Southeast Data, Assessment, and Review

SEDAR 32A
Stock Assessment Report

Gulf of Mexico Menhaden

September 2013

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Preface

This regional assessment was completed through the SouthEast Data, Assessment, and Review (SEDAR) process and the Gulf States Marine Fisheries Commission (GSMFC). The GSMFC coordinated the Data and Assessment Workshops, while SEDAR coordinated the Review Workshop. This report is the culmination of a two-year effort to gather and analyze available data for Gulf menhaden from the commercial purse-seine fishery, fishery-independent sampling programs of the Gulf States, and the recreational sector. The Gulf's five marine resource agencies provided experts through the GSMFC's Menhaden Advisory Committee (MAC), which served as the technical committee throughout the assessment process. The GSMFC provided travel and facilitated several conference calls and webinars in preparation for the workshops. Participants in the conference calls and webinars included the MAC members and a number of individuals representing Non-Governmental Organizations with interest in Gulf menhaden. All meetings and workshops were held at NOAA's Beaufort Laboratory in North Carolina.

The SEDAR32A draft report was generated and provided to three reviewers from the Center for Independent Experts (CIE), two members from the Statistics and Science Committee of the South Atlantic, and an expert representing the GSMFC. The Review Workshop was held in Morehead City, NC on August 27-30, 2013 in conjunction with the SEDAR 32 South Atlantic blueline tilefish review. At the Workshop, the reviewers had opportunities to address concerns they had with the data and models and query the analysts and agency representatives regarding any additional questions that arose during their reviews. Finally, a Review Workshop Report (Section II) was generated with comments and overall opinions about the data sources, models, and assessment results. Following the receipt of the Review Workshop Report by the SEDAR office, the MAC continued to discuss and develop potential management goals and reference points for the Gulf menhaden stock and the fishery. The results will be included in the revision to the Gulf Menhaden Fishery Management Plan.

The GSMFC and the MAC wishes to thank the reviewers for their expertise and time that supported the completion of the regional stock assessment for Gulf menhaden.

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Gulf of Mexico Menhaden

Assessment Report

August 2013

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Executive Summary

Gulf menhaden, *Brevoortia patronus*, range from the Yucatan Peninsula in Mexico, across the western and northern Gulf of Mexico to Tampa Bay, Florida, but they are most abundant in the central portion of their range from eastern Texas to western Alabama. Gulf menhaden are estuarine-dependent: adult Gulf menhaden generally occur in the near-shore waters of the Gulf of Mexico proper, while juveniles spend most of their first year of life in estuarine waters, including brackish and near-freshwater habitats. Spawning peaks in winter and larvae enter the estuaries in the early spring after riding the prevailing currents from the offshore spawning grounds. Genetic evidence suggests a single unit stock of Gulf menhaden in the northern Gulf of Mexico and tagging studies indicate that the species does not exhibit extensive east-west migrations; generally, older adults tend to occur near the Mississippi River delta and the central Louisiana coast.

The modern Gulf menhaden fishery began after World War II as the worldwide demand for fish meal and fish oil increased. Annual landings of Gulf menhaden in the early 1940s were less than about 40,000 mt, but by the early 1960s landings in the Gulf fishery – 437,500 mt in 1963 – exceeded those in the Atlantic menhaden fishery. During the 1960s and 1970s, the Gulf menhaden fishery continued to expand and fleet size ranged about 70 to 80 vessels. Landings peaked in 1984 at 982,800 mt. Thereafter through the 1990s, landings, fleet size, and participants in the fishery declined because of corporate consolidation, weak product prices, and weather conditions. Since 2000, the fishery has been reasonably stable with four fish factories – at Abbeville, Cameron and Empire, Louisiana and Moss Point, Mississippi – and about forty vessels.

The commercial purse-seine reduction fishery for Gulf menhaden has been extensively sampled by the National Marine Fisheries Service. Fishery-dependent data sources from 1977-2011 that inform this Gulf menhaden stock assessment include: 1) detailed catch records that enumerate daily vessel landings, 2) port samples that include comprehensive dockside sampling of vessels throughout the fishing season at all menhaden factories for size and age composition of the catch, and 3) daily logbooks that itemize catch and fishing locations for individual purse-seine sets. Landings of gulf menhaden for bait are generally less than 2% of total landings for the species. Bait landings and recreational landings of Gulf menhaden, which are minimal, were combined with landings from the reduction fishery to provide a complete time series (1977-2011) of removals.

The five Gulf States collect a significant amount of fishery-independent data on finfish from their inshore surveys. Although Gulf menhaden are generally not the target species of these surveys, total Gulf menhaden numbers and lengths are recorded. Gulf menhaden data from state surveys form the basis for two indices of relative abundance: 1) a recruitment index from 1996 to 2010 based on the seine survey data from Louisiana, Mississippi, and western Alabama, and 2) an adult abundance index from 1988 to 2011 based on Louisiana gill net survey data. The recruitment index showed large year classes of juveniles in 1996, 2003, 2009, and 2010; when compared against a CPUE index based on the catches by the commercial fishery at age-1, the correlation with a one-year lag was quite high. The adult index showed an increasing trend from the late 1980s to the mid-1990s, then a stable trend through the mid-2000s, and high adult abundances in the most recent years. Likewise, the adult index was highly correlated with a CPUE index based on age-2 catch from the commercial reduction fishery. For the adult index, length composition data were available 1996-2011 and were used to estimate selectivity of the index given that age data from the survey were unavailable.

In this assessment, we employed two separate modeling approaches: the Beaufort Assessment Model (BAM, a forward-projecting age-structured model) and a surplus production model (A Stock Production Model Incorporating Covariates or ASPIC). The base configuration of the BAM incorporated: fishing seasons 1977-2011, ages 0 to 4+, spawning occurring on January 1, age-varying natural mortality scaled to an estimated based on a tagging study, a single time series of landings, commercial age compositions, a recruitment index based on seine data, an adult abundance index based on Louisiana gill net data, length compositions from the gill net survey, a Beverton-Holt stock recruitment curve with a fixed value for steepness, logistic selectivity for the gill net index, and dome-shaped selectivity for the reduction fishery. Uncertainty was explored with BAM using sensitivity runs and Monte Carlo bootstrapping (MCB), with additional exploration in ASPIC using bootstrapping. Sensitivity runs for BAM investigated differences in the start year of the model, selectivity for the fishery, values of natural mortality, the stock-recruitment curve, weighting, and growth. MCB runs (N = 5,000) included uncertainty in all of the data streams, maturity, selectivity, the stock recruitment curve, and growth.

The base run fit all of the data streams reasonably well. Highly variable fishing mortalities were noted throughout the time series; highest fishing mortalities occurred in the 1980s, with declining fishing mortalities into the 2000s. Nevertheless, Gulf menhaden are not fully selected until age-2, thus the fishing mortality rate on other ages is much lower. Throughout the time series, the age-2 fish produced most of the total estimated number of eggs spawned annually, although age-3 and -4 fish have contributed more significantly in recent years. Sensitivity analyses revealed differences from the base run configuration depending upon the assumption tested, and the MCB runs demonstrated the amount of uncertainty around the base run values. None of the results were unexpected.

At this time, the Gulf’s agency managers are working to define the goals for the fishery and to specify objectives for the fishery. Once that has been completed, appropriate benchmarks can be discussed and formally adopted. In the meantime, general stock status declarations have been made based on a suite of benchmark options. Based on those benchmarks presented, the results suggest that generally the current stock status is not overfished and overfishing is not occurring. Moreover, most of the sensitivity runs and the MCB uncertainty analysis runs resulted in a current stock status of not overfished and overfishing not occurring. The assessment panel discussed factors necessary to adequately account for the ecosystem value of Gulf menhaden in defining fishery reference points and concluded that data and techniques are insufficient at present to incorporate them into the assessment; data specifically addressing the value of menhaden in the ecosystem as prey biomass for other stocks (e.g., piscivorous, avian, and mammalian predators) are lacking.

Gulf Menhaden Stock Assessment Terms of Reference
For SEDAR 32 RW

1. Evaluate the data used in the assessment, addressing the following:
    a. Are data decisions made by the Assessment Workshop sound and robust?
    b. Are data uncertainties acknowledged, reported, and within normal or expected levels?
    c. Are data applied properly within the assessment model?
    d. Are input data series reliable and sufficient to support the assessment approach and findings?

2. Evaluate the methods used to assess the stock, taking into account the available data.
    a. Are methods scientifically sound and robust?
    b. Are assessment models configured properly and used consistent with standard practices?
    c. Are the methods appropriate for the available data?

3. Evaluate the assessment findings with respect to the following:
    a. Are abundance, exploitation, and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?
    b. Is the stock overfished? What information helps you reach this conclusion?
    c. Is the stock undergoing overfishing? What information helps you reach this conclusion?
    d. Is there an informative stock recruitment relationship? Is the stock recruitment curve reliable and useful for evaluation of productivity and future stock conditions?
    e. Are the quantitative estimates of the status determination criteria for this stock reliable? If not, are there other indicators that may be used to inform managers about stock trends and conditions?

4. Consider how uncertainties in the assessment, and their potential consequences, are addressed.
    - Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods
    - Ensure that the implications of uncertainty in technical conclusions are clearly stated.

5. Consider the research recommendations provided by the Assessment workshop and make any additional recommendations or prioritizations warranted.
    - Clearly denote research and monitoring that could improve the reliability of, and information provided by, future assessments.
    - Provide recommendations on possible ways to improve the SEDAR process.

6. Provide guidance on key improvements in data or modeling approaches which should be considered when scheduling the next assessment.

7. Prepare a Peer Review Summary summarizing the Panel's evaluation of the stock assessment and addressing each Term of Reference. Develop a list of tasks to be completed following the workshop. Complete and submit the Peer Review Summary Report in accordance with the project guidelines.

The panel shall ensure that corrected estimates are provided by addenda to the assessment report in the event corrections are made in the assessment, alternative model configurations are recommended, or additional analyses are prepared as a result of review panel findings regarding the TORs above.

1.0 Introduction

1.1 Species Composition of the Fishery

The commercial fishery in the U.S. Gulf of Mexico catches three species of menhaden:

Gulf menhaden:	*Brevoortia patronus*
Yellowfin menhaden:	*Brevoortia smithi*
Finescale menhaden:	*Brevoortia gunteri*

Gulf menhaden comprise over 99% of the catch in the commercial purse-seine fishery (Ahrenholz 1981) with a minor aggregation of the other menhaden species and other clupeids.

Guillory and Hutton (1982) reviewed previous studies, which characterized bycatch in the reduction fishery, and in a number of those studies, additional clupeid species occurred with differing regularity. While Dunham (1975) noted that Atlantic thread herring (*Opisthonema oglinum*) was encountered 2.33% by weight, Guillory and Hutton (1982) found threadfin shad (*Dorosoma petenense*) occurred in the catch at 13.2% (by numbers), while skipjack herring (*Alosa chrysochloris*), gizzard shad (*D. cepedianum*) and scaled sardine (*Harengula pensacolae*) each accounted for a mere 0.1% by number or weight. Similarly, Condrey (1994) found that Atlantic thread herring made up less than 1% of the catch in the two years he sampled directly from the reduction fleet.

1.2 Brief Overview and History of Fisheries

For those interested in the history and evolution of the Gulf menhaden fishery, unfortunately, a volume equivalent to that which Goode (1887) compiled for the Atlantic menhaden (*B. tyranus*) fishery is unavailable. Goode (1887) surveyed fishermen, fish factory owners, and various seaside observers for insights about the seasonality, movements, and habits of Atlantic menhaden, as well as information on fishing operations and disposition of the catch along the U.S. Eastern Seaboard. Goode (1887) was able to cobble together a history of the Atlantic menhaden fishery back to the mid-1800s. No such author or tome has chronicled the history of the early days of the menhaden fishery in the northern Gulf of Mexico (Figure 1.1). Several sources however provide us with glimpses of the Gulf menhaden fishery beginning in the mid-twentieth century.

Frye (1978) delved into the genealogy of menhaden factory ownership for the Gulf fishery. He recounts that numerous corporate families active in the Atlantic menhaden fishery moved some or all of their operations to the northern Gulf of Mexico just before and after World War II. Simmons and Breuer (1964) make brief reference to the establishment of menhaden fishing operations in Texas in 1951. Kutkuhn (1965) was among the first to recognize that the surging landings in the Gulf menhaden fishery during 1958-1961 were primarily due to the "vastly improved efficiency of the fishing fleet rather than to greater abundance or availability of the resource." Fishing fleet innovations included spotter aircraft, nylon seines, fish pumps, power blocks, refrigerated fish holds, and larger carrier vessels. Henry (1969) noted that the Gulf menhaden fishery "started much later than that for the Atlantic species." He reported that the annual catch of Gulf menhaden in the early 1940s was less than about 40,000 mt, but that the fishery had grown steadily and in 1963, for the first time in history, the Gulf menhaden catch of about 445,000 mt exceeded that of the Atlantic fishery. Henry (1969) also pointed out that although the Atlantic menhaden fleet tended to make one-day trips to the fishing grounds, the Gulf menhaden fleet generally made multiple-day trips, thus the need for refrigerated fish holds. Additionally, he categorized Gulf menhaden landings by state, noting that in 1966,

> "70% of the menhaden catch from the Gulf of Mexico was landed in Louisiana, 24% in Mississippi, 5% in Texas, and 1% in Florida".

Perhaps, Nicholson (1978) best summarized the evolution of the Gulf menhaden fishery. He canvassed confidential company records and statistical digests for landings in the Gulf menhaden fishery from the first half of the 1900s. Nicholson (1978) reported that although a menhaden fishery had existed along the U.S. Gulf coast since the late 1800s, records of catches, the location and years of operation of plants, and the numbers of vessels prior to 1946 were fragmentary at best. Historically, up to 13 menhaden processing plants existed in the northern Gulf of Mexico, ranging from Apalachicola, Florida, to Sabine Pass, Texas. One plant was known to have operated in Texas from around the turn of the century until at least 1923; another near Port St. Joe and Apalachicola, Florida, from about 1918 to 1961; and another near Pascagoula, Mississippi, from the 1930s until 1959.

Nicholson (1978) claimed that the modern Gulf menhaden fishery began after World War II as the worldwide demand for fish meal and fish oil increased. The first plant in Louisiana opened around 1946; shortly thereafter, additional plants opened in Mississippi, Louisiana, and Texas. As older plants were closed, larger and more efficient plants replaced them. During the 1950s to the early 1970s, the number of menhaden plants fluctuated between 9 and 13 (Nicholson 1978). Between the mid-1970s to the early 1980s, the number of processing plants in the Gulf was stable at 11 (Smith 1991). Two periods of corporate consolidation followed. In 1985 the number of plants fell to seven and then increased during 1989-1990 to nine. The number of plants declined to seven in 1991, to six in 1992, then to five between 1996 and 1999. After the 1997 fishing season, the menhaden company at Morgan City, Louisiana, was acquired by one of its competitors, who closed the facility after 1999. That left only four factories (owned by two companies, i.e., Omega Protein, Inc. [OPI] and Daybrook Fisheries, Inc. [DFI]) operational throughout 2000 to 2011, one each at Moss Point, Mississippi [OPI], and Empire [DFI], Abbeville [OPI], and Cameron [OPI], Louisiana.

In 1945, only about ten menhaden vessels were reported operating in the Gulf of Mexico (Nicholson 1978). After World War II, the fleet grew rapidly and reached 81 vessels by 1956. During the 1960s and 1970s, fleet size fluctuated and ranged from 65 vessels in 1973 to 92 vessels in 1966 (Nicholson 1978, Smith 1991). Fleet size peaked at 82 vessels in 1982, followed by two major downsizings. The first occurred in 1985 when the fleet was reduced from 81 to 73 vessels (Smith 1991); the second occurred in 1991 when the fleet was reduced from 75 to 58 vessels (Vaughan et al. 1996). Between 1995 and 1999, fleet size was about 50-55 vessels. Through the past decade, number of Gulf menhaden vessels declined slightly from 47 in 2000 to 41 in 2006. Since 2006, the fleet has been reasonably stable at about 40 vessels. [See Section 4.1 for more detailed information on the modern reduction fishery (post WWII).]

1.3 Geographic Distribution and Management Unit

Geographic Distribution: Gulf menhaden range from the Yucatan Peninsula in Mexico, across the western and northern Gulf of Mexico to Tampa Bay, Florida. Finescale menhaden occur from Mississippi Sound southwestward to the Gulf of Campeche in Mexico. Yellowfin menhaden range from Chandeleur Sound, Louisiana, southeastward to the Caloosahatchee River, Florida (and presumably around the Florida peninsula), to Cape Lookout, North Carolina (Hildebrand 1948, Suttkus 1956 and 1958, Christmas and Gunter 1960, Gunter and Christmas 1960, Reintjes and June 1961, Reintjes 1964, Turner 1969 and 1970). The yellowfin menhaden was reported from Grand Bahamas Island and became the first authenticated record of a North American species from beyond the Continental Shelf (Levi 1973).

Management Unit: Gulf menhaden dominate the reduction fishery in the Gulf with other menhaden species representing less than 1% of the annual catch (Ahrenholz 1981). Considering that *B. patronus* is the only significant species in the fishery and is biologically considered to be a unit stock in the Gulf, the management unit is defined as the total population of *B. patronus* in the U.S. Gulf of Mexico.

Genetic evidence: Genetic evidence suggests a single unit stock of Gulf menhaden in the northern Gulf of Mexico (see Section 3.1 for genetics details). In the western Gulf, a single population of Gulf menhaden has been identified using mtDNA (Anderson 2007). Anderson and McDonald (2007) noted that Gulf and finescale menhaden may hybridize occasionally. East of the Mobile River, Anderson and Karel (2007) indicate that there is considerable hybridization between Gulf and yellowfin menhaden. Gulf menhaden genes have been found in the southeastern Atlantic in populations of *B. tyrannus*, while *B. tyrannus* genes have not been found in the Gulf of Mexico populations of the other three menhaden species.

Biogeographical break: The hybridization zone east of the Mobile River is further supported in additional literature. An overlapping region usually defines the geographical separation between two closely related species. The northern Gulf of Mexico is no exception, with general separation occurring at the Mississippi River or to the east at Mobile Bay. It is postulated, that the glacial melting within these two watersheds provided a fresh water barrier extending out into the Gulf of Mexico (Hoese and Moore 1998, McEachran and Fechhelm 1998). Increased winter and spring river flows coming out of Mobile Bay provided a boundary that determined species composition due to sediment type and nutrient load. Additionally, the Loop Current moving north and then easterly along the Florida panhandle adds to a boundary that explains species distributions (Hoese and Moore 1998). Brackish water collections of *Brevoortia* in the bays of Alabama to the Florida line have yielded only *B. patronus*, with no mention of *B. smithi* (Boschung et al 2004, Mettee et al. 1996). The distribution of *B. patronus* is reported as rare east of Pensacola, FL and that of *B. smithi* being limited to the west by the Chandeleur Sound (Hoese and Moore 1998, McEachran and Fechhelm 1998, Walls 1975). Providing an equidistant division of the overlapping region (Fort Morgan, AL, 88ºW) based on a biogeographical break, provides an equal probability of including and excluding each species.

1.4 Regulatory History and Data Monitoring

The Gulf menhaden reduction fishery is one of the largest fisheries by volume in the United States and has been successfully managed under a regional Fishery Management Plan since 1978. The fishery continues to be classified by the National Marine Fisheries Service (NMFS) as 'not overfished' with 'no overfishing occurring', and a population that is sustainable based on the most recent stock assessment (Vaughan et al. 2007). Through the partnerships, which have been developed among NMFS Beaufort Laboratory, the state marine agencies, the menhaden industry, and the Gulf States Marine Fisheries Commission (GSMFC), the Gulf menhaden fishery-dependent data set is one of the most detailed and data-rich of the fisheries currently operating in the Gulf of Mexico.

The NMFS personnel have had access to the catch at each of the plants for biostatistical and stock assessment purposes since 1964, and the menhaden companies report daily vessel unloads to the NMFS on a daily or weekly basis throughout the fishing season. Additionally, vessel captains complete daily logs of each vessel's activities called Captain's Daily Fishing Reports (CDFRs). They include an at-sea catch estimate, fishing location, set duration, and weather conditions for each and every set; compliance is 100% and they are provided to NMFS on a weekly or bi-weekly basis throughout the fishing season. The NMFS continues to publish monthly menhaden landings in the form of a status memo, which is available on the NOAA's Fishery Market News (http://www.st.nmfs.noaa.gov/st1/market_news/doc77.txt).

1.4.1 Fishing Season

The five Gulf States have common regulations for season duration, which traditionally lasted 26 weeks from April through mid-October. In 1993, the fishing season was extended two additional weeks to approximately 28 weeks creating the current season, which starts on the third Monday in April and runs through November 1 each year. In 1989, Louisiana established a special bait season for menhaden, which extended the season until December 1 or until the Louisiana Department of Wildlife and Fisheries (LDWF) determines that the bait quota of 3,000 metric tons has been met. Any menhaden taken during the bait season shall be sold only for use as bait and requires a special permit issued by the LDWF.

1.4.2 Quotas

As the Gulf menhaden fishery generally operates in state waters, the respective state marine agencies are responsible for regulating and monitoring the Gulf menhaden fishing activities in their waters and provide management for the fishery directly.

In the state waters off Escambia and Santa Rosa counties along the Florida Panhandle (inside the COLREGS, the line that divides inland waterways and coastal waterways), a quota of 1.0 million pounds (454 mt) is in place for commercial harvest of menhaden by all gears combined. The quota applies to the inside waters of Escambia and Santa Rosa counties only, not any offshore fishery. Purse seines are not allowed to harvest menhaden anywhere else in the state within the COLREGS other than off these two counties. The purse seines within the COLREGS must be less than 500 sq foot. The closing date for the inside waters is based upon

> "[t]he total commercial harvest of menhaden in Escambia and Santa Rosa Counties during a particular commercial fishing season shall consist of those menhaden commercially harvested by all forms of gear from all waters of these counties and waters of the federal Exclusive Economic Zone (EEZ) contiguous to such waters, based on projections from official statistics collected and maintained by the Florida Department of Environmental Protection pursuant to Florida's Marine Fisheries Information System."

Purse-seine gear used by the extant reduction fishery precludes reduction vessels from operating in Florida state waters, however they would be free to operate offshore of the COLREGS. The Florida quota is designed to control landings by a Gulf menhaden bait fishery inside the COLREGS in those two particular counties of Florida.

The extended bait season in Louisiana is managed for a 3,000 mt quota. The bait season is intended solely for harvest of menhaden for bait after the reduction fishing season ends on November 1. The extended bait season runs from November to December 1 or until the 3,000 mt quota is reached. Additionally, an early bait season begins on April 1 (about three weeks before the reduction season opens) if the quota has not been reached.

Currently, Texas is the only state with a quota or 'cap' on the reduction removals of Gulf menhaden from state waters. In March 2008, the Texas Parks and Wildlife Commission approved changes to the statewide hunting and fishing regulations that included establishing a Total Allowable Catch (TAC) on menhaden catches in the Texas Territorial Sea, the waters off Texas out to nine nautical miles. The TAC is 31.5 million pounds (14,288 mt) per year, which was set at the approximate five-year average of Texas catches during 2002-2006 (with penalties for overages).

1.4.3 Fishing Area Closures

Each state has its own designation of closed or restricted areas to purse-seine fishing for Gulf menhaden. In 1995, Florida banned all gill and entangling nets, and any nets greater than 500 square feet in state waters; thus, purse-seine reduction vessels were virtually excluded from state waters. In the decade prior to the Florida Net Ban, the purse-seine fishery for reduction rarely operated in Florida waters. Minor removals were made along the western Panhandle by vessels from the port of Moss Point, Mississippi.

In Alabama, reduction fishing is restricted to Mississippi Sound and the Gulf of Mexico west of roughly Point aux Pines, Bayou La Batre, and Isle aux Herbes (Coffee Island). There is also no purse fishing allowed within a radius of one mile from the western point of Dauphin Island.

Mississippi prohibits purse-seine fishing within one mile of the shoreline of Hancock and Harrison counties and the adjacent barrier islands. Jackson County has no restrictions relative to the shoreline other than around the barrier islands. Commercial fishing (including purse seining for menhaden) is prohibited north of the CSX bridge in the Pascagoula River system.

In Louisiana, the harvest of menhaden is restricted to waters seaward of the inside-outside line described in R.S. 56:495, including waters in the federal EEZ and in Chandeleur and Breton sounds. All other inside waters and passes are permanently closed to menhaden fishing. Waters on the south side of Grand Isle from Caminada Pass to Barataria Pass in Jefferson Parish, from the southeast side of Caminada Bridge to the northwest side of Barataria Pass at Fort Livingston, extending from the beach side of Grand Isle to 500 ft beyond the shoreline into the Gulf of Mexico, are designated closed zones. These waters are closed to the taking of fish with saltwater netting, trawls, and seines from May 1 to September 15.

In Texas, menhaden may not be fished in any bay, river, or pass within 0.5 mile from shore in Gulf waters or within one mile of any jetty or pass. The menhaden industry has had a "gentleman's" agreement with TPWD not to fish within 1 mile of Gulf beaches, and has agreed to leave Texas waters if significant quantities of game fish are documented by TPWD to be in the vicinity.

1.4.4 Bycatch

Individual states regulate incidental bycatch in the menhaden fisheries. There are no bycatch restrictions on the purse net fishery in Florida waters. In Alabama, menhaden purse-seine boats may not possess more than 5% by number of species (excluding game fish) other than menhaden, herrings, and anchovies.

In Mississippi, it is unlawful for any boat or vessel carrying or using a purse seine to have any quantity of red drum on board in Mississippi territorial waters. It is unlawful for any person, firm, or corporation using a purse seine or having a purse seine aboard a boat or vessel within Mississippi territorial waters to catch in excess of 5% by weight in any single set of the net or to possess in excess of 10% by weight of the total catch of any of the following species: spotted seatrout (*Cynoscion nebulosus*), bluefish (*Pomatomus saltatrix*), Spanish mackerel (*Scomberomorus maculatus*), king mackerel (*Scomberomorus cavalla*), dolphinfish (*Coryphaena hippurus*), pompano (*Trachinotus carolinus*), cobia (*Rachycentron canadum*), or jack crevalle (*Caranx hippos*).

In Louisiana waters, anyone legally taking menhaden shall not have in their possession more than 5% by weight, of any species of fish other than menhaden and herring-like species.

In Texas, purse seines used in taking menhaden may not be used to harvest any other edible products for sale, barter, or exchange. Purse-seine catches may not contain more than 5% by volume of other edible products.

1.5 Assessment History

Quantitative analyses of Gulf menhaden began in the early 1970s, as the time series of detailed data developed (accurate reduction landings have been recorded since 1948, and detailed biostatistical sampling began in 1964). The first quantitative analysis was that based on a Schaefer-type surplus production model using CPUE and effort data (Chapoton 1972). Schaaf (1975) updated this analysis and provided some cautionary comments on applying this model in a developing fishery. A further update of this analysis can be found in the original management plan for this stock (Christmas and Etzold 1977). Ahrenholz (1981) developed estimates of rates of exploitation, population movements, and recruitment into the fishery from returns of tagged juveniles and adults. An important result from this study that has been used in subsequent assessments was the estimate for natural mortality ($M = 1.1$) based on tagged adults.

Two formal stock assessments were completed during the 1980s. First, Nelson and Ahrenholz (1986) included data through 1978, and the second, Vaughan (1987) included data through 1985. These assessments used an untuned virtual population analysis (VPA) approach based on the cohort-linked method described by Murphy (1965) to estimate age- and year-specific fishing mortality and population numbers from the catch-at-age matrix computed from the reduction fishery landings and biostatistical samples. Yield-per-recruit analyses, spawner-recruit relationships, and surplus production models were then developed from the VPA output. Results of these two assessments appeared in revisions to the Fisheries Management Plan (Christmas et al. 1983 and 1988). Stock assessment results were also summarized in the special menhaden issue of Marine Fisheries Review (Vaughan and Merriner 1991).

Two formal stock assessments were conducted during the 1990s (Vaughan et al. 1996, Vaughan et al. 2000) and results incorporated into further revisions to the Gulf Menhaden Fisheries Management Plan (Leard et al. 1995, VanderKooy and Smith 2002). Vaughan et al. (1996) included fisheries data through 1992. In addition to applying the VPA approach of Murphy (1965), they also applied the separable VPA approach of Doubleday (1976). The separable VPA was fit to the full catch-at-age matrix (1964-1992) and discrete fits to two separate time periods (1964-1975, 1976-1992). Vaughan et al. (2000) continued these methods, applying the method of Murphy (1965) to the early time period (1964-1975) and updating the separable VPA to the later time period (1976-1997). As in the 1980s, results from the VPAs were used in developing, yield-per-recruit analyses, spawner-recruit relationships, and surplus production models. Vaughan et al. (2000) also began investigating the utility of recruitment indices from Louisiana (trawl survey) and Texas (bag seine). They also updated the relationship between menhaden recruitment and Mississippi River flow reported by Govoni (1997).

As noted above, assessment methods used the untuned VPA method of Murphy (1965) and later separable VPA (SVPA) of Doubleday (1976) as the primary assessment methodology through 2000. The next completed assessment of the status of the Gulf menhaden stock was Vaughan et al. (2007). As before, data included abundance indices, recorded landings, and samples of annual size and age compositions from the landings through 2004. Several important improvements were made for this assessment. First, age-varying natural mortality was implemented based on the approach of Boudreau and Dickie (1989). Natural mortality was related inversely to the weight at age of Gulf menhaden and scaled to M estimated by Ahrenholz (1981) for adult menhaden. More importantly, a flexible forward-projecting statistical model similar to that currently used for Atlantic menhaden (ASMFC 2004, ASMFC 2010) was applied to these data. Finally, given this added flexibility, a recruitment index that was developed from fishery-independent seine and trawl data from three states was incorporated into the model structure. A base assessment model run was developed and sensitivity model runs were made to evaluate performance of the assessment model. The forward-projecting statistical modeling approach was found to be more useful in characterizing the temporal trends and status of the Gulf menhaden stock, than the heretofore used VPA approaches. The status of the stock was based on the terminal year (2004) estimates relative to their corresponding limits (or threshold), and these benchmarks corresponded to the approach used by ASMFC for Atlantic menhaden (ASMFC 2004). Benchmarks were estimated based on the results of the updated base run, and the terminal year estimate of fishing mortality rate (F_{2+}) was estimated to be 75% of its limit (and 116% of its target). Correspondingly, the terminal year estimate of population fecundity (*FEC*) was estimated at 93% of its spawning stock biomass target or SSB_{target} (and 186% of its limit). Hence, the stock was not considered to be overfished, nor was overfishing occurring.

Finally, in 2011, the most recent benchmark stock assessment was completed through the SouthEast Data, Assessment, and Review (SEDAR) process (SEDAR27). As in the Vaughan et al. (2007) assessment, this assessment used a statistical catch at age framework. During the SEDAR assessment process, several new data sources came to light, as did many new questions. During the data call, each state from Texas through Florida provided both seine and trawl data collected during fishery-independent sampling and each state from Texas through Alabama provided gill net data collected during fishery-independent sampling. The last assessment was the first time these fishery independent data were available for review for an assessment. In addition, questions arose regarding the age composition data, landings hopper measurements, adequacy of sampling the last set of the day for biostatistical data, and whether or not a fishery dependent CPUE index could be provided and be useful. The assessment completed for the SEDAR27 process was not deemed useful for management because of the uncertainties surrounding the gill net data and the fishery-dependent data. For this current assessment, these topics have been analyzed with the best available data and science and have been explored to determine the implications on the uncertainty surrounding the assessment results.

1.6 Historical Retrospective

Historical retrospective can be investigated using stock assessments that have been conducted consistently over the years (Cadrin and Vaughan 1997). These analyses compare estimates of important management variables from the most recent assessment with contemporary estimates from prior stock assessments. In particular, Cadrin and Vaughan (1997) compared three management variables (or “triggers”) in their analysis, including spawning stock biomass, recruitment to age-1, and maximum spawning potential (*%MSP*). For the purpose of this analysis, we have replaced *%MSP* with adult fishing mortality (*F*). The management variables analyzed in this report are:

> Fishing Mortality (*F*) – calculated unweighted age-specific *F* for ages-2 and older.
>
> Spawning Stock Biomass (*SSB*) – calculated as the weight of mature females in the population for ages-2 and older assuming a sex ratio of 1:1.
>
> Recruits to Age-1 – directly estimated as number of age-1 fish in the population at the start of the fishing year (January 1 for Gulf menhaden).

The first two assessments (Nelson and Ahrenholz 1986, Vaughan 1987) used the Murphy (1965) approach to VPA. Catch in numbers at age were divided into four seasons, and the program was applied a cohort at a time. Subsequent assessments used the SVPA approach developed by

Doubleday (1976). Because the SVPA program provided diagnostics suggesting the separability assumption was poorly met prior to 1976, the results from the earlier Murphy VPA's were retained for 1964, and the SVPA was applied from 1976 through the terminal year for subsequent assessments (Vaughan et al. 1996, Vaughan et al. 2000). A forward-projecting age structured model was developed in ADMB (Automatic Differentiation Model Builder, which is a program used for non-linear statistical modeling) to incorporate recruitment index and age-varying natural mortality (Vaughan et al. 2007). A short report was prepared for GSMFC updating the SVPA applied to the period 1976-2004, and comparing results to the ADMB assessment. In summary, the following modifications have been made to the assessments over the years:

> Methods applied:
> Murphy (1965) approach: Nelson and Ahrenholz (1986), Vaughan (1987)
> SVPA approach: Vaughan et al. (1996), Vaughan et al. (2000), GSMFC (2007)
> ADMB approach: Vaughan et al. (2007)
> Catch at age matrix based on reduction fishery only through 2000, small amount of bait landings added for 2007 assessments (Vaughan et al. 2007, GSMFC 2007)
> Constant natural mortality (*M* = 1.1) for all ages and years, except in Vaughan et al. (2007).

Outputs from these historical stock assessments were compared as a series of figures (Figure 1.2-1.4). Nomenclature for labeling the individual lines in Figures 1.2-1.4 were as follows: Nelson and Ahrenholz (N&A_1986), Vaughan (V_1987), Vaughan et al (V_1996), Vaughan et al. (V_2000), GSMFC (2007) (SVPA_2007), and Vaughan et al. (ADMB_2007).

Mean fishing mortality for age-2 and older were compared in Figure 1.2. Murphy estimates of *F* showed occasional large peaks, while the separable assumption for SVPA tended to smooth these out. Ignoring these peaks, all assessments showed similar patterns over years of overlap.

Estimates of spawning stock biomass (weight of mature females ages 2 and older) were compared in Figure 1.3. The ADMB provided higher estimates of recruitment compared to the SVPA approach, especially since the early 1990s. Patterns were similar among these assessments with the exception of the divergence of the ADMB approach beginning in the early 1990s.

Recruits to age-1 were compared in Figure 1.4. The ADMB provided higher estimates of recruitment compared to the SVPA approach, especially since the late 1980s. Patterns were similar among these assessments with the exception of the divergence of the ADMB approach beginning in the late 1980s.

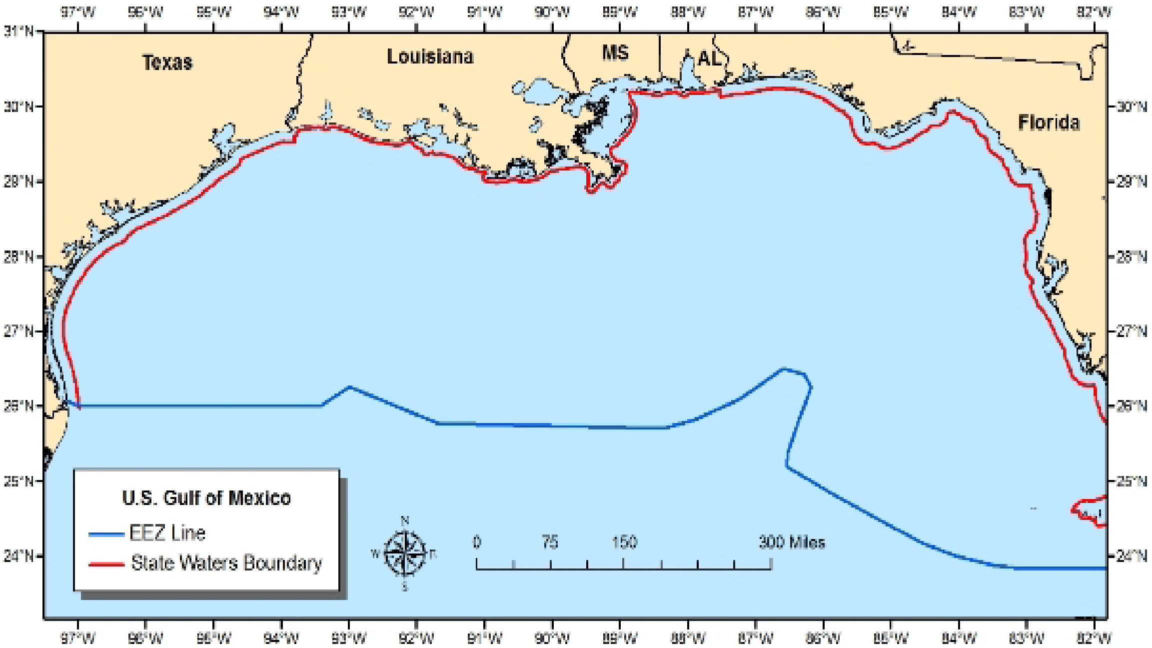


Figure 1.1 Map of the northern Gulf of Mexico showing state waters boundary and the EEZ line.

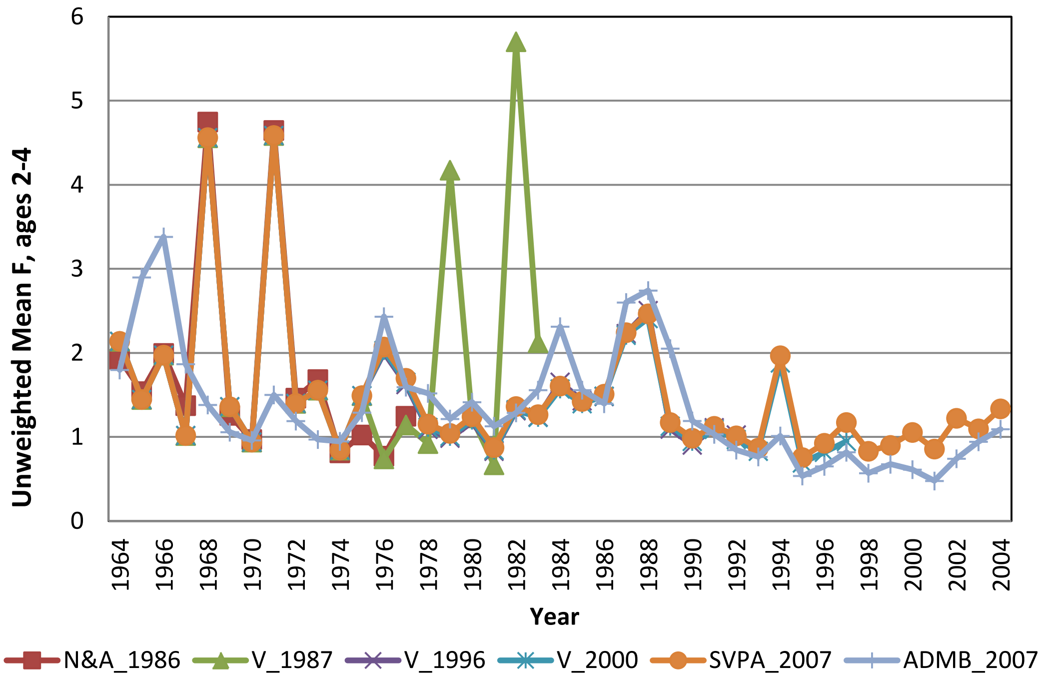


Figure 1.2 Historical retrospective on fishing mortality (F) from Nelson and Ahrenholz (N&A_1986), Vaughan (V_1987), Vaughan et al (V_1996), Vaughan et al. (V_2000), GSMFC report (SVPA_2007), and Vaughan et al. (ADMB_2007).

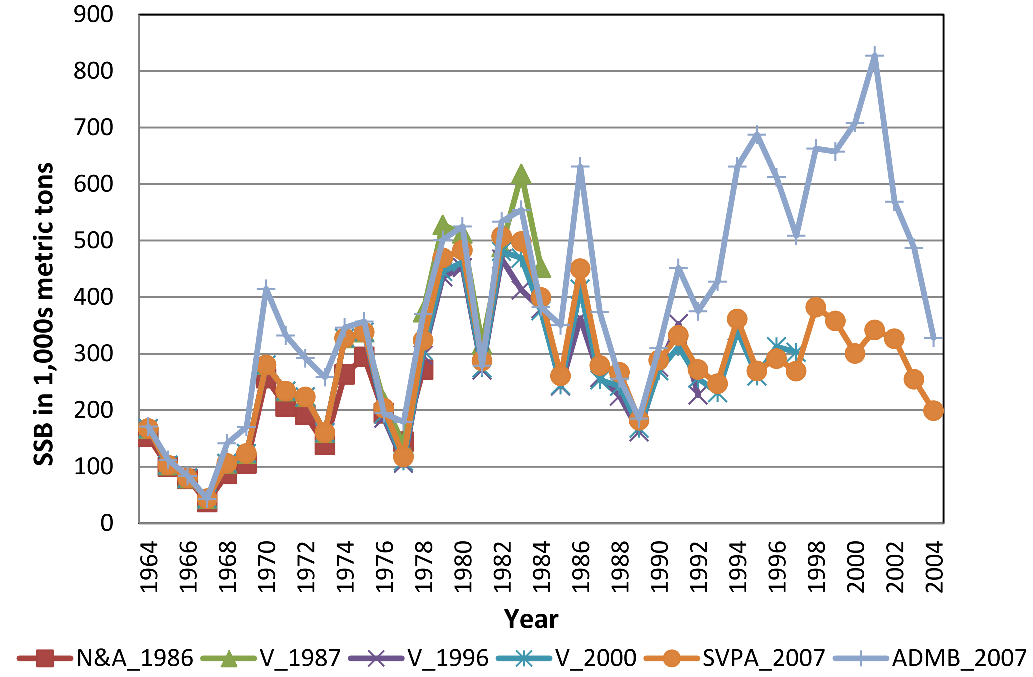


Figure 1.3 Historical retrospective on spawning stock biomass (*SSB*) from Nelson and Ahrenholz (N&A_1986), Vaughan (V_1987), Vaughan et al (V_1996), Vaughan et al. (V_2000), GSMFC report (SVPA_2007), and Vaughan et al. (ADMB_2007).

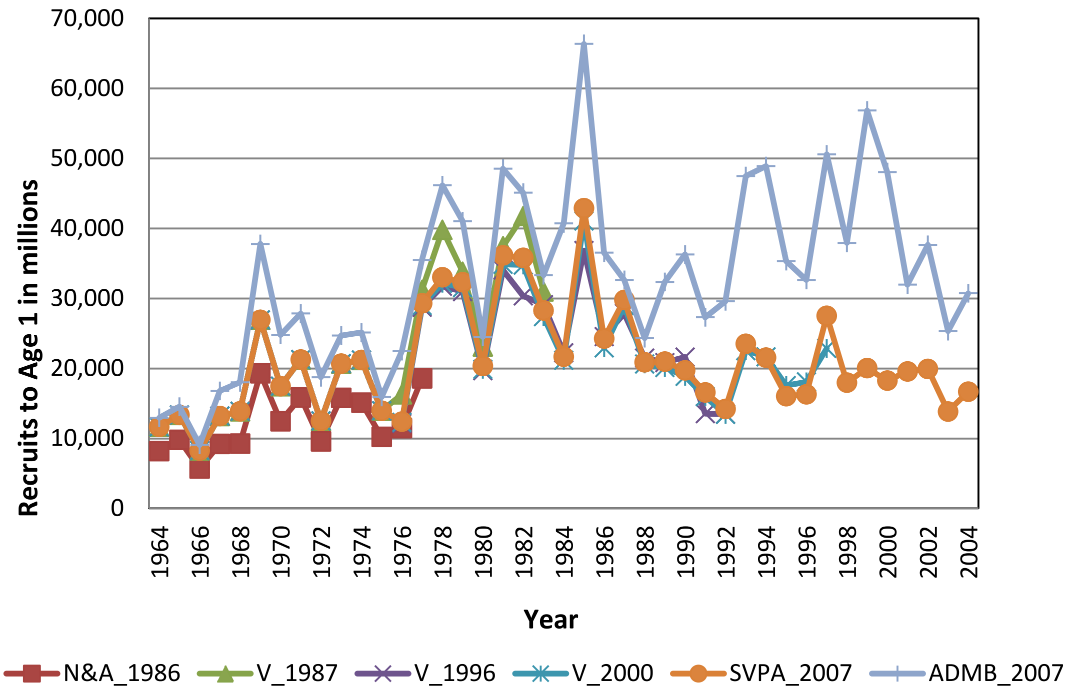


Figure 1.4 Historical retrospective on recruits to age-1 (R_1) from Nelson and Ahrenholz (N&A_1986), Vaughan (V_1987), Vaughan et al (V_1996), Vaughan et al. (V_2000), GSMFC report (SVPA_2007), and Vaughan et al. (ADMB_2007).

2.0 Habitat Description

2.1 General Conditions

Gulf menhaden range throughout the Gulf of Mexico from the Yucatan Peninsula to Tampa Bay, Florida; however, they are most abundant in the north-central Gulf (Christmas et al. 1982). Gulf menhaden are found in a wide range of salinities, from offshore to freshwater, since their life cycle includes offshore spawning, mostly during winter, with recruitment to and maturation in coastal rivers, bays, bayous, and other nearshore habitats. Upon maturation, the fish return to offshore waters to complete the life cycle.

While juveniles and adults are typically found in open water with non-vegetated bottoms, larvae and early juveniles are often found associated with estuarine marsh edges where adequate forage and protection from predators can be found (Reintjes 1970). Upon entering estuaries, post-larvae occupy quiet, low salinity waters to bottom depths of 6.6 ft (Fore and Baxter 1972b). After transformation, most juvenile menhaden remain in nearshore estuaries until they are approximately 100 mm FL (Lassuy 1983).

2.2 Physical Habitat

Gulf menhaden are found throughout the northern Gulf of Mexico and utilize a number of brackish and freshwater habitats. Larvae arrive in the upper estuaries in the early spring after riding the prevailing currents from the offshore spawning grounds (June and Chamberlin 1959, Christmas et al. 1982, Minello and Webb 1997).

The Gulf of Mexico is bordered by 207 estuaries (Buff and Turner 1987) that extend from Florida Bay, Florida, to the Lower Laguna Madre, Texas. Perret et al. (1971) reported 5.62 million ha of estuarine habitat in the five Gulf States including 3.2 million ha of open water and 2.43 million ha of emergent tidal vegetation (Lindall and Saloman 1977) and includes 1 million ha of salt marsh (USEPA 1992). Emergent vegetation is not evenly distributed along the Gulf coast with the majority of the Gulf’s salt marshes (63%) being located in Louisiana. These areas provide structure for protection and foraging areas to larval and early juvenile Gulf menhaden (Minello and Webb 1997).

2.3 Salinity

Offshore spawning necessitates that Gulf menhaden eggs and larvae be euryhaline. Gulf menhaden eggs and larvae have been collected in waters with salinities ranging from 6-36 ppt (Fore 1970, Christmas and Waller 1975); 88% of the eggs were collected from waters over 25 ppt. Collections of eggs and larvae were made throughout the Gulf of Mexico at the peak of spawning from waters ranging in salinity from 20.7-36.6 ppt (Table 2.1; Christmas et al. 1982). As the larvae move inshore, they require low salinity waters to complete metamorphosis from the larval body form to the deeper–bodied juvenile/adult form. June and Chamberlin (1959) observed that arrival in estuaries may be essential to the survival of larvae and their metamorphosis to juveniles based on food availability and lower salinities. Combs (1969) found that gonadogenesis occurred only in menhaden larvae that arrived in euryhaline, littoral habitats.

The value of low salinity marsh habitat to juvenile Gulf menhaden is well known, but not well documented. Only a few studies have looked at the dependence of nektonic menhaden on low salinity marshes as nursery habitat. Gunter and Shell (1958) reported that young menhaden enter upper marshes with salinities around 0.9 ppt at Grand Lake, part of the Mermentau River Basin, Louisiana. Copeland and Bechtel (1974) investigated the environmental parameters associated with several commercial and recreational species and reported juvenile Gulf menhaden were most frequently collected in primary rivers and secondary streams at salinities ranging from 0-15 ppt. The authors point out that these low salinity waters supported the greatest numbers of juvenile menhaden (Copeland and Bechtel 1974). Likewise, Chambers (1980) found a similar relationship among young Gulf menhaden and both freshwater and low salinity, brackish areas in the upper Barataria Basin of Louisiana.

Tolan and Nelson (2009) determined that after examining a number of abiotic factors in three tidal streams in the Matagorda Bay estuary, Texas, salinity was the driving factor in determining fish assemblages. Juvenile and sub-adult Gulf menhaden were found be the most abundant species in all three tidal creeks over the course of their study and community responses were based on the prevailing salinity regime more than dissolved oxygen.

Recent observations by Haley et al. (2010) found larval and juvenile menhaden up to 79 river miles upstream on the Alabama River, near the Claiborne Lock and Dam. Although the authors did not record station salinities, the drought situation that occurred during their sampling season may have pushed the salt wedge, and consequently associated ichthyoplankton, farther upriver than during ‘normal’ years.

2.4 Temperature

Gulf menhaden occupy a wide range of habitats; therefore, temperature may be more critical to egg development than to juveniles and adults, although Gulf menhaden are occasionally victims of large fish kills related to freeze events (Hildebrand and Gunter 1951, McEachron et al. 1994).

Turner (1969) collected eggs and larvae from stations off northern Florida at surface water temperatures ranging from 11.0°C (February) to 18°C (March). In southern Florida, samples were taken from 16°C (January) to 23°C (March), and in Mississippi Sound, temperatures ranged from 10°C (January) to 15°C (December).

Larval and juvenile menhaden have been collected in Gulf estuaries at temperatures ranging from 5-35°C (Table 2.1; Christmas and Waller 1973, Perret et al. 1971, Swingle 1971). Reintjes and Pacheco (1966) cited references indicating that larval menhaden may suffer mass mortalities when water temperatures are below 3°C for several days or fall rapidly to 4.5°C. Likewise, juvenile and adult menhaden suffer cold kills during periods of freezing winter conditions, especially in narrow or shallow tidal areas.

McEachron et al. (1994) documented one such cold kill in Texas. In December 1983, the entire Texas coast suffered a freeze that was one of the most severe in recorded history. Water temperatures dropped about 15°C in about 10 days to near 0.0°C and remained between 0.0-

5.0°C for about seven days. Two more cold-kill events occurred in February and December 1989 which resulted in additional widespread fish kills. Coastwide, about 980,000 Gulf menhaden died in 1983 and around 600,000 died in the two freezes of 1989. Gulf menhaden that succumbed to the cold ranged in size from 80-130 mm TL.

Cold kills of Gulf menhaden are uncommon in the central northern Gulf. Overstreet (1974) suggests that:

> "Lack of proper acclimation probably determines why mass mortalities occur more frequently in Texas and Florida than in Mississippi. Fishes in Mississippi, living in water normally cooler than in Texas, are necessarily acclimated to lower temperatures. Consequently, a sudden drop to near-freezing levels would affect those fishes less."

2.5 Dissolved Oxygen (DO)

Large fish kills occur in summer as well, often resulting from plankton blooms and low dissolved oxygen (DO) or hypoxic conditions. Mass fish mortalities, which include Gulf menhaden, attributed to low DO concentrations have occurred in most Gulf estuaries (Crance 1971, Christmas 1973, Etzold and Christmas 1979).

Post-larvae and juveniles are frequently killed by anoxic conditions in backwaters (e.g., dead-end canals) during summer. Hypoxic and anoxic conditions may also occur in more open estuarine areas as a result of phytoplankton blooms. In Louisiana, west of the Mississippi River delta, low DOs in nearshore Gulf waters may serve to concentrate schools of Gulf menhaden closer to shore as they avoid hypoxic areas known as the 'dead zone'. The 'dead zone' results from increased levels of nutrient influx from freshwater sources coupled with high summer water temperatures, strong salinity-based stratification, and periods of reduced mixing (Justic et al. 1993). Most life history stages of Gulf menhaden, from eggs to adults, occur inshore (i.e., inshore of the 10 fathom curve) of areas where historically the hypoxic zone 'sets up' by midsummer. Gulf menhaden appear to be only moderately susceptible to low DOs and probably move out of hypoxic areas, resulting in displacement rather than mortality.

Preliminary analyses of menhaden logbook data suggest that, during some years, exceptionally low catches of Gulf menhaden off the central Louisiana coast may have been a result of hypoxic waters impinging upon nearshore waters in midsummer (Smith 2001). The close association that Gulf menhaden have with estuaries during summer tends to decrease the effects these offshore hypoxic areas have on the population.

2.6 Habitat Elasticity

O'Connell et al. (2004) examined the fish assemblages that occurred in the Lake Pontchartrain estuary from roughly 1950-2000 using museum specimens and collections. Over the 50 years of records, they found that although the estuary had deteriorated substantially in environmental quality, Gulf menhaden did not change in their frequency or position within the estuary while a number of other species had. Overall the assemblage shifted from a croaker-dominated complex to an anchovy-dominated complex, suggesting that Gulf menhaden are very elastic in their ability to handle changing environmental conditions, both short and long-term (O'Connell et al. 2004).

Table 2.1 Optimum temperature and salinity conditions for the egg and larval stages based on the habitat suitability indices (HSI) for Gulf menhaden (Christmas et al. 1982).

Life History Stage	**Salinity (ppt)**	**Temperature (°C)**
eggs/yolk-sac larvae (marine)	25-36*	14-22*
feeding larvae (marine)	15-30*	15-25*
feeding larvae/juveniles (estuarine)	5-13*	5-20*

*lowest mean monthly winter value

3.0 Life History

3.1 Stock Definition

3.1.1 Genetics

Appropriate management of a species must consider the potential for multiple stocks or genetic populations. In addition to influencing jurisdictional and logistical aspects of management, the implications of stock assessments are more accurately interpreted within the context of a well-defined genetic background.

Anderson (2006) measured genetic stock structure with extensive sampling across the range of the fishery and found little evidence of genetic structure that would indicate the presence of multiple stocks. Instead, stock structure in Gulf menhaden is more accurately described by an isolation-by-distance model, in which measurable genetic structure is shown to be largely a function of the upper limits on dispersal of individuals within a stock. In this model, genetic distance among samples is expected to increase linearly with geographic distance, which was demonstrated by Anderson (2006). While the specimen sampling was adequate, the study was limited in scope by a small genetic sample. In particular, five DNA microsatellites were assayed, with one of the five being removed due to stability/reliability issues identified prior to analysis. A mitochondrial DNA (mtDNA) locus was also assayed to test repeatability of the pattern found in the microsatellite data set, and a similar pattern (single stock) was indeed found. However, resolution of the issue of stock structure could be definitively achieved with more extensive genetic sampling.

Anderson (2007) identified a single population of Gulf menhaden in Texas waters using mtDNA, and Anderson and McDonald (2007) noted that despite the similarities between Gulf and finescale menhaden, the two sympatric species may hybridize occasionally although there is little introgression. Anderson and Karel (2007) found unidirectional gene flow has occurred in the eastern Gulf between Gulf and Atlantic menhaden with 'Gulf' genes flowing into the Florida Atlantic coast but not in reverse; 'Atlantic' genes have not been found in the Gulf of Mexico population.

Along Florida's Panhandle, Turner (1969) found extensive hybridization and introgression between Gulf and yellowfin menhaden. Hybridization is so common that the FWC now only identifies menhaden to the genus level in their fishery-independent sampling (R. McMichael, personal communication). Anderson (2006) reported that from Charlotte Harbor, Florida, 1 in 30 individuals was a Gulf and yellowfin menhaden hybrid.

In summary, Anderson (2006) noted that:

> "There appears to be no organized structure of Gulf menhaden populations which would indicate distinctive genetic 'stocks' delineated by geographic boundaries… Samples of Gulf menhaden taken from southern Texas to southern Florida are not significantly different, and variation across the entire northern Gulf of Mexico exhibits only a modest degree of genetic isolation by distance. It appears that the

> very large and semi-migratory spawning aggregates of Gulf menhaden have resulted in high Gulf-wide genetic variation which demonstrates only a limited geographic component."

3.1.2 Migration and Movement

Gulf menhaden are generally estuarine, shallow-water fishes, and while some age-0 (young-of-year) fish may overwinter in estuaries (Turner and Johnson 1973, Deegan 1985); the overwhelming majority of juveniles and adults migrate offshore throughout summer and fall although the extent of that 'offshore' range is unknown. Suttkus (1956) reported that migration of age-0 menhaden from Lake Pontchartrain, Louisiana, appeared to occur in August or September. Copeland (1965) found that the greatest migration of advanced juveniles from estuaries at Port Aransas, Texas, occurred from November through May. Roithmayr and Waller (1963) reported catches of adult Gulf menhaden from December-February in the northern Gulf from 4-48 fathoms both east and west of the Mississippi River Delta. They concluded that at least some fish do not move far offshore, but winter on the inner and middle continental shelf area just off the Mississippi River delta. Christmas and Gunter (1960) reported capturing Gulf menhaden in mid-water trawls at depths ranging from 40-55 fathoms, although in very low numbers. Likewise, some menhaden have been reported in the SEAMAP bottom trawl sampling throughout the northern Gulf of Mexico, but in very low numbers and infrequently (see Section 5.4).

Gulf menhaden do not exhibit extensive east/west migrations, and generally, older adults are believed to tend to occur near the center of the population's range (around the Mississippi River delta). Ahrenholz (1981) tagged 38,445 Gulf menhaden from 1970-1972 using ferromagnetic tags from southeast Texas to the Florida Panhandle. Juveniles were tagged in estuaries during late summer or early fall just before emigration and adults were obtained, tagged and released from the commercial fishing grounds during late spring. Those tags were subsequently recovered later in the year on magnets in the reduction factories during processing of the catch. Because reduction vessels at that time tended to fish more intensively in the area near their home ports, most tags recovered at a specific port were assumed to have been from fish caught in the waters closest to that port. As a result, Ahrenholz (1981) concluded that fish first entered the fishery primarily in the same geographic area in which they were tagged. As fish aged, there appeared to be a slow movement of fish from eastern and western fishing grounds toward the Mississippi River delta. Fish tagged in the two most western areas (southeast Texas and Galveston) were captured in greater numbers their second year after release at the two more central ports in Louisiana (Morgan City and Dulac).

Likewise, Pristas et al. (1976) tagged about 76,000 adult Gulf menhaden from 1969-1971 using internal metallic tags, which were also recovered on magnets at the various reduction plants. Adult fish were tagged and released from commercial purse boats operating on the menhaden fishing grounds. They noted very little east/west movement of adults as many of the returns were from plants near the release sites. Second-year returns showed the same pattern with little east/west mixing. Most of the adult fish that had moved offshore to over-winter returned to the areas where they had been released the previous season.

3.2 Ageing

In 1964, the National Marine Fisheries Service (NMFS) Beaufort Laboratory (formerly the U.S. Bureau of Commercial Fisheries) began monitoring the Gulf menhaden purse-seine fishery for size and age composition of the catch (Nicholson 1978). From the outset, program managers realized using otoliths to age Gulf menhaden was impractical because 1) sagittal otoliths were so small and fragile, and 2) large amounts of time and effort would be required to extract, process, and read whole or sectioned sagittae. Moreover, large numbers of ageing parts (> ca. 10,000) would be required to adequately characterize the fishery with annual landings of several hundred thousand metric tons. Thus, scales were selected for Gulf menhaden ageing.

Chapoton (1967) determined that scale development on Gulf menhaden began on larval specimens at ca. 21 mm FL and was complete in specimens > ca. 27 mm FL. Gulf menhaden scales are generally thin and translucent (Figure 3.1). Unlike most herrings, the posterior margin of Gulf menhaden scales is pectinate or serrated. The anterior field is embedded in the integument. The entire scale is sculptured with fine circuli, which are roughly semi-circular and parallel the anterior and lateral margins. The largest and most symmetrical (nearly rectangular) scales occur in a median lateral band above the lateral line and below the dorsal fin. Scale samples for ageing are removed from this area.

A scale patch is removed with a blunt-edged scalpel and placed in a small vial of water. The patch is removed from the vial, blotted dry, and rubbed between the thumb and forefinger to remove residual integument. Individual scales are then mounted between two glass microscope slides. Ten individual scales (two rows of five) are placed on the first slide with pectinations pointing down, and then covered with the second slide. Slides are fastened together with short lengths of transparent tape. The cover slide is labeled with a unique port and specimen number combination.

3.2.1 Age Determination

Gulf menhaden scales, which are mounted between microscope slides, are viewed on an Eberbach macro-projector at 48x magnification. Age rings on Gulf menhaden scales are defined as compressions or interruptions of uniformly spaced circuli in the anterior field of the scale, which are continuous through the lateral fields. Under transmitted light age rings form narrow, continuous, dark bands roughly paralleling the lateral and anterior margins of the scale. A focus is arbitrarily chosen near the center of the posterior field at the base of the circuli. Straight-line measurements are made from the focus to successive scale rings and the scale edge (Figure 3.1).

Nicholson and Schaaf (1978) found that ageing Gulf menhaden with scales was problematic; citing that only about 50% of the fish examined during 1971-1973 could be aged by scale annuli. They determined that many fish had well-defined scale rings, but others had no rings or rings that were oddly spaced. Their criteria for scale ageing were based on appearance of the scales, number and spacing of the rings, and fish fork length at time of capture. Although admitting some subjectivity, they determined that fish with one or two scale rings displayed true annuli. For fish with oddly-spaced rings, it was possible to separate out age classes by ring location. Finally, for fish with no discernible rings, they believed age could be estimated by length frequency distributions.

In an attempt to increase the probability of encountering legible scales with true annular rings, Menhaden Program personnel at the Beaufort Laboratory in the early 1990s instructed port agents to mount ten scales for ageing per specimen versus the previous directions to mount six scales. Percent legibility increased; for example in fishing year (2003), 86% (6,780 of 7,839) of Gulf menhaden scale samples had legible annular rings (compared to ca. 50% by Nicholson and Schaaf [1978]; see above). Age assignments based on ring spacing and/or length frequencies were only required for 14% of the samples.

Gulf menhaden spawn between October and April, with peak activity from December through March (Turner 1969, Fore and Baxter 1972a). Scale annuli form in winter, and by convention the birth date for Gulf menhaden is January 1. Since the purse-seine fishery operates April through October, advancing ages because of calendar date (and unformed rings) is not an issue relative to the fishing season.

3.2.2 Ageing Error Matrix

The data for the ageing error analysis comes from two unpublished studies conducted at the NMFS Beaufort Laboratory. The first was a scale-to-otolith comparison by Smith and Levi (unpublished manuscript), and the second was a scale-to-scale comparison by Smith and Hall (unpublished manuscript). The comparison between scale and otolith readings was completed by two separate readers, one for the scales and one for the otoliths (n = 228). The comparison between scale readings was completed by one reader who read all of the scales from the 2005 fishing season, then re-read 54.9% of the scales from that same fishing season (n = 3,405).

Accounting for error in age estimation is important for age composition data used in stock assessments (Punt et al. 2008). Thus, to account for any error associated with the age estimation process for Gulf menhaden and to get contemporary precision estimates, an ageing error analysis was completed using a program called “Agemat” developed by André Punt. Agemat uses age estimation data from multiple readers to 1) estimate the coefficient of variation and standard deviation associated with age estimates and 2) to provide an ageing error matrix. This program has been used to create ageing error matrices for other SEDAR assessments (ASMFC 2010, Anonymous 2010 (SEDAR 24)).

Agemat requires some model specifications, such as the minimum and maximum age of the species, a reference age, and the type of standard deviation to be estimated, in addition to inputting the ageing data and number of readers in the appropriate format. The minimum age used for this analysis was age-0, and the maximum age used was age-6. The reference age was age-2. The standard deviation was estimated using an asymptotic function. The maximum allowable standard deviation was input as 5; however, the standard deviation for neither comparison came near that bound. All specifications were the same for both comparisons analyzed.

For the scale-to-otolith comparison, the standard deviation was an increasing, asymptotic curve, which started at a low of 0.16 at age-0 and increased to a maximum of 0.55 for fish age-6 (Figure

3.2). The coefficient of variation was a curve, which increased from 0.16 at age-0 to 0.20 at age-2, and then decreased to 0.09 at age-6 (Figure 3.2). The ageing error matrix is provided in Table 3.1. Similarly, for the scale-to-scale comparison, the standard deviation was an increasing, asymptotic curve, which started at a low of 0.04 at age-0 and increased to maximum of 0.54 for fish age-6 (Figure 3.3). The coefficient of variation was a curve, which increased from 0.04 at age 0 to 0.17 at age 2, and then decreased to 0.09 at age-6 (Figure 3.3). The ageing error matrix is provided in Table 3.2.

Both comparisons indicate a relatively low level of ageing error and had similar ageing error matrices. The scale-to-otolith comparison gives an indication of the error using scales compared to the true age of the fish. This comparison requires the assumption that the otolith provides an accurate true age for each individual (ongoing work at Old Dominion University with Atlantic menhaden, *B. tyrannus*, indicates good agreement between paired scale and otolith age estimates ages-0 through age-3; J. Schaffler pers. comm.). The scale-to-scale comparison looks at reader error within a reader because the reader is ageing scales multiple times to determine precision of age estimates.

3.2.3 Longevity, Maximum Size, and Contemporary Age Composition

Gulf menhaden as old as age-6 occur in the annual NMFS biostatistical data bases (from port samples); however, these specimens are rare and only eight age-6 individuals have been sampled (in 1981 [2], 1982 [2], 1990 [1], 1992 [1], 1993 [1], and 2005 [1]) from over 520,000 fish processed from 1964 to 2011. Gulf menhaden older than age-4 are uncommon in the landings, including eighty-eight age-5 Gulf menhaden and the eight age-6 Gulf menhaden already mentioned.

Over 220,000 Gulf menhaden were aged between 1988 and 2011. These data were summarized in the form of an age-length key based on 10 mm FL intervals (Table 3.3). The years 1988 to 2011 were used for creation of the age length key because those are the years of the gill net index and the associated length compositions. Only sixty-two age-5 and three age-6 Gulf menhaden were recorded during those years. As noted elsewhere, most Gulf menhaden landed in the reduction fishery were either age-1 or age-2, representing 59% and 36%, respectively. The statistical distribution of fork length at age was summarized in Table 3.4. Columns represented the age, sample size, mean fork length (Obs), standard deviation (SD), and coefficient of variation (CV). Predicted fork length at age was based on the von Bertalanffy growth equation discussed in the next section (Section 3.3).

Maximum fork length (FL) of Gulf menhaden as recorded in the NMFS biostatistical data bases is about 308 mm FL (n=520,583); maximum weight of Gulf menhaden from the same data bases is about 571 grams (n=520,583). Because of the size of this data base, more realistic values for maximum size might be based on 99th percentiles; e.g., 213 mm for fork length and 203 grams for weight. Fork length frequencies by age for 2011 port samples of Gulf menhaden are shown in Figure 3.4.

3.3 Growth

Weightings by catch in numbers by year, season and fishing area were applied to the Gulf menhaden biostatistical data base to calculate average fork lengths (mm) and weights (g) by age and year (Tables 3.5 and 3.6). Values based on a single fish are highlighted in color. These mean values represent mean size at age at approximately mid-fishing year (July).

Pair-wise Pearson correlations were estimated for the time series of weighted mean lengths and weights aligned by cohort (year class) or by calendar year (Table 3.7) for ages-1 to -4 for 1964-2010. The differences in the correlations between these two alignments suggest that the relationship is slightly stronger when aligned by cohort for lengths, but not for weights. Thus, growth information was inspected for annual values, rather than by cohort.

The Gulf states use standard and total length measurements for their surveys, while NMFS uses fork lengths in their biostatistical data base. To rectify this data mismatch, each Gulf state collected and measured lengths [fork length (FL), standard length (SL), and total length (TL)] for several hundred fish in late March and early April 2011 (Schueller et al. 2012). The sampled fish included both juveniles and adults and a broad range of sizes and geographic locations.

For the length-length conversions, Texas provided data from the 1970s for which both SL and TL were measured (n = 9,158). A recent study funded by Omega Protein (Brown-Peterson 2010) was also included where both FL and SL were measured (n = 195). Additionally, 927 fish lengths were collected by the individual states in spring 2011 for which all three lengths were measured. Sample sizes by state are summarized in Table 3.8. Separate regressions were conducted relating FL with SL and with TL for direct use in the Beaufort Assessment Model (BAM; Table 3.8). Other exploratory regressions were conducted, but results highlighted in yellow are used in this assessment.

As in previous menhaden assessments, regressions of fork length (FL in mm) on age (yr) are based on the von Bertalanffy growth curve:

$$\mathrm{FL} = L_\infty(1 - \exp(-K(\mathrm{age} - t_0))) \qquad (1)$$

using the Marquardt algorithm for the nonlinear minimization (PROC NLIN in SAS). Overall and annual parameters for these regressions are summarized with sample sizes (number of fish measured) in Table 3.9. The annual values of L_∞ are also shown in Figure 3.5. Because little change in L_∞ has occurred over time, the DW decided to use the overall parameters of the growth function as estimated with the commercial reduction fishery data to represent the growth for the fishery portion of the stock assessment model.

Overall and annual regressions of weight (W in grams) on fork length (FL in mm) were conducted based on the natural logarithm transformation:

$$\ln \mathrm{W} = a + b \ln \mathrm{FL}, \quad (2)$$

and corrected for transformation bias (root MSE) when retransformed back to:

$$\mathrm{W} = a(\mathrm{FL})^{b}. \quad (3)$$

Annual estimates for parameters *a* and *b*, along with sample size and root MSE, are summarized in Table 3.9. Note that length and weight for age-0 menhaden is offset to 0.75 since they are not recruited to the fishery until late summer. Given the small difference in growth as estimated on the annual time step, the overall weight-length relationship was used in the stock assessment model. This decision is consistent with using an overall von Bertalanffy growth curve and was supported by the assessment panelists.

Former assessments used the annual von Bertalanffy growth fits and annual weight-length relationships to construct matrices of weight at ages-0 to -4+, representing the average size-at-age of menhaden at the start of the fishing year (i.e., spawning biomass for appropriate ages) and middle of the fishing year (i.e., weight of fish landed). For the current assessment, we selected an overall von Bertalanffy growth curve and an overall weight-length relationship to estimate time-invariant weights-at-age for the fishery in the middle of the year and time–invariant weights-at-age for spawning stock biomass at the beginning of the year (Table 3.10).

3.4 Reproduction

Spawning Times and Locations: In general, Gulf menhaden life history is typical of the cycle followed by most estuarine-dependent species in the Gulf of Mexico. Spawning occurs offshore, and young move into estuarine nursery areas where they spend the early part of their lives (Reid 1955). Maturing adults return to offshore waters to spawn completing the cycle.

Peak spawning periods for Gulf menhaden fluctuate from year to year probably in response to varying environmental conditions (Suttkus 1956). Lewis and Roithmayr (1981) agreed with several earlier researchers (Suttkus and Sundararaj 1961, Combs 1969, Turner 1969, Fore 1970, Christmas and Waller 1975) that spawning in Gulf menhaden generally begins in October and ends about March with a peak between December and February. Combs (1969) and Lewis and Roithmayr (1981) reported that Gulf menhaden were multiple, intermittent spawners with ova being released in batches or fractions over a protracted spawning season. The duration of individual, batch spawns has not been reported. Spawning periods and areas have been substantiated by collections of eggs, larvae, juveniles, and adults with ripe gonads and by the examination of ovarian components.

Actual spawning sites have not been delineated, but data indicate that Gulf menhaden spawn offshore. Turner (1969) presented indirect evidence of spawning areas in the eastern Gulf from collections of menhaden eggs and larvae off Florida. He observed that eggs were collected within the five fathom curve and suggested that spawning takes place nearshore in Florida waters. Combs (1969) did not delineate the geographical areas of Gulf menhaden spawning, but he provided evidence that spawning occurs only in high-salinity waters.

Based on the distribution of eggs, Fore (1970) indicated that spawning of Gulf menhaden occurs mainly over the continental shelf between Sabine Pass, Texas, and Alabama. Greatest concentrations were found in waters between the 4-40 fathom (ca. 8-70 m) contours off Texas and Louisiana and near the Mississippi Delta. Sogard et al. (1987) found high densities of larvae near the Mississippi River supporting the conclusions of Fore (1970) and Christmas and Waller

(1975) that spawning is concentrated near the mouth of the Mississippi River.

Shaw et al. (1985) found highest egg densities between the 10-m and 23-m isobaths and at temperatures of 15-18°C and salinities of 30-36 ppt, respectively. Christmas and Waller (1975) found highest egg densities at temperatures >15°C and salinities >25 ppt.

Maturity Schedule: Lewis and Rothmayr (1981) concluded "that Gulf menhaden spawn for the first time at age-1, after they have completed two seasons of growth, and then continue to spawn each year thereafter." In our model, fish surviving two seasons of growth would become age-2 fish on January 1, our theoretic birth date. The maturity schedule shown in Table 3.10 (age-0 and age-1 immature, and full maturity for age-2 and older) has been used in subsequent stock assessments (Nelson and Ahrenholz 1986, Vaughan 1987, Vaughan et al. 1996, Vaughan et al. 2000, Vaughan et al. 2007). The stock assessment panelists agreed to use the maturity schedule above, but agreed to account for uncertainty in maturity in the Monte Carlo bootstrapping runs.

Fecundity: Batch fecundity estimates have not been calculated, and estimates of egg production have been based on the total number of ova produced by individual fish over an entire season. The number of eggs spawned by a mature female usually increases with the size of the fish. Suttkus and Sundararaj (1961) examined ovaries of female Gulf menhaden at age-1, -2, and -3 and reported that the mean numbers of eggs per fish per age group were 21,960, 68,655, and 122,062, respectively. Lewis and Roithmayr (1981) examined spawning age and egg number per cohort to determine the reproductive potential of Gulf menhaden. Lewis and Roithmayr (1981) provide the following relationship for Gulf menhaden:

$$E = 0.0000516\ L^{3.8775} \quad (4)$$

where L is the length of the individual. Estimates from Eq. (4) are useful in stock assessments because they ascribe a measure of relative reproductive value for larger (and older) fish in the population. Many stock assessments for which such a relationship is unavailable will use female or spawning stock biomass. Figure 3.6 illustrates the difference in perspective between using egg production and spawning stock biomass. Assuming a 1:1 sex ratio, fecundity at age was calculated and summarized in Table 3.10 as determined from the overall von Bertalanffy growth equation parameters.

Vaughan et al. (2007) estimated that total fecundity for the entire stock of spawners in the 1964-2004 data set varied from 7.9 to 164.9 trillion eggs with an average fecundity of approximately 24,450 eggs per mature female, somewhat higher than the average fecundity for age-2 Gulf menhaden (22,100). Fecundity increased with length and age, but since numbers of older fish constitute only a small fraction of the overall spawning population, age-2 fish contributed the bulk of stock fecundity. The relative contribution of eggs from age-2 Gulf menhaden to total population fecundity shows a general decline since early 1990s as obtained from the last Gulf menhaden stock assessment (Figure 3.7).

3.5 Natural Mortality

Age-structured models attempt to reconstruct the fish population and fishing mortality rates by age and year, where total instantaneous mortality rate (*Z*) is the sum of instantaneous rates of fishing (*F*) and natural (*M*) mortality. Historically, natural mortality has been assumed to be constant over ages and years. In many stock assessments, constant values for *M* have been obtained from life history analogies (e.g. maximum age, growth rate parameters, etc.). Because younger fish are thought to be more vulnerable to predation, natural mortality may decline with size or age. Several approaches have been considered to provide size-varying estimates of natural mortality. For purposes of stock assessments, sizes are related to age to provide age-varying estimates of natural mortality.

This section summarizes decisions made by the assessment panel. Several life history based approaches were explored for developing estimates of *M*, as well as tagging estimates of *M*. Often *M* is related to the parameters from the von Bertalanffy growth equation (K, L_∞), or as an inverse function of size-at-age, so consideration of growth of Gulf menhaden is relevant to this section.

3.5.1 Life-History Based Approaches

Age-Constant M Approaches: Several methods are available to determine an age-constant *M* based on life history characteristics, notably maximum age (t_{max}), and von Bertalanffy growth parameters (K, L_∞). Methods using average water temperature were discussed, but selecting a representative temperature over such a large area was not feasible or realistic. Thus, methods based on water temperature were excluded from further consideration.

The maximum age used in calculations was age-4. The "rule of thumb" method has a long history in fisheries science, but its source has been difficult to identify. Hewitt and Hoenig (2005), recently compared the "rule of thumb" approach to that of Hoenig (1983) and noted that the Hoenig (1983) method provides an estimate of *M* only when fishing mortality can be assumed small ($F \sim 0$).

Methods used to determine a constant natural mortality rate over age and time:

Alverson and Carney (1975)	$M = 3K/(\exp(0.38 * t_{max} * K)-1)$
Hoenig (1983; $F \sim 0$)	$M = \exp(1.46 - 1.01 * \ln(t_{max}))$
Jensen (1996)	$M = 1.5 * K$
"Rule of thumb" (Hewitt and Hoenig 2005)	$M = 3/ t_{max}$

Assessment panelists agreed that a constant value for natural mortality over ages for Gulf menhaden was inappropriate because younger age classes are more susceptible as a prey source and likely had higher natural mortality rates.

Age-Varying M Approaches: Several approaches have been developed to provide age-varying, yet time-invariant estimates of *M* (Peterson and Wroblewski 1984, Boudreau and Dickie 1989, Lorenzen 1996, Charnov et al. 2012). All use an inverse relationship between size and natural mortality (*M*). To apply these methods, weight-at-age was calculated for the middle of the calendar year (July 1). Because the middle of the fishing year is approximately July 1, or 6 months into the calendar year, the fraction 1⁄2 a year (6 months), was added to each age in the overall von Bertalanffy growth equation to calculate corresponding length on July 1, then converted to weight using the overall corresponding weight-length relationship.

The method of Peterson and Wroblewski (1984) recently was used to describe natural mortality for young-of-year Atlantic menhaden (Heimbuch et al. 2007), and uses a dry weight as its independent variable. The method of Boudreau and Dickie (1989) has been applied in several assessments, notably for Gulf menhaden in Vaughan et al. (2007). However, the method of Lorenzen (1996) has gained favor in recent years, especially in the SEDAR arena (e.g., SEDAR 10, SEDAR 15, SEDAR 17, SEDAR 18, and SEDAR 24).

Assessment panelists discussed all age-varying approaches, but the Lorenzen method was recognized as the favored approach due to the direct use of wet weight and its use in past SEDAR assessments. The shape of the Lorenzen curve was very similar to the curves estimated using Peterson and Wroblewski and Boudreau and Dickie. The assessment panelists suggested using the Charnov et al. (2012) curve as a sensitivity run in order to explore how a somewhat different shape in *M* at age would influence the overall results.

3.5.2 Estimates Based on Tagging

The only field estimate of natural mortality known for Gulf menhaden was based on tagging data (Ahrenholz 1981). Adult fish were tagged with internal ferro-magnetic tags from 1969 to 1971 (Ahrenholz 1981); later tags were recovered on magnets at commercial reduction plants. The number of tags recovered was adjusted for tag loss. Estimates of *M* varied between 0.69 and 1.61 for the western, central, and eastern Gulf of Mexico after adjusting for a 20% tag loss rate and had a mean *M* of 1.10. Ahrenholz (1981) estimated natural mortality, $M = 1.05$, for Gulf menhaden using tagging data from 1969-1971 for the entire area with upper and lower confidence intervals of 1.09 and 1.01, respectively.

The assessment panelists decided that the estimates of natural mortality from the comprehensive tagging study completed by Ahrenholz (1981) likely gave an indication of the scale of natural mortality for Gulf menhaden in the Gulf of Mexico. These values constitute the best available data for natural mortality of Gulf menhaden. Thus, age varying natural mortality rates, in the form of the Lorenzen curve, were scaled to *M* estimated from the tagging study. The Lorenzen was scaled to the mean *M* of 1.10 estimated from the tagging data across the entire Gulf of Mexico, and this estimate was suggested for the base run (Table 3.11). The vector was scaled to a value of 1.10 at age-2 because age-2 represents the adult age class most likely represented in the tagging study. Each of the scaled vectors was scaled using age-2 as the anchor age. The uncertainty surrounding natural mortality was 0.69-1.61 and was based on the range of *M* estimated for areas of the Gulf of Mexico for 1969 and 1971. These values were suggested as potential sensitivity runs (Table 3.11).

3.5.3 Estimates from Multi-Species VPA (MSVPA-X)

Beginning in 2003, age-varying estimates of *M* from the MSVPA-X have been favored in Atlantic menhaden stock assessments due to the ability of MSVPA to explicitly account for predation effects through the incorporation of diet data (ASMFC 2004). This approach was discussed for Gulf menhaden; however, a MSVPA-X for the northern Gulf of Mexico is not available, nor are estimates of age- and year-varying *M* for Gulf menhaden. The estimates from the Atlantic menhaden MSVPA-X were deemed inappropriate for Gulf menhaden because of the difference between longevity of the two species and the difference in ecosystems between the Gulf of Mexico and Atlantic Ocean.

3.6 Environmental Factors

Environmental factors that affect recruitment are generally viewed as density independent. These factors include physical processes, for example transport mechanisms, water temperature, dissolved oxygen, freshwater inflow, and nutrient loadings. Biological factors, such as amount of food and competition for food, or predation by higher trophic levels, which control survival and growth of young-of-the-year menhaden prior to recruitment to the fishery, can be either density independent or density dependent. Environmental factors can also affect the fishing process itself. We provide a brief description of two additional topics in this section: 1) a recurring hypoxic zone that forms along the northern Gulf of Mexico and 2) the British Petroleum (BP) Deep Water Horizon (DWH) disaster in 2010. Environmental factors influence population dynamics; however, these factors are often difficult to quantify and therefore, were not included in the current stock assessment. Those factors that could be quantified were not included in the assessment analyses because they were low priority when compared to other uncertainties surrounding the assessment.

3.6.1 Physical Processes

Nelson et al. (1977) developed a Ricker spawner-recruit model relating coastwide spawning stock of Atlantic menhaden as number of eggs produced to subsequent recruits. These authors further developed a recruit survival index from the deviations around the Ricker curve, which they then regressed on several environmental parameters. Most significant was zonal Ekman transport, acting as a mechanism for transporting larval menhaden from offshore spawning areas to inshore nursery grounds. One of the authors, W. Schaaf of the Beaufort Laboratory, later retested the model in the mid-1980s [referred to in Myers (1998)]. Because one value (the 1958 year class) had high statistical leverage in the original analysis, the addition of more years of data diluted the significance of the metric for Ekman transport, thus reducing its statistical significance. Such indices, while valuable in exploratory analysis, often fail in long time series. For example, Myers (1998) reviewed environment-recruitment correlations, finding that “the proportion of published correlations that have been verified upon retest is low.”

Stone (1976) conducted a series of stepwise regressions of Gulf menhaden catch and effort related to a wide range of environmental data (air temperature, water temperature, rainfall, tides, and wind speed and direction). Not unexpectedly, several significant correlations were found including minimum and mean air temperature, maximum water temperature, and wind direction at several locations, resulting in an R^2 value of 0.86. Subsequently, Guillory et al. (1983) refined much of this work to forecast Gulf menhaden harvest in Louisiana. Environmental data sources for these forecasts are described in greater detail in the next subsection.

Environmental Data Sources for Louisiana Harvest Forecasts: Environmental data were obtained from several sites and sources. January water temperature at Grand Isle (TEMP°C) and March salinity (ppt) were derived from a LDWF constant recorder on Grand Terre Island. Coastal rainfall data were procured from NOAA weather summaries. Mississippi River discharge data were provided by the U. S. Army Corps of Engineers. Environmental conditions during the winters of 2008-2009 and 2009-2010 influenced year class strength of both the 2009 (age-2s in 2011) and 2010 (age-1s in 2011) year classes.

The mean 2010 January temperature (TEMP) of 12.4°C was below the long-term mean of 13.6°C. The 2009 January temperature was 15.3°C, which was above the long-term average. The two-year 2009-2010 running mean of 13.8°C was near the long-term mean of 13.5°C. The Mississippi River discharge in March 2010 of 688,970 cubic feet per second (cfs) was near the long-term mean of 696,000 cfs. The 2009 river discharge of 571,645 cfs was below average. The cumulative January-March 2010 rainfall in coastal Louisiana of 12.9 inches was lower than the long-term mean of 14.8 inches. Cumulative rainfall for 2009 was 13.9 inches. Grand Isle March salinity was 19.2 ppt in 2010 and 15.8 ppt in 2009. The long-term mean is 20.6 ppt.

Overall, the winter of 2009-2010 had below average water temperature, average salinity, below average rainfall, and average river discharge. The ‘cold, dry’ winter is characterized not only by low temperatures and low rainfall rates but also by low tide levels, low Mississippi River discharge, high salinities, low wind speeds and low incidence of south winds. Besides high temperatures and high rainfall rates, the ‘warm, wet’ winter is typified by high tide levels, high Mississippi River discharges, low salinities, high wind speeds and high incidence of south winds. ‘Cold, dry’ winters are associated with good recruitment and ‘warm, wet’ winters with poor recruitment. The winter of 2009-2010 was a cold winter characterized by cold temperatures and average salinities. These environmental data sets are available for consideration in this Gulf menhaden stock assessment.

Juvenile abundance data sources are also used in the Louisiana Harvest Forecast. These are based on the LDWF 16-foot trawl samples described in the Section 5.3.2. Because the Louisiana Harvest Forecast predicts harvests of menhaden by the reduction fishery, it also uses fishing effort data as well. Abbreviations for units of measurement, environmental factors, juvenile indices and commercial harvest parameters are summarized in Table 3.12 while several predictive models used for forecasting Louisiana menhaden catches are summarized in Table 3.13.

Other Environmental Factors: Govoni (1997) demonstrated an association between the discharge of the Mississippi and Atchafalaya Rivers and Gulf menhaden recruitment. In particular, he found an inverse association between Mississippi River discharge (Figure 3.8) and estimates of half-year old recruits, using recruitment data from Vaughan et al. (1996). Vaughan et al. (2000) updated this relationship with regression analysis. Vaughan et al. (2007) revisited this relationship with additional years of data through 2004. They found that the inverse relationship still held. In addition, they reframed this relationship to produce a 1-yr ahead prediction model for forecasting recruitment to age-1 from Mississippi River flow for consideration in fishery management. Finally, they revisited the stock assessment model of Vaughan et al. (2007), and they demonstrated improved model performance when information on annual river flow was incorporated.

El Niño [also referred to as El Niño Southern Oscillation (ENSO)] is a change in the eastern Pacific's atmospheric system, which contributes to major changes in global weather (Figure 3.9). El Niño is characterized by a dwindling or sometimes reversal of equatorial trade winds causing unusually warm ocean temperatures along and on both sides of the equator in the central and eastern Pacific. The change in ocean temperature affects global atmosphere and causes unusual weather patterns around the world. In the southeastern United States, winter droughts are sometimes followed by summer floods. These conditions may have an impact on freshwater inflow patterns into the Gulf of Mexico and could ultimately affect menhaden distribution, recruitment success, and can influence oil yield from the reduction fishery. In many parts of the world, fish migration has been attributed to El Niño (Arntz and Tarazona 1990, Bakun and Broad 2003).

The effects of La Niña are nearly opposite that of El Niño and is characterized by a warmer than normal winter in the southeast United States. This provides favorable conditions for a strong hurricane season. Likewise, these abnormal conditions may influence fish migration and occurrence in the Gulf of Mexico (Lewis et al. 2011).

Historically, the menhaden fishing season frequently reflects the tropical activities during a particular year (Figure 3.10). For example, in years of minimal tropical activity, fishing effort and landings generally increased. The opposite was true in years of high tropical activity. Landings were low in 1998 due to the high number of storms that entered the Gulf and reduced the number of fishable days. In 2005, the high frequency of storms and the direct impacts to the fleet and fishery from hurricanes Katrina and Rita virtually eliminated fishing after August. Effort remained low as the reduction plants were put back on-line and the vessels, in some cases, were returned to the water. Other factors such as visibility for spotter planes can affect the ability of the fleet to fish and the 'dead zone' (Section 3.6.3) can move fish into areas inaccessible to the fleet. It should be noted that many of these environmental parameters and events described in this section are probably related with each other, possibly mediated through such processes as El Niño and La Niña events.

3.6.2 Biological Processes

Predation is a process that potentially plays a major role in controlling recruitment level. Ahrenholz et al. (1991) noted that all life stages of menhaden are potential prey for a variety of predators, and describe in general terms how some of these predators may impact life stages of menhaden. Juvenile and adult menhaden are prey to piscivorous fishes, seabirds, and marine mammals. Food and nutrition during the larval and juvenile stages are dependent on amounts and types of available prey and, as such, may serve to control menhaden recruitment. As larvae, menhaden eat zooplankton, which are captured as individual particles. As juveniles and adults, menhaden are filter-feeders, consuming phytoplankton and zooplankton. Consequently, variability in plankton concentrations in the coastal ocean could affect survival and growth, and be a significant factor controlling or regulating recruitment.

3.6.3 Hypoxic Zone

Extensive areas of low DO (<2 ppm) occur in offshore waters along the Louisiana and Texas coasts during summer (Rabalais et al. 1999; Figure 3.11). Increased levels of nutrient influx from freshwater sources coupled with high summer water temperatures, strong salinity-based stratification, and periods of reduced mixing appear to contribute to what is now referred to in the popular press as the 'dead zone' (Justic et al. 1993). Most life history stages of Gulf menhaden, from eggs to adults, occur inshore of areas where historically the hypoxic zone 'sets-up' during mid-summer. Gulf menhaden, although susceptible to low DO conditions, probably move out of hypoxic areas, resulting in displacement, rather than mortality. After analyzing menhaden logbook data, Smith (2000) suggested that during some years exceptionally low catches of Gulf menhaden off the central Louisiana coast may have been a result of hypoxic waters impinging upon near shore waters in mid-summer. He further speculated that the hypoxic zone might force Gulf menhaden into narrower corridors of more normoxic waters near shore where they could be more vulnerable to the fishery.

3.6.4 BP Deep Water Horizon Oil Spill in 2010

The 2010 Gulf menhaden fishing season opened on Monday, April 19th, 2010. The BP DWH oil rig exploded and sank on Tuesday, April 20th, 2010 (Figure 3.12). Beginning about two weeks after the DWH disaster, the Gulf menhaden fishery experienced unprecedented closures of long-established fishing grounds because of the subsequent oil spill. Over the course of the next three months, the fishery was gradually restricted to fish in a narrow corridor of state territorial sea (0-3 miles from the shore line), west of about Morgan City, Louisiana. In mid-summer landings were down 30-40% from landings in recent years. By August many of the restricted areas had re-opened to commercial fishing, and the Gulf menhaden fleet returned to fish traditional areas.

During the last week of April (second week of the DWH disaster), the winds in the Gulf of Mexico shifted from the south and oil from the spill began moving shoreward. With the potential for the Port of Pascagoula to close due to the threatening oil, menhaden vessels from the fish factory at Moss Point left Mississippi about April 28th, 2010 for Abbeville, Louisiana. In early May, the NMFS closed the EEZ east of the Mississippi River and the LDWF closed Breton and Chandeleur sounds east of the River, although Mississippi Sound remained open to commercial fishing. In mid-May, the LDWF closed state waters west of the Mississippi River to about Point Au Fer (in the vicinity of Morgan City); thus, most of the menhaden fleet fished west of Morgan City during the latter half of May, although a few of the vessels from Empire fished in Mississippi Sound. Catches in May were best adjacent to the factory at Abbeville, Louisiana (Table 3.14).

In early June, vessels from Mississippi began moving back to the factory at Moss Point. For about two weeks in mid-June, LDWF re-opened Breton and Chandeleur sounds, and vessels from Empire and Moss Point made good catches there. Through June, Gulf menhaden landings were down 14% from 2009, and down 17% from the previous 5-yr average, for equivalent time.

By early July, Mississippi Department of Marine Resources (MDMR) closed Mississippi Sound to commercial fishing and LDWF re-closed waters east of the Mississippi River. Moreover, the NMFS extended the EEZ closure for commercial fishing to almost the Texas border. Hence, during July menhaden fishing was restricted to west of about Morgan City and in Louisiana state waters. Total landings of 8,340 mt in July were the lowest monthly total on record in the NMFS Beaufort data base. What few catches were made in July came from the Cameron area. Through July, Gulf menhaden landings were down 39% from 2009, and down 41% from the previous 5-yr average, for equivalent time.

Restricted fishing areas were gradually re-opened in early August, as MDMR re-opened Mississippi Sound and LDWF re-opened east of the Mississippi River. By mid-August, LDWF re-opened most areas west of the River. Fair landings occurred at the ports of Cameron, Abbeville, and Empire. Notwithstanding, cumulative landings for the 2010 fishing season still lagged recent years. Through August, Gulf menhaden landings were down 32% from 2009, and down 35% from the previous 5-yr average, for equivalent time.

In September, the NMFS re-opened the EEZ west of the Mississippi River to about the Morgan City area, but poor weather hampered fishing operations through mid-month. Fair weather prevailed throughout October, and landings were exceptionally good at all four fish factories. Much of the cumulative landings deficit from mid-summer was narrowed in October as final landings for the 2010 Gulf menhaden fishery amounted to 379,727 mt; this was down 17% from 2009, and down 15% from the previous 5-yr average.

Table 3.1 Ageing error matrix from a scale to otolith comparison of ages.

	0	1	2	3	4	5	6
0	1.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	1.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.11	0.78	0.11	0.00	0.00	0.00
3	0.00	0.00	0.16	0.68	0.16	0.00	0.00
4	0.00	0.00	0.00	0.17	0.65	0.17	0.00
5	0.00	0.00	0.00	0.00	0.18	0.64	0.18
6	0.00	0.00	0.00	0.00	0.00	0.18	0.82

Table 3.2 Ageing error matrix from a scale to scale comparison of ages.

	0	1	2	3	4	5	6
0	1.00	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	1.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.08	0.85	0.08	0.00	0.00	0.00
3	0.00	0.00	0.14	0.71	0.14	0.00	0.00
4	0.00	0.00	0.00	0.16	0.67	0.16	0.00
5	0.00	0.00	0.00	0.00	0.17	0.65	0.17
6	0.00	0.00	0.00	0.00	0.00	0.17	0.82

Table 3.3 Number of Gulf menhaden by age and 10-mm fork length intervals, 1988-2011. Intervals represent their mid-point.

Fork Length (mm)	**Age**							
	0	**1**	**2**	**3**	**4**	**5**	**6**	**Total**
55	0	0	0	0	0	0	0	0
65	0	0	0	0	0	0	0	0
75	0	1	0	0	0	0	0	1
85	0	10	0	0	0	0	0	10
95	2	105	0	0	0	0	0	107
105	19	408	1	0	0	0	0	428
115	25	1,163	2	0	0	0	0	1,190
125	6	3,164	16	1	1	0	0	3,188
135	4	8,980	17	0	0	0	0	9,001
145	1	20,701	62	0	0	0	0	20,764
155	0	30,652	795	2	0	0	0	31,449
165	0	25,019	11,928	10	0	0	0	36,957
175	0	9,595	30,784	94	2	0	0	40,475
185	0	1,403	35,449	733	7	0	0	37,592
195	0	167	20,039	3,929	77	0	0	24,212
205	0	6	5,455	5,410	414	7	0	11,292
215	0	2	711	2,058	442	24	0	3,237
225	0	0	92	301	197	23	2	615
235	0	0	14	29	28	7	1	79
245	0	0	3	7	2	0	0	12
255	0	0	1	1	2	1	0	25
265	0	0	0	0	1	0	0	1
275	0	0	0	0	0	0	0	0
285	0	0	0	0	0	0	0	0
295	0	0	0	0	0	0	0	0
305	0	0	0	0	0	0	0	0
Total	57	101,376	105,369	12,575	1,173	62	3	220,615
Percent	0.03%	45.95%	47.76%	5.70%	0.53%	0.03%	0.00%	100.00%

Table 3.4 Statistics for Gulf menhaden fork length at age, 1988 – 2011.

Age	**N**	**Obs FL (mm)**	**SD (mm)**	**CV = SD/P**	**Pred FL (mm)**
0.5	57	113.4	10.0	0.083	121
1	101,376	153.5	13.7	0.090	152
2	105,369	181.9	10.9	0.060	181
3	12,575	201.8	8.6	0.043	200
4	1,173	211.1	9.7	0.046	213
5	62	219.3	8.4	0.038	222
6	2	228.7	4.0	0.018	228
Sum/ Average	220,615		9.32	0.050	

Table 3.5 Weighted mean fork length (mm) at age, with weightings based on annual catch in numbers by season and area. Shaded areas sampled only 1 fish.

Year	0	1	2	3	4	5	6
1964	122.4	154.7	184.9	201.7	213.5		
1965	113.0	148.5	183.9	205.7	237.1		
1966	116.0	154.3	182.4	203.3	227.0		
1967	98.8	151.6	182.1	204.1			
1968	109.4	155.9	183.8	218.2	235.0		
1969	122.8	150.0	186.3	208.1			
1970	105.9	158.7	181.2	207.8			
1971	110.9	156.2	188.7	203.2	221.4		
1972	108.1	161.1	187.7	210.6	212.9		
1973	119.5	164.8	188.5	214.2	240.4		
1974	102.0	163.1	200.3	214.6			
1975	119.6	162.9	196.3	219.6	258.0		
1976		154.7	192.1	221.7			
1977		146.4	182.3	210.7	237.6		
1978		154.5	183.1	208.8	230.8		
1979		157.7	188.0	204.1	213.7	223.0	
1980	91.8	149.3	187.4	206.7	216.9	227.6	
1981		147.1	178.1	202.2	214.4	223.0	229.4
1982		149.9	183.6	201.2	212.8	229.3	240.1
1983		154.2	185.5	203.5	215.7	224.5	
1984		148.8	183.7	204.5	214.3	227.0	
1985		148.9	181.0	206.2	213.9		
1986		139.8	175.7	198.8	214.4	216.9	
1987		146.3	173.1	195.8	210.1		
1988		144.2	174.6	200.1	205.8		
1989		147.8	176.7	199.4	210.5		
1990		148.6	182.7	201.9	209.1	223.0	225.0
1991		160.3	179.9	204.1	216.2	218.6	
1992		155.0	184.3	202.6	211.7	218.3	228.0
1993	118.8	156.3	185.0	204.1	213.4	217.5	233.0
1994		155.7	183.5	205.6	216.0	224.6	
1995		158.3	183.7	207.3	210.6	223.0	
1996		154.6	182.2	205.4	215.9	225.4	
1997		155.0	183.7	203.6	212.0	217.8	
1998		154.6	180.0	203.7	211.4	217.6	
1999		162.2	185.8	202.6	214.6		
2000		156.2	181.8	202.2	210.0	218.5	
2001		168.2	187.7	205.9	213.1	223.0	
2002		158.9	184.5	204.0	212.8		
2003		149.5	177.9	200.9	212.0		
2004		149.8	177.6	194.6	205.5		
2005	128.0	151.2	176.7	196.3	204.0		
2006		152.0	177.1	192.3	200.3		
2007		152.5	177.0	195.5	205.8	208.0	
2008		158.4	181.9	196.9	203.2		
2009		163.1	183.6	200.3	204.5	221.0	
2010		153.6	180.9	197.0	202.9	209.0	
2011	107.5	151.6	181.2	199.3	205.2	215.4	

Table 3.6 Weighted mean weight (g) at age, with weightings based on annual catch in numbers by season and area. Shaded areas sampled only 1 fish.

Year	0	1	2	3	4	5	6
1964	34.2	71.3	130.7	178.9	213.2		
1965	29.0	66.4	134.3	192.0	285.9		
1966	30.7	76.3	130.6	176.4	229.0		
1967	18.2	68.3	124.3	172.6			
1968	25.3	78.0	131.1	218.4	289.0		
1969	35.8	67.2	136.0	197.6			
1970	26.8	80.6	124.4	186.7			
1971	26.7	78.2	142.6	181.1	224.1		
1972	23.6	83.0	137.7	186.8	191.1		
1973	34.3	97.6	152.1	219.2	299.6		
1974	26.0	89.4	167.0	203.1			
1975	32.1	88.3	157.1	215.4	359.0		
1976		74.6	138.6	199.8			
1977		60.2	116.6	177.0	243.2		
1978		73.6	125.3	189.8	251.2		
1979		75.3	133.4	169.7	188.4	213.5	
1980	26.7	63.4	137.2	184.3	213.4	264.3	
1981		65.8	116.4	166.6	196.6	218.4	229.8
1982		67.0	129.2	168.2	195.2	234.0	270.4
1983		73.2	135.1	178.6	207.9	224.3	
1984		67.0	129.9	180.2	209.3	217.0	
1985		63.8	117.1	172.3	189.6		
1986		56.8	114.0	160.9	179.5	215.9	
1987		62.2	105.0	151.0	185.0		
1988		61.0	108.3	156.5	171.1		
1989		66.5	115.5	162.9	183.0		
1990		70.8	133.0	183.6	197.0	212.0	252.0
1991		86.2	126.4	185.2	224.3	212.5	
1992		83.1	135.2	172.9	195.6	216.6	218.0
1993	29.8	85.2	141.1	184.3	211.9	219.6	255.0
1994		76.1	125.3	173.6	198.4	219.0	
1995		84.6	136.2	190.1	195.5	227.0	
1996		73.9	125.8	181.7	208.8	226.3	
1997		75.3	128.7	174.2	198.4	223.9	
1998		75.6	120.9	169.4	187.6	197.8	
1999		87.7	135.6	175.0	200.5		
2000		70.2	112.9	149.8	164.9	186.4	
2001		100.8	144.5	188.0	205.4	235.3	
2002		78.5	126.1	169.1	189.0		
2003		65.0	111.1	152.3	176.7		
2004		67.7	117.2	152.4	176.1		
2005	42.0	69.6	115.4	156.2	178.6		
2006		68.4	112.5	143.5	160.2		
2007		72.5	117.0	157.5	185.4	176.0	
2008		79.0	125.9	161.9	170.7		
2009		86.2	123.1	156.3	168.2	180.0	
2010		73.6	121.1	153.9	168.6	187.0	
2011	21.9	66.1	116.8	155.6	169.3	184.4	

Table 3.7 Correlation analysis (Pearson correlation coefficients) of 1964-2010 Gulf menhaden weighted mean fork length-at-age (L1-L4) and weighted mean weight-at-age (W1-W4). Cohort correlations are lagged to line up lengths and weight by year class, while annual (year) correlations are unlagged.

Correlations by fishing year

	L2	L3	L4
L1	0.632	0.398	0.046
L2		0.744	0.426
L3			0.755

	W2	W3	W4
W1	0.699	0.516	0.251
W2		0.802	0.577
W3			0.836

Correlations by cohort

	L2	L3	L4
L1	0.654	0.431	0.123
L2		0.778	0.570
L3			0.742

	W2	W3	W4
W1	0.521	0.288	0.048
W2		0.561	0.361
W3			0.506

Table 3.8 Results of length-length regressions from historical and recently collected data for Gulf menhaden (Schueller et al. 2012).

Source	Relationship	Years	Gears	FL (mm)	SL (mm)	TL (mm)	N	R^2	Intercept	Slope
Alabama	TL = f(SL)	2011	Gill net, Trawl, BPL	-	21-201	25-258	90	0.9994	-3.270	1.299
Louisiana	TL = f(SL)	2011	Gill net, Trawl, Seine	-	23-192	27-247	409	0.9962	-1.389	1.298
Mississippi	TL = f(SL)	2011	Gill net, Trawl, BPL	-	19-246	23-296	235	0.9983	1.049	1.237
Texas	TL = f(SL)	1975-1978 & 2011	Gill net, push net, bag seine, trawl, rotenone & fish trap	-	18-315	23-390	9,158	0.9903	2.993	1.261
Overall	**TL = f(SL)**	**2010-2011**		-	**18-315**	**23-390**	**9,892**	**0.9927**	**1.739**	**1.267**
Alabama	FL = f(SL)	2011	Gill net, Trawl, BPL	23-222	21-201	-	90	0.9996	-0.956	1.109
Louisiana	FL = f(SL)	2011	Gill net, Trawl, Seine	26-206	23-192	-	409	0.9964	0.378	1.088
Mississippi	FL = f(SL)	2011	Gill net, Trawl, BPL	21.5-255	19-246	-	235	0.9984	3.547	1.046
Omega Protein	FL = f(SL)	2010	Purse Seine	115-201	103-184	-	195	0.9657	1.768	1.107
Texas	FL = f(SL)	2011	Seine, Trawl				191	0.9987	1.814	1.045
Overall	**FL = f(SL)**	**2010-2011**		**21.5-255**	**19-246**	**-**	**1,120**	**0.9968**	**0.110**	**1.094**
Alabama	FL = f(TL)	2011	Gill net, Trawl, BPL	23-222	-	25-258	90	0.9996	1.869	0.854
Louisiana	FL = f(TL)	2011	Gill net, Trawl, Seine	26-206	-	27-247	410	0.9974	1.571	0.838
Mississippi	FL = f(TL)	2011	Gill net, Trawl, BPL	21.5-255	-	23-296	236	0.9990	2.710	0.846
Texas	FL = f(TL)	2011	Seine, Trawl				191	0.9986	1.506	0.840
Overall	**FL = f(TL)**	**2010-2011**		**21.5-255**	**-**	**23-297**	**927**	**0.9987**	**1.191**	**0.850**

Table 3.9 Overall (1977-2011) and annual estimated parameters obtained from weight-length and length at age regressions from biological sampling of Gulf menhaden, 1964-2011.

Year	Weight-Length				Von Bertalanffy Curve			
	n	a	b	RMSE	n	L_∞	K	t_0
1964	12,376	-12.70	3.37	0.010	12,260	236.9	0.429	-0.958
1965	15,673	-12.48	3.33	0.008	15,185	427.8	0.128	-1.790
1966	12,705	-11.59	3.16	0.007	12,429	284.2	0.269	-1.303
1967	14,401	-11.27	3.09	0.008	14,065	234.2	0.506	-0.516
1968	15,831	-11.67	3.17	0.008	15,273	284.1	0.316	-0.911
1969	15,044	-11.37	3.11	0.009	14,764	426.4	0.121	-2.148
1970	10,531	-11.96	3.22	0.006	10,402	231.3	0.537	-0.535
1971	7,848	-12.19	3.27	0.008	7,654	239.5	0.474	-0.691
1972	9,975	-11.76	3.18	0.008	9,886	222.5	0.674	-0.372
1973	8,954	-11.66	3.18	0.008	8,953	343.2	0.198	-1.592
1974	10,085	-10.79	3.00	0.010	10,086	227.9	0.800	-0.066
1975	9,528	-11.56	3.14	0.008	9,527	565.7	0.092	-2.022
1976	13,532	-10.79	2.99	0.008	13,389	335.8	0.233	-1.102
1977	14,910	-11.38	3.10	0.006	14,897	374.7	0.167	-1.448
1978	12,983	-12.05	3.24	0.006	12,944	409.8	0.122	-2.336
1979	11,618	-12.24	3.27	0.005	11,121	243.4	0.392	-1.149
1980	9,948	-13.05	3.43	0.023	9,883	234.3	0.606	-0.095
1981	10,405	-11.68	3.17	0.010	10,273	240.1	0.435	-0.636
1982	10,678	-12.67	3.36	0.011	10,341	282.4	0.230	-1.845
1983	14,837	-12.26	3.28	0.008	14,523	232.8	0.509	-0.572
1984	15,955	-11.91	3.22	0.007	15,936	232.2	0.542	-0.336
1985	13,227	-11.53	3.13	0.008	13,225	232.0	0.533	-0.391
1986	16,495	-11.78	3.19	0.006	16,494	235.5	0.480	-0.339
1987	16,458	-11.71	3.17	0.006	16,458	258.7	0.285	-1.370
1988	12,403	-11.36	3.11	0.011	12,402	222.5	0.552	-0.345
1989	13,951	-11.82	3.20	0.007	13,950	247.8	0.347	-1.051
1990	11,500	-11.71	3.18	0.012	11,456	232.3	0.481	-0.600
1991	11,637	-12.18	3.27	0.008	11,378	239.6	0.383	-1.269
1992	15,231	-10.41	2.93	0.010	14,214	234.1	0.443	-0.920
1993	15,347	-11.31	3.11	0.012	14,576	243.5	0.364	-1.280
1994	16,785	-10.98	3.03	0.007	16,062	238.5	0.456	-0.741
1995	14,275	-12.04	3.25	0.008	13,489	238.3	0.416	-1.060
1996	13,052	-12.58	3.34	0.018	12,115	243.8	0.393	-1.004
1997	10,634	-11.64	3.16	0.006	9,923	224.7	0.568	-0.481
1998	10,034	-10.97	3.03	0.005	9,043	230.4	0.466	-0.834
1999	11,774	-11.70	3.18	0.006	10,641	242.4	0.354	-1.565
2000	9,588	-10.03	2.83	0.012	8,383	230.1	0.466	-0.851
2001	7,351	-10.90	3.03	0.009	6,222	247.7	0.301	-2.184
2002	6,611	-11.34	3.10	0.005	5,597	227.3	0.520	-0.736
2003	9,239	-11.14	3.06	0.005	7,839	238.1	0.420	-0.795
2004	7,655	-11.85	3.20	0.006	6,644	224.0	0.450	-0.908
2005	7,202	-11.04	3.05	0.009	6,206	244.9	0.278	-2.042
2006	5,763	-11.36	3.11	0.006	4,698	210.7	0.577	-0.631
2007	5,151	-11.78	3.19	0.006	3,989	218.5	0.506	-0.829
2008	5,877	-12.26	3.28	0.006	4,663	210.6	0.644	-0.643
2009	7,419	-10.87	3.01	0.006	6,193	251.8	0.253	-2.569
2010	4,530	-11.07	3.05	0.007	3,678	212.2	0.689	-0.313
2011	8,306	-11.91	3.20	0.006	7,254	234.1	0.401	-1.101
Overall	388,831	-11.72	3.18	0.010	366,710	239.5	0.400	-1.013

Table 3.10 Estimated fork lengths and weights for Gulf menhaden calculated for the start of the year (January 1) and middle of the fishing year based on the overall von Bertalanffy and weight-length equations for the years 1977-2011, as well as, female maturity at age from Lewis and Roithmayr (1981) and fecundity at age.

