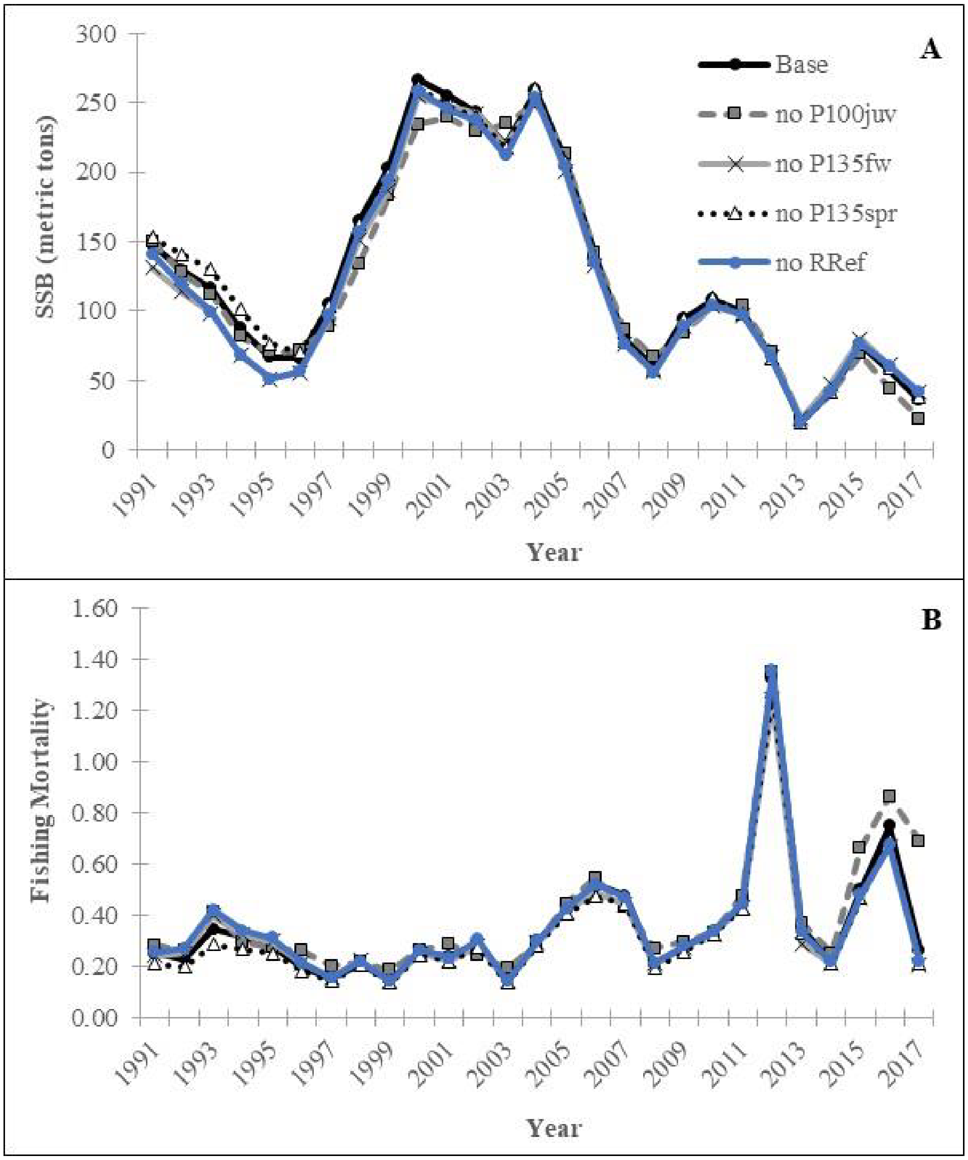

Figure 3.48. Sensitivity of model-predicted (A) female spawning stock biomass (SSB) and (B) fishing mortality rates (numbers-weighted, ages 3–5) to removal of different fisheries-independent survey indices from the base run of the stock assessment model, 1991–2017.

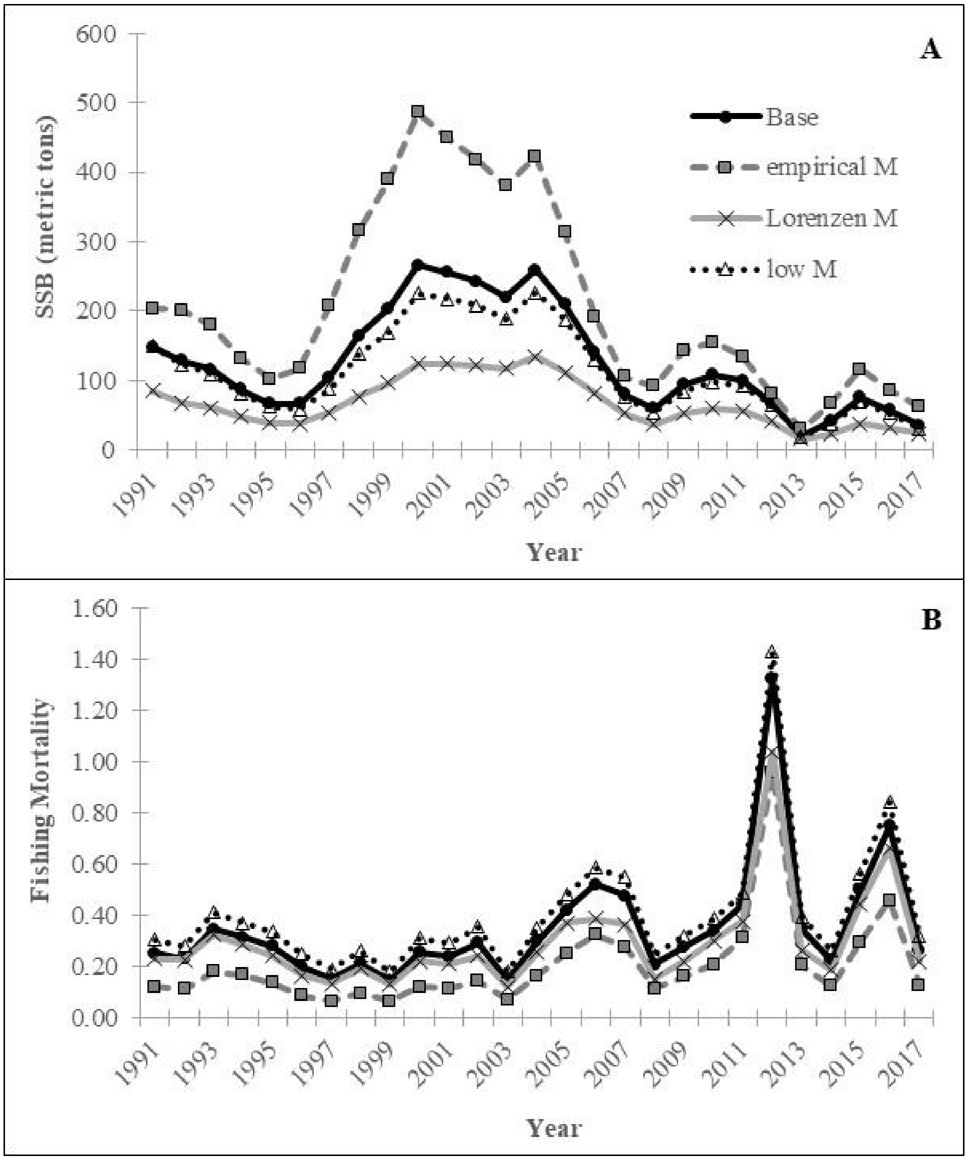

Figure 3.49. Sensitivity of model-predicted (A) female spawning stock biomass (SSB) and (B) fishing mortality rates (numbers-weighted, ages 3–5) to the assumption about natural mortality, 1991–2017.