Year	FL (mm) start	Weight (g) start	FL (mm) middle	Weight (g) middle	Maturity (%)	Fecundity (ova)
0	-	-	121.2	34.2	0	0
1	132.4	45.3	151.8	69.9	0	8,728
2	167.7	95.9	180.7	121.6	100	21,814
3	191.4	145.9	200.1	168.1	100	36,385
4	207.3	187.9	213.1	205.3	100	49,542
5	217.9	220.3	221.8	233.1	100	60,146
6	225.0	244.0	227.6	253.1	100	68,139

Note: FL and Weight at the start of the year were later modified by the assessment panelists to reflect a population L_∞ of 250mm FL.

Table 3.11 Lorenzen age-specific estimates of M scaled to the mean, upper, and lower range of estimates of M from the tagging study throughout the Gulf of Mexico by Ahrenholz (1981) and as determined by the assessment panelists. The assessment panelists suggested the vector scaled to the mean as the M for the base run, and the vectors scaled to the lower and upper values as sensitivity analyses runs.

Age	Scaled to mean value	Scaled to lower value	Scaled to upper value
0	1.62	1.02	2.37
1	1.30	0.82	1.91
2	1.10	0.69	1.61
3	1.00	0.63	1.46
4	0.94	0.59	1.37
5	0.90	0.57	1.32
6	0.88	0.55	1.29

Table 3.12 Abbreviations for units of measurement, environmental factors, juvenile indices, and commercial harvest parameters.

Identification	Abbreviation
Metric ton	MT
Vessel-ton-week	VTW
In year j (or 2006)	(j)
In year j-1 (or 2005)	(j-1)
Overall Louisiana harvest by weight (1,000 MT)	HARWT
Overall Louisiana harvest by number (1,000,000 fish)	HARNO
Mean Jan Grand Isle water temperature (centigrade)	TEMP
Mean Mar Grand Isle salinity (ppt)	SAL
Percent frequency of 16-ft trawl samples with more with more than 50 menhaden, Jan-Jul	F50
Percent frequency of 16-ft trawl samples with more than 10 menhaden, Jan-Jul	F10
Two year running mean [(j-1)+(j-2)]/2	2
Calcasieu	CAL

Table 3.13 Predictive models used for forecasting Louisiana menhaden catches. Total harvest by number in 1,000,000 fish, total harvest by weight (x 1,000 mt), and effort (x 1,000 vtw).

Total harvest by number (HARNO)

1. HARNO(j) = -2629.9 + 15.27 Effort(j) + 121.84 F50_2 CAL
   [$R^2 = 0.78$ ($p>0.0001$)]
2. HARNO(j) = 4815.0 + 13.83 Effort(j) – 349.6 TEMP_2
   [$R^2 = 0.73$ ($p>0.0001$)]
3. HARNO(j) = -3002.6 + 17.24 Effort(j) + 163.38 F10_2
   [$R^2 = 0.72$ ($p>0.0001$)]

Total harvest by weight (HARWT)

1. HARWT(j) = -76.1 + 0.95 Effort(j) + 12.40 F50_2 CAL
   [$R^2 = 0.76$ ($p>0.0001$)]
2. HARWT(j) = 284.7 + 0.87 Effort(j) – 9.21 TEMP_2
   [$R^2 = 0.45$ ($p>0.0024$)]
3. HARWT(j) = -128.6 +1.30 Effort(j) + 13.11 F10_2
   [$R^2 = 0.45$ ($p>0.0024$)]

Table 3.14 Cumulative monthly purse-seine landings of Gulf menhaden for reduction in 2010 (year of the BP DWH disaster), and percent change, as compared to 2009 and the previous five-year average.

Total landings through	Cumulative 2010 (*t*)	Cumulative 2009 (*t*)	Cumulative previous 5-yr mean (*t*)	Change from 2009	Change from previous 5-yr mean
Apr	20,790	9,775	21,998	+113%	-5%
May	84,587	86,553	90,009	-2%	-6%
Jun	154,242	179,151	185,827	-14%	-17%
Jul	162,472	264,759	274,026	-39%	-41%
Aug	236,465	347,495	360,969	-32%	-35%
Sep	290,880	431,060	417,079	-33%	-30%
Oct	379,727	457,457	446,982	-17%	-15%

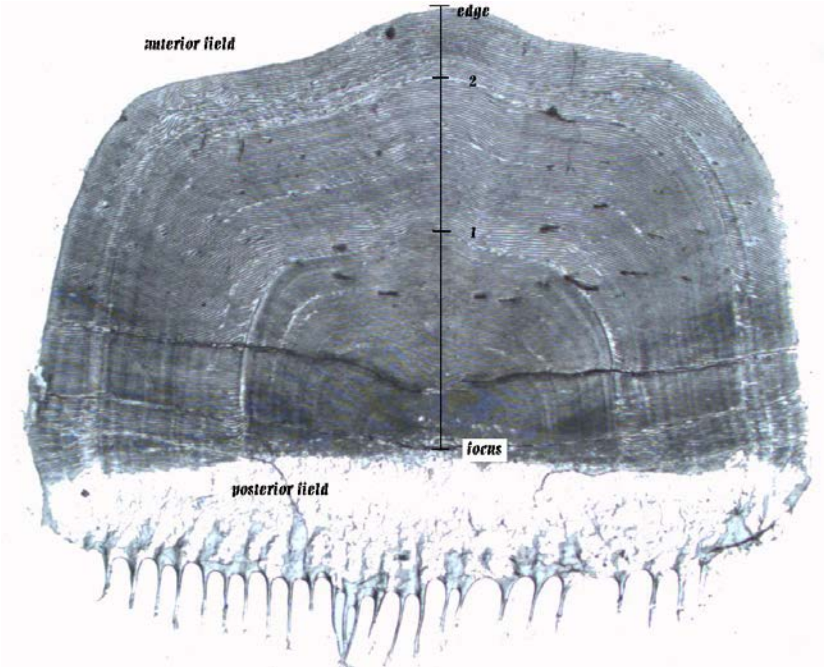
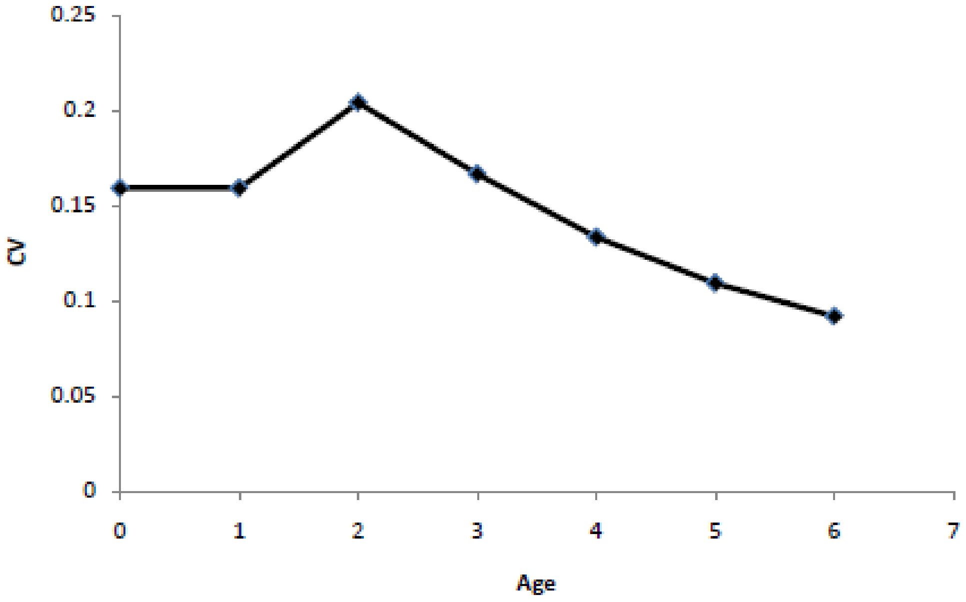


Figure 3.1 Scale sample from age-2 Gulf menhaden.



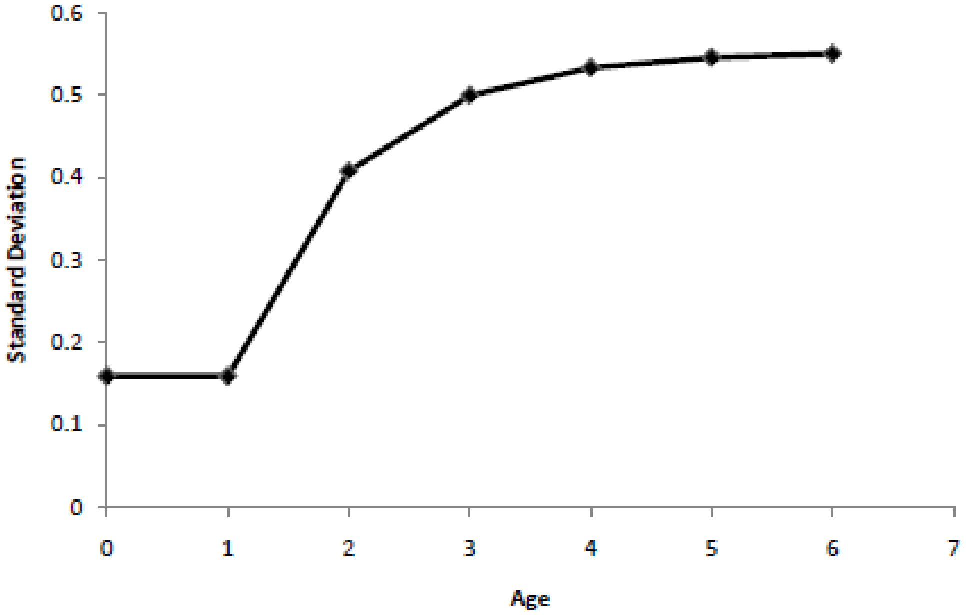


Figure 3.2 The estimated coefficient of variation (CV) and standard deviation for Gulf menhaden using data from paired age estimates of scales and otoliths and the program AGEMAT.

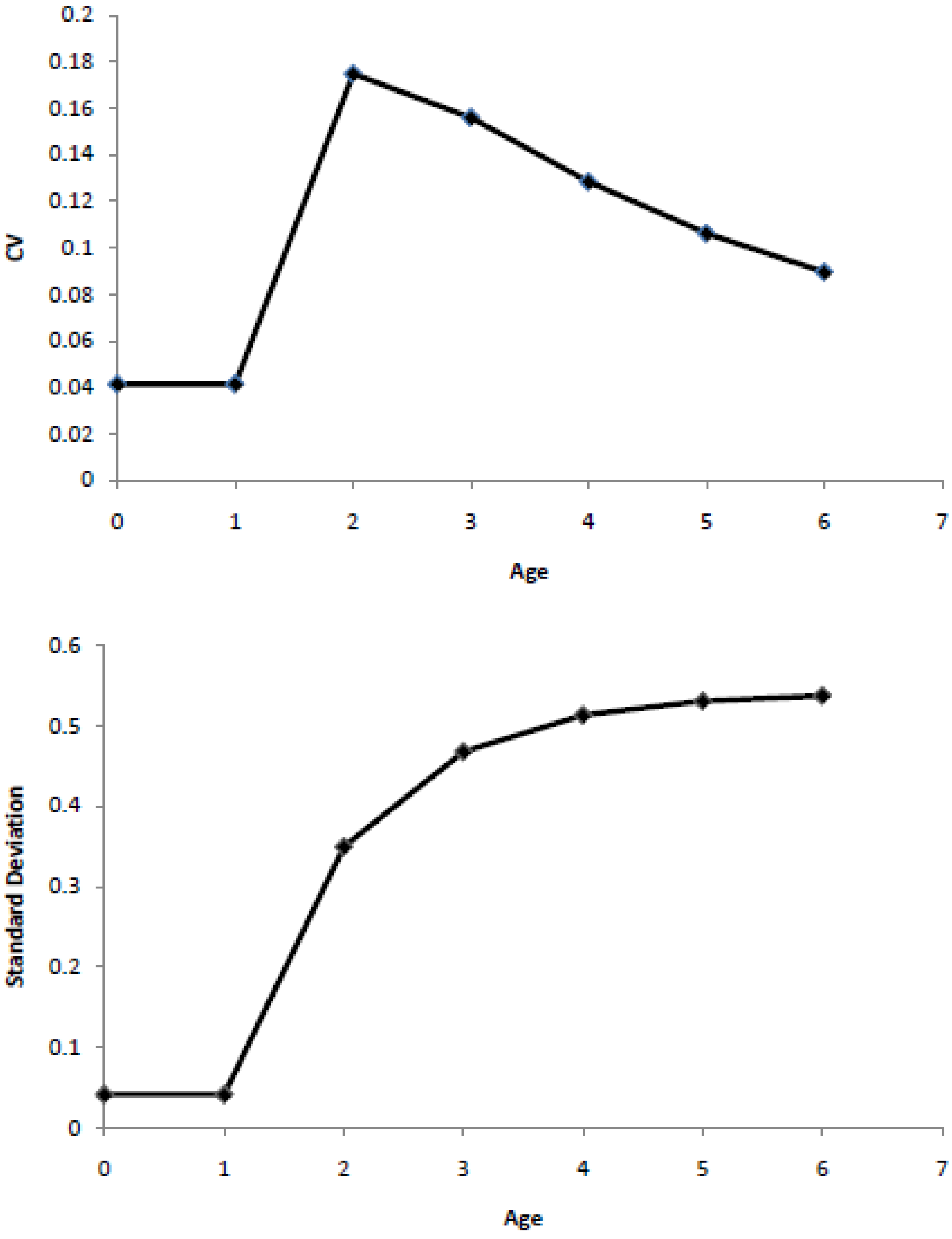


Figure 3.3 The estimated coefficient of variation (CV) and standard deviation for Gulf menhaden using data from paired age estimates of scales and the program AGEMAT.

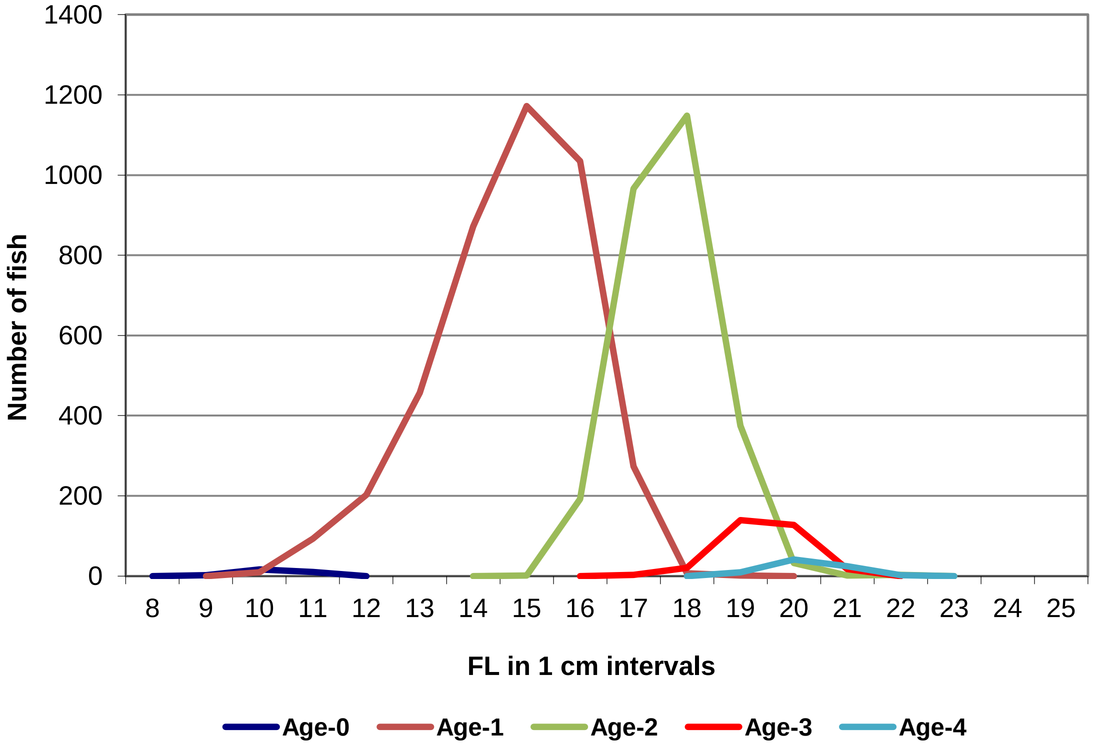


Figure 3.4 Fork length (cm) frequencies by age of Gulf menhaden in the 2011 port samples.

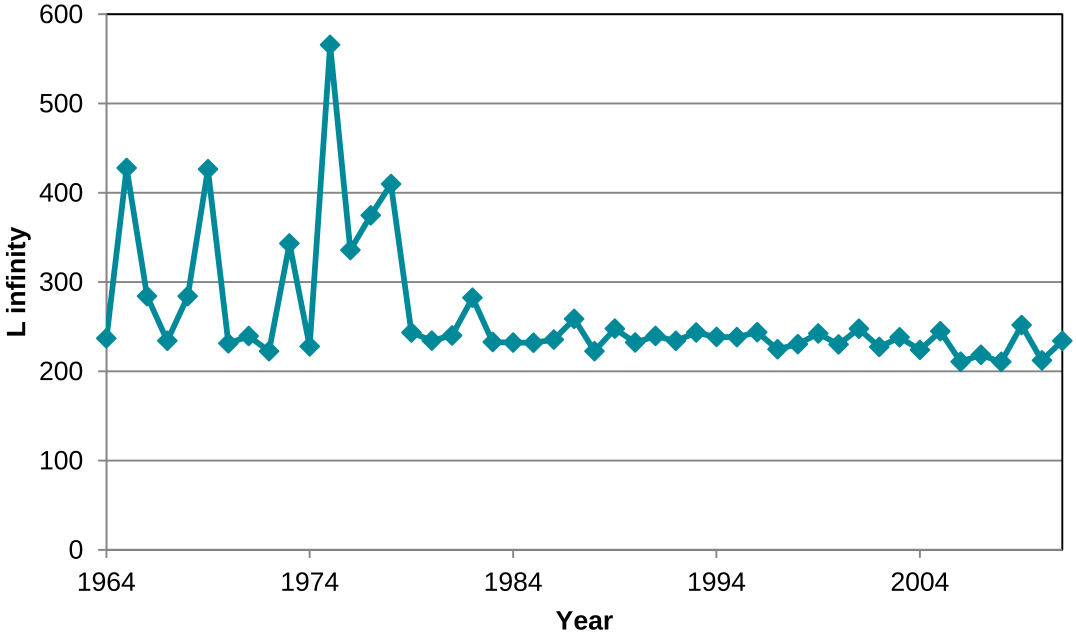


Figure 3.5 The annual values of L_∞ based on annual fits to the von Bertalanffy growth curve for 1977-2011.

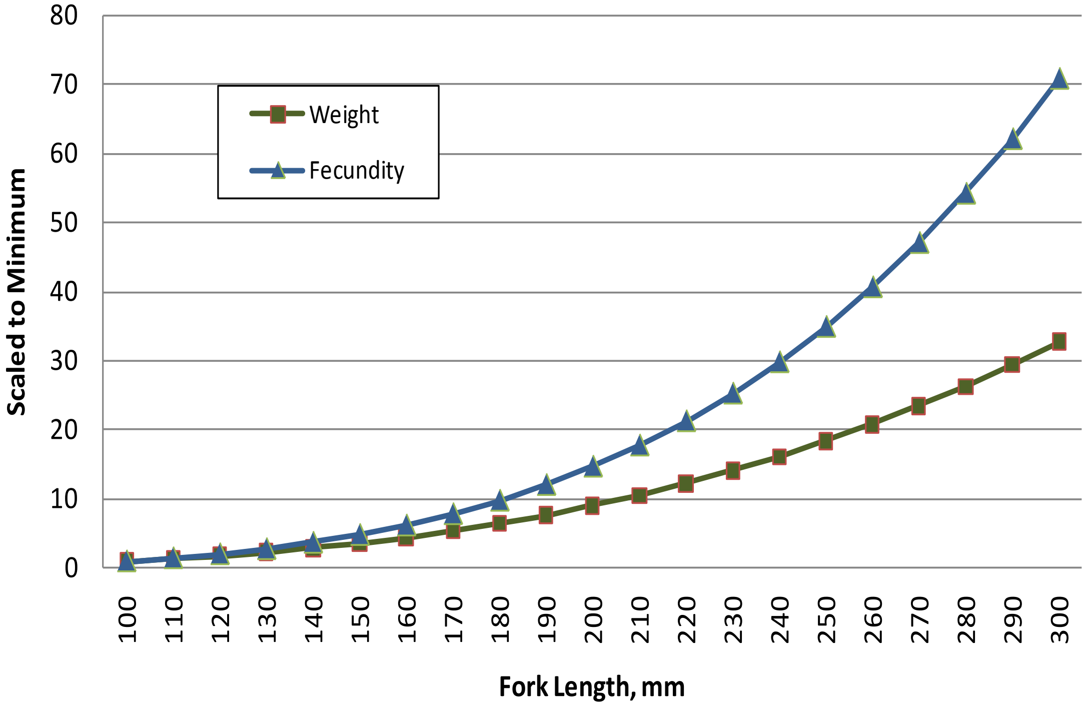


Figure 3.6 Comparison of female weight and fecundity (no. of maturing or ripe ova) as a function of fork length (mm) for Gulf menhaden. Fecundity relationship from Lewis and Roithmayr (1981).

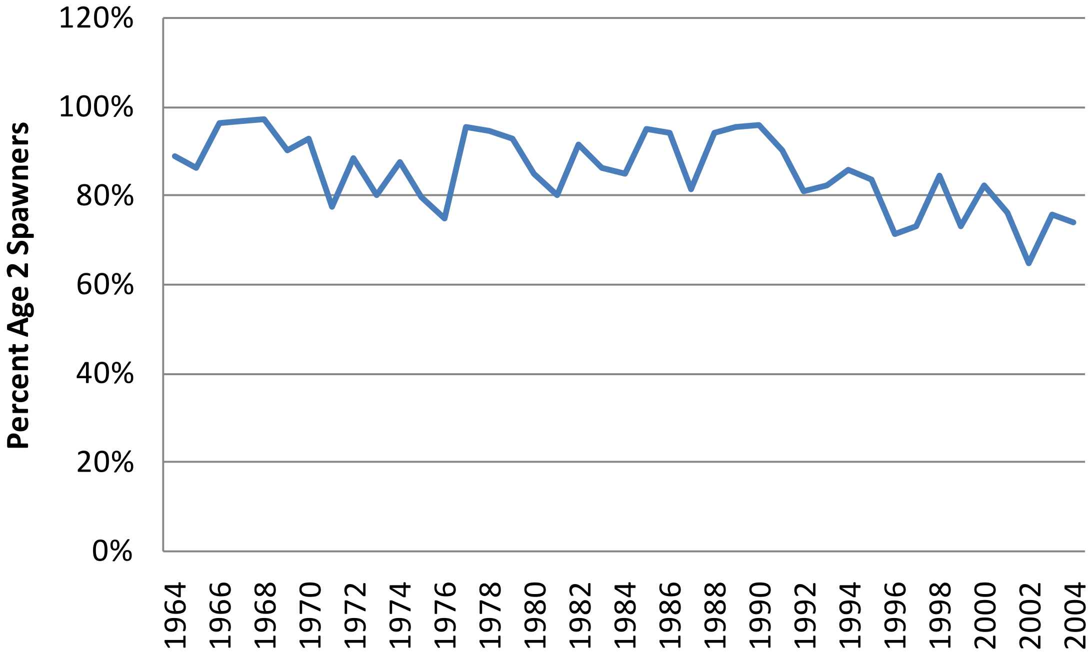


Figure 3.7 Proportion of eggs from age-2 spawners (first time spawners) to total population egg production as estimated in latest stock assessment (Vaughan et al. 2007), 1964-2004.

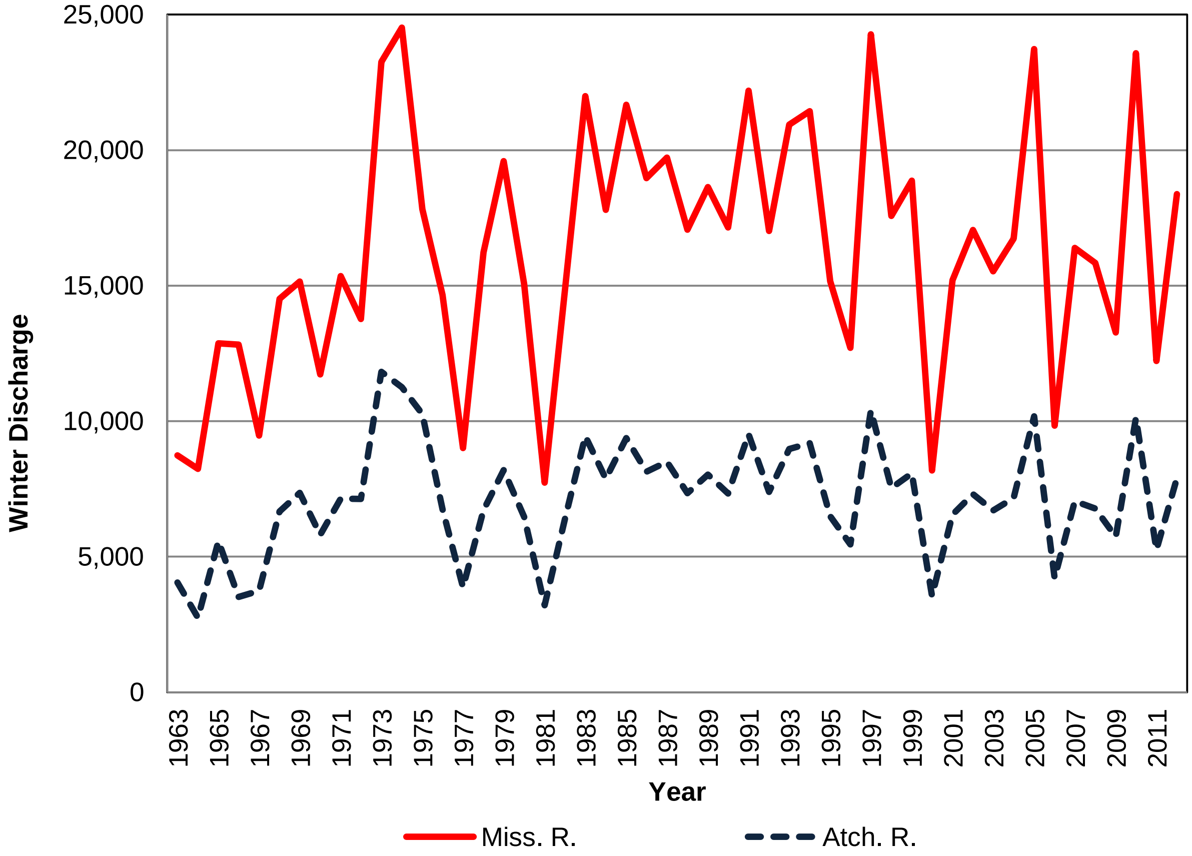


Figure 3.8 Winter (Nov-Mar) Mississippi River flow measured at two US Corps of Engineers gauges (Simmesport, Louisiana, on the Atchafalaya River and Tarbert Landings, Mississippi, on the Mississippi River) for 1963 to 2011.

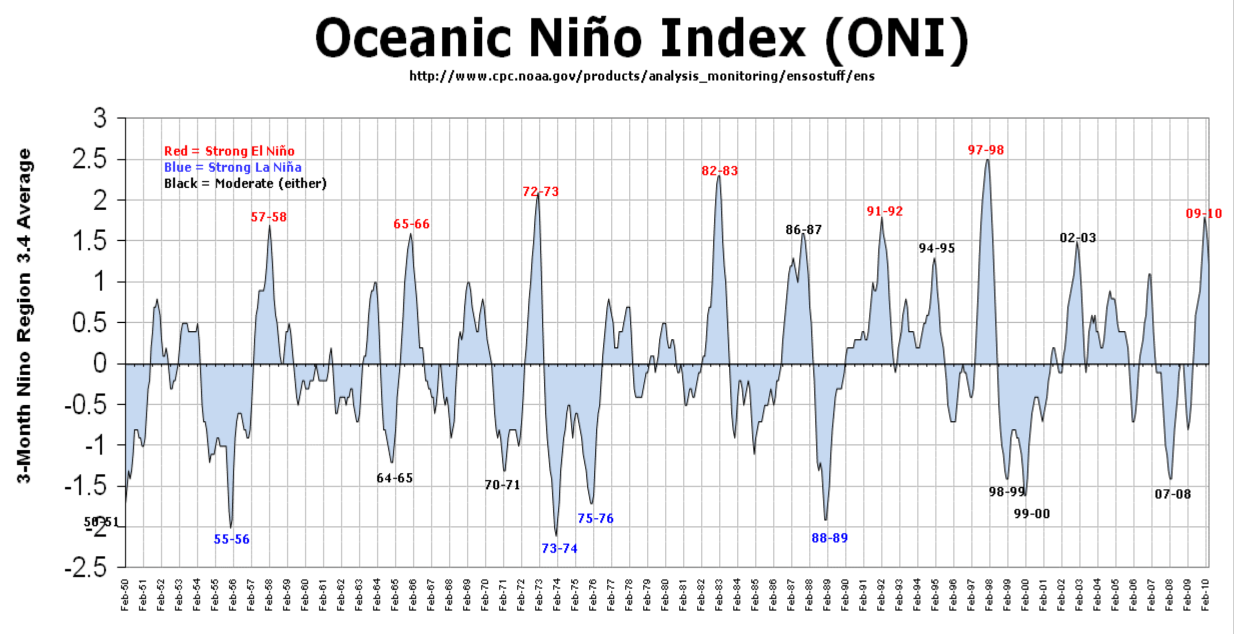


Figure 3.9 Warm (red) and cold (blue) episodes based on a threshold of +/- 0.5^{o}C for the Oceanic Niño Index (ONI) [each month is 3 month (center month noted) running mean of ERSST.v3b SST anomalies in the Niño 3.4 region (5^{o}N-5^{o}S, 120^{o}-170^{o}W)], based on the 1971-2000 base period. For historical purposes cold and warm episodes (blue and red colored numbers) are defined when the threshold is met for a minimum of 5 consecutive over-lapping seasons.

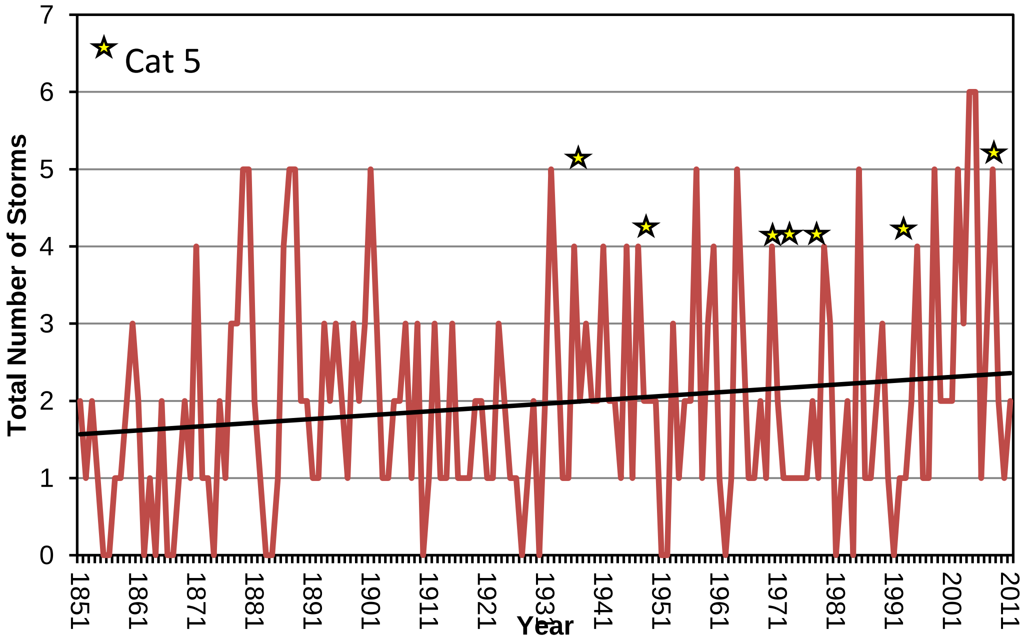


Figure 3.10 Number of tropical storms and hurricanes in the northern Gulf of Mexico, 1851-2011.

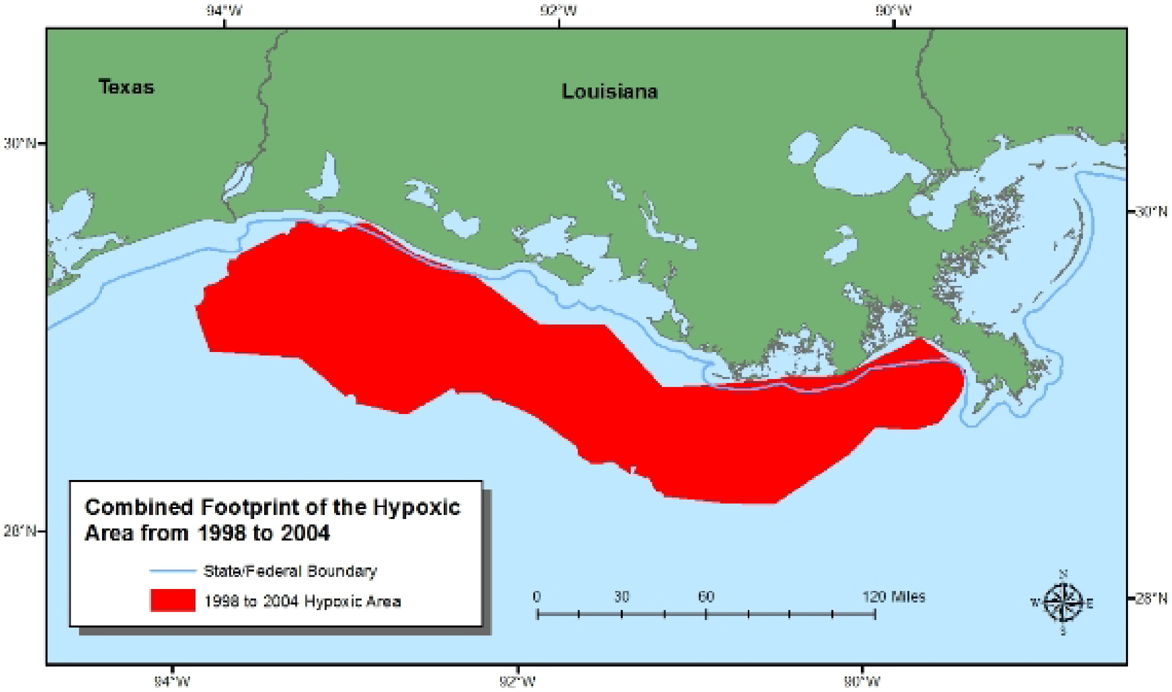


Figure 3.11 Map of the Gulf of Mexico showing the combined footprint of the Hypoxic Area or 'Dead Zone' for the period 1998-2004.

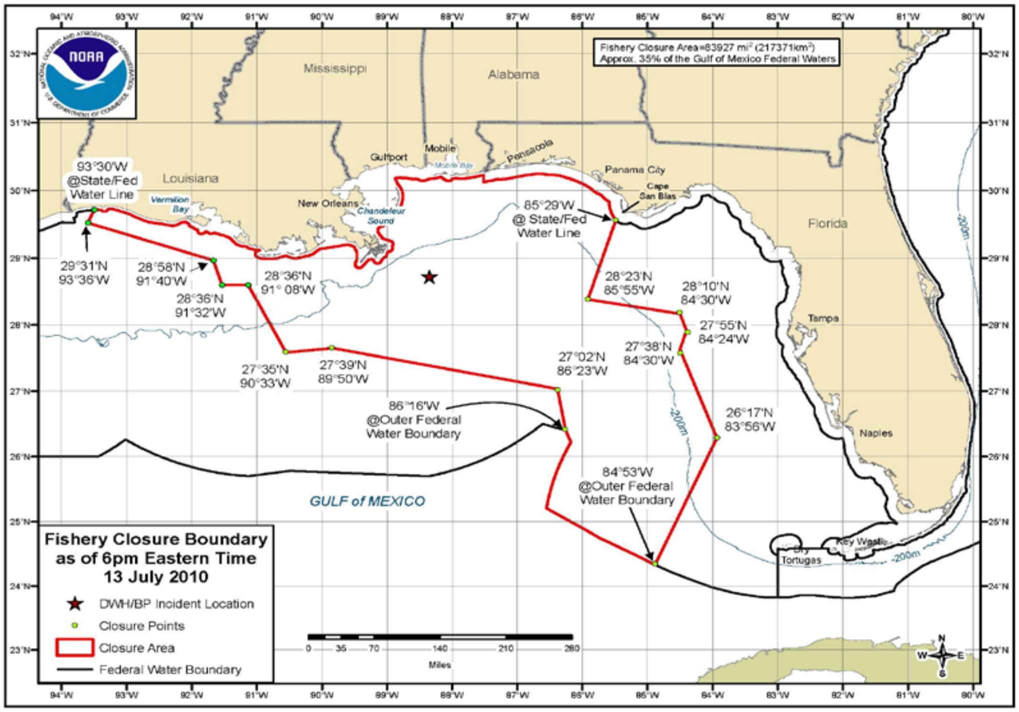


Figure 3.12 Map of the Gulf of Mexico showing the site of the BP Deepwater Horizon (DWF) Oil Spill and fishery closure boundary on 13 July 2010 (Source: NOAA/SERO).

4.0 Fishery-Dependent Data Sources

Commercial menhaden landings for the bait and reduction fisheries tend to be limited to the northern Gulf as the range of Gulf menhaden is predominantly east and west of the Mississippi River with the majority of commercial purse-seine fishing activities occurring off Louisiana (89.9% based on 2008-11 average) with smaller contributions from Mississippi 7.8%, Texas 2.3%, and Alabama <1%.

4.1 Development of Historical Commercial Landings (1873-1947)

Landings of Gulf menhaden for reduction purposes prior to about 1948 are limited and occur intermittently in a series of historical publications to be described in the next two subsections.

4.1.1 Commercial Catch Statistics from Historical Reports, 1880-2000

Data from various annual reports (Fishery Industries of the United States, 1920-1939; Fishery Statistics of the United States, 1939-1977; and Fisheries of the United States, 1966-2007) are summarized for 1880-2000 (NOAA various years). However, other than 2,000 pounds of Gulf menhaden reported in 1902, positive landings appear in the records in about 1918; they are not identified by gear or use, but are assumed to be for reduction and for other commercial gears/uses (e.g., bait). Intermittent landings from the west coast of Florida were reported from 1918-1948, after which consistent annual landings were shown through 2000. Alabama only reported consistent values starting in the 1980s. Landings from the other Gulf States were inconsistent until 1948. This generally agrees with our understanding of the historical development of the fishery in the Gulf of Mexico. Because of the gaps in these data, we used a process of linear interpolation to ‘smooth’ data between 1918 and 1948.

4.1.2 Menhaden Fishery, 1873-1964

During the recent Atlantic menhaden assessment (ASMFC 2010), we discovered a report titled Menhaden Fishery, 1873-1964. This report, which can be found in USFWS (1966), contains summary statistics for the menhaden fishery (both coasts combined) from 1873-1964. Atlantic menhaden landings were extended back to 1873 during SEDAR 20 (ASMFC 2010). We also used these data to extend Gulf menhaden landings back as well. The average proportion of Gulf to total menhaden for 1918-1940 was calculated at 2.46% when data were more robust (1918 onward). This proportion was applied to the total menhaden landings from 1873-1917 to separate landings between the two coasts (SEDAR 20). These landings are shown in Figure 4.1, along with subsequent landings developed for 1948-2011. The important point taken from these reconstructed data is that overall commercial Gulf menhaden landings were generally small prior to World War II (averaging about 5 mt for 1873-1939). Landings rose during WWII to about 133 mt estimated for 1947. As described in the next section, detailed landings from the reduction fishery became available in 1948. These reconstructed landings were made available for surplus production (ASPIC) modeling described later in Section 6.

4.2 Commercial Reduction Fishery (1948-2011)

4.2.1 Overview of fishery

The commercial fishery for Gulf menhaden consists primarily of a directed purse-seine fishery for *B. patronus* for reduction purposes and is almost exclusively a single species fishery for Gulf menhaden. Small and relatively insignificant amounts of other menhaden species, i.e., yellowfin menhaden or finescale menhaden, may be incidentally harvested as these species may overlap with *B. patronus* at the extreme east and west ranges of the Gulf menhaden fishery (Ahrenholz 1991). Occasionally, vessels in the menhaden fishery make directed purse-seine sets on schools of Atlantic thread herring, *Opisthonema oglinum*. This occurs primarily in the central portion of the northern Gulf of Mexico by vessels fishing from Empire, Louisiana.

Official commercial landings of Gulf menhaden from the reduction purse-seine fleet have been maintained by the Beaufort Laboratory of the NMFS. When the Menhaden Program began at the Beaufort Laboratory in the early 1950s, staff visited menhaden plants along the Gulf of Mexico coast, obtaining detailed fishery landings for the reduction fishery consistently back to 1948. Subsequently, detailed dockside landings from the reduction fishery have been maintained on computer files by calendar year. These landings are considered the best available data for purposes of stock assessments.

The reduction fishery for Gulf menhaden is a daytime fishery, which employs purse-seine gear to encircle schools of menhaden. Two purse boats (ca. 40 ft long), each holding one-half of the seine, are deployed from a large carrier vessel (ca. 160-200 ft long; also called a ‘steamer’). A pilot in a spotter aircraft directs the purse boats via radio to the fish schools and assists in directing the purse boat crews to set the net. The fish are ‘hardened’ into the bunt of the net, and then pumped onboard the steamer. The contemporary purse-seine fleet averages about 4-5 sets per fishing day and median catch size per set is about 17-22 mt (Smith et al. 2002). At the end of the fishing trip, which is often a multi-day trip, the catch is pumped at dockside into the fish factory. Then, the catch is reduced into the three main processed products of the menhaden industry - fish meal, fish oil, and fish solubles.

Prior to World War II, most menhaden was dried and sold as ‘fish scrap’ for fertilizer. By the early 1950s, the demand for fish meal as an ingredient in poultry feeds increased as the ‘fryer’ chicken industry expanded. During the latter half of the twentieth century, menhaden meal also became an integral component in swine and ruminant feeds. By the 1990s, menhaden meal was being milled in greater quantities into aquaculture feeds. Historically, most menhaden oil was exported to Europe where it was processed into cooking oil or margarines. Since the late 1990s, greater quantities of menhaden oil, a high-grade source of omega-3 fatty acids, are being utilized by the pharmaceutical, processed-food, and aquaculture industries of the U.S.

Location and activity of the reduction plants are summarized in Table 4.1 for 1964-2011. Number of plants ranged between 10 and 14 between 1964 and 1984. After that plant consolidation occurred. Four extant fish factories existed on the U.S. Gulf coast from 2000-2011. Of these four factories, three are owned by Omega Protein, Inc. (at Moss Point, Mississippi, and Abbeville and Cameron, Louisiana) and one is owned by Daybrook Fisheries, Inc. (at Empire, Louisiana). Through the past decade, the number of Gulf menhaden vessels gradually declined from 47 in 2000 to 41 in 2006. Since 2007, the fleet has been reasonably stable fielding 37 to 40 steamers.

Fishery-dependent data for the Gulf menhaden reduction fishery are maintained at the NMFS Beaufort Laboratory in three large data sets. Commercial catch and effort data (Table 4.2) for the reduction fishery are available from 1948 through 2011. Contemporary landings data are supplied to the Beaufort Laboratory by the menhaden industry on a daily or weekly basis; catches are enumerated as daily vessel unloads. The biostatistical data, or port samples, for length and weight at-age are available from 1964 through 2011, and represent one of the longest and most complete time series of fishery data sets in the nation. The Captains Daily Fishing Reports, or CDFRs (daily logbooks), itemize purse-seine set locations and estimated catch, and vessel compliance is 100%. Annual CDFR data sets for the Gulf menhaden fleet are available from 1983 to 2011.

4.2.2 Data Collection Methods

Biological sampling for the menhaden purse-seine fishery is based on a two-stage cluster design and is conducted over the range of the fishery, both temporally and geographically (Chester 1984). The number of fish sampled in the first cluster was reduced during the early 1970s from 20 fish to 10 fish to increase sampling of the second cluster (number of purse-seine sets). Port agents randomly select vessels and at dockside retrieve a bucket of fish (first cluster) from the top of the vessel's fish hold. The sample is assumed to represent fish from the last purse-seine set of the day, not the entire boat load or trip. The agent ascertains from the crew the location and date of the last set. From the bucket the agent randomly selects ten fish (second cluster), which are measured (fork length in mm), weighed (grams), and have scales removed for ageing. Nicholson and Schaaf (1978) performed detailed examinations of Gulf menhaden scales and determined that rings on the scales were reliable age marks (Section 3.3).

The original premises of the Gulf menhaden port sampling routines remained relatively unchanged for over thirty years; namely, sampling is based on a two-stage design (above) and port agents, who were employed by the NMFS, collected and processed the fish samples. Prior to about 1995, NMFS agents were hired as temporary Federal workers on an intermittent basis, that is, they (mostly undergraduate or graduate students) were employed during the fishing season to collect and process Gulf menhaden from about May through October. In about 1994, the Federal government eliminated most temporary positions, and the NMFS was no longer able to hire seasonal port agents.

Beginning in about 1995, the solution to acquiring Gulf menhaden port samples without temporary Federal hires was two-faceted. First, dockside personnel at each fish factory in Louisiana were identified and asked to acquire a target number of fish samples each week of the fishing season; factory personnel are paid a nominal fee per sample. Samples are labeled with date, vessel, and catch location, then frozen in a chest freezer. Second, between about 1995 and 2003 GSMFC wrote "independent contracts" to temporary employees who retrieved frozen samples at the fish factories, then processed the fish samples for size and age composition, mailing data and scale samples to the NMFS Beaufort Laboratory. Beginning in 2004, the LDWF has processed the fish samples from Empire, Abbeville, and Cameron. Port samples from Moss Point, Mississippi, beginning about 1995 were acquired and processed by an employee of the NMFS Pascagoula Laboratory. In recent years, the task of processing the samples from Moss Point has been performed by an independent contractor through GSMFC. Over the past fifteen years, supervision of port sampling efforts has remained under the direction of the NMFS Beaufort Laboratory.

4.2.3 Reduction Fishery Landings

Nicholson (1978) suggested that the "modern" Gulf menhaden fishery began just after World War II; he documented that 103,000 mt of Gulf menhaden were landed in 1948 at ports in Florida, Mississippi, Louisiana, and Texas. He noted that landings were incomplete for 1946 and 1947 (Table 4.3). Chapoton (1970 and 1971) reviewed the history and status of the fishery from 1946 to 1970. He cited a general trend toward greater landings over the 25-year period. This upward trend in landings continued during the 1980s culminating with six consecutive years of landings over 800,000 mt (1982 through 1987) and record landings of 982,800 mt in 1984 (Smith et al. 1987, Smith 1991). The historical pattern in landings and corresponding nominal fishing effort (discussed later) are shown in Figure 4.2.

Consolidation within the menhaden industry (plant closures and fewer vessels), weak product prices, and weather were the major contributing factors to declining landings during the 1990s; annual landings during the decade averaged 552,000 mt per year and ranged from 421,400 mt in 1992 (Hurricane Andrew) to 761,600 mt in 1994. During 2000 to 2011, landings averaged 490,700 mt annually, a decline of ~11% from the average of the previous decade. Nevertheless, landings since 2000 have been less variable than during the 1990s ranging from 379,700 mt in 2010 [BP's Deep Water Horizon (DWH) Disaster] to 613,300 mt in 2011.

Tropical weather systems in the northern Gulf have played a major role in depressing landings in recent years (Figure 3.10). In 2004 (468,700 mt), the Gulf menhaden fleet lost considerable fishing time because of Hurricanes Charley and Ivan. In 2005 (433,800 mt), Hurricanes Katrina and Rita severely damaged all four menhaden plants and a number of vessels, shortening the fishing season for most of the factories. In 2008 (425,400 mt), Hurricane Ike delivered significant damage to the two plants in western Louisiana. Moreover, in 2010 (379,700 mt), the DWH Disaster forced major closures to traditional menhaden fishing grounds (Figure 3.12).

Since 1964, the menhaden fishery in the northern Gulf of Mexico has reported Gulf menhaden landings for reduction during the fishing year directly to the Beaufort Laboratory. Daily vessel unloads are provided in thousands of standard fish (1,000 standard fish = 670 lbs), which are converted to kilograms. Between 2009 and 2011 the reduction fleet (ca. 38 vessels) unloaded an average of 2,884 times during each fishing year; the average unload per vessel was 168 mt.

4.2.4 Age and Size Composition

Detailed sampling of the reduction fishery permits landings in biomass to be converted to landings in numbers-at-age. For each port/week with landings, biostatistical sampling provides an estimate of mean weight and the age distribution of fish caught. Hence, dividing landings for that port/week caught by the mean weight of fish allows the numbers of fish landed to be estimated (Table 4.4). The age proportion then allows numbers-at-age to be estimated.

Developing the catch matrix at the port/week caught-level of stratification provides for considerably greater precision than is typical for most assessments.

About 5,700 Gulf menhaden from the reduction fishery have been processed annually for size and age composition over recent fishing seasons, 2009-2011 (Table 4.4). In comparing menhaden sampling intensity to the old rule-of-thumb criteria once used by the NOAA Northeast Fisheries Science Center (e.g. <200 t/100n), this sampling level might be considered low, although the results of Chester (1984) suggest this sampling level is relatively high. Because of these high numbers of fish sampled, and the two-stage sampling procedure, we also provide the number of sets sampled by the port samplers (Table 4.4). Number of sets, was favored over number of fish, in the recent Atlantic menhaden stock assessment (ASMFC 2010 - SEDAR 20) and in the most recent Gulf menhaden assessment (Vaughan et al. 2007).

Over the 48-year period that the NMFS has collected fishery-dependent data from the Gulf menhaden fishery (1964-2011), age-2 fish have been increasingly represented in the catch-at-age matrices (Figure 4.3). Indeed, age-2 Gulf menhaden represented 73% of the total numbers-at–age in the catch-at-age matrix for 2009. Reasons for the increase in age-2 fish in the landings over time, and the subsequent decline of age-1 fish, are not well understood. Surely, recruitment success of juveniles into estuarine areas, which are believed to be largely driven by environmental factors, plays a major role. Additionally, decreased fishing pressure over time is another plausible explanation. However, several additional hypotheses have been proposed (at the GMAC meeting in Orange Beach, Alabama, in March 2010) such as: 1) contraction of the fishery over time from the extremes of the species' range (Texas and Florida, where smaller and younger fish are more abundant) towards the center of the species' range (Louisiana and Mississippi); 2) re-distribution over time of age-1 fish toward more 'inside' waters (where they become unavailable to the fishery) due to marsh habitat loss across the Gulf (this is somewhat supported by data from systematic gill net surveys in Louisiana and Texas); and, 3) a 'corralling-effect' that hypoxic waters of the northern Gulf may have on the distribution of Gulf menhaden (Smith 2000).

4.2.4.1 Run Boats

Since 2000, one Gulf menhaden plant has employed carry vessels or 'run boats' to transport some of the catch from the fishing grounds to the factory. Run boats are former menhaden steamers that are not involved with setting the net. Rather, they rendezvous with regular steamers on the fishing grounds, pump fish from the fish holds of the steamers into their own fish hold, then transport accumulated catches back to the fish factory. Run boats have been used almost exclusively at Moss Point (briefly used at Cameron in 2000). For most years, about two run boats have been utilized each fishing season since 2000 and on average they have operated during 23 weeks of the 28-week fishing season.

It should be reiterated that the use of run boats is not pervasive throughout the fishery. On the contrary, run boats (usually about two per year) are only used at the Moss Point fish factory. We examined the port sampling databases for the past decade to determine number of run-boat sampling events and to compare samples for size and age from run boats to those of samples from regular fishing steamers (Table 4.5).

For three of four years when port samples from run boats were acquired, they represented less than 1% of all samples obtained for the menhaden fishery; 2 of 670 (0.3%) in 2002, 6 of 929 (0.6%) in 2003, and 2 of 515 (0.4%) in 2007. Greatest number of samples from run boats occurred in 2011: 23 of 812 (2.8%). For years with samples from run boats, we compared weekly size and age composition of the run boat samples to the regular steamer samples (Table 4.5); for most weekly comparisons, size and age differences varied only slightly. Hence, we conclude that run boat samples are minimally represented in the Gulf menhaden port sampling data base and that their effect on the size and age composition of the catch is negligible. However, beginning in 2012, we have instructed port agents to avoid sampling run boats.

4.2.5 Nominal Reduction Fishing Effort

4.2.5.1 Background on Units of Observed Fishing Effort in the Menhaden Purse-Seine Fisheries.

Often, menhaden vessels unload their catches daily, although trips of 2-3 days are common. The menhaden plant records, while showing the date and amount of fish unloaded per vessel, do not list number of days fished, or days when the catch was zero. Logbooks were placed on Atlantic menhaden vessels during the late 1950s and early 1960s to try and collect better information on ‘fishing’ and ‘non-fishing’ days at sea (Roithmayr 1963), but compliance was incomplete (Nicholson 1971). Similar attempts to maintain logbooks on Gulf menhaden vessels (1964-1969) also met with mixed results (Nicholson 1978). Thus, through about the 1970s there was no satisfactory way to acquire a complete at-sea history of each menhaden vessel.

Considering that menhaden vessels generally operate continuously over the course of a fishing season and fish every day that weather permits, Nicholson (1971) argued that the vessel-week (one vessel fishing at least one day of a given week) was a satisfactory unit of nominal fishing effort for the Atlantic menhaden purse-seine fishery. Thus, a vessel unloading a catch at least one time during a given week was assigned one vessel-week of effort. Vessel-weeks for all vessels in the Atlantic fleet were calculated across all months of operation, and then summed for an estimate of annual nominal or observed fishing effort for the fishery. For the Gulf menhaden fishery, Chapoton (1971) noted that fish catching ability is more directly related to size of the vessel and its fish hold capacity. Thus, the vessel-ton-week (VTW - one vessel fishing at least one day of a given week times its net tonnage) is used as a measure of nominal fishing effort for the Gulf menhaden fishery, as it better accounts for efficiencies among different sized vessels (Figure 4.2). Similar to Atlantic menhaden, the correlation between landings and nominal fishing effort (VTW) for the Gulf menhaden fishery is statistically significant ($r^2 = 0.83$ for 1955-2011). The regression of landings on nominal effort is presented with observed values in Figure 4.4.

As a rule, estimates of nominal fishing effort have only been used by the Menhaden Program at the NMFS Beaufort Laboratory for forecasting annual catches for the Gulf and Atlantic menhaden fisheries. In a general predictive sense, the amount of nominal fishing effort expended is a good indicator of the amount of fish that may be removed from the stock in a given year. Save for production models such as ASPIC and SRA (see SEDAR27 2011), estimates of nominal fishing effort have not been used in menhaden statistical catch-at-age models for reasons outlined below.

4.2.5.2 CPUEs for the Fishery

In a general sense for many fisheries, catch-per-unit-effort (CPUE) is used as an index of abundance, where a proportional change in CPUE is expected to represent the same proportional change in stock size. However, for purse-seine fisheries it has been demonstrated that CPUE and nominal or observed fishing effort are poor measures of population abundance (Clark and Mangel 1979), which is especially true for those fisheries that utilize spotter aircraft. Thus, we have been wary of using fishery-dependent CPUEs as a measure of population abundance for the menhaden fisheries. Specifically, there is concern about hyperstability in the CPUE measure because the effectiveness of spotter pilots and the schooling nature of menhaden stongly suggest that catch level could be maintained relatively constant in the presence of declining population abundance. For reference purposes, CPUEs in total landings divided by vessel-ton-weeks (VTW) for the Gulf menhaden fishery for 1948-2010, are shown in Figure 4.6.

That said, while attempting to develop indices of abundance for this assessment, we were intrigued with the relationships between two exploratory CPUE indices - numbers of age-1s and age-2s caught by the fishery and observed fishing effort of the Gulf menhaden fleet (in terms of number of purse-seine sets; Table 4.7) – when compared to fishery-independent indices developed for the assessment, namely, the juvenile seine index and the adult gill net index. The exploratory indices were calculated by dividing annual numbers of age-1s and age-2s from the catch-at-age matrices by the annual number of purse-seine sets made by the fishery from the CDFR data bases. CDFR data are incomplete for years 1994-95 and 2005; effort for these years was estimated by averaging adjacent years where the data sets were complete. The resulting CPUEs were scaled to their respective means. The age-1 index was assumed to be a signal of incoming recruitment to the fishery; it was lagged one year and was plotted with the juvenile fishery-independent seine survey data (Figure 5.31). The correlation between the age-1 fishery-dependent index and the seine index was 0.87. The age-2 index was assumed to be a signal of adult abundance in the fishery; it was plotted with the adult fishery-independent gill net data (Figure 5.42). The correlation between the age-2 fishery-dependent index and the gill net index was 0.73. Although both indices seem closely correlated with their fishery-independent analogs, the fishery-dependent indices were ultimately deemed inappropriate for use in the assessment because of concerns related to fishery hyperstability as noted above.

4.2.5.3 Alternate Measures of Nominal Fishing Effort in the Gulf Menhaden Fishery

In fall 2007, the GSMFC’s Menhaden Advisory Committee (MAC) requested that the NMFS Beaufort Laboratory explore alternate units of nominal fishing effort for the Gulf menhaden fishery that might replace the traditional effort unit, the VTW, for predicting annual menhaden forecasts. Since annual CDFR data sets are available electronically for most years with 100% compliance beginning in 1983 (except 1992, 1993, and 2005), we explored two potential alternate units of nominal fishing effort: 1) total number of purse-seine sets, and 2) total number of fishing days when at least one purse-seine set was made (Table 4.8). Some conclusions of this exercise were that:

1) total number of sets and number of days with >=1 purse-seine set were closely correlated with the traditional unit of observed effort, VTWs, and

2) VTWs were adequate for current use in NMFS landings forecast models.

During the Data Workshop portion of SEDAR20 for Atlantic menhaden (ASMFC 2010), catch per trip was investigated as an alternate unit of CPUE for the Atlantic menhaden purse-seine fishery. Therefore, we explored the use of catch per fishing trip as a unit of CPUE for the Gulf fishery. Catch-per-trip was calculated simply as the total annual landings of Gulf menhaden for reduction divided by the number of times Gulf menhaden vessels unloaded during the fishing season (unload events for 1983 and 1984 are incomplete). Surprisingly, catch per trip for the Gulf fleet has risen steadily from the mid-1980s to present (Table 4.9). Reasons for this increase are probably: 1) longer trip duration, hence greater volumes of fish at each unloading, 2) as older vessels are retired, newer vessels in the fleet have greater fish hold capacities, and 3) improved efficiencies within the fleet, notably use of stern ramps or similar devices by most vessels to launch and retrieve the purse boats, permitting greater number of sets per fishing day (NMFS Beaufort Lab unpublished data).

These three measures of nominal fishing effort were scaled to the terminal year (2010) for comparison purposes in Figure 4.5. Similarly, CPUE based on these three measures of nominal fishing effort are compared in Figure 4.6. From about 1980 onwards, similar trends were found for all three measures. However for the period from 1964 to about 1980, there were differences found between VTW and trips as measures of fishing effort. Changes in fleet characteristics since about the 1980s may explain this divergence. As older and smaller vessels were phased out of the Gulf menhaden fleet during the 1970s and early 1980s, newer vessels with larger fish holds and greater net tonnages joined the fleet (net tonnage is a calculation of the volume of cargo space within a ship). Vessels with larger fish hold capacities presumably can stay on the fishing grounds longer and necessarily make fewer trips in a given fishing year. Table 4.10 illustrates this trend toward greater mean vessel net tonnage in the Gulf menhaden fleet over the past forty years. Indeed, mean net tonnage of the fleet has increased over 100 net tons since 1970.

4.2.6 Commercial Reduction Catch-At-Age

Methodology for estimating catch in numbers at age from the fishery has been used consistently over time (Nelson and Ahrenholz 1986, Vaughan 1987, Vaughan et al. 1996, Vaughan et al. 2000, Vaughan et al. 2007). Catch in numbers at age are developed by week and port based on the detailed port sampling and weekly catch records. In two of the past four years, age-2 Gulf menhaden have comprised 68% (2008) and 73% (2009) of the total numbers of fish landed (Table 4.5). However, in 2010 the age composition of the coastwide landings was more evenly distributed with 53% of the catch age-1s and 40% age-2s. In 2011, the age composition was skewed towards age-1 individuals even more with 63% of the catch being age-1s and 31% of the catch being age-2s.

4.2.7 Potential Biases, Uncertainty, and Measures of Precision

4.2.7.1 Catch-Measuring Conventions and Devices Used by the Fishery

When the menhaden program began in the early 1950s at the NMFS Beaufort Lab, staff visited all menhaden plants along the Gulf coast to obtain detailed information back to 1948. These landings and those subsequently collected are thought to be quite accurate. A study (Kutkuhn 1966) was conducted to determine the quantity of fish passing through a given plant based on the number of dumps of the fish hopper. The results suggest that these are accurate to about 3.7% coefficient of variation. It was noted that greater uncertainty was associated with fish spoilage (more likely in the earlier years with unrefrigerated fish holds on vessels).

The menhaden industry self-reports landings in 1,000s of standard fish. This convention dates to the early days of the fishery on the Atlantic coast when 1,000 standard fish were taken to weigh 670 pounds and the volume of a standardized hopper used at reduction plants to offload landings held 1,000 standard fish. The question of consistency among measuring devices for landings at menhaden factories on the Atlantic and Gulf coasts no doubt concerned staff during the early stages of the Menhaden Program at the NMFS Beaufort Laboratory. Kutkuhn (1966) noted that the traditional unit of measurement for landings in the menhaden fishery is the ‘quarter-box’ dump [or hopper], which volumetrically, by the menhaden industry’s definition, measures 22,000 cubic inches, and traditionally recognized to hold 667 lbs. Kutkuhn empirically showed that

> “the factor 0.667 - or 0.67, whichever is more convenient - should now be affirmed as the official standard for converting to weight all landings of menhaden measured volumetrically in ‘quarter-box’ dumps and reported by the industry in terms of thousands-fish units (i.e., 1,000 ‘standard’ fish weigh on the average, 667 pounds or one-third short ton).”

Furthermore, a coefficient of variation about his results of 3.7% suggested a high degree of accuracy for the landings. Kutkuhn also recognized that some extant fish plants at the time used continuous weighing machines to measure landings. Such devices were calibrated to tally one thousand standard fish with each passage of 755 lbs; the difference (88 lbs from the 667 lb value above) was “attributed to additional water, dirt, and slime that adhere to the fish as they are pumped from the vessel.” June and Reintjes (1976), in describing the evolution and methods of the menhaden fishery, reaffirmed that each segment of the rotating hopper device used to measure landings holds volumetrically 22,000 cubic inches, “representing a unit measure of 1,000 ‘standard’ fish.” They also noted that regardless of the weighing equipment employed, this “unit of measure [1,000 standard fish] is used throughout the industry to express the quantity of catch.” Based on the information above, the conversion factor of 0.670 (1,000 standard fish = 670 lbs) was adopted by the NMFS Beaufort Lab’s Menhaden Program.

To address any contemporary concerns about the consistency of hopper dimensions and weigh-out devices, plant managers at the four extant Gulf menhaden factories were queried about the dimensions and operation of their fish weigh-out machines. It was learned that two factories, at Moss Point and Empire, still use rotating hopper devices, or ‘quarter-box’ dumps, to measure their landings. On the other hand, the other two factories, at Abbeville and Cameron, use continuous weigh-out conveyors, or belts, to measure their fish unloads.

Prior to the start of the 2012 fishing season, the plant engineer at the Moss Point factory measured the internal volume of the fish hopper at the Mississippi facility. He provided: 1) photographs of the hopper's dimensions and 2) the subsequent calculations for the hopper's volume. The hopper at Moss Point measured 21,935.6 in^3, remarkably close to the convention of 22,000 in^3 per 1,000 standard fish.

Plant personnel at the Empire fish factory had no available drawings of their fish measuring devices. However, they did report that their fish hoppers are 1.5 times larger than the traditional menhaden fish dump, and as such, they measure approximately 33,264 in^3 in volume (33,264 in^3 / 22,000 in^3 = 1.5).

The fish factories at Abbeville and Cameron use continuous belt scales to measure their Gulf menhaden landings. The scales and systems at both plants are virtually identical. The fish are pumped from the vessels and discharged onto a conveyor belt with an in-line belt scale and integrator. The scale measures the mass of fish and an optical speed sensor measures the belt velocity; weight and speed data are integrated into an instantaneous mass flow value. Belt scales are calibrated at the start of the fishing season. Adjustments (proprietary information) to weigh-outs are made for excess water and slime in the fish stream. Dry weight of fish is determined to be 667 lbs.

In summary, the fish measuring convention for landings in the menhaden industry has been exceptionally consistent over the course of the fishery's long history. The basic unit-of-measure remains the fish hopper, or dump, which holds 1,000 'standard' fish, or one-third of a short ton. Vessel crews, and to some extent spotter pilots, are paid based on each measure of 22,000 in^3 of fish unloaded. For convenience, the NMFS has used the conversion factor of 670 lbs/1,000 'standard' fish measure reported by the industry. Reduction landings of menhaden since the 1940s are believed to be both accurate and precise compared to most other U.S. fisheries. Assessment panelists agreed to use a CV of 0.04 for the Gulf menhaden landings over time.

4.2.7.2 Catch-at-Age Matrices

Development of catch matrices depended on three data sources, including the landings, sampling for weight, and age determination. The landings are thought to be both accurate and precise, and the hopper measurements have been reevaluated recently. The sampling for size and age has been conducted weekly by port since 1964 (Smith 1995). The catch matrix was built from samples by port, week, and area fished as noted above. There are two main uncertainties associated with ageing of the port samples. The first concern is precision and accuracy of ageing over time. The second concern is the implicit assumption that the samples taken from the top of the hold represent the catch throughout the hold on a week by port basis.

Precision and accuracy of ageing over time: During the early decades of the Menhaden Program at the NMFS Beaufort Laboratory, scales from individual menhaden specimens were read multiple times by several readers. Disagreements on age estimates were decided by an additional reading. By the early 1970s, probably because of budget constraints, only a single reader was retained on staff to age menhaden scales. This NMFS employee, Mrs. Ethel A. Hall, has been reading menhaden scales from 1969 to the present. Two in-house ageing error analyses were conducted and described in Section 3.2.2. The first as a scale-to-otolith comparison by Smith and Levi (1990), and the second was a scale-to-scale comparison by Smith and Hall (2009). The method of Punt et al. (2008) was employed to create ageing error matrices for use in the stock assessment model (BAM).

There has been some concern (SEDAR27 2011) that the current menhaden scale reader at the Beaufort Laboratory has read scales since 1969 and that there "may be some drift in her readings" over time (from younger to older age assignments). We resolved to check the consistency of her age readings throughout the whole time series. To address this issue, we retrieved archived Gulf menhaden scale samples from storage at the Beaufort facility and had E.A. Hall re-read sub-samples of scales that she had read from previous decades. Scales from three years for each of four decades were randomly chosen. Years selected were 1972, 1974, and 1978; 1981, 1984, and 1988; 1992, 1995, and 1999; 2002, 2005, and 2010. Within each year, 600-650 scale samples were chosen (Thompson 2002) representing three or four fishing ports. Our scale reader was instructed to re-age the scales under original conditions, that is, she had access to specimen collection date, port of landing, fork length and weight. Only annual ages were re-recorded with no measurements made to successive annuli.

The general condition of the archived scales samples was quite remarkable, considering their age, number of times they were moved and re-packaged, and conditions under which they were stored. However, scales from two (1972 and 1992) of the twelve years were deemed in poor to fair condition, as mold and/or debris had occluded some of the scales and the two microscope slides between which the scales are sandwiched. A total of 6,631 scales were re-read and assigned ages. Across all years, agreement between original and second readings was 82% (annual ranges: 70-90%). Least agreement occurred in 1972 (71%) and 1992 (70%), years when scales were obscured by contaminants. Across all years but within age classes, agreement for age-1s was 80% (range: 66-100%), for age-2s was 85% (range: 72-94%), and for age-3s was 76% (range: 50-90%, but with generally low N's for all years).

If an 'ageing drift' had occurred, then considerable disagreement in the paired age readings would have been expected during analysis years in the 1970s and 1980s. On the contrary, age agreements across most years and age classes were somewhat invariate, save for 1972 and 1992 as noted above.

To compare the initial reading with the re-read, confidence intervals for a proportion were calculated to see if they overlapped for the ages and years resampled. Additionally, simultaneous multinomial confidence intervals were calculated for each year to determine if there was a significant difference in the proportions at age for the re-reads as compared to the original reading of the scales. Based on the multinomial confidence intervals, which are the more appropriate statistical test, the years 1972, 1974, 1988, and 1992 had significantly different age proportions (Figure 4.7).

Based on these analyses, no apparent ageing drift has been occurring over time. If ageing drift had been occurring over time, we would have seen systematic differences between the initial age read and the re-read; however, that was not the case. As discussed in Section 3.2.2, the assessment panelists did exclude age composition data from the earliest years.

Representative sampling of the catch: There has been additional concern (SEDAR27 2011) about the potential bias associated with sampling only the last purse-seine set of the trip. Are there sampling biases and are they toward larger/older fish or smaller/younger fish? Are the samples from the last set of the day on a port-week basis representative of what is contained throughout the hold on a port-week basis? To address these issues, ideally one would place agents onboard menhaden vessels to serially sample purse-seine sets for size and age composition during assigned fishing trips throughout the fishing season. Unfortunately, our sampling resources are limited. Alternately, we devised a plan to sample vessels at dockside and to acquire fish samples from throughout the fish hold during the vessel unloading operation, not just the top of the fish hold. Fish factory dockside workers at each menhaden plant were asked to sample several vessels seasonally in 2012 as the vessels were unloading their catches. For each vessel, a sample was acquired (as per regular sampling protocols; see Section 4.2.2) from the top of the fish hold, with three additional samples taken periodically during the pumpout process and from the fish stream at the hopper or catch-measuring device (see Section 4.2.7.1), i.e., start, middle and end of the unloading process. Samples from the fish stream were not necessarily assumed to represent identifiable purse-seine sets of the fishing trip, rather, they were assumed to be mixed fish from many sets of the given trip.

Sampling efforts varied by port and season. A total of 31 pumpout events were sampled with four replicates each (top of the hold and start, middle and end of the pumpout); overall, 1,240 fish were sampled for size and age composition. At Moss Point, three pumpout events were sampled (one in August and two in October); at Empire 11 pumpout events were sampled (one in May, one each in August and September, and eight in October); at Abbeville, 13 pumpout events were sampled (three each in June, August, and September, and four in October); at Cameron, four pumpout events were sampled (one in August and three in October).

These pumpout data were explored a number of ways, but because sample sizes were small statistical analyses were limited and generalizations about the data could not be provided. First, the samples were looked at overall across all pumpout dates and ports. No difference was apparent between the traditional sample and the samples from throughout the hold (Figure 4.8). Second, samples were looked at within the month of August, but across all ports. The samples in August were collected from August 6-10, so within a shortened period of time. The traditional sample did not collect any age-4 individuals, collected more age two individuals, and fewer age-1 and age-3 individuals (Figure 4.9); however, the samples sizes were inadequate to make any generalized statement about the adequacy of sampling from the top of the fish hold, as traditionally done. Third, samples were looked at within the month of October, but across all ports. The samples in October were collected from October 8-30. The traditional sample did not collect any age-4 individuals, but did collect similar proportions of the other age classes (Figure 4.10). Samples sizes were larger than in August, but were still small and inadequate to make any generalized statement about the adequacy of sampling from the top of the fish hold, as traditionally done. Lastly, samples were looked at within a port for the month of October. The samples in October were from Moss Point (n = 2), Empire (n = 4), Abbeville (n = 8), and Cameron (n = 3) with samples sizes being the number of boats sampled at each port. For Moss

Point, the end position was different from the traditional sample; for Empire, the traditional sample captured age-0 but no age-4 individuals; for Abbeville, the traditional sample captured age-0 and age-3; and for Cameron, the traditional sample didn’t capture any age-0 individuals (Figure 4.11). The traditional sample was different at individual ports, but samples sizes were still small and inadequate to make any generalized statement about the adequacy of sampling from the top of the fish hold, as traditionally done. Although there doesn’t seem to be any concern at the moment, the assessment panelists would like this explored further and have included this in their research recommendations.

4.3 Commercial Bait Fishery (1950-2011)

The bait fishery for menhaden has historically accounted for only a minute portion of the total landings of Gulf menhaden. Until the mid-1980s, the bait purse-seine fishery for Gulf menhaden occurred almost exclusively in Florida. Louisiana and Alabama began landing menhaden for bait in 1984, and Louisiana's landings increased substantially through the mid to late 1980s. Through the 1990s, two companies in Morgan City and Cameron, Louisiana, were responsible for a majority of the Gulf menhaden landings for bait in the central northern Gulf. Bait landings of Gulf menhaden have declined substantially in the past decade.

4.3.1 Bait Fishery Overview

Although little published information exists on menhaden bait fisheries (Smith and O’Bier 2011), the majority of Gulf menhaden harvested for bait in the northern Gulf of Mexico probably are used as bait in the blue crab trap fishery and the crawfish fishery. Some bait is sold fresh at dockside; however, most is probably frozen and trucked throughout the Gulf region. Menhaden are also used commercially by long-line and hook and line fishermen as bait and chum for red snapper, grouper, and other reef fishes. In the recreational fishery, menhaden are used for bait and chum by sport fishermen and the charter boat industry.

Historically, Florida and Louisiana have been the main participants in the Gulf menhaden bait fisheries. Purse-seine landings of Gulf menhaden for bait in Florida increased substantially during the mid-1980s, peaked in about 1990, declined to lower levels in the 1990s, and have shown a steady downward trend since 2000 (Table 4.11). During the peak years, Florida bait landings were concentrated in Tampa Bay and off the Panhandle region. Closure of Tampa Bay to purse-seine fishing by about 1991-1992 and the Florida Net Ban in 1995 (prohibiting purse-seine gear in most state waters; see Section 1.4) no doubt were reasons for the decline in landings.

Purse-seine landings of Gulf menhaden for bait in Louisiana increased significantly in the late 1980s when two companies began using surplus reduction fishery steamers to harvest Gulf menhaden in the northern Gulf near Morgan City and Cameron (Table 4.11). The operation in Cameron was closed in 2000. The company in Morgan City closed in 2007; consequently, Gulf menhaden landings for bait in Louisiana declined sharply.

4.3.2 Bait Landings

Gulf menhaden commercial bait landings are available by gear through the NMFS Office of Science and Technology, Fisheries Statistics Division's Commercial Landings website (1950-2011), particularly for 1950-1961 prior to availability of data from the NOAA Accumulated Landings System (NOAA ALS) for 1962-2011. The NOAA ALS data were provided by NOAA Southeast Fisheries Science Center staff in Miami, Florida in March of 2013. Two gears (codes 100 and 125) are associated with reduction landings, while the remaining gear codes are associated with bait landings.

Purse-seine fisheries for Gulf menhaden for bait were active off the west coast of Florida and Louisiana during the 1980s through about 2000, but landings for bait were minor compared to the reduction fishery. A mixed-species aggregate by-catch of Gulf menhaden mostly from gill nets and haul seines also exists in several states, but these landings are minor compared to the reduction fishery as shown below.

Purse-seine landings were the dominant gear for bait landings. Gill nets and haul seines also were important gears for landing Gulf menhaden for bait with the remaining bait landings caught by a variety of gears. We provided estimates of Gulf menhaden bait landings by major gears for 1950-2011 (Table 4.11). An annual plot of these landings by gear demonstrates a period between 1986 and 2000 when purse seines dominated the bait landings (Figure 4.12). Peaks in the other gears also occurred during the 1980s and 1990s. Bait landings were very small prior to 1980 and more recently. Bait and recreational landings are compared with reduction landings in Figure 4.13.

The assessment panelists recommended using average bait landings for 1950-1959 (9 mt) for 1948-1949. For the recent period 2000-2011, bait landings averaged 342 mt or 0.07% of the average of 490,700 mt for the reduction fishery. However, bait landings did range between 1% and 2% of the coastwide landings between 1987 and 1999.

4.3.3 Commercial Bait Catch-At-Age

The small amount of bait landings was combined with reduction landings to produce a single landings stream for 1948-2011 and a single catch at age matrix for use in stock assessment models for 1964-2011 (Table 4.12).

4.3.4 Potential Biases, Uncertainty, and Measures of Precision

Uncertainty associated with bait landings is likely to be substantial, but no formal means is available for estimating either bias or precision. We suspect that these estimates are more likely to be underestimates, but the degree to which this might be true is unknown.

4.4 Recreational Fishery (1981-2011)

A small amount of Gulf menhaden harvest can be attributed to the recreational fishery, predominantly by cast net. Comparable data for Atlantic menhaden were considered in the recent assessment on that species (ASMFC 2010 – SEDAR 20). To examine the potential recreational landings, the Marine Recreational Information Program (MRIP), its predecessor, the

Marine Recreational Fisheries Statistical Survey (MRFSS), and the ongoing Texas Parks and Wildlife Department (TPWD) Creel Survey were queried. The level of catch from the TPWCS was too small to provide estimates. However, the MRIP/MRFSS provided the information that follows.

4.4.1 Data Collection Methods

Data from the MRIP/MRFSS were downloaded from the NMFS Office of Science and Technology, Fisheries Statistics Division's Recreational Landings website using the Custom Query option (NOAA unpublished data). Data from the TPWD Creel Survey were requested directly from staff. See MRIP/MRFSS online for discussion of methods. Insufficient biological samples were available to develop a catch at age matrix. See below for a discussion of the treatment of recreational landings.

4.4.2 Recreational Landings and Discards

Estimated recreational catches are reported as number of fish harvested (Types A and B1), released alive (Type B2), and total caught (Types A+B1+B2). The fundamental cell structure for estimating recreational catches is by state [Florida - Texas], mode of fishing [beach/bank, man-made, shore, private/rental, charter], fishing area [inland, ocean (<=3mi), ocean (>3mi)], and wave [six 2-month periods]. To determine total removals, an estimate of release mortality to apply to the B2-caught fish was required. The assessment panelists suggested using a value of 100% mortality. Based on this value, the total number of fish dying due recreational fishing would then be given by A+B1+B2. To provide estimates of harvest (Type A+B1) in weight, the catch records were retained at the basic cell level for which both harvest in numbers and harvest in weights were available. These landings were then pooled and the ratio was used to obtain an average weight. For lack of data, we make the assumption that the size (mean weight) of the B2-caught fish is similar to that of the A+B1 fish and combine them in calculating our harvest in weight. Thus, the average weight (133 g) was applied by region to total harvest (A+B1+B2) in numbers to obtain harvest in weight. Recreational landings for 1981-2011 are summarized in Table 4.2. Similar to filling in missing values for matching landings to the reduction fishery for 1948-2011, average values were obtained from 1981-1990 for the earlier years 1948-1980.

To put these removals into perspective, for 2000-2011, reduction landings have averaged 490,700 mt, bait landings have average about 342 mt, and recreational landings have averaged about 114 mt. In general, the recreational landings represent about 0.02% of the reduction landings and about 33% of the bait landings.

4.4.3 Recreational Catch-at-Age

The combined landings by bait and recreational fisheries are compared with those by the reduction fishery in Figure 4.13. This small amount of recreational catches was combined with reduction and bait landings to produce a single catch at age matrix for use in stock assessment models (Table 4.12). Specifically, the total landings in weight based on all three fisheries were divided by the reduction landings to calculate an annual expansion factor. This expansion factor was multiplied by the catch at age matrix in Table 4.4.

4.4.4 Potential Biases, Uncertainty, and Measures of Precision

Uncertainty associated with recreational landings is substantial, but probably no worse than for bait. The MRIP/MRFSS provides estimates of PSE (proportional standard error) as a measure of precision. These values (not reported here) ranged between 22% and 99%, and averaged 42%.

4.5 Discards and Bycatch

Discarding of Gulf menhaden from the shrimp trawl fishery prosecuted across the northern Gulf of Mexico has been shown to occur. However, data regarding the magnitude of the discards is unavailable. Thus, other methods were used to try to get at the scale of the discards.

First, a Gulf menhaden CPUE from the SEAMAP program for the period 1987 – 2011 was developed. These results (catch of Gulf menhaden in numbers per trawl hour) are summarized in Table 4.13 with a few caveats. First, the data are only from summer and fall seasons. Second, they exclude data sampled by the state of Texas because Texas trawls are smaller than trawls from other agencies. Other agencies sample in zones offshore of Texas (zones 18-21) so sufficient data are available within zones 18-21 to calculate CPUE. Zone locations can be found in Figure 4.14.

Dr. Elizabeth Scott-Denton (NMFS Galveston) was contacted about access to shrimp fishery data. She provided background information on bycatch in the shrimp trawl fishery (NMFS 1998, Scott-Denton 2007), as well as information on shrimp trawl landings and effort. Effort data were used in conjunction with CPUE to obtain estimates of Gulf menhaden discards. Effort data are summarized in Table 4.14 by area (zone groupings) for 1987-2011. Because effort data were available at the area level (not the zone level), zone-specific CPUE in Table 4.13 were averaged based on proportion of shrimp landings within each zone to the total landings for each area. That is, the offshore (depth zones 1-3 in the shrimp effort file) proportion of shrimp landings in zones 10-12 were used to weight CPUE from these zones to arrive at area 2 CPUE. Similar calculations were done for zones 13-17 for area 3 and zones 18-21 for area 4. No calculations were needed for zones 1-9 in area 1. Figure 4.15 presents the CPUE for these areas 2-4. Based on these caveats above, estimated Gulf menhaden discards are summarized in Table 4.14 and Figure 4.16.

In general, these discards are thought to be age-0 to age-4 individuals based on length composition data from SEAMAP trawls (Figure 4.17). Mean lengths at age from the Gulf Menhaden fishery were used with a cumulative distribution function of Gulf Menhaden lengths from SEAMAP to calculate proportions at age in the SEAMAP data. The percentages that resulted were 26.6% age-0, 35.6% age-1, 27.5% age-2, 7.9% age-3, and 2.4% age-4. Under that assumption, the estimated number of discards can be converted to weight in metric tons based on the mean weight of menhaden at mid-year (Table 3.10 and summarized in Table 4.15). The assumption was that SEAMAP trawls would catch similar sized menhaden as shrimp trawls would.

The magnitude of these landings is small, but on par with bait landings. We do not recommend use of this data stream in the base model, but they can be considered for sensitivity runs of BAM and alternate models under consideration. For BAM, the discard stream can be added to the appropriate catch at age. For ASPIC, the additional biomass can be added to the biomass stream based on reduction, bait, and recreational landings.

4.5.1 Potential Biases, Uncertainty, and Measures of Precision

Uncertainty in the discard estimates from the shrimp trawl fishery is probably large, but generally unknown. Potential biases exist. We are assuming that the CPUE for summer and fall seasons represent the full year. However, summer and fall effort represents about 85% of total effort for the period 1987-2009. Likewise we are assuming that the CPUE for area 4 (zones 18-21 off Texas) is representative, despite lacking Texas data. We are also assuming that the catches from SEAMAP are similar to catches that would likely be found in shrimp trawl gear, and that mean lengths at age of menhaden captured in the Gulf Menhaden fishery are similar to lengths of menhaden caught in SEAMAP trawls and therefore shrimp trawls.

Table 4.1 Years of activity for individual menhaden reduction plants along the U.S. Gulf of Mexico coast, 1964-2011.

Year	Plant																	Total Plants
	54	55	56	57	58	59	60	61	62	63	64	65	68	69	70	71	72	
1964	●	●	●	●	●	●	●		●	●	●	●						11
1965	●	●	●	●	●		●		●	●		●	●	●	●			12
1966	●	●	●	●	●		●	●	●	●	●	●	●	●				13
1967	●	●	●	●	●		●		●	●	●	●	●	●		●		13
1968	●	●	●	●	●		●	●	●	●	●	●	●	●		●		14
1969	●	●	●	●	●			●	●	●	●	●	●	●		●		13
1970	●	●	●	●	●		●		●	●	●	●	●	●		●		13
1971	●	●	●	●	●		●		●	●	●	●	●	●		●		13
1972	●	●	●	●	●				●	●	●		●	●		●		11
1973		●	●	●	●				●	●	●		●	●		●		10
1974		●	●	●	●				●	●	●		●	●		●		10
1975	●	●	●	●	●				●	●	●		●	●		●		11
1976	●	●	●	●	●				●	●	●		●	●		●		11
1977	●	●	●	●	●				●	●	●		●	●		●		11
1978	●	●	●	●	●				●	●	●		●	●		●		11
1979	●	●	●	●	●				●	●	●		●	●		●		11
1980	●	●	●	●	●				●	●	●		●	●		●		11
1981	●	●	●	●	●				●	●	●		●	●		●		11
1982	●	●	●	●	●				●	●	●		●	●		●		11
1983	●	●	●	●	●				●	●	●		●	●		●		11
1984	●	●	●	●	●				●	●	●		●	●		●		11
1985		●	●	●							●		●	●		●		7
1986		●	●	●	●						●		●	●		●		8
1987		●	●	●	●						●		●	●		●		8
1988		●	●	●	●						●		●	●		●		8
1989		●	●	●	●						●		●	●		●	●	9
1990		●	●	●	●						●		●	●		●	●	9
1991			●	●	●								●	●		●	●	7
1992			●		●								●	●		●	●	6
1993			●		●								●	●		●	●	6
1994			●		●								●	●		●	●	6
1995			●		●								●	●		●	●	6
1996			●		●								●			●	●	5
1997			●		●								●			●	●	5
1998			●		●								●			●	●	5
1999			●		●								●			●	●	5
2000			●		●								●			●		4
2001			●		●								●			●		4
2002			●		●								●			●		4
2003			●		●								●			●		4
2004			●		●								●			●		4
2005			●		●								●			●		4
2006			●		●								●			●		4
2007			●		●								●			●		4
2008			●		●								●			●		4
2009			●		●								●			●		4
2010			●		●								●			●		4
2011			●		●								●			●		4

Table 4.1 (*cont.*)

Plant	Name	Location
54	Fish Meal Company	Moss Point, MS
55	Standard Product Company	Moss Point, MS
56	Haynie Products Company, currently Omega Protein, Inc.	Moss Point, MS
57	Empire Menhaden Company	Empire, LA
58	Quinn Menhaden Fisheries, currently Daybrook Fisheries, Inc.	Empire, LA
59	Fish Meal & Oil Company (Bennett)	Dulac, LA
60	Quinn Menhaden Fisheries	Dulac, LA
61	Smith Meal Company	Apalachicola, FL
62	Fish Meal Company	Morgan City, LA
63	Gulf Menhaden Company	Cameron, LA
64	Louisiana Menhaden Company	Cameron, LA
65	Texas Menhaden Company	Sabine Pass, TX
68	Seacoast Products, currently Omega Protein, Inc.	Intracoastal City, LA
69	Terrebonne Menhaden Company	Dulac, LA
70	Florida Reduction Plant	Dulac, LA
71	Omega Protein, Inc.	Cameron, LA
72	Gulf Protein	Morgan City, LA

Table 4.2 Gulf menhaden landings and effort (vessel-ton-weeks, VTW) from the reduction purse-seine fishery, 1948-2010; landings from the bait fisheries, 1950-2011; landings estimated from the recreational fishery (MRFSS), 1981-2011, and combined landings for all fisheries. Recreational landings represent removals of A+B1+B2 by weight. Average values used for shaded areas: subsequent 10-yr average for early years.

Year	Reduction Landings (1000 mt)	Reduction Effort (vtw)	Bait Landings (1000 mt)	Recreational Catches (1000 mt)	Combined Total Landings (1000 mt)
1948	74.6	40.7	0.009	0.199	74.81
1949	107.4	66.2	0.009	0.199	107.61
1950	147.2	82.2	0.000	0.199	147.40
1951	154.8	94.2	0.003	0.199	155.00
1952	227.1	113.3	0.004	0.199	227.30
1953	195.7	104.7	0.001	0.199	195.90
1954	181.2	113.0	0.001	0.199	181.40
1955	213.3	122.9	0.011	0.199	213.51
1956	244.0	155.1	0.014	0.199	244.21
1957	159.3	155.2	0.003	0.199	159.50
1958	196.2	202.8	0.040	0.199	196.44
1959	325.9	205.8	0.009	0.199	326.11
1960	376.8	211.7	0.005	0.199	377.00
1961	455.9	241.6	0.011	0.199	456.11
1962	479.0	289.0	0.009	0.199	479.21
1963	437.5	277.3	0.020	0.199	437.72
1964	407.8	272.9	0.038	0.199	408.04
1965	461.2	335.6	0.196	0.199	461.59
1966	357.6	381.3	0.254	0.199	358.05
1967	316.1	404.7	0.058	0.199	316.36
1968	371.9	382.8	0.207	0.199	372.31
1969	521.5	411.0	0.137	0.199	521.84
1970	545.9	400.0	0.280	0.199	546.38
1971	728.5	472.9	0.366	0.199	729.06
1972	501.9	447.5	0.292	0.199	502.39
1973	486.4	426.2	0.446	0.199	487.04
1974	587.4	485.5	0.319	0.199	587.92
1975	542.6	538.0	0.211	0.199	543.01
1976	561.2	575.8	0.328	0.199	561.73
1977	447.1	532.7	0.298	0.199	447.60
1978	820.0	574.3	0.404	0.199	820.60
1979	777.9	533.9	1.727	0.199	779.83
1980	701.3	627.6	0.999	0.199	702.50
1981	552.6	623.0	1.073	0.036	553.71
1982	853.9	653.8	1.577	0.051	855.53
1983	923.5	655.8	1.739	0.023	925.26
1984	982.8	645.9	2.317	0.005	985.12
1985	881.1	560.6	2.870	0.424	884.39
1986	822.1	606.5	1.675	0.244	824.02
1987	894.2	604.2	11.660	0.197	906.06
1988	623.7	594.1	10.287	0.462	634.45
1989	569.6	555.3	12.201	0.416	582.22
1990	528.3	563.1	10.210	0.128	538.64

1991	544.3	472.3	5.325	0.048	549.67
1992	421.4	408.0	7.902	0.130	429.43
1993	539.2	455.2	9.308	0.161	548.67
1994	761.6	472.0	9.987	0.179	771.77
1995	463.9	417.0	8.068	0.053	472.02
1996	479.4	451.7	12.270	0.077	491.75
1997	611.2	430.2	11.927	0.019	623.15
1998	486.2	409.3	7.403	0.045	493.65
1999	684.3	414.5	8.137	0.049	692.49
2000	579.3	417.6	0.793	0.196	580.29
2001	521.3	400.6	0.760	0.045	522.11
2002	574.5	386.7	0.467	0.102	575.07
2003	517.1	363.2	0.487	0.112	517.70
2004	468.7	390.5	0.417	0.122	469.24
2005	433.8	326.0	0.261	0.069	434.13
2006	464.4	367.2	0.174	0.079	464.65
2007	453.8	369.2	0.251	0.042	454.09
2008	425.4	355.8	0.139	0.027	425.57
2009	457.5	377.8	0.134	0.052	457.69
2010	379.7	320.3	0.069	0.157	379.93
2011	613.3	367.2	0.156	0.370	613.83

Table 4.3 Purse seine catch of Gulf menhaden, in thousands of metric tons, by State, 1945-73 (Table 3 *from* Nicholson 1978); **NA** = Records not available.

Year	**Florida**	**Mississippi**	**Louisiana**	**Texas**	**Total**
1945	3.2	26.0	0.0	0.0	29.2
1946	**NA**	**NA**	8.9	0.0	**NA**
1947	**NA**	10.1	24.0	0.0	**NA**
1948	15.4	34.8	40.0	12.7	102.9
1949	11.2	30.1	75.2	19.0	135.5
1950	0.6	31.1	94.3	21.2	147.2
1951	1.5	43.4	96.7	13.2	154.8
1952	4.8	70.7	129.2	24.0	228.7
1953	2.0	22.1	142.1	30.3	196.5
1954	0.0	36.0	121.8	23.4	181.2
1955	0.9	56.0	135.1	23.0	215.0
1956	0.0	70.3	144.6	29.9	244.8
1957	0.0	59.3	74.5	26.1	159.9
1958	4.6	56.1	109.5	31.3	201.5
1959	8.2	79.7	191.5	55.9	335.3
1960	2.8	99.1	213.2	65.6	380.7
1961	1.9	136.7	260.2	60.7	459.5
1962	0.0	119.5	314.1	47.1	480.7
1963	0.0	113.6	288.4	35.8	437.8
1964	0.0	107.8	271.4	30.2	409.4
1965	0.0	126.4	308.6	28.1	463.1
1966	3.1	86.4	252.0	17.6	359.1
1967	0.0	75.5	231.4	10.4	317.3
1968	0.3	67.8	282.2	23.2	373.5
1969	0.0	102.2	388.3	33.2	523.7
1970	0.0	93.4	435.2	19.5	548.1
1971	0.0	138.8	560.9	28.5	728.2
1972	0.0	80.8	420.9	0.0	501.7
1973	0.0	80.4	405.7	0.0	486.1

Table 4.4 Sample size as number of fish (N Fish) and number of sets (N Sets), landings in numbers and biomass of fish, and mean weight of fish landed from the Gulf menhaden reduction fishery, 1964-2011.

Year	Sample Size (N Fish)	Sample Size (N Sets)	Landings		Mean Weight (g)
			(millions)	(1000 mt)	
1964	12,260	625	4,949.61	407.8	82.4
1965	15,185	790	6,232.41	461.2	74.0
1966	12,429	640	4,244.05	357.6	84.3
1967	14,065	721	4,640.74	316.1	68.1
1968	15,273	795	4,579.55	371.9	81.2
1969	14,764	759	7,413.81	521.5	70.3
1970	10,402	527	5,646.10	545.9	96.7
1971	7,654	393	7,924.12	728.5	91.9
1972	9,886	998	4,892.95	501.9	102.6
1973	8,953	896	4,290.77	486.4	113.4
1974	10,086	1,009	5,378.89	587.4	109.2
1975	9,527	953	4,510.51	542.6	120.3
1976	13,389	1,355	6,169.25	561.2	91.0
1977	14,897	1,492	6,107.66	447.1	73.2
1978	12,944	1,300	9,587.37	820.0	85.5
1979	11,121	1,163	7,922.39	777.9	98.2
1980	9,883	1,014	7,220.39	701.3	97.1
1981	10,273	1,042	7,539.08	552.6	73.3
1982	10,341	1,076	9,014.50	853.9	94.7
1983	14,523	1,485	8,902.67	923.5	103.7
1984	15,936	1,599	11,119.14	982.8	88.4
1985	13,225	1,324	11,451.55	881.1	76.9
1986	16,494	1,652	9,369.73	822.1	87.7
1987	16,458	1,647	11,115.25	894.2	80.4
1988	12,402	1,240	8,088.53	623.7	77.1
1989	13,950	1,392	7,241.50	569.6	78.7
1990	11,456	1,152	5,824.35	528.3	90.7
1991	11,378	1,164	4,803.74	544.3	113.3
1992	14,214	1,524	3,916.22	421.4	107.6
1993	14,576	1,537	5,241.47	539.2	102.9
1994	16,062	1,680	7,316.97	761.6	104.1
1995	13,489	1,470	3,896.31	463.9	119.1
1996	12,115	1,506	4,566.80	479.4	105.0
1997	9,923	1,124	5,950.04	611.2	102.7
1998	9,043	1,073	4,598.36	486.2	105.7
1999	10,641	1,183	6,198.27	684.3	110.4
2000	8,383	969	5,607.89	579.3	103.3
2001	6,222	740	3,951.25	521.3	131.9
2002	5,597	836	4,999.81	574.5	114.9
2003	7,839	1066	5,274.69	517.1	98.0
2004	6,644	942	5,001.29	468.7	93.7
2005	6,206	899	4,398.26	433.8	98.6
2006	4,698	594	4,895.06	464.4	94.9
2007	3,989	657	4,750.05	453.8	95.5
2008	4,663	594	3,608.25	425.4	117.9
2009	6,193	748	3,603.26	457.5	127.0
2010	3,678	461	3,891.65	379.7	97.6
2011	7,254	835	7,208.81	613.3	85.1

Table 4.5 Estimated reduction landings of Gulf menhaden in numbers by age (in millions) from 1964-2011.

Year	0	1	2	3	4	5	6	Total
1964	2.76	3,329.28	1,495.15	118.07	4.35	0.00	0.00	4,949.61
1965	43.43	5,031.39	1,076.63	80.27	0.70	0.00	0.00	6,232.41
1966	30.45	3,314.42	865.16	33.76	0.26	0.00	0.00	4,244.05
1967	22.44	4,267.65	337.66	13.00	0.00	0.00	0.00	4,640.74
1968	65.06	3,475.23	1,001.30	37.45	0.50	0.00	0.00	4,579.55
1969	20.80	6,075.00	1,286.34	31.66	0.00	0.00	0.00	7,413.81
1970	50.19	3,279.85	2,279.98	36.08	0.00	0.00	0.00	5,646.10
1971	21.59	5,761.13	1,955.45	181.84	4.12	0.00	0.00	7,924.12
1972	19.11	3,047.74	1,733.53	88.54	4.03	0.00	0.00	4,892.95
1973	49.90	3,033.00	1,106.98	99.62	1.27	0.00	0.00	4,290.77
1974	1.41	3,846.75	1,471.65	59.08	0.00	0.00	0.00	5,378.89
1975	108.77	2,440.51	1,499.21	461.83	0.19	0.00	0.00	4,510.51
1976	0.00	4,591.39	1,373.94	203.92	0.00	0.00	0.00	6,169.25
1977	0.00	4,659.95	1,331.72	110.37	5.63	0.00	0.00	6,107.66
1978	0.00	6,787.44	2,742.01	52.67	5.24	0.00	0.00	9,587.37
1979	0.00	4,701.22	2,877.16	337.20	6.06	0.75	0.00	7,922.39
1980	65.86	3,409.41	3,261.11	436.15	46.30	1.56	0.00	7,220.39
1981	0.00	5,750.53	1,424.94	329.40	29.66	3.34	1.22	7,539.08
1982	0.00	5,146.74	3,301.96	503.54	58.47	2.05	1.74	9,014.50
1983	0.00	4,685.73	3,809.23	382.61	23.77	1.33	0.00	8,902.67
1984	0.00	7,749.55	2,881.49	438.36	49.03	0.72	0.00	11,119.14
1985	0.00	8,682.70	2,498.62	233.71	36.52	0.00	0.00	11,451.55
1986	0.00	4,275.99	4,892.04	174.92	25.82	0.96	0.00	9,369.73
1987	0.00	6,699.48	3,975.56	427.77	12.45	0.00	0.00	11,115.25
1988	0.00	5,337.69	2,581.40	151.47	17.97	0.00	0.00	8,088.53
1989	0.00	5,550.44	1,622.02	66.98	2.06	0.00	0.00	7,241.50
1990	0.00	3,889.22	1,785.01	136.21	13.14	0.34	0.43	5,824.35
1991	0.00	2,217.51	2,339.91	215.62	28.16	2.54	0.00	4,803.74
1992	0.00	2,187.28	1,505.75	197.12	24.22	1.70	0.16	3,916.22
1993	4.81	3,492.05	1,532.49	193.48	15.69	2.80	0.15	5,241.47
1994	0.00	3,627.60	3,195.61	441.16	48.96	3.65	0.00	7,316.97
1995	0.00	1,369.16	2,423.43	99.65	3.92	0.15	0.00	3,896.31
1996	0.61	1,784.16	2,513.17	251.08	16.84	0.94	0.00	4,566.80
1997	0.00	3,235.59	2,398.83	276.10	38.22	1.30	0.00	5,950.04
1998	0.00	1,804.82	2,587.12	189.66	15.19	1.57	0.00	4,598.36
1999	0.00	3,368.77	2,392.99	416.85	19.66	0.00	0.00	6,198.27
2000	0.00	2,029.80	3,164.53	347.67	62.51	3.38	0.00	5,607.89
2001	0.00	987.61	2,653.34	290.52	18.93	0.84	0.00	3,951.25
2002	0.00	1,585.63	2,863.10	533.96	17.12	0.00	0.00	4,999.81
2003	0.00	1,910.07	3,011.72	339.55	13.35	0.00	0.00	5,274.69
2004	0.00	2,799.37	1,764.03	400.32	37.57	0.00	0.00	5,001.29
2005	82.00	1,731.94	2,380.94	188.97	13.58	0.00	0.83	4,398.26
2006	0.00	2,246.46	2,301.27	317.77	29.57	0.00	0.00	4,895.06
2007	0.00	2,199.69	2,421.38	111.75	13.33	3.90	0.00	4,750.05
2008	0.00	960.56	2,465.66	160.32	21.71	0.00	0.00	3,608.25
2009	0.00	455.00	2,633.36	466.61	47.92	0.38	0.00	3,603.26
2010	0.00	2,057.65	1,572.35	238.80	22.45	0.40	0.00	3,891.65
2011	49.11	4,553.35	2,287.46	266.98	49.48	2.44	0.00	7,208.81

Table 4.6 Weeks at Omega Protein fish factory in Moss Point, MS, where port samples were collected from run boats; size and age compositions are compared to samples from regular fishing steamers for the same week in 2002, 2003, 2007, and 2011; no samples were acquired from run boats in 2004, 2006, or 2008-2010 (samples from 2005 lost due to Hurricane Katrina).

2011

Week ending date: 6/4/2011

Run Boats					Steamers				
Age	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**	**Age**	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**
1	21	35	139	52	1	73	36	145	60
2	34	57	182	120	2	123	61	179	117
3	5	8	196	145	3	7	3	200	160
total	60				**total**	203			

Week ending date: 6/11/2011

Run Boats					Steamers				
Age	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**	**Age**	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**
1	41	31	152	67	1	48	39	151	66
2	90	67	180	111	2	73	59	179	113
3	3	2	202	151	3	3	2	200	149
total	134				**total**	124			

2007

Week ending date: 5/19/2007

Run Boats					Steamers				
Age	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**	**Age**	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**
1					1	9	20	157	77
2	9	90	172	108	2	36	78	175	113
3	1	10	195	148	3	1	2	194	154
total	10				**total**	46			

Week ending date: 7/07/2007

Run Boats					Steamers				
Age	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**	**Age**	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**
1	1	13	154	63	1	18	16	154	71
2	7	87	176	107	2	87	79	177	113
3					3	5	5	194	145
total	8					110			

2003

Week ending date: 5/24/2003

Run Boats					Steamers				
Age	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**	**Age**	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**
1	4	14	160	75	1	2	22	149	67
2	24	86	174	103	2	7	78	171	96
3					3				
total	28				**total**	9			

Week ending date: 8/02/2003

Run Boats					Steamers				
Age	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**	**Age**	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**
1	1	11	152	59	1	4	11	164	85
2	8	89	175	103	2	33	89	179	117
3					3				
total	9				**total**	37			

Week ending date: 8/30/2003

Run Boats					Steamers				
Age	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**	**Age**	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**
1	6	35	165	84	1	2	8	165	88
2	9	53	182	117	2	24	92	184	126
3	2	12	194	132	3				
total	17				**total**	28			

2002

Week ending date: 7/06/2002

Run Boats					Steamers				
Age	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**	**Age**	**N at age**	**% age comp**	**Mean FL (mm)**	**Mean wgt (g)**
1	3	30	166	92	1	25	48	162	84
2	6	60	189	139	2	24	46	182	121
3	1	10	209	162	3	3	6	200	172
total	10				**total**	52			

Table 4.7 Standardized fishery-dependent indices of age-1 and age-2 Gulf menhaden (from the catch-at-age matrix) divided by fishery effort (number of purse-seine sets per year).

Year	Age-1 index	Age-2 index
1983	0.12	0.10
1984	0.18	0.07
1985	0.35	0.10
1986	0.14	0.16
1987	0.19	0.11
1988	0.19	0.09
1989	0.21	0.06
1990	0.14	0.06
1991	0.09	0.09
1992	0.11	0.06
1993	0.11	0.06
1994	0.14	0.12
1995	0.06	0.11
1996	0.08	0.11
1997	0.14	0.10
1998	0.08	0.12
1999	0.14	0.10
2000	0.09	0.13
2001	0.05	0.13
2002	0.07	0.13
2003	0.08	0.13
2004	0.12	0.08
2005	0.11	0.11
2006	0.10	0.11
2007	0.11	0.12
2008	0.06	0.16
2009	0.02	0.14
2010	0.14	0.11
2011	0.23	0.12

Table 4.8 Nominal fishing effort information for the Gulf menhaden fishery from CDFRs, 1983-2011. ***Note:*** *CDFR data sets for 1992, 1993, and 2005 are incomplete.*

Year	**Gulf menhaden landings (1000 mt)**	**CDFR data**				**Catch (mt)/set**
		Total no. of sets	**No. of vessel-days w/ 1 or more sets**	**Total no. of possible vessel-days**	**Percent days fished [at least one set made]**	
1983	923.5	37,587	7,764	10,412	0.75	24.6
1984	982.8	42,040	7,821	10,023	0.78	23.4
1985	881.1	25,145	4,987	6,921	0.72	35.0
1986	822.1	33,860	6,634	9,027	0.73	24.3
1987	894.2	34,898	7,026	8,779	0.80	25.6
1988	623.7	28,262	6,115	8,430	0.73	22.1
1989	569.6	26,427	6,174	8,621	0.72	21.6
1990	528.3	28,163	6,711	8,829	0.76	18.8
1991	544.3	26,648	5,624	7,372	0.76	20.4
1992	421.4	-	-	-	-	
1993	539.2	-	-	-	-	
1994	761.6	26,234	5,272	6,975	0.76	29.0
1995	463.9	21,264	4,662	6,824	0.68	21.8
1996	479.4	22,777	4,870	6,718	0.72	21.0
1997	611.2	23,378	4,707	6,623	0.71	26.1
1998	486.2	21,317	4,153	6,552	0.63	22.8
1999	684.3	24,704	4,617	6,058	0.76	27.7
2000	579.3	23,733	4,077	5,592	0.73	24.4
2001	521.3	21,223	4,043	5,788	0.70	24.6
2002	574.5	22,579	4,056	5,655	0.72	25.4
2003	517.1	22,825	3,940	5,391	0.73	22.7
2004	468.7	22,839	3,973	5,557	0.71	20.5
2005	433.8	-	-	-	-	
2006	464.4	21,913	3,772	5,193	0.73	21.2
2007	453.8	19,428	3,570	5,396	0.66	23.4
2008	425.4	15,532	3,112	5,409	0.58	27.4
2009	457.5	18,260	3,752	5,579	0.67	25.1
2010	379.7	14,604	2,868	5,384	0.53	26.0
2011	613.3	19,644	3,513	5,082	0.69	31.2

Table 4.9 Number of fishing trips, catch per trips, and standard error of mean catch per trip by the Gulf menhaden reduction fleet, 1964-2011. Note that trip information is incomplete (*) for 1983 and 1984.

Year	**All Data**		
	N	**Catch/Trip (mt)**	**SE (mt)**
1964	4,692	87.3	1.186
1965	4,235	109.4	2.508
1966	3,617	99.3	1.617
1967	3,221	98.6	1.521
1968	3,176	117.6	1.736
1969	3,638	144.0	1.840
1970	3,769	145.5	1.854
1971	4,453	163.6	1.755
1972	3,659	137.2	1.609
1973	3,437	141.5	1.654
1974	3,943	149.0	1.676
1975	3,987	136.1	1.515
1976	4,066	138.0	1.576
1977	3,724	120.1	1.417
1978	4,474	183.3	1.727
1979	4,078	190.8	1.880
1980	4,186	167.5	1.717
1981	3,811	145.0	1.566
1982	4,695	181.9	1.712
1983	1,218*	151.0	3.280
1984	2,128*	190.6	2.487
1985	3,343	263.6	2.139
1986	4,028	204.1	1.793
1987	4,427	202.0	1.694
1988	3,629	171.9	1.757
1989	3,618	157.4	1.743
1990	3,557	148.5	1.657
1991	2,977	182.8	2.060
1992	2,468	170.8	1.955
1993	2,928	184.2	1.952
1994	3,238	235.2	2.137
1995	2,587	179.3	2.135
1996	2,693	178.0	2.090
1997	2,831	215.9	2.222
1998	2,447	198.7	2.307
1999	2,811	243.4	2.339
2000	2,600	222.8	2.622
2001	2,434	214.2	2.613
2002	2,552	225.1	2.533
2003	2,370	218.2	2.666
2004	2,371	197.7	2.499
2005	2,083	208.3	2.675
2006	2,088	222.4	2.807
2007	2,193	206.9	2.731
2008	1,896	224.4	3.041
2009	2,280	200.6	2.579
2010	1,755	216.4	3.223
2011	2,457	249.6	2.667

Table 4.10 Mean net tonnage (metric) of the Gulf menhaden purse-seine fleet by selected fishing years since 1970.

Fishing Year	Mean net tonnage	No. of vessels in calculation	Range of net tonnages
1970	248	72	80-386
1980	315	79	139-453
1990	317	75	147-447
2000	338	43	197-453
2011	353	37	187-453

Table 4.11 Gulf menhaden bait landings (mt) by gear from NOAA Fisheries OST and NOAA ALS data bases, 1950-2011.