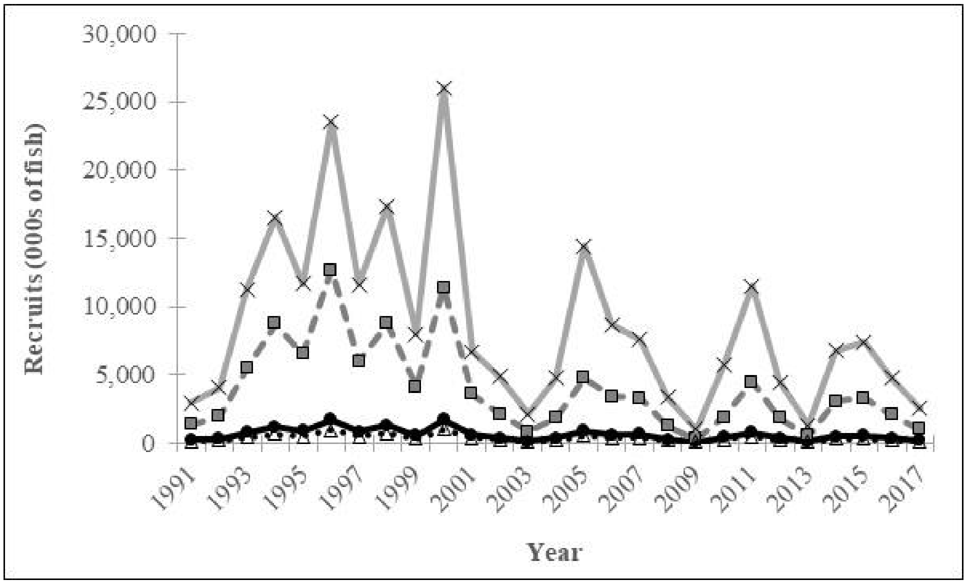

Figure 3.50. Predicted recruitment from the sensitivity runs in which the assumption about natural mortality was changed, 1991–2017.

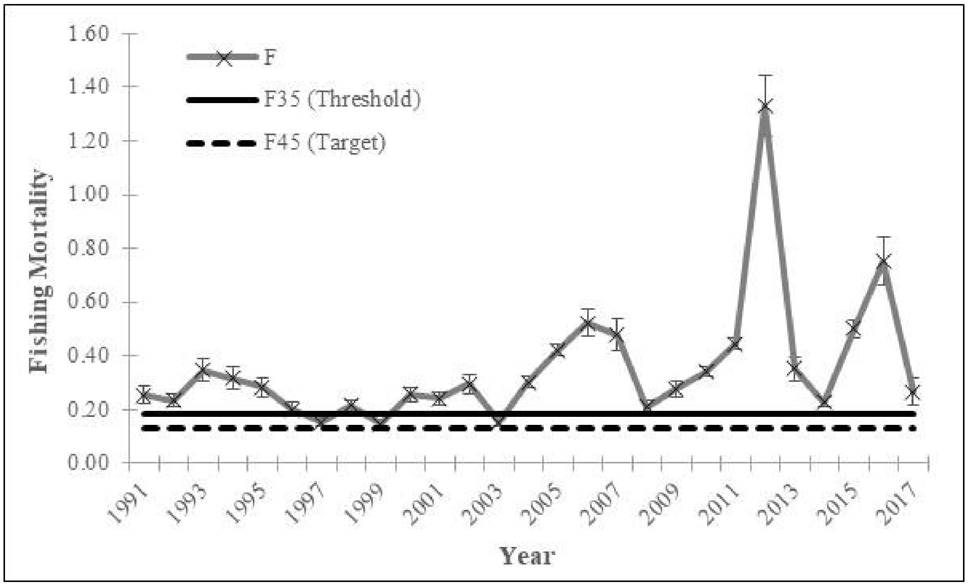

Figure 4.1. Estimated fishing mortality (numbers-weighted, ages 3–5) compared to fishing mortality target ($F_{45\%}$=0.18) and threshold ($F_{35\%}$=0.13). Error bars represent ± two standard errors.

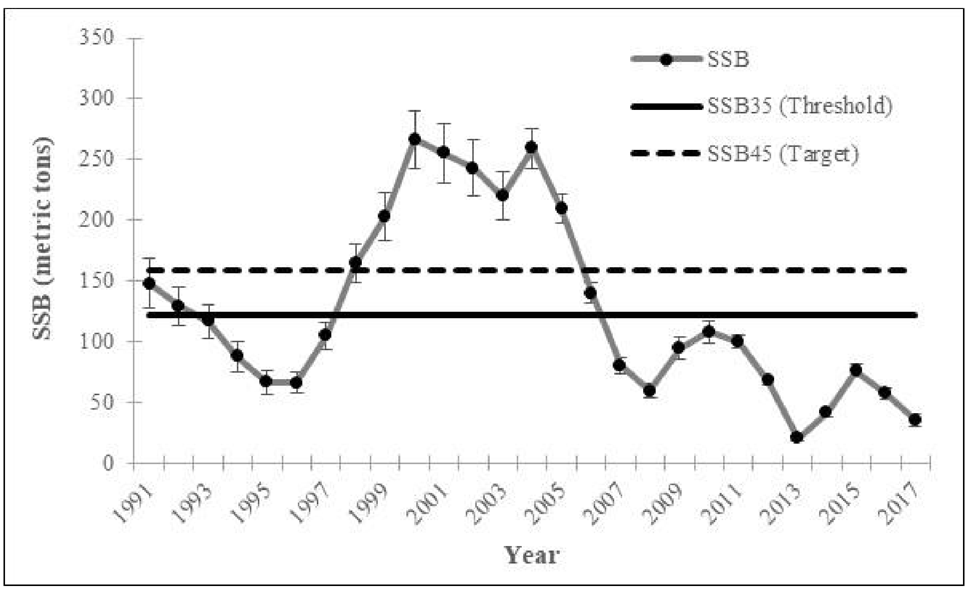

Figure 4.2. Estimated female spawning stock biomass compared to spawning stock biomass target ($SSB_{45\%}$=159 mt) and threshold ($SSB_{35\%}$=121 mt). Error bars represent ± two standard errors.

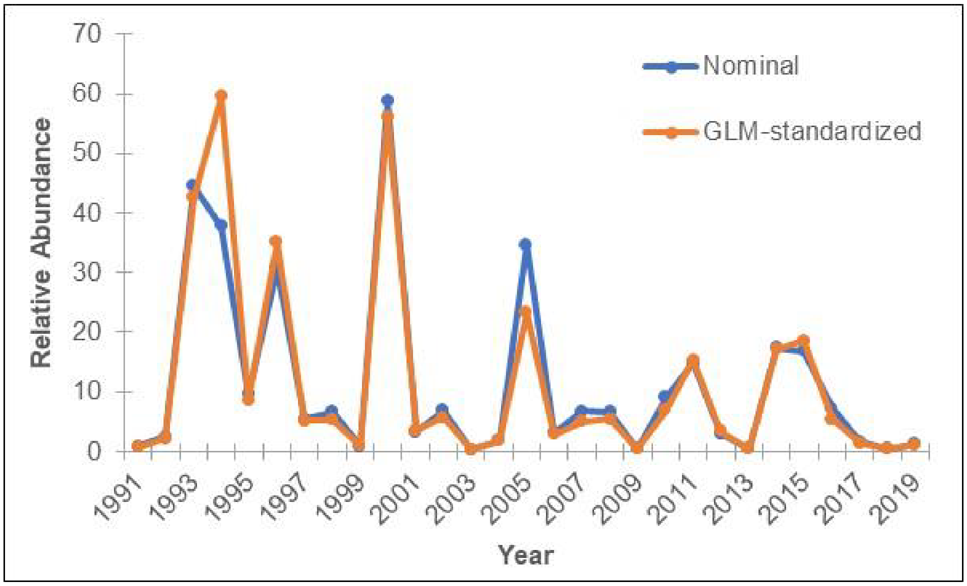

Figure 5.1. Update of the nominal and GLM-standardized indices of relative age-0 abundance derived from the Juvenile Abundance Survey (P100), 1991–2019.