Year	Gear				Total Bait
	Purse	Gill	Haul	Other	
1950	0.0	0.0	0.0	0.0	0.0
1951	0.0	0.0	2.9	0.0	2.9
1952	0.0	0.0	3.7	0.0	3.7
1953	0.0	0.0	1.2	0.0	1.2
1954	0.0	0.0	1.1	0.0	1.1
1955	0.0	1.5	9.3	0.0	10.8
1956	0.0	11.2	2.0	1.1	14.4
1957	0.0	2.9	0.5	0.0	3.4
1958	0.0	31.0	9.0	0.0	40.1
1959	0.0	3.7	5.5	0.0	9.2
1960	0.0	2.9	2.4	0.0	5.4
1961	0.0	4.3	5.7	1.5	11.4
1962	0.0	8.9	0.0	0.0	8.9
1963	0.0	0.5	0.0	19.6	20.2
1964	0.0	33.8	0.5	3.9	38.1
1965	0.0	140.3	44.8	10.8	195.9
1966	0.0	190.0	51.4	12.8	254.1
1967	2.3	38.6	13.5	3.4	57.7
1968	41.8	129.3	34.4	1.7	207.2
1969	0.0	83.1	52.4	1.8	137.3
1970	0.5	231.5	42.2	5.6	279.8
1971	2.3	255.6	92.8	15.2	365.9
1972	39.2	97.2	153.4	2.3	292.2
1973	125.4	66.3	253.0	1.1	445.9
1974	54.5	124.6	138.4	1.1	318.6
1975	45.9	48.9	113.0	3.6	211.5
1976	102.2	52.1	173.1	0.1	327.5
1977	98.0	30.1	169.1	0.4	297.6
1978	134.2	32.0	236.9	0.5	403.6
1979	838.7	37.0	849.4	1.7	1,726.8
1980	502.9	22.9	472.8	0.1	998.7
1981	544.6	21.4	507.0	0.0	1,073.0
1982	797.6	40.0	739.1	0.0	1,576.7
1983	883.4	36.3	819.5	0.0	1,739.2
1984	1,167.3	72.7	1,077.3	0.0	2,317.4
1985	1,447.5	359.3	1,063.0	0.2	2,870.0
1986	251.3	1,353.5	70.5	0.1	1,675.4
1987	8,567.7	2,931.3	155.9	5.6	11,660.5
1988	8,485.8	1,594.9	205.5	1.0	10,287.2
1989	11,226.7	894.3	79.6	0.2	12,200.8
1990	9,996.4	178.7	2.0	32.5	10,209.6
1991	4,958.6	91.6	272.4	2.4	5,325.0
1992	6,503.1	1,295.0	57.0	47.3	7,902.4
1993	6,470.1	836.8	46.6	1,954.4	9,308.0
1994	7,320.8	670.3	0.1	1,995.8	9,987.1
1995	5,828.3	1,276.1	0.0	963.7	8,068.0
1996	10,758.4	1,500.2	0.0	11.5	12,270.1
1997	10,349.4	1,559.0	9.6	8.7	11,926.8

1998	6,505.3	892.0	0.0	5.4	7,402.8
1999	7,210.4	914.7	0.1	11.5	8,136.5
2000	0.0	744.8	0.3	48.0	793.1
2001	1.2	698.9	0.1	59.9	760.1
2002	0.0	439.3	0.2	27.7	467.2
2003	0.0	460.6	0.5	25.6	486.6
2004	0.0	370.8	0.9	45.8	417.5
2005	12.8	214.8	2.9	30.4	260.9
2006	4.7	158.3	0.6	10.1	173.7
2007	1.4	210.8	5.2	33.7	251.0
2008	0.0	119.7	0.1	19.6	139.3
2009	1.0	85.3	2.2	45.5	134.1
2010	0.1	33.6	0.0	34.9	68.7
2011	0.0	139.3	5.1	11.2	155.5

Table 4.12 Catch in numbers per trawl hour from SEAMAP database for zones 10-21, 1987-2011. Data is only from summer and fall seasons, and does not include data from the state of Texas (shallow inshore waters for zones 18-21). All CPUEs for zones 1-9 (Gulf coast of Florida) were 0.

Year	**Shrimp statistical zone**												**Total yearly CPUE**
	10	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	
1987	0	0	0	1.56	1.63	1.91	0.68	9.01	0.19	0.67	0.11	0	1.40
1988	0	0	0	2.31	2.26	1.79	2.40	3.15	0.49	0.56	0	2.56	1.34
1989	0	3.92	0	1.45	5.30	2.86	29.71	20.65	43.74	4.85	3.42	0.11	10.73
1990		0.43	0	3.93	5	0.32	0.90	8.26	0.27	3.16	0.18	0	1.86
1991		0.02	0	2.89	0.23	0.09	3.80	0.34	0.12	2.10	0.09	0	0.86
1992	0	0		6.77	2.13	0.24	1.63	7.59	0.14	3.44	0	0.39	1.97
1993	0	0.81		8.88	0.43	12.03	0.40	42.38	0.41	2.08	0.18	0.24	4.66
1994	0	0.05		0.14	1.44	5.40	7.10	3.19	0.65	0.63	0.27	0.05	1.67
1995	0	0.18		63.51	1.72	0.07	28.19	4.12	0.93	14.91	1.48	1.71	6.90
1996	0	1.12		0.80	1.60	3.47	1.72	0.96	1.88	2.08	3.43	0.05	1.45
1997	0	2.36		1.73	2.48	1.07	5.36	1.01	0	16.93	15.04	21.99	5.78
1998		1.10	0	6.21	3.64	0.11	3.27	0.54	1.04	22.61	1.80	1.22	4.27
1999	0	0.03	6.32	8.74	1.53	1.03	10.85	1.27	4.37	2.58	6.55	0.37	3.55
2000	0	5.09		5.29	0.14	0.60	0.38	14.73	2.46	14.47	0.52	1.35	4.97
2001	0	0.65	0	0.18	0.23	0.23	0.23	1.57	0.06	3.55	0.09	0	0.71
2002	0	2.42		11.67	0.15	0.59	15.81	0.57	6.46	13.80	3.86	0.89	5.87
2003	0	1.11		1.02	8.62	1.70	1.55	2.13	0.66	3.48	6.02	0	2.53
2004		0.41		0	1.06	0.87	0	8.26	1.09	0.66	0.40	0.10	1.63
2005		1.89		20	5.19	0.34	0.22	25.27	0	9.89	0.03	20.54	7.81
2006	0	0.09		19.71	8.32	0.29	1.66	0.92	20.28	6.10	3.32	5.36	4.70
2007		0.11		2.69	4.41	1.58	7.29	3.32	4.13	4.43	0.14	0	3.05
2008	0	0.29		0	0	0.12	0.16		0.42	1.80	0.07	0.08	0.32
2009	0	0.12		4.26	3.38	2.59	0.20	60.79	1.08	0.07	0	0.29	0.84
2010	0.07	0	0	1.23	0	0.52	7.68		2.92	0.04	0	0	1.13
2011	0	0.64		0	0	0.14	0		7.76	6.88	1.66	0.72	1.56

Table 4.13 Shrimp trawl effort for areas 2-4 (zones 10-21) in trawl days for 1987-2010 (multiply by 24 to obtain trawl hours to match CPUE from SEAMAP in Table 4.10).

Year	Sum of Effort By Area (Zone)			
	2 (10-12)	3 (13-17)	4 (18-21)	Grand Total
1981	9,004.88	83,826.73	56,832.70	149,664.31
1982	12,063.27	79,616.86	60,064.49	151,744.62
1983	15,510.11	80,866.28	50,145.99	146,522.38
1984	22,360.10	81,633.55	59,584.15	163,577.80
1985	17,816.78	94,021.39	58,590.26	170,428.43
1986	13,512.48	118,469.61	67,432.41	199,414.50
1987	11,371.29	127,128.63	79,052.17	217,552.09
1988	15,565.00	98,849.00	69,597.11	184,011.11
1989	22,485.80	107,676.93	70,333.23	200,495.96
1990	20,189.36	98,710.74	74,483.82	193,383.92
1991	16,816.93	117,474.76	72,102.96	206,394.65
1992	14,221.96	105,725.43	73,269.02	193,216.41
1993	12,341.67	101,779.99	71,341.26	185,462.92
1994	12,777.94	94,333.81	65,306.94	172,418.69
1995	13,740.72	81,487.97	52,299.04	147,527.73
1996	8,988.45	80,988.28	61,338.58	151,315.31
1997	12,658.43	96,275.07	64,090.93	173,024.43
1998	15,628.14	96,989.34	62,262.04	174,879.52
1999	15,425.83	103,817.84	58,255.60	177,499.27
2000	14,499.53	98,164.15	61,635.12	174,298.80
2001	13,617.96	104,378.35	59,280.54	177,276.85
2002	14,974.47	111,110.53	54,592.74	180,677.74
2003	11,024.51	90,969.60	43,997.76	145,991.87
2004	9,435.66	69,114.11	47,036.45	125,586.22
2005	8,702.81	46,082.19	32,125.24	86,910.24
2006	8,068.15	50,321.48	24,018.94	82,408.57
2007	9,474.54	43,996.96	21,156.03	74,627.53
2008	8,447.54	30,474.54	19,212.48	58,134.56
2009	9,155.80	38,472.16	20,508.61	68,136.57
2010	2,387.25	32,068.89	19,201.89	53,658.03
2011	5,739.44	33,684.65	21,532.44	60,956.53

Table 4.14 Estimates discards of Gulf menhaden from the U.S. shrimp trawl fishery in the northern Gulf of Mexico, 1987 – 2011. Estimates are given in numbers and metric tons. Estimates based on CPUE and Effort given in Tables 4.10 and 4.11.

Year	**Number**	**Biomass(mt)**
1987	8,703,305	745.30
1988	6,947,247	594.90
1989	49,060,306	4,201.00
1990	11,781,644	1,008.80
1991	5,699,281	488.00
1992	12,397,633	1,061.60
1993	25,778,681	2,207.40
1994	7,599,184	650.70
1995	61,648,749	5,278.90
1996	5,867,204	502.40
1997	25,385,937	2,173.80
1998	25,532,420	2,186.30
1999	18,824,065	1,611.90
2000	22,285,006	1,908.20
2001	3,733,412	319.70
2002	26,960,567	2,308.60
2003	10,324,054	884.00
2004	3,047,685	261.00
2005	19,247,314	1,648.10
2006	16,465,110	1,409.90
2007	4,950,289	423.90
2008	480,027	41.10
2009	15,429,052	1,321.20
2010	1,171,023	100.30
2011	2,655,240	227.40

Table 4.15 Gulf menhaden catch in numbers (in millions) at age from the reduction, bait and recreational fisheries combined, 1964-2011.

Year	0	1	2	3	4	5	6	Total
1964	2.80	3,331.20	1,496.00	118.10	4.40	0.00	0.00	4,952.48
1965	43.50	5,035.70	1,077.50	80.30	0.70	0.00	0.00	6,237.74
1966	30.50	3,318.60	866.30	33.80	0.30	0.00	0.00	4,249.42
1967	22.50	4,271.10	337.90	13.00	0.00	0.00	0.00	4,644.51
1968	65.10	3,479.00	1,002.40	37.50	0.50	0.00	0.00	4,584.54
1969	20.80	6,078.90	1,287.20	31.70	0.00	0.00	0.00	7,418.58
1970	50.20	3,282.70	2,282.00	36.10	0.00	0.00	0.00	5,651.05
1971	21.60	5,765.60	1,957.00	182.00	4.10	0.00	0.00	7,930.26
1972	19.10	3,050.70	1,735.20	88.60	4.00	0.00	0.00	4,897.73
1973	50.00	3,037.00	1,108.40	99.70	1.30	0.00	0.00	4,296.46
1974	1.40	3,850.10	1,472.90	59.10	0.00	0.00	0.00	5,383.63
1975	108.90	2,442.40	1,500.30	462.20	0.20	0.00	0.00	4,513.92
1976	0.00	4,595.70	1,375.20	204.10	0.00	0.00	0.00	6,175.03
1977	0.00	4,665.10	1,333.20	110.50	5.60	0.00	0.00	6,114.44
1978	0.00	6,792.40	2,744.00	52.70	5.20	0.00	0.00	9,594.41
1979	0.00	4,712.90	2,884.30	338.00	6.10	0.80	0.00	7,942.00
1980	66.00	3,415.20	3,266.70	436.90	46.40	1.60	0.00	7,232.72
1981	0.00	5,762.10	1,427.80	330.10	29.70	3.30	1.20	7,554.22
1982	0.00	5,156.60	3,308.30	504.50	58.60	2.10	1.70	9,031.68
1983	0.00	4,694.70	3,816.50	383.30	23.80	1.30	0.00	8,919.65
1984	0.00	7,767.90	2,888.30	439.40	49.10	0.70	0.00	11,145.41
1985	0.00	8,715.20	2,508.00	234.60	36.70	0.00	0.00	11,494.37
1986	0.00	4,286.00	4,903.50	175.30	25.90	1.00	0.00	9,391.61
1987	0.00	6,788.30	4,028.30	433.40	12.60	0.00	0.00	11,262.64
1988	0.00	5,429.70	2,625.90	154.10	18.30	0.00	0.00	8,227.93
1989	0.00	5,673.40	1,658.00	68.50	2.10	0.00	0.00	7,401.91
1990	0.00	3,965.30	1,819.90	138.90	13.40	0.30	0.40	5,938.32
1991	0.00	2,239.40	2,363.00	217.70	28.40	2.60	0.00	4,851.16
1992	0.00	2,229.00	1,534.40	200.90	24.70	1.70	0.20	3,990.88
1993	4.90	3,553.40	1,559.40	196.90	16.00	2.80	0.20	5,333.52
1994	0.00	3,676.00	3,238.30	447.00	49.60	3.70	0.00	7,414.64
1995	0.00	1,393.10	2,465.90	101.40	4.00	0.20	0.00	3,964.52
1996	0.60	1,830.10	2,577.90	257.50	17.30	1.00	0.00	4,684.42
1997	0.00	3,298.80	2,445.70	281.50	39.00	1.30	0.00	6,066.33
1998	0.00	1,832.50	2,626.70	192.60	15.40	1.60	0.00	4,668.80
1999	0.00	3,409.10	2,421.60	421.80	19.90	0.00	0.00	6,272.41
2000	0.00	2,033.30	3,169.90	348.30	62.60	3.40	0.00	5,617.47
2001	0.00	989.10	2,657.40	291.00	19.00	0.80	0.00	3,957.36
2002	0.00	1,587.20	2,865.90	534.50	17.10	0.00	0.00	5,004.77
2003	0.00	1,912.30	3,015.20	339.90	13.40	0.00	0.00	5,280.80
2004	0.00	2,802.60	1,766.10	400.80	37.60	0.00	0.00	5,007.04
2005	82.10	1,733.30	2,382.80	189.10	13.60	0.00	0.80	4,401.60
2006	0.00	2,247.70	2,302.50	317.90	29.60	0.00	0.00	4,897.72
2007	0.00	2,201.10	2,422.90	111.80	13.30	3.90	0.00	4,753.12
2008	0.00	960.90	2,466.60	160.40	21.70	0.00	0.00	3,609.66
2009	0.00	455.20	2,634.40	466.80	47.90	0.40	0.00	3,604.73
2010	0.00	2,058.90	1,573.30	238.90	22.50	0.40	0.00	3,893.96
2011	49.20	4,557.30	2,289.40	267.20	49.50	2.40	0.00	7,214.99

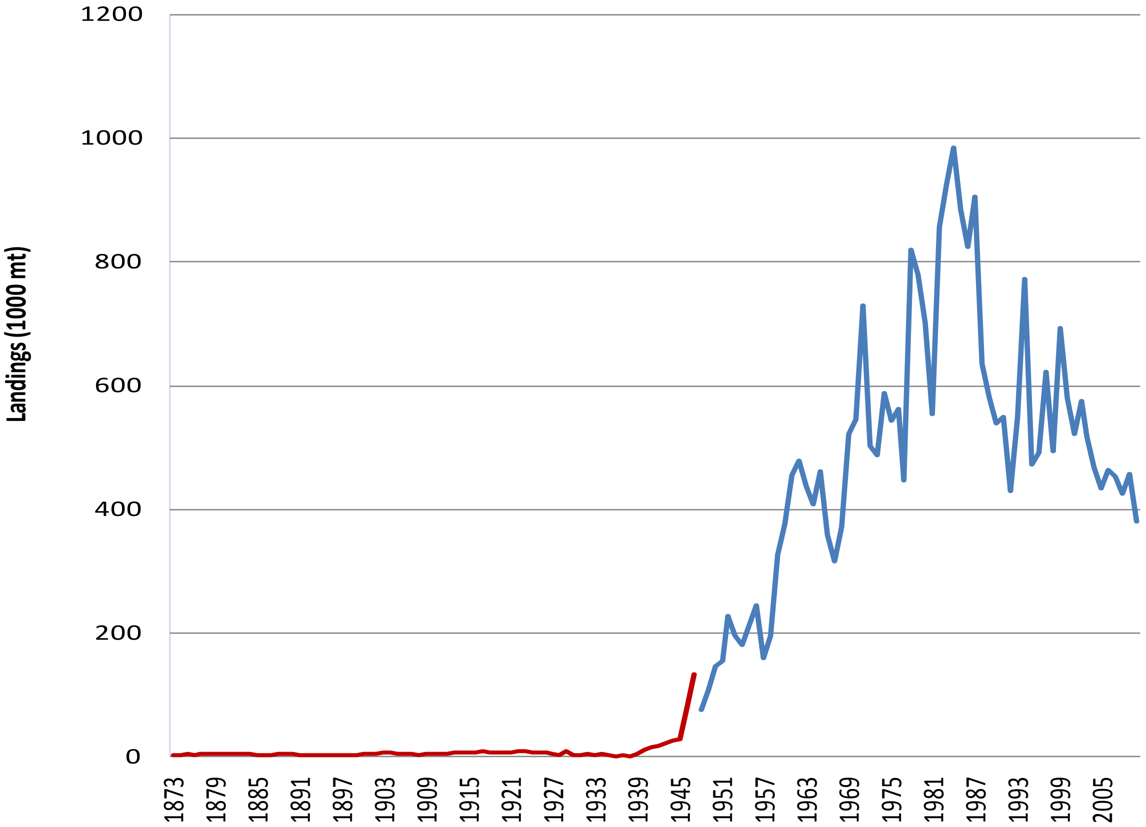


Figure 4.1 Total Gulf menhaden landings along the Gulf of Mexico coast of the U.S., 1873-2010. Reconstructed landings were developed from historical reports for 1873-1947. Reduction landings maintained at NMFS Beaufort are combined with bait and recreational landings for 1948-2010.

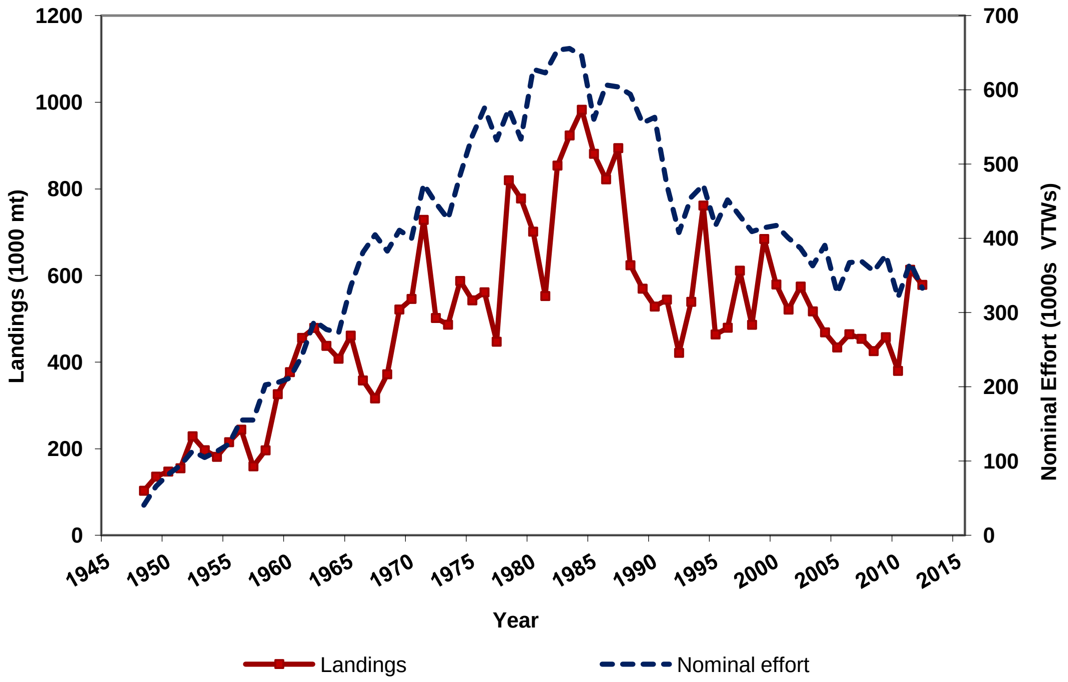


Figure 4.2 Annual values of Gulf menhaden reduction landings (1000 mt) and nominal effort (vessel-ton-week), 1948-2012.

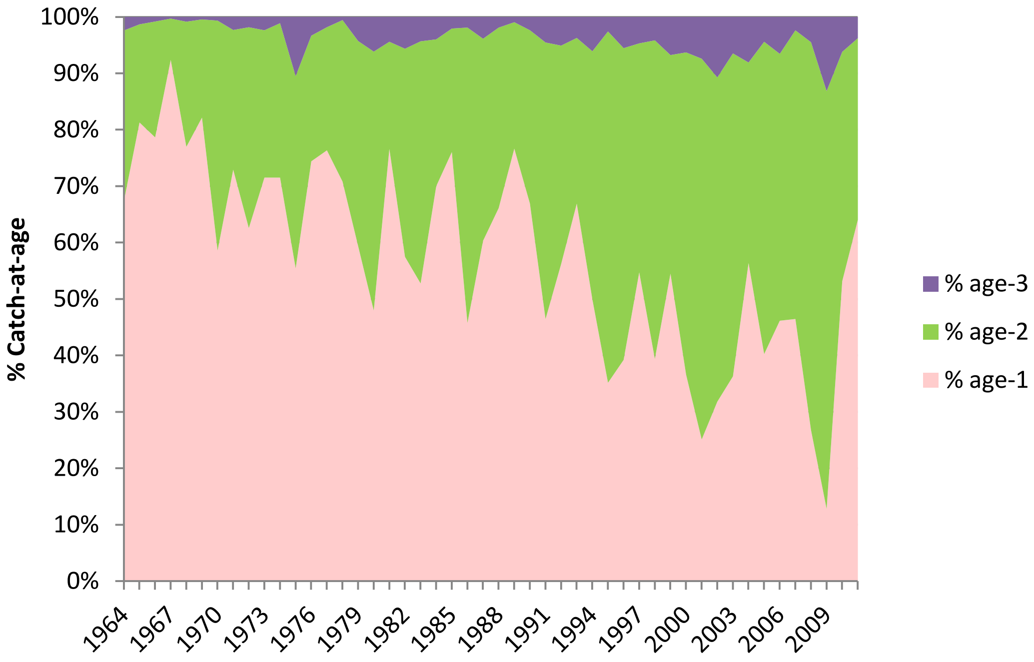


Figure 4.3 Percent age-1, age-2, and age-3 Gulf menhaden in the catch-at-age matrix, 1964-2011.

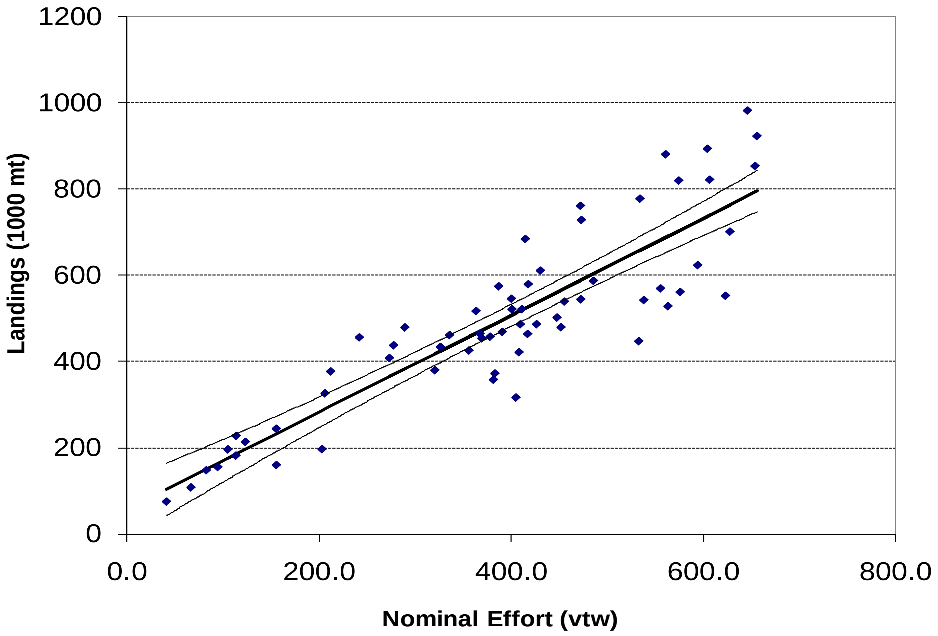


Figure 4.4 Relationship between Gulf menhaden reduction landings (1000 mt) and nominal fishing effort (vessel-ton-week), 1948-2010. The linear regression of landings on effort explains 79% (r^2) of the annual variability in landings.

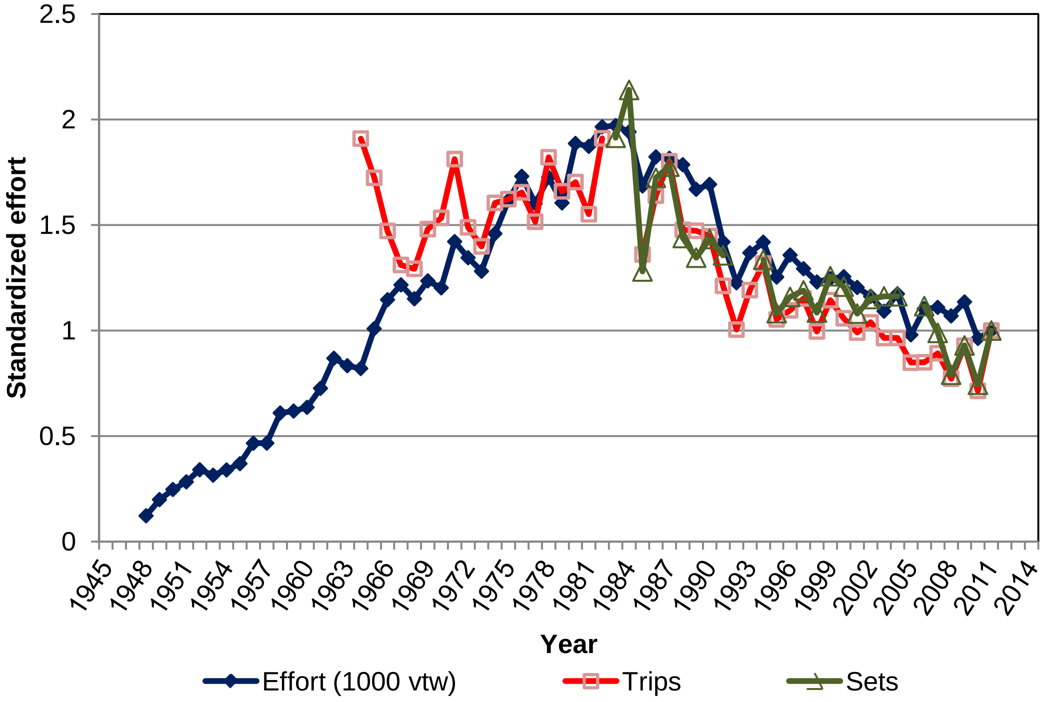


Figure 4.5 Comparison of nominal fishing effort for Gulf menhaden reduction fleet. Effort compared includes: (1) vessel-ton-week, 1948-2011, (2) trips, 1964-2011, and (3) purse-seine sets, 1983-2011. All effort estimates are standardized by dividing by the respective value in 2011 to put them on a common scale. Years with incomplete data (sets in 1992, 1993, and 2005 and trips in 1983-1984) are left blank.

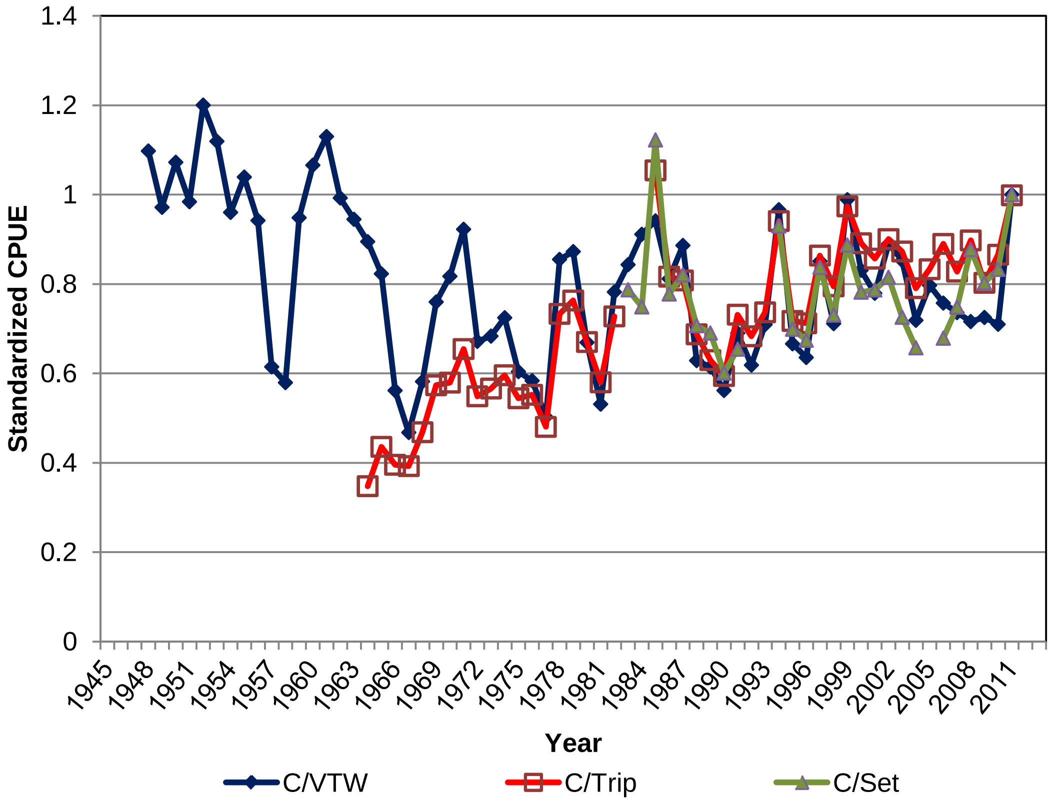


Figure 4.6 Comparison of calculated CPUE across different measures of fishing effort 1948-2011, including landings per vessel-ton-week (C/VTW), landings per trip (C/Trip) and catch per set.

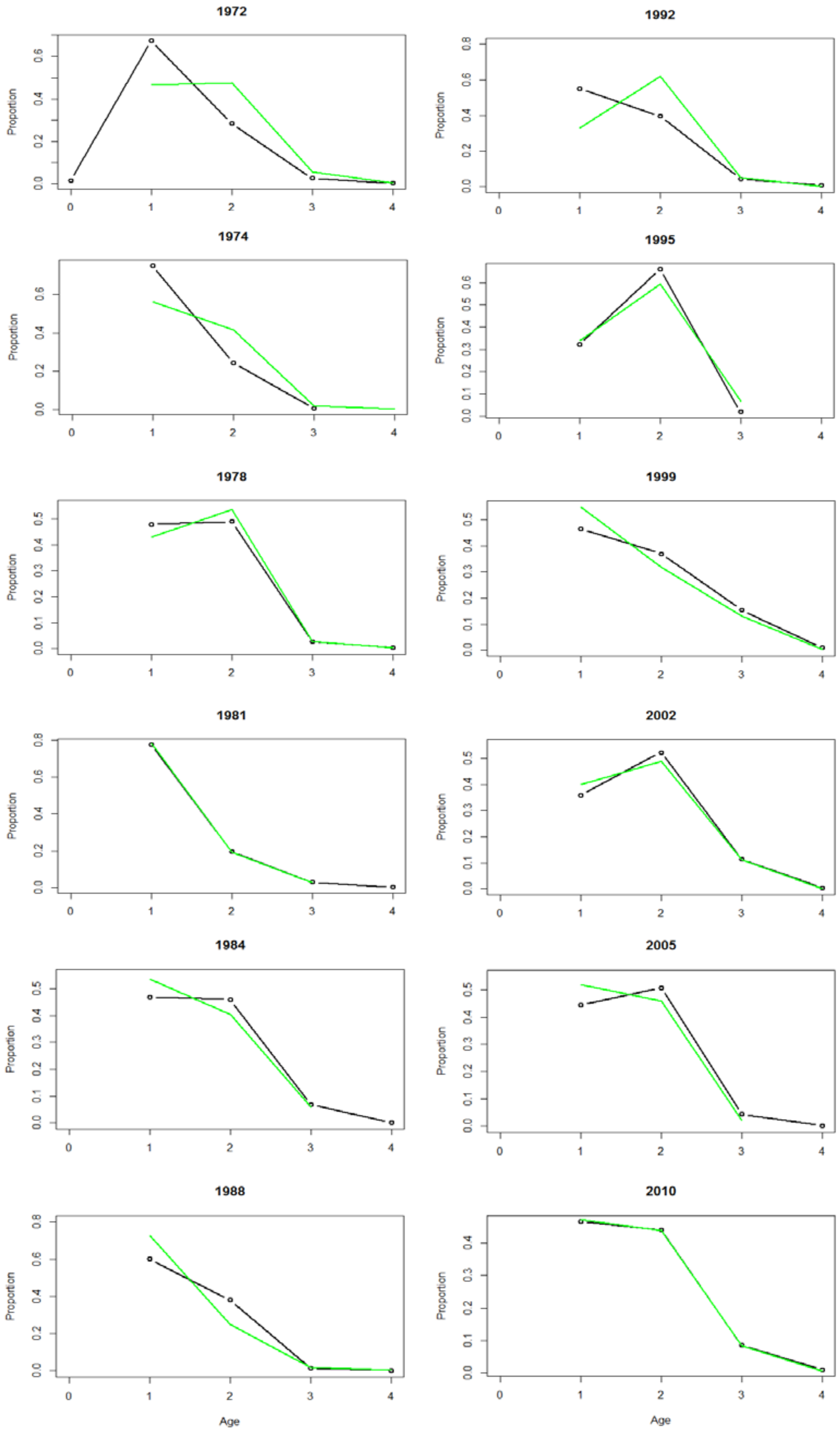


Figure 4.7 Plots of the proportion at age by year for the initial age reading done in the specified year (black) and for the re-read of the scale completed in 2012 (green).

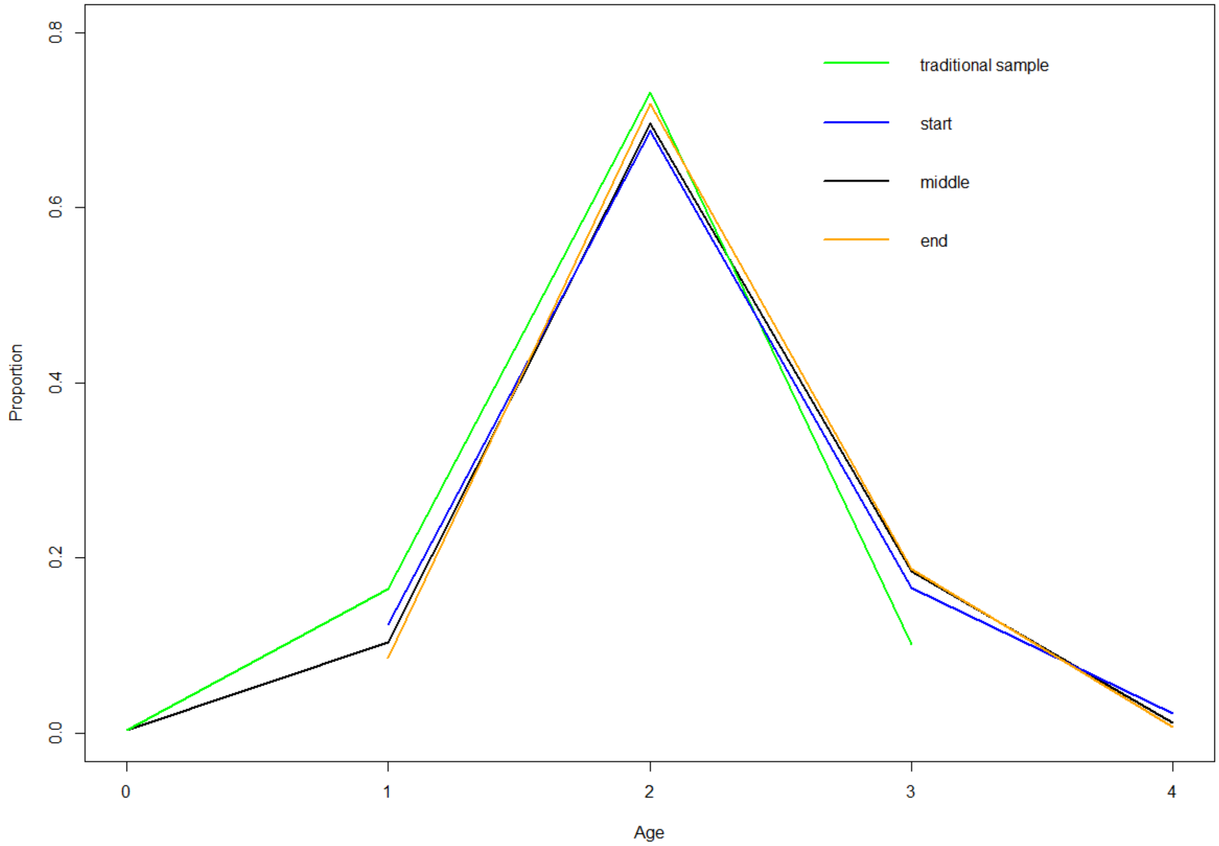


Figure 4.8 Age proportions across all pumpouts at all ports from all samples collected in 2012 for the traditional sample taken from the top of the hold and from samples from throughout the hold.

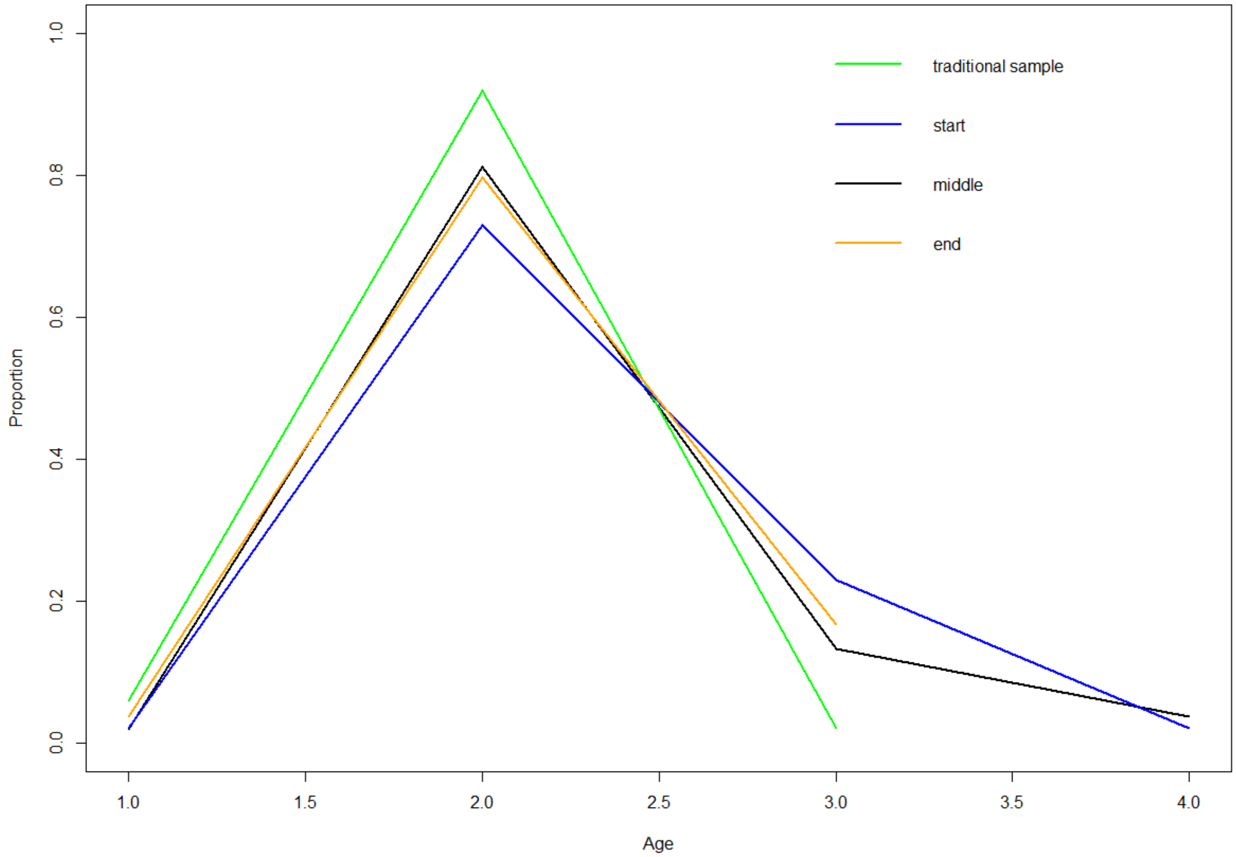


Figure 4.9 Age proportions across pumpouts during August 6-10 across all ports from samples collected in 2012 with the traditional sample taken from the top of the hold and the other samples taken from throughout the hold.

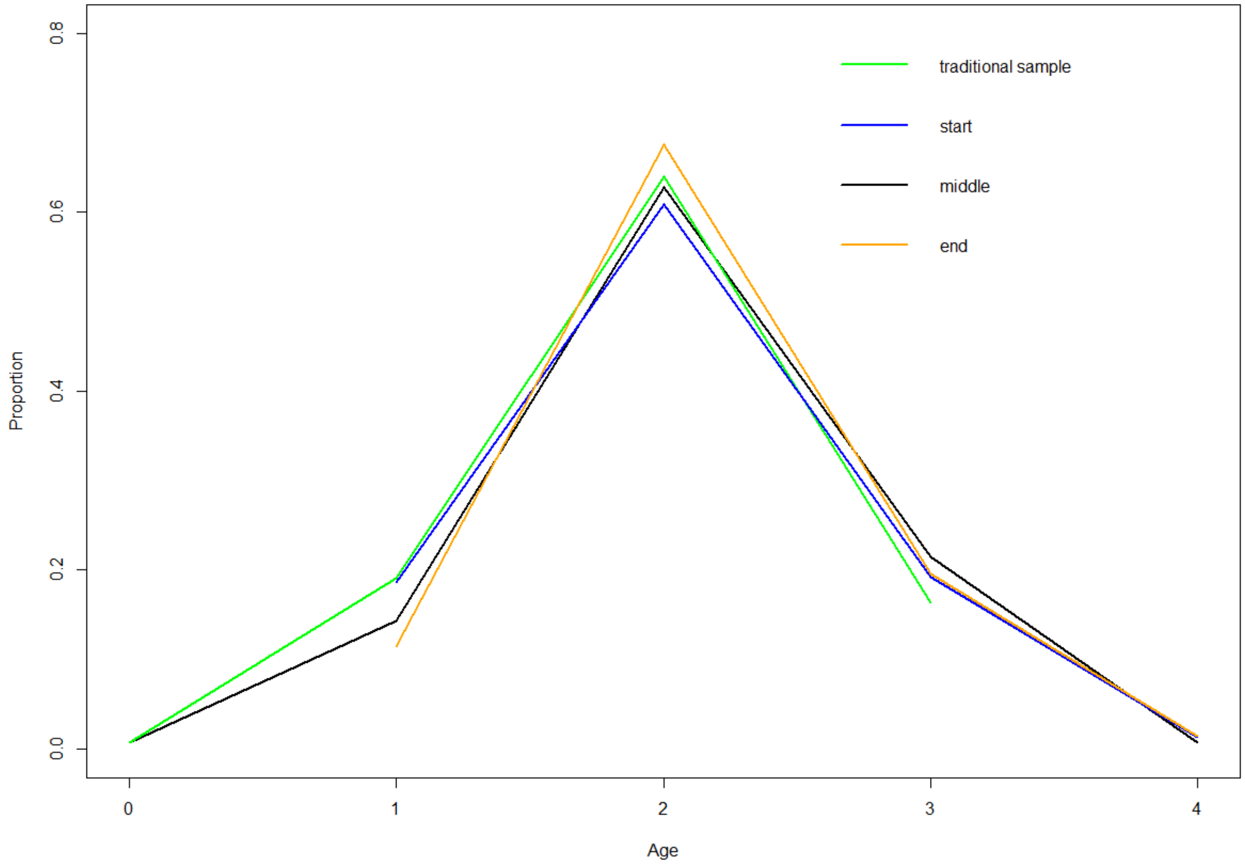


Figure 4.10 Age proportions across pumpouts during October 8-30 across all ports from samples collected in 2012 with the traditional sample taken from the top of the hold and the other samples taken from throughout the hold.

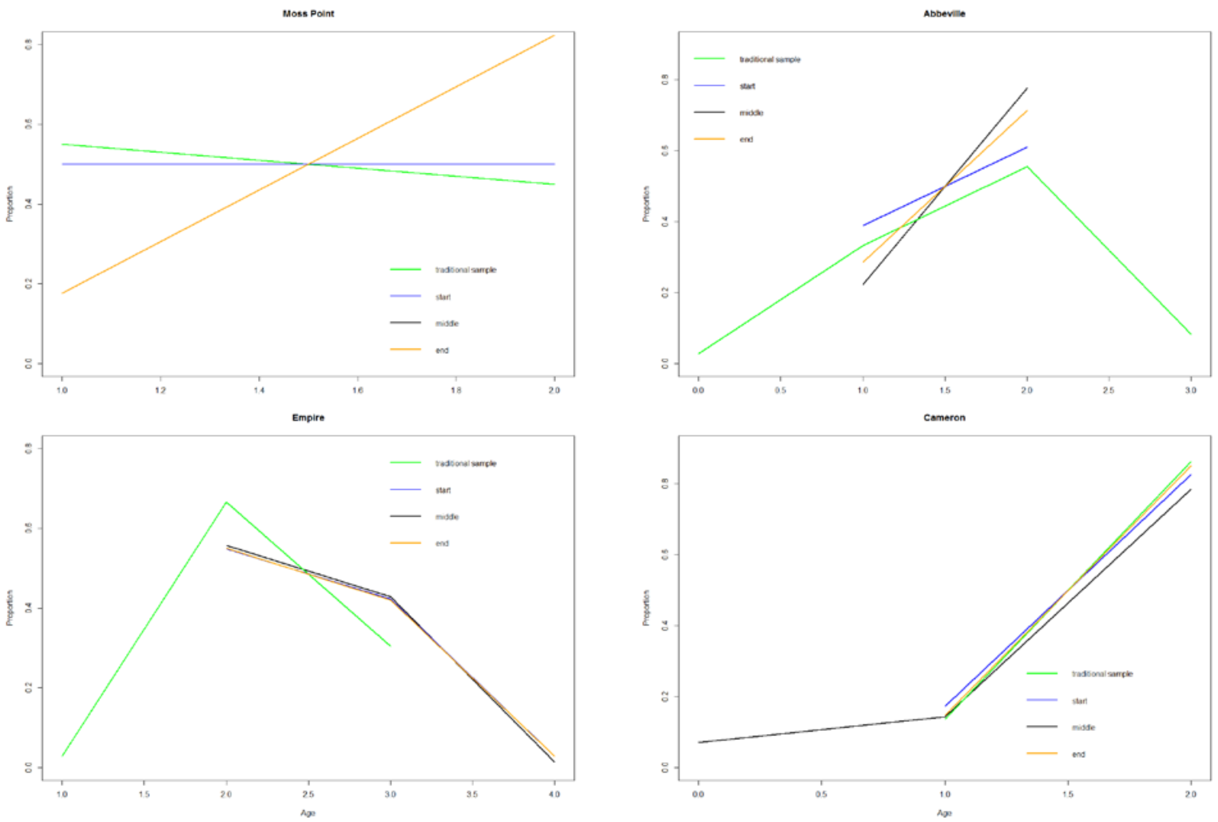


Figure 4.11 Age proportions across pumpouts during October 8-30 for each port from samples collected in 2012 with the traditional sample taken from the top of the hold and the other samples taken from throughout the hold.

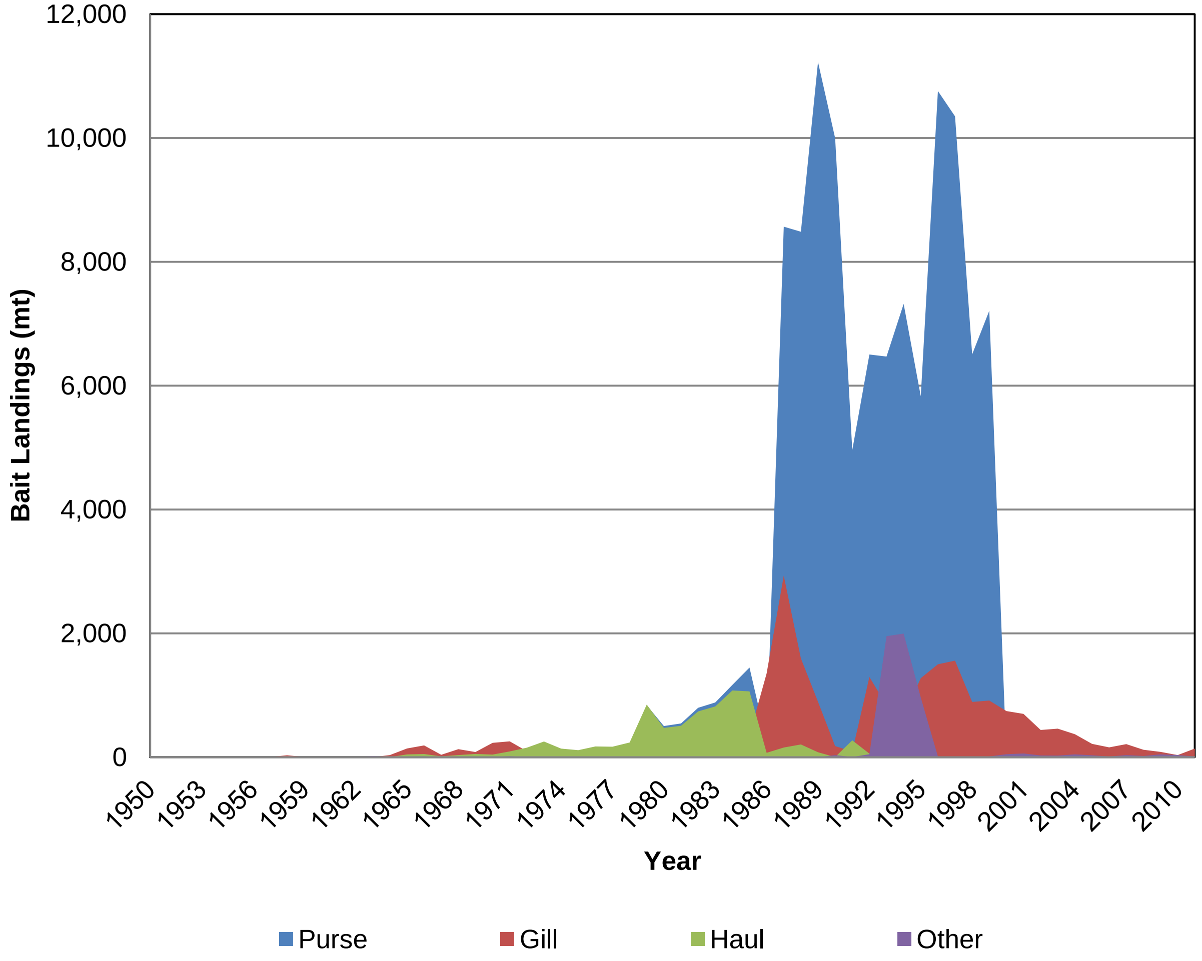


Figure 4.12 Gulf menhaden bait landings obtained from the NOAA Fisheries Commercial Landings database (NOAA ALS), 1950-2011; primarily purse seine, gill nets, haul seines, and other gears.

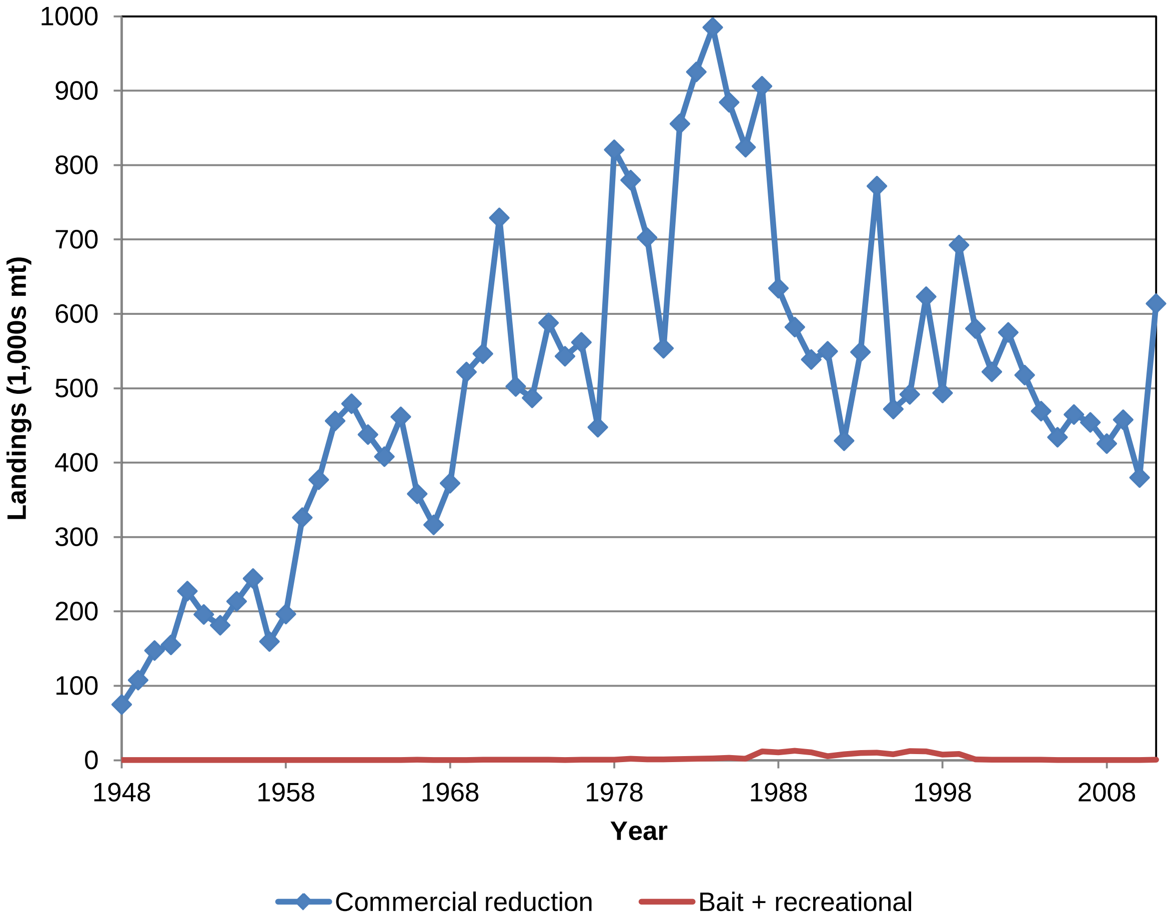


Figure 4.13 Comparison of reduction fishery with combined bait and recreational fisheries, 1948-2011.

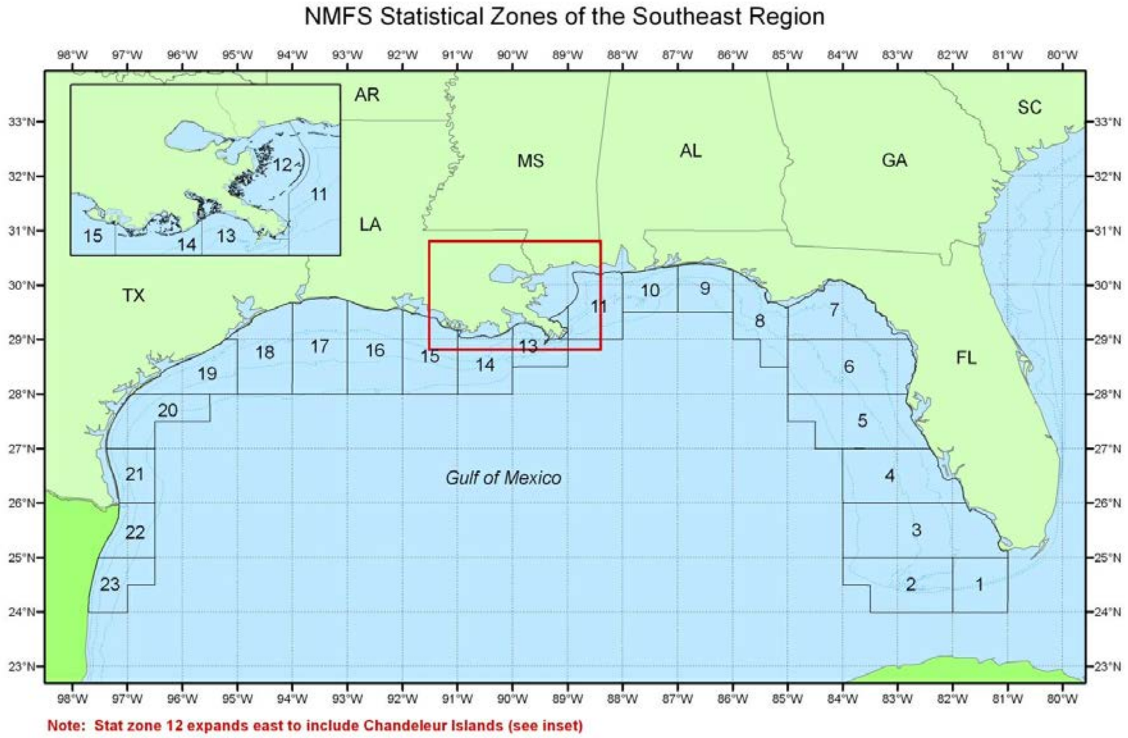


Figure 4.14 National Marine Fisheries Service Gulf Shrimp Landing Statistical Zones used for SEAMAP sampling with trawls.

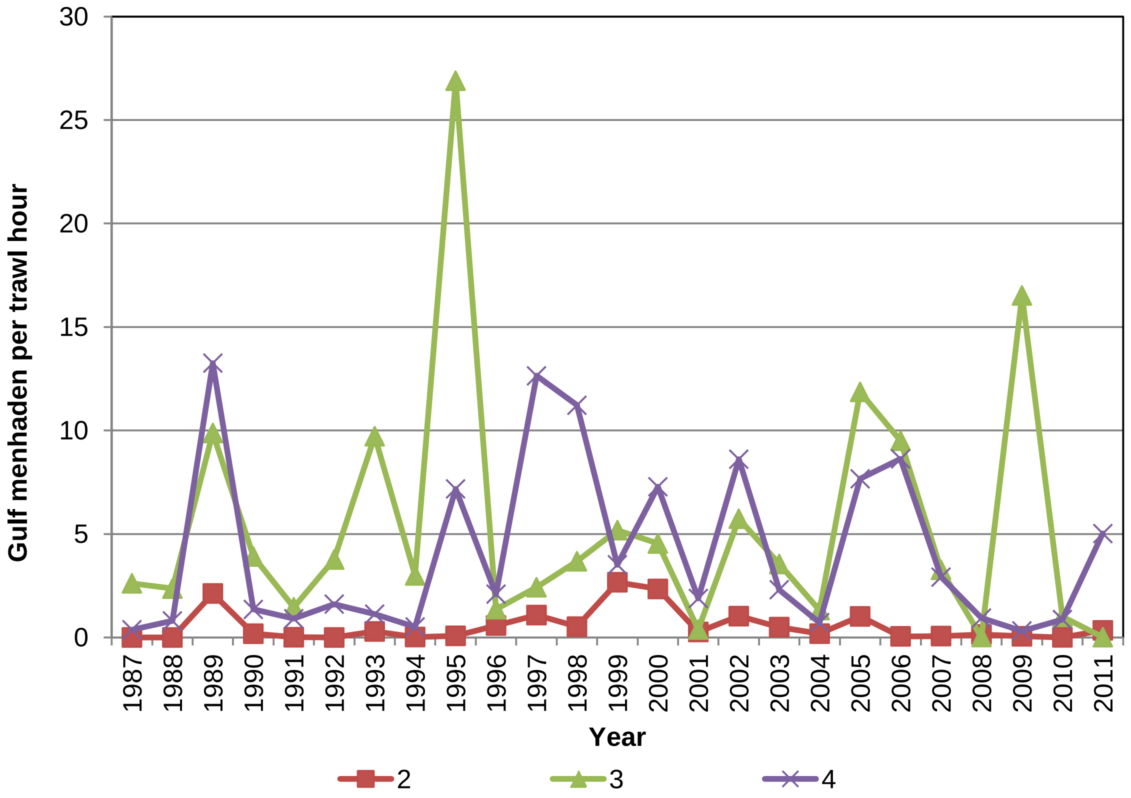


Figure 4.15 The offshore (depth zones 1-3 in the shrimp effort file) proportion of shrimp landings from 1987-2011 in Area 2 (zones 10-12), Area 3 (zones 13-17), and Area 4 (zones 18-21) used to weight CPUEs of potential shrimp discards.

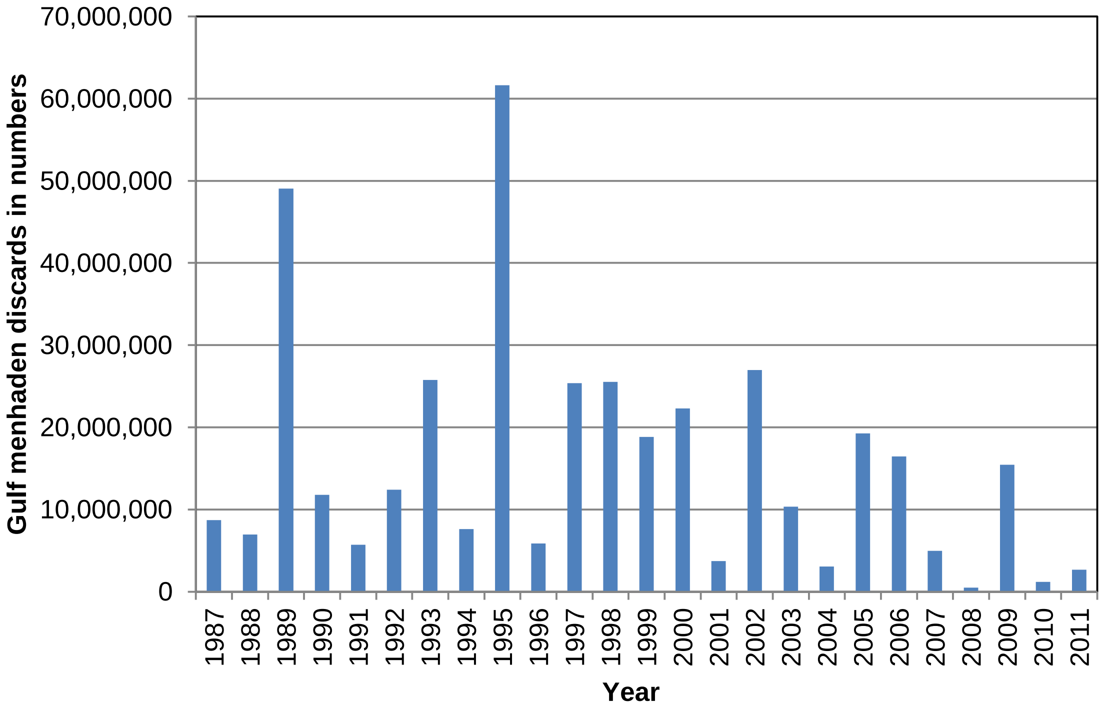


Figure 4.16 Estimated Gulf menhaden discards from 1987-2011 based on SEAMAP landings applied to NOAA shrimp landings.

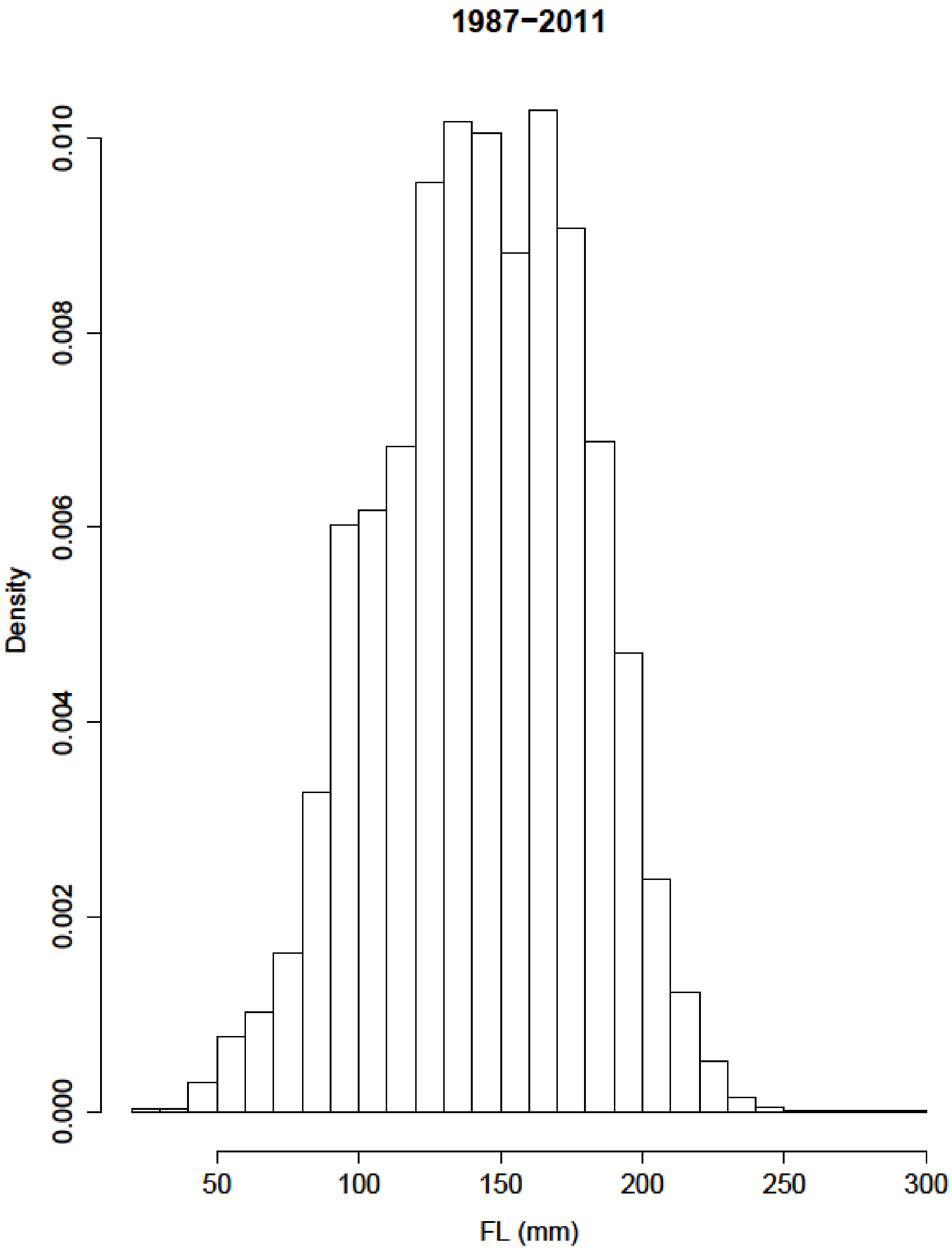


Figure 4.17 Histogram of fork lengths (FL) from the SEAMAP survey for 1987-2011 during June-November. Samples from trawls taken by the state of Texas were excluded due to identification questions.

5.0 Fishery-Independent Data Collection and Treatment

Data collected in Texas, Louisiana, Mississippi, Alabama, and Florida were considered for use in order to calculate two coast-wide indices of juvenile abundance based on bag seine data and trawl data. Gill net data were available from each state except Florida to calculate an adult index of abundance. Each state conducts separate surveys, which collect Gulf menhaden, however Gulf menhaden are not the target species. Below is a brief description of the data for each individual state sampling program. Tables 5.1-5.3 provide specifics on the states fishery-independent gears. In addition, SEAMAP plankton and trawl data were considered for creation of an index.

5.1 Seines

5.1.1 Texas Seine Data

Texas Parks and Wildlife Department's (TPWD) fishery-independent bag seines are utilized to determine relative abundance, size, species composition, and temporal and spatial distribution of various life history stages of fish and invertebrates in Texas coastal waters.

5.1.1.1 Survey Methods (Including Coverage, Intensity)

Each bay system and Gulf area in Texas serves as a non-overlapping stratum with a fixed number of samples per month (Figure 5.1). Sample locations are drawn independently and without replacement for each combination of gear, stratum, and month (season). Bag seine sample locations are randomly selected from grids (1-minute latitude by 1-minute longitude) that contains >15.2 m of shoreline. Each selected grid is subdivided into 144 5-second gridlets. All gridlets containing >15.2 m of shoreline are used to randomly choose sample sites. Prior to September 1984, sites were randomly selected from 100 fixed stations in each bay system, with random site selection since September 1984.

Bag seines are used in each of ten Texas estuarine systems: Sabine Lake, Galveston, Cedar Lakes, East Matagorda, Matagorda, San Antonio, Aransas, Corpus Christi, upper Laguna Madre, and lower Laguna Madre (Figure 5.1). Bag seines have been employed in seven Texas bay systems since October 1977; sample collection began in the East Matagorda Bay system February 1983, Sabine Lake in January 1986, and Cedar Lakes in January 1996.

Bag seines are pulled parallel to the shoreline for 15.2 m. The area swept (0.03 ha) is determined using distance pulled and actual width of the bag seine when pulled. One half of the monthly bag seine samples are collected during each half (days 1-15 and 16-31) of the month to ensure good temporal distribution of samples. No grid is sampled more than once in a month. Prior to October 1981, six bag seine samples were collected each month in each bay system (except during June 1978 when no samples were collected). From October 1981 through March 1988, 10 bag seine samples were collected each month in each bay system, with half of the samples collected during each half of the month. From April 1988 through December 1989, 12 bag seine samples were collected each month in each bay system. Beginning January 1990, 16 bag seine samples were collected each month in each bay system. Beginning January 1992, 20 samples were collected in each bay system each month, except in East Matagorda Bay and Cedar Lakes where 10 samples were collected per month.

5.1.1.2 Biological Sampling Methods (Including Coverage, Intensity)

Lengths [total (TL) or standard (SL)] of organisms caught are recorded. In bag seines, up to 19 specimens are measured for each species in each sample collected. Surface salinity (ppt), water temperature (°C), dissolved oxygen (ppm) and turbidity [Nephelometric Units (NTU)] are measured for each bag seine sample.

5.1.1.3 Ageing Methods

TPWD does not collect hard parts for age determination of Gulf menhaden at this time.

5.1.1.4 Use for an Index

Bag seine data from Texas were examined to be used in combination with data from other states to create an index for use in the base run. However, after analyzing coast-wide length frequencies of Gulf menhaden (*B. patronus*) from TPWD bag seines and other monitoring gears, the presence of larger individuals than previously reported in literature or commercial landings was questioned. In general, finescale menhaden (*B. gunteri*) grows to a considerably larger size than Gulf menhaden (*B. patronus*), making the presence of larger individuals of Gulf menhaden in the Texas data questionable due to potential identification issues with adult fish and consequently juvenile fish, because juvenile individuals are more difficult to identify to species level than adults. Finally, the assessment panel also explored the catches of finescale menhaden in each of the gears as well. Few catches of finescale menhaden occur in the gears that are catching juvenile individuals, but some adult individuals are captured with the gill net gear. If the adults are being sampled, where are the juveniles? The lack of small individuals captured in the seine and trawl gears again brought into question species identification. As a consequence, the assessment panel decided to exclude TPWD data and a recommendation that DNA testing be conducted across their size range to clarify this issue.

5.1.2 Louisiana Seine Data

The Louisiana seine is generally used to sample juvenile finfish, shellfish, and other marine organisms to monitor relative abundance, size distribution, and seasonal and long-term trends but is used more for environmental characterization.

5.1.2.1 Survey Methods (Including Coverage, Intensity)

The sampling design for Louisiana seines consists of fixed stations selected by coastal study areas to target areas known to have fish and shellfish when the sampling programs started (Figures 5.3 and 5.4).

At some sampling stations, land loss due to subsidence, storms or anthropogenic activities, has forced the station locations to move inland (e.g., shoreline seines, gill nets). In October of 2010, new fixed stations were added for each gear. However, these stations were excluded from all of the analyses because they are not long-term stations. In addition, seine sampling was changed to quarterly sampling in October of 2010. Although the survey period for the seine data is 1986-2010, there were a few years in the late 80s and early 90s when length measurements were not required and thus not recorded in some of the coastal study areas, which lead to systematic differences between areas. After 1991, the Department reinstituted the taking of length measurements; however, implementation didn't become consistent across all CSAs until late 1995. Prior to October of 2010, during the months of September-December, seine sampling would double from monthly samples to semi-monthly samples at all stations.

The seine is 50 ft in length, 6 ft in depth and has a 6x6 ft bag in the middle of the net. The nylon, tarred ace webbing, has a mesh size of 1⁄4 in bar. A lead and float line runs the entire length of the seine. The ends of the seine are held open with 6-ft poles, which are attached to the float and lead lines. Seine sampling techniques can be subdivided into two general types: soft bottom and hard bottom. Sampling methodology utilized at each station is identified. The line is anchored to the shoreline by tying the end to a push pole, paddle, anchor, or other structure. The boat is quietly reversed until the line is fully extended. At this point the boat is turned 90º astern (parallel to the shoreline) and the seine is fed out over the boat's bow while making sure the cork line and bag are not tangled. As the end of the seine is placed overboard, the boat proceeds shoreward and is anchored or tied to the bank. The seine is hauled in by the two tow lines, with care being taken to keep the lead line on the bottom. Once on shore, the catch in the wings of the net is shaken down to the bag, and removed. Gear specifications for the seines can be found in Table 5.2.

5.1.2.2 Biological Sampling Methods (Including Coverage, Intensity)

All organisms collected in seine samples are identified to species and counted. Sizes of up to 30 randomly selected individuals of targeted species are measured to the nearest mm total length. More specimens are measured if measurement of 30 (or general inspection of the sample) indicates that there may be more than one mode of length. The remaining individuals of these species are counted. Other non-target species are counted and weighed in aggregate. Water temperature and salinity are measured at each station during each sampling event.

5.1.2.3 Ageing Methods

LDWF does not collect hard parts for age determination of Gulf menhaden at this time.

5.1.2.4 Use for an Index

Fishery-independent data from the Louisiana seines were combined with the data from other states to create an index for use in the base run (see Section 5.6.1).

5.1.3 Mississippi Seine Data

5.1.3.1 Survey Methods (Including Coverage, Intensity)

Mississippi Department of Marine Resources (MDMR) and the Gulf Coast Research Laboratory (GCRL) collect fishery-independent seine data, which has been collected since January 1974. Seines are sampled at fixed stations (Figure 5.5) and do not target any specific species. Seines are 50 ft bag seines with 1⁄4 in bar mesh. Bag seines are set by hand and pulled at various distances from the shoreline depending on the topography of the bottom of each station. No changes in methodology have occurred over time.

5.1.3.2 Biological Sampling Methods (Including Coverage, Intensity)

All samples are returned to GCRL. Target species (commercially important species of fish and shellfish) were sorted from samples, measured, and weighed up to a minimum aliquot of 50 specimens. The minimum and maximum sizes were measured when the total number of a species exceeded 50. When 50 or fewer animals of a species were present, all were measured. For non-target species, only the smallest and largest specimens were measured for each taxon. The total number (calculated in instances where aliquots were used) and total weight of both target and non-target species were recorded. Since 2009, all species (vertebrates and invertebrates) are sorted from samples, measured, and weighed with a minimum aliquot of 20 specimens. The minimum and maximum sizes were measured when the total number of a species exceeded 20. When 20 or fewer animals of a species are present, all specimens are measured. Total numbers (calculated in instances where aliquots were used) and total weights of all species are recorded.

5.1.3.3 Ageing Methods

Mississippi does not collect hard parts for age determination of Gulf menhaden at this time.

5.1.3.4 Use for an Index

Fishery-independent seine data from Mississippi were combined with the data from other states to create an index for use in the base run (see Section 5.6.1).

5.1.4 Alabama Seine Data

5.1.4.1 Survey Methods (Including Coverage, Intensity)

Seines have been used at fixed stations from 1981 to the present (Figure 5.6). The seine gear has not changed over time. Seines are 4 ft by 50 ft bag seines with bag dimension of 4 ft cubed. The mesh is knotless 3⁄16 in mesh. Seines are pulled 60 ft toward shore, which means all pulls are perpendicular to shore. Stations are fixed at sites, collected monthly, and numerous stations have been added or dropped over time, although some long running stations are consistent throughout the time series. The target species for the seine survey was juvenile mullet for two specific stations (34 and 38), otherwise no particular species was targeted. Station 34 was dropped due to shifting of the shoreline, which made the site inaccessible. Current stations are; 36, 37, 38, 132 and 135. All seine sites have a sandy shoreline to which the seine can be drawn.

5.1.4.2 Biological Sampling Methods (Including Coverage, Intensity)

Samples taken during seining are preserved in 5% formalin solution in the field and held in solution until processing. Large specimens, if caught, are measured for appropriate length, weighed using a spring scale, and released alive at the collection site. The entire sample is returned to the lab and sorted to species level. In November of 1998, sampling was altered to quarterly and after a period of evaluation was returned to monthly in October 2000. Lab processing prior to 2010 entailed measuring up to 50 individuals by species in mm SL and obtaining the weight of the entire catch of each species on a bench scale. Current lab processing entails weighing and measuring up to 20 individuals in mm SL for finfish and obtaining the weight of the 20 individuals and the entire catch of each species on a bench scale. Water temperature (°C), salinity (ppt), and dissolved oxygen (Mg/L) are sampled at the surface for each station when the sample is taken.

5.1.4.3 Ageing Methods

AMRD does not collect hard parts for age determination of Gulf menhaden at this time. The standard length of most Gulf menhaden collected in the seine is less than 40mm and considered to be young-of-year.

5.1.4.4 Use for an Index

Seine fishery independent data from Alabama were combined with the data from other states to create an index for use in the base run (see Section 5.6.1). Samples that were taken from east of 88º longitude were excluded due to the potential hybridization between *B. patronus* and *B. smithi* east of Perdido Bay towards Apalachicola, Florida (see Section 1.3 for more details on the biogeographic break in the northern Gulf).

5.1.5 Florida Seine Data

5.1.5.1 Survey Methods (Including Coverage, Intensity)

Two sampling designs (stratified-random and fixed-station) were initially employed by the Florida Fish and Wildlife Conservation Commission’s (FFWCC) Fisheries-Independent Monitoring (FIM) program to assess the status of fishery stocks in Florida estuaries. Fixed-station samples, however, cannot be statistically expanded to describe the fishery stocks beyond the actual sampling sites, while stratified-random samples can be extrapolated to describe an entire estuary. Monthly fixed-station sampling, therefore, was terminated in 1996. Monthly stratified-random sampling is currently conducted year-round using 70 ft bag seines. A number of locations have been sampled in the FIM program but not all are continuous. Figure 5.7 indicates the location and duration of the various collections in Florida. The primary sampling areas since 1997 along the west Florida coast are Apalachicola, Cedar Key, Charlotte Harbor, and Tampa Bay.

For stratified random sampling, estuarine systems are subdivided into zones delineated primarily on geographic and logistical criteria but which also define areas of greater biological and hydrographic homogeneity than the system as a whole. Zones are identified as being either bay or riverine. Both bay and riverine zones are subdivided into grids based upon a 1 x 1 minute cartographic grid that is overlaid on the entire system. Grids are further subdivided into micrograms using a 10 x 10 cell grid overlay.

In bay zones, grids have been stratified by depth and may be further stratified by habitat type. Depth identifies the gear types (trawl or seine) that can be used to sample each grid. Habitat stratification is gear and field lab specific. At field labs that stratify offshore seines by habitat, stratification is by the presence or absence of submerged aquatic vegetation and by the occurrence of a shoreline within the grid. At field labs that stratify the haul seines by habitat, stratification is based on the presence or absence of overhanging vegetation within the grid.

In riverine zones, microgrids are stratified by depth and may be further stratified by habitat type and salinity gradient. As with bay zones, depth identifies the gear types (trawls or seines) that can be used to sample each microgrid. At some field labs, the seines are further stratified by the presence or absence of overhanging vegetation within the microgrid. Rivers may also be stratified into subzones to ensure that the entire salinity gradient of the river is sampled each month.

Differences in the scale of stratification between bay and riverine zones results in slightly different definitions of the primary sampling unit (sampling site) between the two zone types. Bay zone stratification has only been taken to the grid level, so the grid is randomly selected based upon strata, but the microgrid is simply a random number between 0 and 99. Therefore, the primary sampling unit in bay zones is a randomly selected microgrid within a randomly selected grid. In riverine zones, where stratification has been taken to the microgrid level, microgrids are randomly selected based on strata; the primary sampling unit, therefore, is a randomly selected microgrid. The number of sites to be sampled each month, for each gear and stratum within a given zone, is proportional to the total number of sampling sites that can be sampled within a particular stratum by a gear in an estuarine system. All sampling sites are selected and sampled without replacement each month. After site selections have been made for a month, zone boundaries are removed and sample sites are grouped to optimize sampling logistics. Once sampling groups have been identified, the order in which these groups are sampled during a given month is randomized.

Seines have been used for fishery independent sampling from 1991 to the present. The seine used for sampling is a 21.3-m (~70 ft), 1.8-m deep center bag seine and is used to collect juvenile and small adult fish and macrocrustaceans along bay edges, river banks, shallow tidal flats, and most areas where water depth is less than 1.5 m (1.8 m in rivers). Two techniques are currently employed by the FIM program to cover specific habitats. The bay technique samples areas where the water depth is less than 1.5 m, such as tidal flats, mangrove fringes, sea wall habitats, sloping beaches, and banks. The river technique samples riverine areas and tidal creeks where water depth typically increases rapidly (to not more than 1.8 m) from the shoreline, making it impossible to use the bay technique. The beach seine technique sampled shallow sloping beaches and banks and was discontinued in all areas by February 2001. The shoreline stratum was implemented January 1998 and replaced the beach seine technique in all areas by February 2001.

5.1.5.2 Biological Sampling Methods (Including Coverage, Intensity)

Temperature, DO, and salinity are sampled at each site, and all fishery samples collected by the FFWCC's FIM program are processed following a standard set of protocols. All species of fish and select macroinvertebrates are worked up for each sample. Specimens are separated by species, selected randomly to be measured, and counted. The type, amount, and ratio of by-catch are recorded. If samples contain large numbers of specimens (>1,000) sub-sampling may be used.

Menhaden are identified to genus level and standard length is measured. Standard length is the length of a fish from the most anterior part of the body to the end of the hypural plate. Up to 10 individuals for each species <150 mm SL and up to 20 individuals for each species >150 mm SL (40 individuals prior to October 1997) are randomly selected. If multiple size classes of a particular species exist, then 40 specimens from each size class should be measured. More than 40 specimens should be measured when a large size range exists with no clear size classes. If a sample has been sub-sampled and the species is present in both the split and unsplit portions, up to 40 specimens will be measured from each size class within both the split and unsplit portions. Count all individuals that were not measured. If different size classes were measured, then the number collected within each size class must be counted separately.

5.1.5.3 Ageing Methods

FFWCC does not collect hard parts for age determination of Gulf menhaden at this time.

5.1.5.4 Use for an Index

Seine fishery-independent data from Florida were not combined with the data from other states to create an index of juvenile abundance for use in the base run. Because FFWCC does not separate menhaden out to the species level and because there is a lot of mixing with other species of menhaden with Gulf menhaden on the Eastern edge of its range, these data were not used for index creation.

5.2 Gill nets

5.2.1 Texas Gill Net Data

5.2.1.1 Survey Methods (Including Coverage, Intensity)

Each bay system and Gulf area in Texas serves as a non-overlapping stratum with a fixed number of samples per season for gill nets (Figure 5.1 and 5.2). Sample locations are drawn independently and without replacement for each combination of gear, stratum, and month (season). Gill net sample locations are randomly selected from grids (1-minute latitude by 1-minute longitude) that contains >15.2 m of shoreline. Each selected grid is subdivided into 144 5-second gridlets. All gridlets containing >15.2 m of shoreline are used to randomly choose sample sites. Prior to September 1984, sites were randomly selected from 100 fixed stations in each bay system, with random sites selection since September 1984.

Gill nets are utilized to determine relative abundance, size, species composition, and temporal and spatial distribution of various life history stages of fish and invertebrates in Texas coastal waters. Brief descriptions of each gear are included in Tables 5.1, 5.2, and 5.3. Gill nets are set perpendicular to shorelines and target subadult and adult finfish.

Monofilament gill nets are used in each of ten Texas estuarine systems: Sabine Lake, Galveston Bay, Cedar Lakes, East Matagorda Bay, Matagorda Bay, San Antonio Bay, Aransas Bay, Corpus Christi Bay, upper Laguna Madre, and lower Laguna Madre (Figure 5.1 and 5.2). Gill nets have been systematically used in seven Texas bay systems since November 1975; East Matagorda Bay was added in fall 1976, Sabine Lake in spring 1986, and Cedar Lakes in spring 1995.

Gill net samples are collected overnight during each spring and fall season. The spring season begins with the second full week in April and extends for 10 weeks. The fall season begins with the second full week in September and extends for 10 weeks. Between three and five nets are set each week in each bay, except in East Matagorda Bay where only two sets are made during each week, and Cedar Lakes, where only one set is made each week. Prior to fall 1981, no more than 18 overnight gill net sets occurred in each season in each bay system. Since fall 1981, 45 gill nets were set during each season in each bay system except East Matagorda Bay. In East Matagorda Bay from fall 1981 to spring 1984, not less than six nor more than 12 gill nets were set each season; since fall 1984, 20 nets were set each season. In Cedar Lakes, 20 nets were set each season until 2000, when 10 nets were set each season. Each sampling week extends from 1 h before sunset on Sunday through 4 h after sunrise the following Sunday. Gill nets are set perpendicular to shore with the smallest mesh shoreward. Nets are set within 1 hr before sunset and retrieved within 4 h after the following sunrise. Total fishing time is recorded (nearest 0.1 hr).

5.2.1.2 Biological Sampling Methods (Including Coverage, Intensity)

All organisms greater than 5 mm total length caught in gill nets are counted and identified to the lowest phylogenetic unit (genus and species are preferred). Up to nineteen individual Gulf menhaden from each gill net sample are randomly selected and measured to the nearest 1 mm.

Surface salinity (‰), water temperature (^{o}C), dissolved oxygen (ppm), and turbidity [Nephelometric Units (NTU)] are measured at the set and pickup for each gill net. Latitude and longitude, start and completion times, and shallow and deep water depths are recorded for each sample, as is presence or absence of vegetation.

5.2.1.3 Ageing Methods

TPWD does not collect hard parts for age determination of Gulf menhaden at this time.

5.2.1.4 Use for an Index

Gill net data from Texas were examined to be used in combination with data from other states to create indices for use in the base run. However, after analyzing coast-wide length frequencies of

Gulf menhaden (*B. patronus*) from TPWD gill nets, the presence of larger individuals than previously reported in literature or commercial landings was questioned (Figure 5.3). In general, finescale menhaden (*B. gunteri*) grow to a considerably larger size than Gulf menhaden (*B. patronus*) making the presence of larger individuals of Gulf menhaden in the Texas data questionable due to potential identification issues with adult and consequently juvenile fish too. Finally, the assessment panel also explored the catches of finescale menhaden in each of the other gears as well. Few catches of finescale menhaden occur in the gears that are catching juvenile individuals, but some individuals are captured with the gill net gear. If the adults are being sampled, where are the juveniles? The lack of small individuals captured in the seine and trawl gears again brought into question species identification across the entire size range. If these data were used, the model assuming that large, older fish exist and are not available to the fishery; therefore, the assessment panel decided to exclude TPWD data and a recommendation that DNA testing be conducted across their size range to clarify this issue.

5.2.2 Louisiana Gill Net Data

LDWF utilizes a 750-ft experimental monofilament gill net to sample finfish in order to obtain indices of abundance, size distribution of finfish, and ancillary life history information on selected species.

5.2.2.1 Survey Methods (Including Coverage, Intensity)

The sampling design for Louisiana gill nets consists of fixed stations selected by coastal study areas to target areas known to have fish or shellfish when the sampling programs started (Figure 5.4).

At some sampling stations, land loss due to subsidence, storms or anthropogenic activities, has forced the station locations to move inland (Figure 5.5). In October of 2010, new fixed stations were added for gill net sampling without a reduction in effort. These stations were excluded from the analysis because they are not long-term stations. Although the survey period for the gill net data is 1986-2011, there were a few years in the late 1980s and early 1990s when length measurements were not required and thus not recorded in some of the coastal study areas which lead to systematic differences between areas. After 1991, the LDWF reinstituted the taking of length measurements; however, implementation didn't become consistent across all CSAs until late 1995. Gill net sample sites are visited on a monthly basis from October through March and on a semi-monthly basis from April through September across all CSAs.

The experimental gill nets are 750 ft long, 8 ft deep, and comprised of five 150 ft panels. The five panels consist of 1, 1 1⁄4, 1 1⁄2, 1 3⁄4, and 2 in bar mesh or 2.0, 2.5, 3, 3.5, and 4.0 inch stretch mesh. The float line is 3⁄8 in diameter hollow braided polypropylene and the lead line is #60 75 lead core, 5⁄16 in diameter lead core line. Large floats and anchor weights are attached to both ends of the float line and lead line, respectively. Gill net deployment begins with the 1 in bar mesh end. After the float and weight are tossed overboard adjacent to or on a shoreline or reef, the gill net is deployed over the transom of the net well. The net may be set parallel to the shoreline or reef or in a crescent shape. Enough room is left on one side of the net to allow the net skiff to enter and then maneuver within the net. Fish are forced to strike the net by running the net skiff around both the inside and outside of the net a minimum of two or three times in gradually tightening circles. The net is then retrieved and pulled aboard from the downwind or down current end.

5.2.2.2 Biological Sampling Methods (Including Coverage, Intensity)

All organisms captured in gill nets are removed and placed in baskets corresponding to each mesh size or panel of the net. Organisms are noted as gilled or tangled (i.e., those fish which have not penetrated individual meshes to the back of the operculum). Up to 30 individuals of each target species are individually measured (TL in mm) per panel; remaining individuals of these species are counted and the entire sample is weighed in aggregate per panel. Other non-target species are counted and weighed in aggregate per panel. Water temperature and salinity are measured at each station during each sampling event.

5.2.2.3 Ageing Methods

LDWF does not collect hard parts for age determination of Gulf menhaden at this time.

5.2.2.4 Use for an Index

Fishery-independent data from the Louisiana gill net samples were used to create an index of abundance for use in the base run. The assessment panel deemed the Louisiana gill net data appropriate for capturing true fluctuations in population abundance and appropriate for use in the assessment for the following reasons:

1. The sampling stations are within the range of the population of interest.

The gill net sampling stations cover a portion of the range of the Gulf menhaden population and a portion of the range of the commercial fishery; however, the coverage is large enough to sample the large scale dynamics that are occurring in the population. Also, the area of coverage is off the coast of Louisiana, which is the heart of the range of Gulf menhaden.

2. Length samples indicate that the gill net sampling program captures Gulf menhaden smaller and larger than the commercial fishery.

The specimens collected during gill net sampling are both smaller and larger than the specimens collected by the port agents from the commercial reduction fishery (Figure 5.6). This indicates that the gill net sampling is collecting a wider range in sizes, and likely ages, than the commercial fishery and is a better representation of the population as a whole in the Gulf of Mexico.

3. The standardized abundance index created from the gill net index is correlated with the catch at age-2 from the fishery (see Section 5.6.3 below for further discussion).

The final, standardized abundance index created from the gill net data correlates with an index based on the catch at age-2 from the reduction fishery. This provides corroborative evidence that the two pieces of separate information are picking up on a similar signal from the true population abundance.

4. Best available data were used to create an index of adult abundance.

The gill net sampling was not meant to target Gulf menhaden specifically; however, the data provide adequate information to create an index for the assessment. These data are the best data available for creation of an index. Other data are available, such as fishery-dependent data or gill net data from other states. However, concerns about hyperstability (Figure 5.43) in the fishery-dependent data are warranted, and the other fishery-independent data from the states has questionable species identification or a shorter time period. It is believed that the Louisiana gill net data do not suffer from hyperstability of its CPUE. Thus, the Louisiana gill net data are the best data available to provide an adult abundance index, which is critical for the statistical catch at age model.

5.2.3 Mississippi Gill Net Data

Mississippi Department of Marine Resources (MDMR) and the Gulf Coast Research Laboratory (GCRL) have collected fishery-independent gill net data since October 2005.

5.2.3.1 Survey Methods (Including Coverage, Intensity)

Gill nets have been sampled at fixed stations (Figure 5.7), but random stations have also been added since May of 2008. Gill net sampling does not target any specific species. Gill nets are 750 ft long consisting of five panels measuring 150 ft apiece. Mesh sizes include 2, 2.5, 3, 3.5, and 4 in stretch mesh. Gill nets are deployed from the shoreline angling out then turning parallel to the shoreline. The end of the net is turned back towards the shore to form a small hook. The net has a soak time of one hour. The only sampling change since the inception of gill net sampling was the addition of random stations in May 2008. Five areas were divided up into a grid system with grids being randomly drawn for each area once a month.

5.2.3.2 Biological Sampling Methods (Including Coverage, Intensity)

All fish sampled in gill nets (including menhaden since the fall of 2008) are brought back to the lab for processing and are separated by each mesh size and bagged for future analysis. All menhaden lengths are recorded as total length (TL) in mm. When more than one Gulf menhaden specimen was collected at a station a range of lengths was recorded consisting of the smallest and largest length. Weights were recorded in grams. Temperature, salinity, and dissolved oxygen were sampled at each sampling location during each sample.

5.2.3.3 Ageing Methods

Mississippi does not collect hard parts for age determination of Gulf menhaden at this time.

5.2.3.4 Use for an Index

Gill net fishery independent data from Mississippi were combined with the data from Alabama to consider the creation of an index of abundance for use in the base run (see Section 5.6.3 for more information).

5.2.4 Alabama Gill Net Data

A gill net survey has been implemented from 2001 to the present (Figure 5.8). In 2000, a trial period of gears, set types, and locations were explored for assessing multiple finfish species. This trial period was experimental in nature and only covering July – October, therefore it was excluded from the analysis. Gear and study design were decided upon in 2001 and implemented in May 2001. This initial year (2001) was incomplete and also excluded from analysis. Gill nets used for sampling in Alabama are either small mesh gill nets (2001 to current) or large mesh gill nets (2004 to current). The small mesh gill net is composed of five panels (8 by 150 ft) of graduated mesh sizes (750 ft total). Mesh sizes begin with a 2-inch stretch mesh and increase by 1⁄2 inch increments up to 4 in. Each mesh is color coded by a corresponding float (blue = 2, red =2.5, white = 3, green = 3.5, and gold = 4). Each large mesh gill net is presently composed of four panels (8 X 150 ft) of graduated mesh sizes (600 ft total). Mesh sizes begin with a 4.5 in stretch mesh and increase by 1/2-inch increments up to 6 in. Meshes are color coded by a corresponding float (blue = 4.5, red =5, white = 5.5, and green = 6). The configuration of the large mesh net was changed for 2005 when a 4 in mesh was dropped to remove duplicative sampling with this mesh.

5.2.4.1 Survey Methods (Including Coverage, Intensity)

Nets are soaked for a period of one hour and sets do not target any specific species. Stations are selected using stratified random sampling with sampling sites being allocated based on variation in samples. A target of 240 sets per year (120 for each net configuration) is maintained annually.

Area 1 (Figure 5.8), upper Mobile Bay, is characterized by brackish waters with submersed aquatic vegetation (SAV) beds along the northern boundary and eastern shore. Sand and mud sediments are prevalent in the upper reaches giving way to mostly sand substrate in the middle of the bay. Oyster reefs are patchy and common along the western and center portions of the upper bay. Gaillard Island is a man-made island that is bordered by large rip-rap and sandy bottoms.

Area 2, Lower Mobile Bay shorelines are sandy giving way to mud in the deeper portions. Large oyster reefs are present in several locations both on the east and western portions in 8-12 ft of water.

Area 3, Mississippi Sound is quite diverse. Site A has an undeveloped shoreline with extensive savannah and marshes. Due to connectivity to the open Gulf through Petit Bois Pass, the salinity stays high and fosters growth of numerous SAV beds on the open flats. Site B houses two ports (Bayou La Batre and Coden Bayou), which serve as harbors for commercial fishing and ship building industries. In spite of this, the mud and sand bottoms provide substrate for numerous oyster resources. Site C has an undeveloped shoreline with extensive savannah and marshes and shares an expansive oyster reef in lower Mobile Bay. This area is subject to the fresh water inputs flowing down the west side of Mobile Bay. The northern shore of Dauphin Island is sandy with sparse SAV beds and tidal pools that wax and wane with tropical events.

Area 4, Perdido Bay and Little Lagoon comprise this area. Little lagoon (site A) is almost entirely influenced by tides in and out of its Gulf inlet. Water depth averages about 3 feet and SAV are numerous in the clear water. The majority of the shoreline is bordered by residential development and seawall. Site B has muddy water and substrate and is bordered for the most by marsh and savannahs. The remainder of Area 4 has clear, higher salinity waters. SAV beds are numerous. Substrate is sand even in the deeper portions.

5.2.4.2 Biological Sampling Methods (Including Coverage, Intensity)

While nets are being retrieved fish are removed from the net and placed in boxes corresponding to mesh size. Field processing entails identification to species, measuring up to 10 individuals in mm FL or TL (depending on species) from each mesh size per species and obtaining a total count by mesh size per species. Samples are bagged, labeled, placed on ice, and are returned for lab processing. Lab processing includes length, weight, ovary weight, sexing, and otolith extraction (although otoliths have not been removed for Gulf menhaden; see below Section 5.2.4.3). Surface water temperature, salinity, dissolved oxygen, and GPS coordinates are recorded at each site during each sample taken. While net is deployed the water depth at the midpoint of the mesh is recorded as mesh depth.

5.2.4.3 Ageing Methods

The AMRD does not age Gulf menhaden samples collected during fishery-independent monitoring. However, recent protocols have been implemented to begin collecting scales from Gulf menhaden retrieved from the gill net sampling program but no age data exist for the purposes of this analysis.

5.2.4.4 Use for an Index

Gill net fishery independent data from Alabama were combined with the data from Mississippi for consideration in creating an index of abundance for use in the base run (see Section 5.6.3). Due to differences in setting the gear (strike versus passive) the assessment panel decided to separate Alabama and Mississippi from Louisiana for gill net index considerations. In addition, samples that were taken from east of 88 longitude were excluded due to the potential hybridization between *B. patronus* and *B. smithi* east of Perdido Bay towards Apalachicola, Florida (see Section 1.3 for more details on the geographic break in the northern Gulf).

5.3 Inshore Trawls

5.3.1 Texas Inshore Trawl Data

5.3.1.1 Survey Methods (Including Coverage, Intensity)

Each bay system and Gulf area serves as non-overlapping strata with a fixed number of samples per month (Figure 5.2). Sample locations are drawn independently and without replacement for each combination of gear, stratum, and month.

Bay trawl sample locations are randomly selected from grids containing water ≥1 m deep in at least ⅓ of the grid and are known to be free of obstructions. Large bays (Galveston, Matagorda, San Antonio, Aransas and Corpus Christi) are stratified into two zones: Zone 1 (upper bay nearest mouths of rivers) and Zone 2 (lower bay farthest from rivers) to ensure good spatial distribution of samples. Smaller bays (Sabine Lake, East Matagorda Bay, upper Laguna Madre and lower Laguna Madre) are not stratified. One half of the monthly trawl samples in each zone in each bay system are collected during each half (days 1-15 and 16-31) of the month to ensure good temporal distribution of samples. Trawls are towed in a circular pattern near the center of each grid. All tow times are 10 minutes in duration. No grid is sampled more than once per month. Trawl samples have been collected in three bays since January 1982 and seven bays since May 1982. Trawl samples commenced in Sabine Lake beginning January 1986, and in East Matagorda Bay beginning April 1987. Since inception, sample size has been 10 trawls per month per zone.

5.3.1.2 Biological Sampling Methods (Including Coverage, Intensity)

All organisms greater than 5 mm total length caught in trawls are counted and identified to the lowest phylogenetic unit (genus and species are preferred). Up to nineteen individual Gulf menhaden from each trawl sample are randomly selected and measured to the nearest 1 mm.

Bottom salinity, water temperature, dissolved oxygen, and turbidity are measured prior to each trawl sample. Latitude and longitude, start and completion times, and shallow and deep water depths are recorded for each sample, as is presence or absence of vegetation.

5.3.1.3 Ageing Methods

TPWD does not collect hard parts for age determination of Gulf menhaden at this time.

5.3.1.4 Use for an Index

Trawl data from Texas were examined to be used in combination with data from other states to create an index for use in the base run. However, after analyzing coast-wide length frequencies of Gulf menhaden (*B. patronus*) from TPWD trawls and other monitoring gears, the presence of larger individuals than previously reported in literature or commercial landings was questioned. In general, finescale menhaden (*B. gunteri*) grows to a considerably larger size than Gulf menhaden (*B. patronus*) making the presence of larger individuals of Gulf menhaden in the Texas data questionable due to potential identification issues with adult and consequently juvenile fish too, because juvenile individuals are more difficult to identify to species level than adults. Finally, the assessment panel also explored the catches of finescale menhaden in each of the gears as well. Few catches of finescale menhaden occur in the gears that are catching juvenile individuals, but some individuals are captured with the gill net gear. If the adults are being sampled, where are the juveniles? The lack of small individuals captured in the seine and trawl gears again brought into question species identification. If these data were used, the model would assume that large, older fish exist and are not available to the fishery; therefore, the assessment panel decided to exclude TPWD data and a recommendation that DNA testing be conducted across their size range to clarify this issue.

5.3.2 Louisiana Inshore Trawl Data

The 16-ft flat otter trawl is used to sample penaeid shrimp, blue crabs, finfish (bottomfish), and other marine organisms in the larger inshore bays and in Louisiana's territorial waters at fixed stations (Figure 5.4).

5.3.2.1 Survey Methods (Including Coverage, Intensity)

The survey period for 16-ft trawl data is 1967-2010. The 16-ft trawl inshore sampling is conducted semi-monthly during November-February, then weekly during March-October. The offshore trawl samples are taken semi-monthly during November-March and monthly during April-October. New fixed sampling stations were also added in October of 2010 (Figure 5.5).

The trawl body is constructed of 3⁄4 in bar mesh No. 9 nylon mesh while the tail is constructed of 1⁄4 in bar mesh knotted 35 lb tensile strength nylon and is 54-60 in long. The trawl is hung on 3⁄8 in PDP rope with four 3 in by 1.5 in spongex floats on the corkline and with a minimum of 3.5 ft extra rope on the corkline and leadline. The trawl has 16 ft and 20 ft of webbing along the cork and lead lines, respectively. Trawls are dipped in green plastic nylon net dip. The trawl boards are constructed of 3⁄4 in marine plywood and measure 24 in across the top, 14 in at the back, and 10 in at the front with a 4 in rounded corner. The bridle is constructed of four lengths of galvanized 3⁄16 in chain while the bottom slide consists of a 3⁄8 in by 2 in, flat iron bar. The 16-ft trawl is attached to a 1⁄2 in diameter nylon rope or stainless steel tow line and bridle. The length of the bridle is 2-3 times the trawl width. Tow line length is normally at least 4-5 times the maximum depth of water. The trawl is towed for ten minutes (timed from when the trawl first begins to move forward to when it stops forward movement) at a constant speed and in a weaving or circular track to allow the prop wash to pass on either side of the trawl.

5.3.2.2 Biological Sampling Methods (Including Coverage, Intensity)

All organisms collected in trawls are identified by species, counted, and up to 50 of each species measured in 5 mm intervals. Finfish are measured for total length (tip of snout to tip of longest lobe of compressed caudal fin).

5.3.2.3 Ageing Methods

LDWF does not collect hard parts for age determination of Gulf menhaden at this time.

5.3.2.4 Use for an Index

Trawl fishery independent data from the state of Louisiana were considered with the data from other states for creation of a juvenile abundance index for use in the base run. See Section 5.6.2 for more information.

5.3.3 Mississippi Inshore Trawl Data

Trawl data have been collected from January 1974 to the present. Trawls are run at fixed stations (Figure 5.6) and do not target any specific species.

5.3.3.1 Survey Methods (Including Coverage, Intensity)

Tows are 10 minutes at each station and no changes in methodology have occurred over time. The trawl has a 16 ft head rope and a 20 ft foot rope. The nets are made of nylon netting of the following size mesh and thread: 1.5 in stretch mesh #9 thread body, 13⁄8 in stretch mesh #18 thread cod end (80x100 deep) fully rigged with 2 in O.D. nylon net rings for purse rope, and no lazyline. Head and footropes of 3⁄8 in diameter poly-dac net rope with legs extended 3 ft 6 in and rope thimbles spliced in at each end. Six 1.5 x 2.5 in sponge floats spaced evenly on bosom of headrope with 1⁄8 in galvanized chain hung loop style on footrope. Nets treated in latex net dip on completion. Purse rope rigged on nets. Inner liner composed of 3⁄8 in stretch mesh #63 knotless nylon netting inserted and hogtied in cod end to hold small specimens.

5.3.3.2 Biological Sampling Methods (Including Coverage, Intensity)

All samples are returned to GCRL. Target species (commercially important species of fish and shellfish) were sorted from samples, measured, and weighed up to a minimum aliquot of 50 specimens. The minimum and maximum sizes were measured when the total number of a species exceeded 50. When 50 or fewer animals of a species were present, all were measured. For non-target species, only the smallest and largest specimens were measured for each taxon. The total number (calculated in instances where aliquots were used) and total weight of both target and non-target species were recorded. Since 2009, all species (vertebrates and invertebrates) are sorted from samples, measured, and weighed for a minimum aliquot of 20 specimens. The minimum and maximum sizes are measured when the total number of a species exceeded 20. When 20 or fewer animals of a species are present, all specimens are measured. Total numbers (calculated in instances where aliquots were used) and total weights of all species are recorded.

5.3.3.3 Ageing Methods

Mississippi does not collect hard parts for age determination of Gulf menhaden at this time.

5.3.3.4 Use for an Index

Trawl fishery independent data from the state of Mississippi were considered with the data from other states for creation of a juvenile abundance index for use in the base run. See Section 5.6.2 for more information.

5.3.4 Alabama Inshore Trawl Data

5.3.4.1 Survey Methods (Including Coverage, Intensity)

AMRD from 1981 to the present has towed trawls at fixed stations (Figure 5.7). The trawl gear has been consistent over time. Trawls are 16 ft, with 1.25 in stretch mesh (front) and 1.5 in stretch mesh (bag) with a 3/16 in liner. Trawls are towed for 10 minutes at each station. Stations are currently fixed at 24 sites, collected monthly, and numerous stations have been added or dropped over time. In November of 1998, sampling was altered to quarterly and after a period of evaluation was returned to monthly in October 2000. Station habitat varies from within channel, to mud, sand, and grass flats. Three stations within the Mobile Ship Channel are at depths between 40- 45 feet depending on the maintenance activities of the corps. The other station depths are less than 14 feet.

5.3.4.2 Biological Sampling Methods (Including Coverage, Intensity)

Prior to 2007 trawl samples were preserved in 10% formalin, and after 2007 samples were frozen until processing. Large adults if caught were measured for appropriate length, weighed using a spring scale, and released. Lab processing prior to 2010 entailed measuring up to 50 individuals by species in mm SL and obtaining the weight of the entire species catch on a bench scale. Current lab processing entails weighing and measuring up to 20 individuals in mm SL for finfish and obtaining the weight of the 20 individuals and the entire species catch on a bench scale. Water temperature (°C), salinity (ppt), and dissolved oxygen (Mg/L) are sampled at maximum depth for each station when the sample is taken.

5.3.4.3 Ageing Methods

AMRD does not collect hard parts for age determination of Gulf menhaden at this time. Most specimens are less than 70mm SL and are considered to be young-of-year.

5.3.4.4 Use for an Index

Trawl fishery independent data from the state of Alabama were considered with the data from other states for creation of a juvenile abundance index for use in the base run. See Section 5.6.2 for more information.

5.3.5 Florida Inshore Trawl Data

Two sampling designs (stratified-random and fixed-station) were initially employed by the FFWCC FIM program to assess the status of fishery stocks in Florida estuaries. Fixed-station samples, however, cannot be statistically expanded to describe the fishery stocks beyond the actual sampling sites, while stratified-random samples can be extrapolated to describe an entire estuary. Monthly fixed-station sampling, therefore, was terminated in 1996. Monthly stratified-random sampling is currently conducted year-round using 20’ trawls. A number of locations have been sampled in the FIM program but not all are continuous. Figure 5.8 indicates the location and duration of the various collections in Florida. The primary sampling areas since 1997 along the west Florida coast are Apalachicola, Cedar Key, Charlotte Harbor, and Tampa Bay.

For stratified random sampling, estuarine systems are subdivided into zones delineated primarily on geographic and logistical criteria but which also define areas of greater biological and hydrographic homogeneity than the system as a whole. Zones are identified as being either bay or riverine. Both bay and riverine zones are subdivided into grids based upon a 1 x 1 minute cartographic grid that is overlaid on the entire system. Grids are further subdivided into microgrids using a 10 x 10 cell grid overlay.

In bay zones, grids have been stratified by depth and may be further stratified by habitat type. Habitat stratification is gear and field lab specific. In riverine zones, microgrids are stratified by depth. As with bay zones, depth identifies the gear types that can be used to sample each microgrid. Rivers may also be stratified into subzones to ensure that the river's entire salinity gradient is sampled each month.