10 APPENDIX

Addendum to the External Peer Review Report for the 2019 Stock Assessment of the Albemarle Sound-Roanoke River Striped Bass in North Carolina

The SAT was able to satisfactorily resolve several of the RP's concerns in the original base model reviewed during the December 2019 workshop. The growth functions fit to observed length-at-age data external to the assessment model to generate starting values for the assessment model (i.e., empirical growth estimates) showed improved fits to the data and the growth functions predicted by the revised assessment model were more consistent with the empirical growth estimates, particularly for males. Residual patterning from fits to the length composition data in the revised assessment model are still present indicating some model misspecification, but were generally reduced. The corrected P135 indices were more consistent with the decline in recent years observed during the RRef survey, reducing some conflict the original base model was forced to reconcile. It's important to note that the revised model overestimated the index values for both P135 indices and the RRef index during the last three years of the time series, indicating the abundance estimates may still be biased high in these recent years. However, the consistent overfished status determination estimated across the revised model and natural mortality sensitivity runs (see below) lessen this concern.

The revised base model specified an age- and sex-constant natural mortality of 0.72 based on Harris and Hightower (2017). The RP still believes the empirical natural mortality estimates from Harris and Hightower (2017) are higher than reality and suggested sensitivity runs exploring the effects of lower natural mortality rates. The RP was less concerned with variation in natural mortality-at-age, as this can be less influential on parameter bias (Deroba and Schueller 2013) and because model insensitivity to age-specific natural mortality was demonstrated by the SAT in the revised report, and more interested in effects of lower natural mortality for all ages. Therefore, various age-constant life history-based natural mortality estimators were applied to the striped bass data. Ultimately, the Alverson and Carney (1975), Hoenig (1983), and Cubillios et al. (1999) estimators were included in sensitivity runs because they estimated high (relative to the other life history-based estimators, but lower than Harris and Hightower 2017 estimates), moderate, and low natural mortality rates, respectively. Additionally, an average across the estimators, which was slightly lower than the Hoenig (1983) rate, was included in the sensitivity analysis. The SAT conducted a thorough sensitivity analysis of natural mortality with model configurations that included sex-specific and sex-aggregate natural mortality rates with growth fixed or estimated. The sensitivity runs that converged on a solution produced some differences in the scale of estimates, but similar stock trajectories, particularly since the decline in SSB in the mid-2000s (Figures 1-3). The various natural mortality rates had the greatest effect on age-0 recruitment as the model needs to estimate higher recruitment under high mortality scenarios to match the data on subsequent ages that are vulnerable to the fisheries. All sensitivity runs indicated the stock was overfished and experiencing overfishing in the terminal year (Table 1).

The SAT recommended the model with a high, sex-aggregate natural mortality (M=0.40) as the most appropriate to acknowledge estimates from established life history-based methods, but also the higher empirical rates estimated directly from the striped bass population by Harris and Hightower (2017). A sex-aggregate natural mortality rate is consistent with the similar growth estimated between sexes from the available data. Further, a subsequent sensitivity run requested by the RP showed this model configuration is not sensitive to excluding the RRef survey data, as was a primary concern with the original base model. The RP agrees with the SAT's recommendation and recommends this model be used for management advice. The population trajectory and overfished and overfishing stock status estimates from this model are consistent with the available data sets that show poor recruitment in recent years, declining abundance to historically low levels, and a truncated age structure.