Trawls have been used for fishery independent sampling from 1989 to the present. A 6.1-m otter trawl with 38-mm stretch mesh and 3-mm mesh liner is used in the FIM program to sample areas of the estuarine system between 1.8 m and 7.6 m in depth. In addition to sampling areas of the bay not accessible to seines, trawls tend to collect epibenthic fish and macrocrustaceans that are larger than those typically collected in seines. Trawl tows last five to ten minutes based on the type of tow. The trawls are conical in shape with a wide elliptical mouth opening, which gradually tapers backwards toward a narrow bag. Each side of the trawl mouth has lines attached to weighted doors. A tow line is tethered to each of these doors and is used to pull the net through the water. The trawl mouth is leaded at the base and floated on top. Running from the base of the doors is a long chain that is pulled just ahead of the mouth of the trawl. This is called a tickler chain and serves the purpose of scaring bottom organisms into the water column where they can be collected by the trawl. When the net is fishing, the doors are spread apart by the forward motion of the boat. This forward action opens the mouth of the trawl. Organisms on the bottom stirred up by the tickler chain and those already present in the water column are funneled down the trawl toward the bag where they are trapped. The bag is lined with a small-mesh liner and tied off at the end to prevent escapement of organisms.

5.3.5.1 Biological Sampling Methods (Including Coverage, Intensity)

Temperature, dissolved oxygen, and salinity are sampled at each site, and all fishery samples collected by the FFWCC's FIM program are processed following a standard set of protocols. All species of fish and select macroinvertebrates are worked up for each sample. Specimens are separated by species, selected randomly to be measured, and counted. The type, amount, and ratio of by-catch are recorded. If samples contain large numbers of specimens (>1,000) sub-sampling may be used.

Menhaden are identified to genus level and standard length is measured. Standard length is the length of a fish from the most anterior part of the body to the end of the hypural plate. Randomly select up to 10 individuals for each species <150 mm SL and up to 20 individuals for each species >150 mm SL (40 individuals prior to October 1997). If multiple size classes of a particular species exist, then 40 specimens from each size class should be measured. More than 40 specimens should be measured when a large size range exists with no clear size classes. If a sample has been sub-sampled and the species is present in both the split and unsplit portions, up to 40 specimens will be measured from each size class within both the split and unsplit portions.

Count all individuals that were not measured. If different size classes were measured, then the number collected within each size class must be counted separately.

5.3.5.2 Ageing Methods

FFWCC does not collect hard parts for age determination of Gulf menhaden at this time.

5.3.5.3 Use for an Index

Trawl fishery-independent data from Florida were not combined with the data from other states for consideration of creation of an index of juvenile abundance for use in the base run. Because FFWCC does not separate menhaden out to the species level and because there is a lot of mixing with other species of menhaden with Gulf menhaden on the Eastern edge of its range, these data were not used for consideration for index creation.

5.4 SEAMAP Trawl Survey

5.4.1 Survey Methods (Including Coverage and Intensity)

The Southeast Monitoring and Assessment Program (SEAMAP) is a multi-agency collaboration within the Gulf of Mexico to collect fishery-independent sampling data. SEAMAP surveys use trawl gear to collect fishery independent data (i.e. finfish, shrimp, and other invertebrates). State and federal agencies collaboratively coordinate the scheduling of cruise dates and the selection of stations to be sampled by each agency, which results in a coordinated program with common sampling protocols and gear. The program has been operating since 1982 and ranges from Texas to Florida (Figure 5.10). The spatial and temporal extent of SEAMAP covers a greater scale than other data sources under consideration for index creation, and the spatial extent encompasses the range of the commercial menhaden fishery (Figure 5.11).

The Summer and Fall SEAMAP Shrimp/Groundfish surveys have used the same design from 1987 to 2009. Sampling protocols were changed beginning in 1987. At least one day and one night set were located within each depth/statistical unit beginning in 1987 (Craig 2001). Prior to 1987, sets were randomly located within 10x10 minute grid cells, and were set only at night (Craig 2001). The 5,896 samples set prior to 1987 were excluded from the analysis. The removal of surveys prior to 1987 had no noticeable influence on length distributions of captured menhaden because only 35 captured menhaden lengths were recorded prior to 1987. Similarly, the effect of excluding sets taken prior to 1987 on spatial distributions of sampling locations was negligible. Sampling protocols were again changed in 2009. Federal agencies implemented a fixed tow time of 30 minutes for trawls in 2009, and changed the way sampling locations were chosen. Additionally, the designation of “day” and “night” stations was removed. State agencies implemented the changes in 2010; however Texas maintained a 10 minute tow time rather than switching to 30 minutes. Sets taken in 2009-2011 were not excluded because changes in tow time were accounted for by catch per unit effort.

Currently, SEAMAP sampling stations are chosen using a random design with proportional allocation by bottom area within shrimp statistical zones (Figure 4.14). Stations are sampled 24-

hours a day, with a tow time (bottom time) of 30 minutes per station for agencies other than Texas. A 42-foot SEAMAP trawl with 15⁄8 in stretched mesh is lowered to depth at each station and the towline is set at a 5:1 cable length water depth. The desired vessel speed while towing is 2.5-3.0 knots. Texas uses a different sized trawl than the rest of the agencies. However, because of the potential for species misidentification, Texas SEAMAP data were excluded from all analyses.

5.4.2 Biological and Physical Sampling Methods

Temperature (air and water) was collected for each sampling station. Weight of the catch was recorded for individual species and for the catch as a whole. The number of individuals per species was also recorded. Up to 20 individuals of a species are measured for length with the appropriate measurement being used depending upon the species.

5.4.3 Ageing Methods

SEAMAP does not collect hard parts for age determination of Gulf menhaden at this time.

5.4.4 Use for an Index

Data from SEAMAP surveys during 1982-2011 were available, accounting for 28,193 sets, of which 2,240 sets captured menhaden (Table 5.4, Figure 5.12). The proportion of sets that captured menhaden varied between 3.3 and 14.3 percent among years (Table 5.4, Figure 5.13). Positive catches of menhaden ranged from 1-3,407 fish per set. Although not recorded for all captured menhaden, 9,613 lengths were reported as either total length (TL) or fork length (FL) in mm (Figure 5.14).

Some SEAMAP data were excluded from the dataset prior to considering them for use in constructing an index of menhaden abundance. The purpose of excluding some data was to minimize differences in catch caused by factors other than changes in menhaden abundance, and to restrict the spatial extent of the analysis to better reflect the spatial distribution of menhaden. Data sampled in years prior to 1987; in months other than June and July (summer), and October and November (fall); by the state of Texas; and in waters west of 88º W longitude were excluded.

5.5 SEAMAP Ichthyoplankton Survey

5.5.1 Survey Methods (Including Coverage, Intensity)

Plankton survey activities were initiated in the Gulf by NMFS in 1977 as part of the Marine Resources Monitoring Assessment and Prediction program or MARMAP (Sherman et al. 1983, Richards 1987). Most of the plankton sampling during those early annual surveys (1977-1981) was conducted in open Gulf waters in April and May using essentially the same gear and methods as are in use today. Starting in 1982 resource surveys including plankton surveys carried out by the NMFS Mississippi Laboratories were incorporated into SEAMAP (Sherman et al. 1983, Stuntz et al. 1983). Through this joint Federal-State program coordinated through the

GSMFC, the NMFS, and the states of Louisiana, Mississippi, Alabama, and Florida, plankton sampling is conducted cooperatively during resource surveys in the Gulf.

The goal of plankton surveys under SEAMAP has been to assemble a time series of data on the occurrence, abundance, and geographical distribution of fish eggs and larvae, as well as, to collect data on selected physical properties of their pelagic habitat. These data can then be used to more precisely describe the spawning times and areas of Gulf fishes and the relationship of their early life stages to environmental (abiotic) factors. Furthermore it was anticipated (and shown now to be true) that this time series of annual abundance estimates could eventually provide a valuable fishery-independent index of spawning stock size for additional Gulf species as was first demonstrated for tuna from pre-SEAMAP plankton surveys. Larval indices of abundance based on SEAMAP plankton survey data have been developed for Atlantic bluefin tuna (Scott et al. 1993), king mackerel (Gledhill and Lyczkowski-Shultz 2000), red snapper (SEDAR7-DW14; Hanisko et al. 2007), vermilion snapper (SEDAR9-DW24) and gray triggerfish (SEDAR9-DW25). After larval identifications have been verified (as necessary) nominal and model-generated indices of larval abundance over the SEAMAP time series are now routinely provided to SEFSC stock assessment scientists.

The overall SEAMAP sampling area covers the entire northern Gulf from the 10-m isobath out to the EEZ, and comprises approximately 300 designated sampling stations. Most stations are located at 30-nautical mile or ~56 km intervals in a fixed, systematic, 2-dimensional latitude-longitude grid of transects across the Gulf. SEAMAP plankton data have been collected primarily during four survey periods: spring (April to early June, annually, 1982 to present), summer (June and July, annually, 1982 to present), late summer/early fall (typically in September, annually, 1986 to present) and fall (October and November, annually, 1982 to present). The spring survey covers only open Gulf waters (within the EEZ), while the summer and fall (trawl) surveys encompass only continental shelf waters from south Texas to Mobile Bay, Alabama. The late summer/early fall survey encompasses the continental shelf waters from south Texas to south Florida.

The standard sampling gear and methodology used to collect plankton samples during SEAMAP surveys are similar to those recommended by Kramer et al. (1972), Smith and Richardson (1977), and Posgay and Marak (1980). Plankton sampling protocols and guidelines for the two standard SEAMAP gears used during resource surveys (bongo and neuston nets) are described in detail in the SEAMAP Field Operations manual (SEAMAP 2001). A 61 cm (outside diameter) bongo net fitted with 0.335 mm mesh netting is fished in an oblique tow path from a maximum depth of 200 m or to 2-5 m off the bottom at station depths less than 200 m. A single or double, 2x1 m pipe frame neuston net fitted with 0.950-mm mesh netting is the other standard gear employed and is towed at the surface with the frame half submerged for 10 minutes.

Maximum bongo tow depth is calculated using the amount of wire paid out and the wire angle at the ‘targeted’ maximum tow depth or is directly observed using a SBE 19 or Seacat to view and record bongo net depth in real time throughout the tow. A mechanical flow meter is mounted off-center in the mouth of each bongo net to record the volume of water filtered. During surveys in 1982 and part of 1983 a flow meter was placed on only one side of the bongo gear. Water volume filtered during bongo net tows ranges from ~20-600 m^3 but is typically 30-40 m^3 at the shallowest stations and 300-400 m^3 at the deepest stations.

5.5.2 Biological Sampling Methods (Including Coverage and Intensity)

Since the inception of SEAMAP, most plankton samples have been sorted for fish eggs and larvae, and specimens have been initially identified (mostly to the family level) at the Sea Fisheries Institute, Plankton Sorting and Identification Center (MIR ZSIOP), in Gdynia and Szczecin, Poland under a Joint Studies Agreement between the NMFS and the Sea Fisheries Institute. During the period 1989-2002 plankton samples collected by the LDWF were processed by Louisiana state biologists following SEFSC SEAMAP protocols in use at MIR ZSIOP. Vials of eggs and identified larvae, plankton displacement volumes, total egg counts; and counts and body length measurements of identified larvae are sent to the SEAMAP Archive at the Fish and Wildlife Research Institute (FWRI) in St. Petersburg, Florida. No attempt has been made to identify menhaden larvae to species although the larvae of all three Gulf species have now been described. Identification of menhaden larvae (to the genus level) has been possible over the entire time series of SEAMAP collections.

5.5.3 Ageing Methods

SEAMAP does not age Gulf menhaden samples collected during fishery-independent monitoring because the samples contain larval menhaden only.

5.5.4 Use for an Index

Menhaden were consistently captured and abundant from October through April from western Louisiana to Mobile Bay in coastal and continental shelf waters out to the 200-m isobath. Menhaden larvae were captured in waters east of Mobile Bay off the Florida panhandle and west Florida shelf during surveys in fall and winter months especially in February and March during Gulf wide SEAMAP winter surveys in 2007-2009. During these recent cruises larvae were found in abundance off the south Texas coast and beyond the 200-m isobath east of the Mississippi River. Menhaden larvae were found primarily in samples from October through March with a few occurrences in April, May, June, July, and September. The specimens indentified in June and July samples may be problematic and will be re-examined to confirm their identification. Highest mean monthly abundances were observed in November, 181.0 ± 48.1 (n = 563), and March, 223.2 ± 31.9 (n = 324). Discontinuity in the progression of mean monthly abundances from October through March is likely due to reduced sampling effort in December, January and February, i.e. fewer years sampled relative to October and November. Menhaden larvae were captured over a relatively narrow range of water depths; rarely being taken at stations where water depth was > 120 m.

While larval Gulf menhaden were captured during the SEAMAP ichthyoplankton sampling, these data were not deemed as best for creating a juvenile index for Gulf menhaden. First, Gulf menhaden larvae and plankton occur most frequently in winter when SEAMAP sampling is less frequent. Additionally, SEAMAP samples further offshore and most assessment panelists felt that larvae would likely be more inshore during the spring months, when sampling was most regular. Finally, the assessment panelists felt that two other data sets would provide a better idea of recruitment class strength than the SEAMAP ichthyoplankton survey. Thus, these data were considered, but not put forward for use in the base run.

5.6 Indices of Abundance

5.6.1 Seine Index

The seine index was explored by the assessment panel as an option for a recruiment index for the base run. Several versions were compared to determine sensitivity to different data filtering methods. Coastwide (LA, MS, and AL) and Louisiana-only models were compared at two levels of temporal filtering within a year, March-May and December-September. The coastwide model was also explored using the log of the catch/seine as the unit of CPUE. There was little difference between the temporal and spatial filtering methods. The effect of using the log of catch/seine was a dampening of the few peaks in the index. The coastwide December-September index was considered more appropriate and is described here as a recruitment or juvenile index of abundance.

5.6.1.1 Data Compilation for Use in an Index

Seine data from Texas, Louisiana, Mississippi, Alabama, and Florida were explored for creation of a recruitment index for use in the base run. These data are meant to reflect juvenile abundance throughout the range of Gulf menhaden in the Gulf of Mexico. Data from each state were considered and compiled individually before being grouped coastwide. Texas, Florida, and Alabama samples East of Perdido Bay (88º longitude – see Section 1.4) were excluded due to concerns about species misidentification with other *Brevoortia* species. For Mississippi and Louisiana, only data from the long-term sampling stations were retained.

In order for the seine index to represent only juvenile catch, a size cutoff was used. The goal of choosing a small size cut-off was to reduce the confusion with age-1 fish and to evaluate smaller pulses of recruitment thereby limiting the masking effect of counting already recruited fish from previous sampling events. Therefore, the catch from each seine was multiplied by the proportion of fish less than 50 mm FL. If lengths were not measured in FL, then a conversion from Section 3.3 was used to convert the lengths to FL.

Data records for each state were examined and explored to determine if any confounding factors would have an effect on the index's measure of relative abundance. The examination revealed no confounding factors. Each state deploys seines somewhat differently. However, the effect of any differences was accounted for by including state as an explanatory variable in the final index analysis rather than to calibrate the different state collection methods. Seine gear methods were consistent within states for the samples considered.

The number of years of data available differs by state. Louisiana had the longest data set. However, changes in the protocols for length sampling precluded use of data collected prior to 1996. More recent changes in seine sampling protocols eliminated the use of 2011 in the creation of a seine index, leaving 1996-2010. Mississippi only had two long-term stations. Mississippi data were limited to the same years as available from Louisiana. The Alabama data were available from 2001-2011 but 2011 was excluded to match Louisiana.

5.6.1.2 Standardization

CPUE was modeled using the delta-GLM approach (cf., Lo et al. 1992, Dick 2004, Maunder and Punt 2004). In particular, the fits of lognormal and gamma models for positive CPUE were compared, and the combination of predictor variables that best explained CPUE patterns (both for positive CPUE and 0/1 CPUE) were examined. All analyses were performed in the R programming language, with much of the code adapted from Dick (2004).

Response and explanatory variables:

> *CPUE* – Catch per unit effort (CPUE) has units of catch/seine and was calculated as the number of Gulf menhaden caught multiplied by the proportion of fish in the sample that were 50mm FL or less.
>
> *YEAR* – A summary of the total number of trips per year and a summary of the total number of trips with positive Gulf menhaden catch per year is provided in Table 5.5.
>
> *STATE* – State was defined as the state where the survey occurred (Louisiana, Mississippi, or Alabama). The total number of trips by year and state and the total number of trips with Gulf menhaden catches by year and region is provided in Table 5.6.
>
> *MONTH* – Month was used as a factor as catches may be different between months of the year (December, January, February, March, April, May, June, July, August, and September). Seines collected in December were assigned to the following year.
>
> *TEMPERATURE* – Temperature was a continuous environmental factor that was thought to have an influence on juvenile Gulf menhaden catches.
>
> *SALINITY* – Salinity was a continuous environmental factor that was thought to have an influence on juvenile Gulf menhaden catches.

BERNOULLI SUBMODEL: One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching Gulf menhaden during a particular sampling event. First, a model was fit with all main effects in order to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. In this case, the stepwise AIC procedure removed temperature as an explanatory variable.

POSITIVE CPUE SUBMODEL: Then, to determine predictor variables important for predicting positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. Backwards model selection did not eliminate any variables for the lognormal distribution, and the model did not converge for the gamma distribution.

Then both components of the model were fit together (with the code adapted from Dick 2004) using the lognormal distribution with CPUE as the dependent variable. All factors except temperature were included for the Bernoulli submodel, and all factors were included for the positive CPUE submodel (lognormal).

5.6.2 Trawl Index

The trawl index was initially explored by the assessment panel as an option for a recruitment index for the base run. However, the trawl index was not recommended for the base run of the assessment model because trawls are not an optimal gear to capture menhaden and because the seine index was the preferred recruitment index.

5.6.2.1 Data Compilation for Use in an Index

Trawl data from Texas, Louisiana, Mississippi, Alabama, and Florida were explored for creation of a recruitment index for use in the base run. These data are meant to reflect juvenile abundance throughout the range of Gulf menhaden in the Gulf of Mexico. Data from each state were considered and compiled individually before being grouped coastwide. For Texas, data from major bay and minor bay systems that have never caught a menhaden were excluded, as well as data from any station that had never caught a menhaden. For Mississippi and Louisiana, only data from the long-term sampling stations were retained. For Alabama, data from stations that have never caught a menhaden were excluded. Finally, for Florida, only the sampling stations in Apalachicola Bay were retained (other bay systems had little to no menhaden catches).

In order for the trawl index to represent only juvenile catch, the catch from each state was modified to account for the proportion of fish greater than 100 mm FL, which was the length below which individuals were determined to be juveniles. If lengths were not measured in FL, then a conversion from Section 3 was used to convert the lengths to FL.

Data records for each state were examined, and the data were explored in order to determine if any confounding factors would have an effect on the ability of the index to reflect relative abundance. Nothing became apparent that would affect the ability of the data to reflect relative abundance. The biggest challenge with data from many states is the gear differences both in specification and deployment. Thus, the trawl data were considered for creation of a recruitment index.

Different states have different numbers of years of data available. The proposed trawl index included all years of data available from 1967-2010 based on having the key state at the center of the range, Louisiana. If values were missing for any of the factors below, then the trip was deleted, and the model was fit with the remaining trips.

5.6.2.2 Standardization

CPUE was modeled using the delta-GLM approach (cf., Lo et al. 1992, Dick 2004, Maunder and Punt 2004). In particular, the fits of lognormal and gamma models for positive CPUE were compared and combination of predictor variables that best explained CPUE patterns (both for positive CPUE and 0/1 CPUE) were examined. All analyses were performed in the R programming language, with much of the code adapted from Dick (2004).

Response and explanatory variables:

> *CPUE* – Catch per unit effort (CPUE) has units of catch/minute and was calculated as the number of Gulf menhaden caught divided by the number of minutes per tow.
>
> *YEAR* – A summary of the total number of trips per year is provided in Table 5.7, and a summary of the total number of trips with positive Gulf menhaden catch per year is provided in Table 5.8.
>
> *STATE* – State was defined as the state where the survey occurred (Texas, Louisiana, Mississippi, Alabama, or Florida). The total number of trips by year and state is provided in Table 5.7, and the total number of trips with Gulf menhaden catches by year and region is provided in Table 5.8.
>
> *MONTH* – Month was used as a factor as catches may be different between months of the year (January, February, March, April, May, June, July, August, September, October, November, and December).
>
> *TEMPERATURE* – Temperature was a continuous environmental factor that was thought to have an influence on juvenile Gulf menhaden catches.
>
> *SALINITY* – Salinity was a continuous environmental factor that was thought to have an influence on juvenile Gulf menhaden catches.

BERNOULLI SUBMODEL: One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching Gulf menhaden during a particular sampling event. First, a model was fit with all main effects in order to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. In this case, the stepwise AIC procedure did not remove any of the variables.

POSITIVE CPUE SUBMODEL: Then, to determine predictor variables important for predicting positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. Backwards model selection did not eliminate any variables for the lognormal distribution, and the model did not converge for the gamma distribution.

Then both components of the model were fit together (with the code adapted from Dick 2004) using the lognormal distribution with CPUE as the dependent variable. All factors were included for both the Bernoulli submodel and the positive CPUE submodel (lognormal).

5.6.3 Gill Net Index

5.6.3.1 Data Compilation for Use in an Index

Gill net data from Louisiana, Mississippi, and Alabama were considered for creation of an adult Gulf menhaden abundance index for use in the base run. Florida does not collect consistent gill net data, and data from Texas were excluded because of the potential for species mis-identification. Because of differences in gear specifications and deployment, the Louisiana data were considered separately from the Mississippi and Alabama data.

5.6.3.1.1 Louisiana Data

Data records for Louisiana were examined to determine if any confounding factors would have an effect on the ability of the index to reflect relative abundance. Nothing became apparent that would affect the ability of the data to reflect relative abundance, and in fact, the threads of evidence supported the use of the gill net index based on Louisiana data. See section 5.2.2.4 above for more specific information.

Data were available from Louisiana from 1986-2011 for each month January through December. However, because of gear changes in the first two years of the survey, the years 1986-1987 were excluded from the analysis. The months January-March and October-December were also excluded from the analysis because those months had reduced sampling and much smaller catches of Gulf menhaden compared to the months April through September (which has double the sample effort; Figure 5.15). Any stations that had never caught a menhaden were also excluded; while non-long-term stations were also excluded.

To search for similar trends among long-term stations and to see if differences in habitat had an effect on the ability of stations to capture Gulf menhaden, a principal components analysis (PCA) was run. The stations grouped by the proportion of zero catches of Gulf menhaden (Figure 5.16). Indices were compared with and without the long-term stations with few catches of Gulf menhaden; however, excluding the stations with few catches made little difference to the overall abundance index (Figure 5.17). Thus, all long-term stations were included in the analysis.

If values were missing for any of the factors below, then the trip was deleted, and the model was fit with the remaining trips.

5.6.3.1.2 Mississippi and Alabama Data

Data records for Mississippi and Alabama were combined and examined to determine if any confounding factors would have an effect on the ability of the index to reflect relative abundance. Nothing became apparent that would affect the ability of the data to reflect relative abundance. The biggest challenge with data from many states is the gear differences both in size and deployment. The gears across the states were relatively similar and mesh size differences could be accounted for using mesh size as a factor, thus the gill net index based on Mississippi and Alabama data was further explored.

Different states have different numbers of years of data available. Alabama gill net data are available from 2000 to 2011, and Mississippi gill net data are available from 2004 to 2011. The years 2000 and 2001 were excluded from the Alabama data because of changes in methodology. For both states, stations that had never sampled a menhaden were excluded. All stations east of Perdido Bay in Alabama were excluded because of concerns over species identification. Only the months April through September were included in the analysis because those were the months with the greatest amount of sampling and highest catches (Figure 5.15). Finally, because the state of Mississippi does not record individual lengths for Gulf menhaden, the assessment panel assumed that the lengths samples from Alabama would be representative of lengths that are likely sampled in Mississippi.

For each data set, if values were missing for any of the factors below, then the trip was deleted, and the model was fit with the remaining trips.

5.6.3.2 Standardization

The dataset from Louisiana was analyzed for potential use in the base run of the assessment, as was the combined dataset from Mississippi and Alabama.

5.6.3.2.1 Standardization for Louisiana

CPUE was modeled using the delta-GLM approach (cf., Lo et al. 1992, Dick 2004, Maunder and Punt 2004). In particular, the fits of lognormal and gamma models for positive CPUE were compared and combination of predictor variables that best explained CPUE patterns (both for positive CPUE and 0/1 CPUE) were examined. Jackknife estimates of variance were computed using the ‘leave one out’ estimator (Dick 2004). All analyses were performed in the R programming language, with much of the code adapted from Dick (2004).

Response and explanatory variables:

CPUE – Catch per unit effort (CPUE) has units of catch/set. Set was used as the unit of effort because Louisiana gill nets are fished as strike nets, meaning that the gill nets are set and then retrieved with little to no soak time. A log transformation of the CPUE was also explored because of the long tail of positive catches (Figure 5.17). The overall trend of the index was not changed, only the scale of the year to year variability was reduced. However, this index resulted in poorer residual plots overall. As a consequence, the CPUE was not log-transformed and was retained in its original format.

YEAR – A summary of the total number of trips per year is provided in Table 5.9, and a summary of the total number of trips with positive Gulf menhaden catch per year is provided in Table 5.10.

MONTH – Month was used as a factor as catches may be different between months of the year (April, May, June, July, August, and September).

> *TEMPERATURE* – Temperature was a continuous environmental factor that was thought to have an influence on Gulf menhaden catches.
>
> *SALINITY* – Salinity was a continuous environmental factor that was thought to have an influence on Gulf menhaden catches.

MESH SIZE – Mesh size was a factor that was thought to have an influence on Gulf menhaden catches. This factor accounted for differences in catch due to differences in panel catchability.

BERNOULLI SUBMODEL: One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching Gulf menhaden during a particular sampling event. First, a model was fit with all main effects in order to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. In this case, the stepwise AIC procedure did not remove any of the predictor variables.

POSITIVE CPUE SUBMODEL: Then, to determine predictor variables important for predicting positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. Backwards model selection did not eliminate any of the variables for the lognormal distribution, and the model did not converge for the gamma distribution.

Then, both components of the model were fit together (with the code adapted from Dick 2004) using the lognormal distribution with CPUE as the dependent variable. All of the factors were included for both the Bernoulli submodel and the positive CPUE submodel (lognormal).

5.6.3.2.2 Standardization for Mississippi and Alabama

CPUE was modeled using the delta-GLM approach (cf., Lo et al. 1992, Dick 2004, Maunder and Punt 2004). In particular, the fits of lognormal and gamma models for positive CPUE were compared and combination of predictor variables that best explained CPUE patterns (both for positive CPUE and 0/1 CPUE) were examined. All analyses were performed in the R programming language, with much of the code adapted from Dick (2004).

Response and explanatory variables:

> *CPUE* – Catch per unit effort (CPUE) has units of catch/set. Set was used as the unit of effort because both Mississippi and Alabama gill nets are fished for the same length of soak time.
>
> *YEAR* – A summary of the total number of trips per year is provided in Table 5.9, and a summary of the total number of trips with positive Gulf menhaden catch per year is provided in Table 5.10.

STATE – State was defined as the state where the survey occurred (Mississippi or Alabama). The total number of trips by year and state is provided in Table 5.9, and the total number of trips with Gulf menhaden catches by year and state is provided in Table 5.10.

MONTH – Month was used as a factor as catches may be different between months of the year (April, May, June, July, August, and September).

TEMPERATURE – Temperature was a continuous environmental factor that was thought to have an influence on Gulf menhaden catches.

SALINITY – Salinity was a continuous environmental factor that was thought to have an influence on Gulf menhaden catches.

MESH SIZE – Mesh size was a factor that was thought to have an influence on Gulf menhaden catches. This factor accounted for differences in catch due to differences in panel catchability.

<u>BERNOULLI SUBMODEL</u>: One component of the delta-GLM is a logistic regression model that attempts to explain the probability of either catching or not catching Gulf menhaden during a particular sampling event. First, a model was fit with all main effects in order to determine which effects should remain in the binomial component of the delta-GLM. Stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. In this case, the stepwise AIC procedure removed the state predictor variable.

<u>POSITIVE CPUE SUBMODEL</u>: Then, to determine predictor variables important for predicting positive CPUE, the positive portion of the model was fitted with all main effects using both the lognormal and gamma distributions. Stepwise AIC (Venables and Ripley 1997) with a backwards selection algorithm was then used to eliminate those that did not improve model fit. Backwards model selection eliminated the state variable for both the lognormal and gamma distributions. The lognormal distribution was selected for further analyses because of a lower AIC value.

Then both components of the model were fit together (with the code adapted from Dick 2004) using the lognormal distribution with CPUE as the dependent variable. The factors included for the Bernoulli submodel included year, month, temperature, salinity, and mesh size, and the factors included for the positive CPUE submodel included year, month, temperature, salinity, and mesh size.

5.6.4 SEAMAP Index

5.6.4.1 Data Compilation for Use in an Index

Menhaden were captured more often in nearshore, shallower waters. Depth was therefore used to restrict the SEAMAP data to better reflect menhaden distribution. Three depth cut-offs based on the 100%, 90%, and 50% depth quantiles of sets which captured menhaden were used to construct three separate datasets. Depth cutoffs were applied to all sets; sets that captured menhaden as well as sets that did not capture menhaden. The depth quantiles were divided seasonally; depths for the 100%, 90%, and 50% quantiles were 94m, 22m, and 11m for summer sets, respectively, and 106m, 31m, and 15m for fall sets, respectively. Greater depths during fall than during summer likely reflected seasonal movement of menhaden into offshore/deeper waters (Ahrenholz 1991).

After applying the above exclusions, the number of SEAMAP sets was reduced to 15,527, 7,116, and 2,533 for the 100%, 90% and 50% depth quantiles, respectively. The number of sets which captured menhaden for the 100%, 90% and 50% depth quantiles were 1,387 (8.9%), 1262 (17.7%), and 754 (29.8%), respectively. The number of sets each year, as well as the number and percentage of sets that captured menhaden each year are provided for each depth quantile (Table 5.11).

5.6.4.2 Response and Explanatory Variables and Standardization

Indices of relative abundance were developed for each data set based on the 100%, 90%, and 50% depth quantiles. CPUE was the response variable, and year, season (summer or fall), day/night, and depth were possible predictors. Year, season, and day/night were categorical variables whereas depth was a continuous variable. Given the large number of sets without captures of menhaden, a delta-GLM model was used (Lo et al. 1992). The delta-GLM model assumes there are two processes that influence the capture of menhaden in a set: 1) a binomial process of whether menhaden are captured, and 2) if menhaden are captured, a process (herein referred to as the positive process) that influences the number of menhaden captured. The positive process was modeled as either a log-normal or gamma distribution and only included sets that caught menhaden. Model-selection criterion based on AIC was used to choose between a log-normal and a gamma distribution for the positive process, and to determine predictor variables for the binomial and positive processes separately.

Model selection results showed that the log-normal distribution had lower AIC values than the gamma distribution for the positive process, and was therefore chosen for the final indices. The day/night predictor was removed from the final models for the positive process for all depth quantiles, and for the binomial process for the 100% depth quantile. All predictors were included in the final model for the binomial process for the 90% depth quantiles, and year and day/night were included in the final model for the binomial process for the 50% depth quantile.

5.7 Indices of Abundance

Overall, two final indices of abundance were put forward for use in the base run: 1) a recruitment index based on the seine survey data from Louisiana, Mississippi, and western Alabama, and 2) an adult abundance index based on the Louisiana gill net survey data. Both indices were deemed appropriate and likely to reflect true, underlying population dynamics given the high levels of correlations with other corroborative evidence. Below is a discussion on how these decisions were made.

5.7.1 Juvenile Indices of Abundance

Both the trawl index and seine index were explored as potential indices of recruitment in the base run of the model. The seine index showed large year classes of juveniles in 1996, 2003, 2009, and 2010 (Figure 5.18, Table 5.11). The residuals for the Bernoulli portion of the model were normally distributed across years, months, states, and salinities (Figures 5.19-5.22). The residuals for the positive CPUE portion of the model were normally distributed across years, months, state, temperature, and salinity (Figures 5.23-5.27). The density plot of positive catches and the QQ plot provide information on the adequacy of the lognormal distribution (Figures 5.28-5.29). The other distribution tested, gamma, did not converge. Thus, the scaled, standardized index based on the seine data is the best data and science available to produce an index of recruitment for the Gulf menhaden stock assessment.

The trawl index showed large year classes of juveniles in 1984, 1993, 1996, 2001, 2010, and 2011. Both the trawl and seine indices were positively correlated with the correlation for the entire time series of 1996-2010 being 0.79 (Figure 5.30).

Based on the best representation of juvenile abundance, the assessment panelists prioritized the indices with the recruitment seine index being highest priority and trawl index being of lower priority. The seine index was deemed a higher priority because samples are collected closer to shore, the length composition is predominately smaller fish (unlike the trawl samples for some states), the gear is more similar from state to state, and the mesh size of the gear is smaller than trawls allowing for capture of smaller individuals. Additionally, the trawl gear is designed to sample fauna in proximity to the sea floor and is not indicative of pelagic species such as Gulf menhaden. Therefore, the trawl data was excluded in favor of the seine data.

Additionally, the seine data were compared against catches by the commercial fishery at age-1. The correlation between the recruitment index and the catch at age-1 with a one-year lag was 0.87, which is quite high (Figure 5.31). This provides another piece of corroborative evidence that the seine index, trawl index, and the index based on catches of age-1 individuals are reflective of the population dynamics related to recruitment at age-0 and ageing of fish to age-1 individuals. Thus, the assessment panel deemed the seine index as the best source of information for recruitment in the stock assessment model.

5.7.2 Adult Indices of Abundance

The assessment panel considered an index based on gill net data available from Mississippi and Alabama. However, because of small sample sizes during 2002-2005 and the short time period of adequate sample sizes from 2006-2011, an index based on these data was deemed inappropriate.

The assessment panel also considered an index based on SEAMAP data. However, the recommendation by the assessment panel was to exclude the SEAMAP index based on three reasons: 1) the likely incidental capture of menhaden in the SEAMAP survey trawls, 2) variability in the standardized index was greater than expected, and 3) little correlation of the SEAMAP index with other indices. Variability in the SEAMAP indices suggests that menhaden abundance has varied considerably. However, the large swings from year to year apparent in the SEAMAP index calls into question the ability of SEAMAP to track menhaden abundance. Alternatively, peaks in SEAMAP CPUE could reflect chance encounters with groups of menhaden during trawl placement and retrieval rather than increased menhaden abundance. The few positive captures of menhaden also suggest the survey does not commonly encounter menhaden. SEAMAP surveys trawl along the seafloor, but menhaden are a pelagic schooling fish (Ahrenholz 1991), and therefore unlikely to be sampled consistently, or often, by trawls. Information on abundance trends provided by SEAMAP differed from information from other sources. Data on catch per unit effort were available from fishery-dependent data, as well as from a fishery-independent gill net survey managed by the state of Louisiana. The three indices were assumed to sample similar populations because the fishery captured similarly sized menhaden as the SEAMAP index and the gill net index sampled a larger range of menhaden sizes than either SEAMAP or the fishery. Both the commercial fishery and the gill net survey employ gear better suited at capturing menhaden than SEAMAP trawls. Correlations between the nominal SEAMAP index for the 100% depth quantile, scaled to its mean, and nominal CPUE estimates from the Louisiana gill net and fishery-dependent data, scaled to their means, were -0.29 and -0.08, respectively. Correlations between the standardized SEAMAP index for the 100% depth quantile and nominal CPUE estimates from the gill net and fishery-dependent data were poorer, -0.20 and -0.042, respectively. In all instances, correlations were expected to be positive. Although SEAMAP has extensive spatial and temporal scale, the variability in the index and the likelihood of incidental catches, combined with limited correlation with indices from surveys that use gear more appropriate for a pelagic schooling fish, raised concern on the use of SEAMAP data as an index. Ultimately, because SEAMAP is not a survey that targets menhaden, and appeared to capture menhaden intermittently, the index was not recommended for use in the assessment.

Finally, the assessment panel considered an index based on Louisiana gill net data. The gill net index based on the Louisiana data showed an increasing trend from the late 1980s to the mid 1990s, then a stable trend from the mid 1990s to the mid 2000s, and large adult abundances in the most recent years (Figure 5.32; Table 5.12). The uncertainty surrounding the index was smallest in the earliest years and largest for the most recent years (Table 5.13, Figure 5.33-5.34). The proportion of positive trips per year ranged from 0.12 to 0.26 (Figure 5.35). The residuals for the Bernoulli portion of the model were normally distributed across years, months, and mesh sizes (Figures 5.36-3.37). The residuals for the positive CPUE portion of the model were normally distributed across years, months, and mesh sizes (Figures 5.38-5.9). The density plot of positive catches and the QQ plot indicate that the lognormal distribution is not ideal, but none of the other distributions tested nor any of the transformations tested matched the distribution better (in fact, they did worse; Figures 5.40-5.41). Thus, the scaled, standardized index based on the Louisiana gill net data is the best data and science available to produce an index of adult abundance for the Gulf menhaden stock assessment.

The Louisiana gill net index was correlated with age-2 catch from the commercial reduction fishery, and the correlation was 0.73 for the years 1988-2011 (Figure 5.42). An index based on the commercial data was deemed inappropriate for the base run of the assessment model because of concerns over hyperstability of the index because of the use of spotter pilots and search time of the boats (Figure 5.43). Both a linear relationship and a power relationship were fit to the

Louisiana gill net data versus the age-2 catches. Based on the R^2 values for those two fits, the power relationship fit better. One of the fundamental problems for an index is hyperstability, and given the appearance that hyperstability is likely occurring for the fishery, the index based on the fishery data was deemed inappropriate.

The Louisiana gill net index was deemed the most appropriate adult abundance index by the assessment panel because of the reasons discussed in section 5.2.2.4, the large, positive correlation between the index and catches of a similar age class, and because those data are the best data available to provide that information to the assessment model. Given the corroborative evidence available, the Louisiana gill net index likely reflects the true, underlying dynamics of the population.

Finally, the seine and Louisiana gill net index do not correlate well with one another nor do the catches at age-1 and age-2. However, there is corroborative evidence that the seine index reflects recruitment dynamics and that the gill net index reflects age-2 and older population dynamics (Figure 5.43). The lack of a correlation between the two age groups is not entirely surprising for a forage fish species such as Gulf menhaden. Substantial natural mortality occurs during the period between ages-1 and -2, which is likely influenced by both predators and environmental factors. The lack of correlation between the two indices was addressed with sensitivity runs (see section 6 below).

5.7.2.1 Length Compositions for the Louisiana Gill Net Index

All lengths recorded during gill net sampling were standardized to fork length using the length-length conversions in Section 3.4. Yearly length compositions were provided as the proportion in each length class for a given year from 1996-2011 (Table 5.12, Figure 5.33). Some length records exist for years previous to 1996, but lengths were not recorded for all CSAs in Louisiana until 1996.

Lengths from the Louisiana gill net index will be used to estimate selectivity for the gill net index in collaboration with an age-length transition and will be used to help define the functional form of selectivity for reduction fishery. The Louisiana gill nets capture both larger and smaller individuals than the commercial reduction fishery (Figure 5.6), which is evidence that the commercial reduction fishery selectivity may be dome-shaped. In addition, it looked as if cohorts may have been captured by the gill net sampling; however, the apparent cohorts were determined to be size specific selection of individuals by mesh size (Figure 5.44). Additonal evidence for the potential of dome-shaped selectivity for the commercial reduction fishery was investigated further by looking at the only other data available, the age and length data from the fishery. Based on the age and length data from the fishery, dome-shaped selectivity is also suspected because the CV in lengths with age is decreasing as ages get larger, which is unexpected (Figure 5.45). In Figure 5.45, there appears to be a size at which the reduction fishery is no longer capturing menhaden. Given these pieces of data, the functional form of the selectivity for the reduction fishery appears to be dome-shaped. However, the extent of the dome is unknown.

The assessment panelists discussed plausible reasons that one might expect to see dome-shaped selectivity in the commercial reduction fishery. The first possible reason may be fishery targeting. If the fishery targets the largest schools to set a purse seine on, those schools are likely comprised of the most abundant ages or sizes of fish, which would likely be younger fish. Thus, even though schools of age-3 and -4 individuals may be present in an area, the schools are not harvested because they are smaller then the optimum school size for the fishery to set on. The second possible reason is based on work completed by Simpson and Scott (2011), where one would expect dome-shaped selectivity with a spatially heterogenous stock such as Gulf menhaden.

Table 5.1 Fishery-independent gear descriptions by state for gill nets. Length of gear is in feet, all mesh sizes are in stretch mesh in inches, and net height is in feet.

State	Texas	Louisiana	Mississippi	Alabama	Florida
Length	600	750	750	750(1), 600 (2)	NA
Mesh size/type	3,4,5,6	2,2.5,3,3.5,4	2,2.5,3,3.5,4	(1)2,2.5,3,3.5,4 (2) 4.5,5,5.5,6	
	stretch	stretch	stretch	stretch	
Net height	4	8	6	8	
Effort	hours	strike net	1 hour	1 hour	
Rough size ranges	243-289	100-200	180-220	95-241	
Fish length units	TL	TL	TL	FL	

**Note that the rough size ranges are in the length units specified.

Table 5.2. Fishery-independent gear descriptions by state for seines.

State	Texas	Louisiana	Mississippi	Alabama	Florida
Gear length	60-ft bag seine	50-ft bag seine	50-ft bag seine	50-ft bag seine	21.3 m bag seine=69 ft
Gear height			4 ft	4 ft	
Legs length	60ft	50ft	50 ft	50ft	
Bag dimensions	1.8 m wide	6ft by 6ft	4ftx4ftx4ft	4ftx4ftx4ft	1.8 m^3
Mesh size	1/2in	1/4in bar mesh	0.6 cm=0.24in	3/16in knotless	3.1mm
Effort	3229 ft^2	982 ft^2	3432 ft^2	2400 ft^2	1507 and 723 ft^2
Rough size ranges	38-74	25-44	21-54	45	22-55
length units	TL	TL	SL	SL	SL

**Note that the rough size ranges are in the length units specified.

Table 5.3. Fishery-independent gear descriptions by state for trawls.

State	Texas	Louisiana	Mississippi	Alabama	Florida
Gear name	20-ft trawl	16-ft flat trawl	16-ft trawl	16-ft flat 2-seam trawl	20-ft trawl
Door Length	48 in	24 in	36 in	24 in	36 in
Door Height	18 in	14 in	18 in	12.5 in	18 in
Leg length	1.5 ft	1 ft	3 ft	6ft	4ft
Net Footrope			20 ft	17.8 ft	21.5 ft
Net Headrope	20 ft	16 ft	16 ft	14.2 ft	20 ft
Bag Length		4.9 ft	4.9 ft	2 ft	7 ft
Mesh Body/Front	1.5 in stretch	1.5 in stretch	1.5 in stretch	1.37 in stretch	1.5 in stretch
Mesh Cod/Bag	1.5 in stretch	0.5 in stretch	1/4 in knotless bar	1.75 in cover and 3/16 in knotless bar liner	1/8 in knotless bar
No. of weights	1 per foot	1/4 in chain along the footrope webbing	¼ in chain along the footrope webbing	3/16 in chain, 17 links = 1 chain, 7 chains along footrope	1/4 in chain along the footrope webbing
Weight size	2 oz/ weight			7 chains=4 lbs	
No. of Floats		4	4	2	4
Float Dimensions		2.5 in x1 in	2.5 in x1 in	3 in x3 in	2.5 in x1 in
Tickler Length	none	none	none	none	24 ft of ¼ in chain
Effort	10 minute tow	10 minute tow	10 minute tow	10 minute tow	timed tow
Rough size range (mm)	116-151 67-123	20-85	37-85	50-70	21-64
Fish length units	TL	TL	SL	SL	SL

**Note that the rough size ranges are in the length units specified.

Table 5.4 Yearly numbers of SEAMAP sets, SEAMAP sets that caught menhaden (positive sets), and the percentage of SEAMAP sets that caught menhaden.

Year	Number of sets	Number of positive sets	Percentage of positive sets
1982	903	31	3.43
1983	1,332	103	7.73
1984	1,597	52	3.26
1985	1,314	107	8.14
1986	750	26	3.47
1987	1,263	90	7.13
1988	1,313	119	9.06
1989	1,068	147	13.8
1990	942	56	5.94
1991	921	52	5.65
1992	845	59	6.98
1993	914	56	6.13
1994	899	59	6.56
1995	740	55	7.43
1996	878	75	8.54
1997	753	80	10.6
1998	696	88	12.6
1999	1,009	116	11.5
2000	796	101	12.7
2001	701	44	6.28
2002	803	115	14.3
2003	728	84	11.5
2004	741	58	7.83
2005	701	64	9.13
2006	814	101	12.4
2007	730	64	8.77
2008	929	43	4.63
2009	1,294	74	5.72
2010	1,044	52	4.98
2011	775	69	8.9

Table 5.5 Total number of seines for each state as input into the calculation of the seine index.

Year	Seine Samples			
	LA	MS	AL	Total
1996	465	20		485
1997	468	20		488
1998	478	20		498
1999	477	20		497
2000	493	20		519
2001	486	20	60	566
2002	471	19	57	547
2003	485	20	60	565
2004	486	20	57	563
2005	445	20	48	513
2006	464	20	50	534
2007	479	20	50	549
2008	466	20	47	533
2009	436	20	48	504
2010	397	18	39	454

Table 5.6 Total number of seines that caught Gulf menhaden (positive) for each state as input into the calculation of the seine index.

Year	Positive Seine Samples			
	LA	MS	AL	Total
1996	196	16		212
1997	173	15		188
1998	200	14		214
1999	180	14		194
2000	111	10		121
2001	139	11	29	179
2002	152	8	27	187
2003	170	15	29	214
2004	166	13	27	206
2005	162	15	17	194
2006	153	8	12	173
2007	179	7	20	206
2008	161	9	14	184
2009	166	13	24	203
2010	201	13	16	230

Table 5.7 Number of trips by state and year for the fishery-independent data collected by trawls. Louisiana and Mississippi include only long-term stations.

Year	Texas	Louisiana	Mississippi	Alabama	Florida	Total
1967		217				217
1968		183				183
1969		230				230
1970		414				414
1971		461				461
1972		476				476
1973		666				666
1974		739	46			785
1975		678	46			724
1976		620	30			650
1977		476	44			520
1978		394	44			438
1979		570	44			614
1980		825	45			870
1981		927	43	228		1,198
1982	1,033	1,032	76	289		2,430
1983	1,058	961	90	290		2,399
1984	1,107	834	91	257		2,289
1985	1,070	943	87	197		2,297
1986	1,481	808	91	261		2,641
1987	1,486	895	87	331		2,799
1988	1,569	917	89	261		2,836
1989	1,580	866	81	205		2,732
1990	1,448	1,002	48	220		2,718
1991	1,359	990	44	219		2,612
1992	1,300	741	48	260		2,349
1993	1,451	919	44	230		2,644
1994	1,429	908	47	241		2,625
1995	1,447	1,003	45	230		2,725
1996	1,446	980	47	233		2,706
1997	1,363	1,034	48	237		2,682
1998	1,385	1,055	46	188	77	2,751
1999	1,455	1,138	46	146	103	2,888
2000	1,350	1,055	45	181	149	2,780
2001	1,422	1,158	47	274	256	3,157
2002	1,306	1,085	45	278	276	2,990
2003	1,331	1,114	46	281	263	3,035
2004	1,319	1,052	44	301	268	2,984
2005	1,413	1,052	46	291	260	3,062
2006	1,245	1,112	45	290	261	2,953
2007	1,321	1,077	45	292	288	3,023
2008	1,321	1,114	43	287	303	3,068
2009	1,422	1,055	48	273	308	3,106
2010	1,354	1,002	47	263	275	2,941
2011	1,277	745	40	263	288	2,613

Table 5.8 Number of positive trips by state and year for the fishery-independent data collected by trawls. Louisiana and Mississippi include only long-term stations.

Year	Texas	Louisiana	Mississippi	Alabama	Florida
1967		31			
1968		52			
1969		26			
1970		16			
1971		89			
1972		106			
1973		177			
1974		202	16		
1975		148	19		
1976		159	11		
1977		129	18		
1978		91	17		
1979		90	13		
1980		163	15		
1981		145	15	51	
1982	349	209	18	63	
1983	204	255	28	80	
1984	317	328	41	79	
1985	202	215	25	36	
1986	180	213	25	38	
1987	294	220	21	73	
1988	185	227	29	58	
1989	184	229	23	32	
1990	233	255	15	36	
1991	289	226	18	28	
1992	304	221	16	43	
1993	295	304	20	29	
1994	194	235	19	32	
1995	186	274	16	42	
1996	217	318	21	46	
1997	241	214	12	38	
1998	233	335	17	62	2
1999	164	306	18	19	
2000	128	228	9	29	
2001	342	277	13	48	15
2002	240	275	11	41	9
2003	241	252	11	66	21
2004	179	270	14	69	14
2005	259	270	11	37	9
2006	122	225	14	25	6
2007	261	290	8	29	2
2008	135	252	10	35	11
2009	124	287	16	43	6
2010	283	465	11	81	12
2011	163	258	21	67	20

Table 5.9 Number of trips by state and year for the fishery-independent data collected by gill nets.

Year	Louisiana	Mississippi	Alabama
1988	381		
1989	450		
1990	480		
1991	418		
1992	444		
1993	388		
1994	474		
1995	497		
1996	503		
1997	511		
1998	502		
1999	514		
2000	519		
2001	523		
2002	509		79
2003	521		92
2004	523		120
2005	475		108
2006	485	199	121
2007	508	195	93
2008	490	197	108
2009	522	201	92
2010	455	201	63
2011	410	204	74

Table 5.10 Number of positive trips by state and year for the fishery-independent data collected by gill nets.

Year	Louisiana	Mississippi	Alabama
1988	199		
1989	169		
1990	201		
1991	161		
1992	172		
1993	140		
1994	172		
1995	181		
1996	205		
1997	232		
1998	244		
1999	229		
2000	263		
2001	218		
2002	238		34
2003	245		45
2004	230		60
2005	234		48
2006	278	39	44
2007	249	38	23
2008	273	30	24
2009	305	88	29
2010	187	74	11
2011	245	92	28

Table 5.11 Yearly numbers of SEAMAP sets, SEAMAP sets that caught menhaden (positive sets), and the percentage of SEAMAP sets that caught menhaden for each of three depth quantile datasets (100%, 90%, and 50%) after applying data exclusions. Sets taken during 1982-1987; in January-May, August-September, and December; east of 88° W, and by the state of Texas were excluded.

Year	**Number of sets**			**Number of positive sets**			**Percentage of positive sets**		
	100	90	50	100	90	50	100	90	50
1987	904	414	151	65	63	40	7.19	15.2	26.5
1988	1060	468	198	102	100	65	9.62	21.4	32.8
1989	819	442	208	130	108	70	15.9	24.4	33.7
1990	723	405	197	46	42	31	6.36	10.4	15.7
1991	708	389	174	36	35	22	5.08	9	12.6
1992	608	306	126	43	40	31	7.07	13.1	24.6
1993	664	344	106	46	39	24	6.93	11.3	22.6
1994	583	257	89	40	38	30	6.86	14.8	33.7
1995	516	223	72	38	38	20	7.36	17	27.8
1996	651	287	117	57	52	27	8.76	18.1	23.1
1997	554	235	75	68	62	37	12.3	26.4	49.3
1998	522	252	80	71	61	38	13.6	24.2	47.5
1999	821	389	166	108	99	67	13.2	25.5	40.4
2000	623	271	89	73	61	33	11.7	22.5	37.1
2001	509	204	61	25	24	17	4.91	11.8	27.9
2002	562	239	74	76	68	27	13.5	28.5	36.5
2003	525	234	68	51	44	22	9.71	18.8	32.4
2004	551	242	74	43	39	23	7.8	16.1	31.1
2005	534	247	76	50	49	27	9.36	19.8	35.5
2006	565	236	83	65	59	34	11.5	25	41
2007	512	243	78	40	37	26	7.81	15.2	33.3
2008	614	217	57	27	25	13	4.4	11.5	22.8
2009	674	303	70	34	29	12	5.04	9.57	17.1
2010	375	150	29	29	29	13	7.73	19.3	44.8
2011	350	119	15	24	21	5	6.86	17.7	33.3

Table 5.12 Seine and gill net abundance indices and associated coefficient of variation (*CV*) for use in the base run.

Year	Seine	Seine CV	Gill net	Gill net CV
1988			0.27	0.09
1989			0.21	0.10
1990			0.24	0.10
1991			0.25	0.11
1992			0.22	0.13
1993			0.41	0.16
1994			0.84	0.15
1995			0.55	0.15
1996	1.22	0.20	0.67	0.14
1997	0.44	0.19	1.24	0.13
1998	0.98	0.20	0.94	0.13
1999	0.77	0.20	0.80	0.13
2000	0.33	0.23	1.00	0.13
2001	0.67	0.20	1.34	0.13
2002	0.89	0.19	0.99	0.13
2003	1.09	0.18	1.02	0.13
2004	0.72	0.20	0.90	0.14
2005	1.50	0.21	1.24	0.13
2006	0.62	0.21	1.18	0.12
2007	0.76	0.19	0.86	0.13
2008	0.46	0.21	3.52	0.12
2009	1.56	0.20	2.64	0.11
2010	2.97	0.20	0.75	0.14
2011			1.93	0.13

Table 5.13 Annual sample length compositions in mm FL for Gulf menhaden caught in gill nets from 1996-2011 with Fish being the sample size in number of fish measured and Sets being the sample size in number of gill net sets.

Fish	Sets	Year	Annual Menhaden Length Increments								
			(80,90]	(90,100]	(100,110]	(110,120]	(120,130]	(130,140]	(140,150]	(150,160]	(160,170]
2,338	209	1996	0.01	0.01	0.01	0.02	0.07	0.15	0.16	0.09	0.11
3,386	236	1997	0.00	0.01	0.00	0.01	0.06	0.13	0.14	0.11	0.10
3,059	246	1998	0.00	0.01	0.01	0.02	0.06	0.17	0.19	0.11	0.11
2,913	231	1999	0.00	0.01	0.01	0.03	0.07	0.16	0.14	0.10	0.11
4,235	266	2000	0.00	0.00	0.01	0.02	0.06	0.14	0.11	0.07	0.07
3,542	219	2001	0.01	0.01	0.01	0.01	0.06	0.13	0.11	0.08	0.13
3,131	241	2002	0.00	0.01	0.01	0.03	0.06	0.14	0.14	0.08	0.09
3,297	247	2003	0.00	0.01	0.01	0.03	0.09	0.19	0.19	0.10	0.10
2,851	231	2004	0.00	0.01	0.02	0.04	0.11	0.18	0.17	0.11	0.10
3,659	234	2005	0.00	0.01	0.01	0.03	0.06	0.14	0.18	0.12	0.13
4,588	297	2006	0.01	0.01	0.01	0.02	0.08	0.16	0.16	0.15	0.10
3,301	253	2007	0.01	0.01	0.01	0.02	0.04	0.13	0.17	0.15	0.14
5,794	277	2008	0.00	0.01	0.01	0.02	0.04	0.12	0.14	0.10	0.12
5,782	308	2009	0.00	0.01	0.01	0.02	0.04	0.08	0.13	0.12	0.11
2,377	193	2010	0.00	0.01	0.01	0.03	0.07	0.14	0.12	0.09	0.09
4,222	248	2011	0.00	0.01	0.02	0.03	0.09	0.17	0.16	0.09	0.07

Year	Annual Menhaden Length Increments								
	(170,180]	(180,190]	(190,200]	(200,210]	(210,220]	(220,230]	(230,240]	(240,250]	(250,260]
1996	0.11	0.08	0.05	0.05	0.04	0.02	0.01	0.00	0.00
1997	0.13	0.09	0.07	0.07	0.03	0.02	0.01	0.00	0.00
1998	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.00	0.00
1999	0.11	0.08	0.06	0.06	0.03	0.02	0.00	0.00	0.00
2000	0.12	0.12	0.08	0.08	0.06	0.03	0.01	0.00	0.00
2001	0.14	0.08	0.06	0.07	0.05	0.03	0.02	0.01	0.00
2002	0.11	0.09	0.06	0.07	0.06	0.03	0.01	0.01	0.00
2003	0.13	0.07	0.02	0.02	0.02	0.01	0.00	0.00	0.00
2004	0.08	0.07	0.04	0.04	0.02	0.01	0.00	0.00	0.00
2005	0.13	0.08	0.04	0.04	0.02	0.00	0.00	0.00	0.00
2006	0.10	0.08	0.05	0.04	0.02	0.01	0.00	0.00	0.00
2007	0.13	0.07	0.04	0.03	0.02	0.01	0.00	0.00	0.00
2008	0.15	0.11	0.08	0.06	0.03	0.01	0.01	0.00	0.00
2009	0.13	0.12	0.07	0.07	0.05	0.02	0.01	0.00	0.00
2010	0.11	0.10	0.08	0.06	0.05	0.02	0.01	0.00	0.00
2011	0.11	0.10	0.06	0.05	0.02	0.01	0.00	0.00	0.00

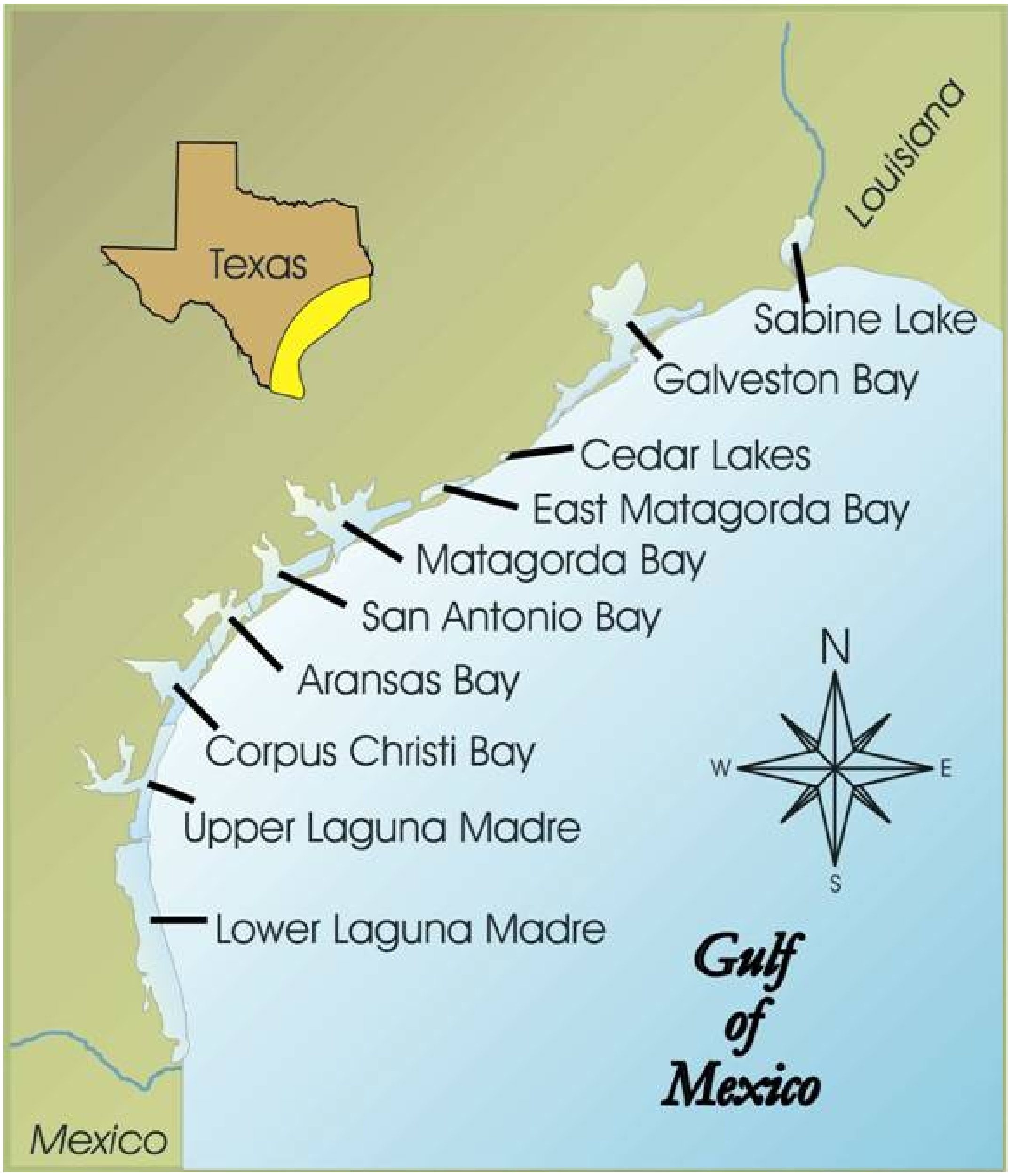


Figure 5.1 Chart of Texas bay systems.

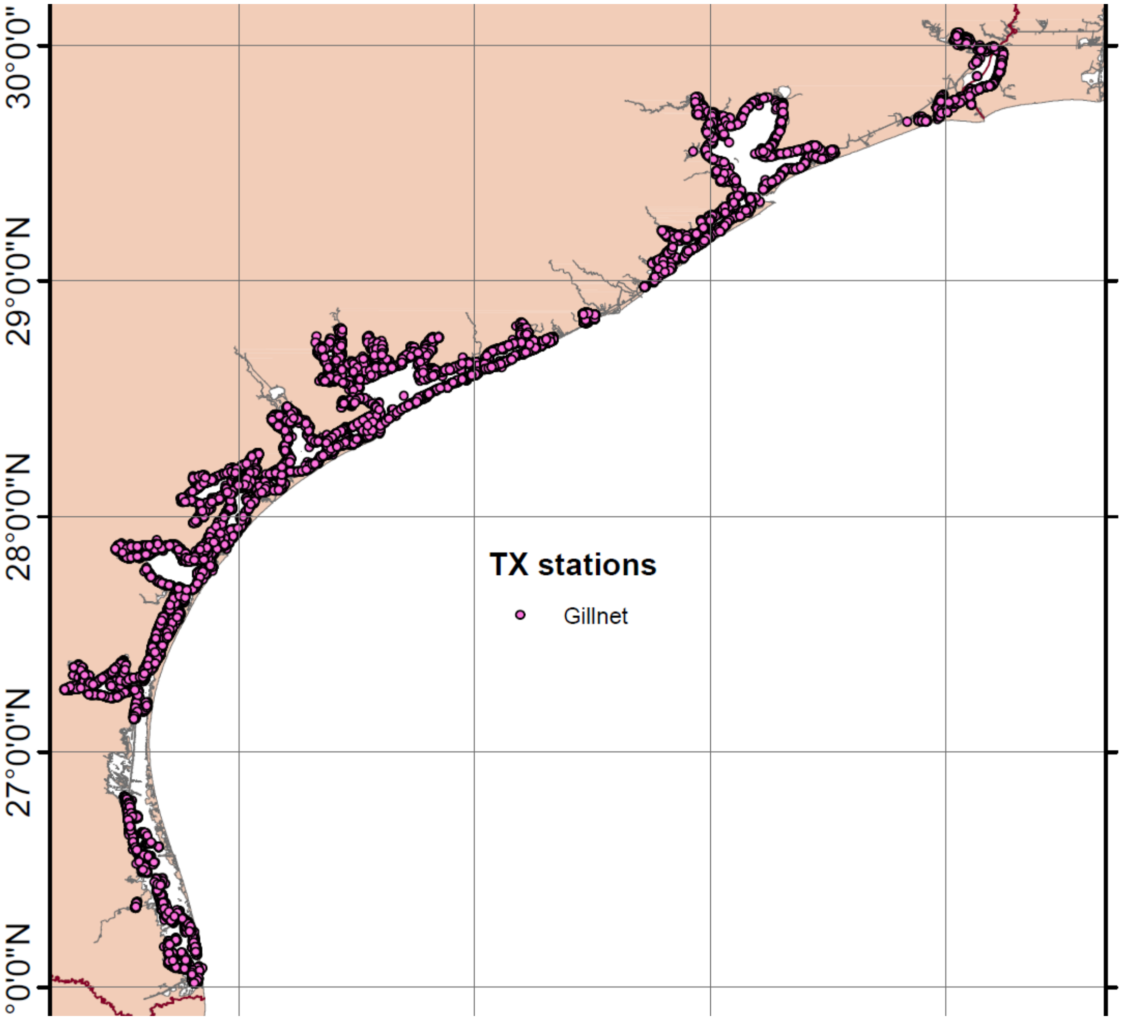


Figure 5.2 Texas sampling locations for the gill net data.

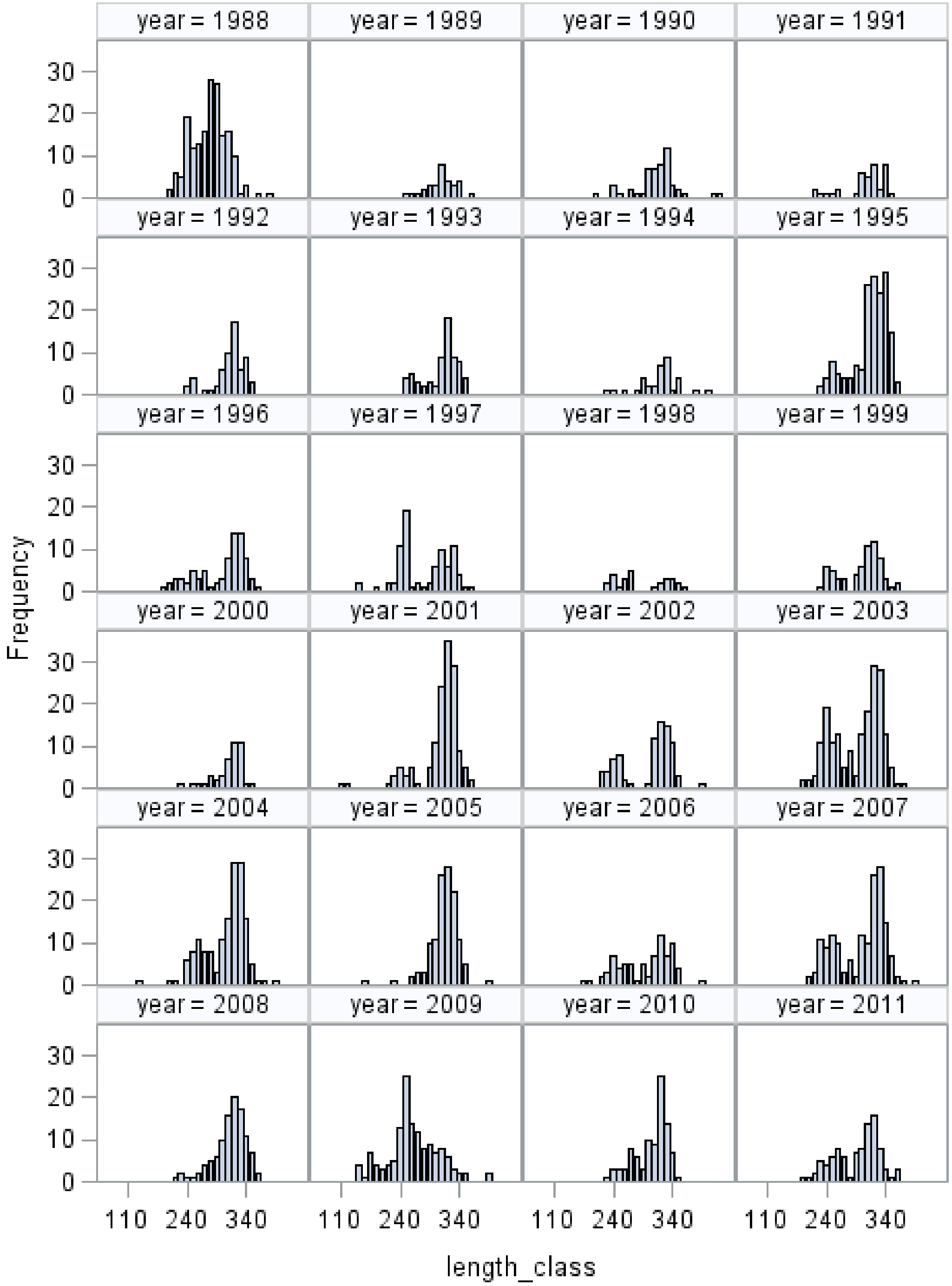


Figure 5.3 Length frequencies of Gulf menhaden from Texas gill net sampling.

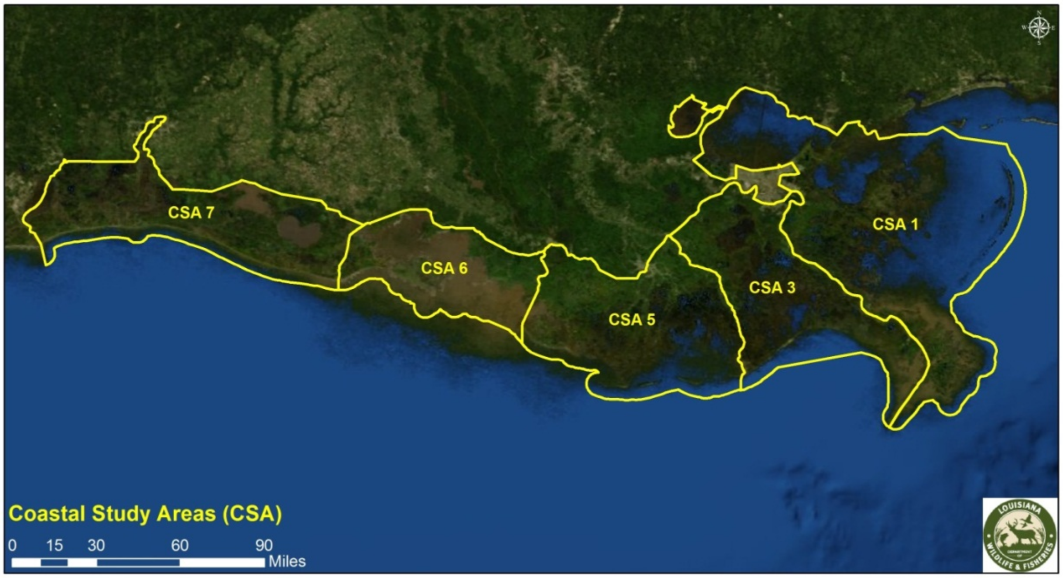


Figure 5.4 Map of the Louisiana Department of Wildlife and Fisheries' Coastal Study Areas (i.e., management units) which are generally delineated by river basins.

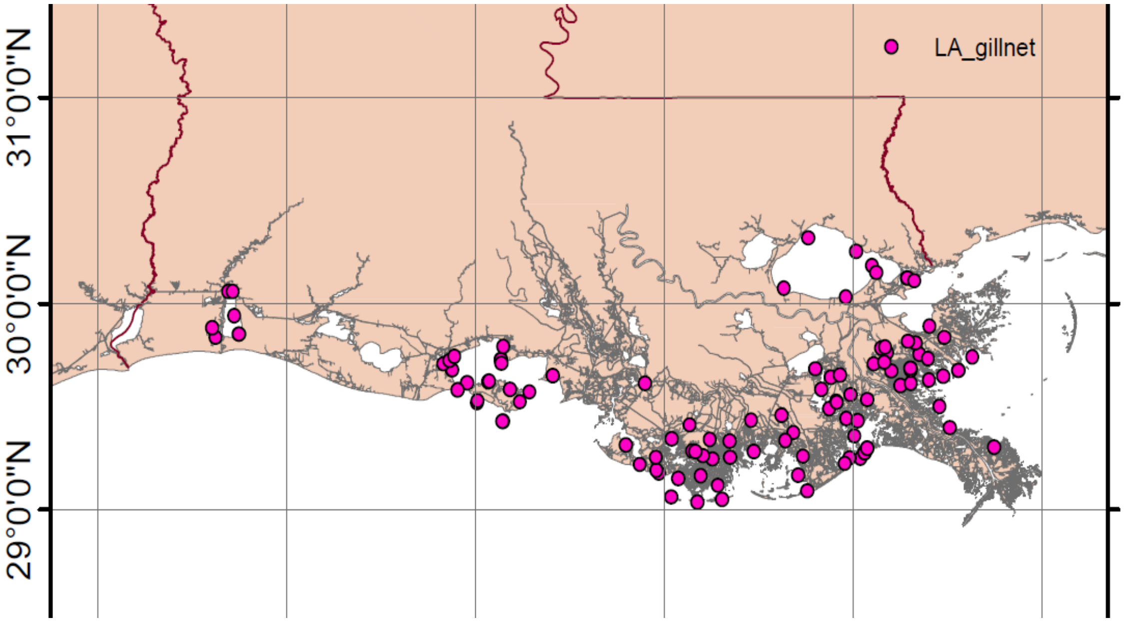


Figure 5.5 Louisiana gill net sampling stations across all Coastal Study Areas.

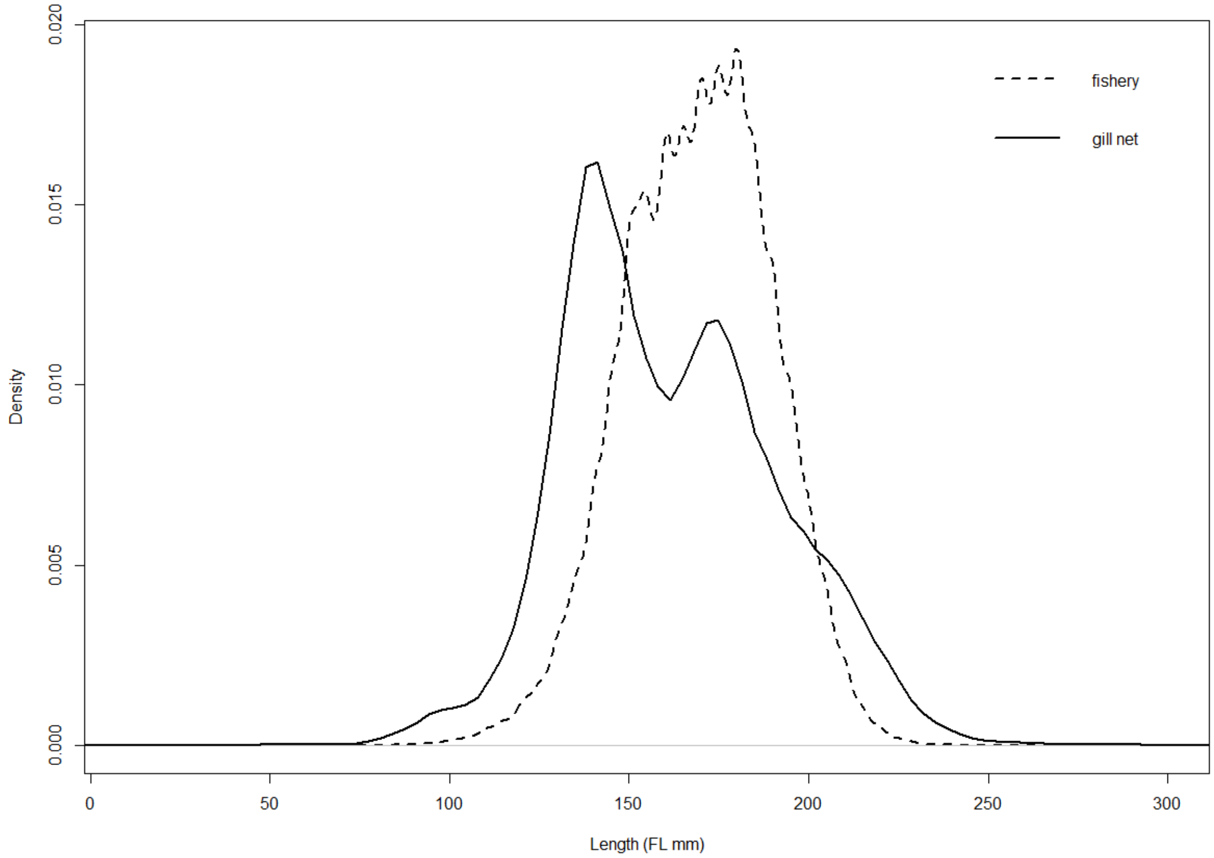


Figure 5.6 Density plots of length sampled by Louisiana gill nets from 1996-2011 and by the commercial reduction fishery from 1977-2011.

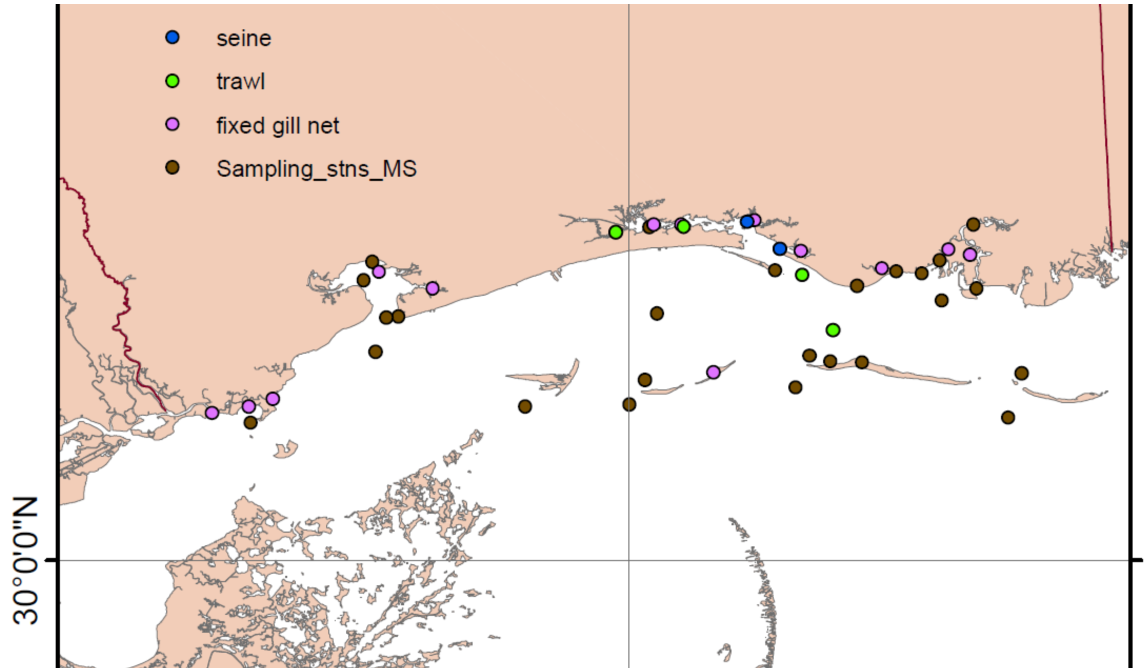


Figure 5.7 Fixed seine, trawl, and gill net stations for fishery-independent sampling conducted by Mississippi Department of Marine Resources.

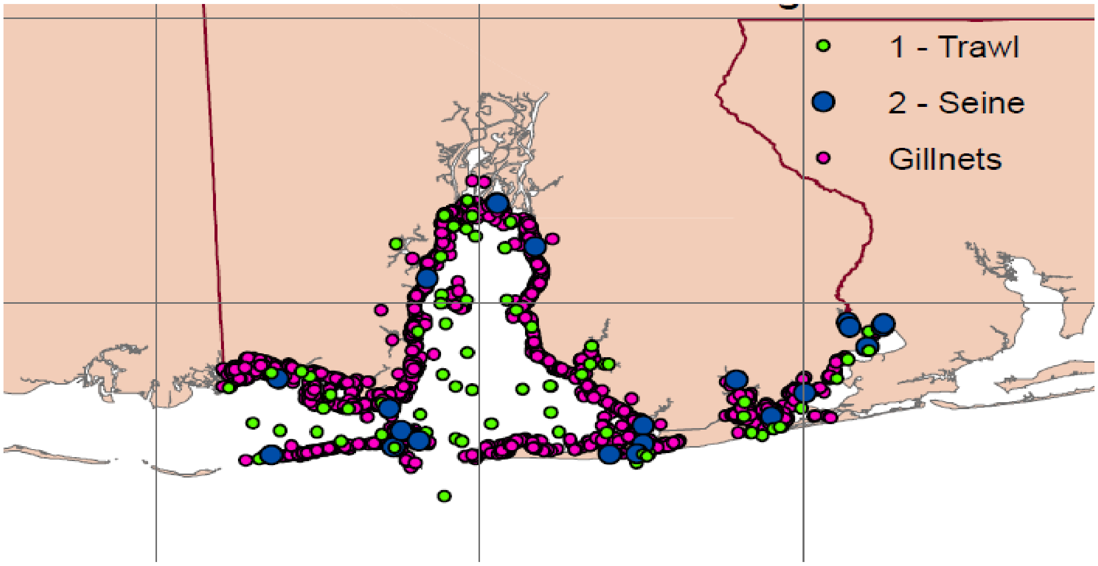


Figure 5.8 Fishery-independent sampling stations for trawls, seines, and gill nets for the Alabama Marine Resources Division.

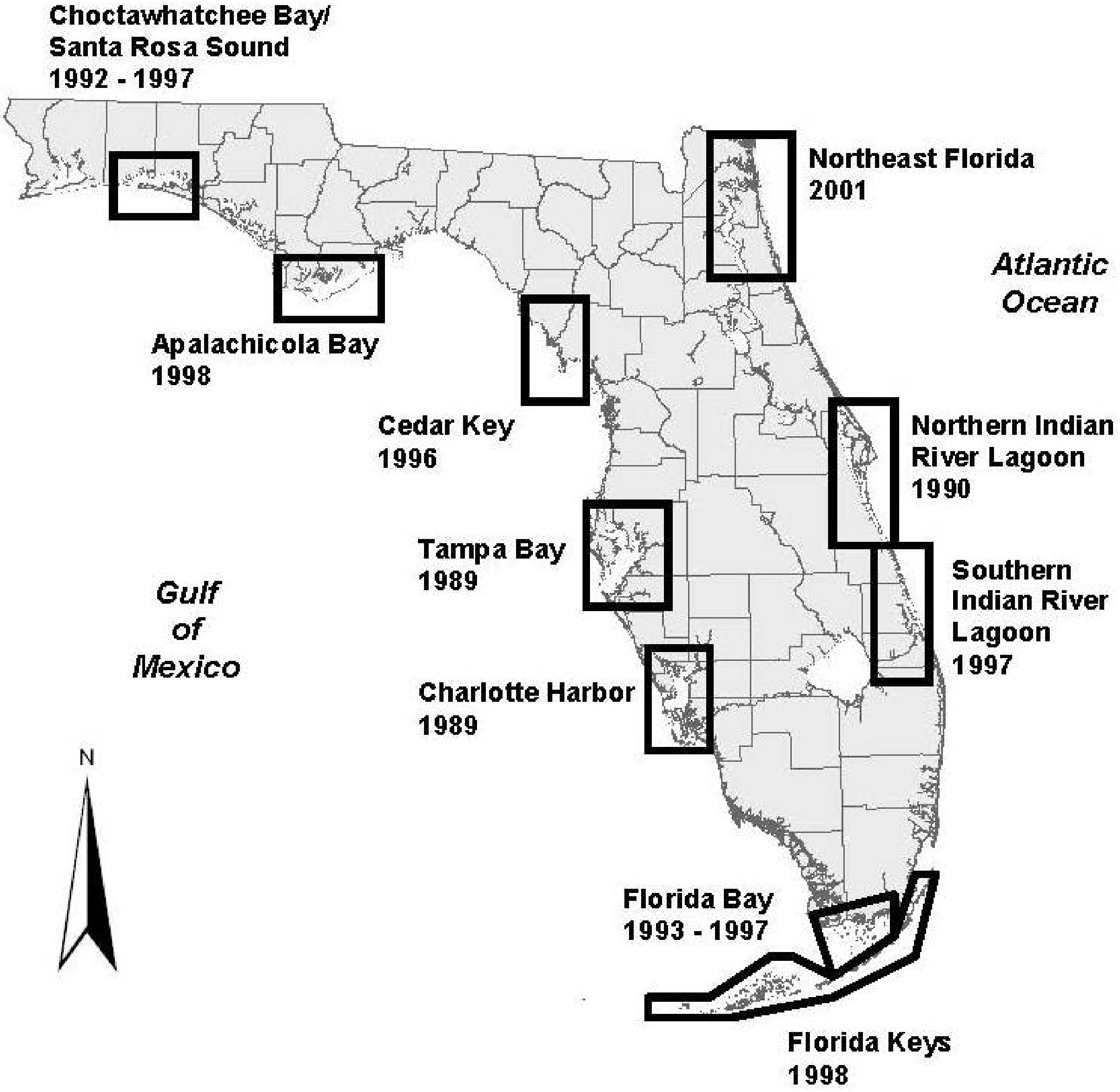


Figure 5.9 Locations of Fisheries-Independent Monitoring (FIM) program field laboratories for FWC. Years indicate initiation of sampling. If sampling was discontinued at a field lab, the last year of sampling is also provided.

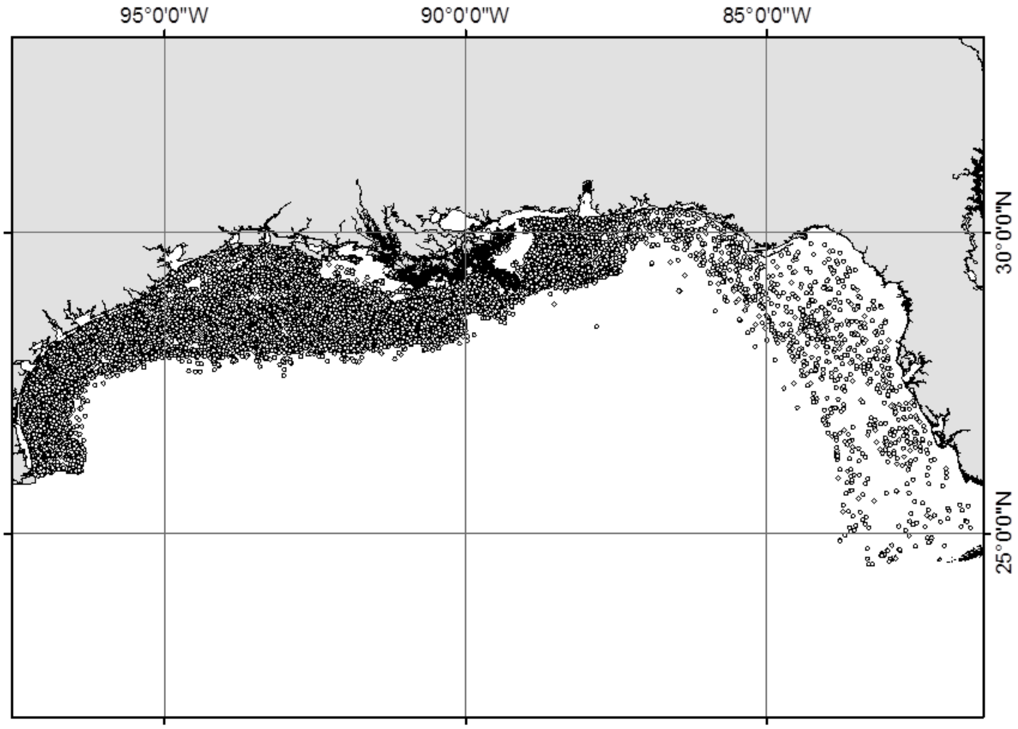


Figure 5.10 Spatial distribution of SEAMAP sets (open circles) in the Gulf of Mexico during 1982-2011, for all months, sampling agencies, locations, and depths.

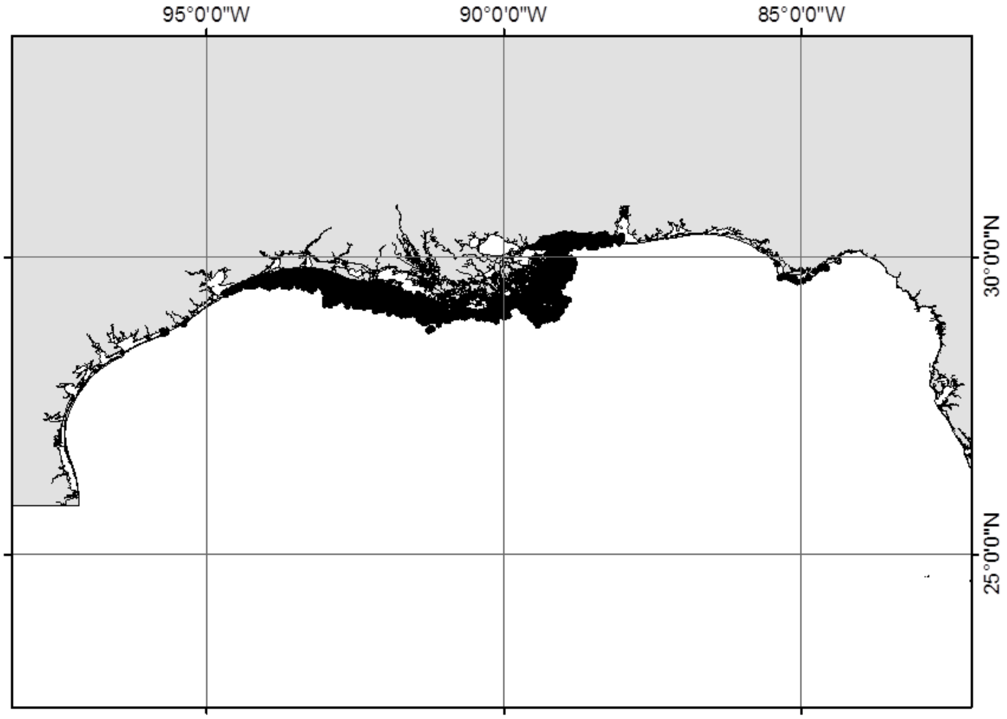


Figure 5.11 Spatial distribution of sets from the commercial menhaden fishery during 1986-2011.

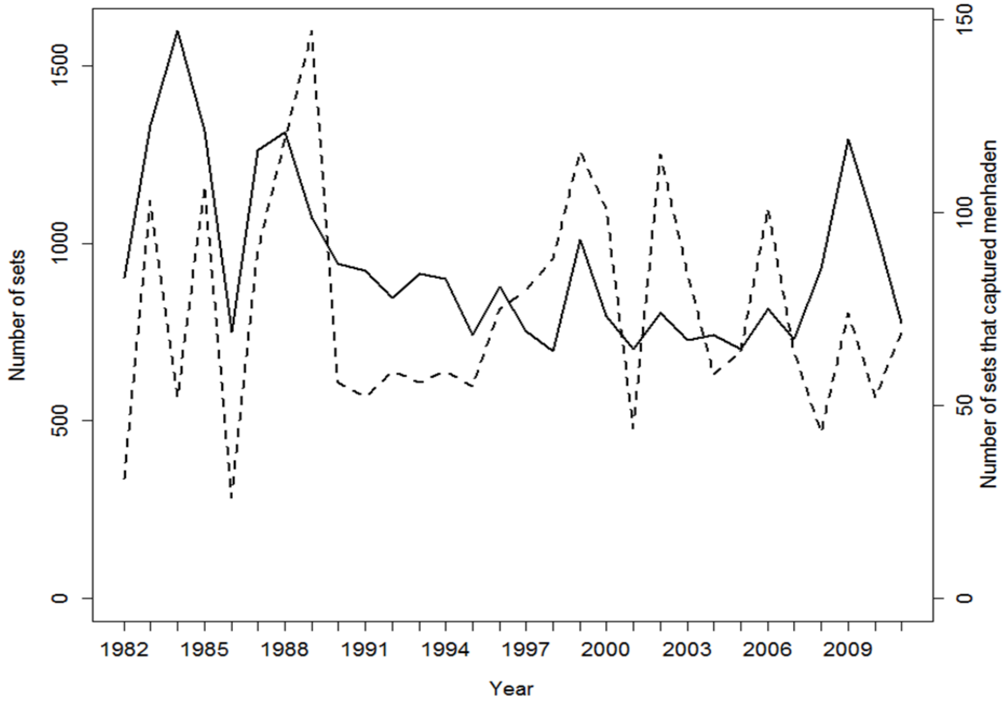


Figure 5.12 Number of SEAMAP sets by year (solid line; primary y-axis) and number of SEAMAP sets that captured menhaden by year (dashed line; secondary y-axis) during 1982-2011, for all months, sampling agencies, locations, and depths.

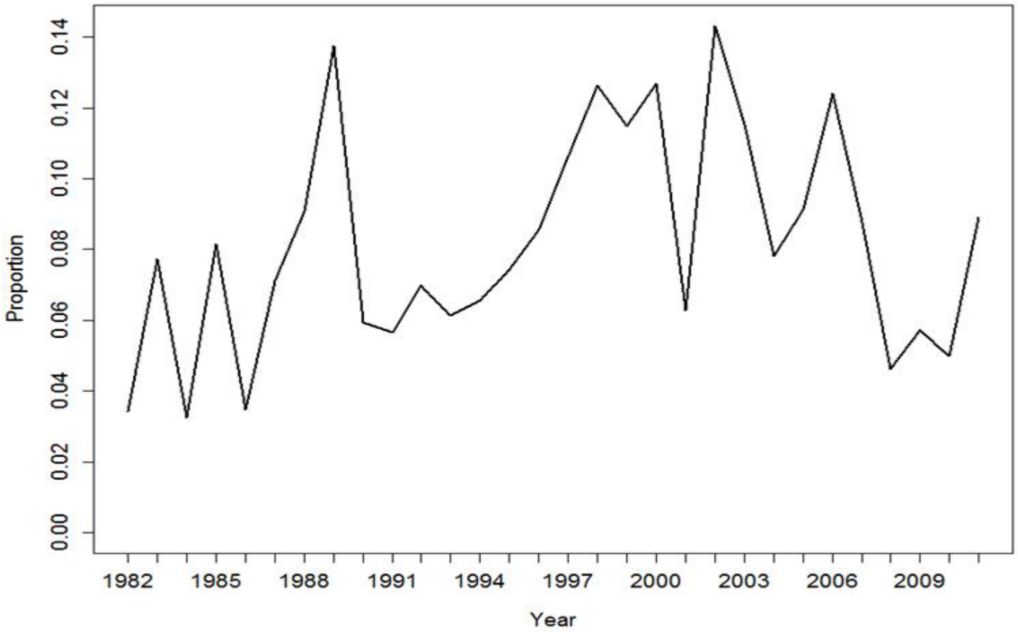


Figure 5.13 Proportion of SEAMAP sets within a year that captured at least one menhaden during 1982-2011 for all months, sampling agencies, locations, and depths.

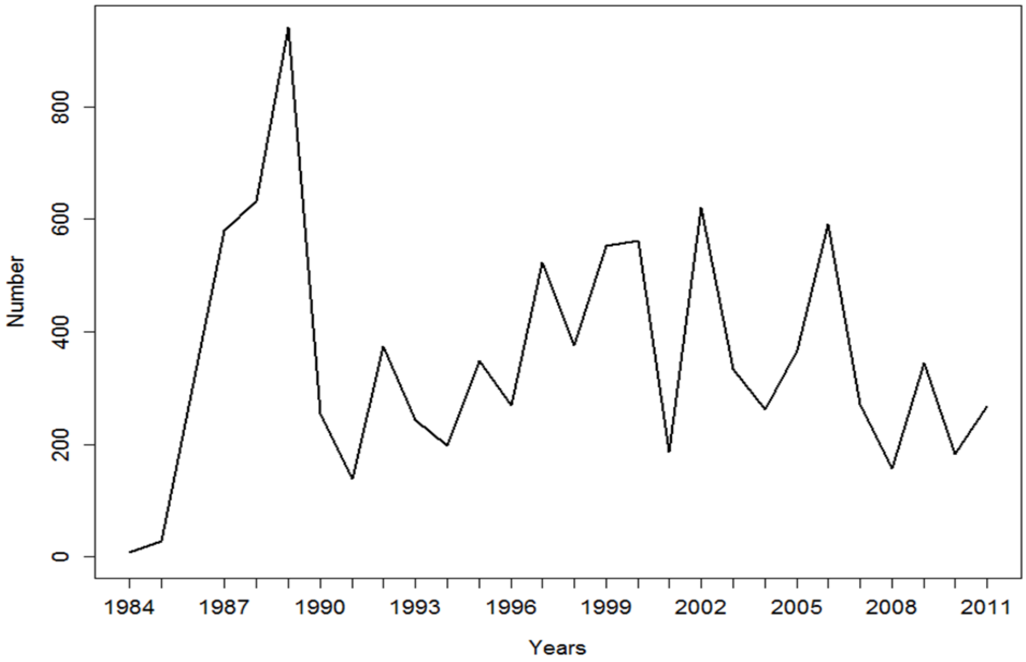


Figure 5.14 Yearly number of menhaden with length measurements captured in SEAMAP sets during 1982-2011, for all months, sampling agencies, locations, and depths. No lengths were recorded in 1982, 1983, and 1986.

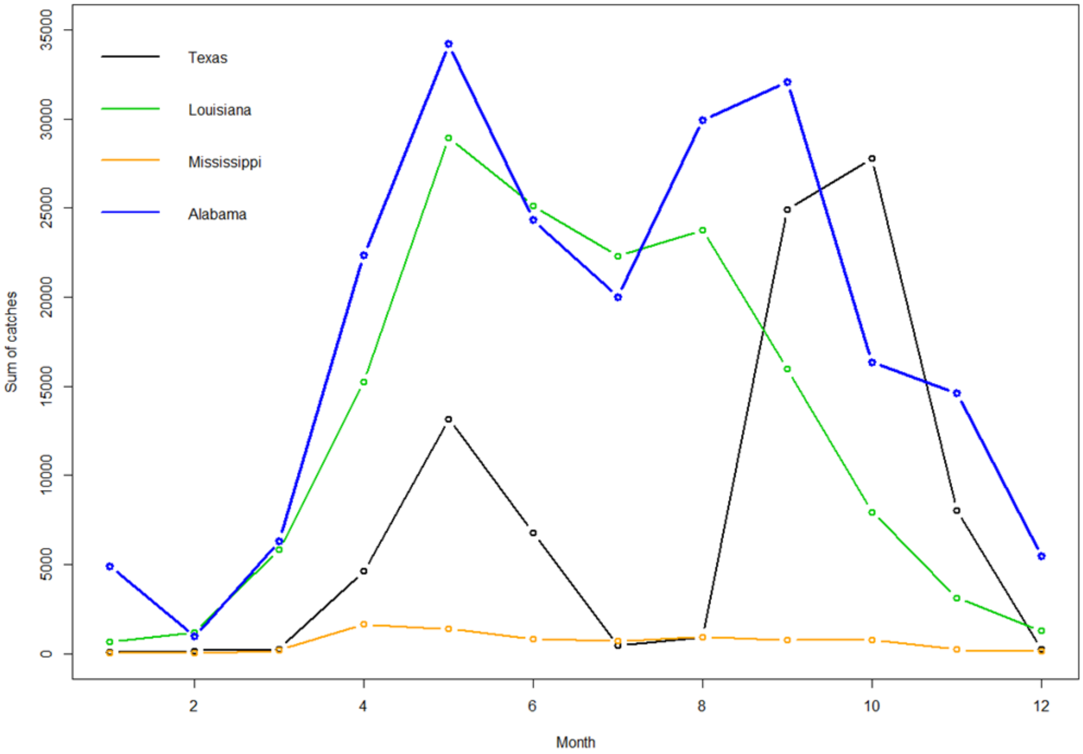


Figure 5.15 Sum of total Gulf menhaden catches by month and state from state fishery-independent gill net sampling.

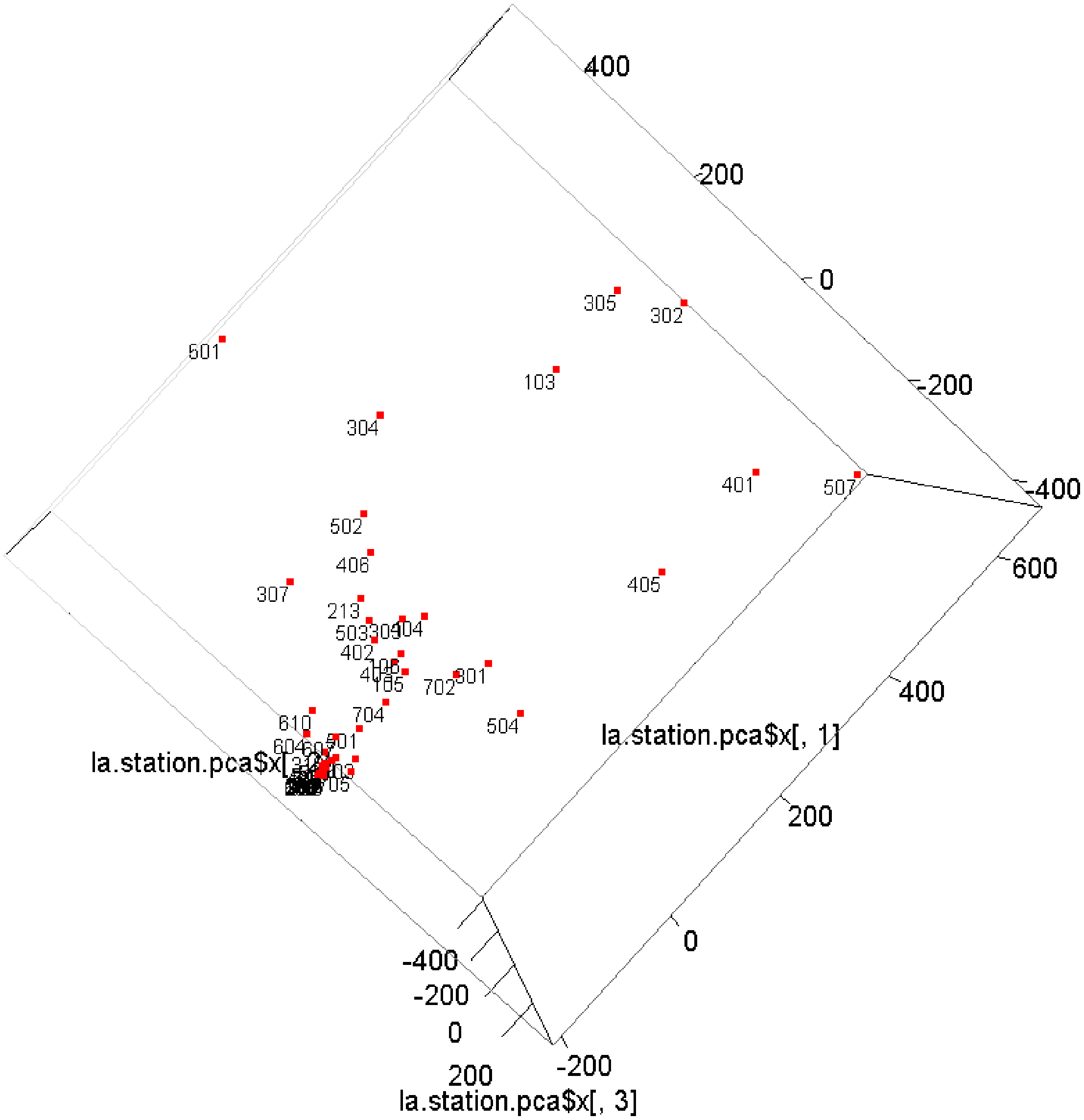


Figure 5.16 Spin plot demonstrating the grouping of long-term stations from the Louisiana gill net data. Each red point is a station.

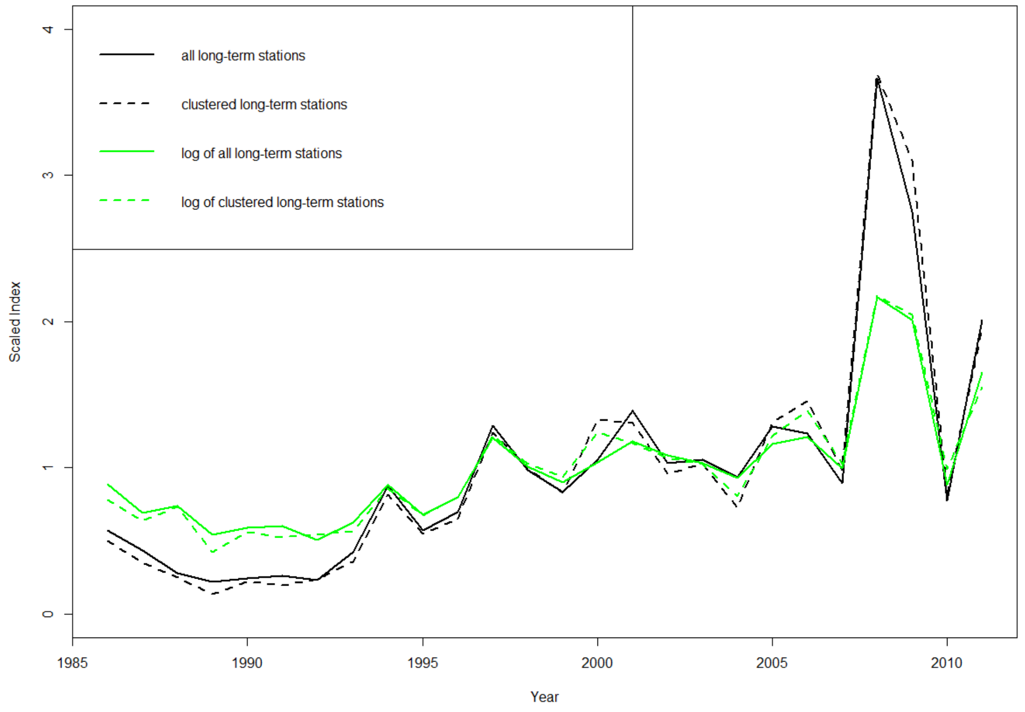


Figure 5.17 Scaled, standardized indices based on the data from Louisiana. The solid lines represent all long-term stations, while the dashed lines represent only those stations with higher levels of menhaden catches as determined using the principal components analysis. The black lines indicate the index based on catches as recorded in the database, and the green lines indicate the index based on catches that are log-transformed.

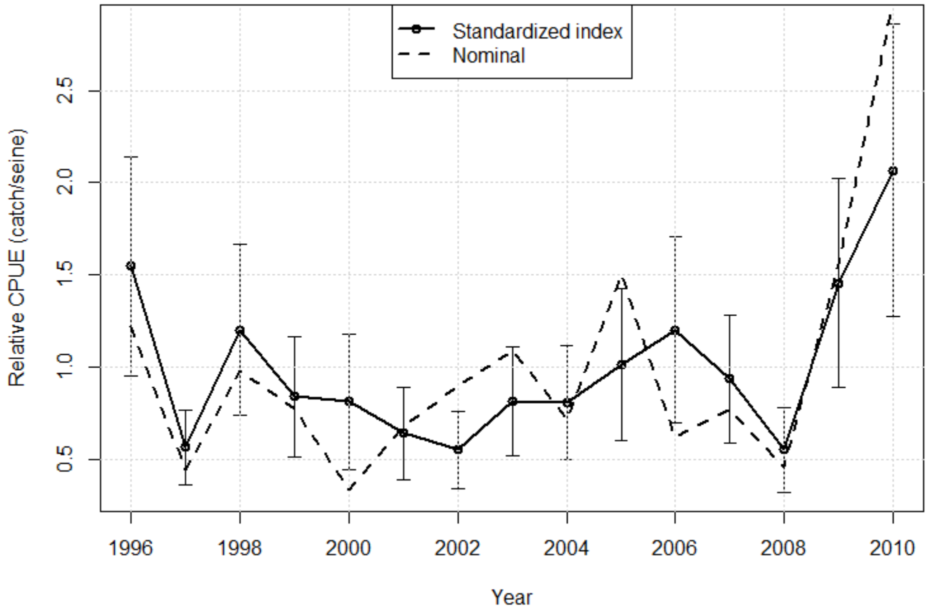


Figure 5.18 The scaled, standardized and scaled, nominal Gulf menhaden seine index for 1988-2010 representing juvenile abundance.

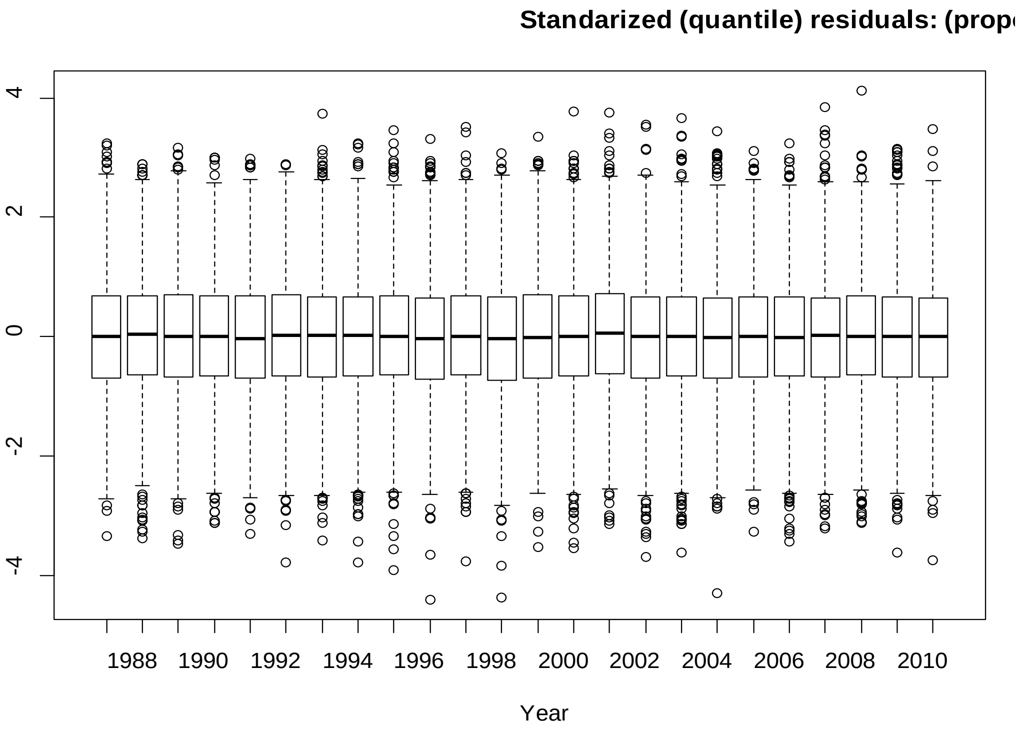


Figure 5.19 Residual plot for the proportion positive by year for the seine index.

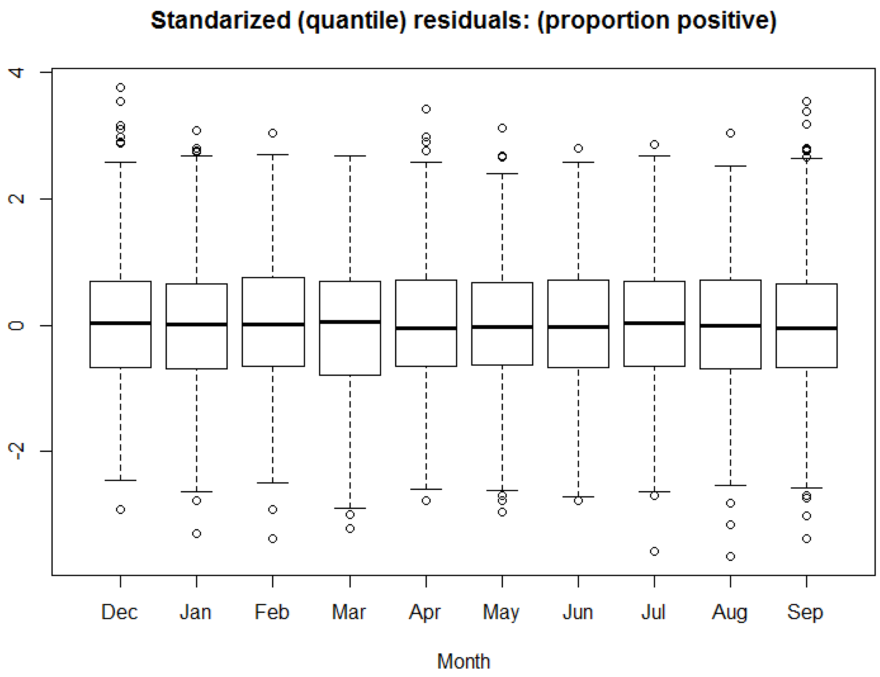


Figure 5.20 Residual plot for the proportion positive by month (Dec-Sep) for the seine index.

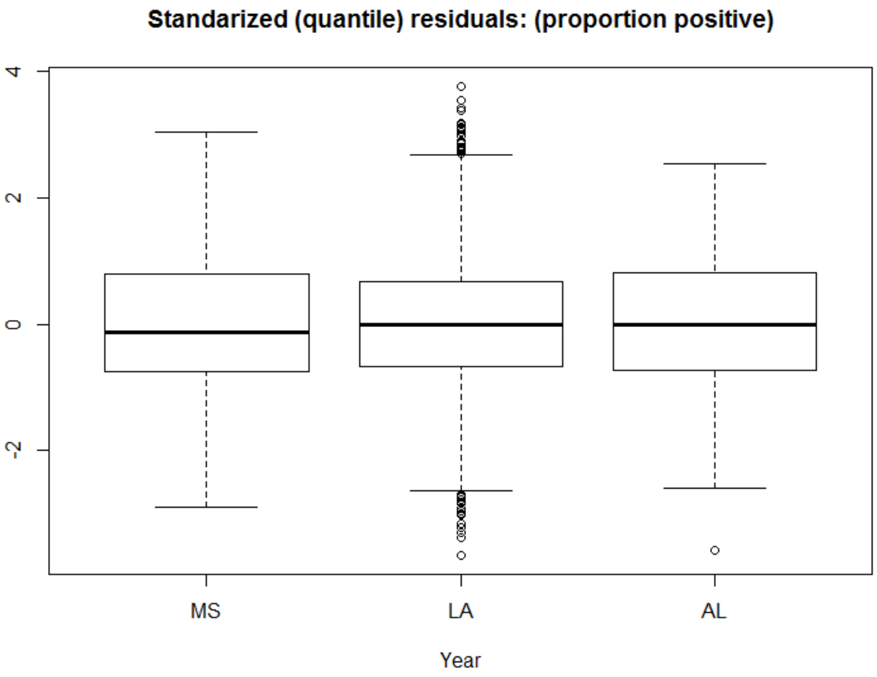


Figure 5.21 Residual plot for the proportion positive by state for the seine index.

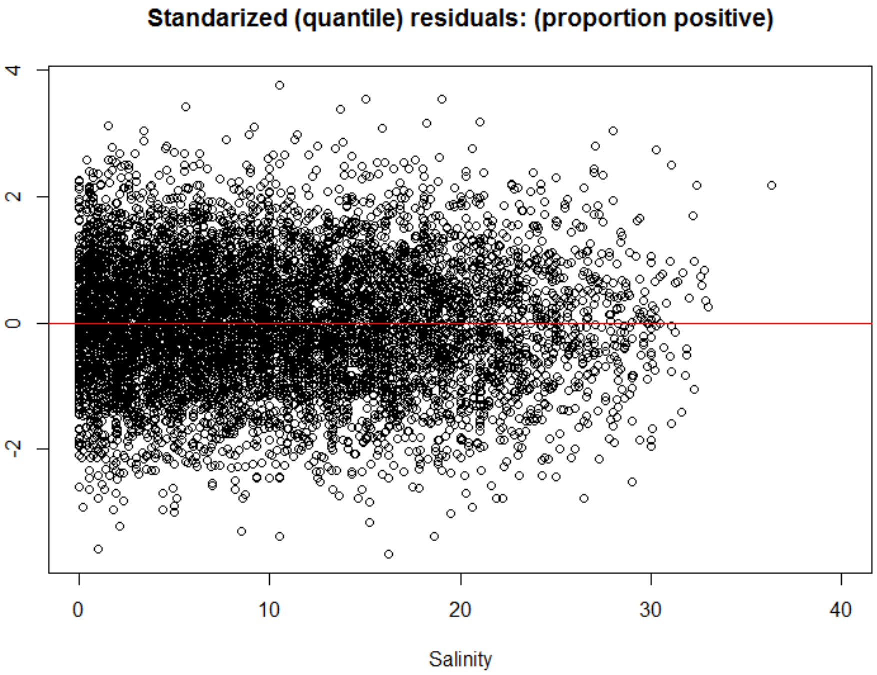


Figure 5.22 Residual plot for the proportion positive by the continuous variable, salinity for the seine index.

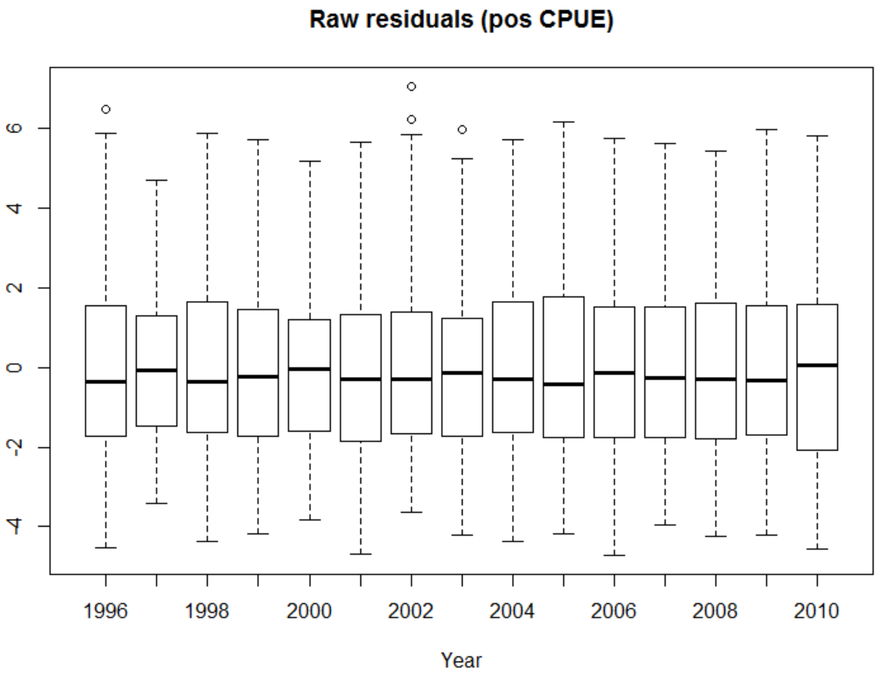


Figure 5.23 Raw residuals for the positive catches by year for the seine index.

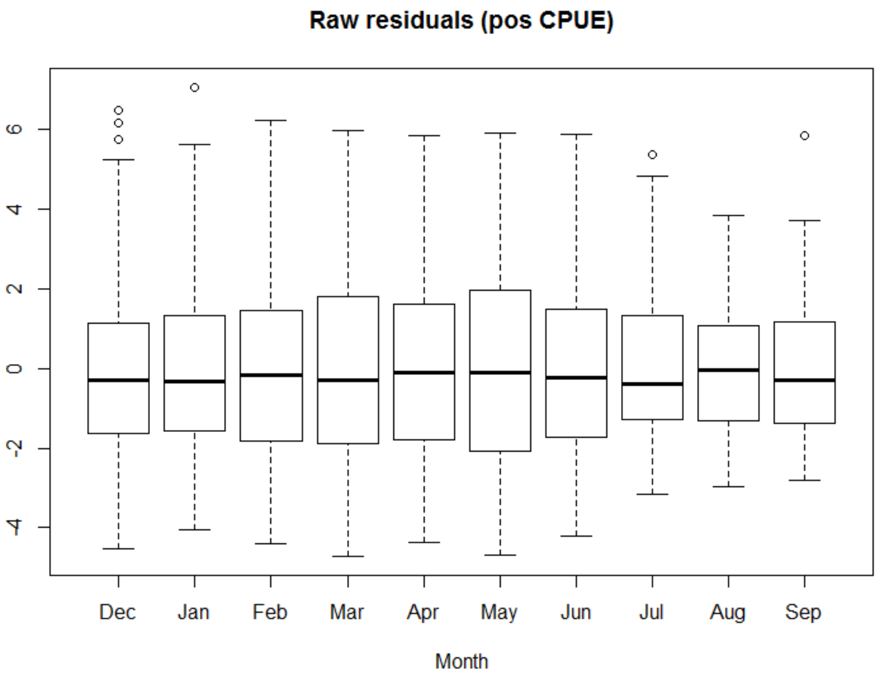


Figure 5.24 Raw residuals for the positive catches by month (Dec-Sep) for the seine index.

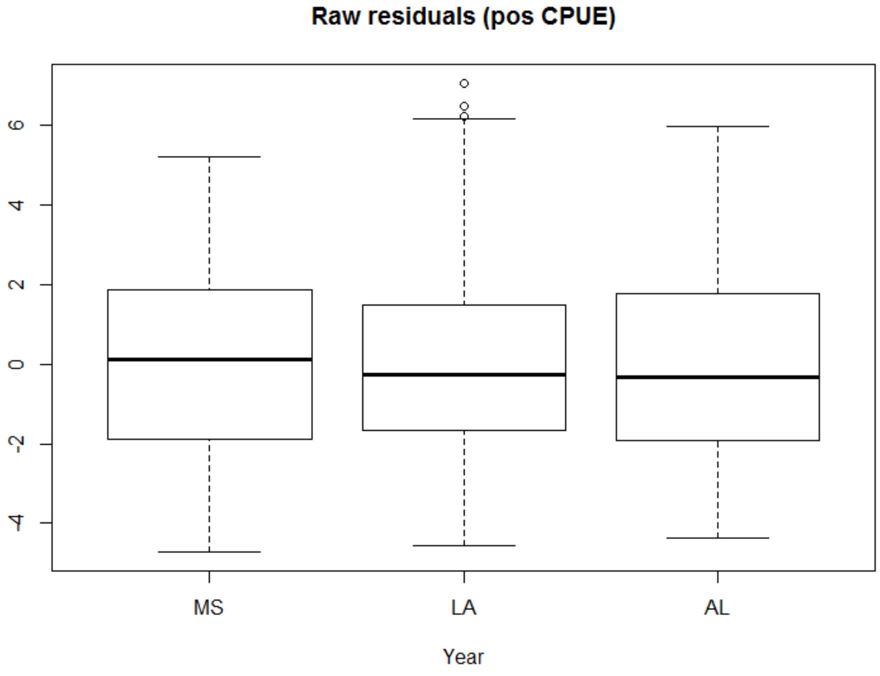


Figure 5.25 Raw residuals for the positive catches by state for the seine index.

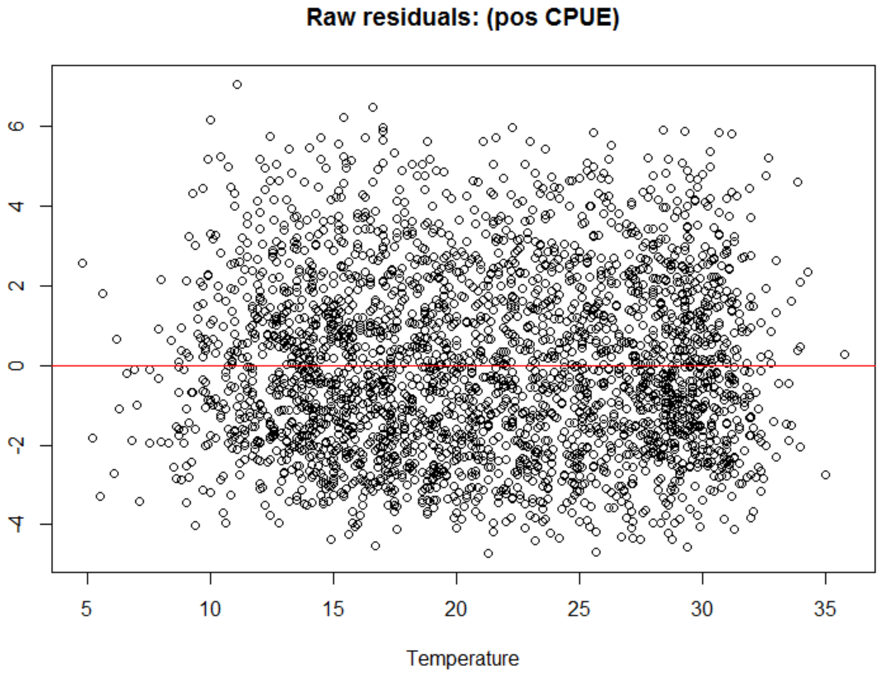


Figure 5.26 Raw residuals for the positive catches by temperature for the seine index.

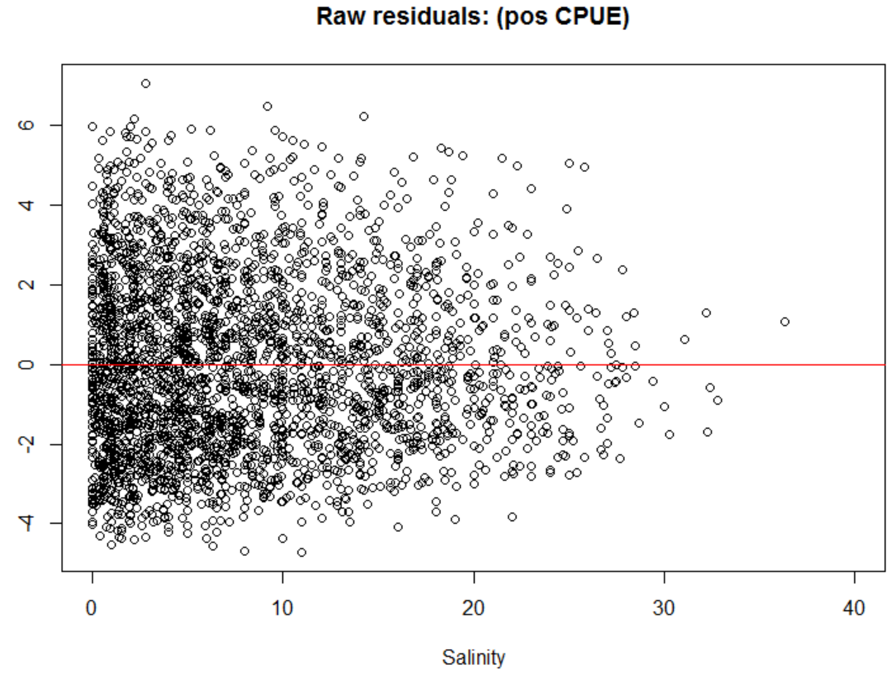


Figure 5.27 Raw residuals for the positive catches by salinity for the seine index.

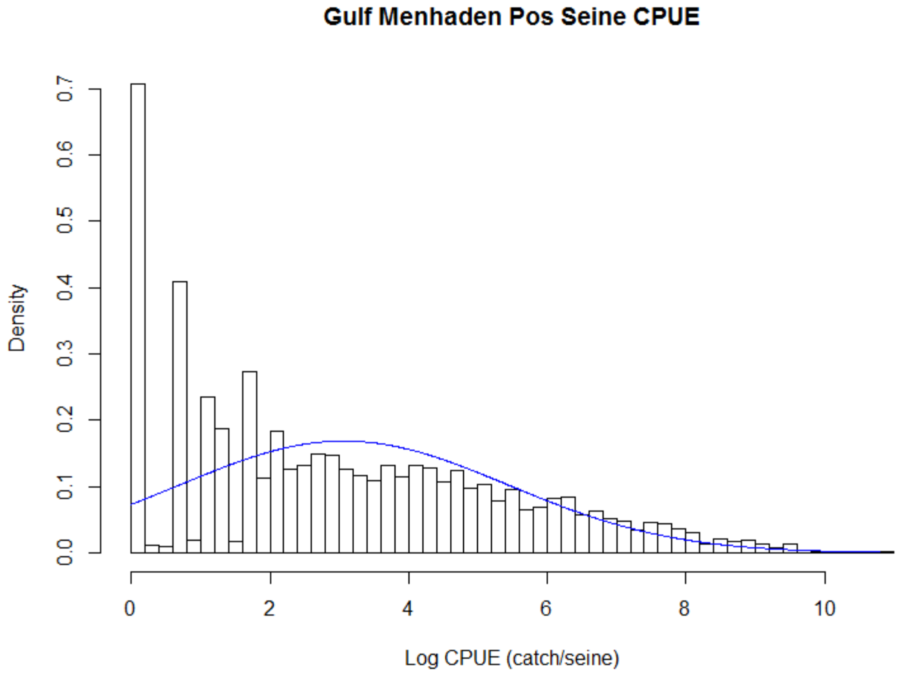


Figure 5.28 Density plot of the positive catches for the seine index.

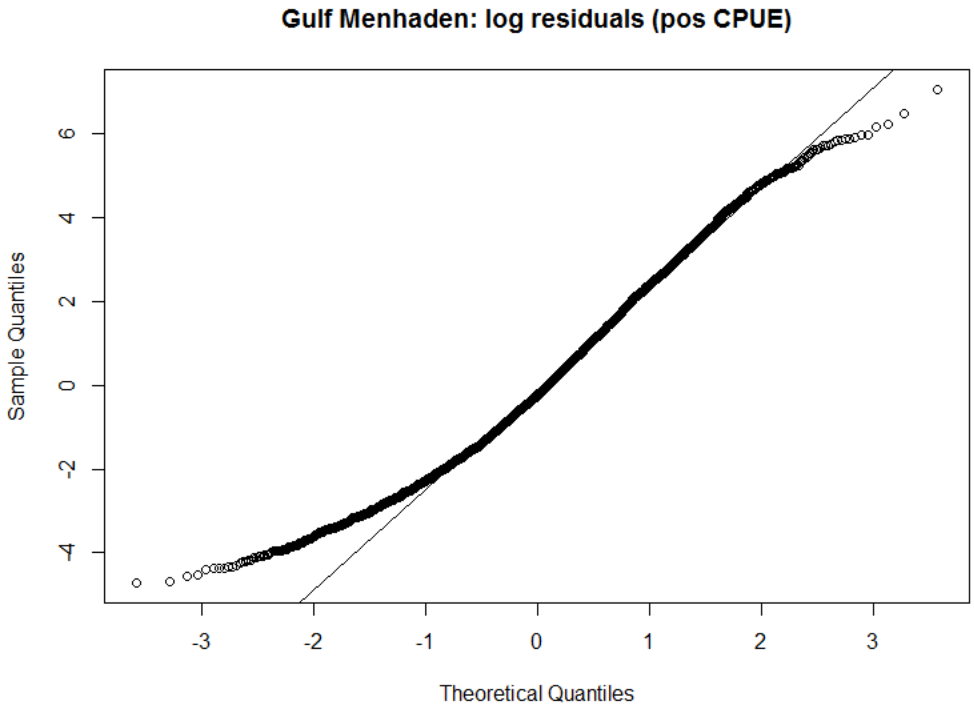


Figure 5.29 QQ plot of the positive catches for the seine index.

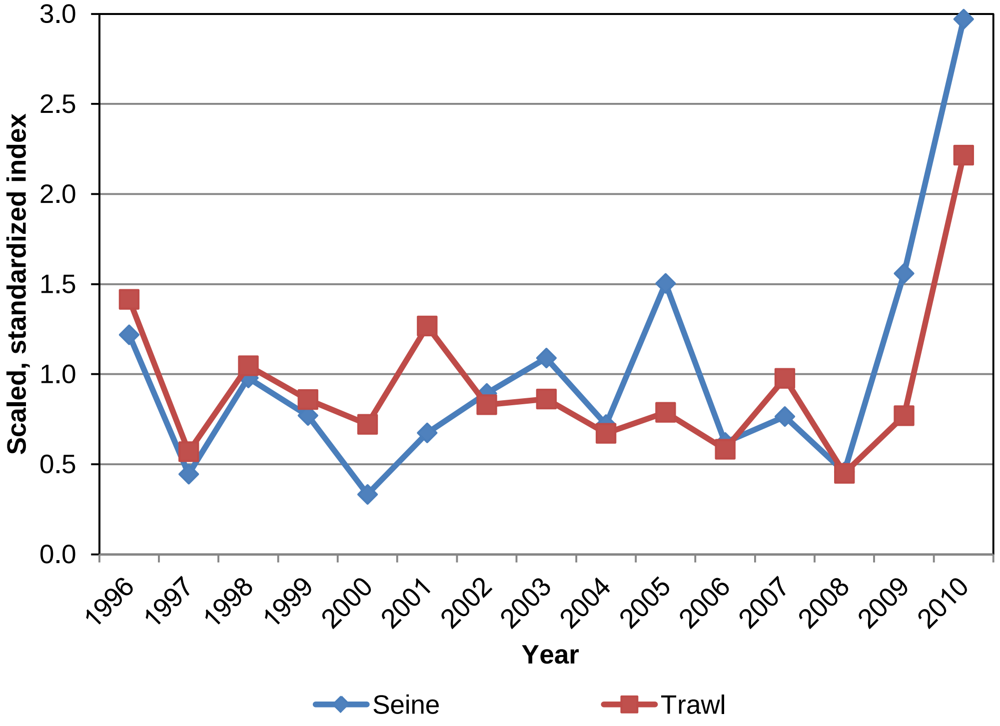


Figure 5.30 Scaled, standardized recruitment indices.

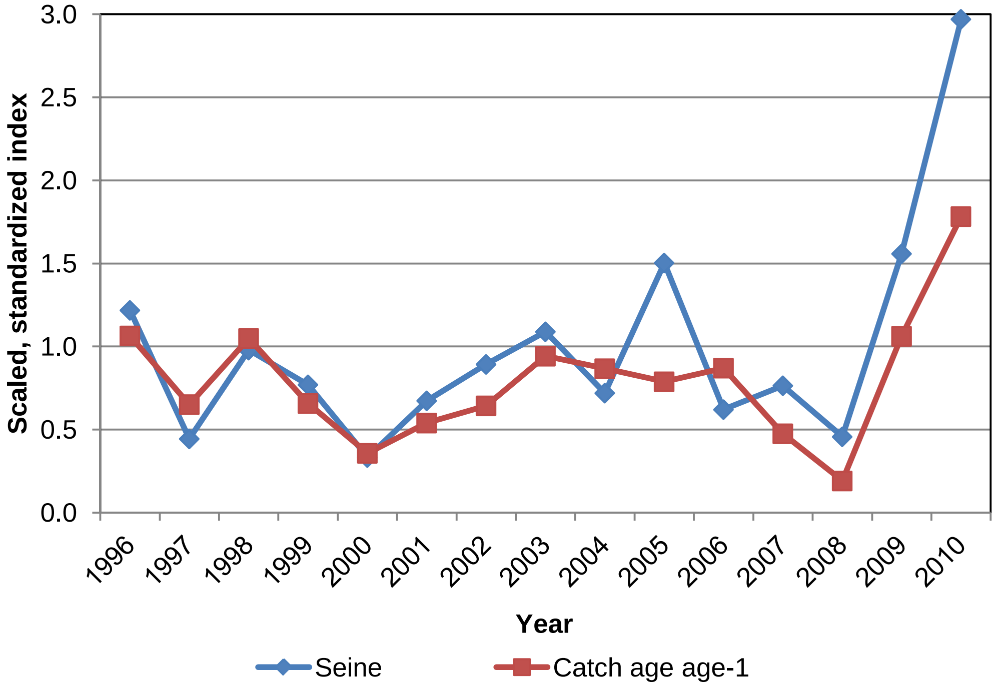


Figure 5.31 Scaled, standardized seine index compared to an index based on catch at age-1 with an appropriate lag.

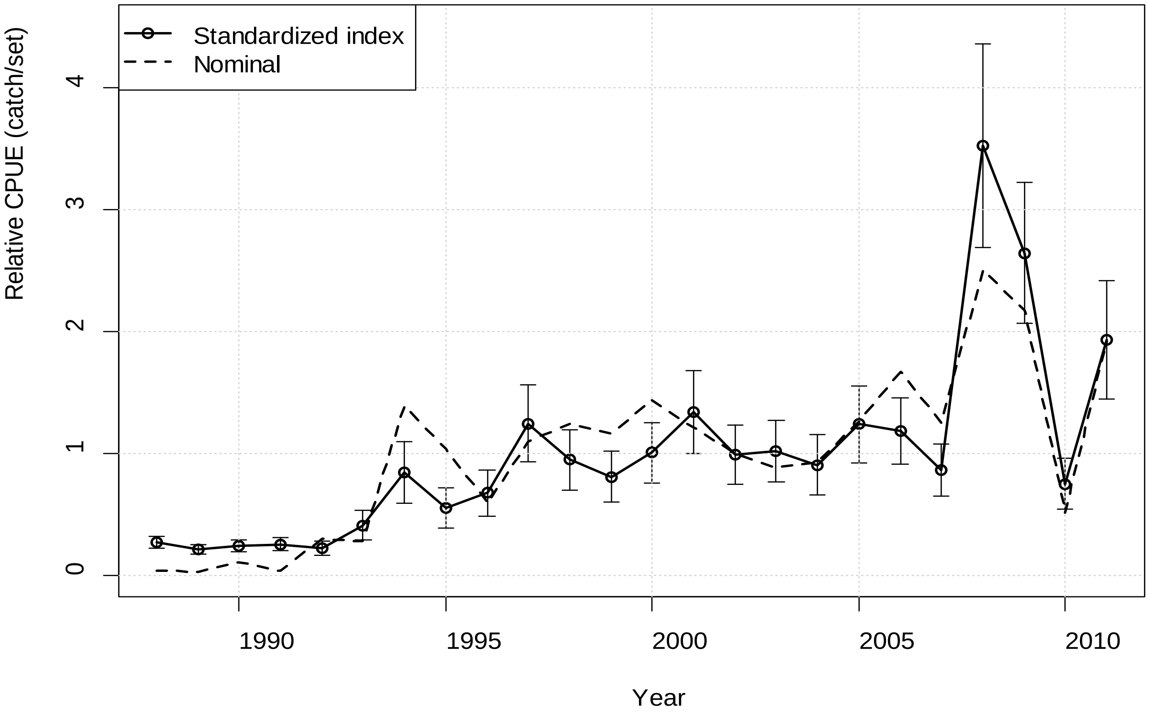


Figure 5.32 The scaled, standardized and scaled, nominal Gulf menhaden gill net index for 1988-2011 representing adult abundance.

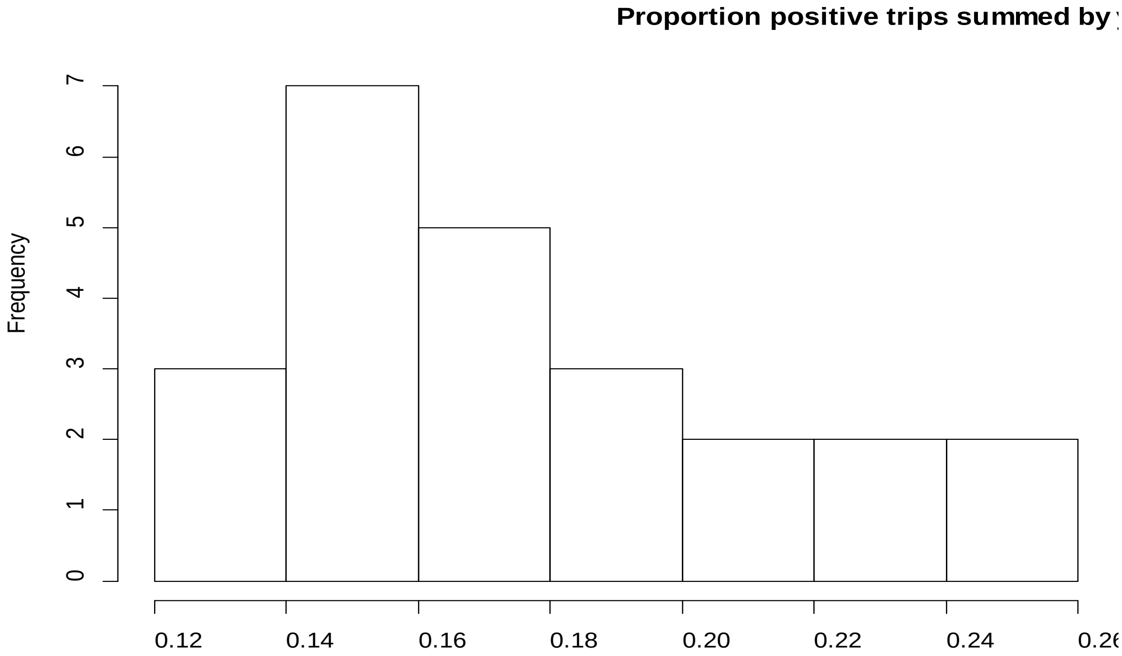


Figure 5.33 Frequency plot of the proportion positive for the years 1988-2011, which were included in the Louisiana gill net index.

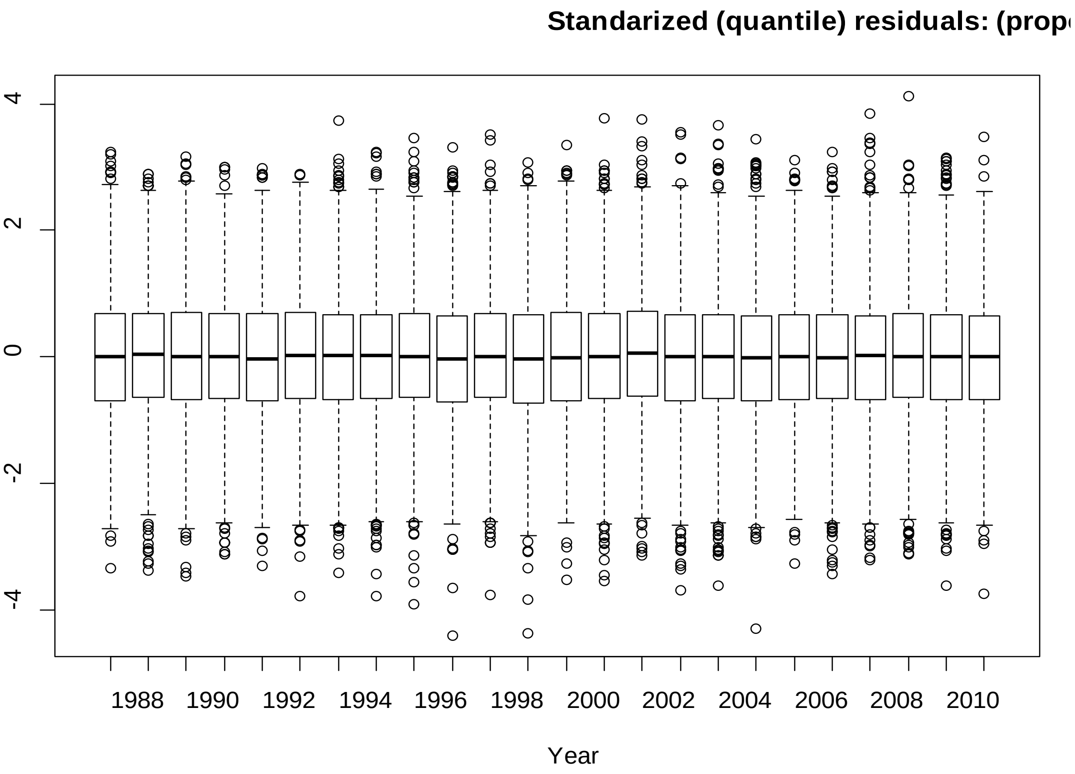


Figure 5.34 Residual plot for the proportion positive by year for the Louisiana gill net index.

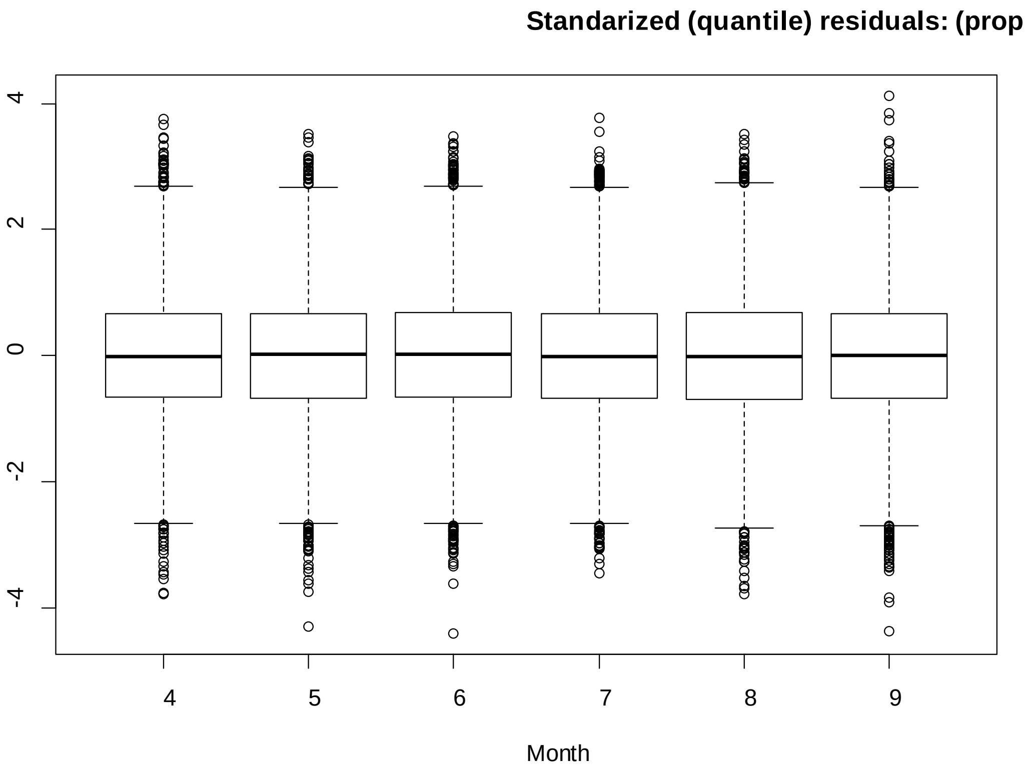


Figure 5.35 Residual plot for the proportion positive by month (April-September) for the Louisiana gill net index.

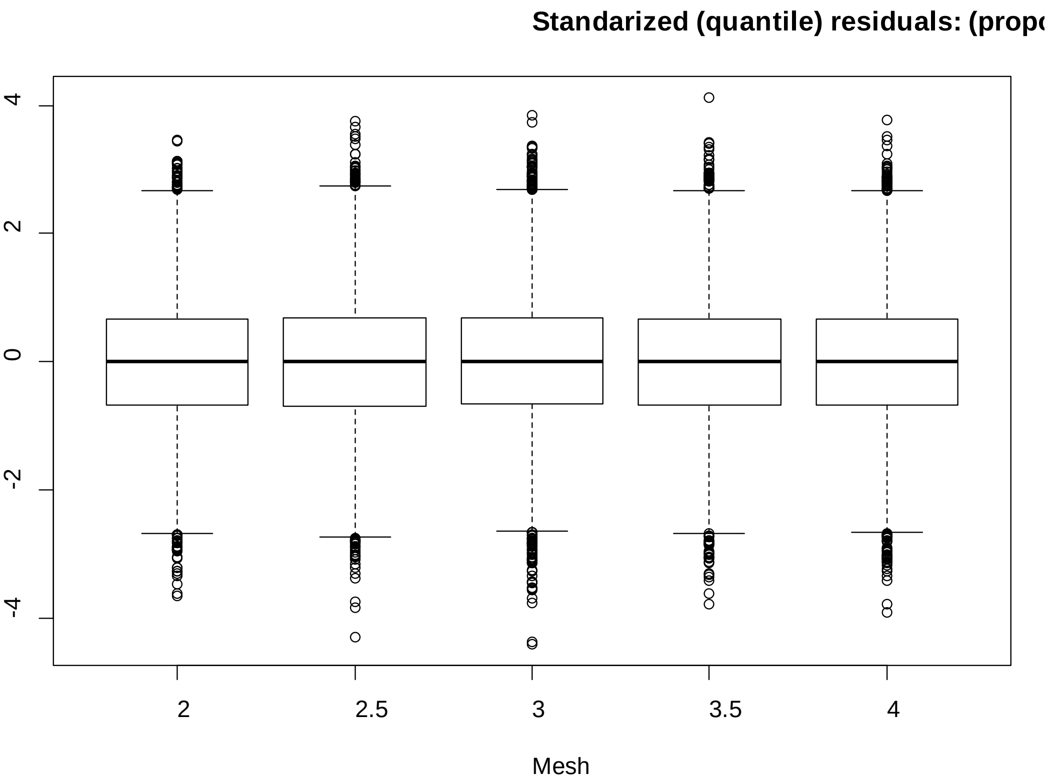


Figure 5.36 Residual plot for the proportion positive by mesh size for the Louisiana gill net index.

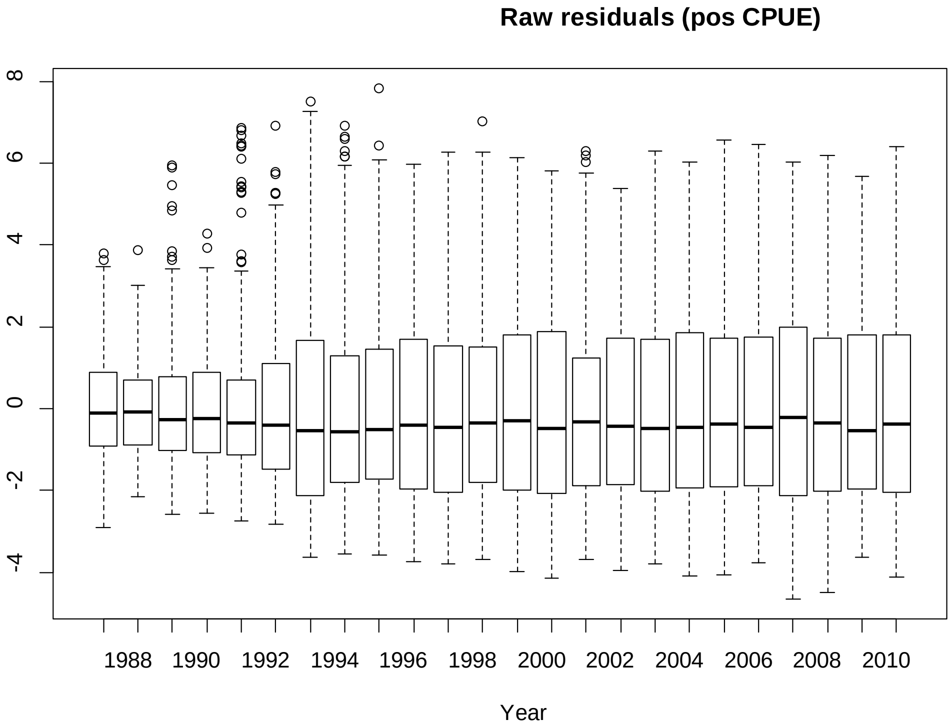


Figure 5.37 Raw residuals for the positive catches by year for the Louisiana gill net index.

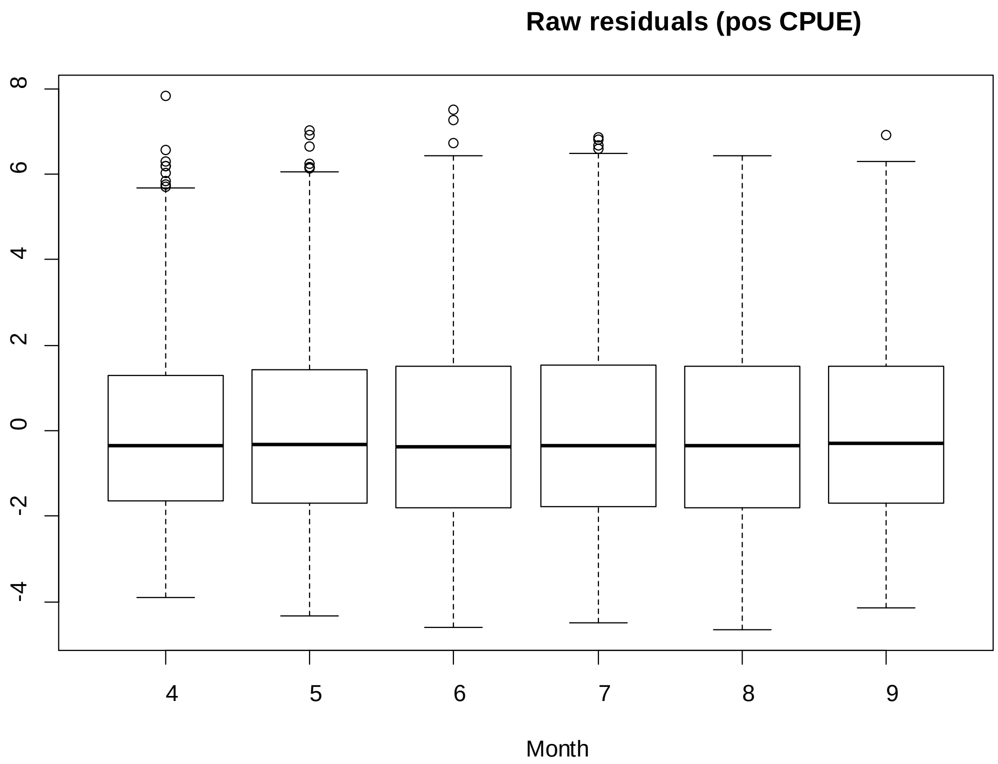


Figure 5.38 Raw residuals for the positive catches by month (April-September) for the Louisiana gill net index.

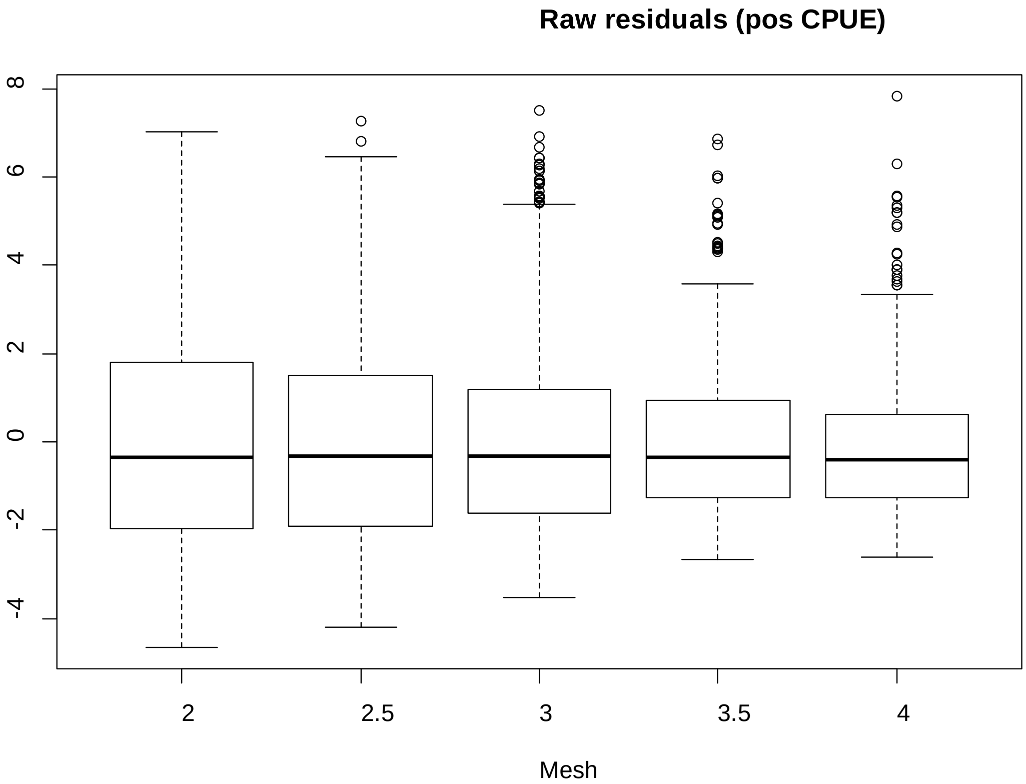


Figure 5.39 Raw residuals for the positive catches by mesh size for the Louisiana gill net index.

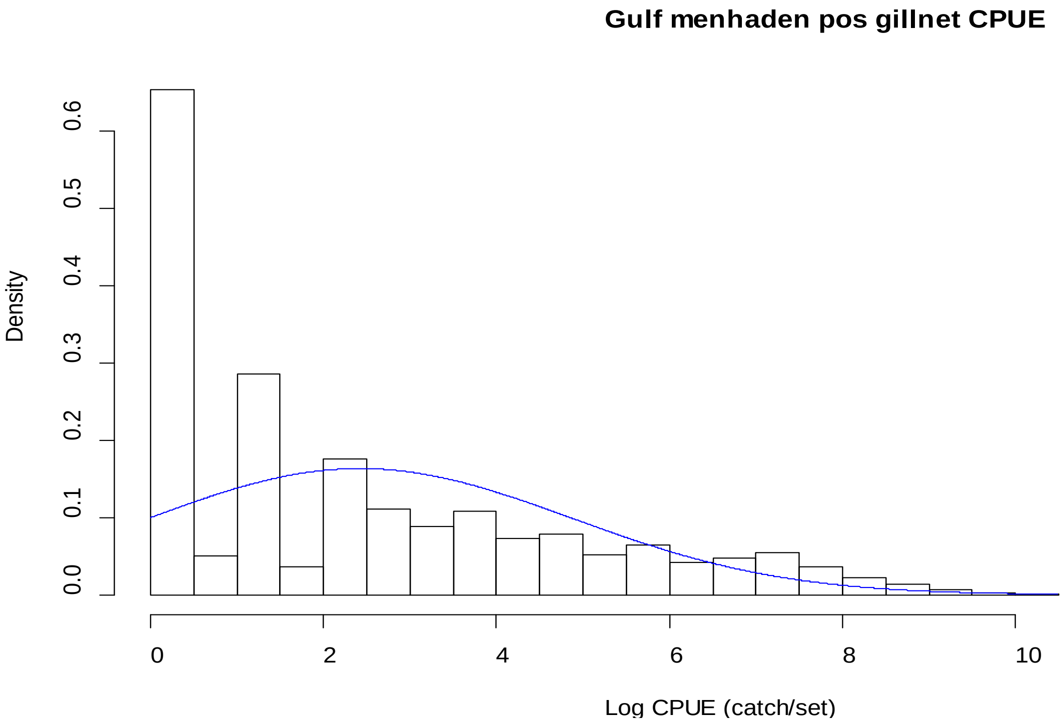


Figure 5.40 Density plot of the positive catches for the Louisiana gill net index.

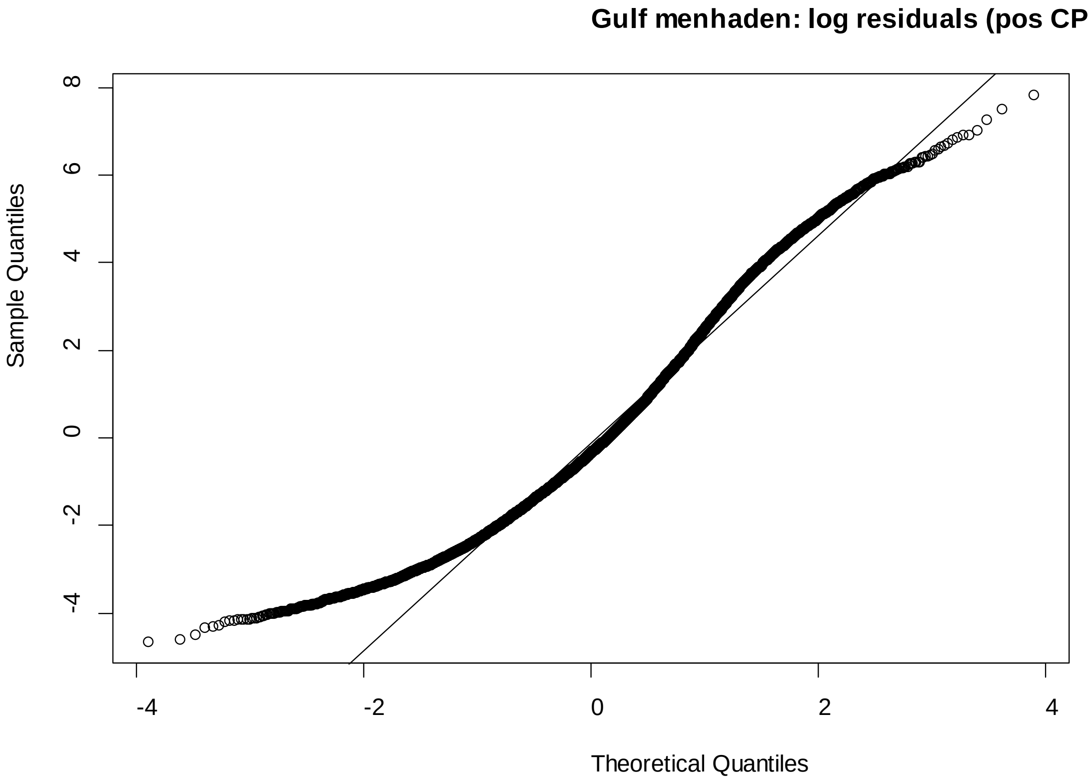


Figure 5.41 QQ plot of the positive catches for the Louisiana gill net index.

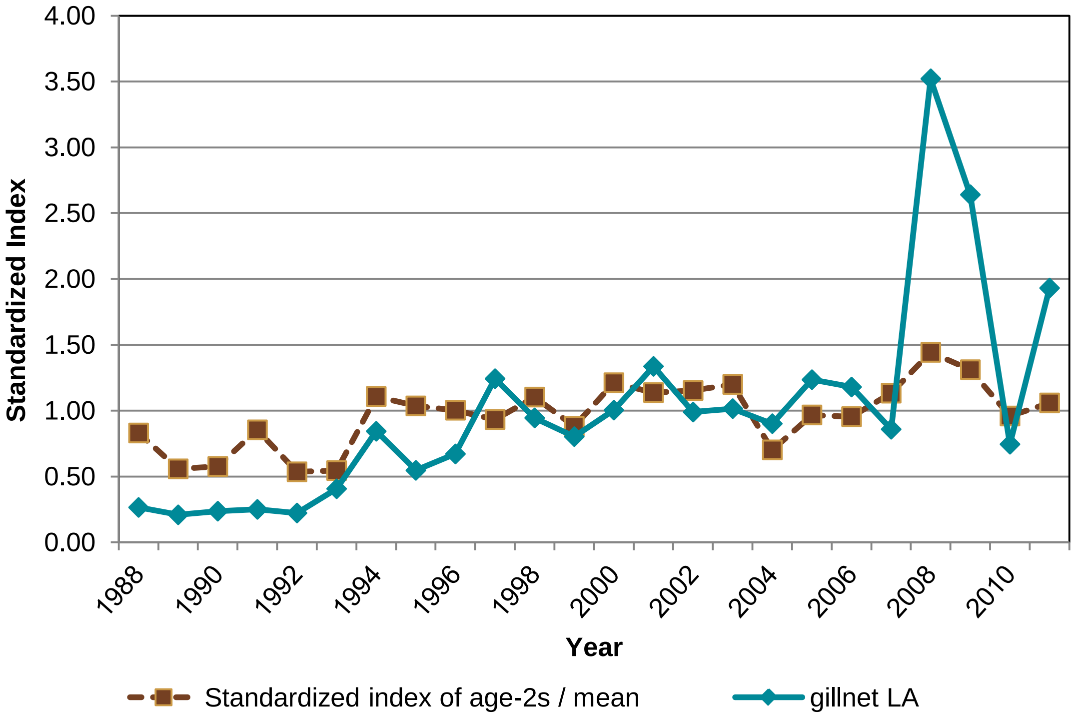


Figure 5.42 Plot of the scaled, standardized Louisiana gill net index and the scaled catches of age-2 individuals from the fishery for 1988-2011. The correlation was 0.73.

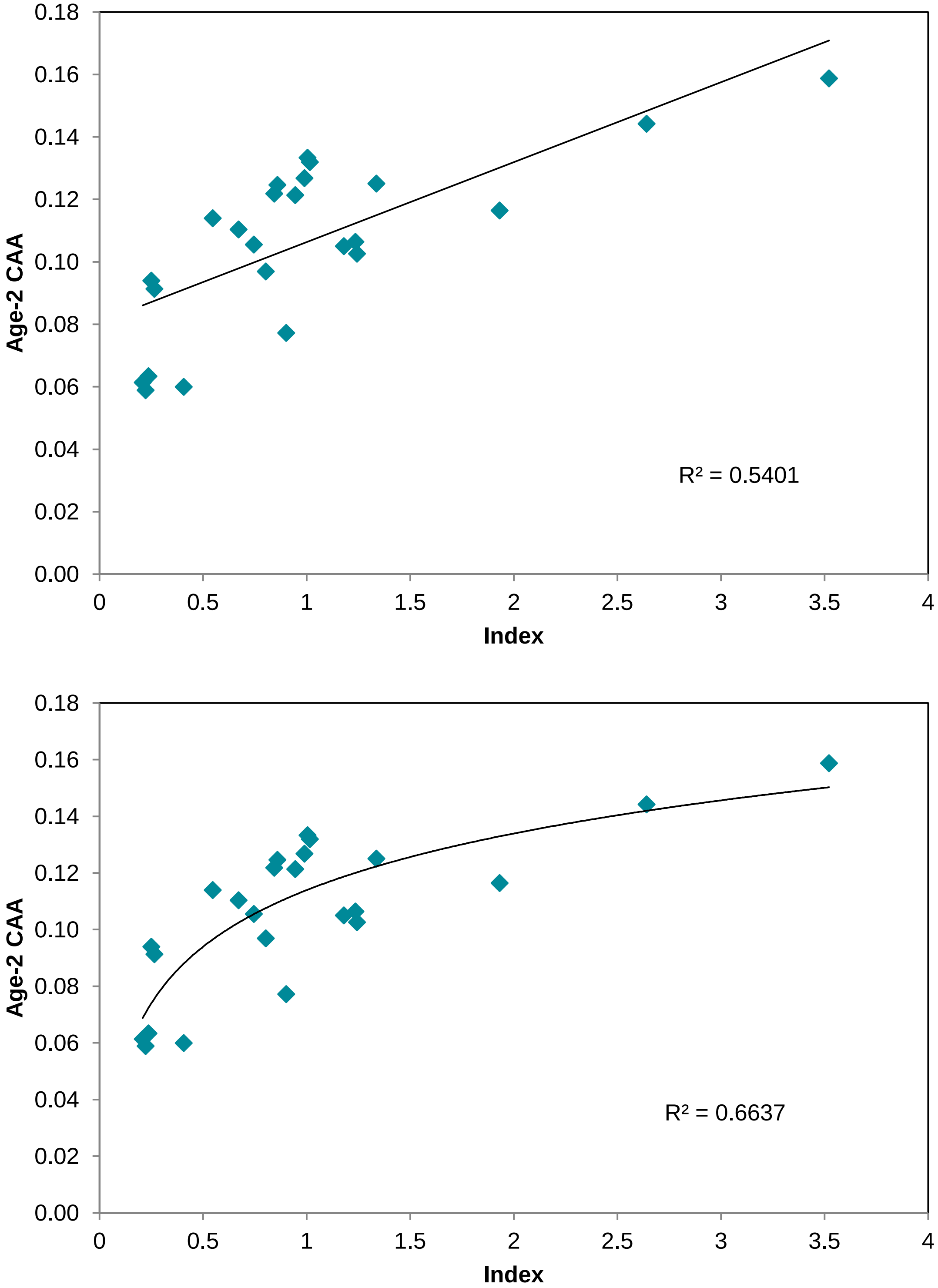


Figure 5.43 Plot of the scaled, standardized Louisiana gill net index versus the proportion of catches of age-2 individuals from the fishery for 1988-2011 with a linear relationship (upper panel) and a power relationship (lower panel).

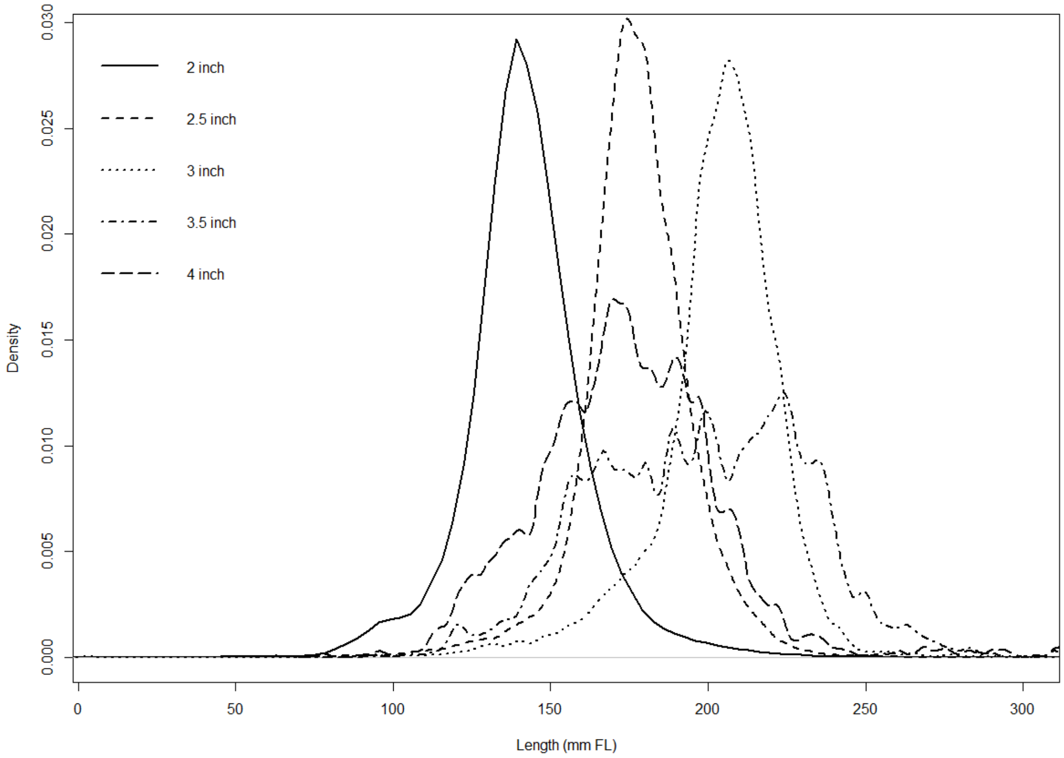


Figure 5.44 Probability density functions of the Louisiana gill net survey length samples in mm FL by mesh size.

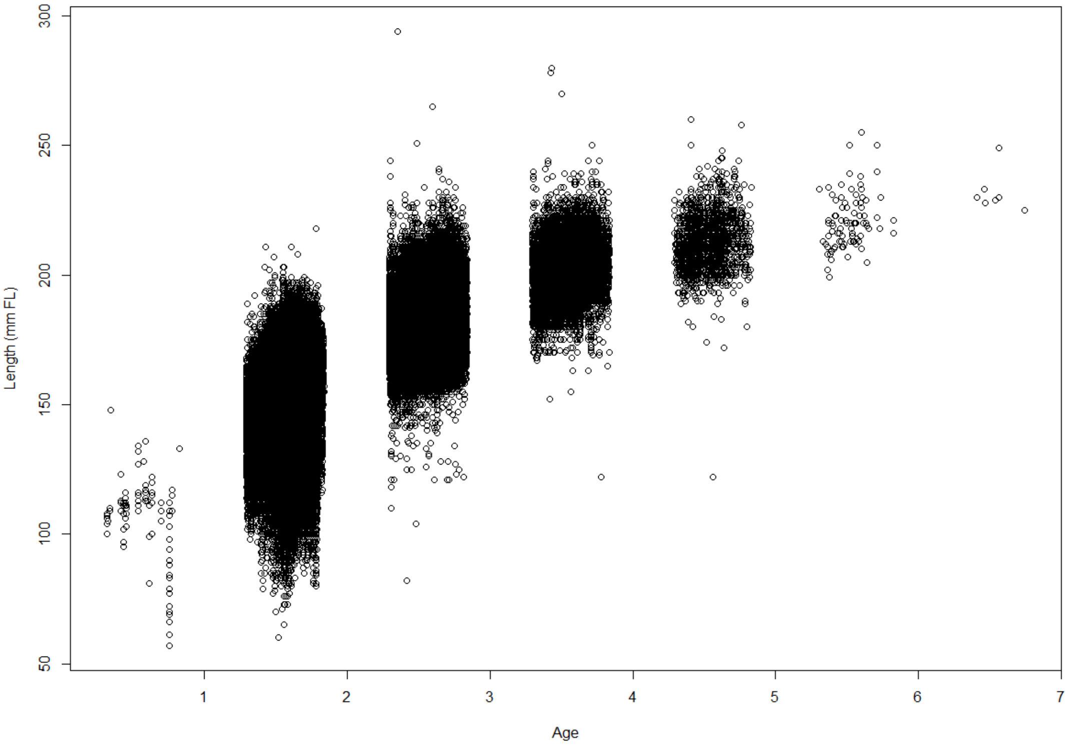


Figure 5.45 Age versus length in mm FL for the commercial reduction fishery for the years 1977-2011.

6.0 Methods

6.1 Assessment Model Descriptions

In this section, we identify two modeling approaches that were considered as potential base models. These modeling approaches include: (1) Beaufort Assessment Model (BAM) and (2) Surplus Production Model (ASPIC). During the assessment workshop (AW), the pros-and-cons of these approaches were discussed in detail and summarized in Table 6.1. This table was prepared for developing our recommendation for the base (preferred) assessment model.

We selected the BAM as the base (preferred) model for the current assessment. However, we also recommend presentation of the results from the other approach (ASPIC approach) because of their different model assumptions and to explore possible ranges in stock status relative to benchmarks.

6.1.1 Beaufort Assessment Model (BAM)

The essence of a forward-projecting age-structured model is to simulate a population that is projected forward in time like the population being assessed. Aspects of the fishing process (e.g., gear selectivity) are also simulated. Quantities to be estimated are systematically varied from starting values until the simulated population's characteristics match available data on the real population as closely as possible. Such data include total catch by year, observed age composition by year, observed indices of abundance, and observed length composition by year. The method of forward projection has a long history in fishery models. It was introduced by Pella and Tomlinson (1969) for fitting production models. Additionally, forward projection was used by Fournier and Archibald (1982) and Deriso et al. (1985) in their CAGEAN model and by Methot (1989) in his stock-synthesis model. Forward-projecting age-structured models share many attributes with ADAPT-style tuned and untuned VPAs. The model developed for this assessment is an elaboration of the CAGEAN and stock-synthesis models and very similar in structure to models used for assessment of Gulf of Mexico cobia (Williams 2001), South Atlantic red porgy (SEDAR 1 - 2002), South Atlantic black sea bass (SEDAR 2 - 2003, SEDAR Update 2005, SEDAR 25 - 2011, SEDAR Update 2013), South Atlantic snowy grouper and tilefish (SEDAR 4 - 2004, SEDAR 25 - 2011), South Atlantic red snapper (SEDAR 15 - 2008, SEDAR 24 - 2010), and Atlantic menhaden (SEDAR 20 - 2010). The BAM was the forward-projecting age-structured model used in the previous Gulf menhaden assessment (Vaughan et al. 2007), and has multiple options for benchmark computation, has many model diagnostics, and can account for uncertainty through sensitivity runs and Monte Carlo bootstrapping.

6.1.2 Surplus Production Model (ASPIC)

Surplus production models can describe the dynamics of exploited fish populations without requiring knowledge of recruitment, individual growth, and mortality characteristics of the populations. These models require times series of data consisting of total landings from the population and one or more standardized index(es) of population abundance. The growth of the population biomass in the absence of fishing mortality is assumed to be a function of population biomass. This function is such that no growth occurs when the population biomass is at zero and at some maximum value, while maximum growth occurs at some intermediate level of biomass. Data were analyzed primarily with a logistic (Schaefer) production model (Schaefer 1954, Schaefer 1957, Pella 1967, Prager 1994), as implemented by the ASPIC software, version 5.43 (Prager 2004). The software provides a continuous-time formulation of the Schaefer production model and a small-step, discrete-time formulation of the Fox and Pella–Tomlinson models. This modeling approach has been used in many SEDAR assessments as an alternate or confirmatory approach to a base forward-projection, age-structure model. Although in general surplus production models, and ASPIC specifically, have been applied to Gulf menhaden (Nelson and Ahrenholz 1986, Vaughan 1987, Vaughan et al. 1996, Vaughan et al. 2000), interpretation has been difficult because of a lack of a fishery-independent adult index. With availability now of the gill net index, this approach is believed to be useful for Gulf menhaden. ASPIC has a variety of model diagnostics, uncertainty in model estimates are available through bootstrapping, and short-term stochastic projections can be made.

6.2 Model Configuration for Base and Alternate Approaches

6.2.1 Assessment Model – Base Model: BAM

The Beaufort Assessment Model (BAM) used for this assessment is a statistical catch-at-age model (Quinn and Deriso 1999), implemented with the AD Model Builder software (developed by Otter Research Ltd – http://otter-rsch.com).

6.2.1.1 Spatial and Temporal Coverage

The BAM model is not a spatially-explicit model and assumes one population of Gulf menhaden. Catches are assumed to come from one population. Commercial reduction fishery catches have ranged from Florida to Texas with the majority of recent catches coming from Louisiana waters. The abundance index data for Gulf menhaden, which includes the seine recruitment index and the gill net abundance index, are assumed to be measures of the coastwide population, as reflected by the age-specific selectivity vector applied to each survey. Little data are available reflecting explicit menhaden movements and patterns, limiting the modeling to the assumption of a single coastwide population, although recent genetic information supports the one stock hypothesis (See Section 3.1).

The BAM model for Gulf menhaden employs annual time steps, modeling the years 1977-2011. The 1977 starting year reflects the first year of age composition data that were used, includes sufficient generations, and was reflected in several other analyses and data sets. The other analyses and data sets included work done by Nicholson and Schaaf (1978) on scale legibility, a VPA completed during previous assessments, principal component analysis (PCA) of the age composition data, re-ageing of scales across 12 historical years, instability in the model, and prevailing knowledge of the fishery during that time period. First, Nicholson and Schaaf (1978) determined that length data could be used to help estimate age from scales with lower legibility. In addition, the number of scales sampled from each individual increased from six to ten, to improve the chances of sampling a scale that was legible for age determination (J. Smith personal communication). Second, the VPA based stock assessments that have been completed in the past always showed a break around the 1976 time period that was unexplained (Vaughan et al. 2000). Third, a PCA was done on the age composition to see if any years grouped differently from the rest. That analysis showed that the earliest years of age composition data grouped separately and were different from the remainder of the years (Figure 6.1). Fourth, an analysis was completed whereby scales from a dozen years over the decades of 1970s to 2000s were re-aged (Section 4.2.7.2). Based on those second age readings, the years 1972 and 1974 were significantly different from the first age reading done in those respective years. All of the other years in the study were not significantly different, which called into question the validity of the years 1972 and 1974. Lastly, when the BAM was started in 1964, the trajectory of F did not align with prevailing knowledge of the fishery. The fishery was building during the 1960s and 1970s, so the F should have been increasing during that time period rather than decreasing. In addition, there were no selectivity changes in the fishery that could account for the difference in the age structure sampled. Based on all of these analyses and evidence, there is an apparent difference in the age composition data from 1964-1976, which led to instability in the model and was contrary to prevailing knowledge of the fishery. Given the uncertainty centered around those data, they were excluded, and the current base run of the BAM model was started in 1977. However, in order to account for the uncertainty related to not using the age composition data for 1964-1976, a sensitivity run was completed (Section 6.2.1.6).

6.2.1.2 Selection and Treatment of Indices

As mentioned above two sources of information were used for abundance indices in the BAM model. Fishery-independent gill net data were used to develop a CPUE adult abundance index. The adult gill net index sampling presumably catches mostly age-1 to 4+ Gulf menhaden, with the majority of them presumed to be age-2+. The index was derived from data collected by the state of Louisiana, which is the center of the stock distribution. The adult gill net index was treated in the model as a representation of the coastwide stock, following the age-specific selectivity vector estimated within the model. The age-specific selectivity vector was estimated within the model as a logistic function. The level of error for this index was determined by the jackknife analysis done on the adult gill net index data records. In the BAM model the estimates of the product of total numbers of fish at the midpoint of the year, a single catchability parameter, and the selectivity schedule were fit to the adult gill net index value in that same year. The error in this abundance index was assumed to follow a lognormal distribution.

The other source of information used in the BAM model was a seine index. The seine index was derived from data from state surveys that were not designed to capture Gulf menhaden. However, the seine index was treated as a Gulf menhaden recruitment index in the stock assessment model, because the gear tends to capture primarily age-0 menhaden. Some older menhaden were captured, but based on size measurements these older fish were removed from the computation of the final CPUE index, leaving only age-0 menhaden upon which to base the index. In the model, the seine index was treated as an age-0 CPUE recruitment index, by fitting the product of the model estimated annual age-0 numbers on April 1 and a single catchability parameter to the computed index values. The index was matched with April as that was the period of highest catches of menhaden by that gear. The error in the recruitment index was assumed to follow a lognormal distribution.

6.2.1.3 Parameterization

The ADMB model code and input data file for the base run are attached as Appendices A.1 and A.2. A summary of the model equations may be found in Table 6.2. The major characteristics of the model formulation were as follows:

- *Natural mortality*: The age-specific natural mortality rate was assumed constant. A Lorenzen curve was scaled such that the age-2 mortality was 1.10, or the mean value from a tagging study (Ahrenholz 1981).
- *Stock dynamics*: The standard Baranov catch equation was applied. This assumes exponential decay in cohort size because of fishing and natural mortality processes.
- *Growth/Sex Ratio/Maturity/Fecundity*: The ratio of males to females, percent of females mature, and fecundity were fixed in the model. The von Bertalanffy growth parameters (L_∞, K, and t_0) were estimated for the fishery in the model and fixed to values based on expert judgment for the population. No fishery-independent age data were available on which to base the population growth curve. The weight-at-age during spawning and during the middle of the fishery were input into the model and were based on the overall estimates of the parameters for the weight-length equation. The ratio of males to females was assumed to be 1:1. The maturity was fixed over time with zero percent of individuals being mature at age-0 and age-1 and one hundred percent of individuals being mature at age-2 and older. Female fecundity at age for each year was fixed in the model and was based on a function of mean length by age for the population (Lewis and Roithmayr 1981).
- *Recruitment:* Spawning was assumed to occur on January 1 in the model; hence the spawning time in months was 0.0. Recruitment to age-0 was estimated in the assessment model for each year with a set of annual deviation parameters, conditioned about a Beverton-Holt stock recruitment curve and estimated in log-space. The steepness of the stock-recruitment curve was fixed at 0.75. The likelihood profile across steepness values showed no information on the model about steepness between the values of 0.5 and 0.99 (Figure 6.2). Therefore, the AW panel decided to fix steepness at 0.75 and then explore the uncertainty in steepness in sensitivity runs and in the MCB runs.
- *Biological benchmarks*: Formal benchmarks have not been adopted for Gulf menhaden. Further discussion of benchmarks can be found in Section 6.2.1.8.
- *Fishing*: One fishery was explicitly modeled. The fishery that was explicitly modeled was a comination of the commercial reduction fishery, which consisted of >99% of all landings, the bait fishery, and the recreational fishery. Because the bait and recreational landings were such a small proportion of the landings in each year, they were combined with the reduction fishery landings. In addition, the bait and recretational fisheries are not sampled; thus, the assessment workshop panel assumed that the commercial reduction fishery was representative of all landings, which is a reasonable assumption. Fishing mortality rates were estimated for each year.
- *Selectivity functions*: Selectivity for the commercial reduction fishery used a parameter for each age, with most parameters being fixed values. Selectivity was dome-shaped for the commercial reduction fishery for all years 1977-2011 (see Section 5.7.2.1). Dome-shaped selectivity was set up such that age-0 selectivity was 0.0, age-2 selectivity was 1.0, ages- 3 and -4 were 0.35, and age-1 selectivity was estimated. The use of dome-shaped selectivity for the commercial reduction fishery was thoroughly explored (Section

5.7.2.1) and discussed during the assessment process. Selectivity for ages-3 and -4 were freely estimated during initial stages of the assessment, and always estimated near zero. While, the AW panel believed the reduction fishery selectivity to be dome-shaped, the AW panel does not know the extent of the doming. Thus, the minimum and maximum extents of doming were determined to range from zero to 0.70. The average value of those two numbers, 0.35, was chosen to be the selectivity value for the base run. However, these selectivity values were explored in both the sensitivity runs and Monte Carlo bootstrapping. Selectivity for the seine index was 1.0 for age-0 and 0.0 for all other ages, which reflects that the seine index was a recruitment index. Selectivity for the gill net index was age varying, but constant over time. The gill net index selectivity was estimated as a logistic function. See Section 5.7.2.1 for further discussion.

- *Discards*: Discards of Gulf menhaden were believed to be negligible and were therefore ignored in the assessment model. A sensitivity run was done using discard estimates of Gulf menhaden from the shrimp fishery in the Gulf, but discards were very low, especially in comparison to the level of landings that the commercial reduction fishery has experienced.
- *Abundance indices*: The model used two indices of abundance that were modeled separately: a recruitment (age-0) index series (1996-2010; seine index) and an adult index series (1988-2011; gill net index).
- *Ageing error matrix*: An ageing error matrix based on a comparison between scales and otoliths was included. The otolith ages were assumed to represent true age.
- *Fitting criterion*: The fitting criterion was a total likelihood approach in which total catch, the observed age compositions from the commercial reduction fishery, the observed length compositions from the gill net index, and the patterns of the abundance indices (both seine and gill net indices) were fit based on the assumed statistical error distribution and the level of assumed or measured error (Section 6.2.1.4).
- *Model testing*: Experiments with a reduced model structure indicated that parameters estimated from the BAM model were unbiased and could be recovered from simulated data with little noise (cf., SEDAR 2007). Additionally, the general model structure has been extensively peer reviewed. As an additional measure of quality control, code and input data for Gulf menhaden were examined by multiple analysts to ensure accuracy. This combination of testing and verification procedures suggests that the assessment model has been implemented correctly and provides an accurate assessment of Gulf menhaden stock dynamics.

6.2.1.4 Weighting of Likelihoods

The likelihood components in the BAM model include reduction landings, reduction catch-at-age, a gill net CPUE index, a seine recruitment index, and gill net length compositions. For each of these components, a statistical error distribution was assumed as follows:

Likelihood Component	Error Distribution	Error Levels
Reduction landings	Lognormal	Constant CV = 0.04
Reduction catch at age	Multinomial	Annual number of trips sampled
Gill net index length compositions	Multinomial	Annual number of sets sampled
Gill net index	Lognormal	Annual CV values from 0.09 to 0.16
Seine index	Lognormal	Annual CV values from 0.18 to 0.23

Iterative reweighting was first used to weight the data components by setting the weights to a value that allowed for the standard deviation of the normalized residuals to be one (Francis 2011). Each of the data components reached an sdnr of approximately one except the age composition data. The age composition data seemed to be in two different states whereby the sdnr could be approximately 0.5 or 2. This behavior was explored by looking at the change in the likelihood for the age composition data over a range of values for the weight. In addition, the change in the likelihood components for the other data sources was also explored. Finally, to look at the agreement between data sources a little bit more, the seine weight was adjusted across a range of values to see how the likelihood components and other model estimates responded.

6.2.1.5 Estimating Precision (e.g. ASEs, Likelihood profiling, MCB)

The BAM model was implemented in the AD Model Builder software, which allowed for easy calculation of the inverse Hessian approximated precision measures. However, in this case where some key values were fixed (e.g., natural mortality), it is believed that precision measures from the inverse Hessian matrix are underestimates of the true precision. Instead, the BAM model employed a parametric bootstrap procedure in which the input data sources were re-sampled using the measured or assumed statistical distribution and error levels provided. The data sources that were re-sampled in 5,000 bootstrap iterations included landings, gill net index, seine index, natural mortality, gill net length compositions, commercial reduction age compositions, age-1 maturity, steepness, selectivity of age-3 and -4 for the commercial reduction fishery, and population growth (specifically fecundity and weight of the population at age). The landings, gill net index, and seine index were all re-sampled using multiplicative lognormal error using the CVs specified in the model input for each respective component. Uncertainty in the landings and indices was applied using a parametric bootstrap. To implement this approach in the MCB runs, random variables (x_s,y) were drawn for each year y of time series s from a normal distribution with a mean of 0 and a variance of $\sigma^{2s,y}$. Each observation was then perturbed from the original values ($O_{s,y}$) using the equation:

$$O_{s,y} = \hat{O}_{s,y}(\exp(x_{s,y}) - \sigma^2_{s,y}/2)$$

where $\sigma^2_{s,y}/2$ is a bias correction that centers the multiplicative error on the value of 1.0. Standard deviations in log space were computed from *CV*s in arithmetic space:

$$\sigma_{s,y} = \sqrt{\log(1 + CV^2_{s,y})}$$

The gill net length compositions and commercial reduction age compositions were recreated for each year by distributing the number of fish sampled for each year to each length or age based on the probability observed. Variability in natural mortality was included as normal error with a mean of 1.10 and a standard deviation of 0.47. The Lorenzen curve was then scaled to the random value, with the random value being the natural mortality at age-2. Age-1 maturity was zero in the base run, but was set up as a triangular distribution for bootstrapping with a range of 0.0 to 0.25 and a mode of 0.0 whereby the mode had a 0.5 probability. Steepness for the stock-recruitment relationship was set up as a uniform distribution from 0.5 to 0.99. The selectivity for ages-3 and -4 for the commercial reduction fishery was a uniform distribution between 0 and 0.7. Finally, the fecundity at age and weight at age in the population was determined by the growth parameters. The values for t_0 and *CV* at age were fixed at the values estimated in the base run. The value for L_∞ was a uniform distribution between 225 and 275 mm FL. The value for *K* of the growth equation was then calculated based on the equation: -0.0059* L_∞+1.8568, which was estimated using the yearly estimated values of the growth parameters from the fishery dependent data. The growth parameters were then used to calculated length at age, which was then incorporated into the equation used to calculate fecundity. The age specific fecundity was then fed in for each bootstrap run. Finally, the length-at-age along with the parameters from the weight-length relationship was used to provide a vector of weight at age for the population, which was fed in for each bootstrap run. The bootstrap runs incorporated all of the major sources of uncertainty in the data and model choices.

6.2.1.6 Sensitivity Analyses

A total of 18 sensitivity runs were completed with the BAM model. These sensitivity runs represent those involving input data and those involving changes to the model configuration.

6.2.1.6.1 Sensitivity to Input Data

Several sensitivity runs were conducted to examine various effects to changes in the input data. The following is a list of these sensitivity runs:

Run Number	Sensitivity Examined
gm-039	Excluded gill net index and gill net length compositions
gm-040	Excluded the seine index
gm-053	Excluded gill net index, gill net length compositions, and seine index
gm-044	Shrimp trawl by-catch included in landings data
gm-028	Population growth same as growth for fishery
gm-041	Age-2 *M* scaled to minimum value estimated in the tagging study
gm-042	Age-2 *M* scaled to maximum value estimated in the tagging study
gm-043	Charnov *M* with age-2 scaled to 1.10 from tagging study

Natural mortality is always a source of uncertainty in stock assessments. To test the sensitivity of the model output to assumptions about natural mortality, sensitivity run numbers gm-041, gm-042, and gm-043 were completed. In runs 041 and 042, natural mortality values were scaled such that age-2 mortality was the upper bound based on the tagging data (Ahrenholz 1981), and age-2 mortality was the lower bound based on the tagging data, respectively. These two sensitivity runs addressed uncertainty in the scale of *M*. Additionally, *M* based on the Charnov curve was also explored in order to address uncertainty in how *M* changes with age.

Gulf menhaden are caught incidentally in the shrimp trawl fishery in the Gulf of Mexico; although, trawl gear are not especially efficient at catching menhaden. However, to address this additional mortality a run, gm-044, included increased landings due to shrimp trawl by-catch of Gulf menhaden. The increase in landings was small when compared to commercial reduction landings.

In order to explore the uncertainty related to data components included in the model, several sensitivity runs were completed with data sources excluded. First, a run was done without the gill net index and gill net length compositions (gm-039). Second, a run was done without the seine index (gm-040). Finally, a run was done without the gill net index, the seine index, nor the gill net length compositions (gm-053). Each of these runs explored the effects of indices on the overall results of the model.

Finally, one additional run was completed to look at the uncertainty surrounding the population growth parameters. Because no age data are available for any other gear besides the commercial reduction fishery, population growth parameters were based on limited external data and expert judgment. One sensitivity run was completed with the assumption that the population growth curve is the same as the fishery growth curve. Therefore, the fecundity at age and weight at age during spawning were all based on one growth curve.

6.2.1.6.1 Sensitivity to Model Configuration

Several sensitivity runs were conducted to examine various effects to changes in the model configuration. The following is a list of these sensitivity runs:

Run Number	Sensitivity Examined
gm-021	Steepness fixed at 0.5
gm-022	Steepness fixed at 0.99
gm-023	Estimated underlying Ricker stock-recruitment curve
gm-024	Deviations in age-1 *M* estimated for 1996-2010
gm-025	Age-3 and -4 commercial reduction selectivity freely estimated
gm-026	Age-3 and -4 commercial reduction selectivity fixed at 1.0
gm-027	Time blocks of 1977-1993 and 1994-2011 for age-1 reduction selectivity
gm-038	All weights equal to 1.0 for all data components
gm-045	Start year of model is 1964, included 1964-1976 age composition data, dome-shaped selectivity estimated for 1964-1976 as a separate time block for commercial reduction fishery
gm-046	Start year of model is 1948, reduction fishery selectivity from 1948-1963 assumed to be same as selectivity estimated for 1964-1976

In order to explore the effect that weighting the likelihood components had on the fit to the various data components as well as estimated parameters, a sensitivity run with all data component weights set to 1.0 was run (gm-038).

A sensitivity run was completed with an underlying Ricker stock-recruit curve (gm-023). This run was completed to see how the Ricker function influenced population dynamics as compared to the base run, which used an underlying Beverton-Holt stock recruitment function. In addition, sensitivity runs were also completed which modified the fixed value of steepness for the Beverton-Holt stock-recruitment curve. Based on the likelihood profile for steepness, the bounds of steepness for Gulf menhaden are likely 0.5 and 0.99. Therefore, two sensitivity runs were completed; one with each of those bounds to determine how steepness affected the overall model results.

One model configuration change was made related to *M*. Specifically, the sensitivity run allowed for the estimate of annual deviations from the mean *M* at age-1 for the years 1996-2010. Correlations between the recruitment and age-1 were apparent, and correlations between the gill net index and age-2 data were apparent. However, correlations were not found between age-1 and age-2. Therefore, this sensitivity run was meant to allow the model to estimate an additional year specific mortality (either positive or negative) for age-1 individuals in order to account for that lack of correlation between the two age classes.

Selectivity is always an uncertainty in stock assessments, and that uncertainty was explored with three sensitivity runs related to the commercial reduction selectivity. The first was to allow the model to freely estimate the selectivity for ages-3 and -4 individuals. The second was to fix the selectivity for age-3 and -4 individuals to a value of 1.0. Lastly, because of an apparent shift in the age composition over time to a greater proportion of age-2s versus age-1s (Figure 6.3), a sensitivity run was completed that allowed for the estimation of age-1 selectivity in two time blocks, specifically 1977-1993 and 1994-2011.

Additional data were available before 1977, so in order to explore the effects of leaving those data out of the base run, two sensitivity runs were completed. The first had a start year of 1964, which is the first year that the age composition data are available. The second had a start year of 1948, which is the first year with reliable landings estimates.

6.2.1.7 Retrospective Analyses

Retrospective analyses were completed by running the BAM model in a series of runs sequentially omitting years 2010 to 2002, as indicated below:

Run Number	Sensitivity Examined
gm-029	Retrospective analysis with modeling ending in 2010
gm-030	Retrospective analysis with modeling ending in 2009
gm-031	Retrospective analysis with modeling ending in 2008
gm-032	Retrospective analysis with modeling ending in 2007
gm-033	Retrospective analysis with modeling ending in 2006
gm-034	Retrospective analysis with modeling ending in 2005
gm-035	Retrospective analysis with modeling ending in 2004
gm-036	Retrospective analysis with modeling ending in 2003
gm-037	Retrospective analysis with modeling ending in 2002

For the run ending in 2009, a prior on L_∞ was required for convergence. The prior for run gm-030 was a loose normal prior with a mean value of 239.5, which was the value estimated from fishery data outside of the model. While a prior was used, the estimated value for the L_∞ for the gm-030 run was 239.5, which essentially fixed the value of L_∞.

For the run ending in 2007, a prior on log of R_0 was required for convergence. The prior for run gm-032 was a loose normal prior with a mean value of 5.3. While a prior was used, the estimated value for the log of R_0 was 4.83.

Finally, because of the appearance of the retrospective runs and the potential for the runs to be exhibiting different states of nature, likelihood profiles were run on R_0 using the base run with the terminal year and for the base run with the terminal years of 2009 and 2005. This allowed the assessment panel to determine how well the estimate of R_0 was defined.

6.2.1.8 Reference Point Estimation – Parameterization, Uncertainty, and Sensitivity Analysis

A suite of options is presented in the current Gulf menhaden stock assessment document in Section 7.1.6 and Table 7.10. The quantities F_{MSY}, SSB_{MSY}, B_{MSY}, and *MSY*, estimated by the method of Shepherd (1982), were infinite and increased to the maximum allowed value of *F* within the model of 10.0. Thus, estimates of *MSY* and associated benchmarks typically used in the federal system were not provided. Although the GSMFC's Menhaden Advisory Committee (MAC) has the ability to recommend reference points to the Gulf States, they are not constrained to the Magnuson-Stevens Act. In the mean time, the MAC has been discussing the goals and objectives for fishery management and potential alternative references points. Therefore, at this point, a suite of options are presented for the assessment purposes, but no one option is presented as best (potentially, none of the presented options are best). F_{MED} was specified as a potential limit reference point and was estimated using the natural mortality, selectivity, and fecundity per recruit for 1977-2011. The F_{Target} was not specified by the panel, therefore 75% of F_{MED} was presented as an option. In addition, $F_{30\%}$, $F_{35\%}$, and $F_{40\%}$ based on SPR was also presented as a suite of options. None of these options are necessarily endorsed by the assessment panel. Because the MAC is still in the process of identifying their goals and objectives in order for discussions on appropriate benchmarks to occur, we have simply provided a range of typical options from the literature.

All benchmark calculations were based upon selectivity, *M*-at-age (which was constant), weight-at-age, and fecundity-at-age from the model inputs (1977-2011).

As was also the case in previous Gulf menhaden stock assessments, population fecundity (*FEC*, number of maturing or ripe eggs) was used as the measure of reproductive capacity. Again, because goals, objectives, and associated benchmarks are still being discussed, a suite of options was presented here as measure of reproductive capacity (*SSB* [spawning stock biomass]=*FEC*). The options presented include $SSB_{MED.\mathrm{thresh}}$, $SSB_{30\%}$, $SSB_{35\%}$, and $SSB_{40\%}$.

6.2.2 Alternative Assessment Model — Production Model — ASPIC

Surplus production models describe the dynamics of exploited populations and do not distinguish between recruitment, individual growth, and mortality as contributing factors to changes in population abundance. Instead, the aggregate effects of these factors are modeled as a single function of the population size. Population growth is a function of stock size and is zero when the stock is at maximum biomass and is maximized at an intermediate level of biomass. Gulf menhaden indices of abundance and harvest were analyzed with a logistic (Schaefer) functional model form (Schaefer 1954) using the ASPIC production model software package (version. 5.34, Prager 1994 and 2004). The software provides formulation of the Schaefer production model and alternative model shapes: the Fox (1970) and Pella–Tomlinson (Pella 1967) models. The use of surplus production model analysis of Gulf menhaden is intended as an alternative approach and used to support the results of the preferred age-structured BAM model presented in this report.

6.2.2.1 Spatial and Temporal Coverage

The surplus production model is not spatially-explicit. The temporal and spatial coverage were the same as that of the base model (coastwide stock evaluated from 1977-2011).

6.2.2.2 Selection and Treatment of Indices

The adult indices were developed from gill net and seine data collected by the Gulf of Mexico states' fisheries management agencies. The temporal range of the landings data in the primary model configuration matched that of the BAM model (1977-2011). Three fishery independent indices of abundance were used in the primary and alternative model configurations. These indices were made by the Assessment Workshop panel and include a gill net adult index and two time lagged recruitment indices that were lagged to represent abundance at +1 and +2 years. Pairwise correlations between indices used in production modeling are illustrated in Figure 6.4.

6.2.2.2.1 Recruitment Indices

A single juvenile index from the seine data was used in the analysis of various model formulations but was adjusted in time for better correspondence with data on removals and with the adult abundance index. The year value associated with the juvenile index datum was increased by one and two years, under the assumption that indicators of age-0 abundance in any given year should be an indicator of age-1 abundance in the following year or age-2 abundance when lagged by two years. Landings are mainly age-1 and age-2 fish. The juvenile index was assumed proportional to unobserved fishable abundance in the following years (one or two). CVs were used as tabulated.

6.2.2.2.2 Adult Abundance Indices

The adult abundance index derived from fishery-independent gill net sampling off Louisiana was used as the main adult index in production modeling, as it was in BAM (Section 6.2.1.6). CVs were used as tabulated.

6.2.2.3 Parameterization

The input file (.INP) for the primary configuration is included as an appendix (Appendix B.1). The parameterization of the primary model configuration is described below.

- *Model structure:* The ASPIC software implements a forward-projecting population model, and thus provides annual estimates of biomass, fishing mortality rate, etc. We report these relative to their corresponding benchmarks (Prager 1994).
- *Stock dynamics*: Population growth is a function of population size and the rate of increase follows a logistic function (Schaefer 1954).
- *Fitting criterion*: We assume that the magnitude of catch has a greater precision than the

indices of abundance. Therefore, fitting of parameters in all runs was conditioned on catch. The objective function was weighted sum of squared residuals. Weights for each indice were calculated as the inverse of the squared coefficient of variation.

- *Abundance indices*: The model used the adult index series (Louisiana gill net index; 1988-2011).
- *Initial biomass:* The fraction of year one biomass, B_1, of the carrying capacity was fixed in each model run. The state of the stock was initialized as year one biomass in the primary configuration ($B_1 = 0.80K$) to reflect the reduction of biomass, relative to carrying capacity, in the fishery.
- *Estimated parameters*: The leading parameters of the ASPIC formulation are K (the carrying capacity), B_1/K (starting biomass relative to K), *MSY* (maximum sustainable yield), and a series of catchability coefficients q_i, $i = 1\ldots m$, where m is the number of abundance indices used. From the leading parameters, quantities of management interest can be computed (Prager 1994).

6.2.2.4 Weighting of Likelihoods

Annual inverse-variance weighting was used, based on the CVs of indices described above. The error in each index was assumed log-normally distributed.

6.2.2.5 Estimating Precision

A bootstrap with 1,000 realizations was used to quantify uncertainty in model estimates for the primary configuration. From the bootstrap, it is possible to obtain bias-corrected confidence intervals (Efron and Gong 1983) on each model parameter and on functions of parameters.

In the bootstrapping method employed by ASPIC, estimated abundance indices and residuals from the original fit are saved (Prager 2004). The saved residuals are then increased by an adjustment factor (Stine 1990), which is generally slightly more than unity and is reported in the ASPIC output file. Then, once for each bootstrap realization, the residuals are randomly added (with replacement) to the estimated values to arrive at a synthetic data set, and the model is refit. Adjustments are made in saving and applying the residuals to account for the original variance structure of the data as specified in the data input file.

6.2.2.6 Sensitivity Analyses

Sensitivity run configurations and estimates are summarized in Table 6.3.

6.2.2.6.1 Sensitivity to Input Data

Configurations were analyzed with the gill net adult index and combinations of the seine juvenile index +1yr and the juvenile index +2yrs.

6.2.2.6.1 Sensitivity to Model Configuration

Two sets of sensitivity runs examined sensitivity to model configuration. The first was a single run (men-40) using the Fox (1970) exponential-yield model instead of the Schaefer (1954 and 1957) model. The Fox model has an asymmetric production curve with $B_{MSY} = 0.37K$, while the Schaefer model has a symmetric production curve with $B_{MSY} = 0.5K$.

The second set included two runs (runs men-32, men-33) examining sensitivity to the assumption $B_1 = 0.80K$ used in the base run. Both runs were similar to the base production model run, except that one assumed $B_1 = 0.60K$ and the other assumed $B_1 = 0.40K$.

6.2.2.7 Retrospective Analyses

A retrospective analysis compared the stock and fishery status estimated by the base run to those runs with 1, 2, 3, 4, or 5 years of the catch and indices of abundance time-series omitted from the end of the data.

Run Number	**Sensitivity Examined**
men-41	men-31 formulation, exclude 2011
men-42	men-31 formulation, exclude 2010, 2011
men-43	men-31 formulation, exclude 2009 to 2011
men-44	men-31 formulation, exclude 2008 to 2011
men-45	men-31 formulation, exclude 2007 to 2011

6.2.2.8 Reference Point Estimation – Parameterization, Uncertainty, and Sensitivity Analysis

Reference-point estimation is inherent in production model analysis. Uncertainty in reference points was estimated through the bootstrap, as described above for each base model. Each sensitivity analysis was also a sensitivity analyses on estimated reference points.

Table 6.1 Model comparisons for use in the Gulf menhaden assessment.

Criteria	**BAM**	**ASPIC**
Applicability to mgmt (benchmarks)	Multiple options for benchmark computation	Internally estimated benchmarks
Used in other stock assessments	Peer reviewed for menhaden and other species (Atlantic and Gulf menhaden, all south Atlantic SEDARs)	Peer reviewed for other species as alternate perspective (red porgy, black seabass, yellowfin tuna, most recent SEDARs)
Data requirements	All available menhaden data	Less data required (limited to landings, effort, and indices)
Model complexity	Moderate	Low
Measures of uncertainty	Bootstrap and sensitivity runs	Bootstrap and sensitivity runs
Understanding model properties and operation	Familiar among committee	Familiar among committee
Appropriateness of model assumptions for menhaden	Very appropriate, flexible relative to benchmarks	Appropriate, *MSY* benchmarks can be obtained
Model diagnostics	Many	Moderate

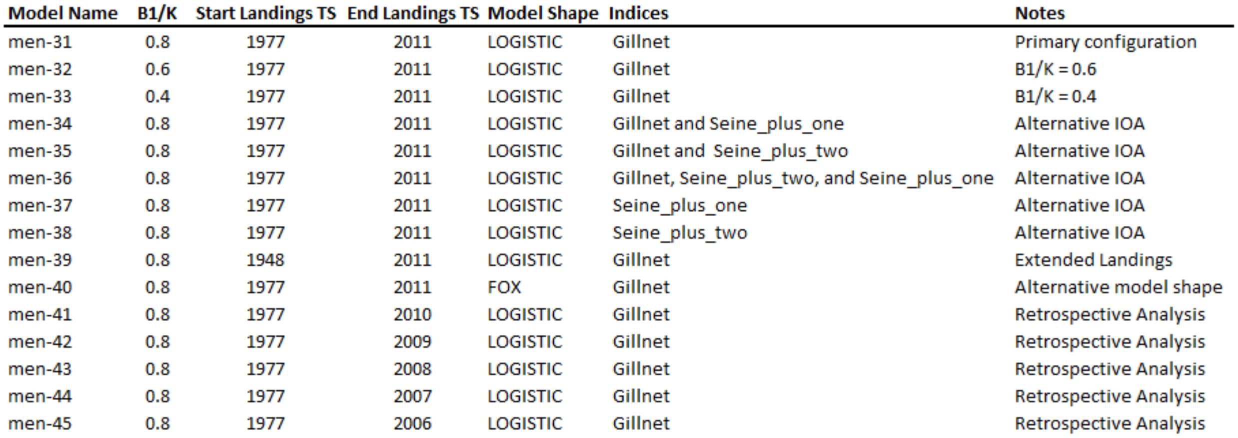
Table 6.2 General definitions, input data, population model, and negative log-likelihood components of the BAM forward-projecting statistical age-structured model used for Gulf menhaden. Estimated parameters are denoted using hat (^) notation, and predicted values are denoted using breve (˘) notation.

General Definitions	Symbol	Description/Definition
Year index: y = {1977,..,2011}	y	
Age index: a = {0,...,4+}	a	
Length index: l = {85,…,295+}	l	
Fishery Weight at age	w_a	Computed from size at age from fishery samples
Population Weight at age	w_a^p	Computed from size at age back-calculated to beginning of year with an L_∞ fixed at 250 mm FL
Maturity at age	m_a	From data workshop
Fecundity at age	γ_a	From data workshop; Based on Lewis and Roithmayr equation
Observed age-0 CPUE y = {1996,...,2010}	$U_{1,y}$	Based on numbers of age-0 fish from state seine surveys
Observed gill net CPUE y = {1988,...,2011}	$U_{2,y}$	Based on gill net survey from Louisiana
Selectivity for U_2	$\hat{s}'_a$	Estimated as a logistic function
Coefficient of variation for U	c_U	Based on annual estimates from samples for U_1 and U_2
Observed length compositions	$\tau_{l,y}$	Computed as percent of length composition at length (l) for each year (y)
Length composition sample sizes	n_y^l	Number of trips sampled in each year (y)
Observed age compositions	$p_{a,y}$	Computed as percent age composition at age (a) for each year (y)
Age composition sample sizes	n_y^a	Number of trips sampled in each year (y)
Observed fishery landings	L_y	Reported landings in weight for each year (y)
Coefficient of variation for L	c_L	Fixed at 0.04, from DW
Observed natural mortality	M_a	From DW, varies with age and is constant across time. Age-2 scaled to empirically based value from Arhenholz (1981).
Fishery selectivity	$\hat{s}_a$	Fixed at 0.0 for age-0, fixed at 1.0 for age-2, fixed at 0.35 for ages-3 and -4, and estimated for age-1. No time blocks.
Fishing mortality (fully selected)	$F_{a,y}$	$F_{a,y} = \hat{s}_a \hat{F}_y$ where F_y values for each year are estimated parameters

General Definitions	Symbol	Description/Definition
Total mortality	$Z_{a,y}$	$Z_{a,y} = M_a + F_{a,y}$
Fecundity per recruit at $F = 0$	ϕ	$\phi = \sum_{a=0}^{4+} N_a m_a \gamma_a 0.5 \Big/ N_0$ where $N_{a+1} = N_a \exp(-Z_a)$ and $N_{4+} = N_3 \exp(-Z_3)/[1-\exp(-Z_{4+})]$ and the sex ratio is assumed to be 1:1.
Population numbers	$N_{a,y}$	$N_{0,1977} = \frac{\hat{R}_0(0.8\varsigma\hat{h}S_{equil} - 0.2\Phi_0(1-\hat{h}))}{(\hat{h}-0.2)S_{equil}} \exp(\hat{R}_{1977})$ $\hat{N}_{1+,1977}$ $N_{0,y+1} = \frac{0.8\hat{R}_0\hat{h}S_{y+1}}{0.2\Phi_0\hat{R}_0(1-\hat{h}) + (\hat{h}-0.2)S_{y+1}} \exp(\hat{R}_{y+1})$ $N_{a+1,y+1} = N_{a,y} \exp(-Z_{a,y})$ $N_{A,y} = N_{A-1,y-1} \frac{\exp(-Z_{A-1,y-1})}{1-\exp(-Z_{A-1,y-1})}$
Population fecundity	ε_y	$\varepsilon_y = \sum_{a=0}^{4+} N_{a,y} m_a \gamma_a 0.5$
Population biomass (age-1+)	B_y	$B_y = \sum_{a=1}^{4+} N_{a,y} w_a^p$
Predicted catch-at-age	$\breve{C}_{a,y}$	$\breve{C}_{a,y} = \frac{F_{a,y}}{Z_{a,y}} N_{a,y} [1-\exp(-Z_{a,y})]$
Predicted landings	$\breve{L}_y$	$\breve{L}_y = \sum_{a=0}^{4+} \breve{C}_{a,y} w_a$
Predicted age composition	$\breve{p}_{a,y}$	$\breve{p}_{a,y} = \breve{C}_{a,y} \Big/ \sum_{a=0}^{4+} \breve{C}_{a,y}$
Predicted age-0 CPUE	$\breve{U}_{1,y}$	$\breve{U}_{1,y} = N_{0,y}\hat{q}_1$ where q_1 is an estimated constant catchability parameter
Predicted gill net CPUE	$\breve{U}_{2,y}$	$\breve{U}_{2,y} = \sum_{a=0}^{4+} N_{a,y}\hat{s}'_a\hat{q}_2$ where q_2 is an estimated constant catchability parameter
Predicted length composition	$\breve{\tau}_{l,y}$	$\breve{\tau}_{l,y} = \hat{s}'_a N_{a,y} * prob(l) \Big/ \sum_{a=0}^{4+} \hat{s}'_a N_{a,y}$ where *prob*(*l*) is the probability of an individual of an age *a* being length *l*

General Definitions	**Symbol**	**Description/Definition**
Negative Log-Likelihood	Symbol	Description/Definition
Robust multinomial age composition	Λ_f	$\Lambda_f = \sum_y 0.5\log(E') - \log\left[\exp\left(-\frac{(p_y - \breve{p}_y)^2}{2E'/(n_y^{\alpha} w_{\alpha}}\right) + x\right]$ where $E' = \left[(1-p_y)(p_y) + \frac{0.1}{mbin}\right]$, *mbin* is the number of age bins, w_l is a preset weight (selected by iterative re-weighting) and x is fixed at an arbitrary value of 0.001.
Lognormal indices	Λ_f	$\Lambda_f = \sum_U \sum_y \frac{\left[\log(U_{u,y} + x) - \log(\breve{U}_{u,y} + x)\right]^2}{2\sigma_{U,y}^2}$ where w_U is a preset weighting factor for both the seine and gill net indices as determined by iterative re-weighting, x is fixed at an arbitrary value of 0.001, and $\sigma_U = \sqrt{\log(1 + (c_U / w_U)^2)}$
Lognormal landings	Λ_f	$\Lambda_f = \sum_y \frac{\left[\log(L_y + x) - \log(\breve{L}_y + x)\right]^2}{2\sigma_L^2}$ where λ_f is a preset weighting factor (w_L) equal to 1.0, x is fixed at an arbitrary value of 0.001, and $\sigma_L = \sqrt{\log(1 + (c_L / w_L)^2)}$.
Robust multinomial length compositions	Λ_f	$\Lambda_f = \sum_y 0.5\log(E') - \log\left[\exp\left(-\frac{(\tau_y - \breve{\tau}_y)^2}{2E'/(n_y^{l} w_l}\right) + x\right]$ where $E' = \left[(1-\tau_y)(\tau_y) + \frac{0.1}{mbin}\right]$, *mbin* is the number of length bins, w_l is a preset weight (selected by iterative re-weighting) and x is fixed at an arbitrary value of 0.001.
Lognormal recruitment deviations	Λ_f	$\Lambda_f = \lambda_f\left[R_{1977}^2 + \sum_{y>1977} \frac{\left[(R_y - R_{y-1}) + (\hat{\sigma}_R^2/2)\right]^2}{2\hat{\sigma}_R^2}\right]$ where λ f is a preset weighting factor of 1.0.

Table 6.3 Initial parameter values, indices of abundance used, length of abundance indices and landings data used for primary model configuration and sensitivity runs.



Model Name	B1/K	Start Landings TS	End Landings TS	Model Shape	Indices	Notes
men-31	0.8	1977	2011	LOGISTIC	Gillnet	Primary configuration
men-32	0.6	1977	2011	LOGISTIC	Gillnet	B1/K = 0.6
men-33	0.4	1977	2011	LOGISTIC	Gillnet	B1/K = 0.4
men-34	0.8	1977	2011	LOGISTIC	Gillnet and Seine_plus_one	Alternative IOA
men-35	0.8	1977	2011	LOGISTIC	Gillnet and Seine_plus_two	Alternative IOA
men-36	0.8	1977	2011	LOGISTIC	Gillnet, Seine_plus_two, and Seine_plus_one	Alternative IOA
men-37	0.8	1977	2011	LOGISTIC	Seine_plus_one	Alternative IOA
men-38	0.8	1977	2011	LOGISTIC	Seine_plus_two	Alternative IOA
men-39	0.8	1948	2011	LOGISTIC	Gillnet	Extended Landings
men-40	0.8	1977	2011	FOX	Gillnet	Alternative model shape
men-41	0.8	1977	2010	LOGISTIC	Gillnet	Retrospective Analysis
men-42	0.8	1977	2009	LOGISTIC	Gillnet	Retrospective Analysis
men-43	0.8	1977	2008	LOGISTIC	Gillnet	Retrospective Analysis
men-44	0.8	1977	2007	LOGISTIC	Gillnet	Retrospective Analysis
men-45	0.8	1977	2006	LOGISTIC	Gillnet	Retrospective Analysis

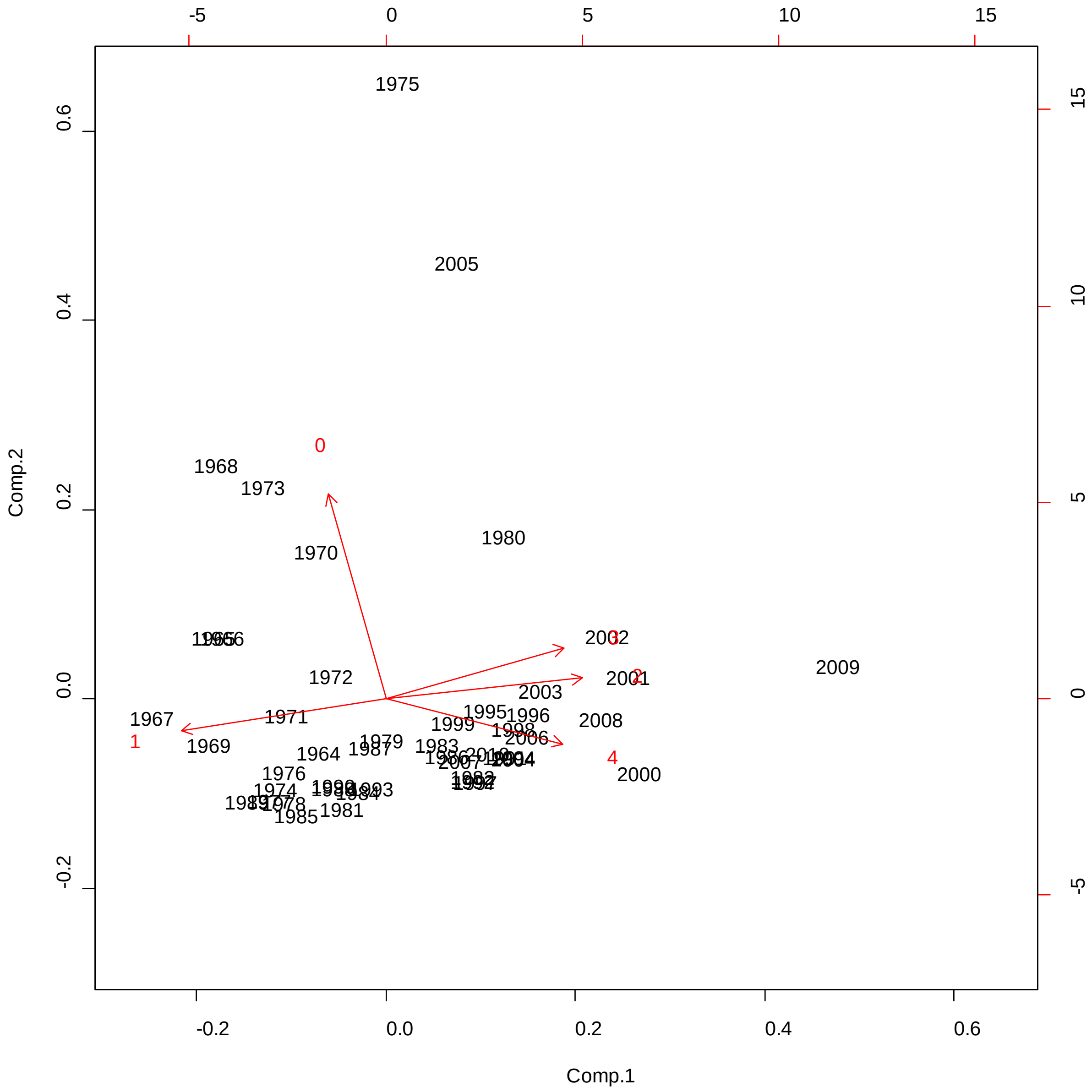


Figure 6.1 Principal components analysis of the commercial reduction fishery age compositions.