Needs for Future Assessments

The RP along with the SAT were collectively concerned about declining recruitment in the time series. One key uncertainty identified in this review is to incorporate the effects of changes in river flow on recruitment. It appears that substantial data exists, but they have not yet been incorporated into the stock assessment. Future assessments should consider key environmental drivers of recruitment such as river flow, because declining recruitment in the time series does not appear to result solely from reduced abundance due to harvest. The RP suggests that future assessments should incorporate flow-recruitment relationships into the stock assessment formally to understand how spring flow conditions influence recruitment and ultimately stock abundance. Another potential influence on the striped bass stock is the prevalence of non-native catfishes, primarily blue catfish *Ictalurus furcatus* and flathead catfish *Pylodictis olivaris*. Both species occur in North Carolina river systems and it seems the blue catfish population is expanding in the Roanoke River and Albemarle Sound areas. Predation by catfishes could potentially impact recruitment of striped bass directly, or could influence food resources for striped bass through competition for prey (e.g., Pine et al. 2005). The degree to which this occurs is not known, but future assessments should consider this as a factor that may influence abundance and is not tied to striped bass harvest.

Moderate and evident differences in growth (Figures 1.2 and 1.3, main report) are not resolved within the model. The effect on estimation of sex-specific M are not readily quantifiable at present. Factors potentially contributing to the poor resolution of male and female growth trajectories, as estimated by the von Bertalanffy growth function, include under-representation of older age classes and lack of sex-specific length data for Ages 0 to 2^+ year old fish. The RP accordingly encourages collection of sex-specific length-at-age data from juveniles (ages 0–2) and as well from older fish to better inform growth estimates.

References

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Cubillos, L.A., R. Alarocan, and A. Brante. 1999. Empirical estimates of natural mortality for Chilean hake (*Merluccius gayi*): evaluation of precision. Fisheries Research 42:147–153.

Deroba, J.J., and A.M. Schueller. 2013. Performance of stock assessments with misspecified age- and time-varying natural mortality. Fisheries Research 46:27–40.

Hoenig, J. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 81(4): 898–903.

Pine, W.E., T.J. Kwak, D.S. Waters, and J.A. Rice. 2005. Diet selectivity of introduced Flathead catfish in coastal rivers. Transactions of the American Fisheries Society 134:901–909.

Tables

Table 1. Specified natural mortality, terminal year and threshold model estimates, and stock status across the revised base model (Baseline) and natural mortality sensitivity runs. The RP recommends the "highMsamesex (est growth)" run be used for a management advice.

Scenario	M (yr^{-1})	Current year (2017)		Threshold		Overfished	Overfishing	Reference
		SSB (mt)	F (yr^{-1})	$SSB_{35\%}$ (mt)	$F_{35\%}$ (yr^{-1})			
Baseline	0.72	62	0.13	89	0.43	Y	N	Harris and Hightower, 2017
avgM (est growth)	0.23F, 0.25M	30.80	0.35	283.88	0.12	Y	Y	
avgM (fix growth)	0.23F, 0.25M	47.46	0.28	153.20	0.13	Y	Y	
midM (fix growth)	0.25F, 0.28M	42.79	0.29	114.46	0.14	Y	Y	Hoenig 1983
highM (fix growth)	0.37F, 0.44M	40.22	0.31	182.06	0.19	Y	Y	Alverson and Camey 1975
highMsamesex (est growth)	0.40	35.64	0.27	121.29	0.18	Y	Y	Alverson and Camey 1975
avgMsamesex (est growth)	0.24	32.91	0.28	150.77	0.11	Y	Y	