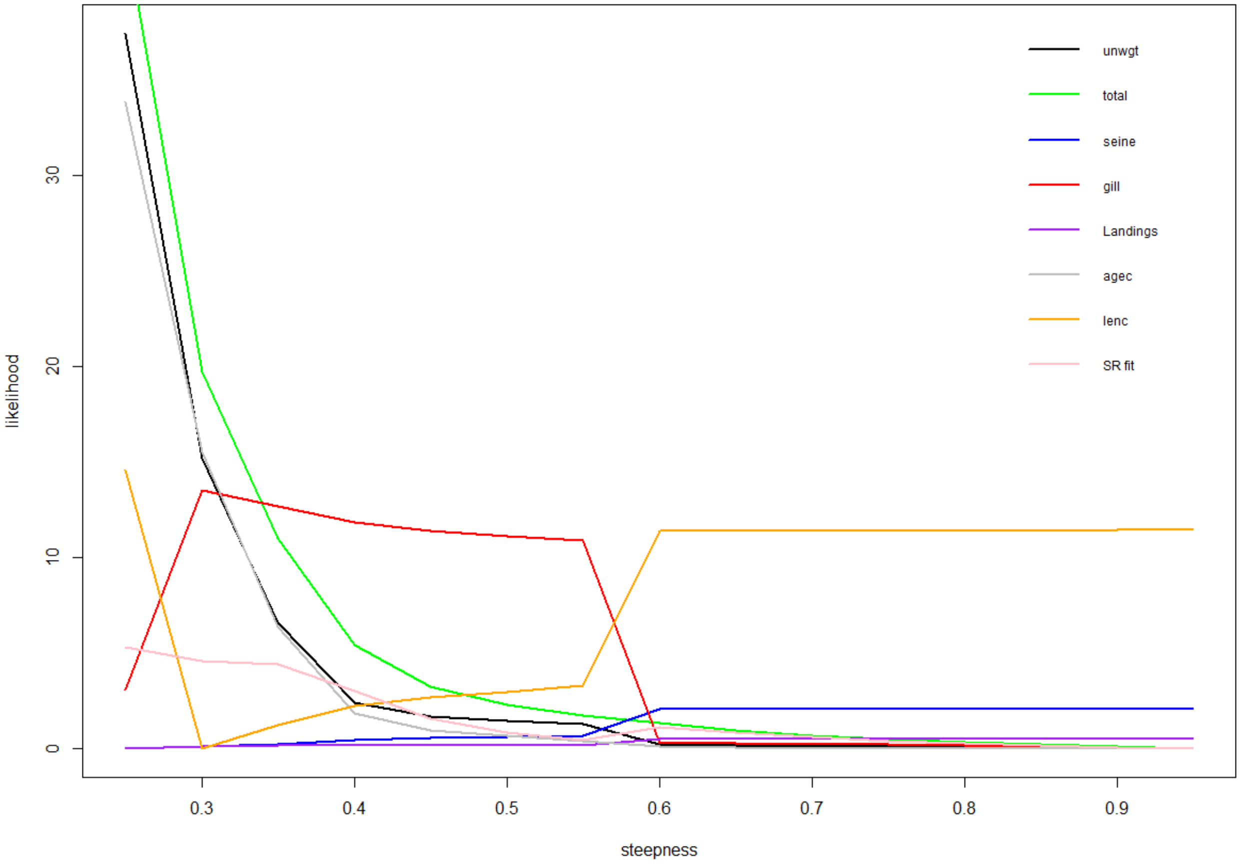


Figure 6.2 Likelihood profile across a range of values for steepness.

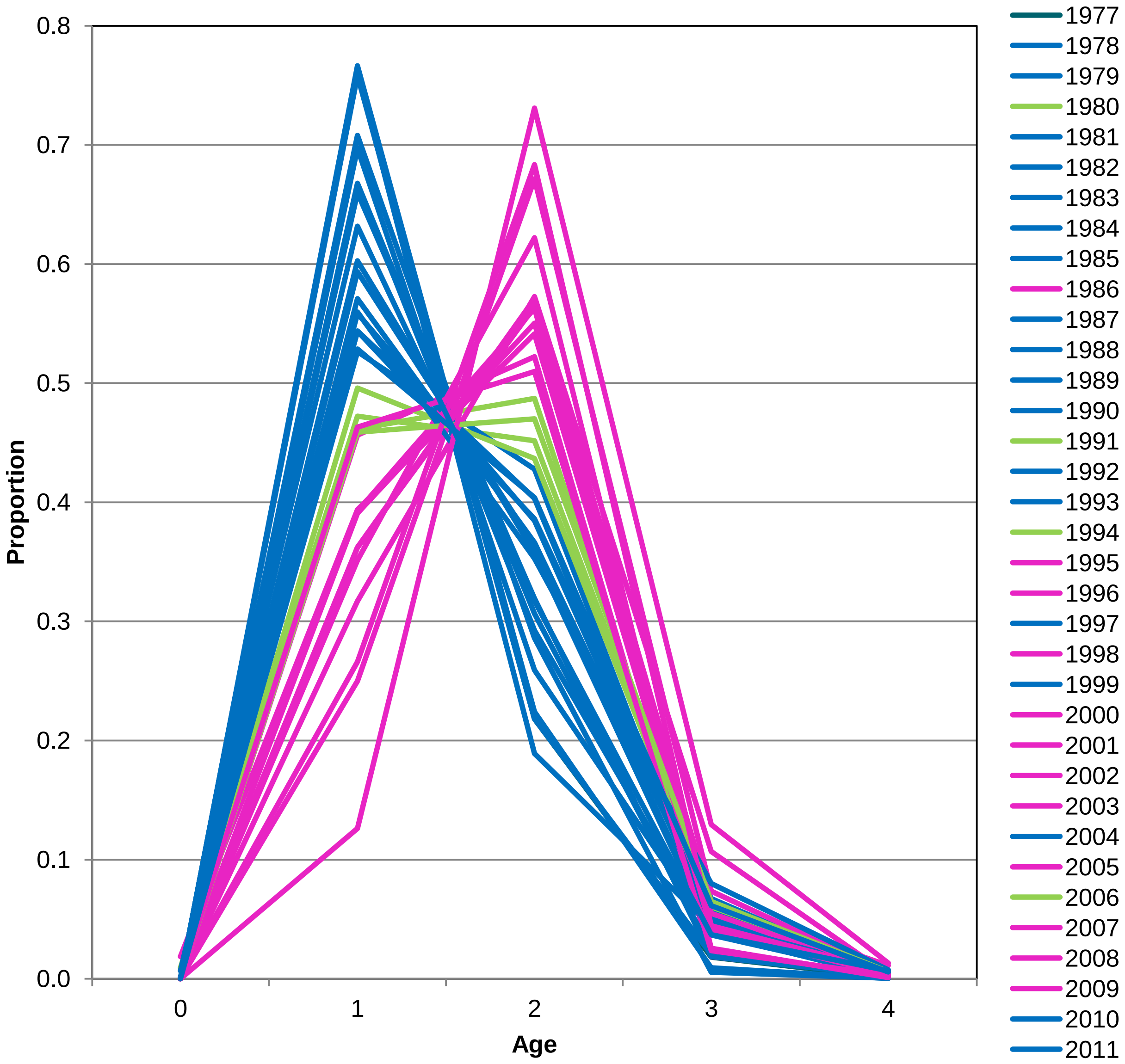


Figure 6.3 Age compositions by year for the commercial reduction fishery color coded so that years with the highest proportion of age-1s are blue, years with the highest proportions of age-2s are pink, and other years are green.

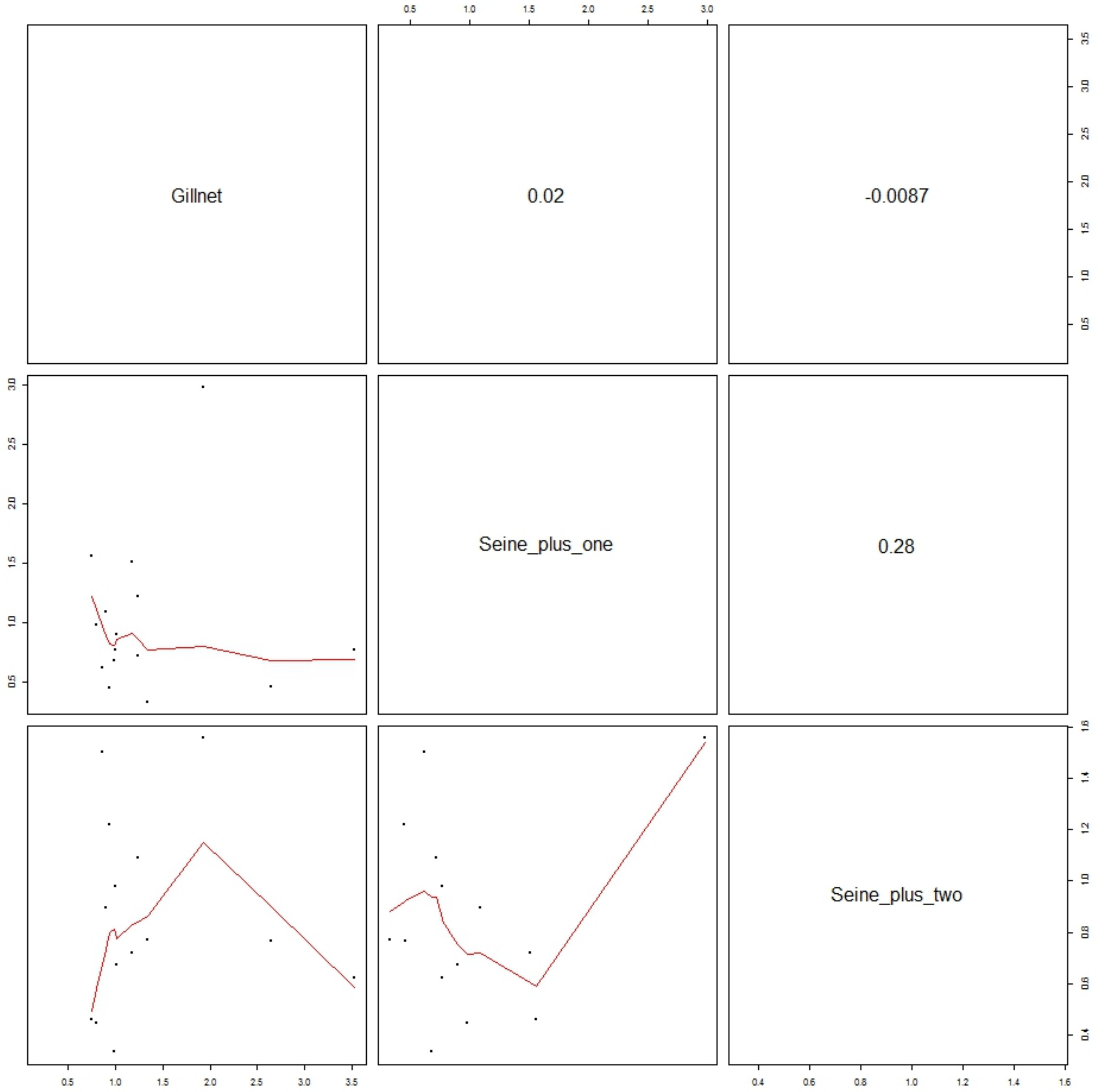


Figure 6.4 Pairs plot of correlations between indices used in production modeling of Gulf menhaden.

7.0 Base and Alternate Assessment Model Results

7.1 Results of Base BAM Model

7.1.1 Goodness of Fit

Goodness-of-fit was governed in the BAM assessment model by the likelihood components in the objective function (Table 6.2). The relative fit among the likelihood components was governed by the weighting terms and the assumed error levels for each data source (see Section 6.2.1.4). During the Assessment Workshop, goodness of fit was also judged for each data source through examination of the model residuals.

Observed and model-predicted landings for the reduction fishery (1977–2011; Figure 7.1) were compared for the base model run. Reduction fishery landings, which are known fairly precisely, fit very well. Patterns in the annual comparisons of observed and predicted proportion catch-at-age for the reduction fishery (Figure 7.2) indicate a good overall model fit to the observed data. The bubble plot for the reduction fishery (Figure 7.3) indicates that the model fit does fairly well estimating age-1 during the time series. There is no patterning observed in the bubble plot that would cause concern.

Observed and predicted coastwide seine recruitment indices were compared for the base model run (1996–2010; Figure 7.4). The residual pattern suggests that the recruitment index data did not fit well when relatively large or small year classes occurred. Visual examination of the fit suggests that the overall pattern fit reasonably well, with the BAM model capturing some of the lows and highs observed in the index values.

The observed and predicted gill net index (1988–2011; Figure 7.5) values appear to fit well. The general patterns are captured. However, the model has a difficult time fitting estimates to the highest observed values in 2008 and 2009. Patterns in the annual comparisons of observed and predicted proportion gill net measurements at length for the gill net index (Figure 7.6) indicate a good overall model fit to the observed data. The bubble plot for the gill net index length compositions (Figure 7.7) indicates that the model fit underestimates lengths near 140 mm FL and overestimates lengths near 120 and 160 mm FL.

7.1.2 Parameter Estimates (Include Precision of Estimates)

7.1.2.1 Selectivities and Catchability

Fishing mortality was related to an overall level of fishing and the selectivity (or availability) of Gulf menhaden to the fishery. Model estimates of selectivity (availability) for the fishery are shown graphically in Figure 7.8. Selectivity parameters were estimated for age-1 and fixed for all other ages. The selectivity for age-1 was estimated in logit space and was estimated at -2.92 (0.05 in normal space) with a standard error (SE) of 0.22.

Selectivity for the gill net index was estimated as a two parameter logistic function as shown in Figure 7.9. The slope of the selectivity curve was estimated at 20.2 with a 269.8 SE, and the L_{50}

of the selectivity curve was estimated at 1.17 with a 23.1 SE. Selectivity for the gill net index was used to fit the gill net length composition data and represents the ages of fish that were captured by the gill net index.

The base BAM model estimates a single, constant catchability parameter for each of the abundance indices, reflecting the assumption that expected catchability for these CPUE indices is believed to be constant through time. This is certainly a good assumption for the fishery-independent recruitment index and gill net adult index since they are based on consistent, scientific survey collections, albeit the surveys are at fixed stations and target other species. Log-catchability was estimated at -4.38 (0.0125 back transformed) for the seine index with a 0.14 SE, while the log-catchability of the gill net index was 1.48 (0.148 back transformed) with a 0.55 SE.

7.1.2.2 Fishing Mortality Rate

Highly variable fishing mortalities were noted throughout the entire time series, with the highest fishing mortalities in the 1980s, with a decline in fishing mortality into the 2000s. In the most recent decade, the full fishing mortality rate has ranged between 1.0 and 3.5 (Table 7.1; Figure 7.10). However, the only age that is fully selected is age-2, thus the fishing mortality rate on other ages is much smaller. In the most recent decade, full fishing mortality on age-1 has ranged from 0.06 to 0.19 (Table 7.2). The estimate of full fishing mortality rate for 2011 is 2.36 (Table 7.1).

7.1.2.3 Abundance, Fecundity, and Recruitment Estimates

The base BAM model estimated population numbers-at-age (ages 0-4+) for 1977–2011 (Figure 7.11 and Table 7.3). From these estimates, along with growth and reproductive data, different estimates of reproductive capacity were computed. Population fecundity was the preferred measure of reproductive output. Population fecundity (*FEC*, number of maturing ova) was slightly lower in the 1980s and has generally been higher with older age classes making up a larger proportion of the *FEC* in the 2000s (Figure 7.12 and Table 7.4). The largest values of population fecundity were present in 2008 and 2009. The time period 1977-2011 produced a median population fecundity of 47 x 10^{12} ova with a minimum of 17 x 10^{12} and a maximum of 77 x 10^{12} and an interquartile range of 36 x 10^{12} to 54 x 10^{12} (Table 7.4). The estimate for population fecundity in 2011 was 50 x 10^{12}, which was between the 50th and 75th percentile. Throughout the time series, the age-2 fish produced most of the total estimated number of eggs spawned annually (Figure 7.13); however, in more recent years, ages-3 and -4 have contributed more significantly to the overall number of eggs.

Age-0 recruits of Gulf menhaden (Figure 7.14 and Table 7.5) were highest during the 1980s, but varied without trend for the time series. The largest year-classes were in 2010, 1984, 1981, 1992, 1980, and 2006. The annual estimated recruitment values relative to the median are shown in Figure 7.15. The recent estimate for 2010 is quite high, but has also shown up in higher catches at age-1 in 2011 and higher catches at age-2 in 2012. The estimate of recruits to age-0 in 2010 (270 billion) is the highest recruitment value during the time series. A plot of the fecundity (mature ova) to the recruits at age-0 indicated a weak relationship, suggesting Gulf menhaden recruitment was only marginally governed by population fecundity (Figure 7.16). The only recruitment parameter estimated in the model was log of R_0, which was estimated at 4.6 with a standard deviation of 0.046.

7.1.2.4 Weighting of the Data Components

The standard deviations of the normalized residuals (SDNR) and likelihood values for the commercial reduction age compositions, gill net length compositions, gill net adult index, and seine recruitment index were explored across a range of age composition weights in order to explore the trade-off in getting a SDNR to 1.0 for each data component and to look at the data incongruence for the age composition data (Figures 7.17-7.21). The SDNR of the age composition data cannot be set to 1.0 because of a large jump in the SDNR as you increase the weight on the age composition data (Figure 7.17). The SDNRs for the length composition data and the gill net index are closest to one when the age composition weight is near 0.02 (Figures 7.18 and 7.19). The SDNR for the seine index was closest to 1.0 when values of the age composition weights were closest to 0.02 or less. Finally, the likelihood components for most of the data sources show that a lower age composition weight is better, and that there is tension between the data sources, specifically the fit of the seine index compared to the fits of the other indices (Figure 7.21). The tension between the data sources is also seen when comparing Figures 7.17-7.20 across the range of age composition weights. Because the age composition data fit fairly well and the SDNRs for the other data components were closest to 1.0 with an age composition weight near 0.02, the assessment panel accepted a SDNR of less than 1.0 for the age composition data.

The tension between the seine index fit and the other data sources was also explored by looking at the fits to the data and model estimates across a range of seine weights (Figure 7.22). The likelihood for the seine index shows that a higher weight would result in a lower likelihood; however, a higher seine index weight results in a higher likelihood for all of the other data components. Thus, there is a fundamental tension in the data between the recruitment index (seine) and the adult data (age compositions, length compositions, and gill net index). Additionally, increasing the seine weight decreased the scale of full *F*; increased recruitment, fecundity, and age-1+ biomass in the latter part of the time series; resulted in a better seine index fit; and resulted in a worse gill net index fit (Figure 7.23). The assessment panel decided that the assessment model should fit the adult data best because those data inform the part of the population managers are most interested in and because the inherent variability in recruitment in fisheries made the panel question how well the model should be fitting the seine index.

7.1.3 Sensitivity Analyses

The results of the sensitivity runs suggest that the base BAM model is fairly robust to model choices made in the base run and data choices made by the assessment panel (Figures 7.24-7.36).

The sensitivity runs associated with natural mortality mostly scaled the outputs from the model. Specifically, the runs that used the minimum and maximum values of *M* from the tagging study (gm-041 and gm-042) scaled the values of full *F* and recruitment. In addition, the maximum value of *M* based on the tagging study lead to an increase in fecundity in the 1990s and 2000s, and resulted in a worse fit to the gill net index in those years. The run based on the Charnov *M* changed very little (gm-043). The run allowing for the estimation of deviations in age-1 natural mortality for 1996-2010 (gm-024) did result in minor changes to full *F*, recruits, and fecundity in the later years because of the flexibility to better fit the seine index. Overall, the behaviors observed from the sensitivity runs changing the input of natural mortality were as expected.

Changes to the stock-recruitment curve did not have much effect on the overall results from the model. Neither the run with the Ricker stock-recruitment function (gm-023) nor the run with steepness set to 0.99 (gm-022) resulted in any changes to the full *F*, recruitment, nor fecundity. The only run that resulted in noticeable changes was with steepness set to 0.5 (gm-021). With a steepness of 0.5, the full *F* was scaled down across the entire time series, and the recruitment and fecundity both increased in the 1990s and 2000s. In order to accommodate a lower value of steepness (and therefore productivity), the model needed to increase population sizes in order to account for the level of landings that was being removed from the population and the increase in the gill net index over the latter half of the time series. Overall, the behaviors observed from the sensitivity runs changing the input for the stock-recruitment curve were as expected.

The sensitivity runs that explored changes in selectivity had some effect on the overall results from the model. The run with the largest effect was the run in which the age-3 and -4 selectivity for the commercial reduction fishery was allowed to estimate freely (gm-025). In this run, the full *F* was scaled down over the entire time series, while the fecundity and recruitment increased in the 1990s and 2000s, and the gill net index was fit much poorer. The sensitivity run (gm-026), which fixed the commercial reduction fishery age-3 and age-4 selectivity to be flat topped or logistic, had a slight effect on the full *F*, but very little to no effect on the population fecundity and recruitment (Figures 7.25c and 7.26c). Finally, the sensitivity run (gm-027) that allowed for time blocks for the estimation of age-1 selectivity resulted in some change to the overall values of full *F* with full *F* being somewhat higher in the early part of the time series and somewhat lower in the latter part of the time series. Overall, the behaviors observed from the sensitivity runs changing the selectivity for the commercial reduction fishery were as expected.

The start year of the model had no effect on the estimates of full *F*, recruitment, or fecundity during 1977-2011. However, the trajectory of full *F*, recruitment, and fecundity were markedly different depending on the start year of the model. Specifically, when the model started in 1948, the trajectory of the results matches with anecdotal evidence of the fishery ramping up from the 1940s to the 1980s. When the model started in 1964, the trajectory of the results is the opposite with very high values of full *F* and lower population sizes, fecundity, and recruitment. Overall, the start year did not have an impact on the determination of population parameters in the more recent time period of interest.

Several runs were completed that changed data inputs including setting all weights to 1.0, omitting the seine index, omitting the gill net index and associated length compositions, including shrimp trawl by-catch in the catch stream, and assuming that the fishery dependent data represent the population growth curve. The run that resulted in the most significant differences from the base run was the run with all weights set to 1.0. In general, full *F* was lower for this run and fecundity was higher in the more recent years. The run that omitted the gill net index and gill net length composition data had the same trends over time but year to year values were different. Overall, these runs resulted in expected model behaviors.

Finally, one additional run was completed that excluded all indices and the gill net length composition data. This run was dependent on the landings and the age composition data from the landings. The overall results from this run are not markedly different from the results of the base run. This run keys in on information in the age composition data, which is correlated with the seine and gill net indices for the correct ages; so the overall results are not unexpected.

The overall trend in the results from 1977-2011 was seen in all of the sensitivity runs. Some sensitivity runs resulted in differing year to year variability depending upon the data sources that were used, which is expected. Some of the sensitivity runs did change the overall scale of the assessment. For example, scaling natural mortality scaled other model components. This is a typical stock assessment result.

Concern arose from the assessment panel that some of the sensitivity runs might represent different states of nature. However, based on the MCB runs discussed below (section 7.1.5) and the likelihood values and parameter estimates (Table 7.6), the sensitivity runs are simply bounds on the uncertainty rather than distinct states of nature. The assessment panel specified these sensitivity runs as the bounds on the uncertainty (for example, h = 0.5 and 0.99; commercial reduction age-3 and -4 selectivity = 0.0 [estimated value] and 1.0). The output distributions from the estimated parameters are smooth distributions that are not bimodal, which suggests that these runs are simply the bounds on the uncertainty of the assessment given the assumptions and data inputs.

Because no formal benchmarks have been adopted for Gulf menhaden and because F_{MSY} was infinite, a suite of benchmarks was calculated and presented for the sensitivity runs (Table 7.7; Figures 7.31-7.36). Even with the differences in the sensitivity runs, most of the runs, given the suite of benchmarks presented, did not result in overfishing or overfished conditions with respect to stock status (Tables 7.7). With F_{MED}, the only runs that resulted in a current status of overfishing were the run with no indices or gill net length composition data and the run that started in 1948 and used the entire time series for benchmark calculation. None of the runs exceed the SSB threshold associated with F_{MED}. The only run classified as overfishing under $F/F_{30\%,\ 35\%,\ or\ 40\%}$ was the run with the M scaled to the minimum from the tagging study (Figures 7.32-7.33). That same run was also below the SSB value. None of the other runs were classified as overfishing, and some of the runs had SSB values near $SSB_{30\%,\ 35\%,\ or\ 40\%}$ (Figures 7.34-7.36).

7.1.4 Retrospective Analyses

The retrospective was run peeling off data back to 2002 (Figures 7.37-7.43). The results indicate that the 2008 and 2009 gill net index data points are influential in determining the past trends in the estimated population values. The terminal full fishing mortality rate is stable until 2006, and then the addition of information in a realm of uncertainty in the past is included (Figure 7.37). This new information helps to define a different R_0 value, which has an overall impact on the scale of the individual retrospective runs (Table 7.8). Several runs were done to determine if a new state of nature was being shown here or if indeed the addition of data points in a novel space helped to define a different set of parameter values. Based on those explorations, the assessment panel determined that these are based on the addition of new data. In addition, likelihood profiles on R_0 were explored for the different terminal years of the assessment (Figure 7.51). Based on these likelihood profiles, the assessment panel deemed that R_0 was well estimated in all of the retrospective runs; therefore, the runs exhibited the different possible states of nature likely due to the addition of data in a data space with no information beforehand. The resulting recruitment, fecundity, and biomass show consistent patterns to full F (Figures 7.38-7.40; Tables 7.8). The fits to the indices are fairly good regardless of the terminal year of the model (Figures 7.41-7.42).

The magnitude of stock status outcomes did not vary much in this set of retrospective model runs. In particular, the ratio of full fishing mortality to the suite of potential benchmarks in the terminal year showed no variation in stock status (Figures 7.43, 7.45, 7.47, and 7.49). The ratio of *SSB* to the suite of *SSB* metrics also did not vary much (Figures 7.44, 7.46, 7.48, and 7.50).

7.1.5 Uncertainty Analysis

Uncertainty was examined in our results in two distinct ways: by considering each data source, in turn, in a series of sensitivity runs (Sections 7.1.3 and 7.1.4), and by using a MCB procedure. The parametric bootstrap procedure was run for 5,000 iterations. For some iterations, the model did not converge; if this was true, then that particular iteration was not included in the results. About 5% of runs did not converge and were not included in the analysis of the results. In addition, some iterations estimated fairly high values for R_0, thus the top 15% of runs were excluded (Figures 7.52). Even with the exclusion of runs due to non-convergence and high R_0 values, 4,068 runs still remained for analysis.

The resulting estimates from the 4,068 runs have been summarized in Figures 7.12, 7.14 and 7.53 and Tables 7.4, 7.5, and 7.9, showing the 95% confidence region. In general, the MCB results are not symmetrical distributions about the base run results because some of the uncertainty specifications were not symmetrical. The uncertainty was quite large and increased in the latter years, especially for fecundity and recruitment.

7.1.6 Reference Point Results – Parameter Estimates and Sensitivity

No formally adopted benchmarks are available for Gulf menhaden; thus a suite of options are provided in order to make a general statement about the likely stock status for Gulf menhaden. In the meantime, managers are working to define the goals for the fishery and to specify objectives for the fishery. Once that has been completed, appropriate benchmarks can be discussed and formally adopted. Thus, below is a suite of potential options.

Fecundity-per-recruit and yield-per-recruit (mt) estimates as a function of full fishing mortality rates are shown in Figures 7.54 and 7.55. These plots are offered as a reference for other fishing mortality rates. For example, the terminal year fishing mortality rate estimate (F_{2011}) of 2.63 is greater than 40% of SPR (Figure 7.51). The age-1+ biomass in the terminal year is 1.28 of B_0, in 2010 it is 0.54 of B_0, and in 2009 it is 0.48 of B_0. Over the entire time series, the age-1+ biomass divided by B_0 averaged 0.62, and over the past decade, the age+1 biomass divided by B_0 averaged 0.65.

The base BAM model estimates for the suite of benchmark options presented and terminal year values are indicated in Table 7.10. This table also indicates the values for some per-recruit-based benchmarks of $F_{40\%}$, $F_{35\%}$, and $F_{30\%}$ and benchmarks based on F_{MED}. Based on the suite of benchmarks presented in this section, the results suggest that generally the current stock status is not overfished and overfishing is not occurring (Table 7.10). Because no benchmarks have been defined, the stock status relative to targets could not be provided.

The entire time series of estimates of full fishing mortality over F_{MED} and $SSB/SSB_{MED.thresh}$ are shown in Figures 7.56 and 7.57, a phase plot of the estimates is shown in Figure 7.58, and cumulative probability density functions are shown in Figures 7.59 and 7.60. Additionally, time series of $F/F_{30\%}$, $F/F_{40\%}$, $SSB/SSB_{30\%}$, and $SSB/SSB_{40\%}$ are also shown in Figures 7.62, 7.63, 7.66, and 7.67, along with the cumulative probability density functions in Figures 7.64, 7.65, 7.68, and 7.69. The history of fishing mortality rates in these figures suggests that overfishing likely occurred in the 1980s, but generally, overfishing is unlikely to be occurring in the present. The population may have been considered overfished in the past, depending upon the benchmark considered.

The uncertainty in the terminal year stock status indicators were expressed using the results of the 4,068 bootstrap runs of the base BAM model, which already excluded runs because of convergence. The results indicate that the fecundity estimates for the terminal year are well above $SSB_{MED.thresh}$, with not a single bootstrap estimate falling below 1.0 (Figure 7.61). The results for the 2011 fishing mortality rate suggests that the base run estimate is below F_{MED} with none of the bootstrap runs exceeding F_{MED} in the most recent years (Figures 7.61).

The estimation of F_{MSY} was infinite, meaning that the maximum F value allowed was 10, and F_{MSY} had still not been maximized. F_{MSY} was infinite because of the nature of the fishery and the population dynamics of the stock. Almost all fish reach maturity and spawn before being harvested by the commercial reduction fishery. Because the stock spawns in the winter and fishing doesn't begin until late April, all fish are allowed to spawn before the fishing season starts. Fish mature at age-2, and the bulk of the fishery take is of age-2 individuals. A very small proportion of the age-1 fish are captured by the fishery, thus, those fish are allowed to escape the fishery, mature, and spawn before being captured the next year. Thus, Gulf menhaden are like an annual crop (although you need to wait 2 years). Once the fish have spawned as age-2 individuals, the fish can be harvested because they have already contributed to the recruitment that year. An infinite value of F_{MSY} will apply as long as the fishery selectivity and season remain unchanged. If the fishery harvests before spawning occurs (either by harvesting earlier than late April or by harvesting age-1 or younger individuals), then F_{MSY} will likely be reduced. Please see the spreadsheet provided for an example and exploration of F_{MSY} for Gulf menhaden.

Overall, the base run may provide more of a worst case type of picture of the stock as most of the uncertainty and sensitivity runs show either a stable or increasing stock structure. Even though no formal benchmarks have been adopted, based on the suite provided here, the assessment panel decided to make a general statement that the Gulf menhaden stock in the Gulf of Mexico is not undergoing overfishing and is not overfished.

7.2 Results of Alternate Model (Production Model — ASPIC)

7.2.1 Goodness of Fit

Goodness of fit is discussed for the base run and selected sensitivity runs. In particular, we describe sensitivity runs in which data series were substituted.

The primary reference configuration (model men-31) of the surplus production model is fit to the gill net index of abundance (IOA; Table 6.3, Figure 7.70, 7.71). The model fits the observed data relatively well for most of the time-series (1988 to 2007, Figure 7.72). During this year range there is no discernible patterning in the residuals and relatively low magnitudes of error. Large residual deviations are apparent in the later years in the time-series, 2008 to 2011 (Figure 7.72). Conspicuous positive points in the gill net IOA, relative to the expected value, are observed in 2008, 2009, and 2011 (Figure 7.72). Negative points are observed in 2007 and 2010. Because these large positive and negative anomalies are interspersed, they do not have a large influence on the population trajectory. The population trajectory at the end of the time-series does not indicate an increasing trend in estimated abundance.

Four model runs (men-34, -35, -36, -37, and 38) were used to investigate how the substitution and replacement of IOA alter model reference points, fishery trajectory, and stock trajectory relative to the base run (men-31). Run men-34 included the gill net IOA and the juvenile seine IOA that was lagged + 1 year (Figure 7.73). The estimated abundance trend was similar to that provided by the primary reference configuration; no large increase in the population trajectory was observed in the final years of the time-series. Similarly, the population trajectory is relatively flat following an increase in the mid-1990s. Similar trends were observed in each of the alternative model IOA combinations (men-35 and men-36, Figure 7.74 and 7.75). Population assessment and fishery dynamics could not be assessed for the model runs using only the lagged + 1 year and +2 year indices (men-36 and men-37). These model runs excluded the gill net IOA (Table 7.11).

7.2.2 Parameter Estimates

The parameter estimates from the primary reference configuration and sensitivity runs are listed in Table 7.11. Each of the model runs used in sensitivity analysis (men-32 to men-40) exhibited similar mean reference points estimates to those of the reference model configuration, men-31. Confidence intervals (80%) and ranges in the mean estimates from the primary reference configuration are presented in Table 7.12. Mean estimate of B_{MSY} is 787 million mt (80% CI: 772 to 831 million mt). Mean estimate of F_{MSY} is 1.05 (80% CI: 0.66 to 1.14).

7.2.2.1 Catchability Estimates

Mean and (80% CI of the mean) catchability estimates appear in Table 7.12.

7.2.2.2 Biomass and Fishing-Mortality Estimates

Estimates of relative biomass and fishing mortality (i.e., stock and fishery status) are emphasized here, because they are estimated disregarding the scaling via the catchability estimate and are of direct management interest. Results of the primary reference configuration of the stock and fishery status are presented in Figure 7.76 and terminal values in Table 7.12.

Most sensitivity runs indicated that population status trajectories very similar to those from the primary reference configuration (men-31). In comparing sensitivity runs, men-34, men-35, and 36 indicated very little difference in stock status over the length of the time series (Figures 7.77, 7.78 and 7.79). Each of these model formulations included the adult gill net IOA. Estimated status trajectories were relatively insensitive to assumptions about the relative starting biomass K (Table 7.11): The time-series of stock status and fishery status differed little for $B_1 = 0.60K$ and $B_1 = 0.40K$ (Figure 7.80 and 7.81), except at the initiation of the time series.

The sensitivity run that exhibited the greatest difference in the estimates of MSY and F_{MSY} was the one that fit the surplus production model using the alternative Fox model shape (men-40, Table 7.11). This model suggests that the stock was greater, relative to B_{MSY}, in the early 1980's and that overfishing was occurring at a greater magnitude, in the mid-1990s, relative to the estimate from primary reference configuration (Figure 7.82 and 7.83). Similarly, stock biomass estimates, relative to B_{MSY}, prior to, and after this period were expected to be greater than that estimated by the primary model configuration (Figure 7.82 and 7.83). The extension of the time series from 1977 used in the base model configuration to 1948 exhibited similar patterns to that of the primary reference configuration (Figure 7.82 and 7.83).

7.2.4 Retrospective Analyses

Results of the retrospective analysis are given in Figure 7.84 and indicate no retrospective pattern.

7.2.5 Reference Point Results – Parameter Estimates and Sensitivity

Reference point estimation is inherent in the output of fitting production models. Uncertainty in the mean estimates was performed by bootstrap (Section 7.2.2 and 7.2.2.1). Sensitivity analyses, described above, include the sensitivity analyses on estimated reference points.

Table 7.1 Estimated annual full fishing mortality rate from the base BAM model.

Year	Full *F*
1977	8.25
1978	10.02
1979	7.63
1980	9.83
1981	7.00
1982	6.37
1983	8.07
1984	13.80
1985	9.09
1986	5.50
1987	12.11
1988	11.58
1989	11.78
1990	8.67
1991	7.97
1992	7.11
1993	5.77
1994	5.20
1995	3.39
1996	3.37
1997	3.43
1998	2.75
1999	4.62
2000	2.92
2001	2.38
2002	3.44
2003	3.40
2004	3.61
2005	2.35
2006	2.88
2007	2.59
2008	1.20
2009	1.51
2010	3.25
2011	2.36

Table 7.2 Estimated full fishing mortality rates at age from the base BAM model.

Year	0	1	2	3	4+
1977	0.00	0.42	8.25	2.89	2.89
1978	0.00	0.51	10.02	3.51	3.51
1979	0.00	0.39	7.63	2.67	2.67
1980	0.00	0.51	9.83	3.44	3.44
1981	0.00	0.36	7.00	2.45	2.45
1982	0.00	0.33	6.37	2.23	2.23
1983	0.00	0.41	8.07	2.82	2.82
1984	0.00	0.71	13.80	4.83	4.83
1985	0.00	0.47	9.09	3.18	3.18
1986	0.00	0.28	5.50	1.93	1.93
1987	0.00	0.62	12.11	4.24	4.24
1988	0.00	0.60	11.58	4.05	4.05
1989	0.00	0.61	11.78	4.12	4.12
1990	0.00	0.45	8.67	3.04	3.04
1991	0.00	0.41	7.97	2.79	2.79
1992	0.00	0.37	7.11	2.49	2.49
1993	0.00	0.30	5.77	2.02	2.02
1994	0.00	0.27	5.20	1.82	1.82
1995	0.00	0.17	3.39	1.19	1.19
1996	0.00	0.17	3.37	1.18	1.18
1997	0.00	0.18	3.43	1.20	1.20
1998	0.00	0.14	2.75	0.96	0.96
1999	0.00	0.24	4.62	1.62	1.62
2000	0.00	0.15	2.92	1.02	1.02
2001	0.00	0.12	2.38	0.83	0.83
2002	0.00	0.18	3.44	1.20	1.20
2003	0.00	0.17	3.40	1.19	1.19
2004	0.00	0.19	3.61	1.26	1.26
2005	0.00	0.12	2.35	0.82	0.82
2006	0.00	0.15	2.88	1.01	1.01
2007	0.00	0.13	2.59	0.91	0.91
2008	0.00	0.06	1.20	0.42	0.42
2009	0.00	0.08	1.51	0.53	0.53
2010	0.00	0.17	3.25	1.14	1.14
2011	0.00	0.12	2.36	0.83	0.83

Table 7.3 Estimated numbers of Gulf menhaden (billions) at the start of the year from the base BAM model.

Year	0	1	2	3	4+
1977	133.81	19.39	1.60	0.00	0.00
1978	122.47	26.45	3.46	0.00	0.00
1979	65.73	24.21	4.31	0.00	0.00
1980	135.23	13.00	4.46	0.00	0.00
1981	145.88	26.73	2.14	0.00	0.00
1982	114.97	28.84	5.08	0.00	0.00
1983	122.85	22.74	5.66	0.00	0.00
1984	174.51	24.29	4.09	0.00	0.00
1985	115.05	34.48	3.26	0.00	0.00
1986	99.83	22.74	5.89	0.00	0.00
1987	84.96	19.74	4.67	0.01	0.00
1988	81.85	16.79	2.89	0.00	0.00
1989	95.30	16.17	2.52	0.00	0.00
1990	70.52	18.83	2.41	0.00	0.00
1991	66.41	13.94	3.29	0.00	0.00
1992	143.17	13.13	2.52	0.00	0.00
1993	99.60	28.31	2.48	0.00	0.00
1994	82.45	19.70	5.74	0.00	0.00
1995	116.45	16.31	4.11	0.01	0.00
1996	101.16	23.04	3.73	0.05	0.00
1997	101.63	20.01	5.28	0.04	0.01
1998	123.66	20.10	4.57	0.06	0.01
1999	113.27	24.46	4.76	0.10	0.01
2000	98.45	22.40	5.26	0.02	0.01
2001	99.54	19.48	5.25	0.09	0.00
2002	80.20	19.69	4.70	0.16	0.02
2003	99.06	15.87	4.50	0.05	0.02
2004	88.54	19.60	3.63	0.05	0.01
2005	82.76	17.51	4.44	0.03	0.01
2006	134.21	16.37	4.23	0.14	0.01
2007	121.11	26.55	3.85	0.08	0.02
2008	47.01	23.96	6.33	0.10	0.01
2009	99.45	9.30	6.14	0.64	0.03
2010	270.27	19.68	2.35	0.45	0.14
2011	107.67	53.46	4.54	0.03	0.07

Table 7.4 Estimated annual fecundity (billions of eggs) from the base BAM model and percentiles from the bootstrap runs.

Year	BAM Base run	2.5 percentile	50 percentile	97.5 percentile
1977	16,971	8,854	19,898	45,790
1978	36,707	18,663	40,845	76,627
1979	45,742	23,202	50,637	87,056
1980	47,338	23,787	51,347	77,218
1981	22,692	11,840	26,600	60,426
1982	53,991	27,752	60,182	103,784
1983	60,194	30,161	65,640	103,114
1984	43,460	22,052	47,947	80,074
1985	34,562	17,887	39,440	83,183
1986	62,516	30,373	67,136	111,791
1987	49,737	25,018	53,952	85,077
1988	30,654	15,516	33,564	58,555
1989	26,787	12,121	27,081	51,633
1990	25,538	11,713	26,047	52,384
1991	34,894	15,641	34,760	60,261
1992	26,780	12,944	28,392	49,950
1993	26,374	13,052	29,518	65,774
1994	60,937	27,237	61,464	109,541
1995	43,822	22,118	54,684	115,333
1996	40,470	21,155	53,934	123,948
1997	56,925	28,166	64,586	135,872
1998	49,677	24,631	67,855	157,647
1999	52,435	28,640	69,041	158,140
2000	56,296	29,249	73,289	168,197
2001	57,531	28,304	78,400	168,144
2002	53,122	28,128	67,741	144,362
2003	49,112	24,433	58,937	133,156
2004	39,610	20,721	52,791	137,306
2005	47,827	23,910	66,276	166,733
2006	47,554	23,842	65,508	177,784
2007	42,753	22,592	76,874	221,253
2008	69,323	30,961	109,129	277,727
2009	77,063	35,442	125,621	311,380
2010	36,426	19,601	75,695	244,904
2011	50,465	26,046	87,054	249,577

Table 7.5 Estimated annual recruitment of age-0 (billions) fish from the base BAM model and percentiles from the bootstrap runs.

Year	BAM Base run	2.5 percentile	50 percentile	97.5 percentile
1977	133.8	22.4	130.0	583.9
1978	122.5	19.8	119.2	549.6
1979	65.7	11.0	64.5	300.4
1980	135.2	21.5	133.6	635.2
1981	145.9	22.8	140.9	664.7
1982	115.0	19.3	111.2	488.9
1983	122.8	22.7	118.8	515.6
1984	174.5	28.9	170.1	788.0
1985	115.0	17.9	109.9	515.2
1986	99.8	17.6	97.2	421.3
1987	85.0	14.3	78.3	348.0
1988	81.9	14.9	77.3	348.9
1989	95.3	15.8	90.2	412.0
1990	70.5	11.6	68.8	320.1
1991	66.4	10.9	65.9	317.4
1992	143.2	21.7	132.2	645.6
1993	99.6	14.5	120.7	656.7
1994	82.5	11.6	92.1	533.5
1995	116.5	15.1	113.5	625.2
1996	101.2	13.4	126.4	743.1
1997	101.6	14.6	111.1	627.3
1998	123.7	16.9	139.9	808.8
1999	113.3	14.3	132.2	820.4
2000	98.4	12.8	100.5	616.1
2001	99.5	13.4	103.0	577.3
2002	80.2	11.3	92.8	541.1
2003	99.1	13.2	122.3	733.0
2004	88.5	11.7	103.5	634.1
2005	82.8	11.8	123.2	762.9
2006	134.2	14.5	169.3	1096.2
2007	121.1	12.7	167.7	1215.8
2008	47.0	6.6	66.9	457.3
2009	99.5	13.1	119.8	721.7
2010	270.3	36.2	301.6	1678.6
2011	107.7	17.1	127.2	655.3

Table 7.6 Table of likelihood components and estimates of R_0, L_{inf}, and terminal year *SSB* from the sensitivity runs that were completed.

Run	total	unweighted	landings	length comps	age comps	gill net index	seine index	priors	M.devs	SR fit	R_0	L_{inf}	terminal year *SSB*
Base run	-540.94	-529.67	0.52	-331.94	-215.45	9.62	7.59	0	0	-11.27	99.9	229.03	50464.53
h = 0.5	-539.15	-528.31	0.18	-340.36	-214.81	20.55	6.14	0	0	-10.84	181.89	280.67	114262.1
h = 0.99	-541.46	-529.75	0.52	-331.87	-215.41	9.39	7.62	0	0	-11.71	87.21	229.14	49846.95
Ricker	-541.94	-529.79	0.49	-331.83	-215.61	9.51	7.66	0	0	-12.15		225.77	49792.32
with M devs	-550.52	-542.47	0.29	-332.8	-218.1	5.98	2.16	0	1.49	-11.03	99.18	216.48	48022.08
cR age3&4 select est.	-544.55	-533.2	0.12	-341.4	-218.64	20.42	6.3	0	0	-11.35	130.19	255.34	130470.6
cR age3&4 select = 1.0	-541.33	-528.71	0.59	-331.33	-214.26	8.51	7.77	-1.22	0	-11.4	98.67	239.5	48451.41
cR age1 select time blocks	-541.34	-529.96	0.45	-332.39	-215.92	10.39	7.52	0	0	-11.38	100.17	227.29	51732.94
pop = fish growth	-540.94	-529.67	0.52	-331.94	-215.45	9.62	7.59	0	0	-11.27	99.81	229.04	51807.17
all weights = 1.0	142.69	153.66	4.33	-187.57	229.89	84.25	22.77	0	0	-10.97	112.29	305.32	81615.98
omit gill net index	-227.29	-215.9	0.03	0	-221.79	0	5.85	0	0	-11.39	101.29	239.5	56264.02
omit seine index	-548.94	-537.66	0.43	-331.84	-214.79	8.54	0	0	0	-11.27	99.12	222.24	47791.74
min M from tagging	-539.72	-530.36	0.71	-331.4	-214.51	7.2	7.64	0.99	0	-10.34	41.53	219.86	41272.54
max M from tagging	-536.65	-526.1	0.21	-336.78	-213.09	16.06	7.51	0.2	0	-10.75	429.84	239.5	87871.81
scaled Charnov M	-541.65	-530.39	0.53	-331.84	-215.84	9.17	7.59	0	0	-11.26	57.1	236.18	49722.22
includes shrimp trawl discards	-541.08	-529.8	0.52	-331.91	-215.44	9.43	7.61	0	0	-11.28	99.98	229.28	50302.79
start year 1964	-634.77	-618.97	0.54	-331.91	-304.62	9.39	7.63	0	0	-15.79	95.54	230.07	48991.42
start year 1948	-627.07	-611.67	0.59	-331.86	-297.08	9	7.68	0	0	-15.4	97.71	232.5	53462.95

Table 7.7 Estimates of $SSB_{MED.thresh}$, $SSB_{30\%}$, $SSB_{35\%}$, $SSB_{40\%}$, and SSB_{2011}/each of the *SSB* based metrics from the sensitivity runs and retrospective analysis that were completed.

Run	$SSB_{MED.thresh}$	$SSB_{30\%}$	$SSB_{35\%}$	$SSB_{40\%}$	SSB_{2011} $/SSB_{MED}$	SSB_{2011} $/SSB_{30\%}$	SSB_{2011} $/SSB_{35\%}$	SSB_{2011} $/SSB_{40\%}$
Base run	22,627	34,750	42,292	49,834	2.23	1.45	1.19	1.01
h = 0.5	32,688	30,603	47,383	64,170	3.50	3.73	2.41	1.78
h = 0.99	22,437	36,047	42,096	48,148	2.22	1.38	1.18	1.04
Ricker	22,671	39,258	44,548	49,131	2.20	1.27	1.12	1.01
with M devs	20,335	34,502	41,990	49,476	2.36	1.39	1.14	0.97
cR age3&4 select est.	36,006	45,287	55,120	64,949	3.62	2.88	2.37	2.01
cR age3&4 select = 1.0	22,098	34,681	41,773	49,223	2.19	1.40	1.16	0.98
cR age1 select time blocks	22,808	34,844	42,406	49,967	2.27	1.48	1.22	1.04
pop = fish growth	23,243	35,541	43,254	50,967	2.23	1.46	1.20	1.02
all weights = 1.0	27,023	39,060	47,538	56,010	3.02	2.09	1.72	1.46
omit gill net index	23,163	35,233	42,880	50,526	2.43	1.60	1.31	1.11
omit seine index	21,723	34,494	41,963	49,448	2.20	1.39	1.14	0.97
min M from tagging	19,373	67,881	82,611	97,335	2.13	0.61	0.50	0.42
max M from tagging	30,892	41,884	41,884	41,884	2.84	2.10	2.10	2.10
scaled Charnov M	22,805	34,335	41,789	49,239	2.18	1.45	1.19	1.01
includes shrimp trawl discards	22,562	34,778	42,326	49,873	2.23	1.45	1.19	1.01

Table 7.8 Table of likelihood components and estimates of R_0 and L_{inf} from the retrospective runs that were completed.

Run	total	unweighted	landings	length comps	age comps	gill index	seine index	SR fit	priors	R_0	L_{inf}
Base run	-540.94	-529.67	0.52	-331.94	-215.45	9.62	7.59	0	0	99.9	229.03
Retrospective 2010	-513.71	-502.46	0.53	-310.99	-209.05	9.3	7.75	-11.25	0	99.11	243.5
Retrospective 2009	-491.31	-479.45	0.19	-296.42	-203.92	14.72	5.99	-11.87	0	118.99	299.5
Retrospective 2008	-463.31	-450.14	0.4	-267.87	-199.41	11.79	4.95	-11.95	-1.22	98.4	239.5
Retrospective 2007	-447.35	-435.94	0.12	-256.87	-190.84	8.5	3.14	-11.75	0.34	125.19	300.71
Retrospective 2006	-422.36	-411.28	0.11	-235.62	-186.1	7.81	2.52	-11.08	0	124.57	317.72
Retrospective 2005	-394.39	-383.88	0.11	-213.91	-180.16	7.57	2.51	-10.51	0	125.1	340.85
Retrospective 2004	-367.27	-356.9	0.1	-192.07	-174.51	7.59	1.98	-10.36	0	122.22	375.1
Retrospective 2003	-341	-331.06	0.1	-170.72	-168.72	6.52	1.76	-9.94	0	122.18	400
Retrospective 2002	-314.04	-304.37	0.1	-149.5	-163.17	6.31	1.88	-9.67	0	120.92	400

Table 7.9 Estimated annual full *F* from the base BAM model and percentiles from the bootstrap runs.

Year	BAM Base run	2.5 percentile	50 percentile	97.5 percentile
1977	8.25	1.38	5.44	12.18
1978	10.02	1.71	6.54	14.47
1979	7.63	1.67	4.98	11.13
1980	9.83	1.75	6.24	14.76
1981	7.00	1.45	4.44	10.79
1982	6.37	1.51	4.16	9.69
1983	8.07	2.03	5.42	11.87
1984	13.80	3.06	9.10	19.96
1985	9.09	2.00	5.82	14.05
1986	5.50	1.51	3.74	8.80
1987	12.11	2.75	8.12	17.98
1988	11.58	2.42	7.91	18.86
1989	11.78	2.46	8.37	20.20
1990	8.67	1.90	6.22	14.61
1991	7.97	1.95	5.77	13.43
1992	7.11	1.51	4.82	11.14
1993	5.77	1.29	4.02	9.80
1994	5.20	1.25	3.49	10.26
1995	3.39	0.65	1.67	5.93
1996	3.37	0.77	1.85	5.56
1997	3.43	0.90	2.11	5.37
1998	2.75	0.55	1.37	4.91
1999	4.62	0.95	2.35	6.84
2000	2.92	0.66	1.48	5.04
2001	2.38	0.62	1.28	4.22
2002	3.44	0.86	2.04	5.56
2003	3.40	0.74	2.01	6.12
2004	3.61	0.59	1.77	6.10
2005	2.35	0.41	1.18	4.29
2006	2.88	0.46	1.36	4.93
2007	2.59	0.33	0.97	4.94
2008	1.20	0.26	0.61	2.27
2009	1.51	0.31	0.70	2.94
2010	3.25	0.43	1.19	5.82
2011	2.36	0.40	1.16	4.17

Table 7.10 Summary of benchmarks and terminal year (2011) values estimated for the base BAM model. Fecundity was used as the metric for *SSB*.

Benchmarks and Terminal Year Values	**Base BAM Model Estimates**
R_0	99.9
Y at F_{MSY}	infinite
F_{2011}	2.36
F_{MED}	4.88
$F_{40\%}$	4.31
$F_{35\%}$	6.75
$F_{30\%}$	9.73
SSB_{2011}	50,464
$SSB_{MED.\mathrm{thresh}}$	22,627
$SSB_{40\%}$	49,833
$SSB_{35\%}$	42,291
$SSB_{30\%}$	34,750

Table 7.11 Estimates from production model base run (ASPIC) and sensitivity runs.

Run ID	**Description**	**F/F_{MSY} in 2010**	**B/B_{MSY} in 2011**	**Equilibrium yield in 2011**	**Yield at F_{MSY} in 2012**	**F_{MSY}**	**MSY**
men-31	Primary configuration	0.46	1.57	554	1,071	1.08	826
men-32	B_1/K = 0.6	0.45	1.57	558	1,071	1.14	831
men-33	B_1/K = 0.4	0.45	1.57	556	1,073	1.11	830
men-34	Alternative IOA	0.45	1.57	559	1,071	1.16	833
men-35	Alternative IOA	0.45	1.57	559	1,071	1.16	833
men-36	Alternative IOA	0.45	1.57	558	1,071	1.15	832
men-37	Alternative IOA	NO FIT	-	-	-	-	-
men-38	Alternative IOA	NO FIT	-	-	-	-	-
men-39	Extended Landings	0.46	1.57	552	1,071	1.05	823
men-40	Alternative model shape	0.40	1.93	508	1,220	0.89	766

Table 7.12 Estimates from production model base run (ASPIC), with confidence intervals from bootstrapping.

BC confidence limits					
Parameter Name	**Point Estimate**	**80% lower**	**80% upper**	**Inter-Quartile Range**	**Relative IQ Range**
B_1/K	8.00E-01	8.00E-01	8.00E-01	0.00E+00	0
K	1.57E+03	1.46E+03	2.33E+03	1.84E+02	0.117
q(1)	8.93E-04	6.54E-04	1.04E-03	1.50E-04	0.168
MSY	8.23E+02	7.72E+02	8.31E+02	1.33E+01	0.016
Ye(2012)	5.52E+02	5.15E+02	5.56E+02	2.10E+01	0.038
Y.(F_{MSY})	5.88E+02	5.87E+02	5.88E+02	7.87E-01	0.001
B_{MSY}	7.87E+02	7.28E+02	1.17E+03	9.19E+01	0.117
F_{MSY}	1.05E+00	6.61E-01	1.14E+00	1.31E-01	0.126
F_{MSY}(1)	1.17E+03	1.02E+03	1.32E+03	1.57E+02	0.134
$B./B_{MSY}$	1.57E+00	1.57E+00	1.57E+00	1.75E-04	0
$F./F_{MSY}$	4.59E-01	4.53E-01	4.88E-01	5.16E-03	0.011
Ye./*MSY*	6.71E-01	6.71E-01	6.75E-01	2.99E-04	0

Note: Ye. is equilibrium yield in 2012. Y.(F_{MSY}) is yield in the next year (2012) at F_{MSY}. $B./B_{MSY}$ is terminal biomass relative to B_{MSY}, etc.

Table 7.13 Estimates from retrospective runs.

Run ID	Description	F/F_{MSY} in 2010	B/B_{MSY} in 2011	Equilibrium yield in 2011	Yield at F_{MSY} in 2012	F_{MSY}	*MSY*
men-41	Retrospective drop 2011	0.27	1.72	397	1,123	1.08	826
men-42	Retrospective drop 2010 to 2011	0.33	1.67	452	1,107	1.09	826
men-43	Retrospective drop 2009 to 2011	0.31	1.69	433	1,113	1.08	826
men-44	Retrospective drop 2008 to 2011	0.33	1.67	456	1,106	1.14	831
men-45	Retrospective drop 2007 to 2011	0.34	1.67	460	1,104	1.08	826

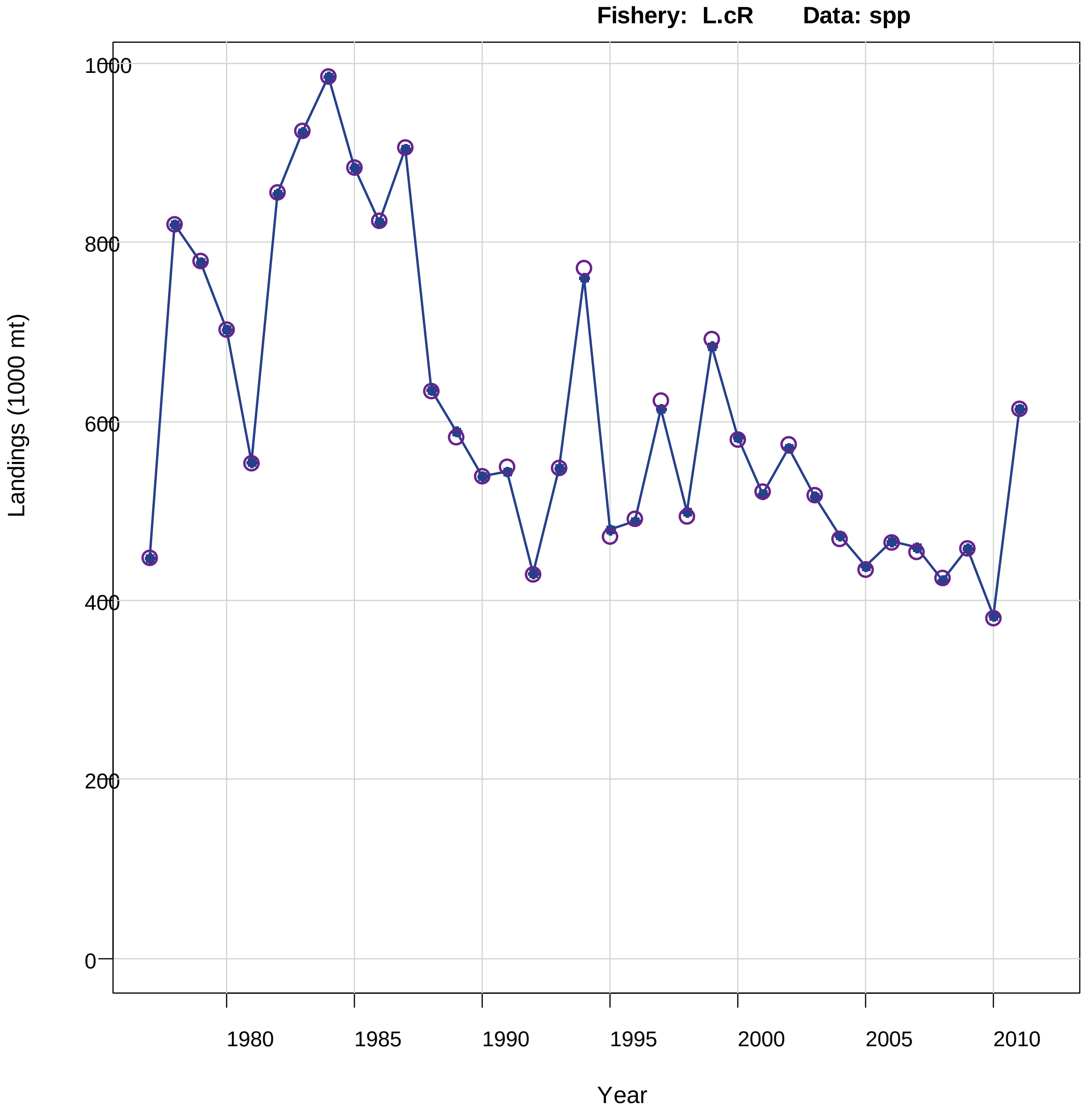


Figure 7.1 Observed and predicted landings for the commercial reduction fishery from 1977-2011.

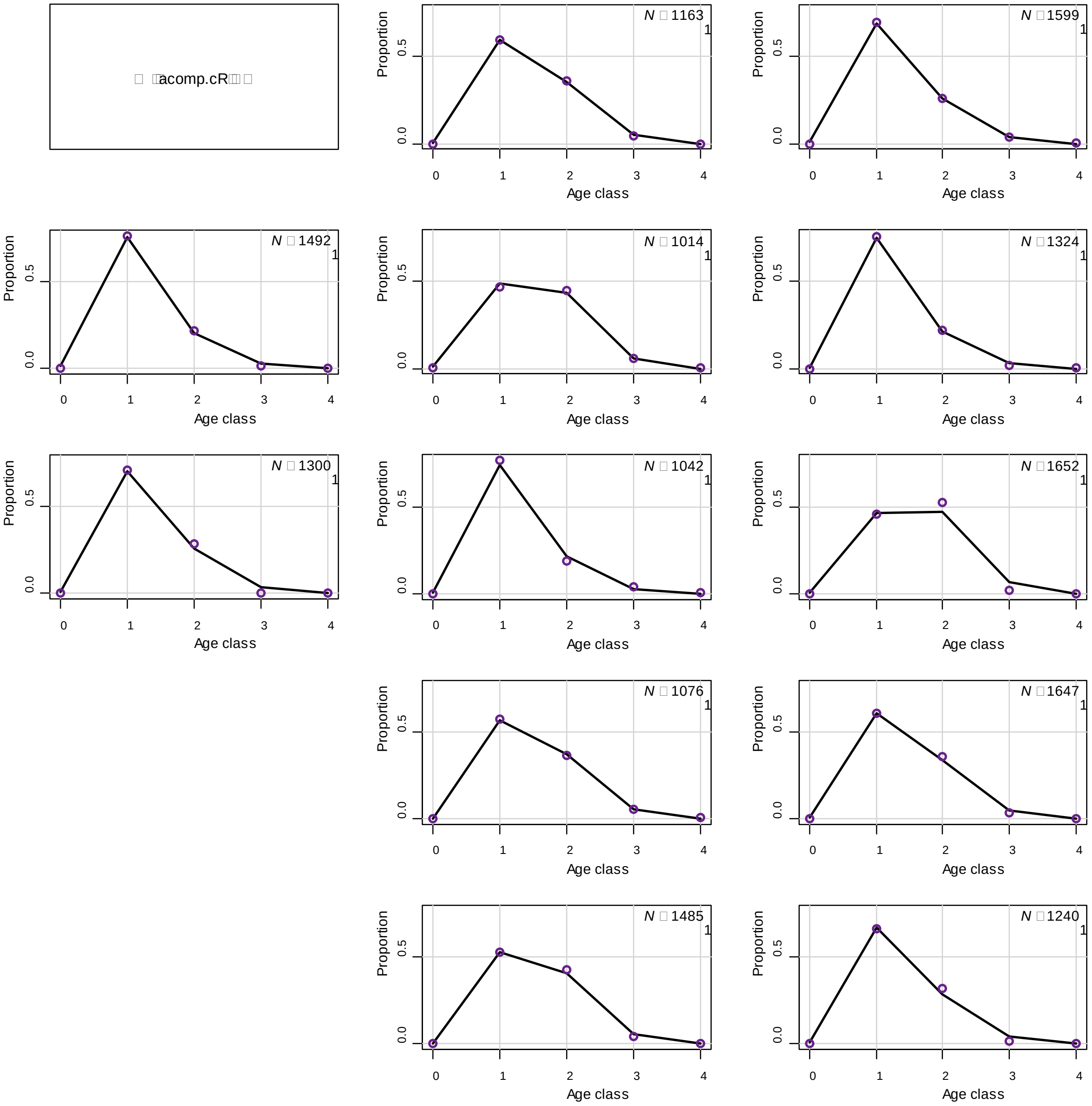


Figure 7.2 Observed and predicted age compositions for the commercial reduction fishery from 1977-2011. Each panel includes the year and associated sample size in the upper right corner.

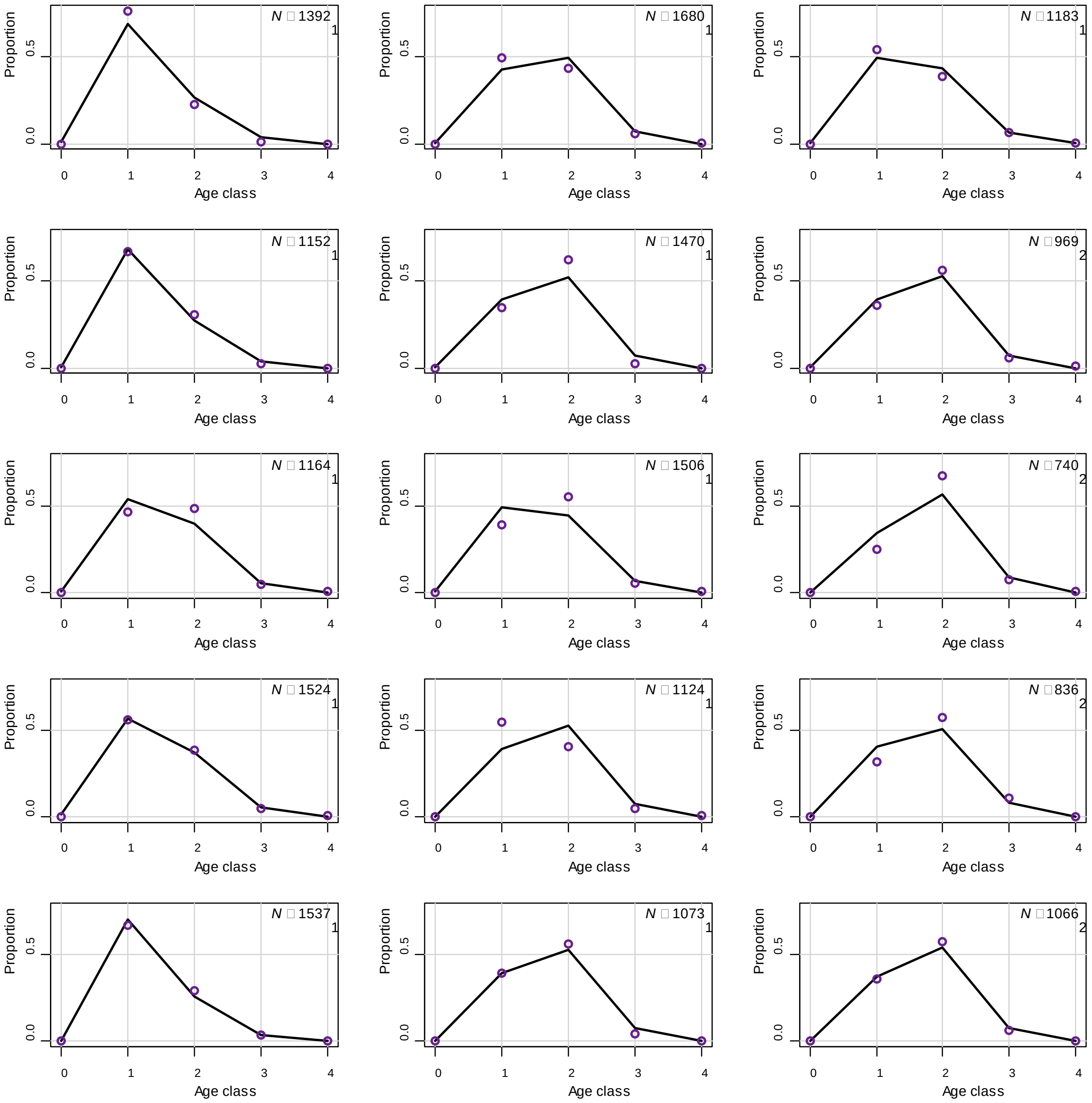


Figure 7.2 (Cont.)

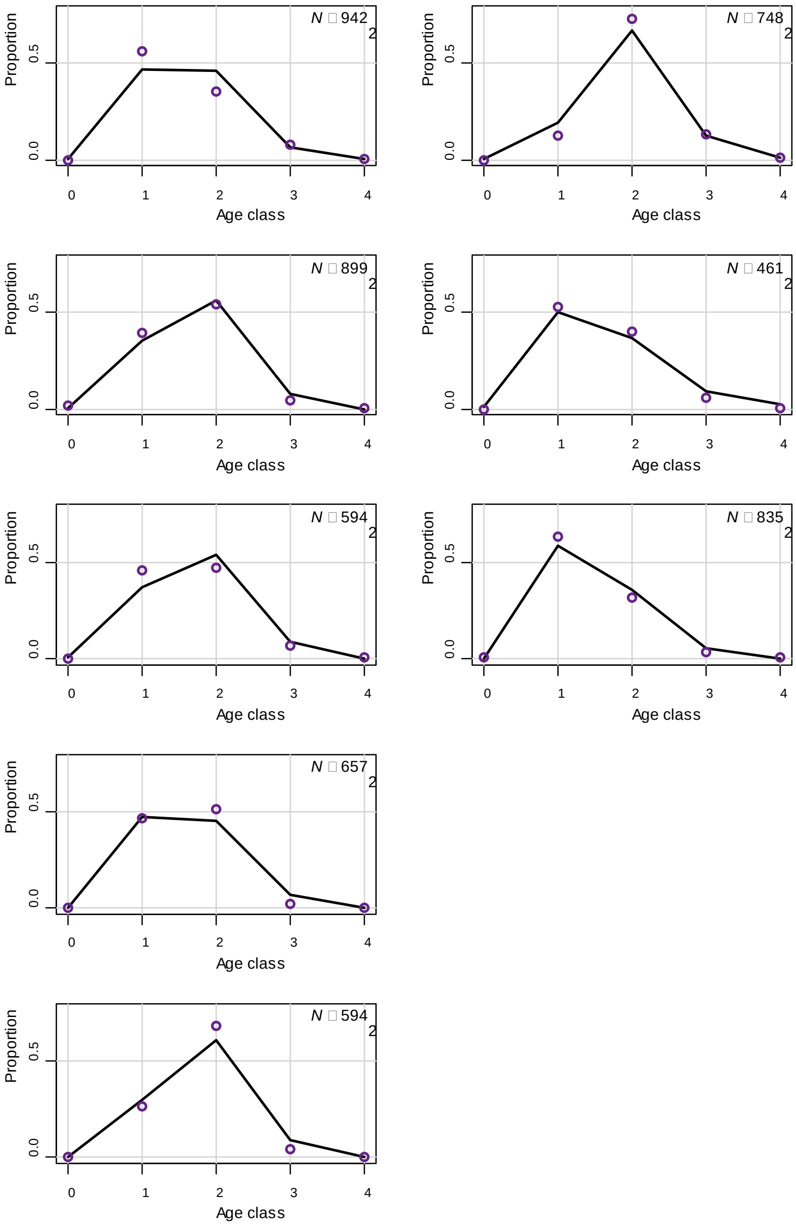


Figure 7.2 (Cont.)

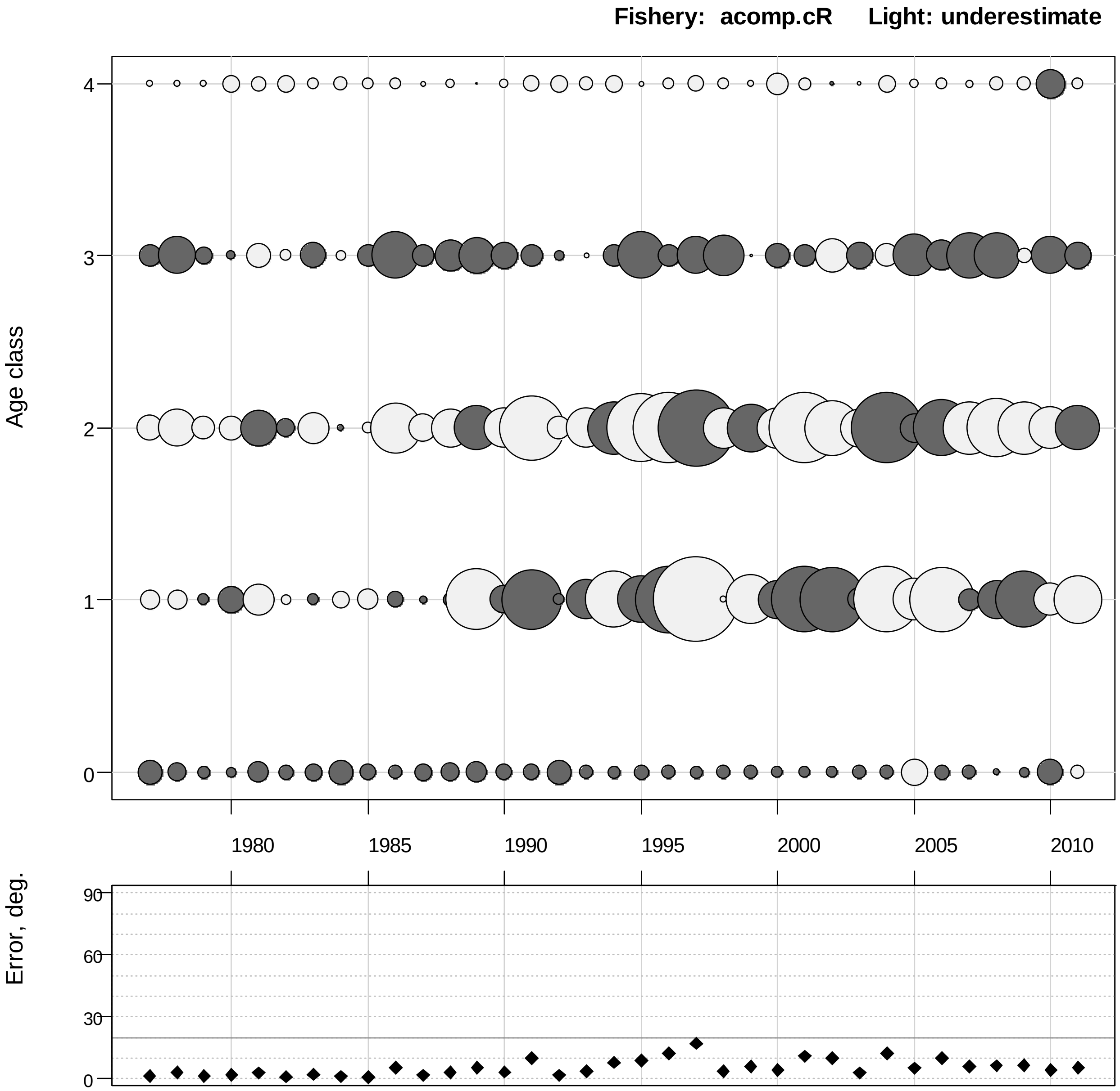


Figure 7.3 Bubble plot of residuals for the age compositions for the commercial reduction fishery from 1977-2011. Light colored circles are underestimated while dark colored circles are overestimated.

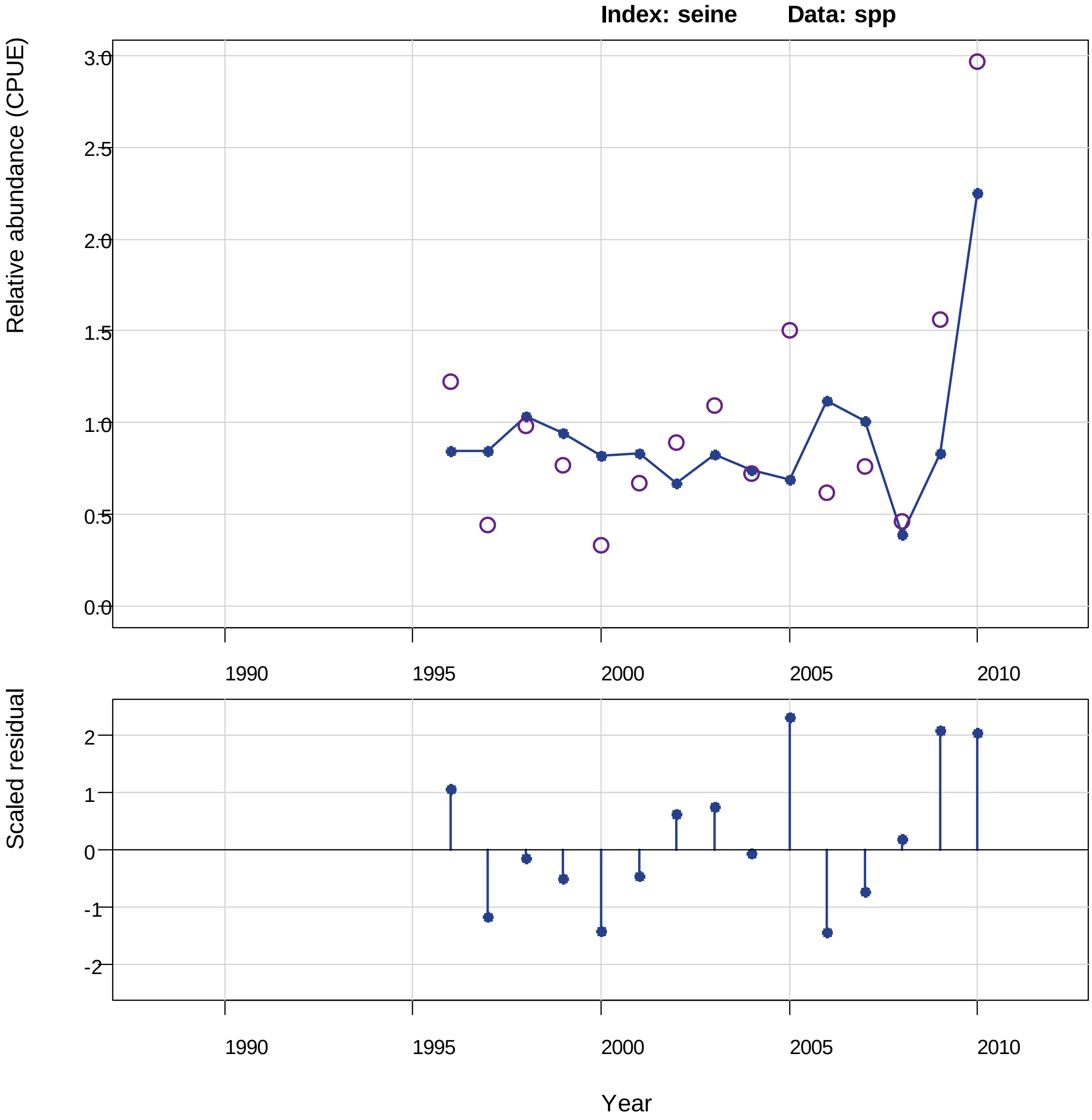


Figure 7.4 Observed and predicted seine index, which was a juvenile abundance or age-0 recruitment index, for 1996-2010.

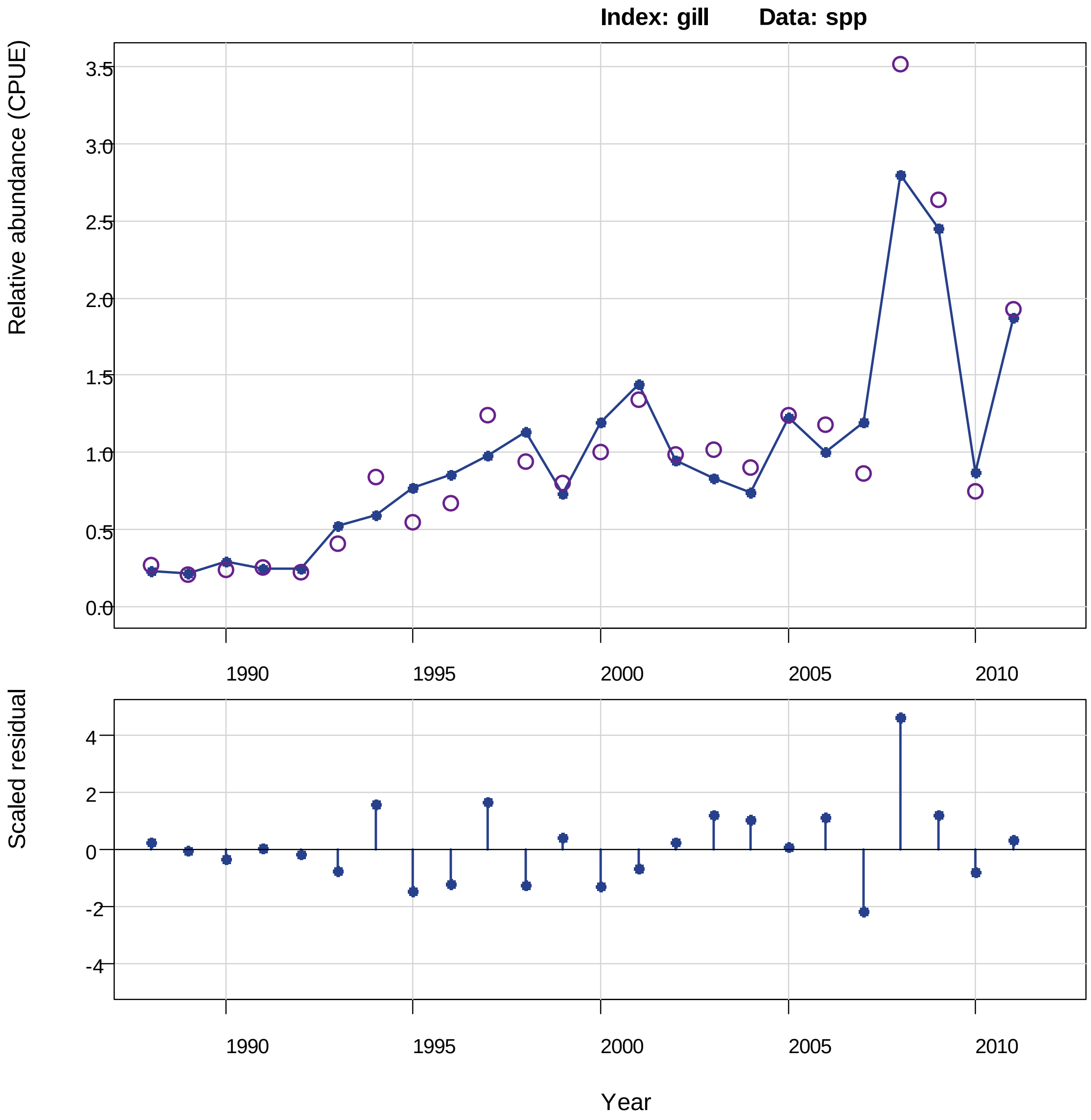


Figure 7.5 Observed and predicted gill net index, which was an adult abundance index, for 1988-2011.

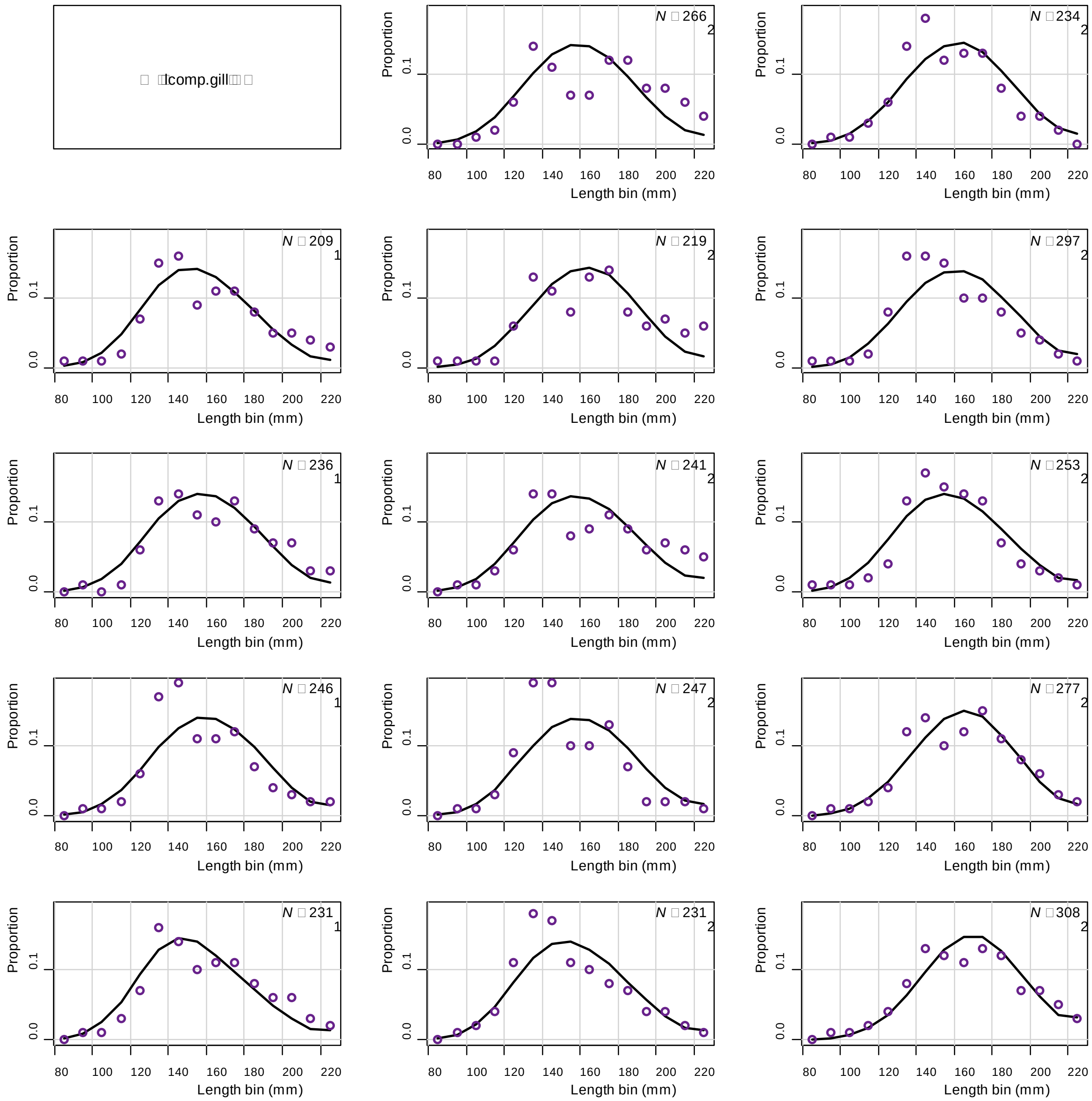


Figure 7.6 Observed and predicted length compositions for the gill net index from 1996-2011. Each panel includes the year and associated sample size in the upper right corner.

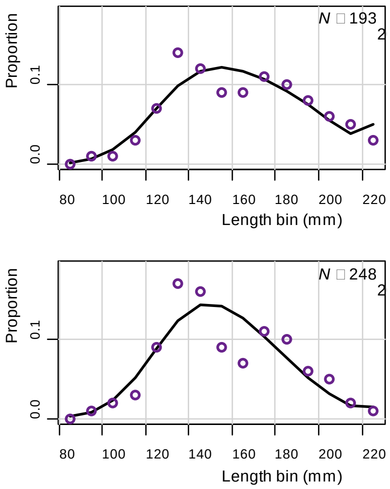


Figure 7.6 (Cont.)

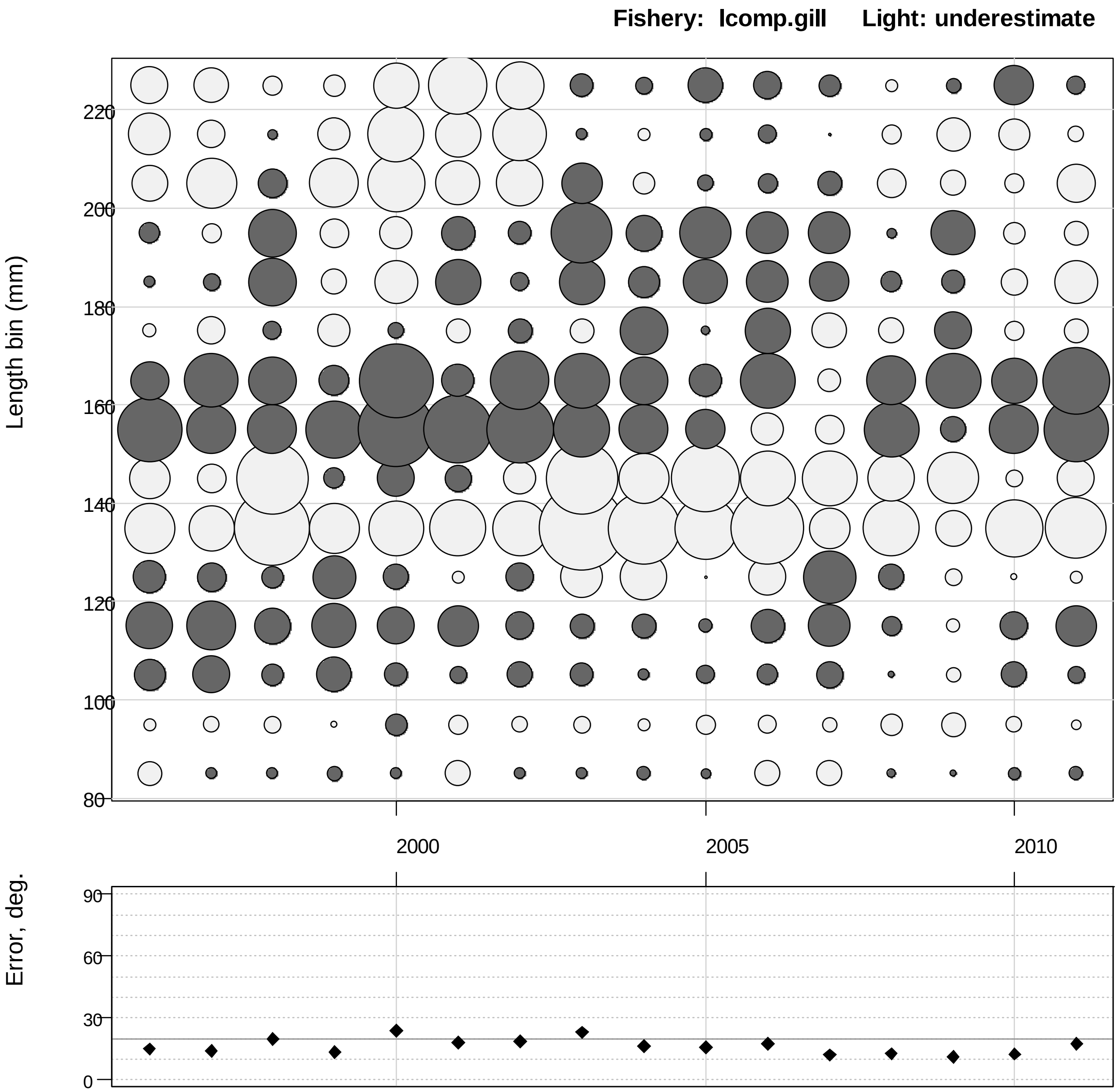


Figure 7.7 Bubble plot of residuals for the length compositions for the gill net index from 1996-2011. Light colored circles are underestimated while dark colored circles are overestimated.

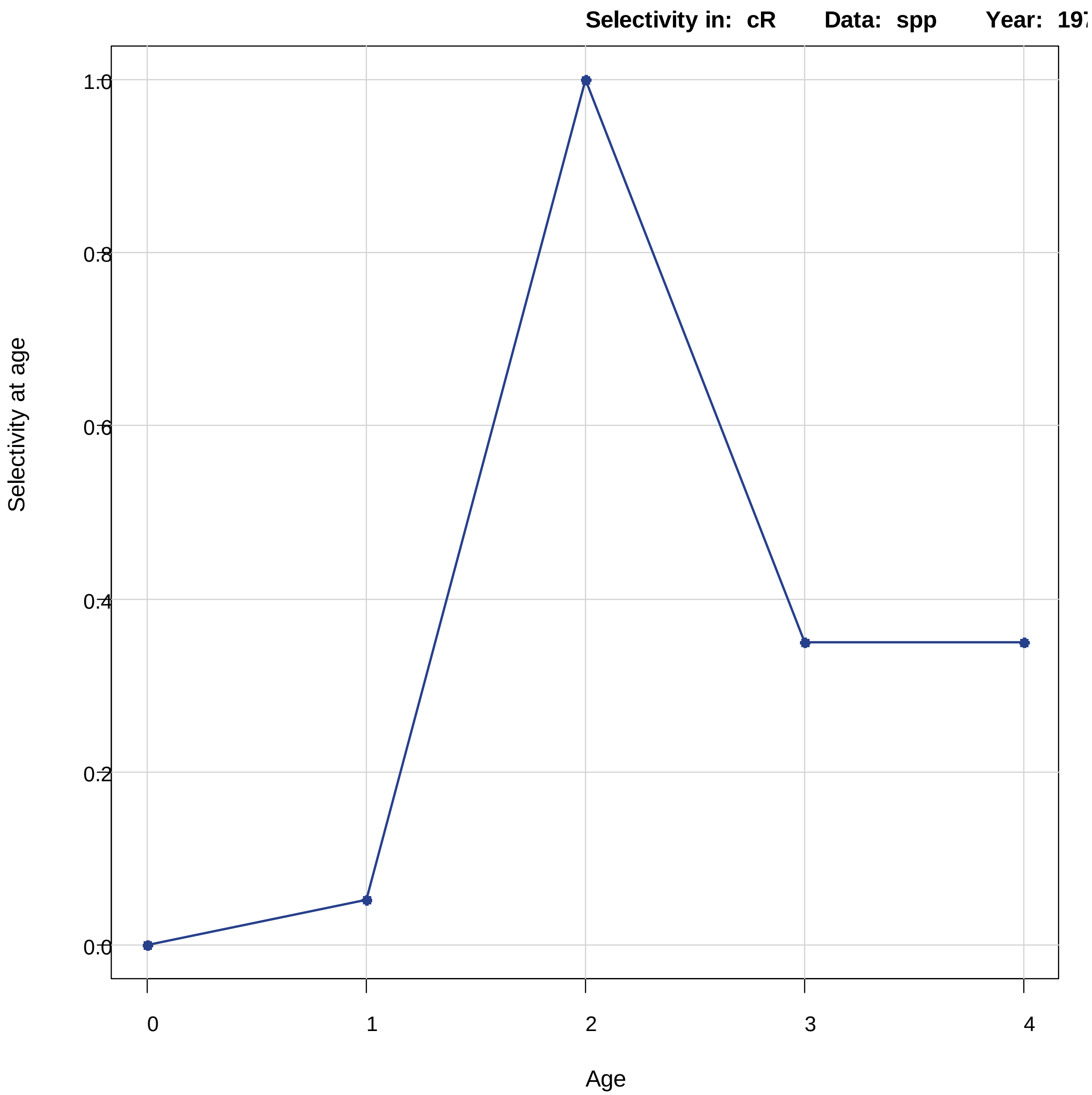


Figure 7.8 Estimated selectivity for the commercial reduction fishery for age one. Age-0 was assumed to be 0.0, age-2 was assumed to be 1.0, and ages-3 and -4+ were assumed to be 0.35. Selectivity was constant from 1977-2011.

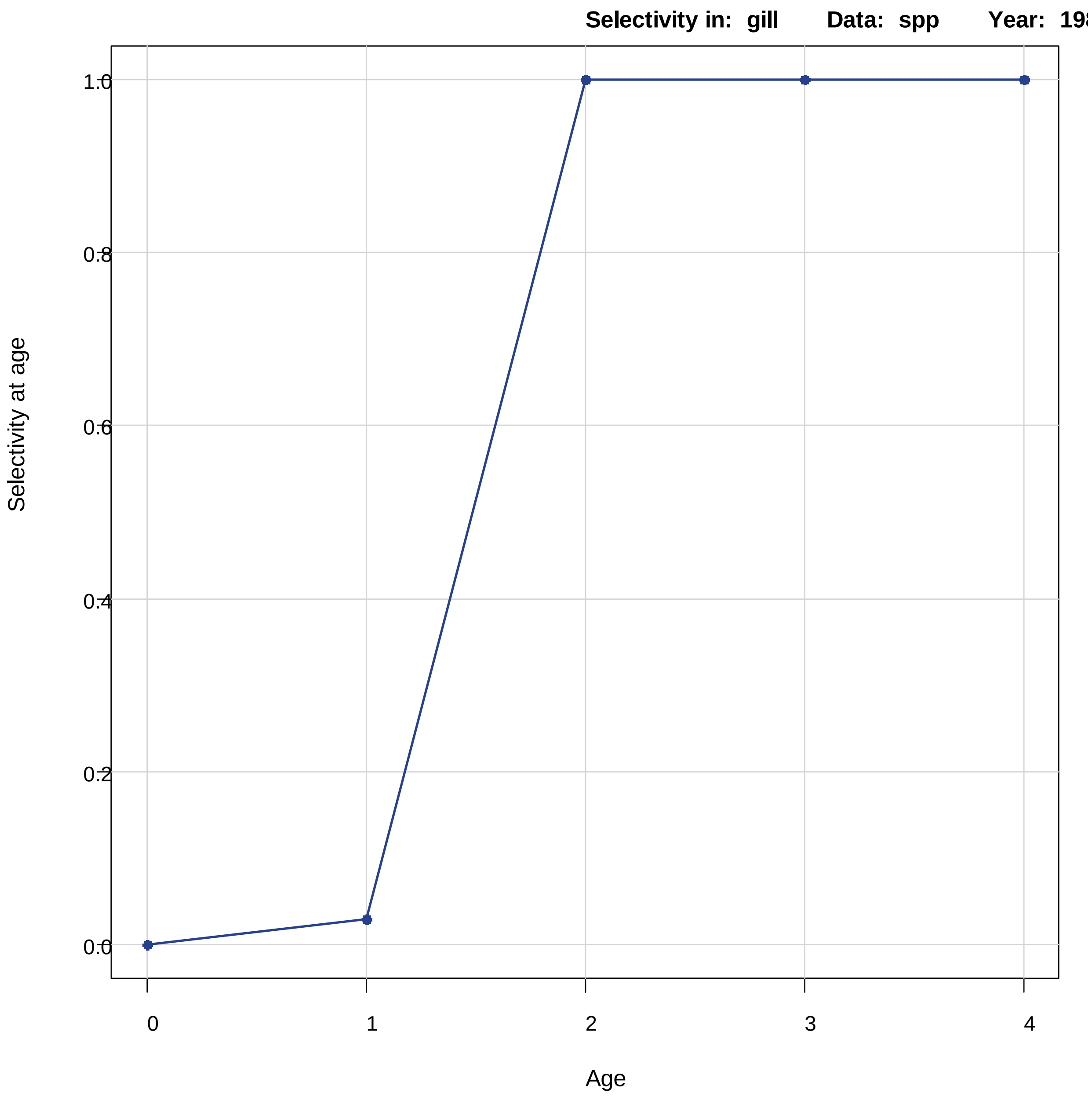


Figure 7.9 Estimated selectivity for the gill net index.

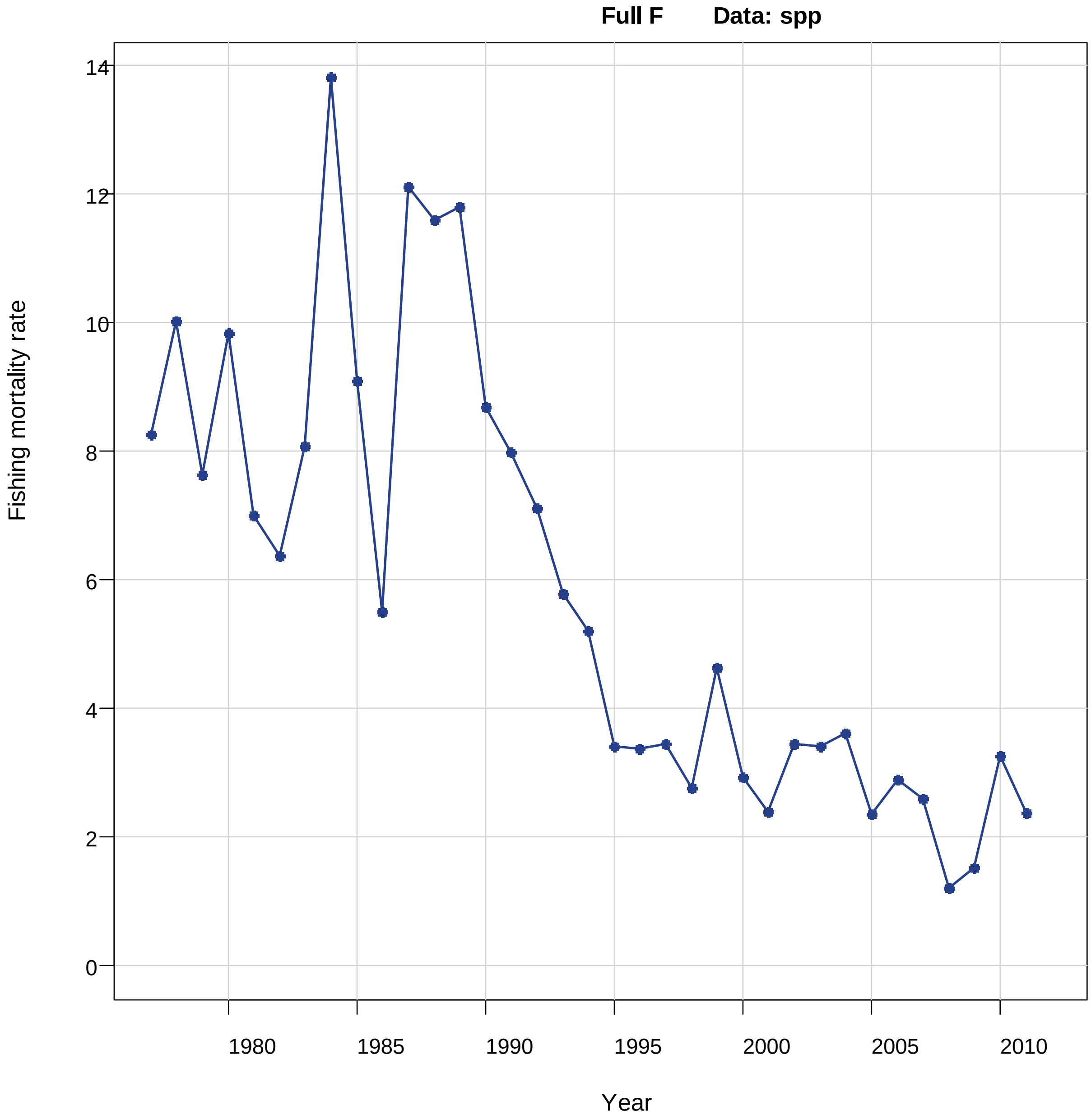


Figure 7.10 Estimated full fishing mortality rate for the commercial reduction fishery from 1977-2011.

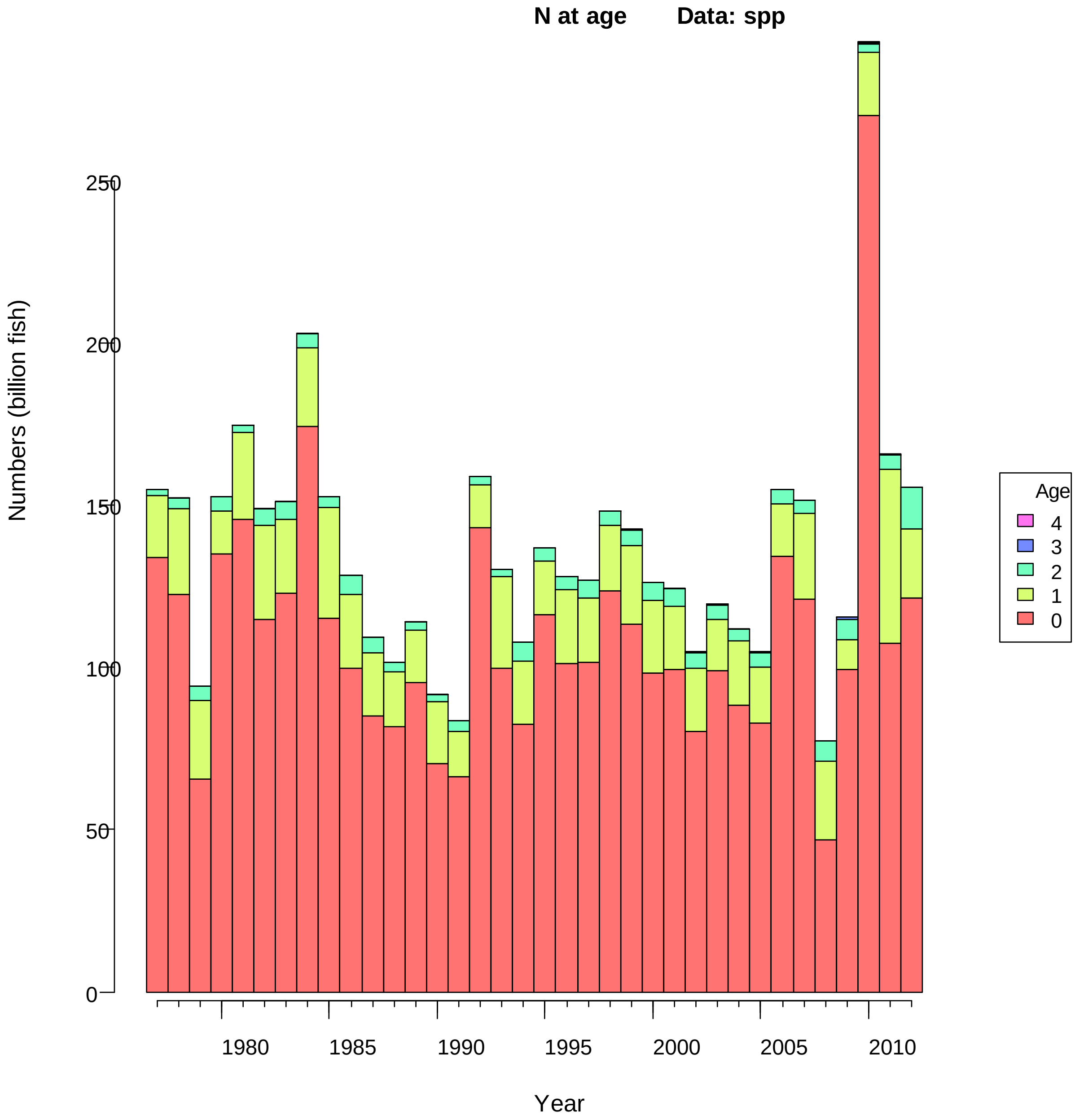


Figure 7.11 Estimated numbers at age of Gulf menhaden (billions) at the start of the fishing year from the base BAM model.

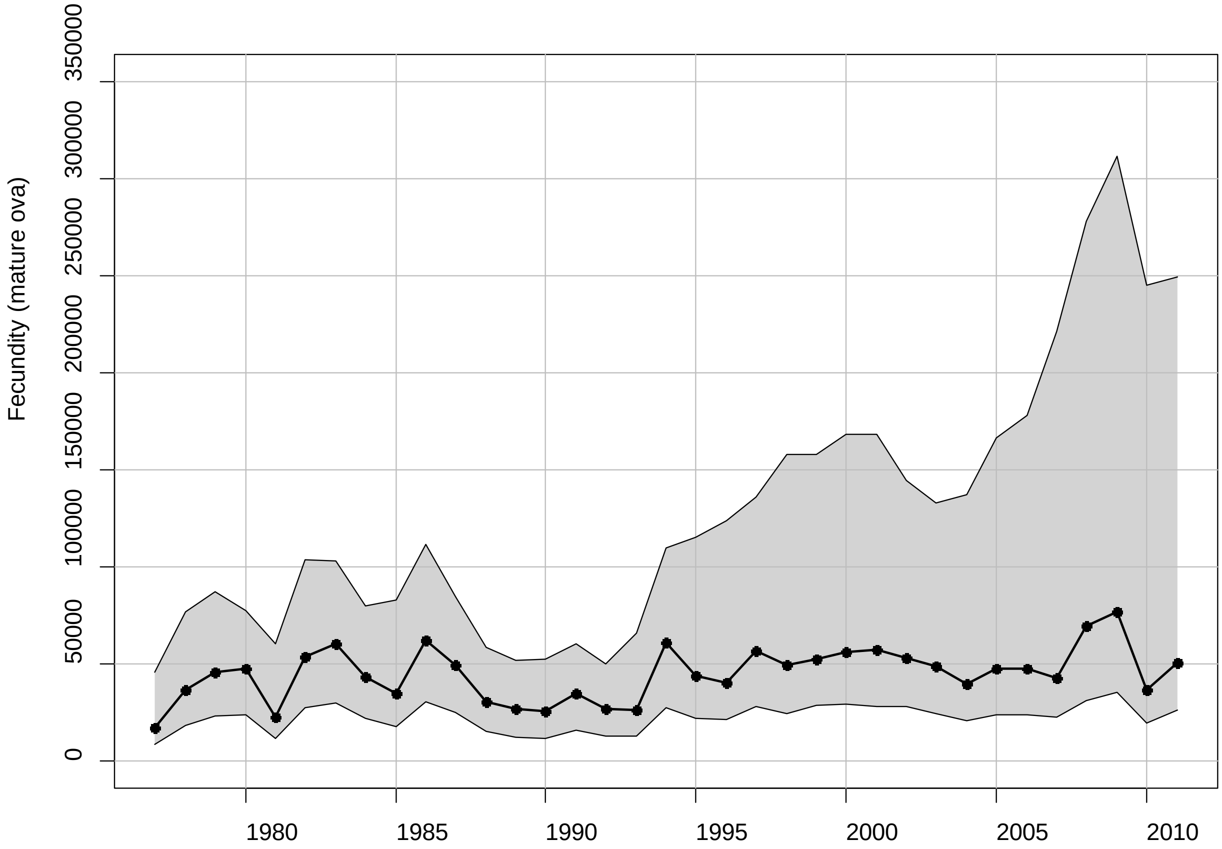


Figure 7.12 Estimated annual fecundity (billions of eggs) from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs after runs were eliminated.

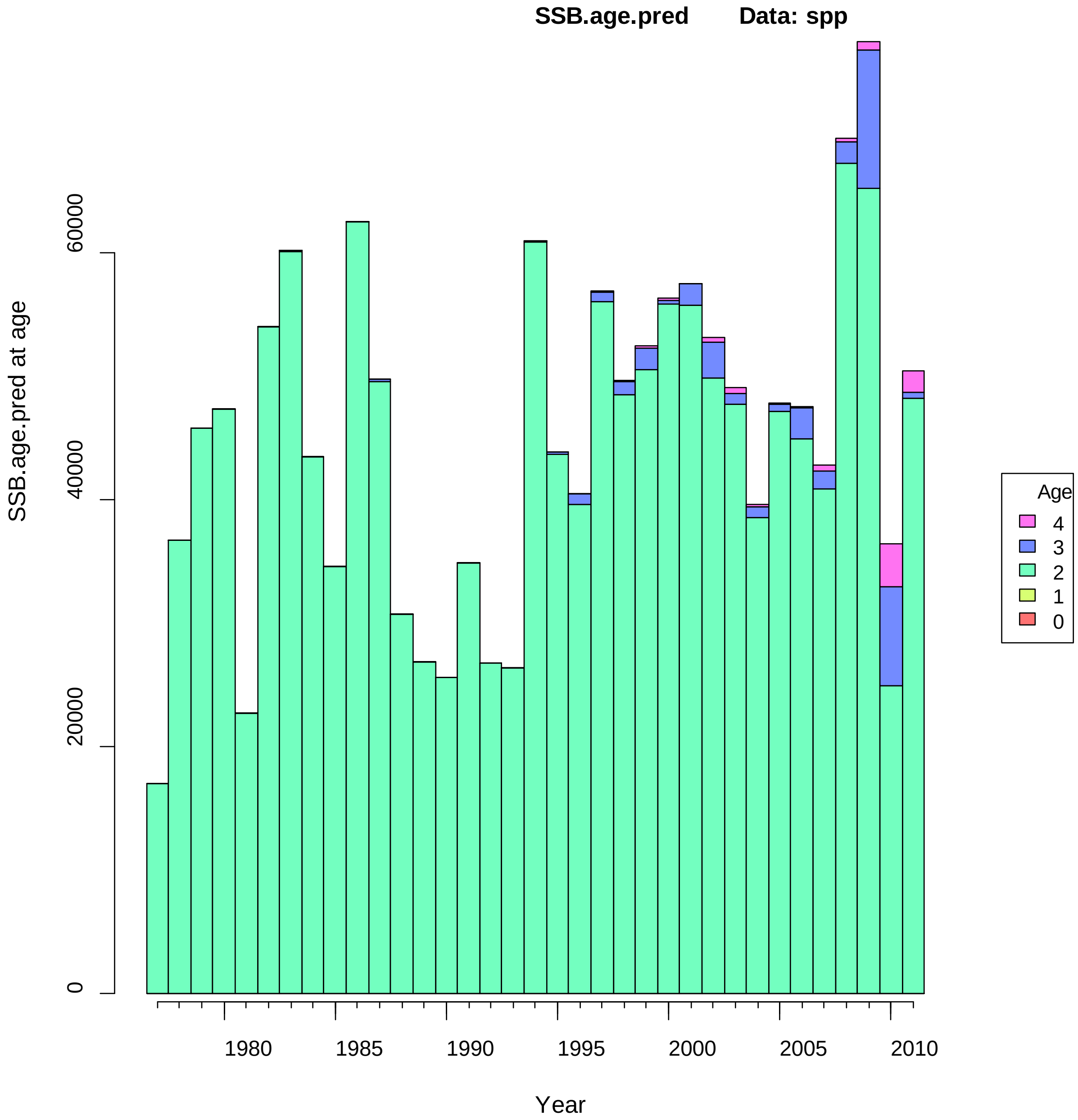


Figure 7.13 Estimated total fecundity (billions of mature ova) at age for Gulf menhaden at the start of the fishing year from the base run of BAM.

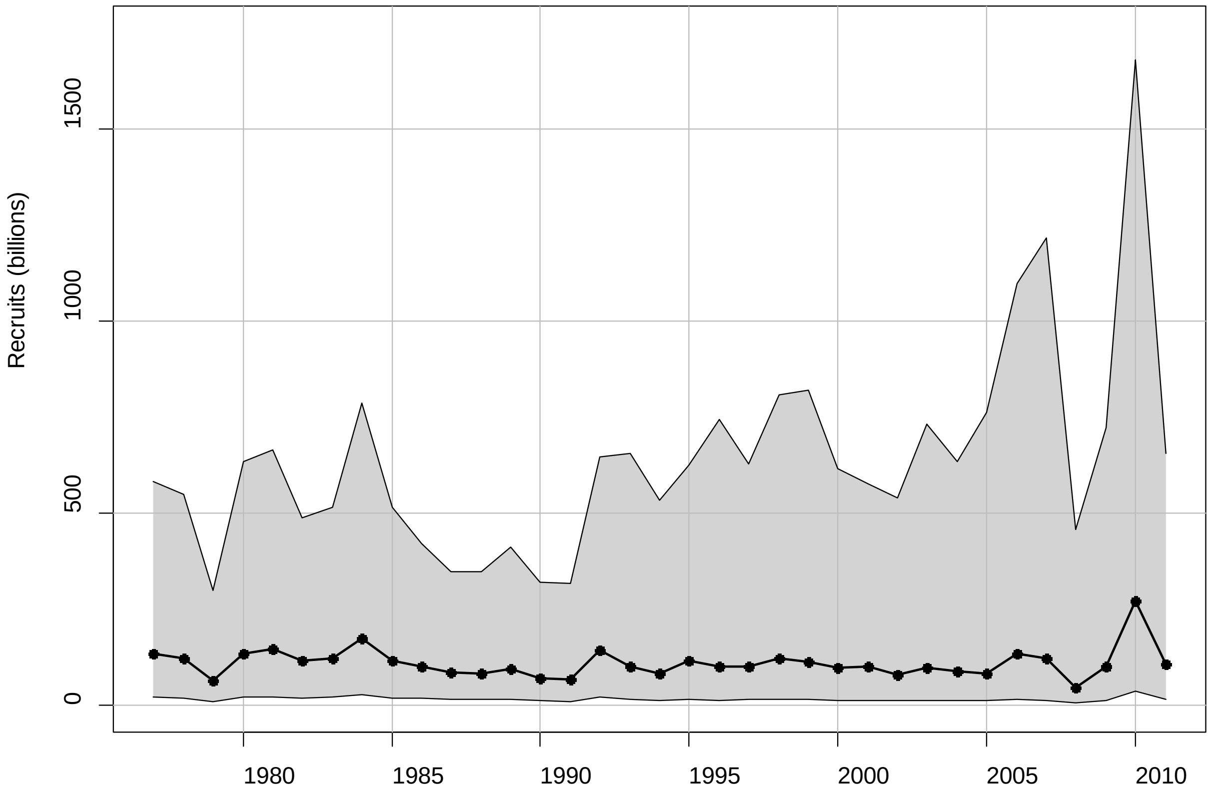


Figure 7.14 Estimated annual recruitment to age-0 (billions) from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs after runs were eliminated.

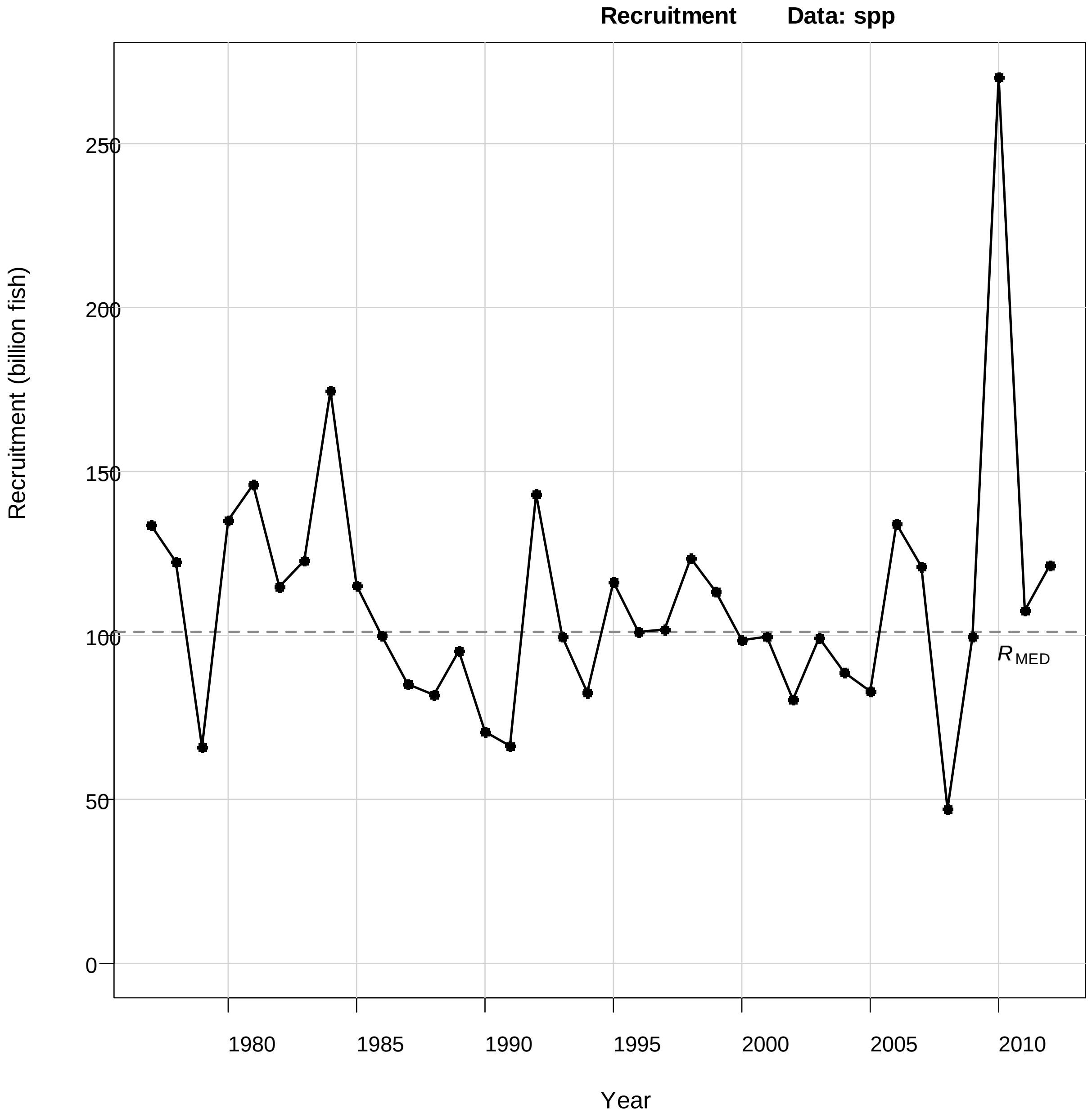


Figure 7.15 Estimated annual recruitment to age-0 (billions) from the base BAM model (connected points). The dashed line represents the median recruitment from the entire time series.

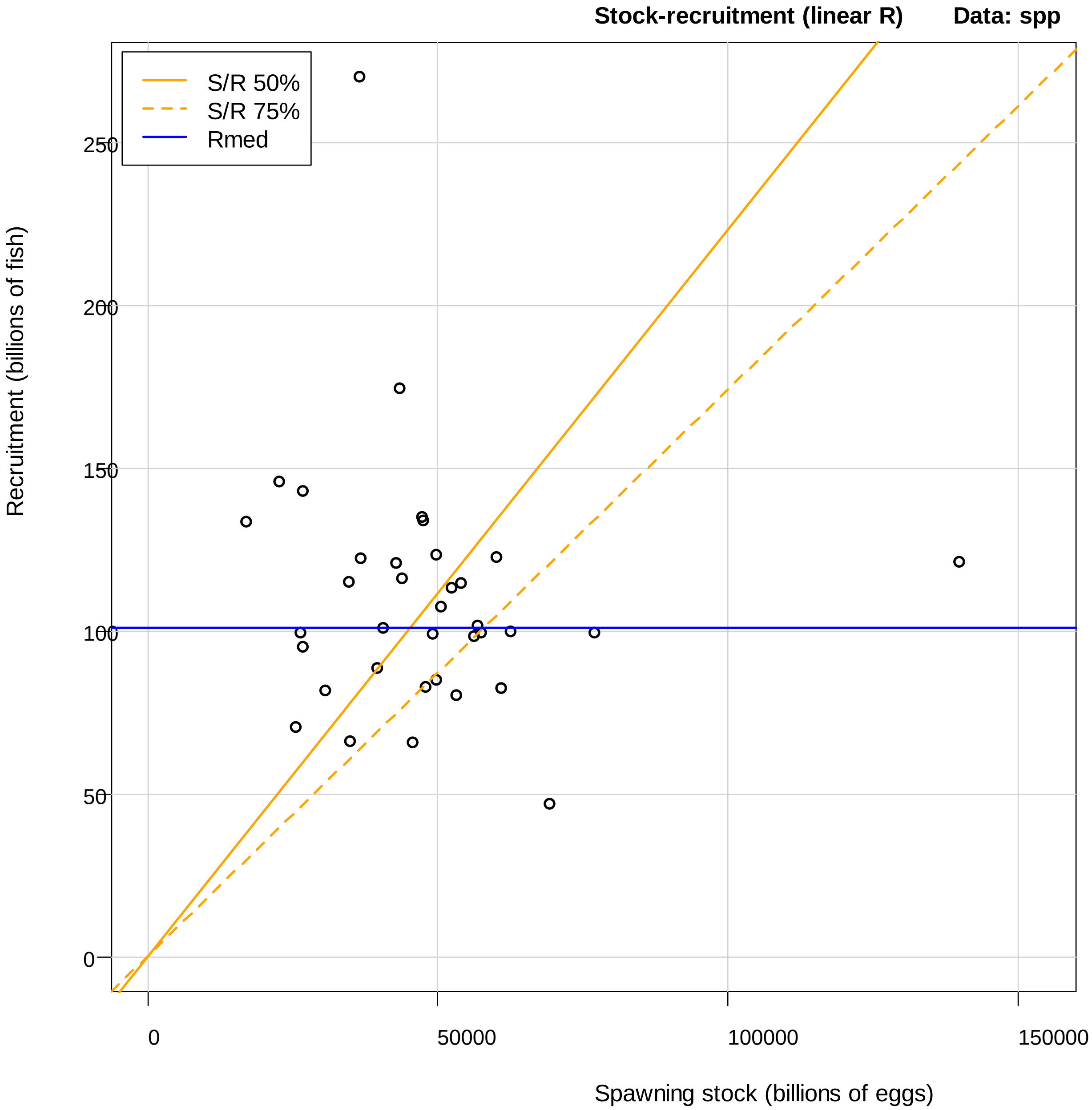


Figure 7.16 Estimated spawning stock (billions of mature ova) and recruitment (billions of age-0 fish) from the base BAM model (points). Lines indicate the median recruitment (horizontal) and the 50th and 75th percentile of spawners-per-recruit.

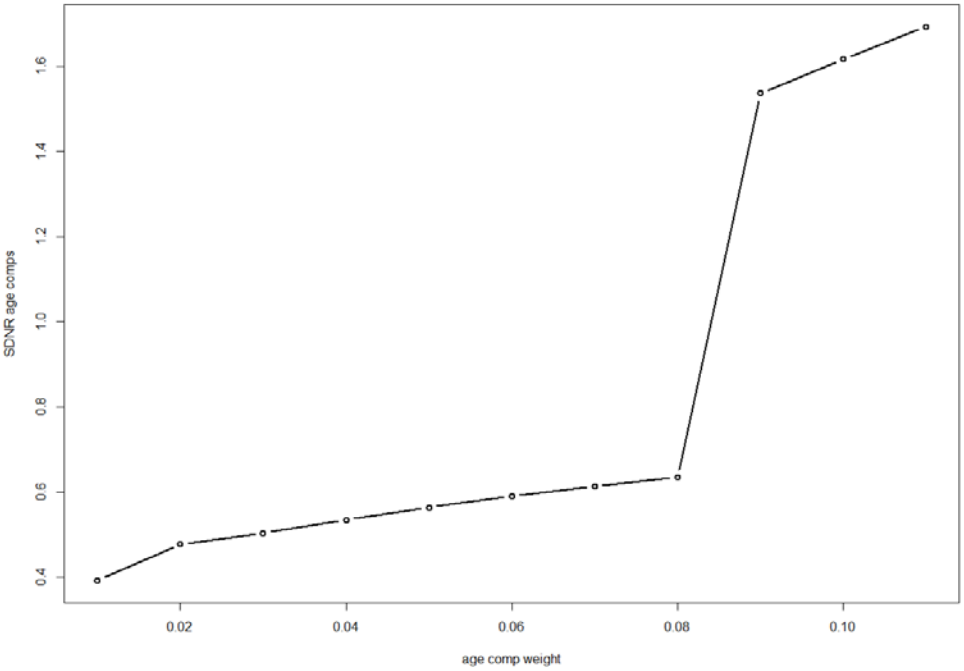


Figure 7.17 Standard deviation of the normalized residuals for the commercial age composition data for various weights on the commercial age composition data for the base run.

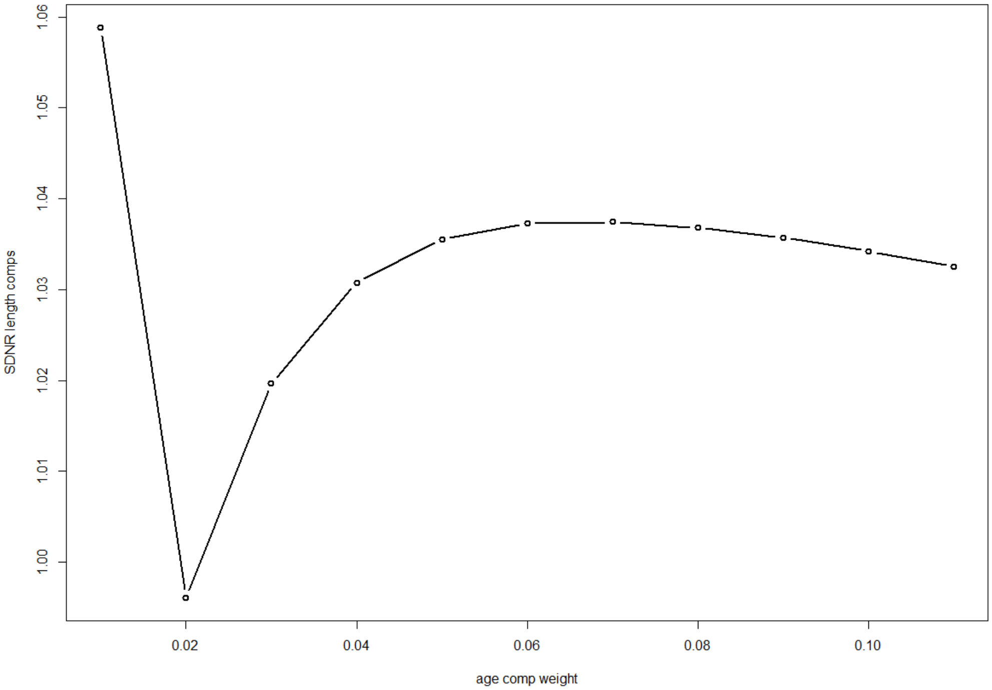


Figure 7.18 Standard deviation of the normalized residuals for the gill net length composition data across various weights on the commercial age composition data for the base run.

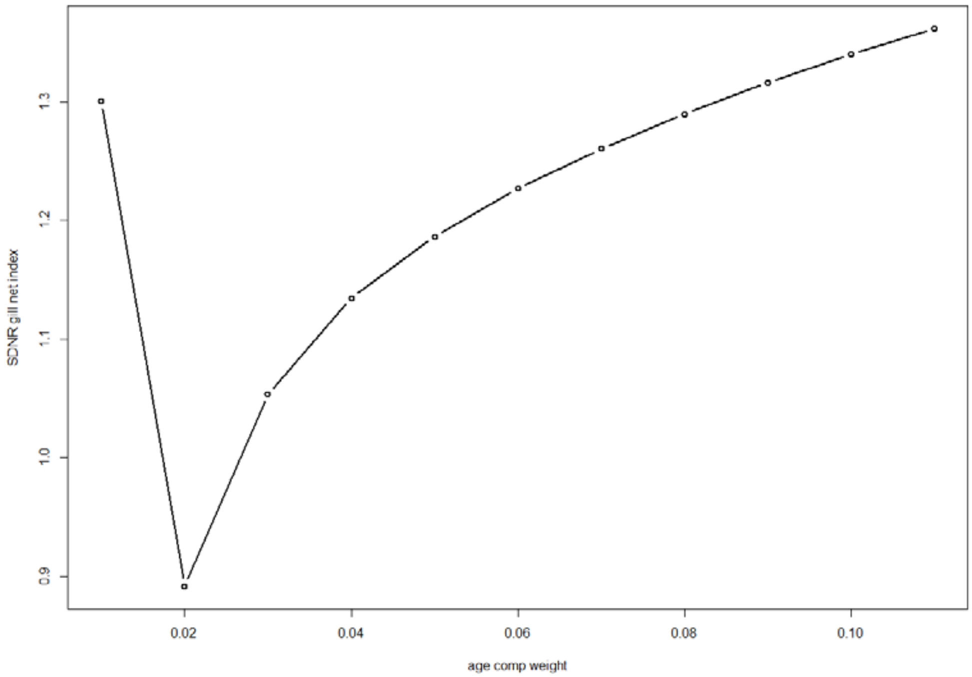


Figure 7.19 Standard deviation of the normalized residuals for the gill net index across various weights on the commercial age composition data for the base run.

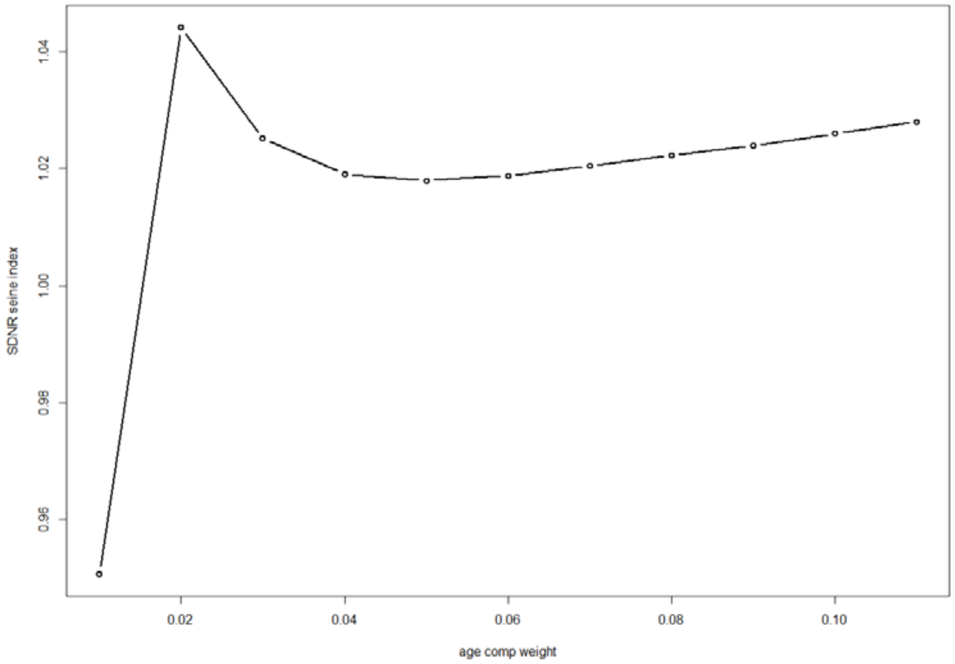


Figure 7.20 Standard deviation of the normalized residuals for the seine index across various weights on the commercial age composition data for the base run.

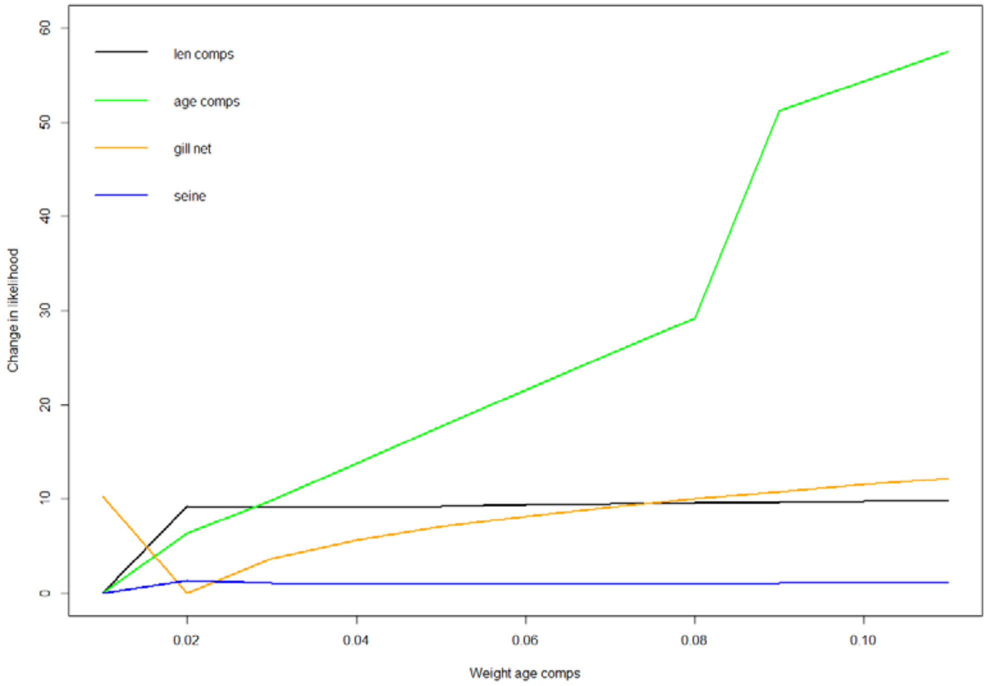


Figure 7.21 Change in the negative log-likelihood for the age compositions, length compositions, gill net index, and seine index across a range of weights on the commercial age composition data for the base run.

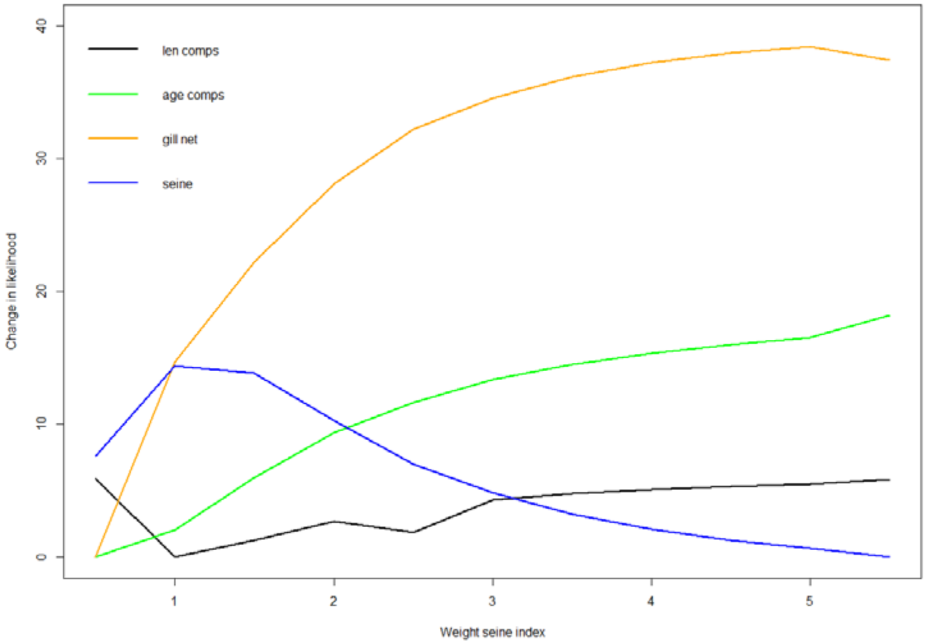


Figure 7.22 Change in the negative log-likelihood for the age compositions, length compositions, gill net index, and seine index across a range of weights on the seine index for the base run.

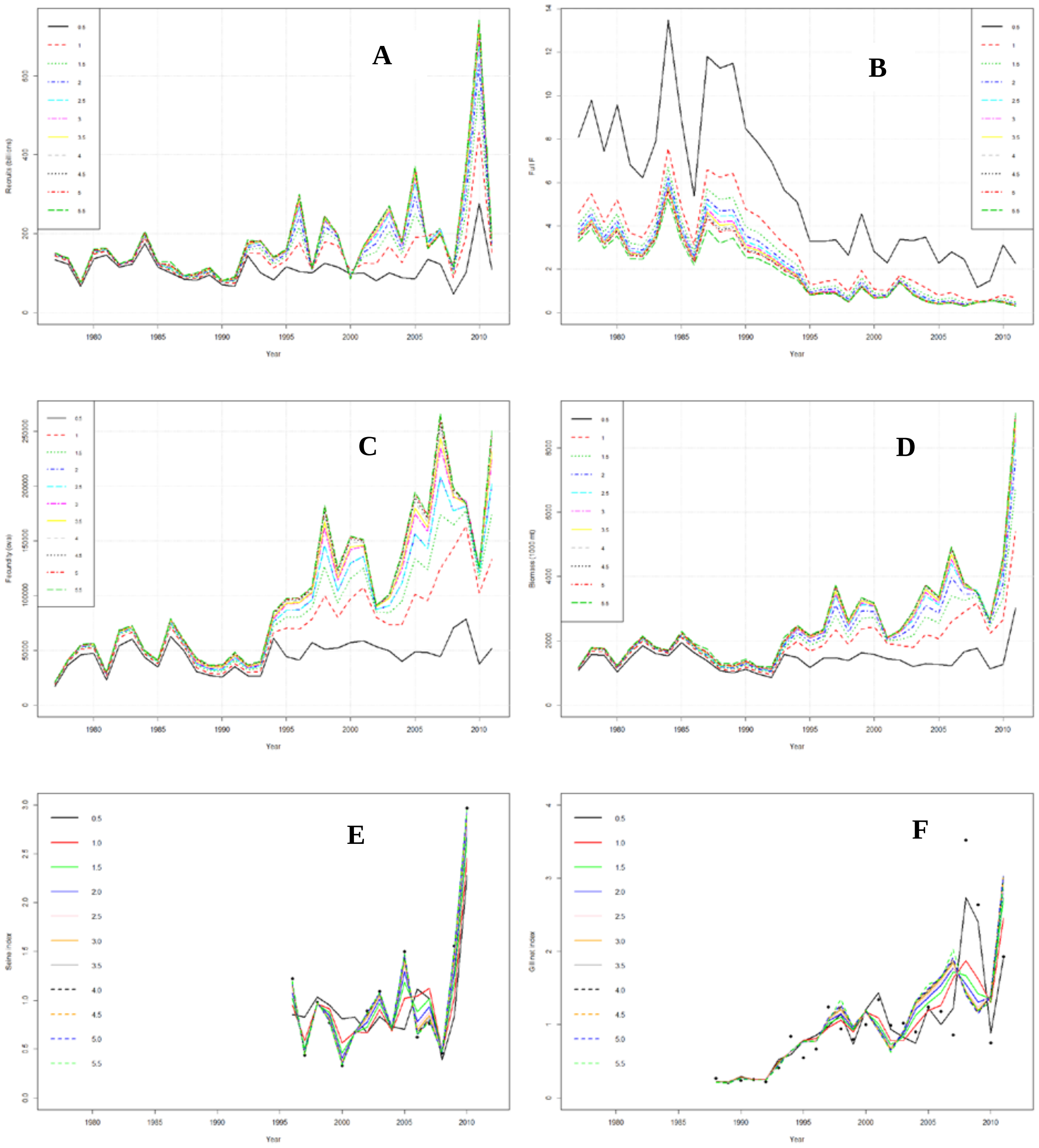


Figure 7.23 Estimated full fishing mortality rate (panel A), estimated recruitment (panel B), estimated fecundity (panel C), estimated age-1+ biomass (panel D), fit to the seine index (panel E), and fit to the gill net index (panel F) for sensitivity runs across a range of seine index weights.

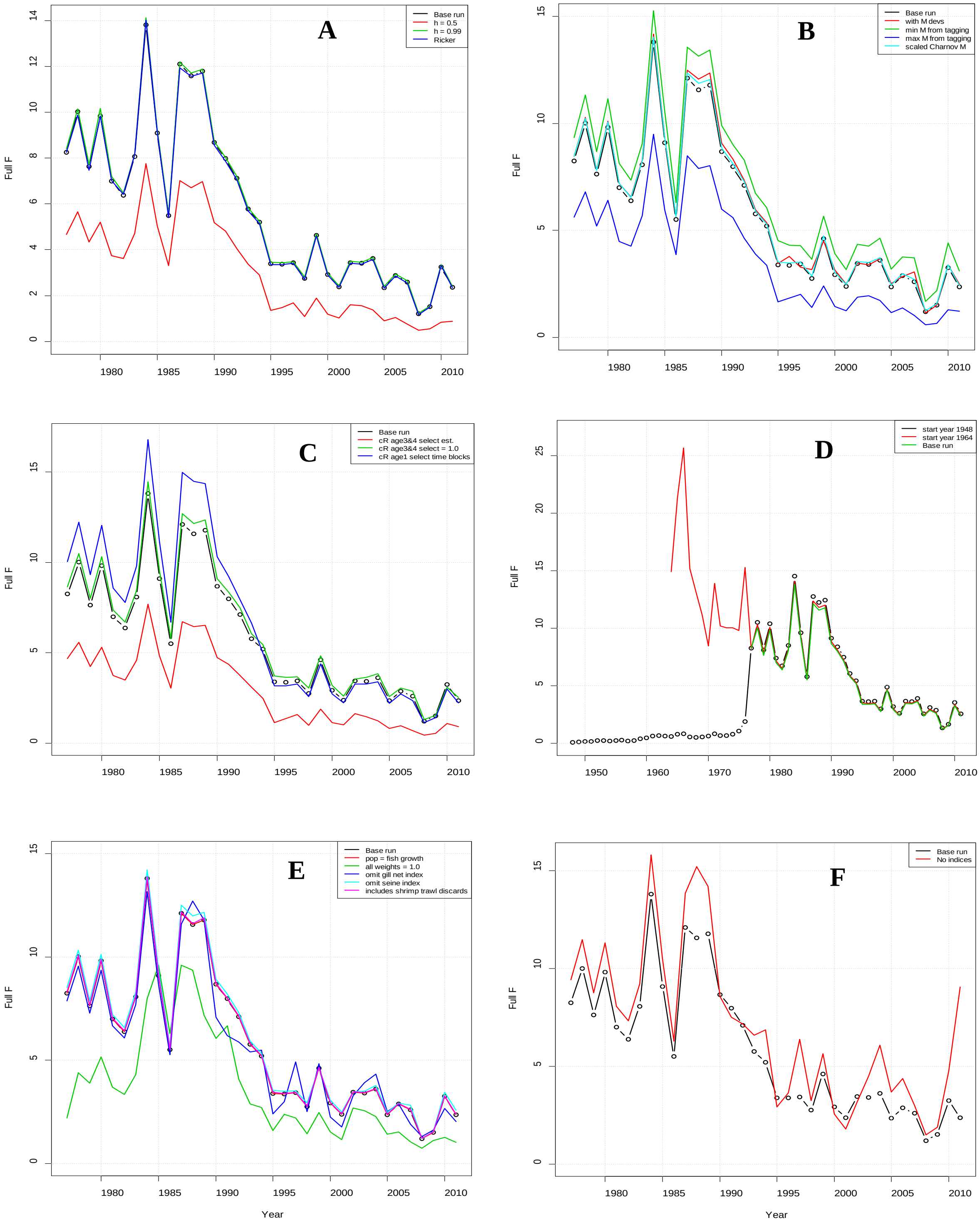


Figure 7.24 Estimated full fishing mortality rate for sensitivity runs related to changes in the input natural mortality rate (panel A), to changes in the stock-recruitment parameters (panel B), to changes in selectivity (panel C), to changes in start year of the model (panel D), to changes in other model components (panel E), and lastly to the exclusion of all of the index data (panel F).

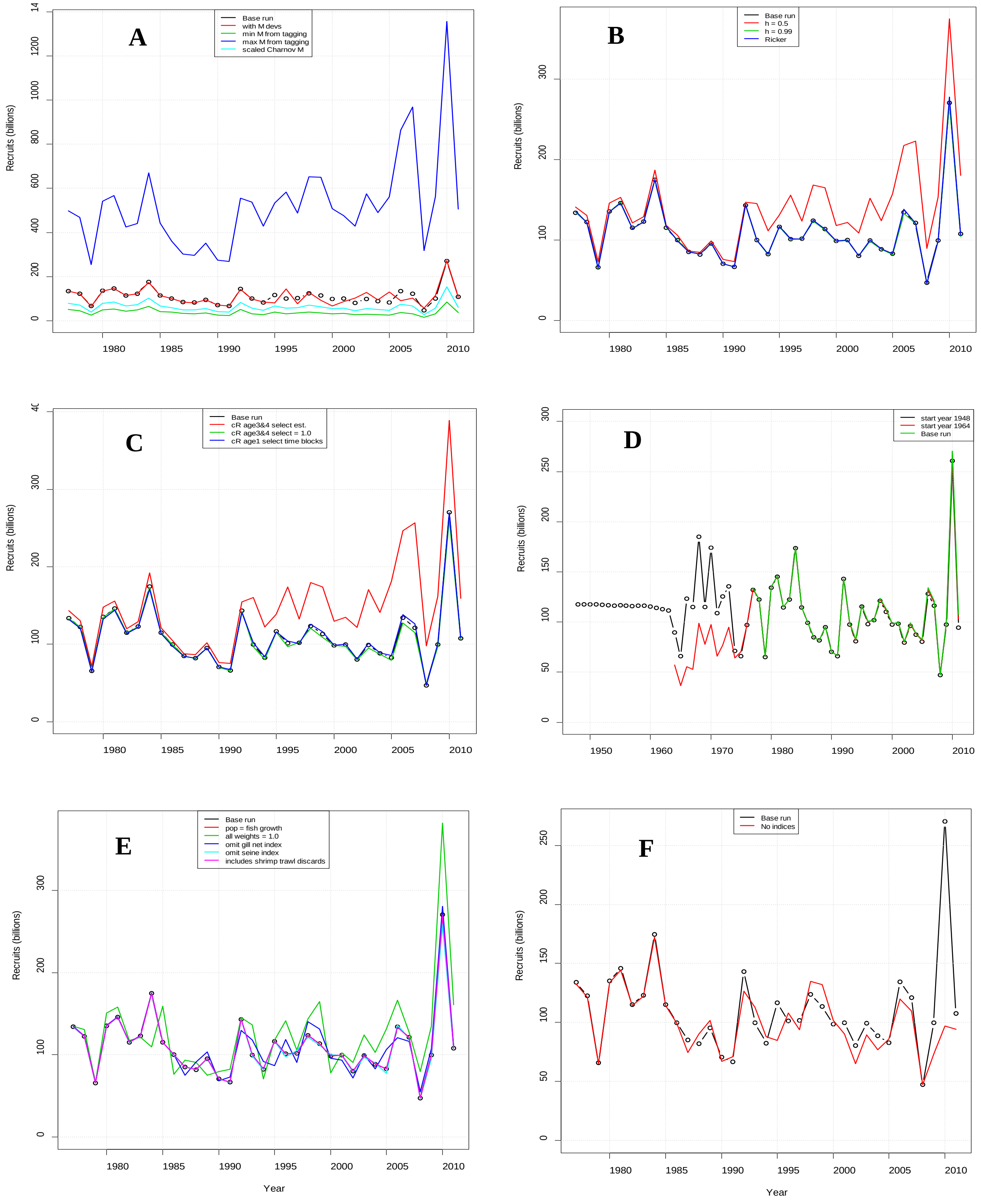


Figure 7.25 Estimated recruitment for sensitivity runs related to changes in the input natural mortality rate (panel A), to changes in the stock-recruitment parameters (panel B), to changes in selectivity (panel C), to changes in start year of the model (panel D), to changes in other model components (panel E), and lastly to the exclusion of all of the index data (panel F).

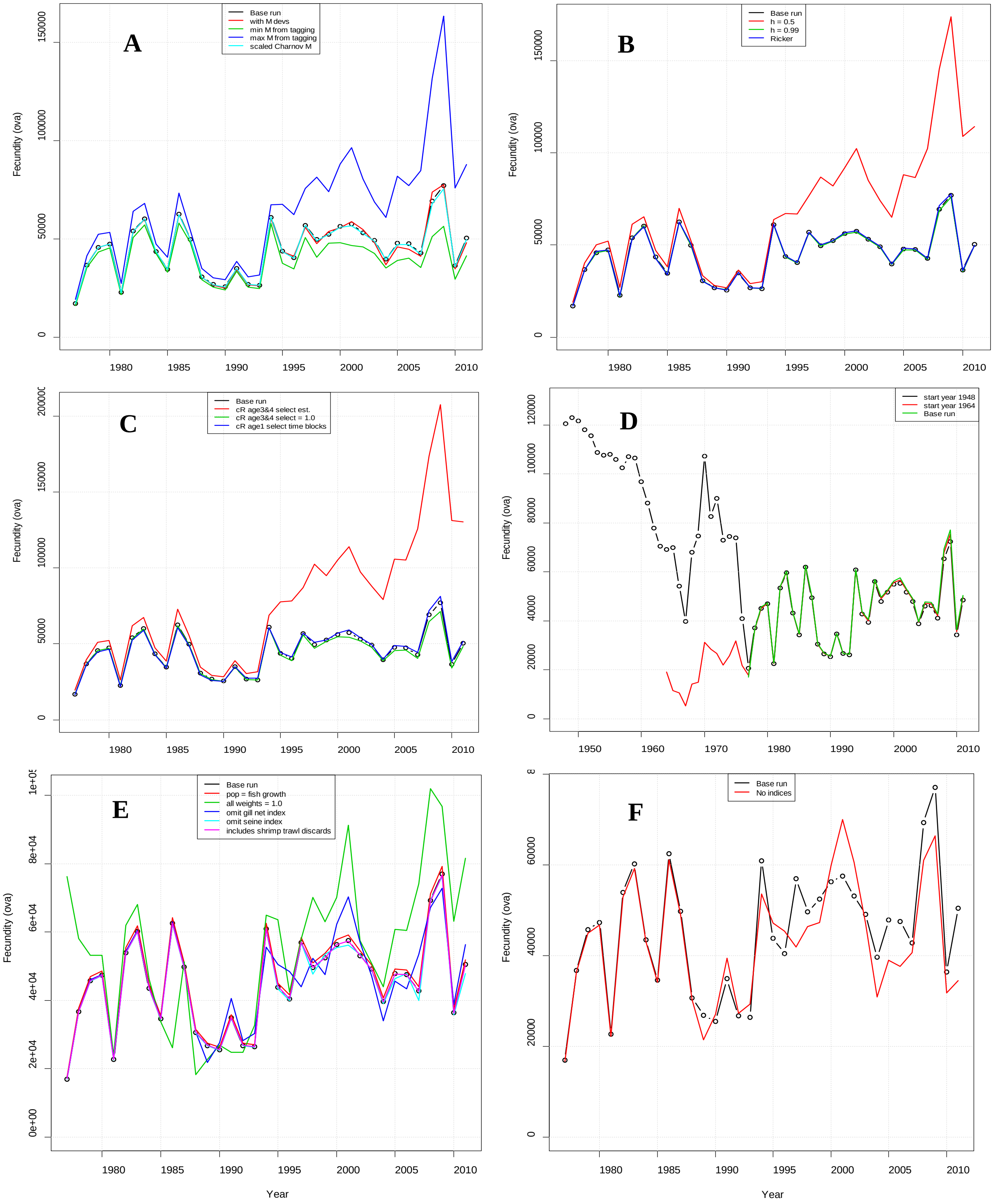


Figure 7.26 Estimated fecundity for sensitivity runs related to changes in the input natural mortality rate (panel A), to changes in the stock-recruitment parameters (panel B), to changes in selectivity (panel C), to changes in start year of the model (panel D), to changes in other model components (panel E), and lastly to the exclusion of all of the index data (panel F).

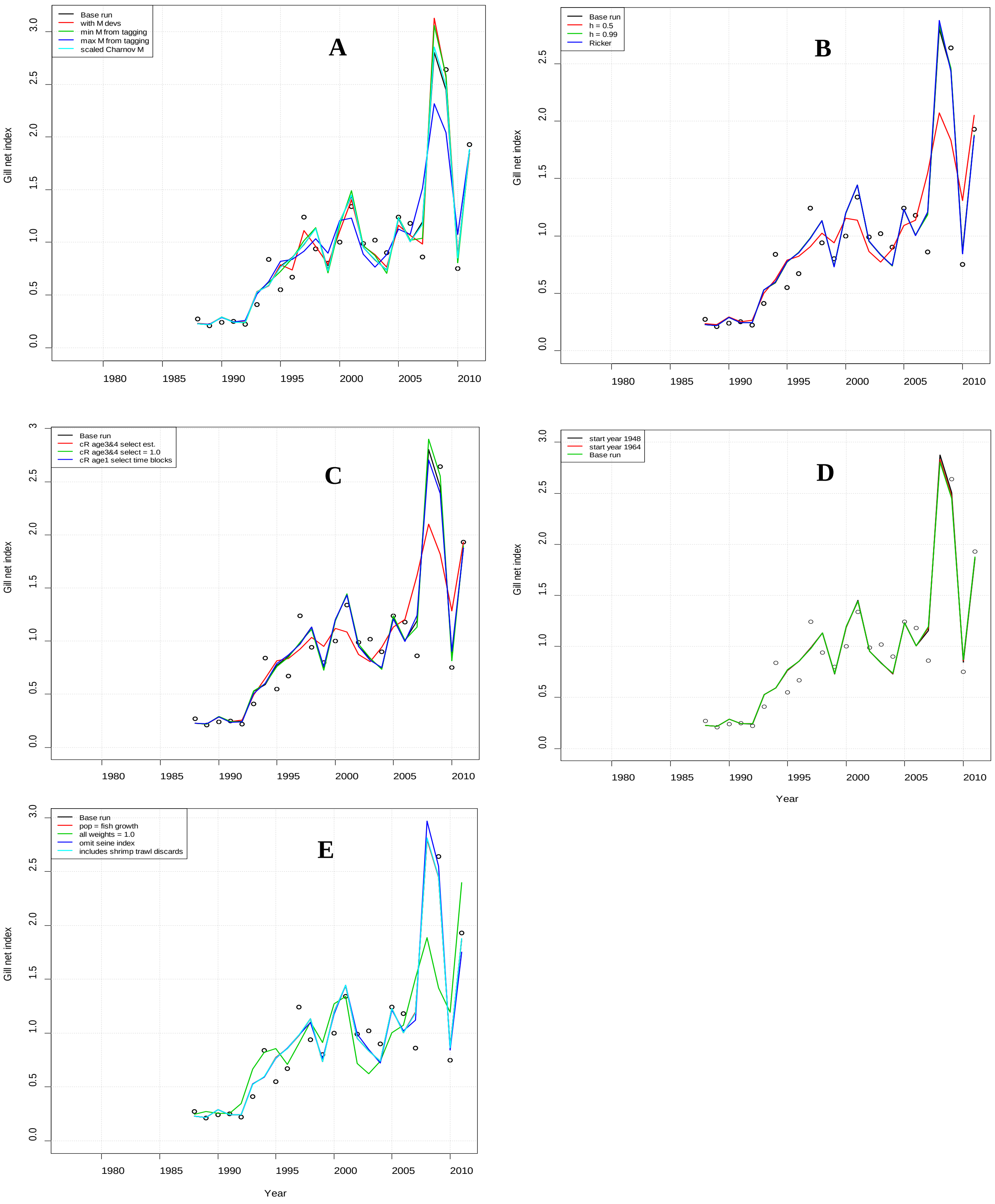


Figure 7.27 Fit to the gill net index for sensitivity runs related to changes in the input natural mortality rate (panel A), to changes in the stock-recruitment parameters (panel B), to changes in selectivity (panel C), to changes in start year of the model (panel D), and to changes in other model components (panel E).

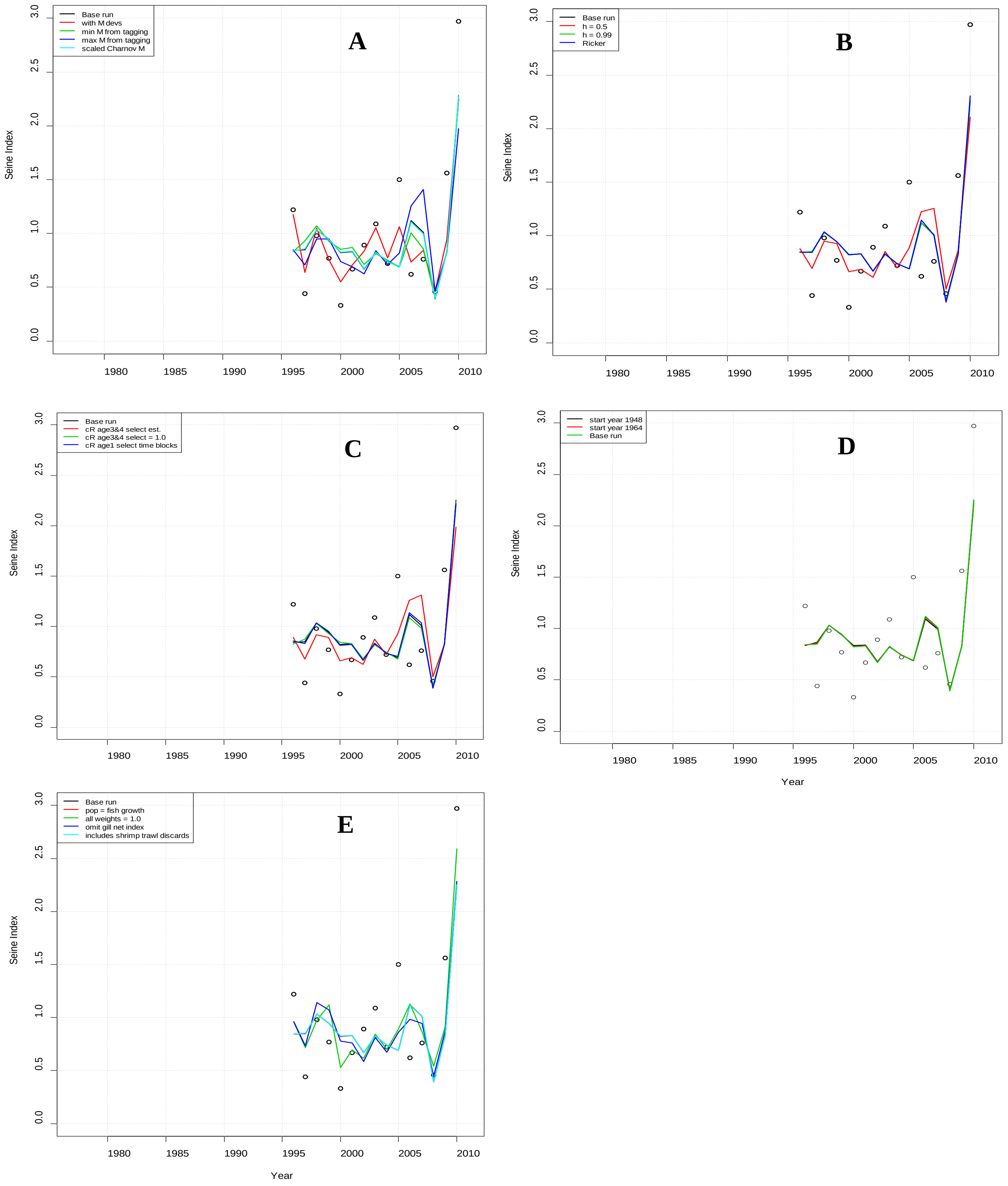


Figure 7.28 Fit to the seine index for sensitivity runs related to changes in the input natural mortality rate (panel A), to changes in the stock-recruitment parameters (panel B), to changes in selectivity (panel C), to changes in start year of the model (panel D), and to changes in other model components (panel E).

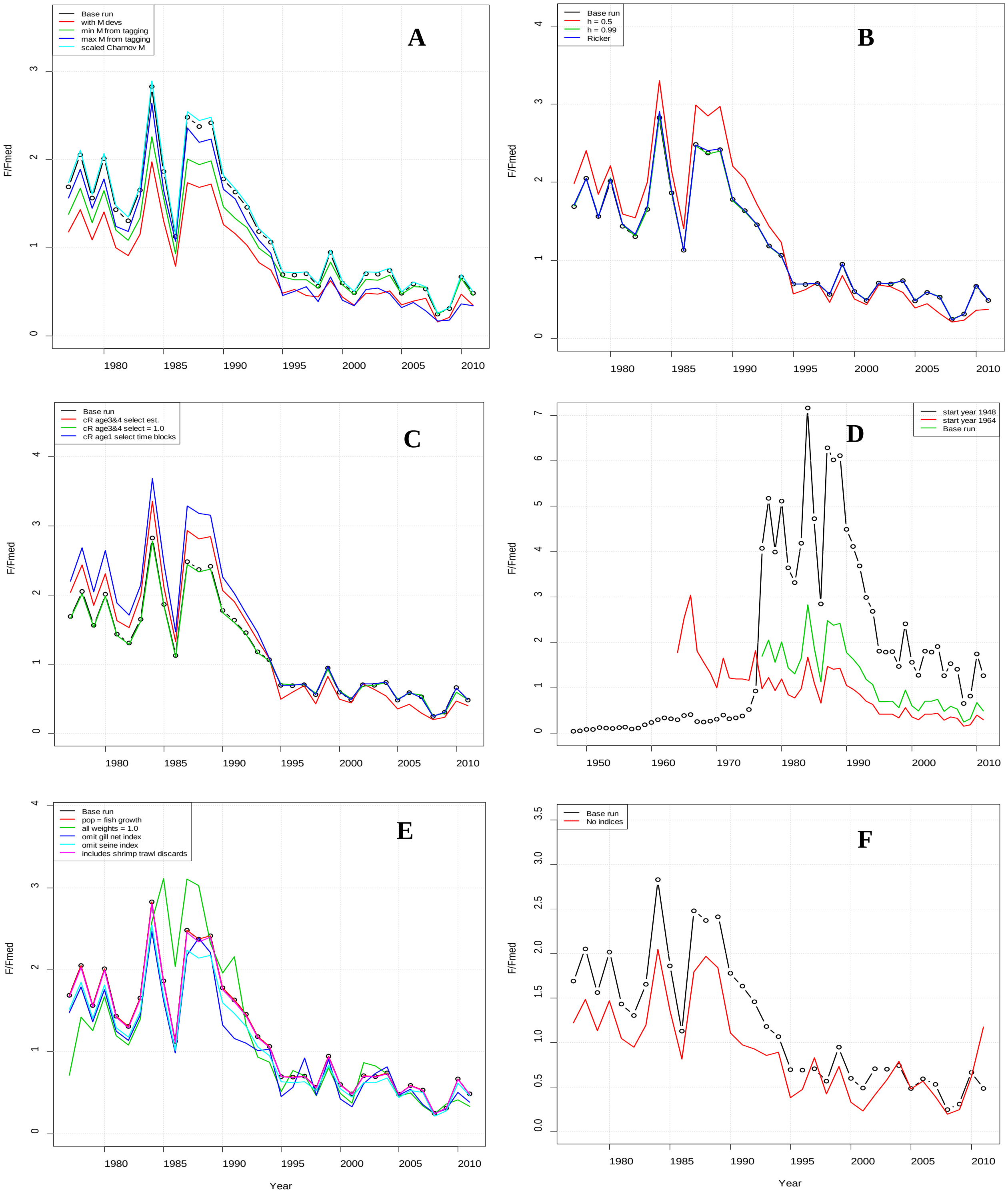


Figure 7.29 Fishing mortality rate over F_{MED} for sensitivity runs related to changes in the input natural mortality rate (panel A), to changes in the stock-recruitment parameters (panel B), to changes in selectivity (panel C), to changes in start year of the model (panel D), to changes in other model components (panel E), and lastly to the exclusion of all of the index data (panel F).

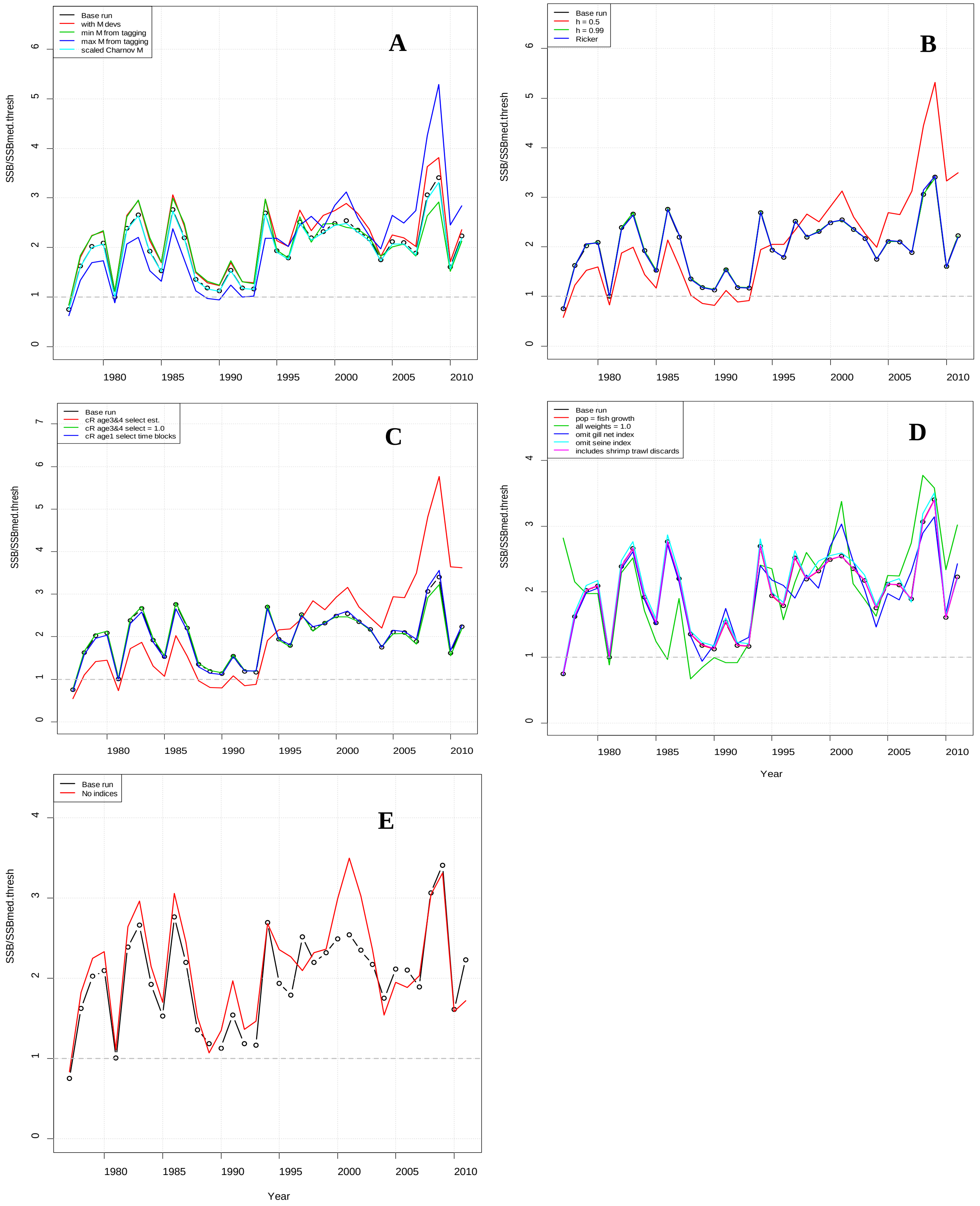


Figure 7.30 Fecundity (*SSB*) over the *SSB* threshold for sensitivity runs related to changes in the input natural mortality rate (panel A), to changes in the stock-recruitment parameters (panel B), to changes in selectivity (panel C), to changes in other model components (panel D), and lastly to the exclusion of all of the index data (panel E).

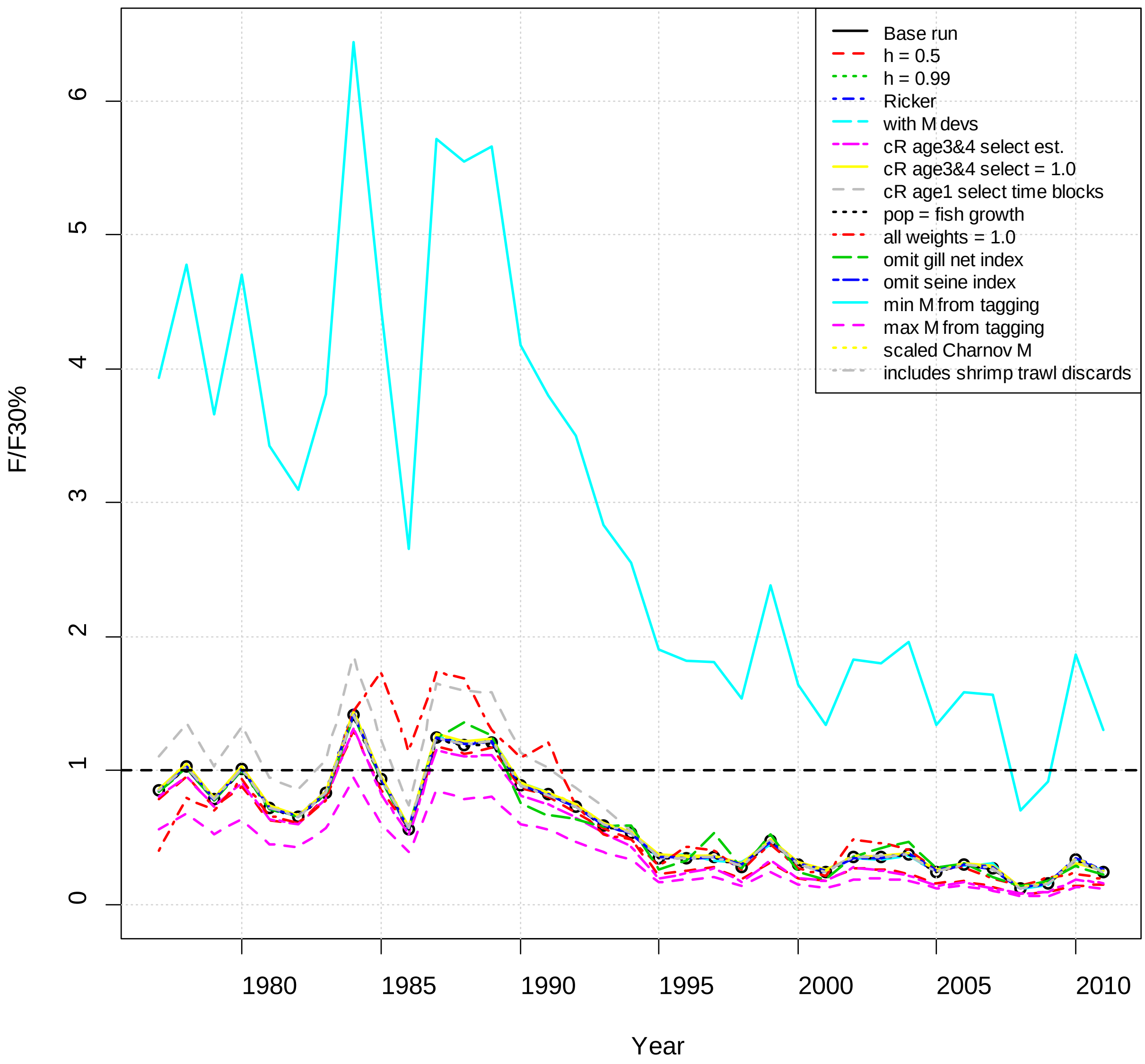


Figure 7.31 Fishing mortality rate over $F_{30\%}$ for sensitivity runs related to changes in the input natural mortality rate, to changes in the stock-recruitment parameters , to changes in selectivity, and to changes in other model components.

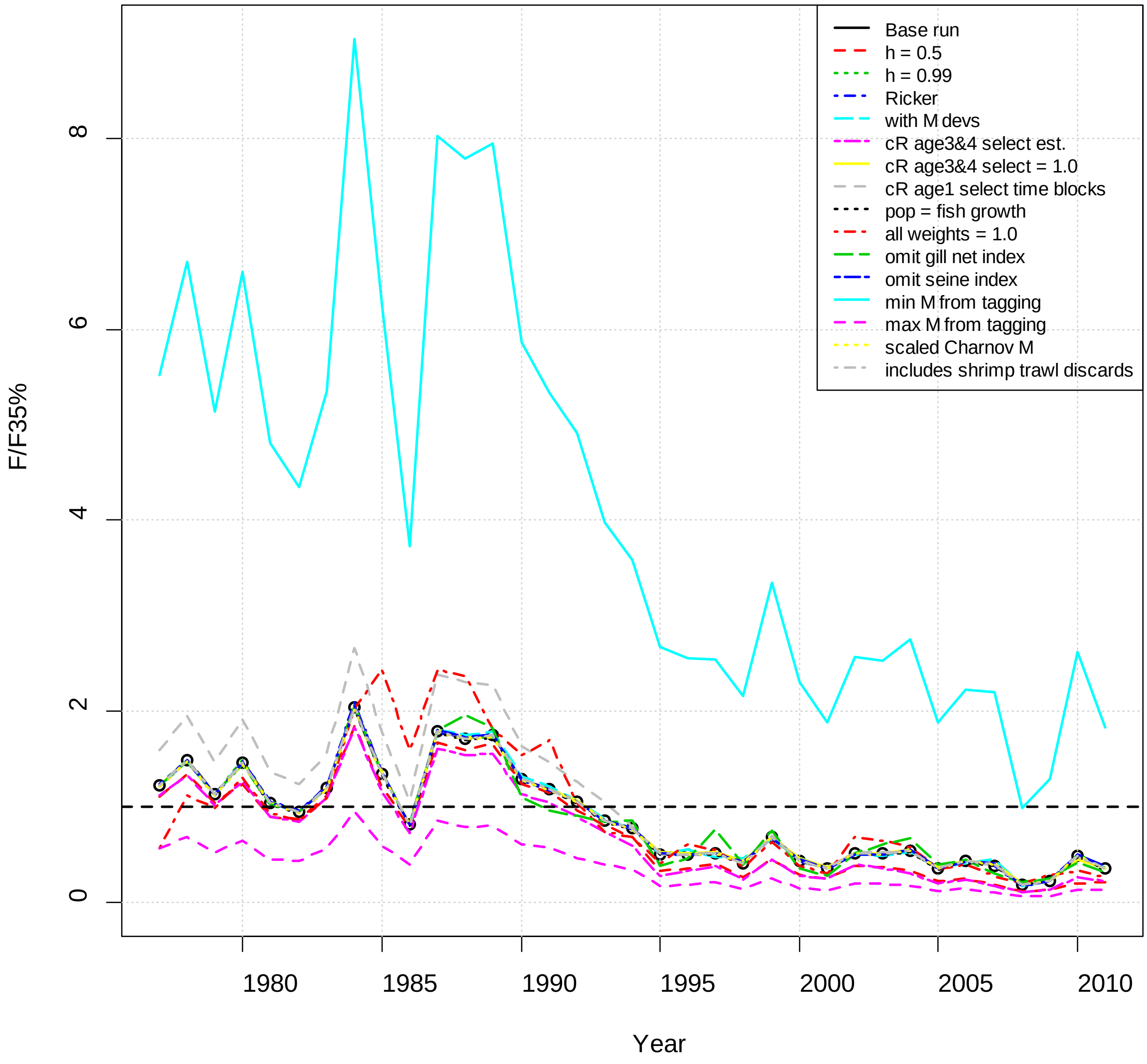


Figure 7.32 Fishing mortality rate over $F_{35\%}$ for sensitivity runs related to changes in the input natural mortality rate, to changes in the stock-recruitment parameters , to changes in selectivity, and to changes in other model components.

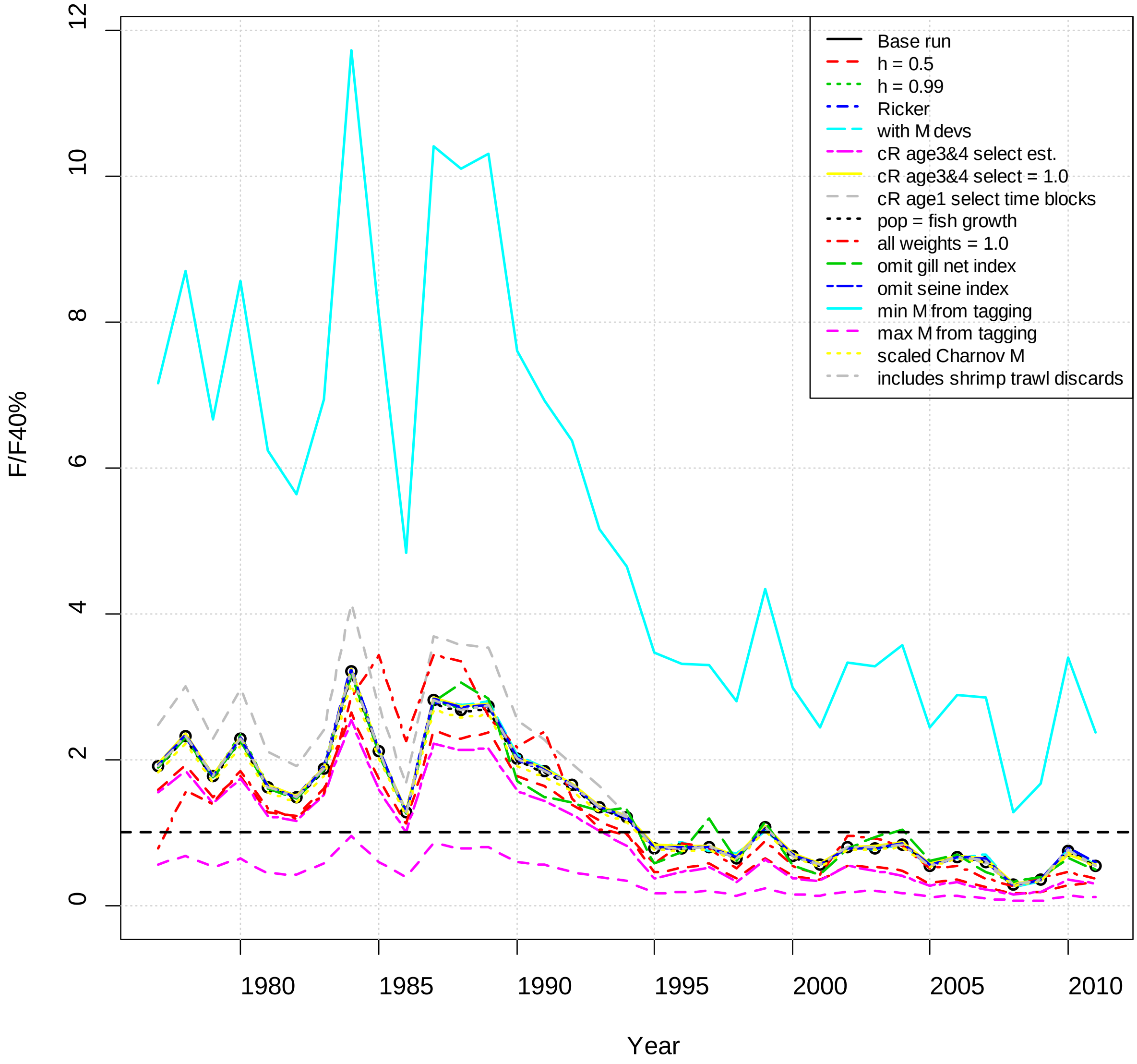


Figure 7.33 Fishing mortality rate over $F_{40\%}$ for sensitivity runs related to changes in the input natural mortality rate, to changes in the stock-recruitment parameters, to changes in selectivity, and to changes in other model components.

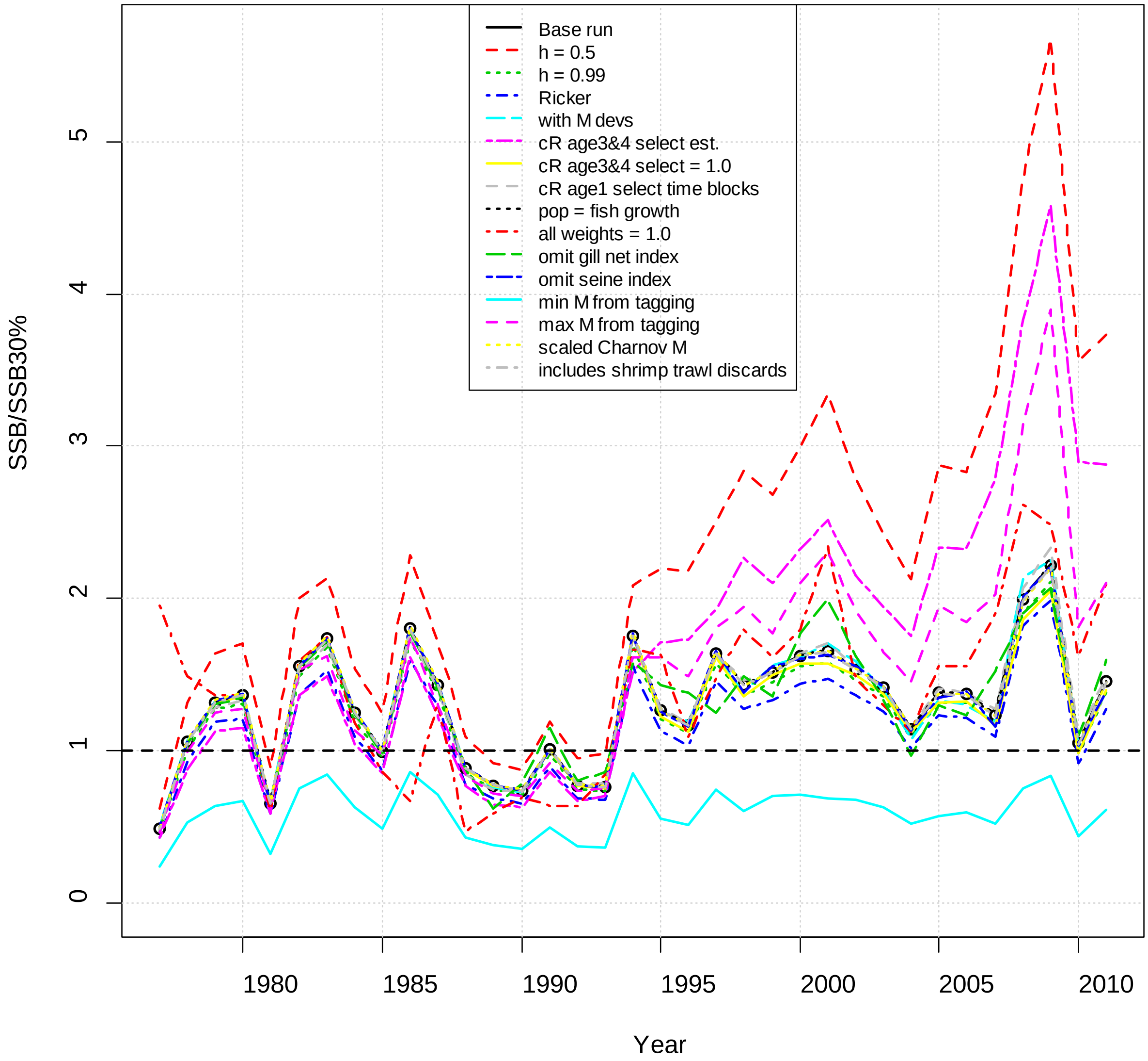


Figure 7.34 Fecundity (*SSB*) over $SSB_{30\%}$ for sensitivity runs related to changes in the input natural mortality rate, to changes in the stock-recruitment parameters , to changes in selectivity, and to changes in other model components.

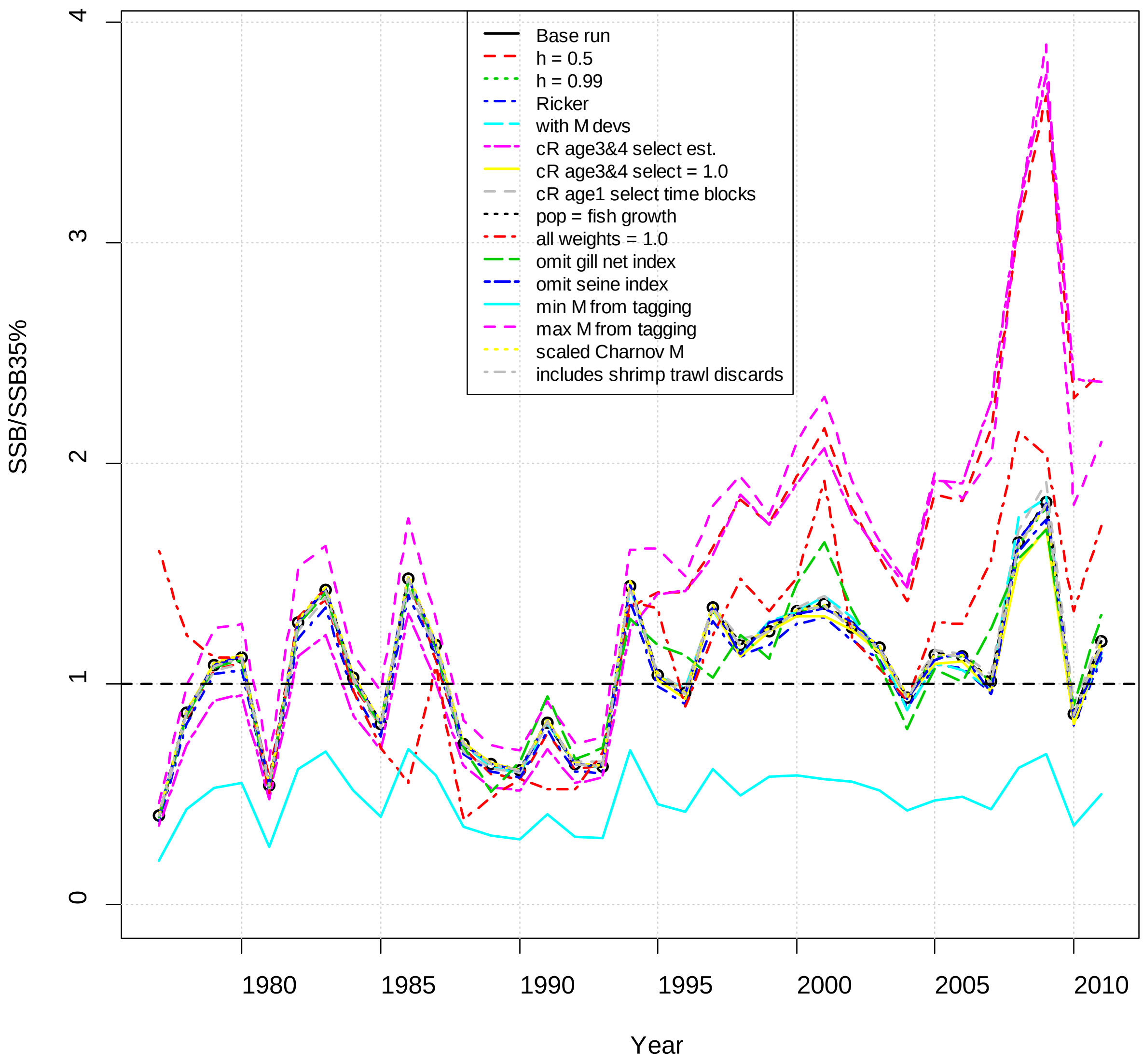


Figure 7.35 Fecundity (*SSB*) over $SSB_{35\%}$ for sensitivity runs related to changes in the input natural mortality rate, to changes in the stock-recruitment parameters , to changes in selectivity, and to changes in other model components.

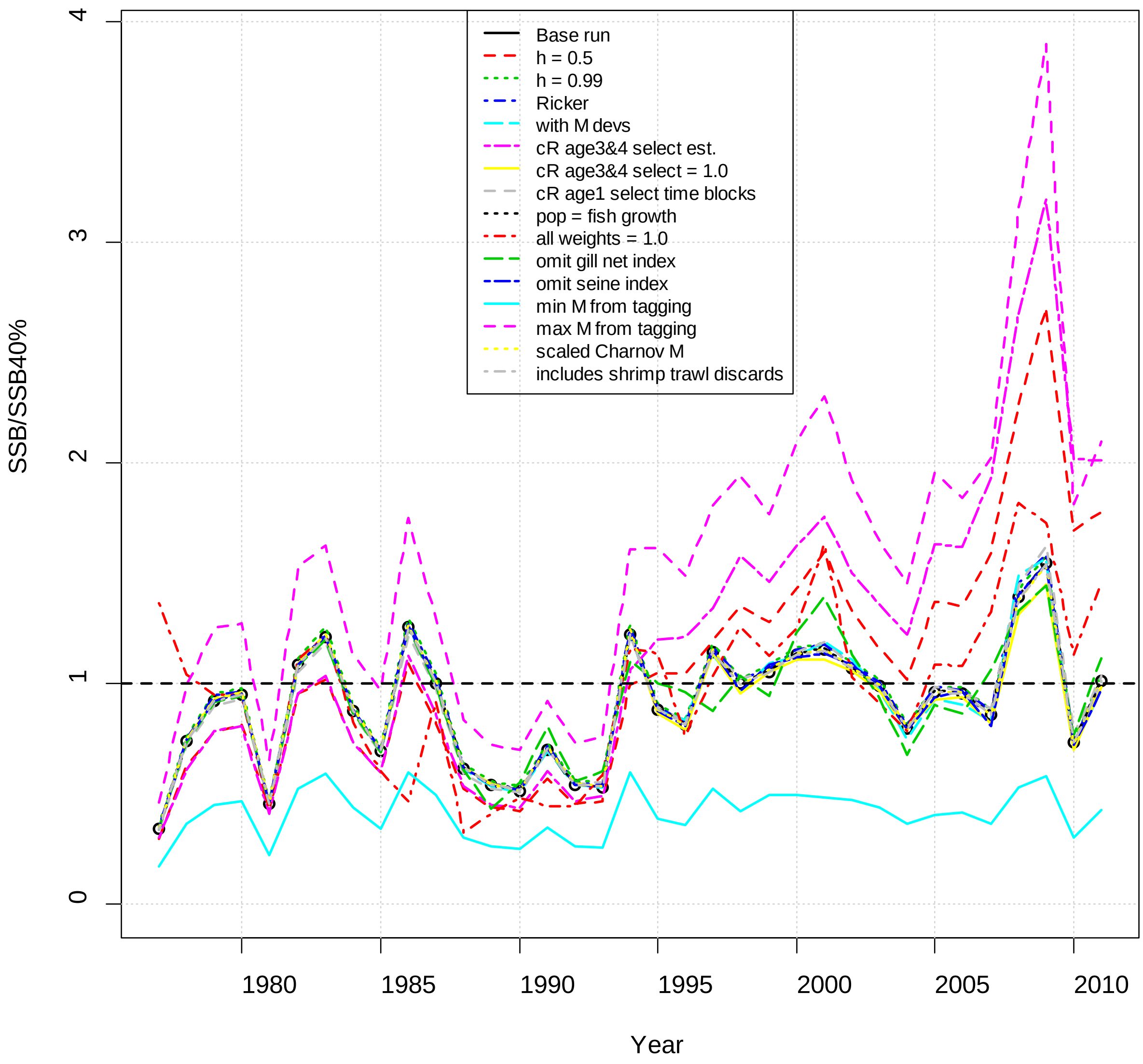


Figure 7.36 Fecundity (*SSB*) over $SSB_{40\%}$ for sensitivity runs related to changes in the input natural mortality rate, to changes in the stock-recruitment parameters , to changes in selectivity, and to changes in other model components.

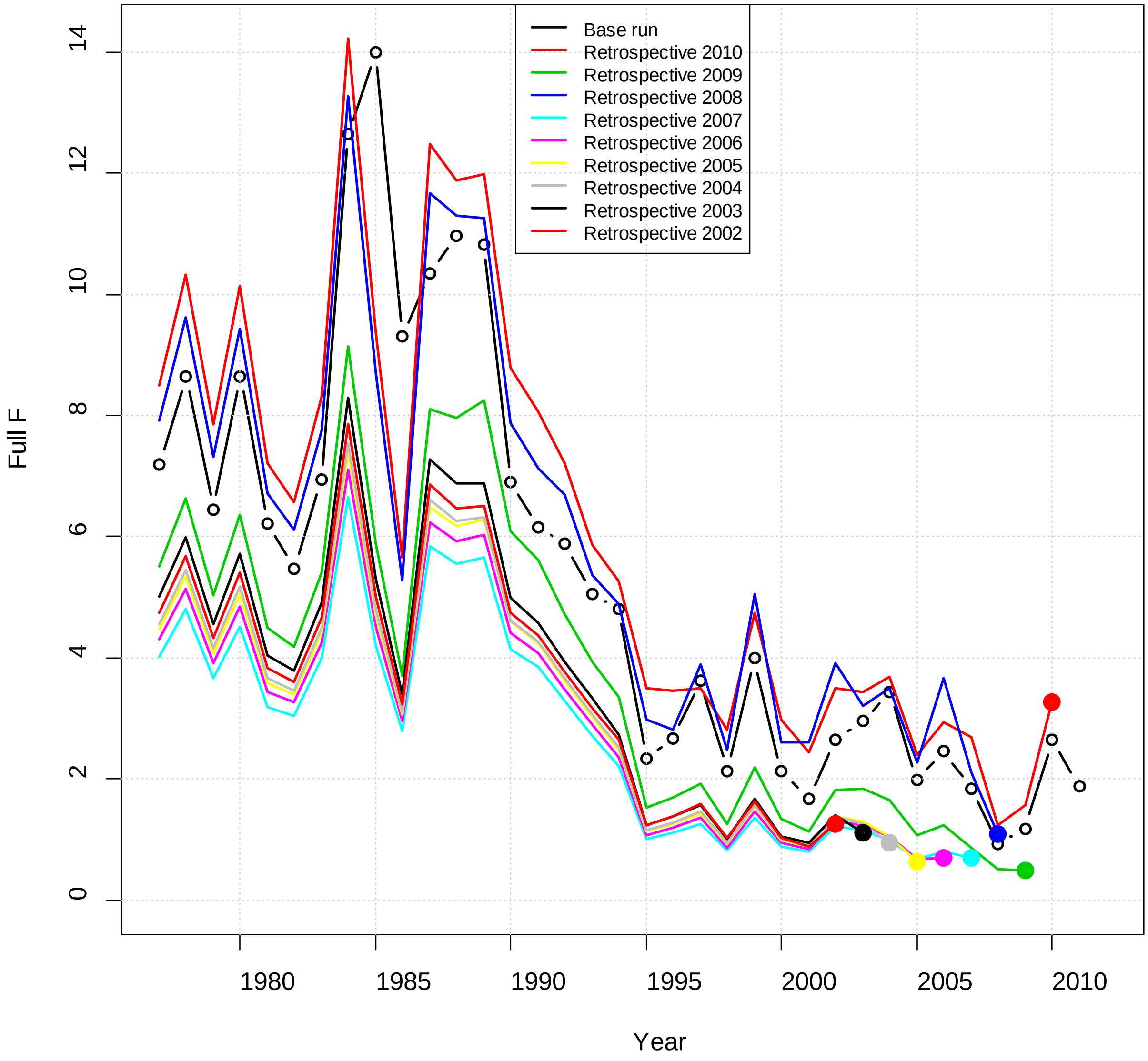


Figure 7.37 Full fishing mortality rate over time for the retrospective analysis.

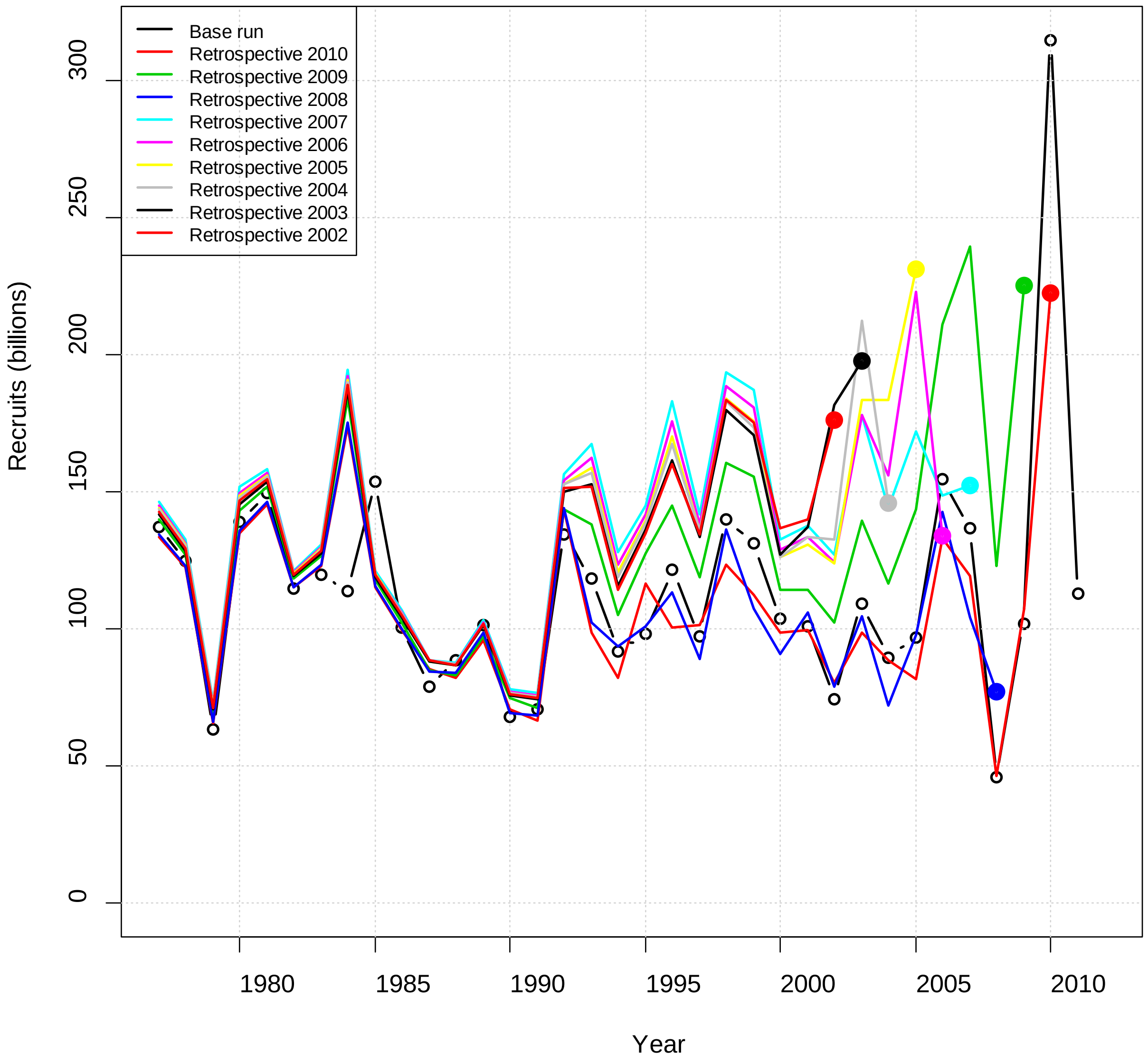


Figure 7.38 Annual recruitments estimated in the base run of BAM and for the retrospective analysis.

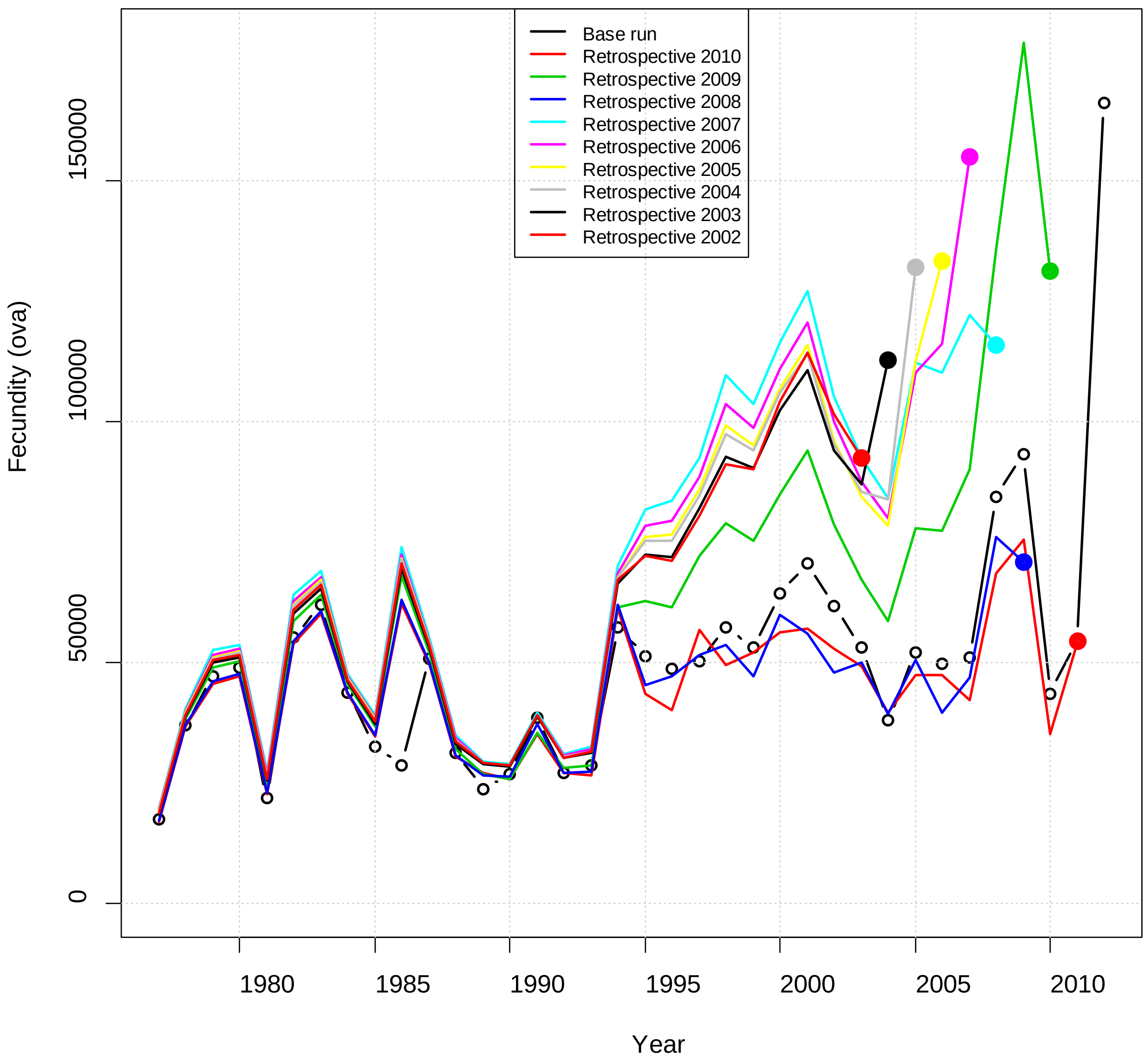


Figure 7.39 Annual fecundity (billions of eggs) estimated in the base run of BAM and for the retrospective analysis.

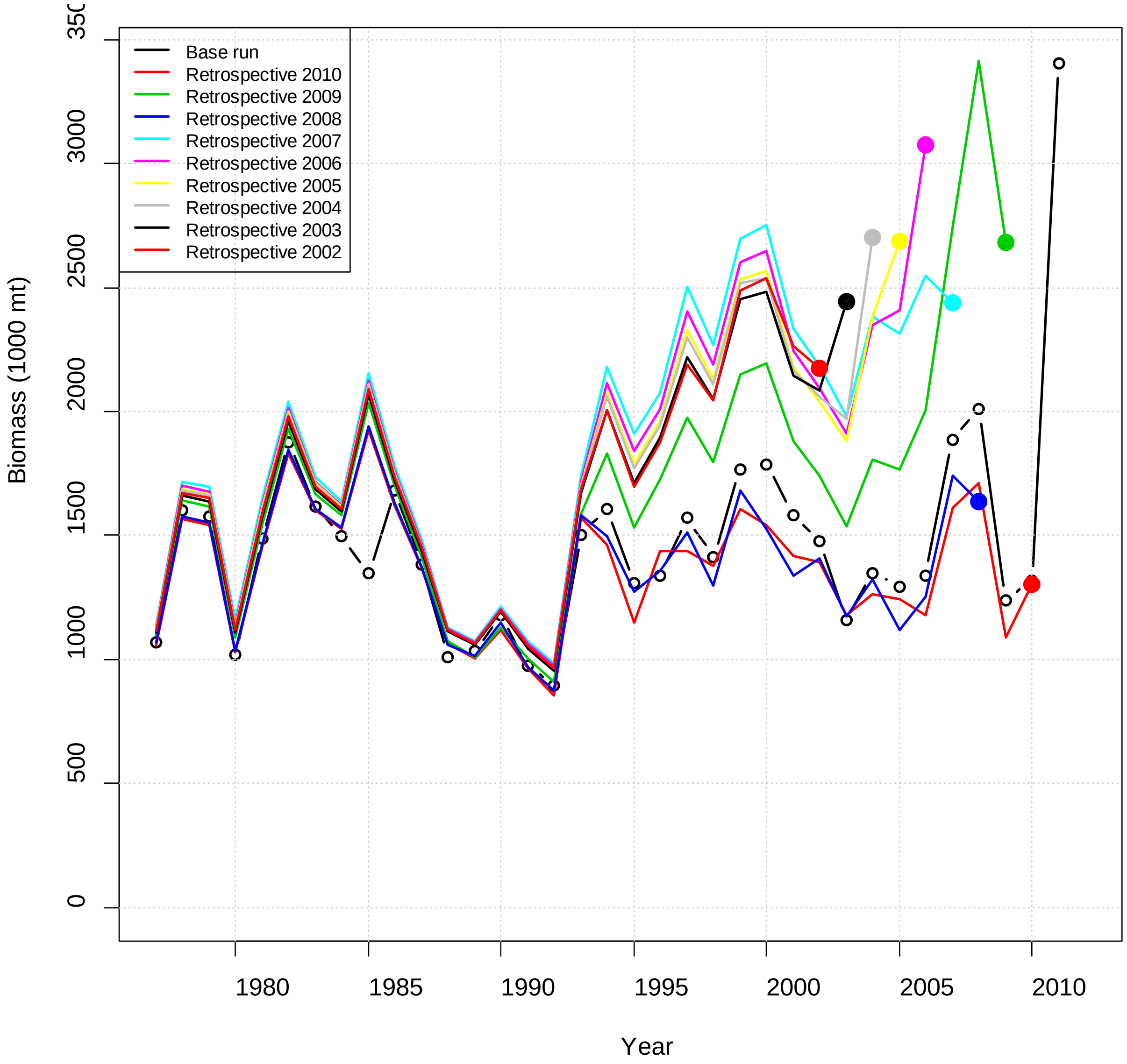


Figure 7.40 Annual age-1+ biomass estimated in the base run of BAM and for the retrospective analysis.

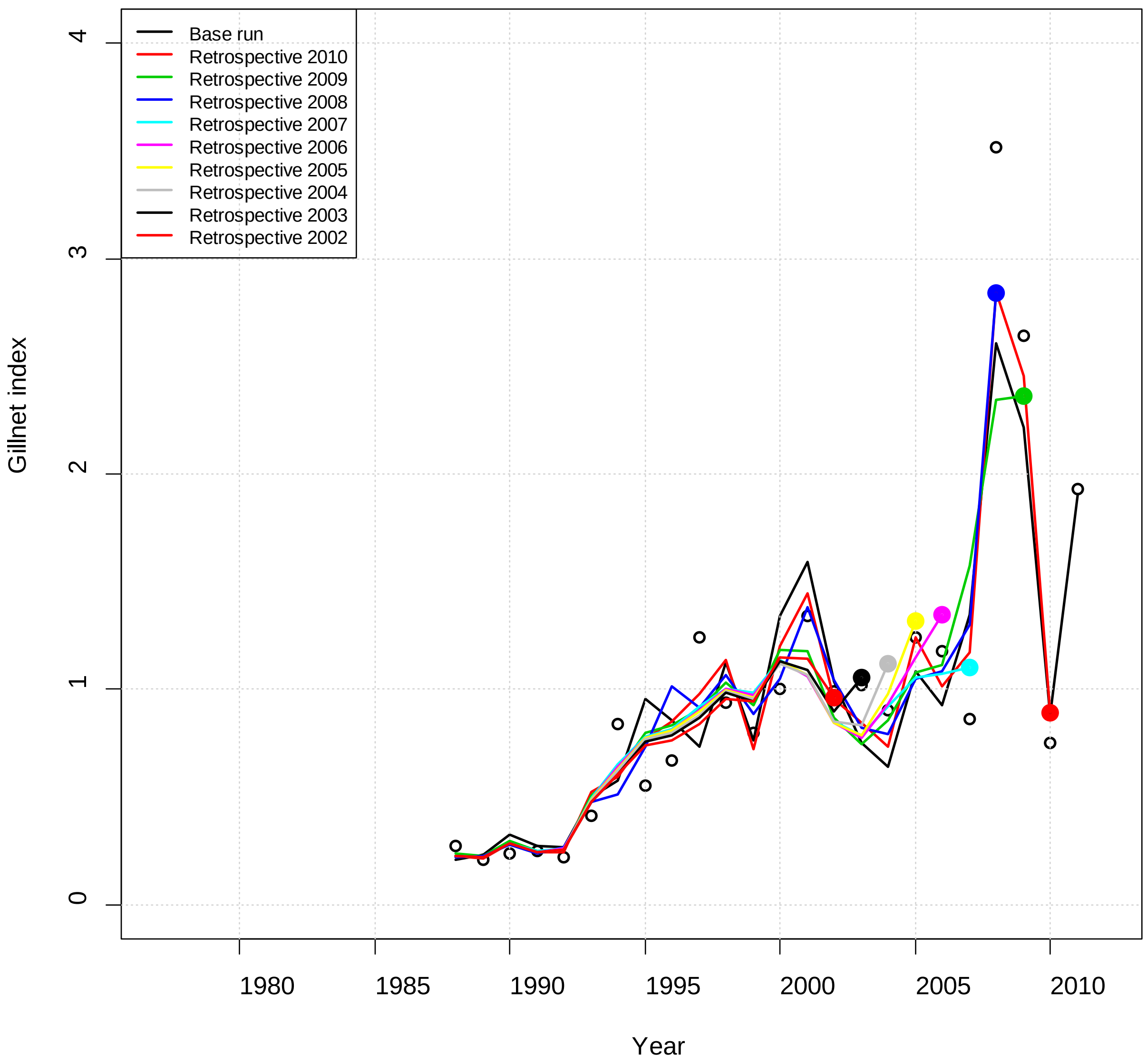


Figure 7.41 Fit to the gill net index for the retrospective analysis.

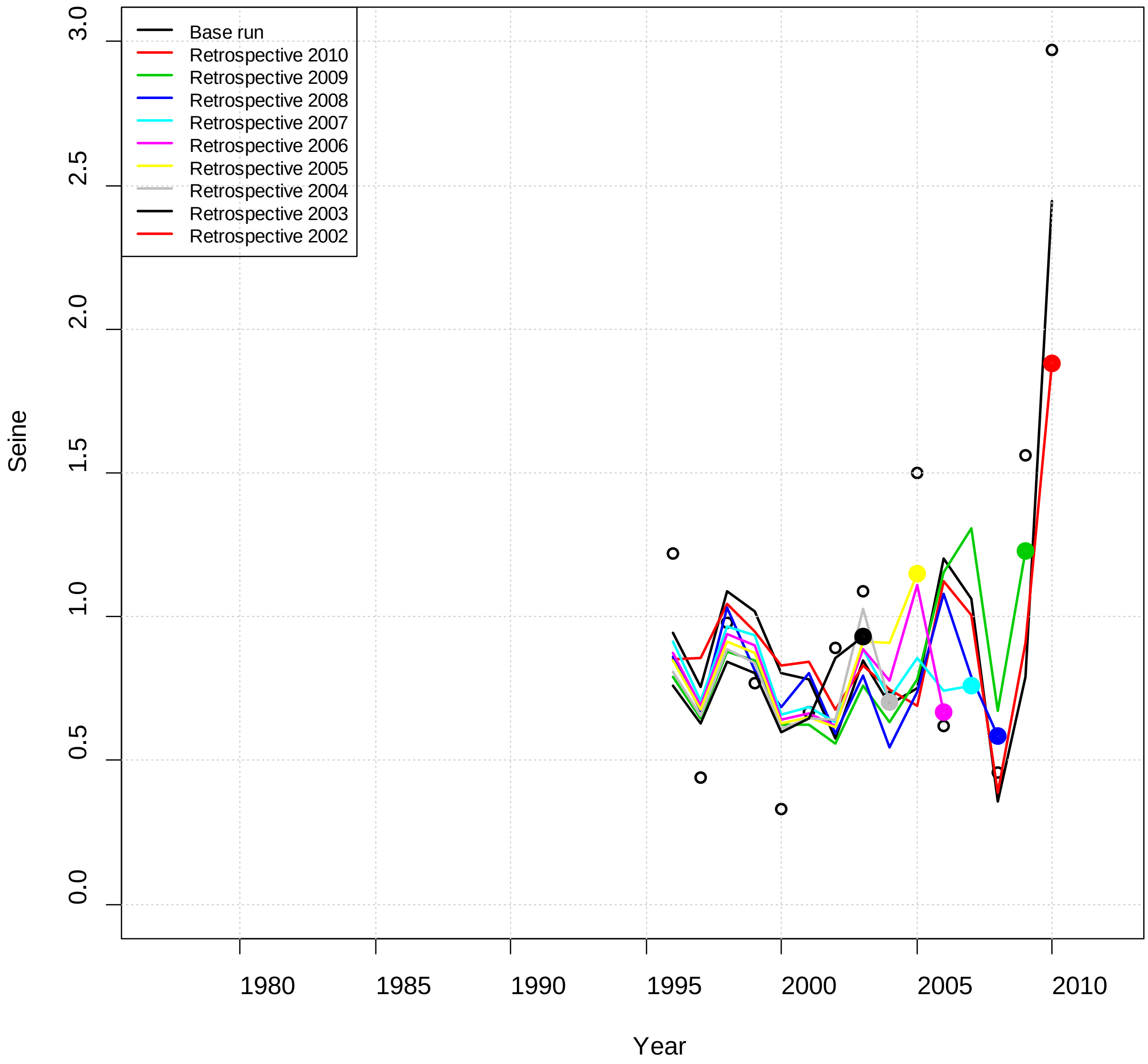


Figure 7.42 Fit to the seine index for the retrospective analysis.

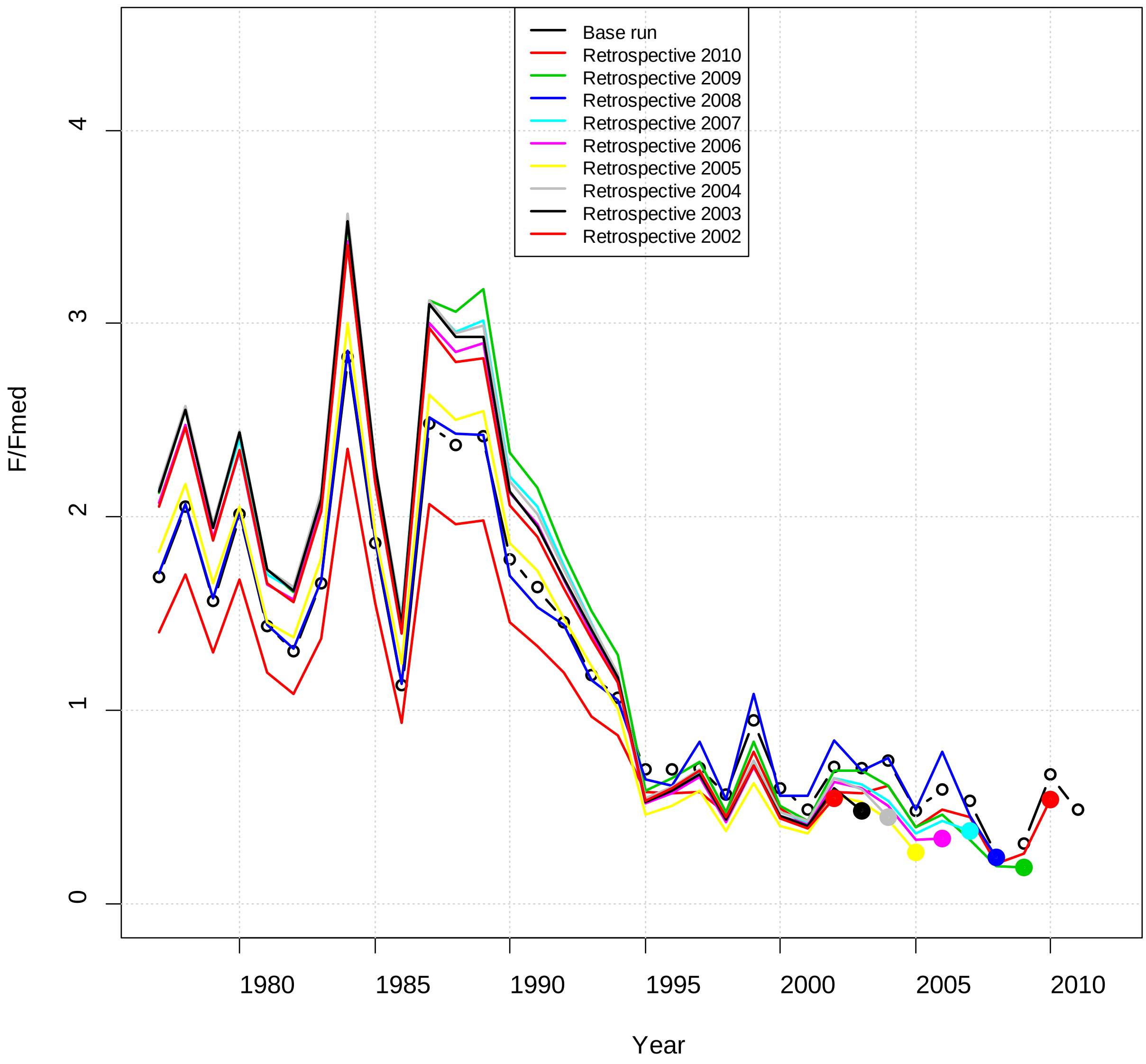


Figure 7.43 Fishing mortality rate over F_{MED} for the retrospective analysis.