Figures

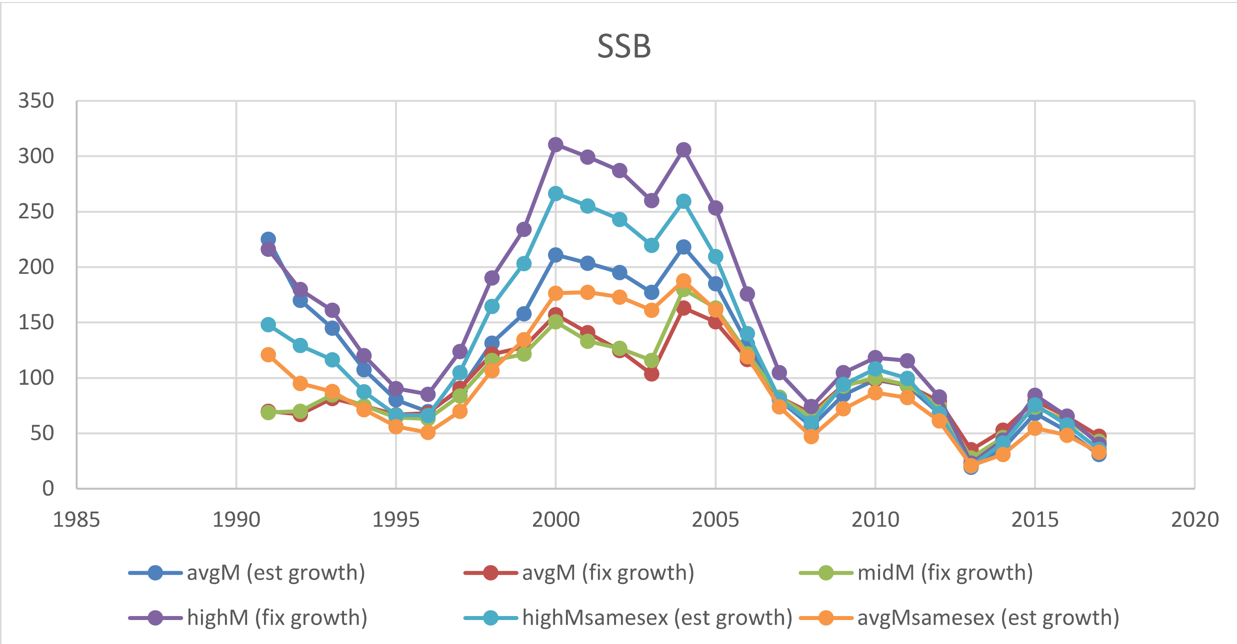

Figure 1. Female spawning stock biomass estimates (metric tons) across natural mortality sensitivity runs.

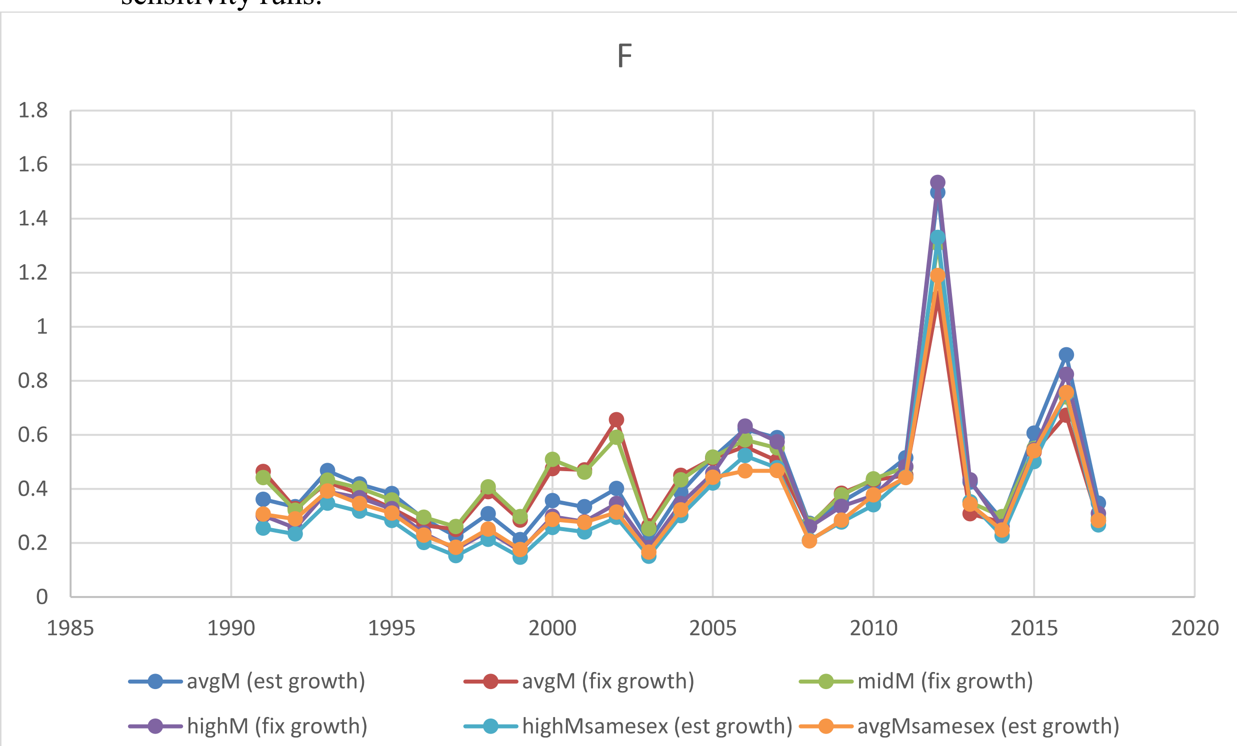

Figure 2. Numbers-weighted ages 3-5 average fishing mortality estimates across natural mortality sensitivity runs.

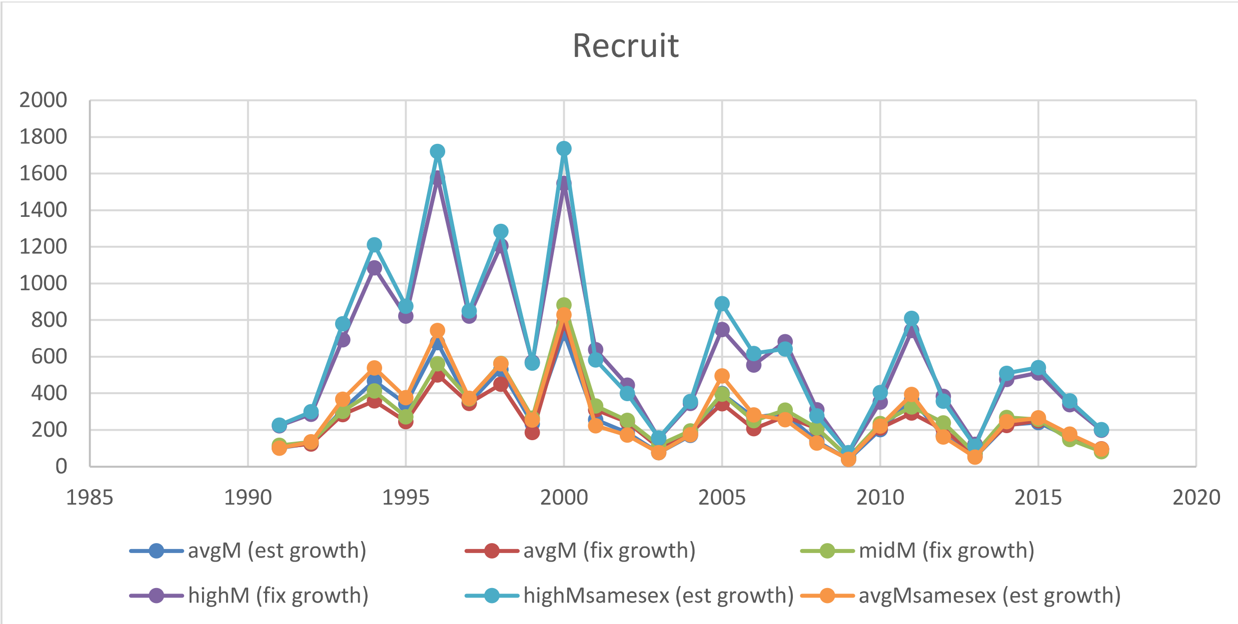

Figure 3. Age-0 recruitment estimates (thousands) across natural mortality sensitivity runs.