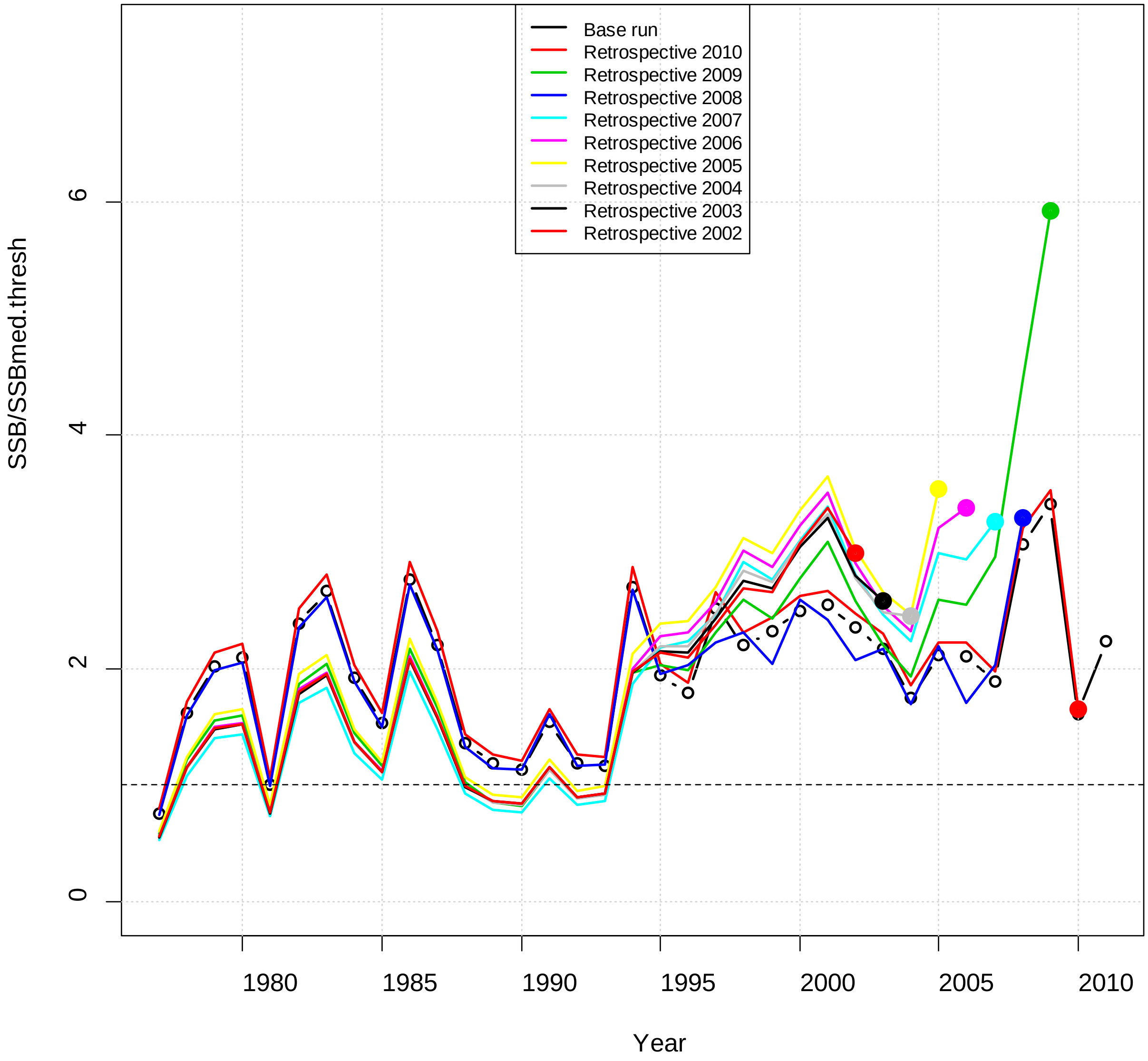


Figure 7.44 Fecundity (*SSB*) over $SSB_{MED.thresh}$ for the retrospective analysis.

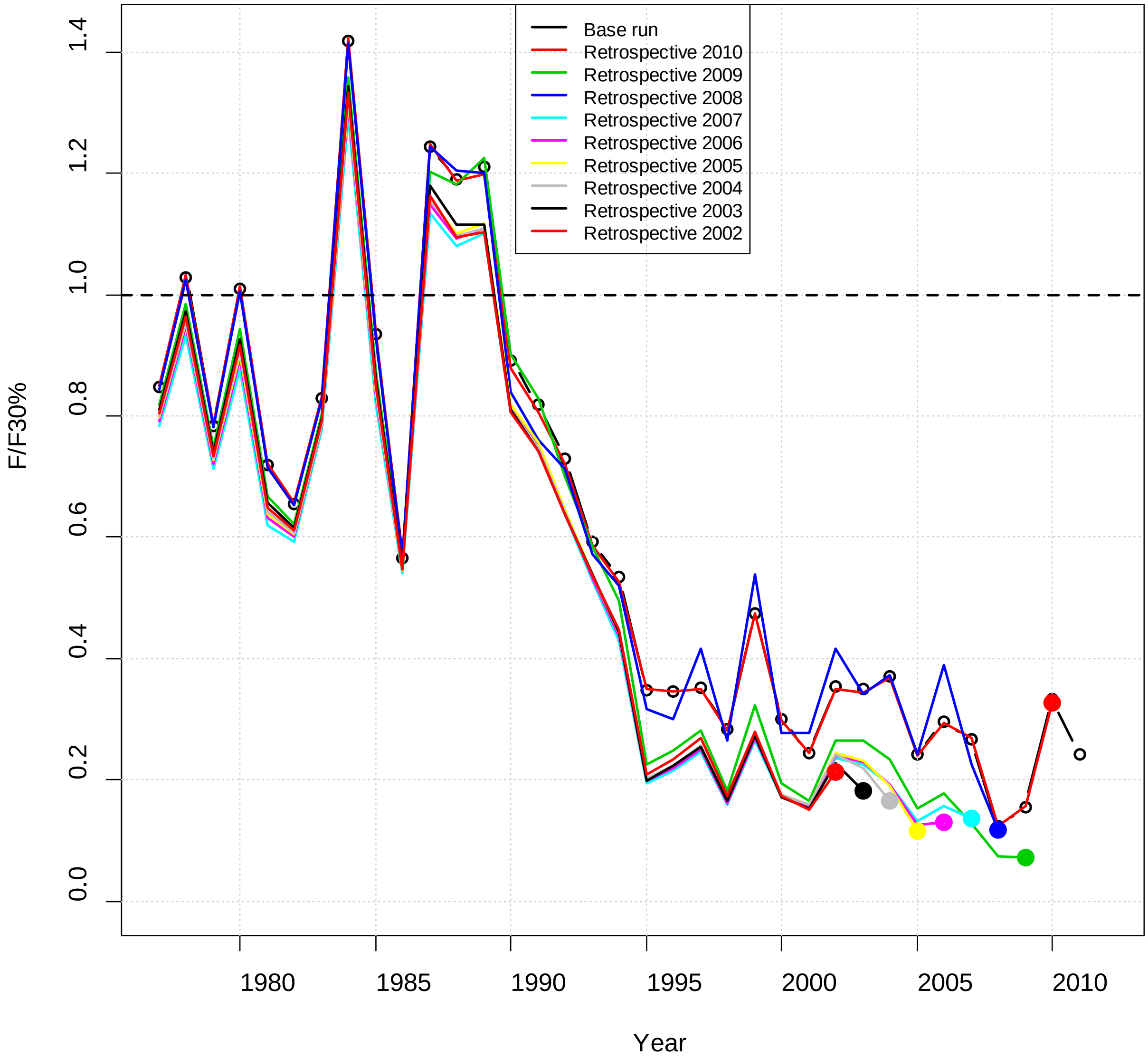


Figure 7.45 Fishing mortality rate over $F_{30\%}$ for the retrospective analysis.

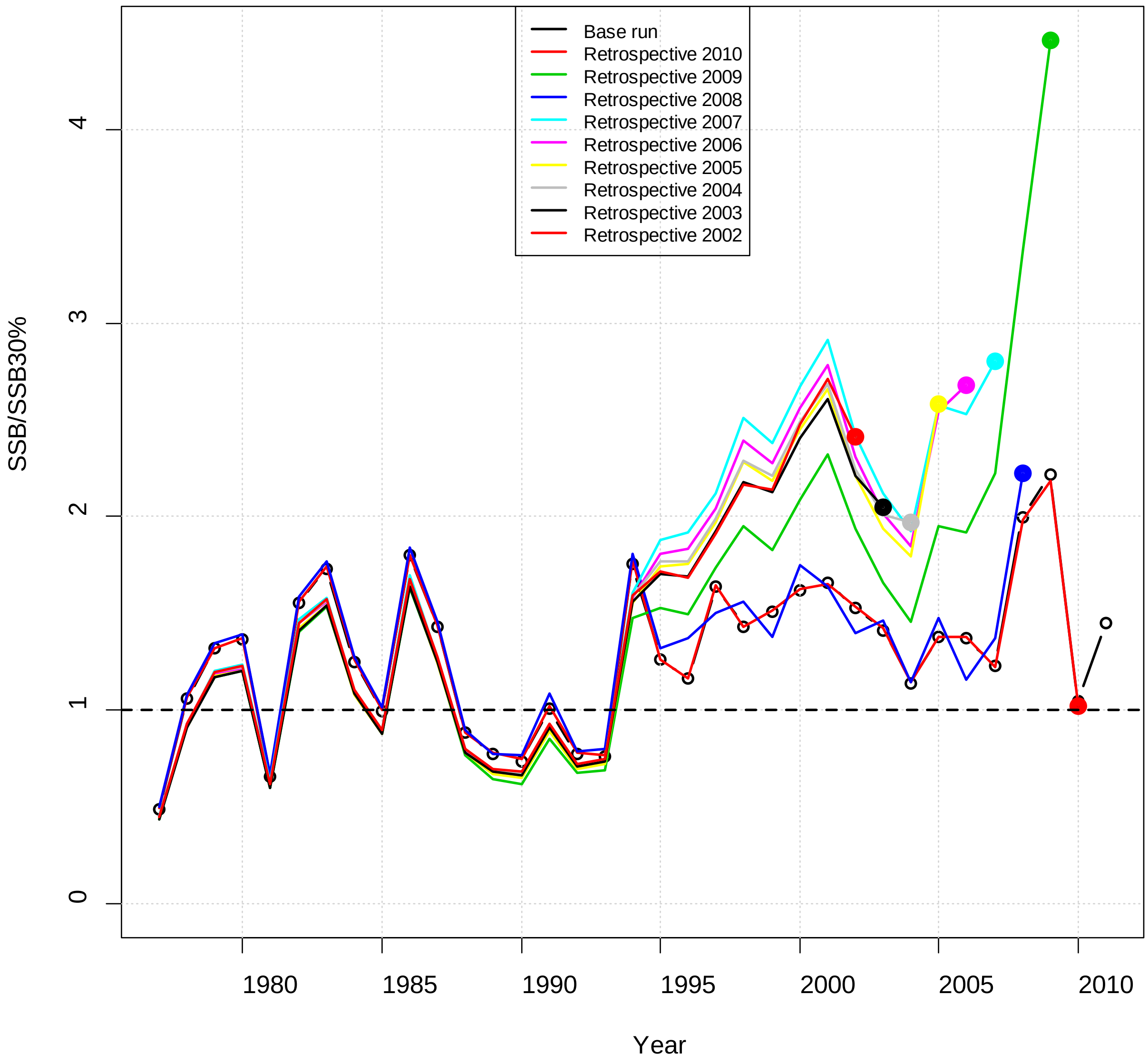


Figure 7.46 Fecundity (*SSB*) over $SSB_{30\%}$ for the retrospective analysis.

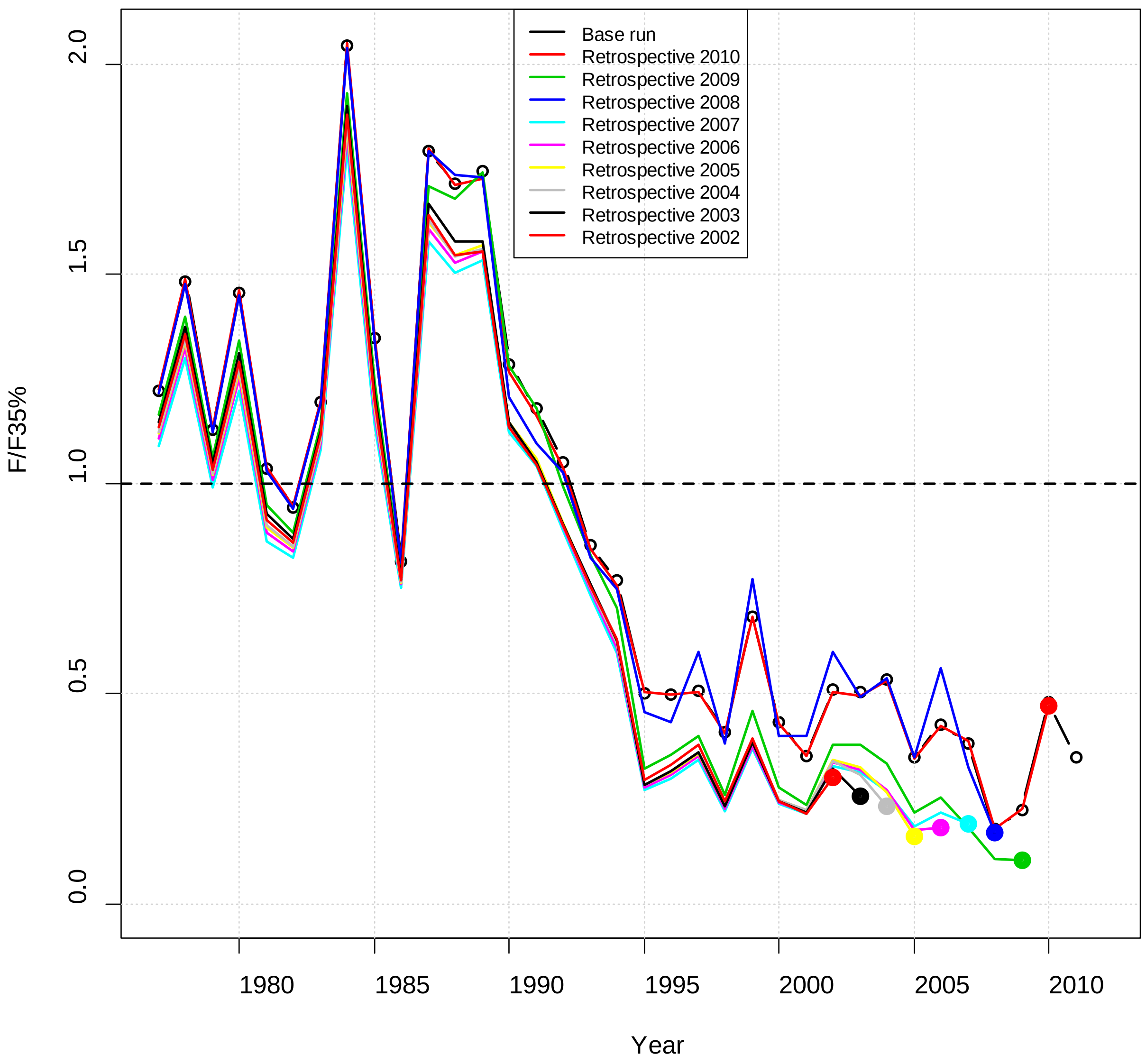


Figure 7.47 Fishing mortality rate over $F_{35\%}$ for the retrospective analysis.

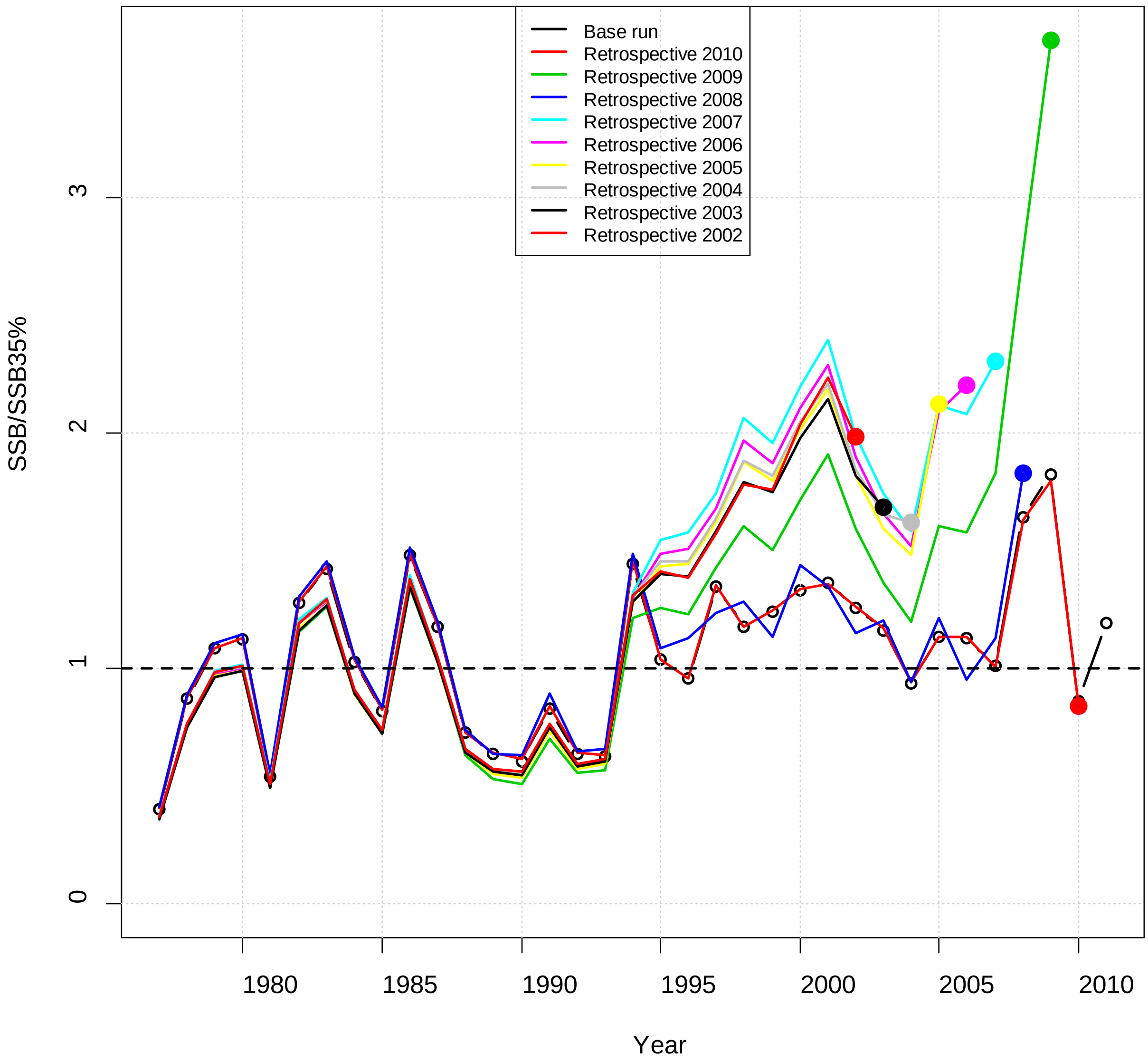


Figure 7.48 Fecundity (*SSB*) over $SSB_{35\%}$ for the retrospective analysis.

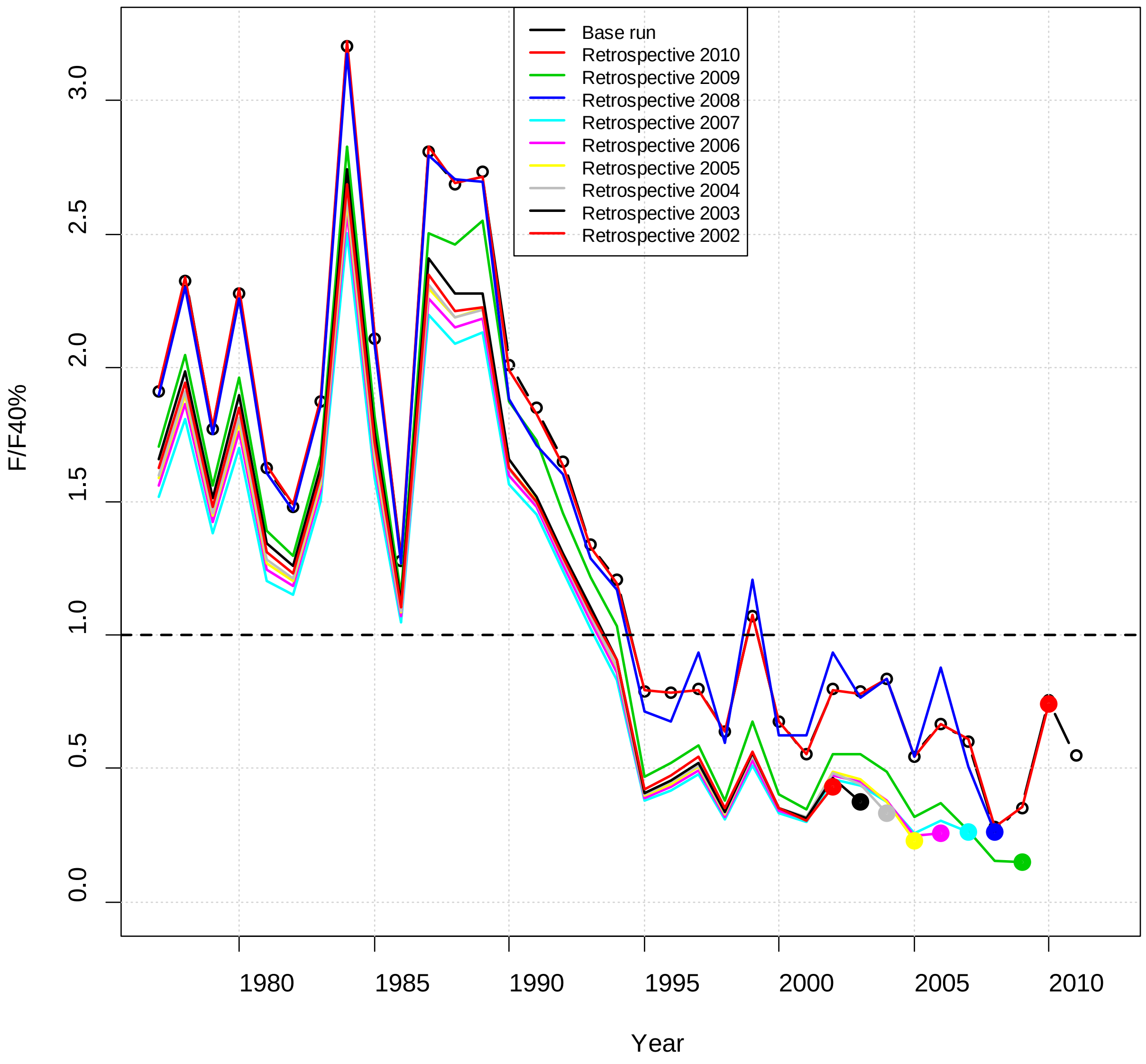


Figure 7.49 Fishing mortality rate over $F_{40\%}$ for the retrospective analysis.

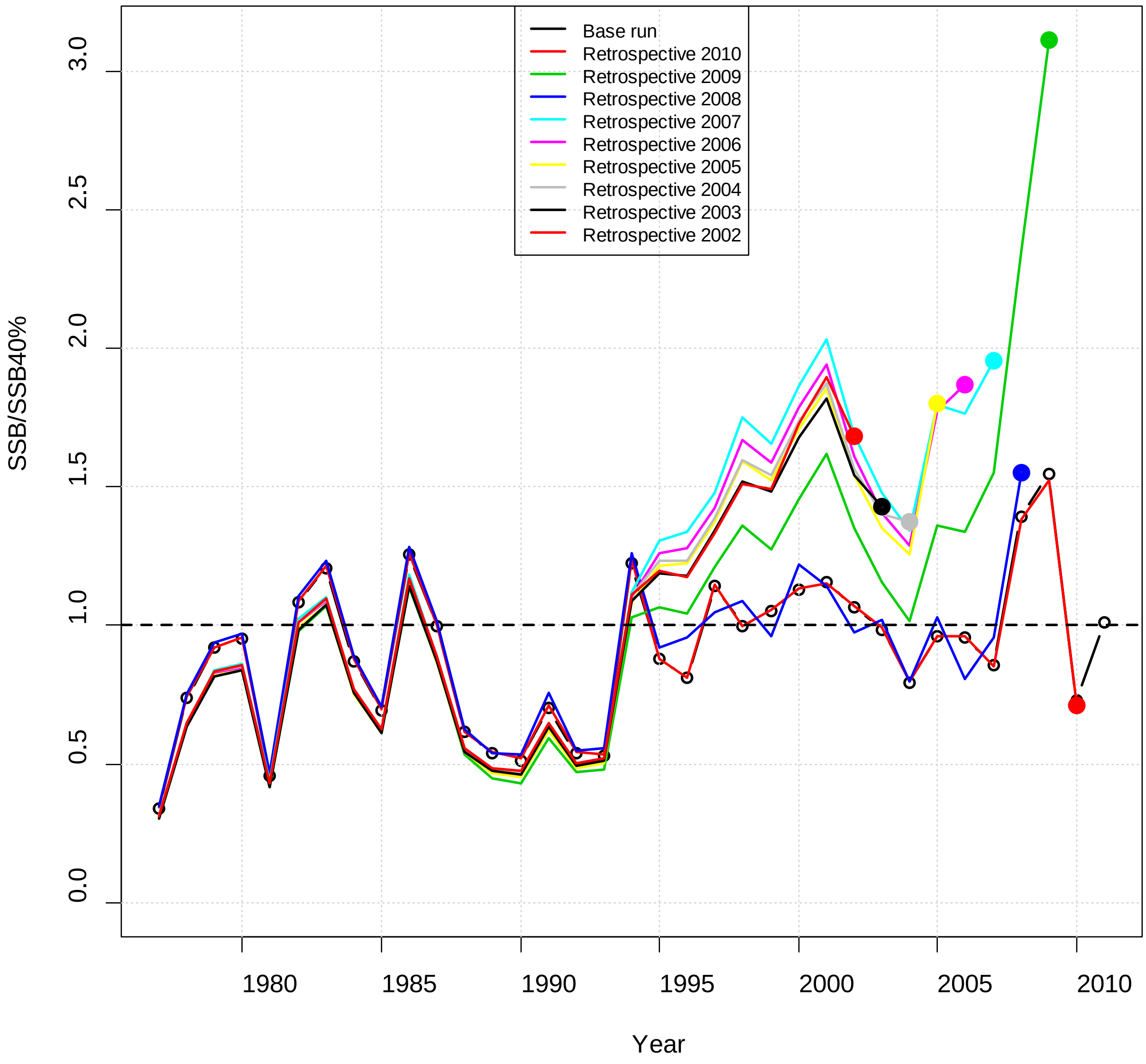


Figure 7.50 Fecundity (*SSB*) over $SSB_{40\%}$ for the retrospective analysis.

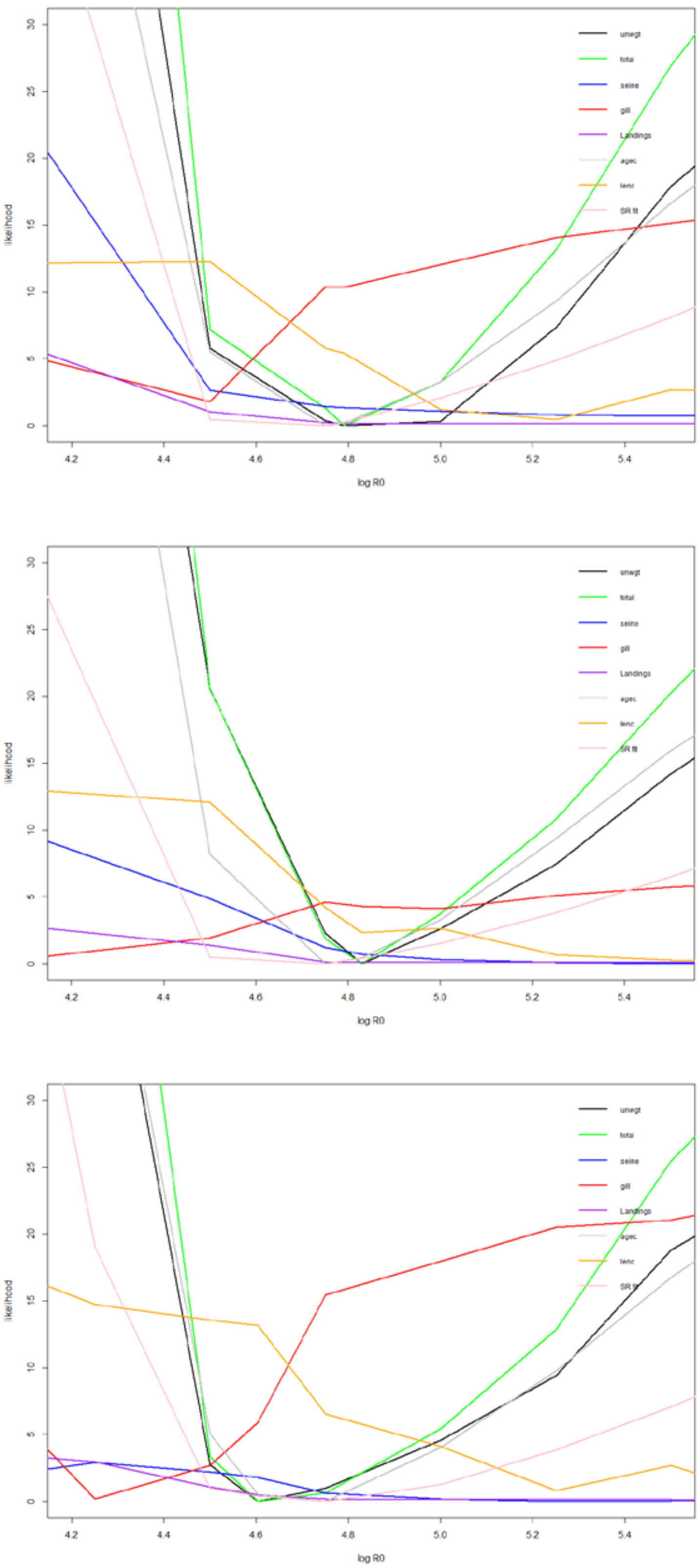


Figure 7.51 Likelihood profiles on R_0 for the base run with a terminal year of 2011 (top), with a terminal year of 2009 (middle), and will a terminal year of 2005 (bottom).

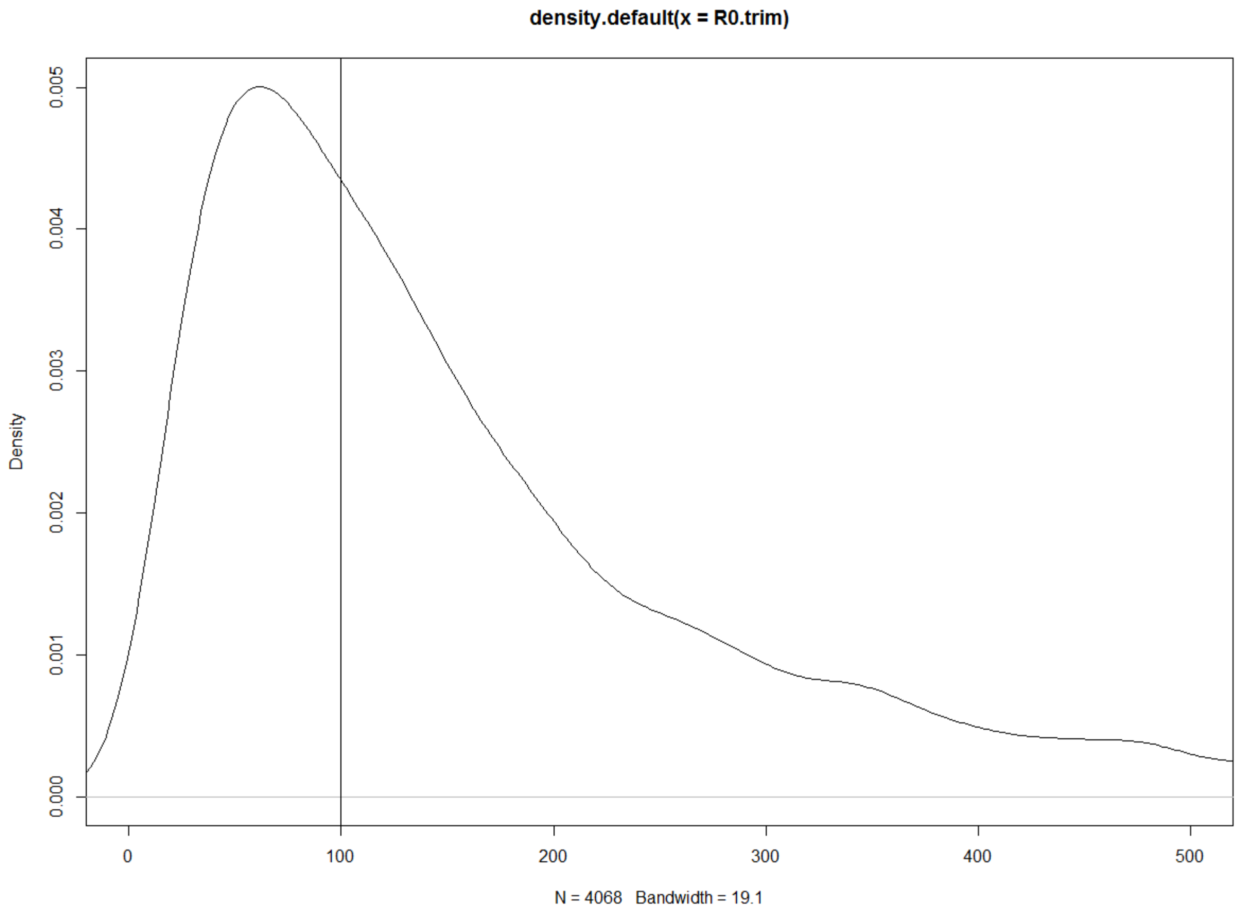


Figure 7.52 Estimated R_0 from the BAM model for the bootstrap runs after some runs were eliminated due to non-convergence.

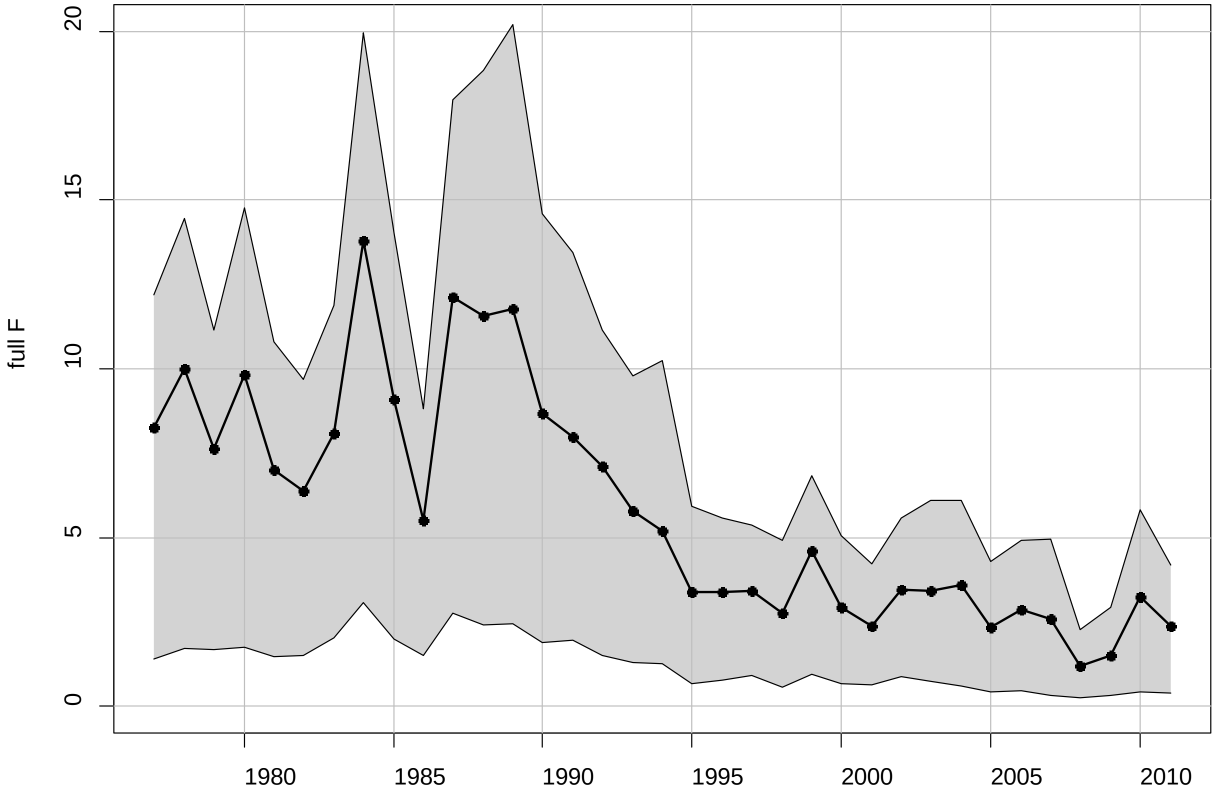


Figure 7.53 Estimated annual full *F* from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs after some runs were eliminated.

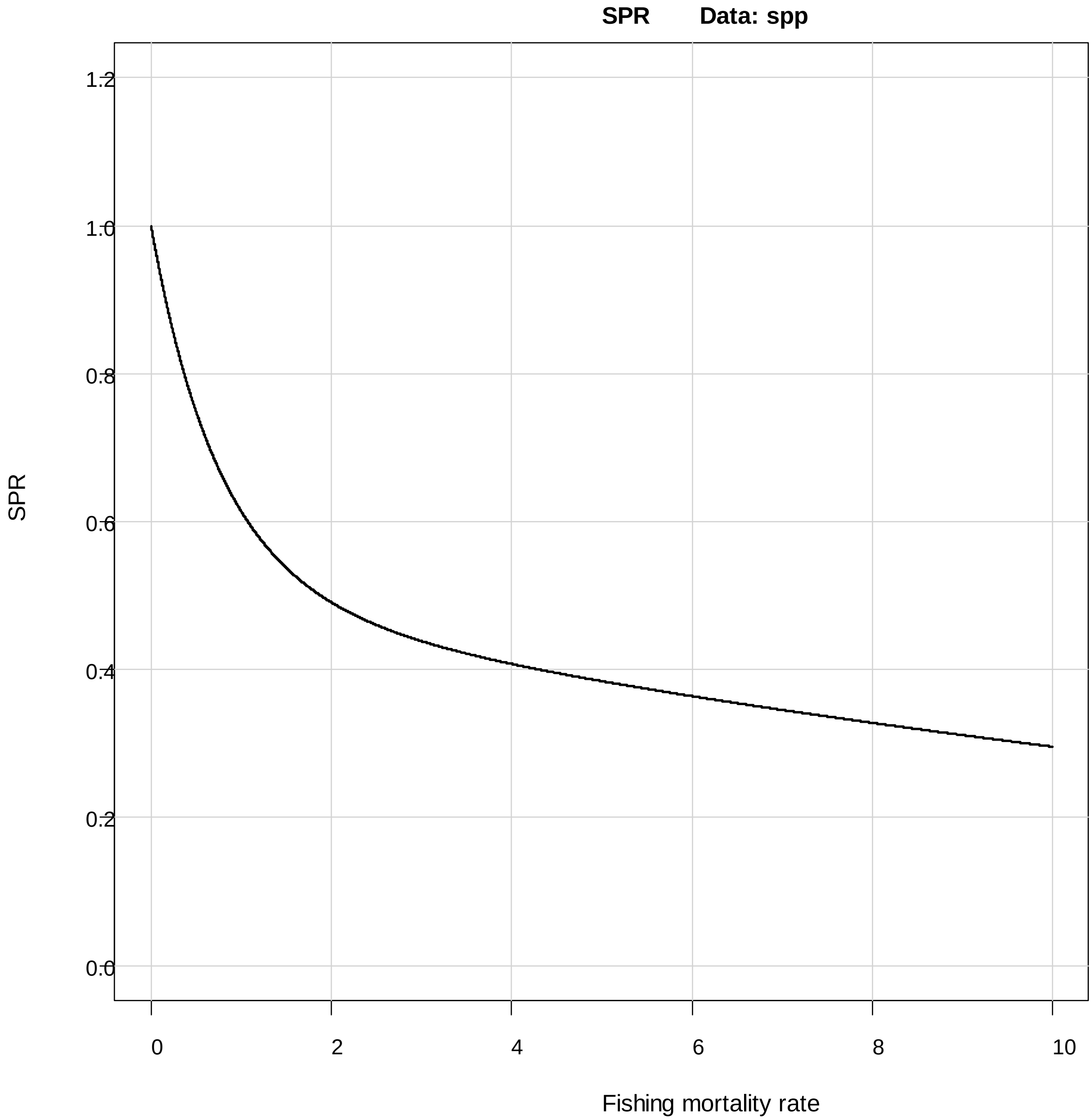


Figure 7.54 Estimates of the proportional (re-scaled to max of 1.0) fecundity-per-recruit as a function of the full fishing mortality rate from the base BAM model.

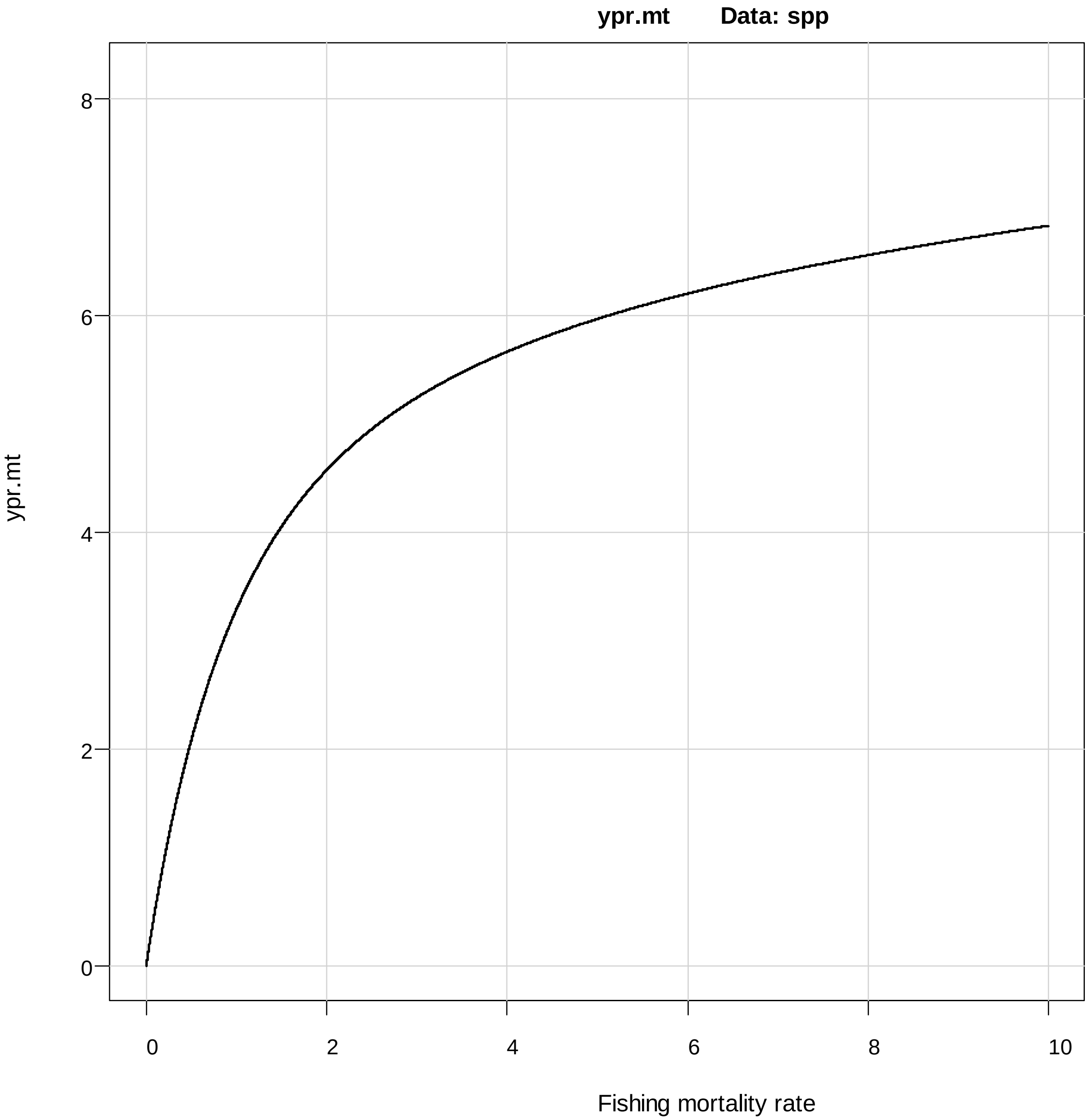


Figure 7.55 Estimates of the yield-per-recruit (mt/million) as a function of the full fishing mortality rate from the base BAM model.

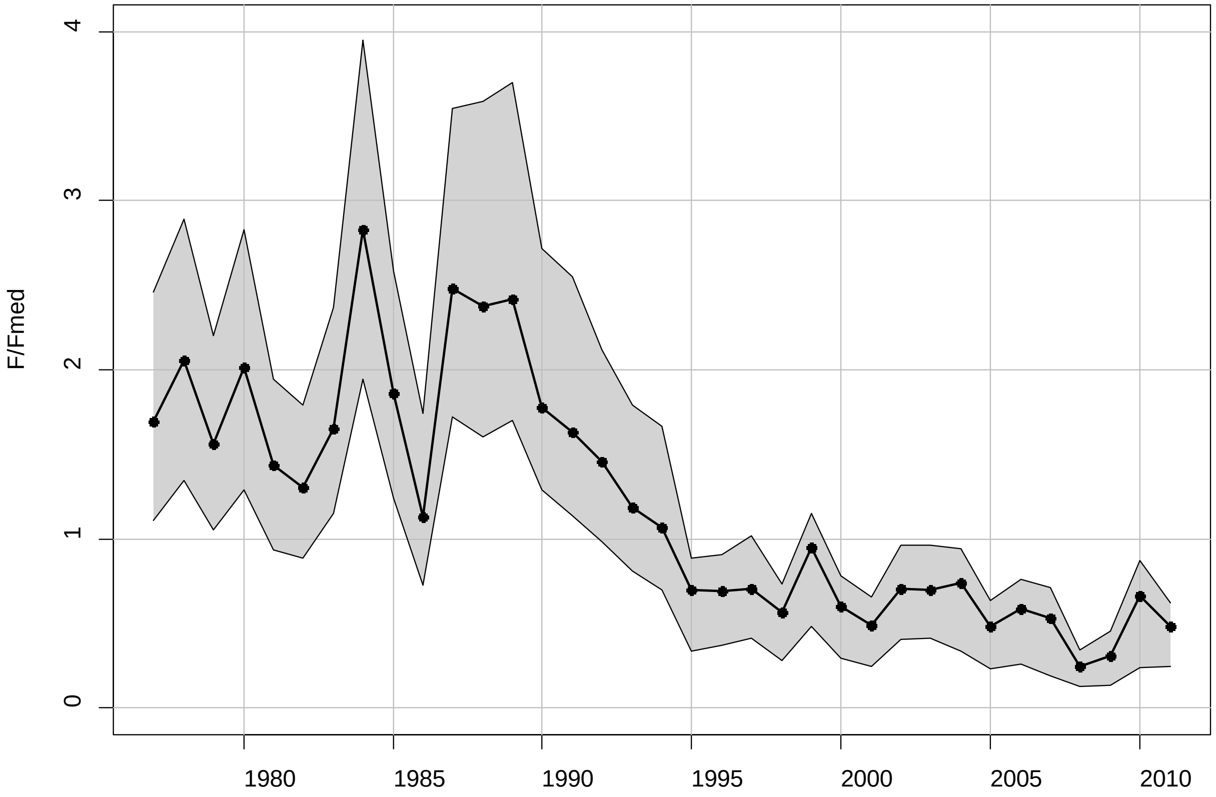


Figure 7.56 Estimates of the full fishing mortality rate relative to F_{MED} from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs.

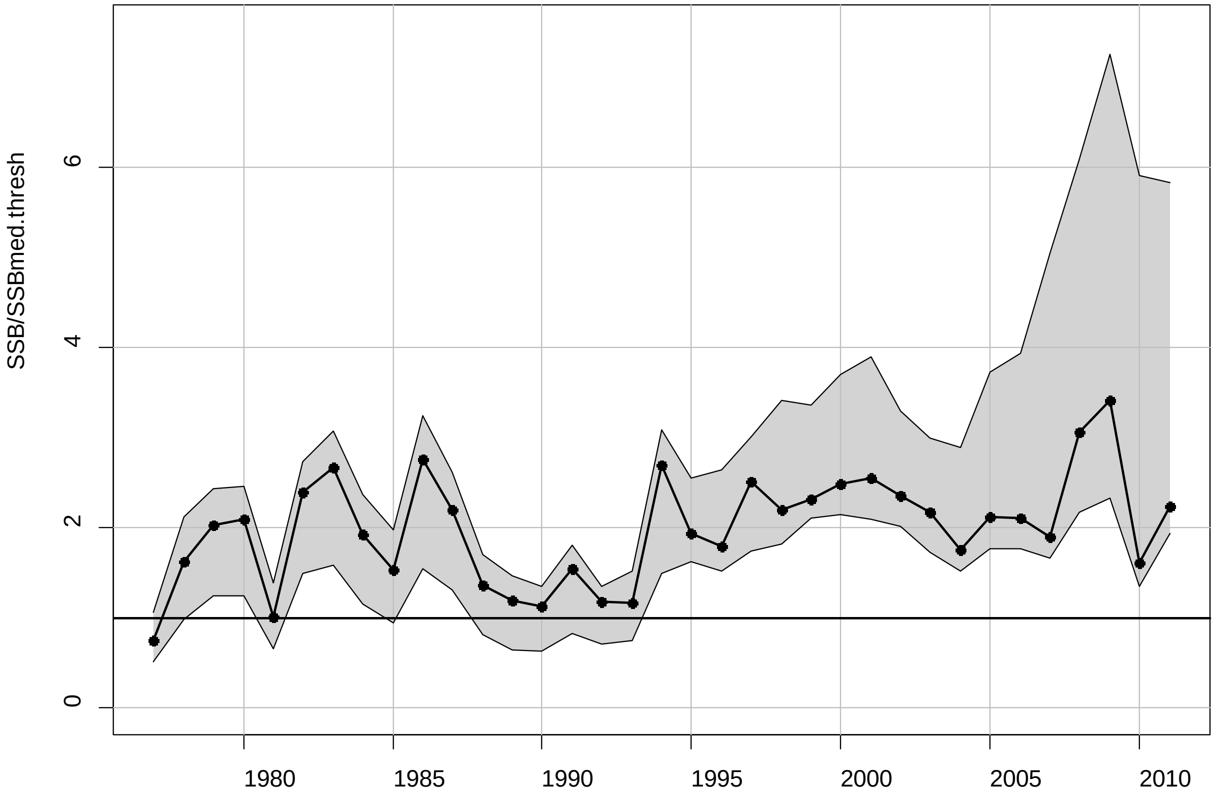


Figure 7.57 Estimates of the population fecundity (*SSB*) relative to $SSB_{MED.thresh}$ from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs.

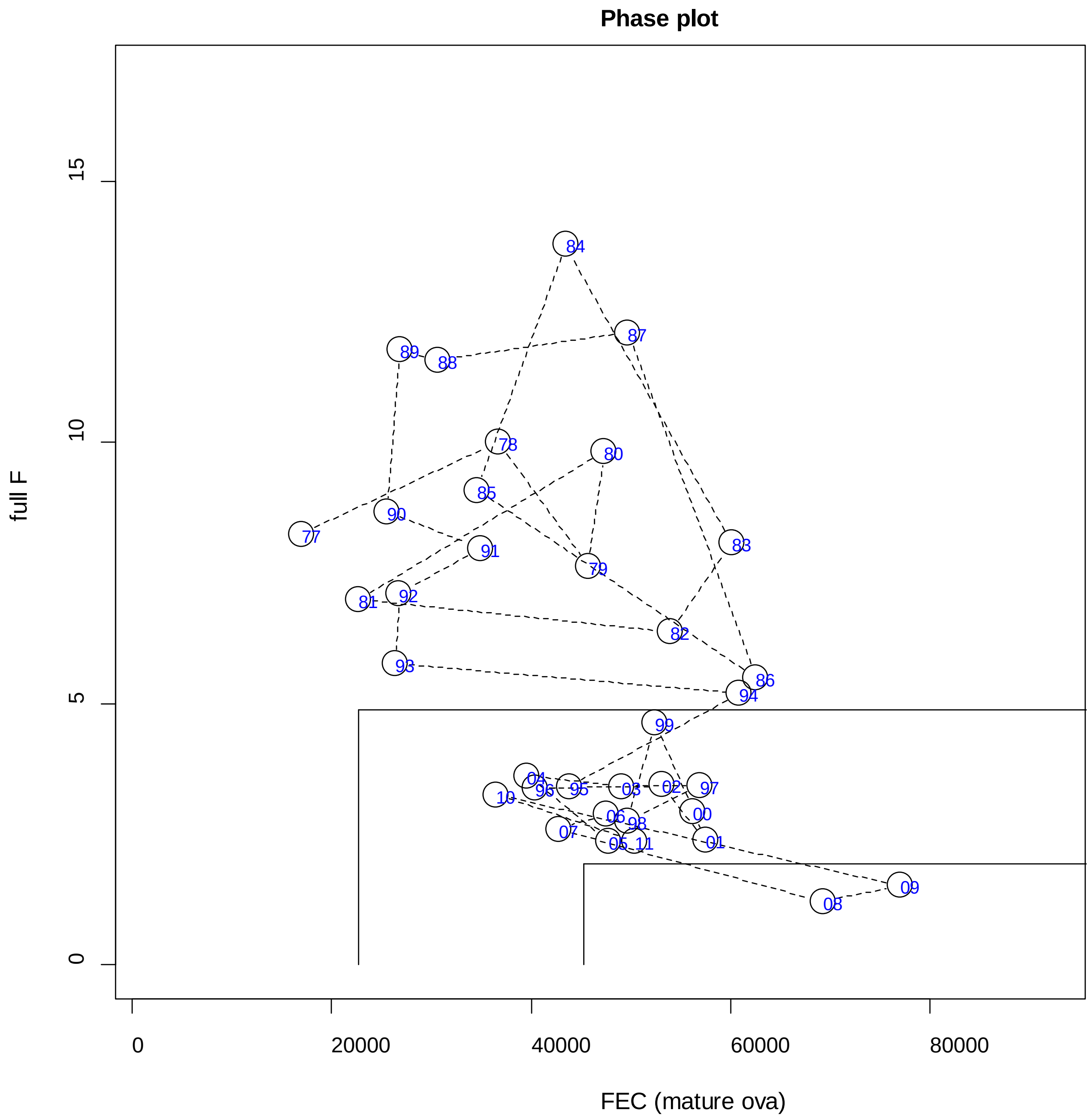


Figure 7.58 Phase plot of recent estimates of the population fecundity (mature ova in billions) and full fishing mortality rate from the base BAM model. Solid vertical and horizontal lines indicate the potential targets and limits for each respective axis. For this phase plot the F_{target} displayed is 0.75 F_{MED}; however, the management board needs to choose the most appropriate management target. Double digit number in circles indicates the year of the point estimate (e.g. 10 = 2010).

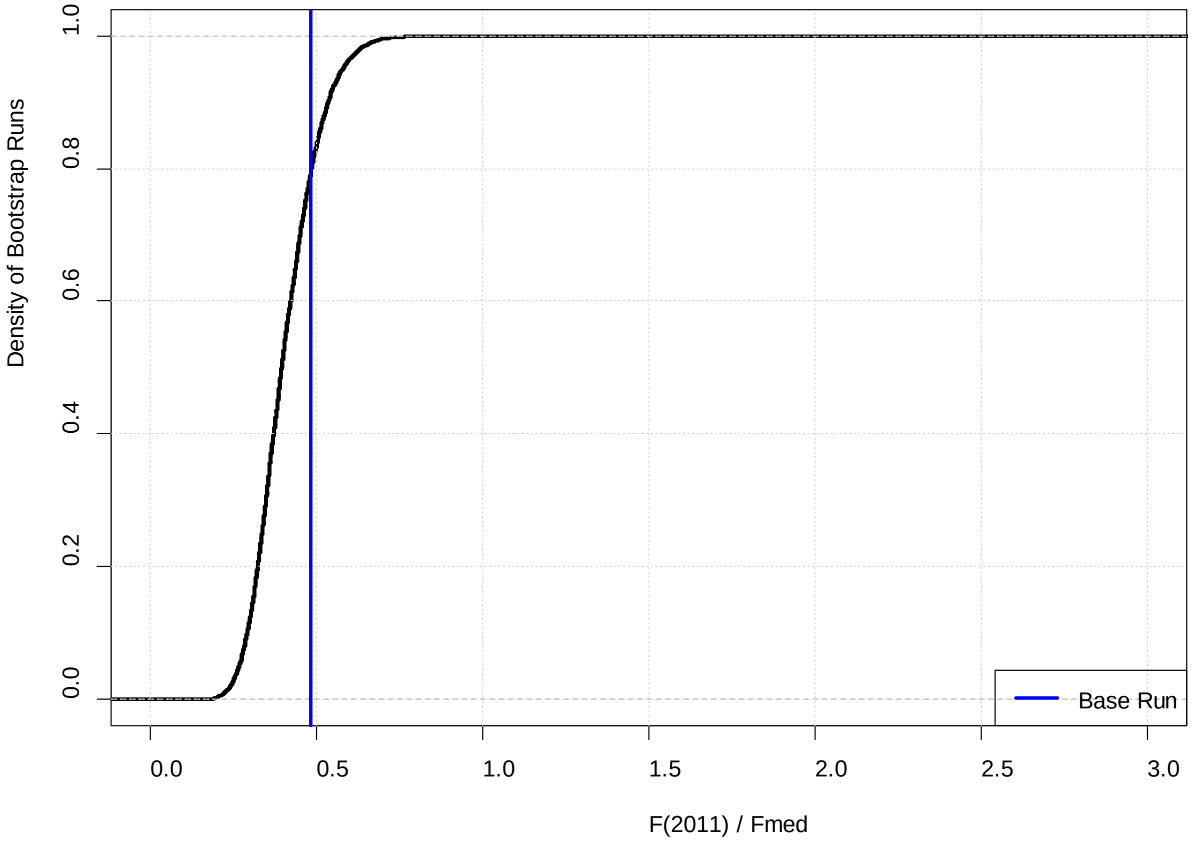


Figure 7.59 Cumulative probability density distribution of the full fishing mortality rate in 2011 relative to F_{MED} from the bootstrap estimates from the base BAM model.

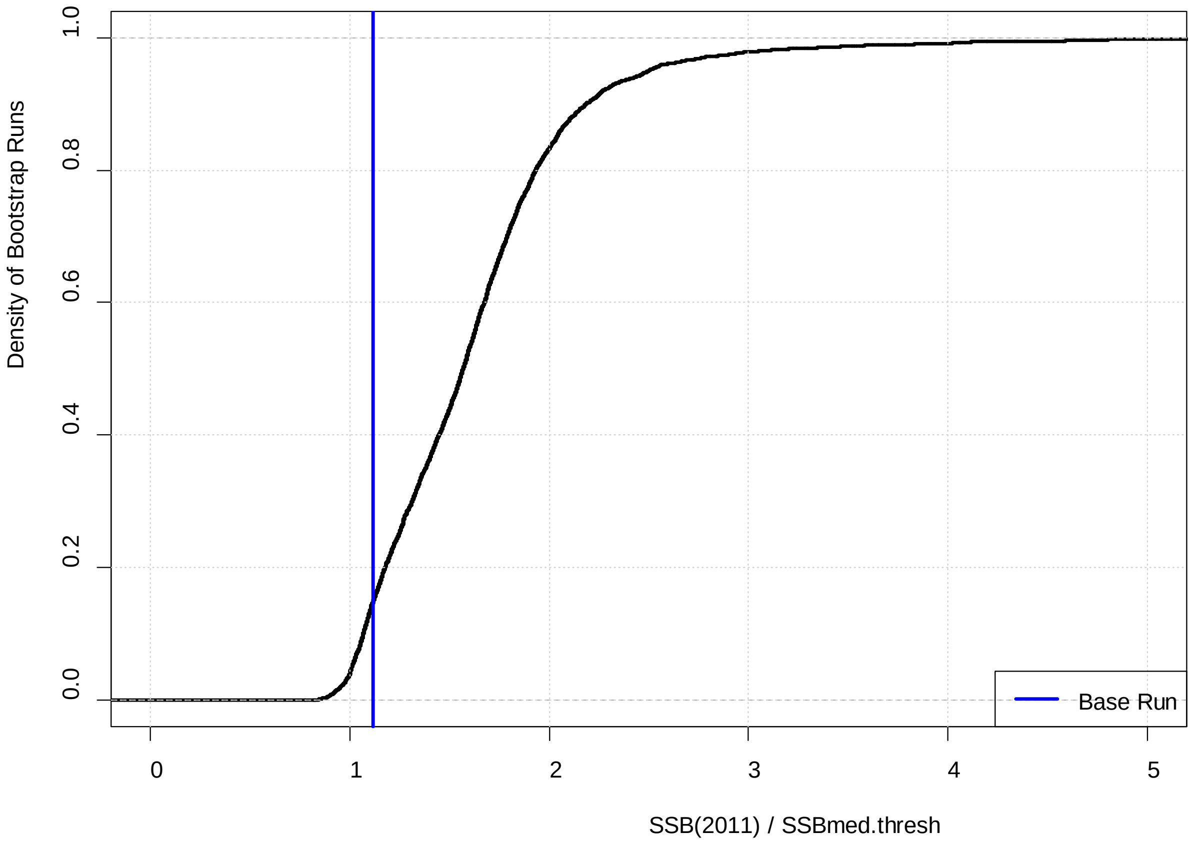


Figure 7.60 Cumulative probability density distribution of the population fecundity in 2011 relative to $SSB_{MED.thresh}$ from the bootstrap estimates from the base BAM model.

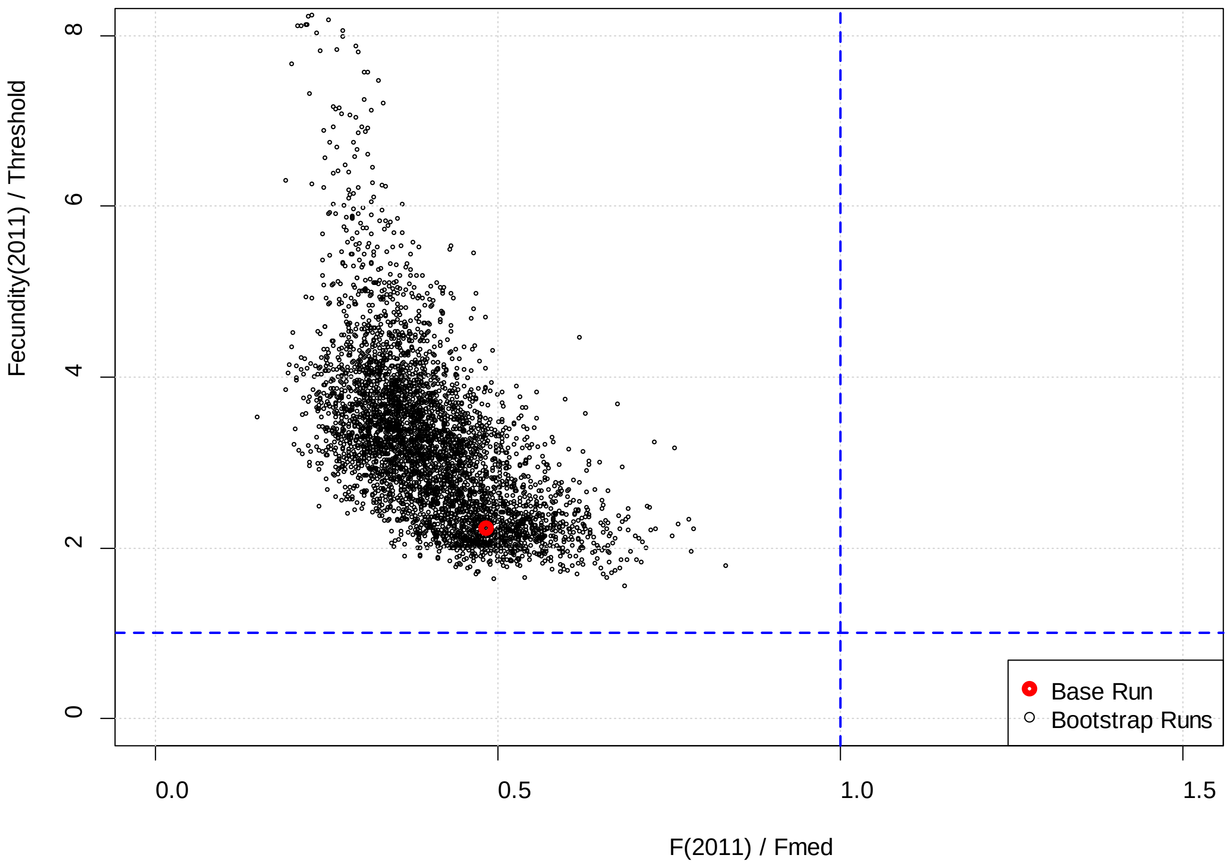


Figure 7.61 Scatter plot of the 2011 estimates relative to F_{MED} and $SSB_{MED.thresh}$ from the 4,068 bootstrap estimates (excluding those that were unable to converge) from the base BAM model.

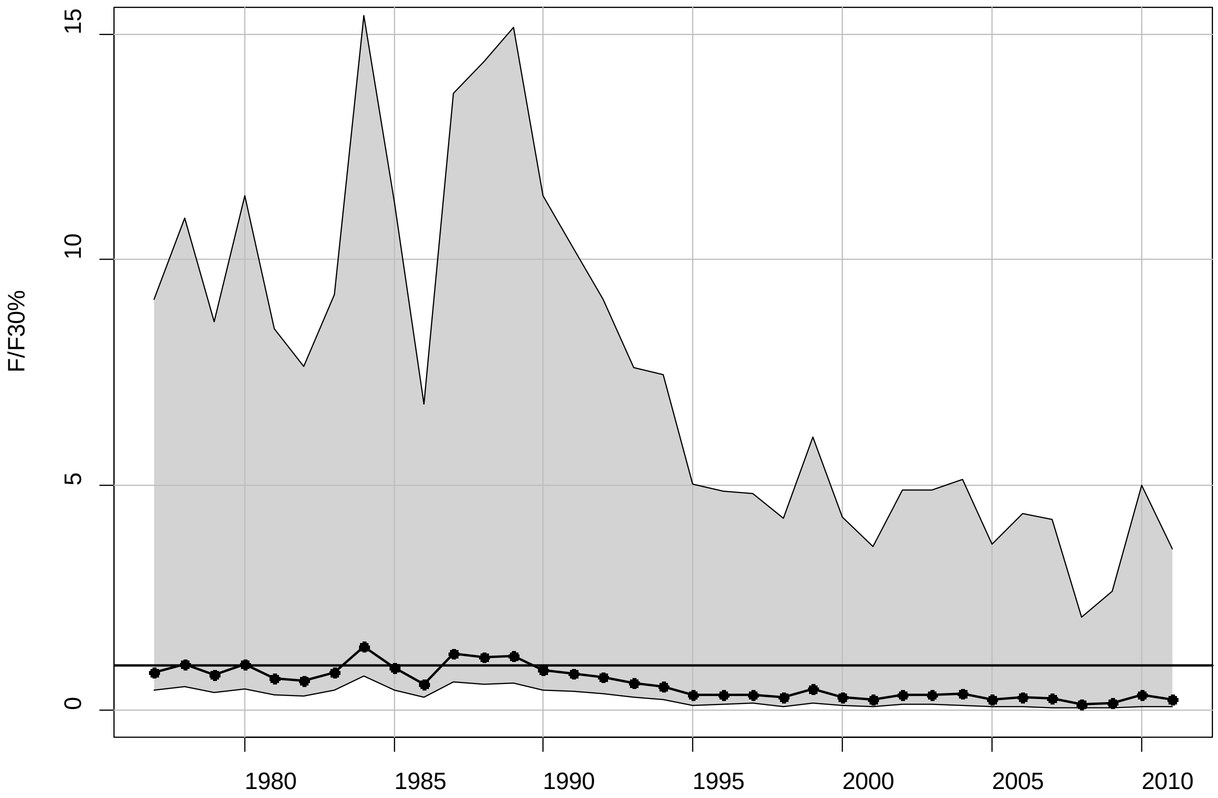


Figure 7.62 Estimates of the full fishing mortality rate relative to the $F_{30\%}$ potential benchmark from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs.

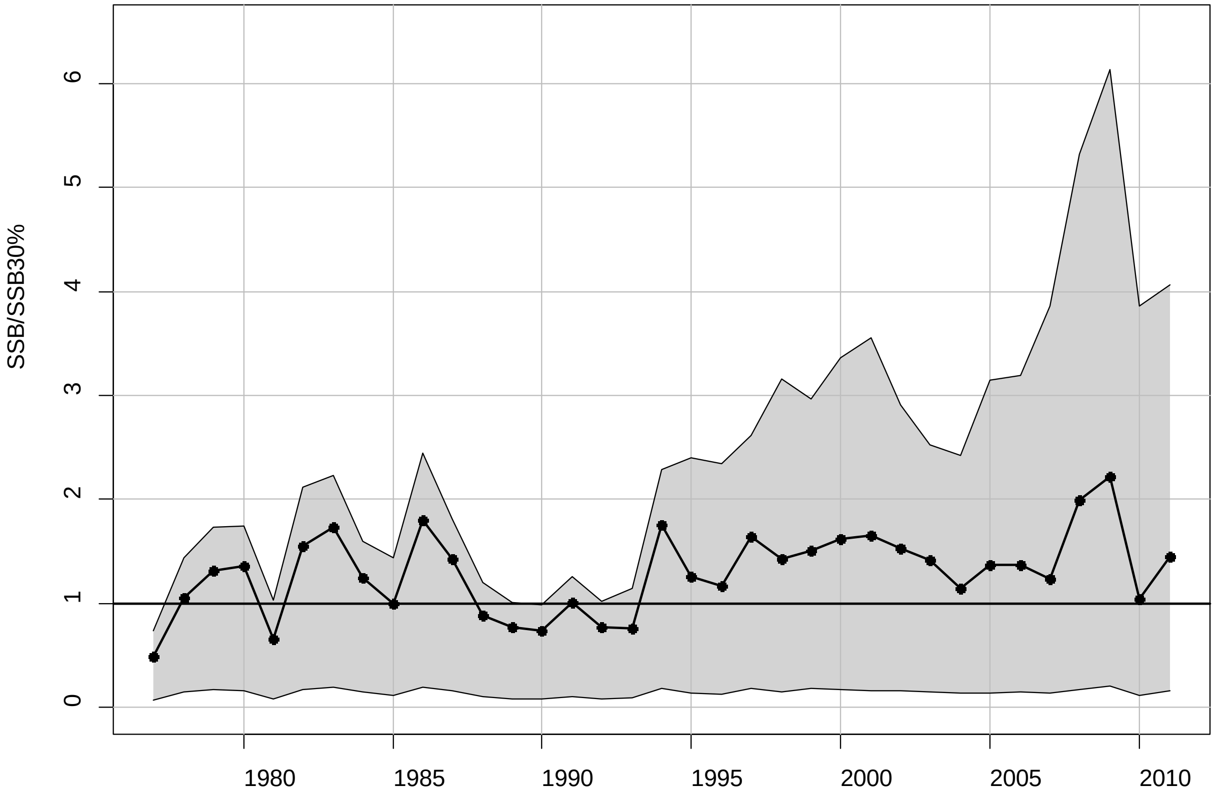


Figure 7.63 Estimates of the population fecundity (*SSB*) relative to $SSB_{30\%}$ from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs.

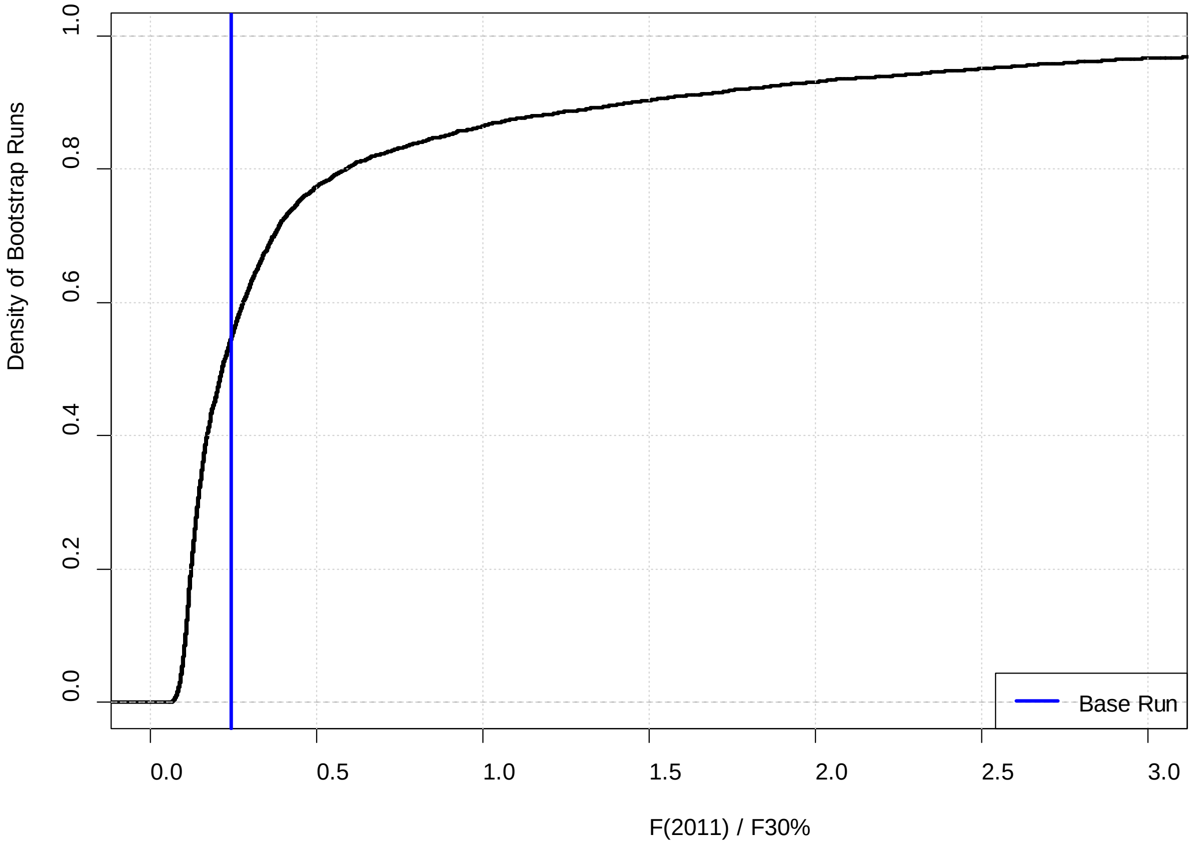


Figure 7.64 Cumulative probability density distribution of the full fishing mortality rate in 2011 relative to $F_{30\%}$ from the bootstrap estimates from the base BAM model.

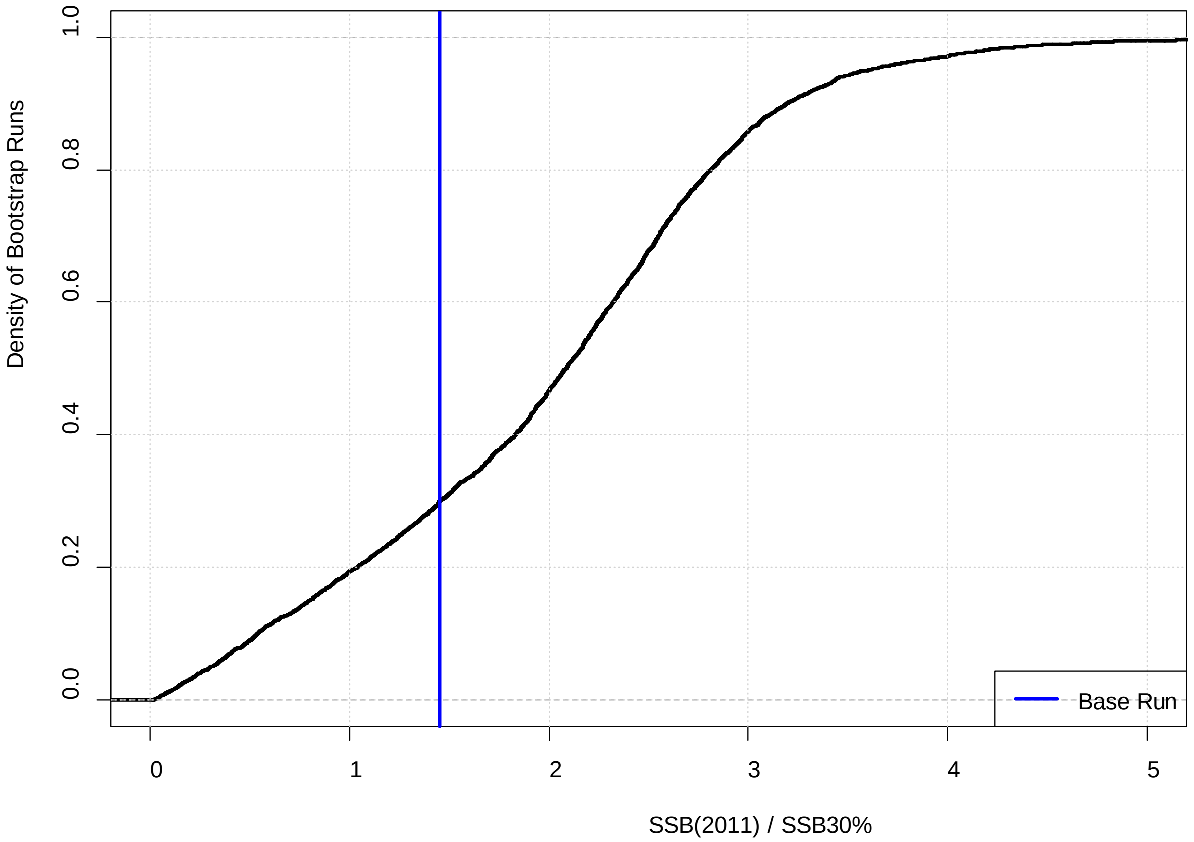


Figure 7.65 Cumulative probability density distribution of the population fecundity in 2011 relative to $SSB_{30\%}$ from the bootstrap estimates from the base BAM model.

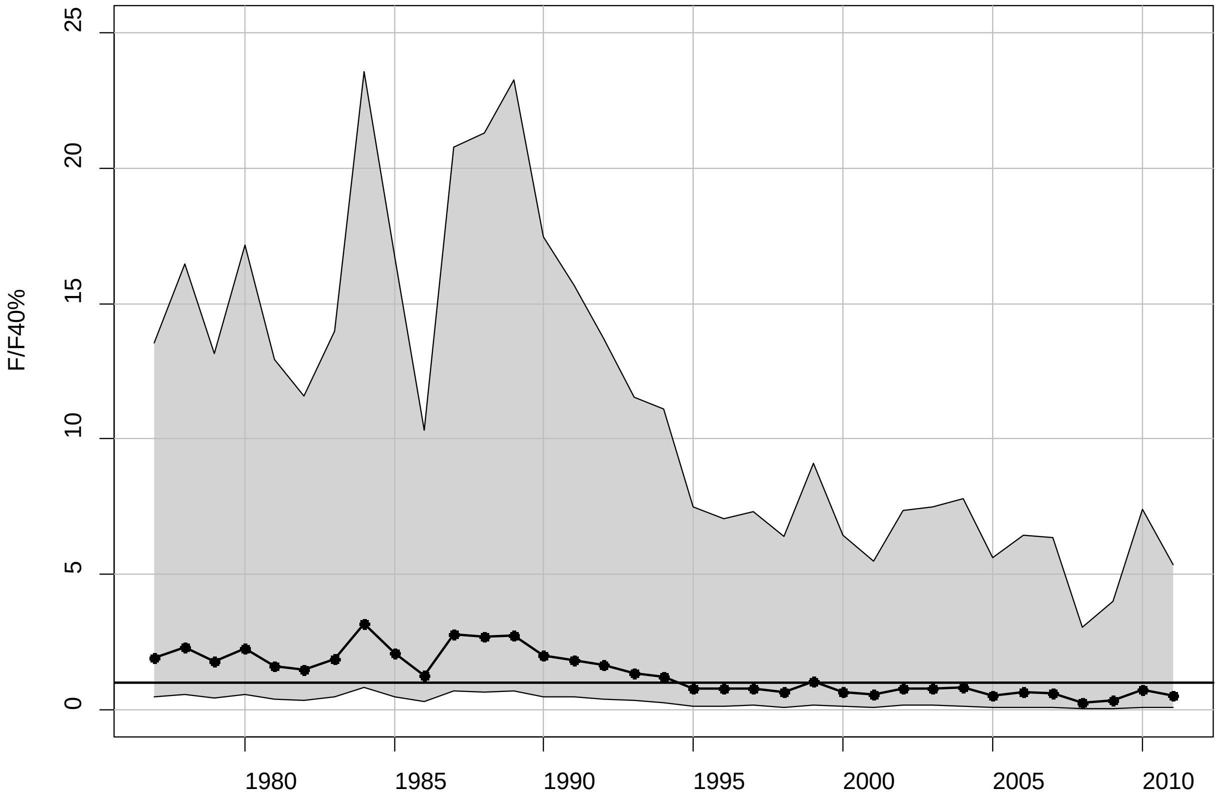


Figure 7.66 Estimates of the full fishing mortality rate relative to the $F_{40\%}$ potential benchmark from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs.

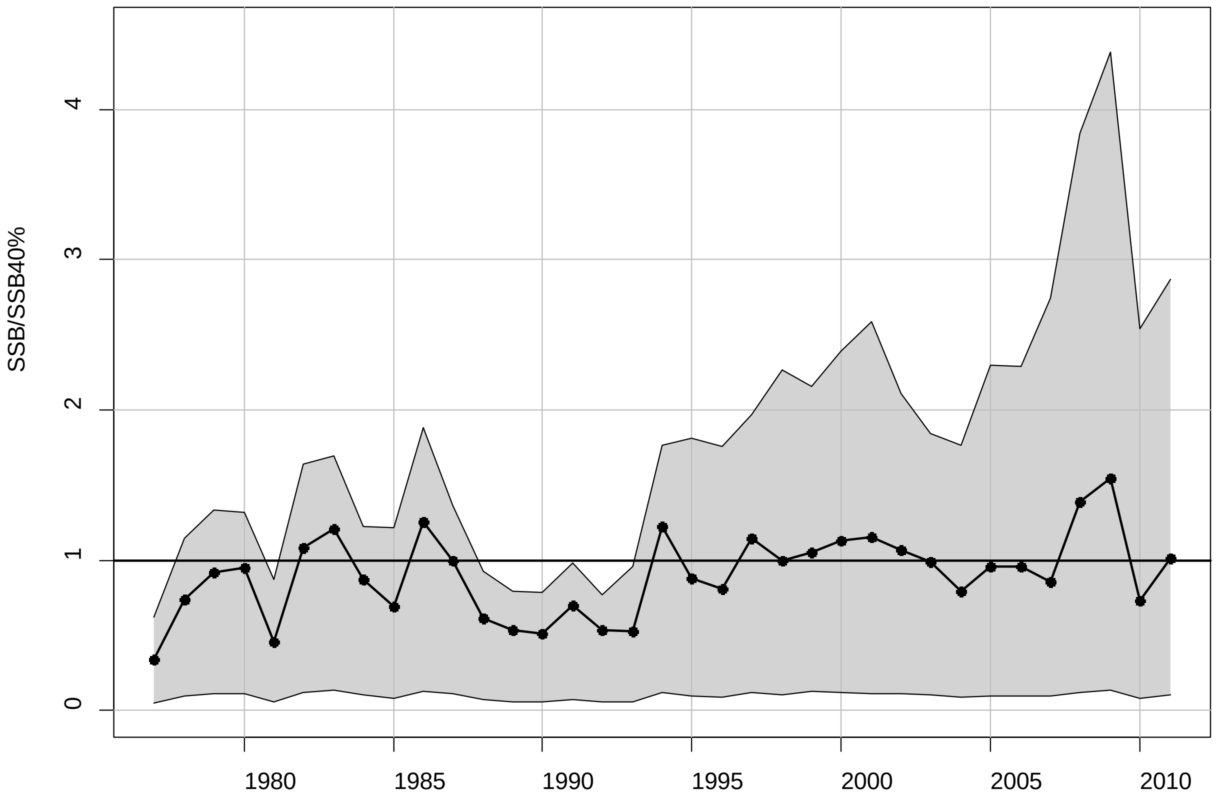


Figure 7.67 Estimates of the population fecundity (*SSB*) relative to $SSB_{40\%}$ from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs.

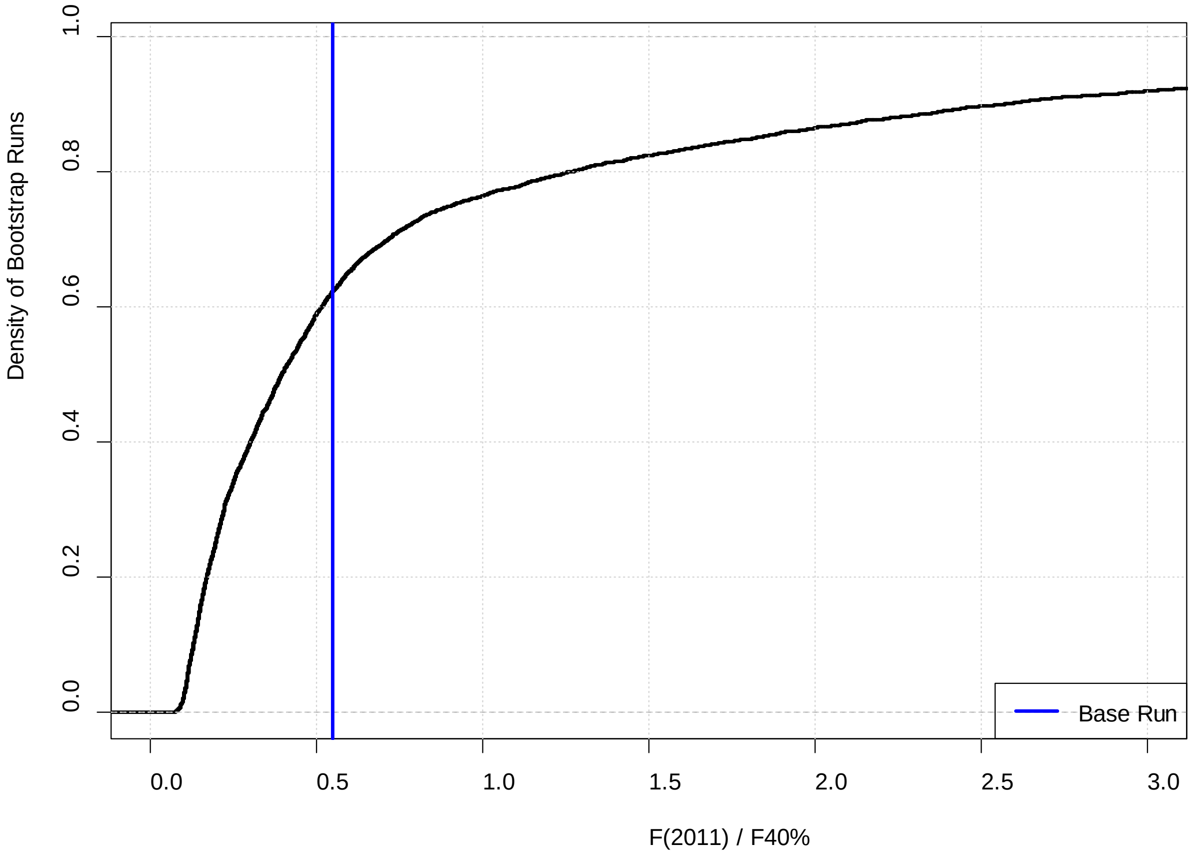


Figure 7.68 Cumulative probability density distribution of the full fishing mortality rate in 2011 relative to $F_{40\%}$ from the bootstrap estimates from the base BAM model.

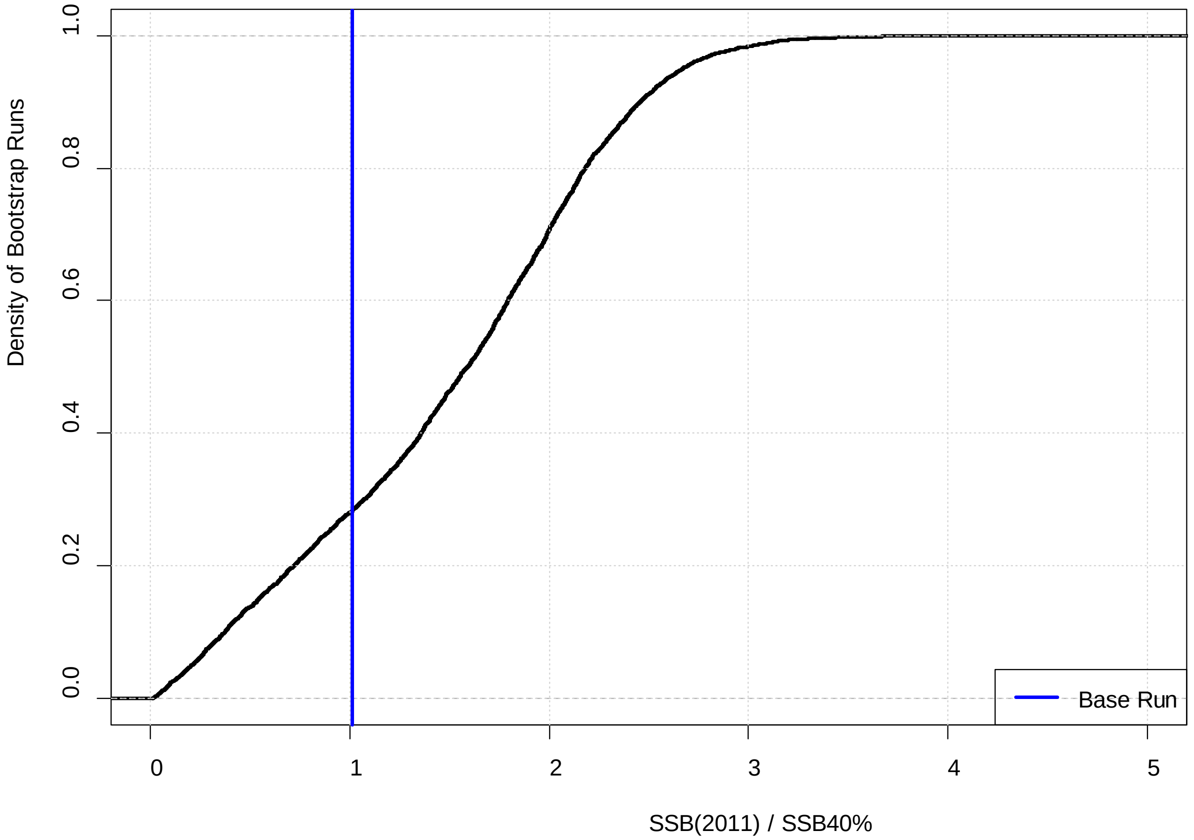


Figure 7.69 Cumulative probability density distribution of the population fecundity in 2011 relative to $SSB_{40\%}$ from the bootstrap estimates from the base BAM model.

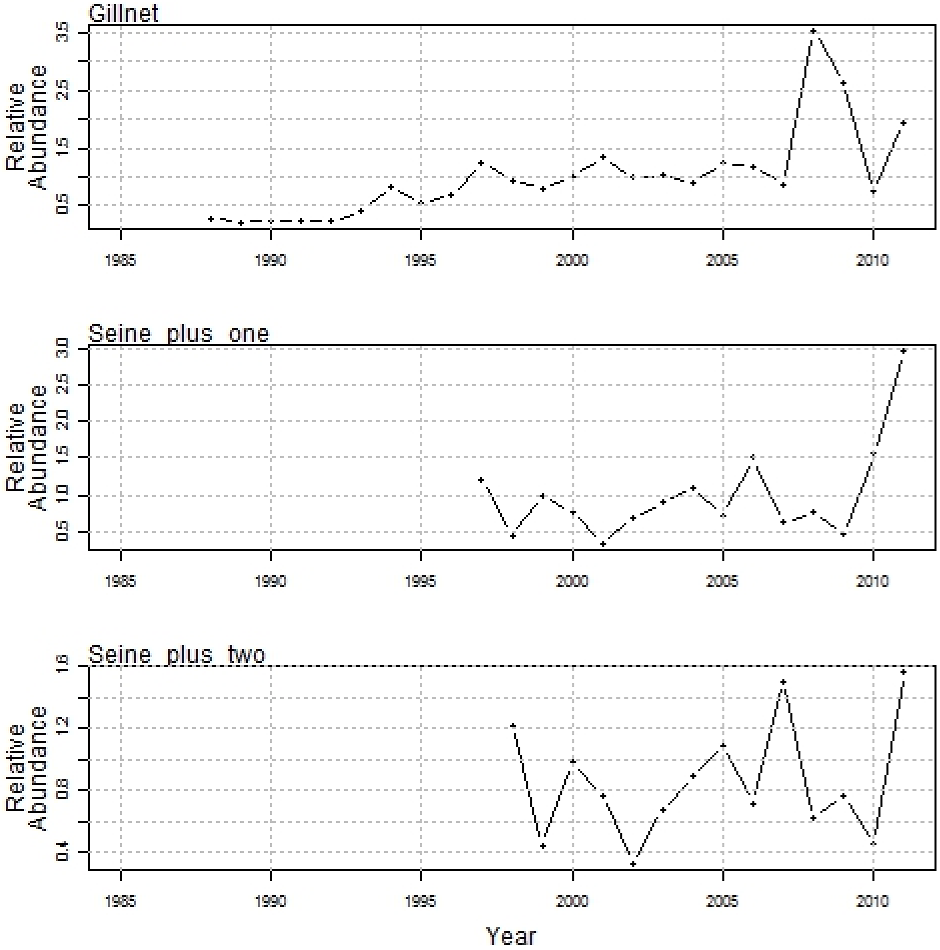


Figure 7.70 Abundance indices used in production modeling of Gulf menhaden.

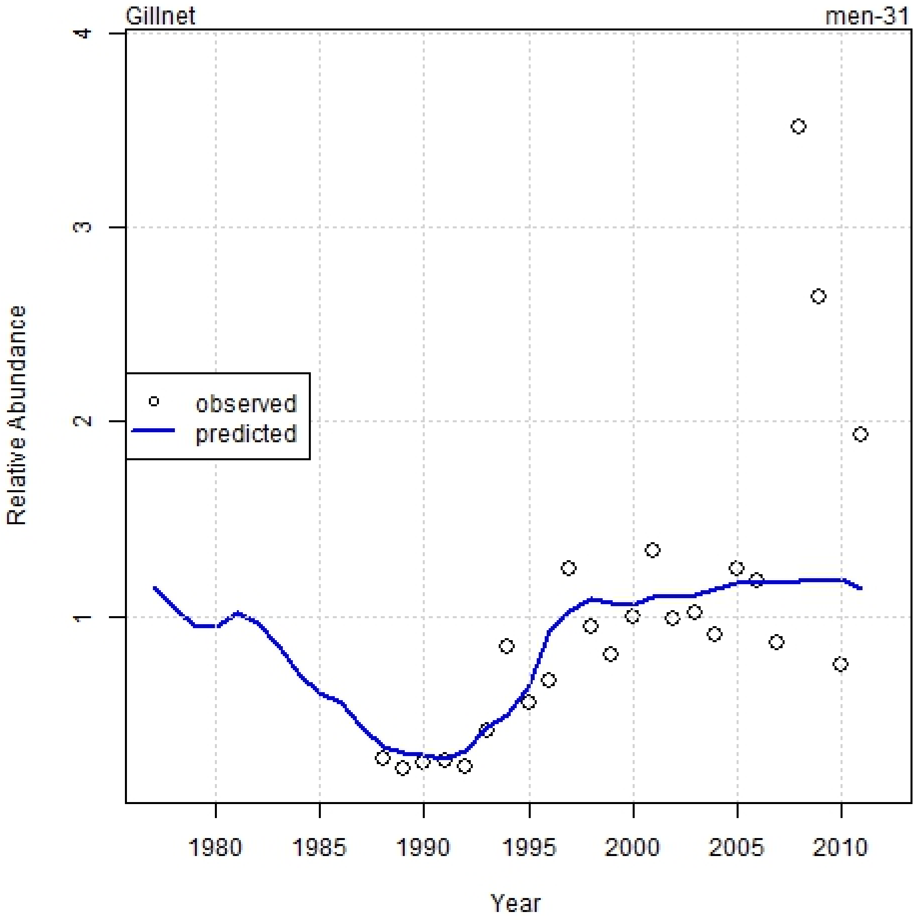


Figure 7.71 Fit of base production model (men-31) to adult gill net index.

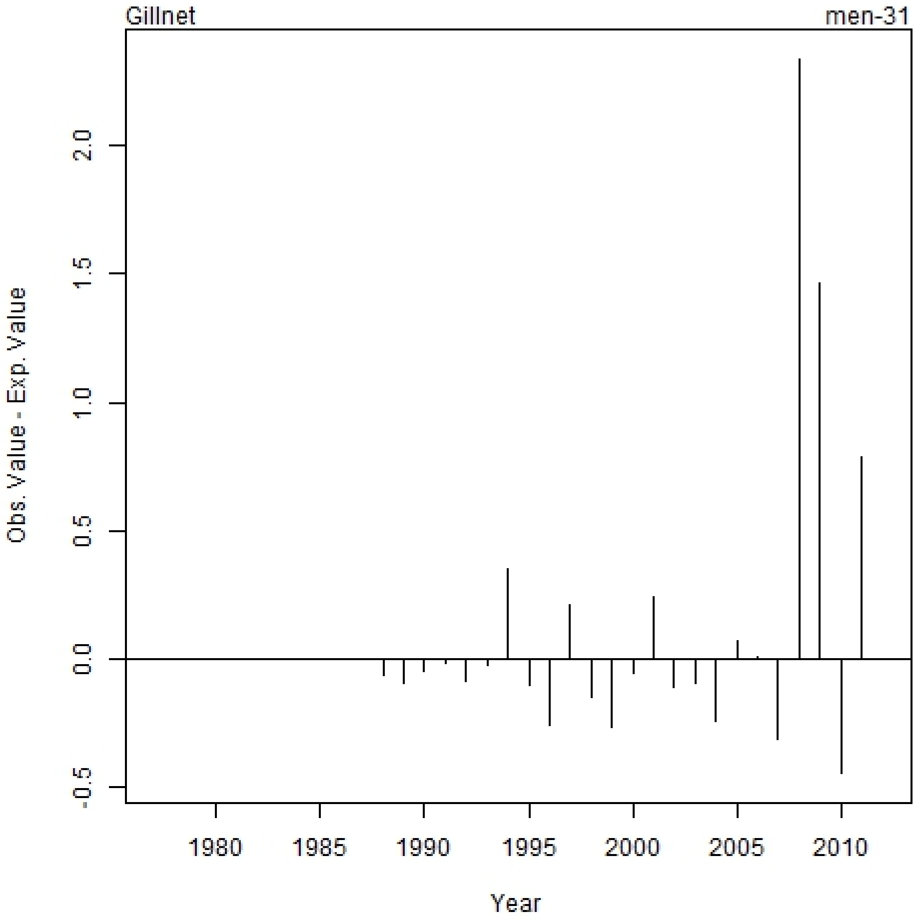


Figure 7.72 Residual pattern of abundance (observed – expected) of base production model (men-31) to adult gill net index.

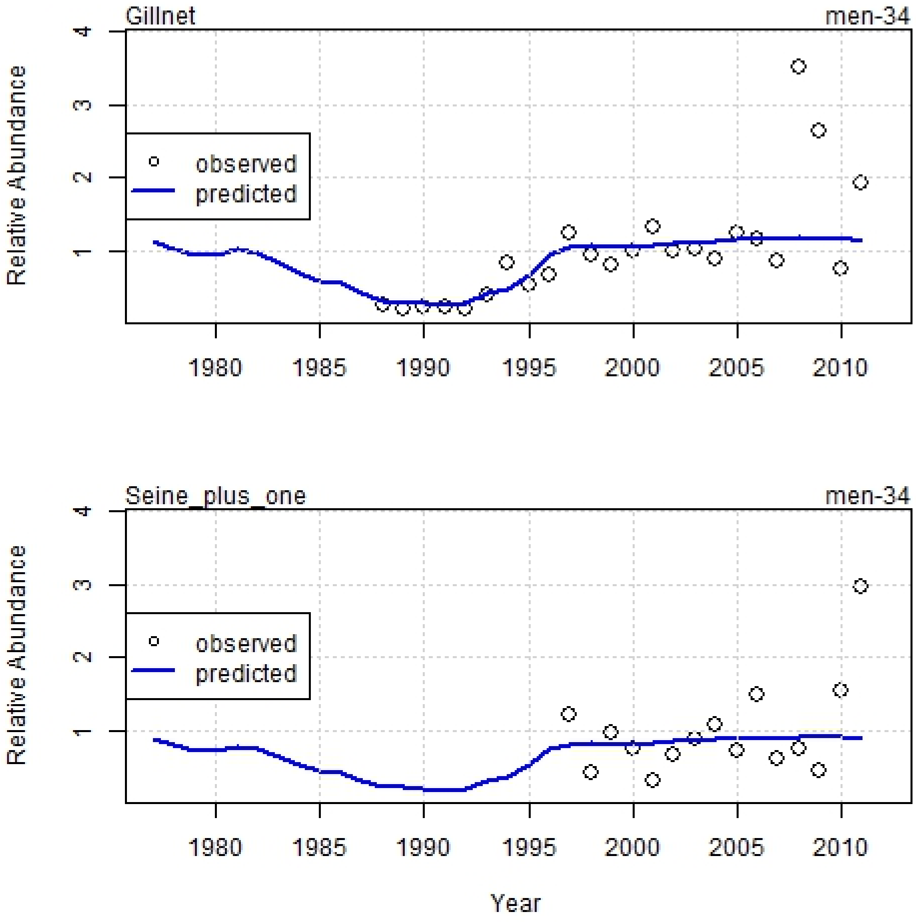


Figure 7.73 Fit of production model sensitivity run with recruitment seine index +1 and adult gill net index (men-34).

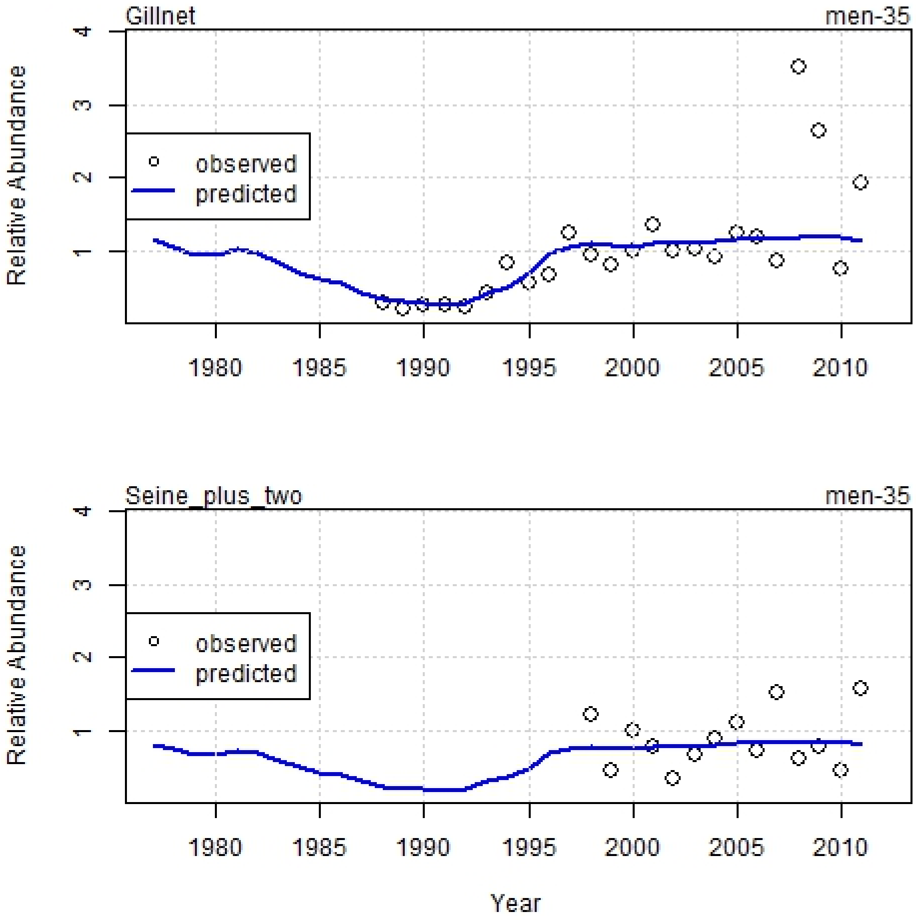


Figure 7.74 Fit of production model sensitivity run with recruitment seine index +1 and adult gill net index (men-35).

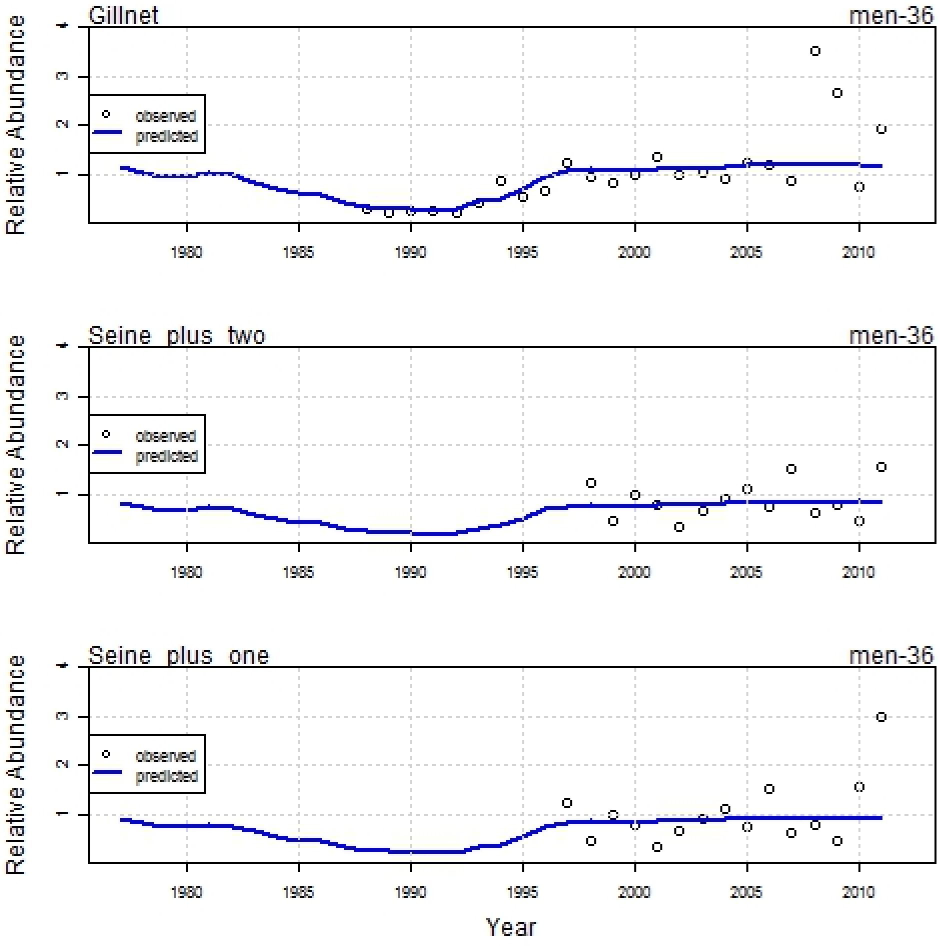


Figure 7.75 Fit of production model sensitivity run with recruitment seine index +1, recruitment index + 2, and adult gill net index (men-36).

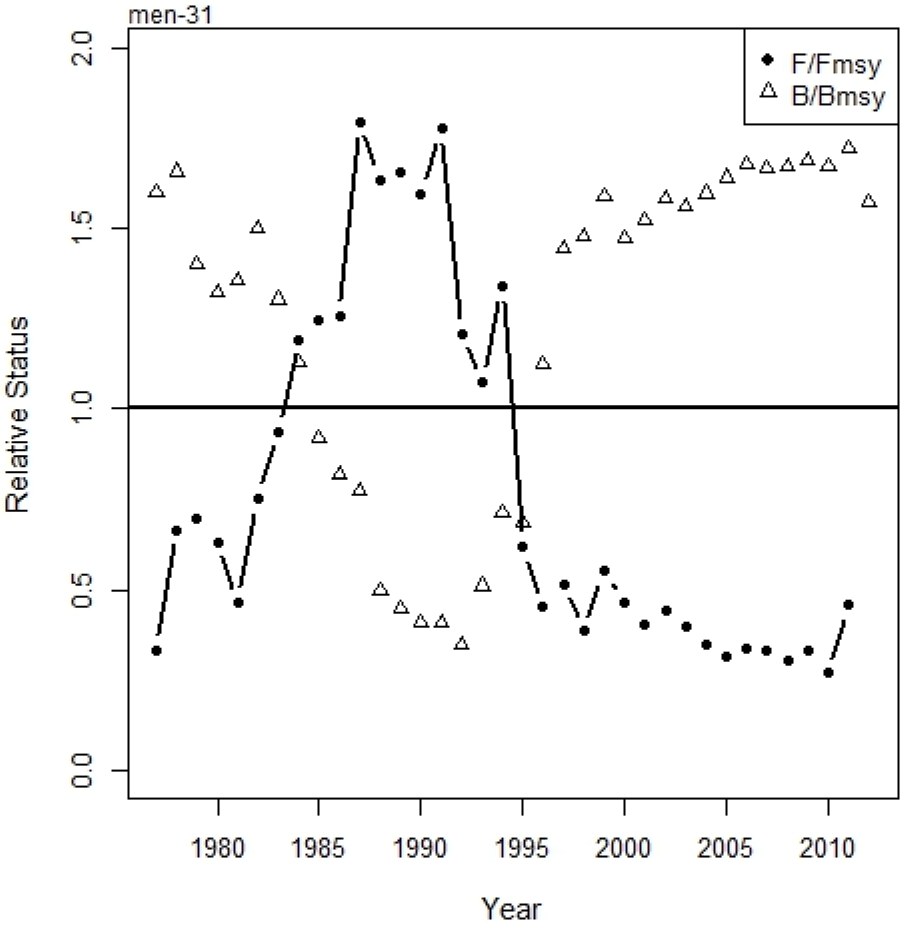


Figure 7.76 Trajectories of relative biomass and fishing mortality estimated from primary model configuration.

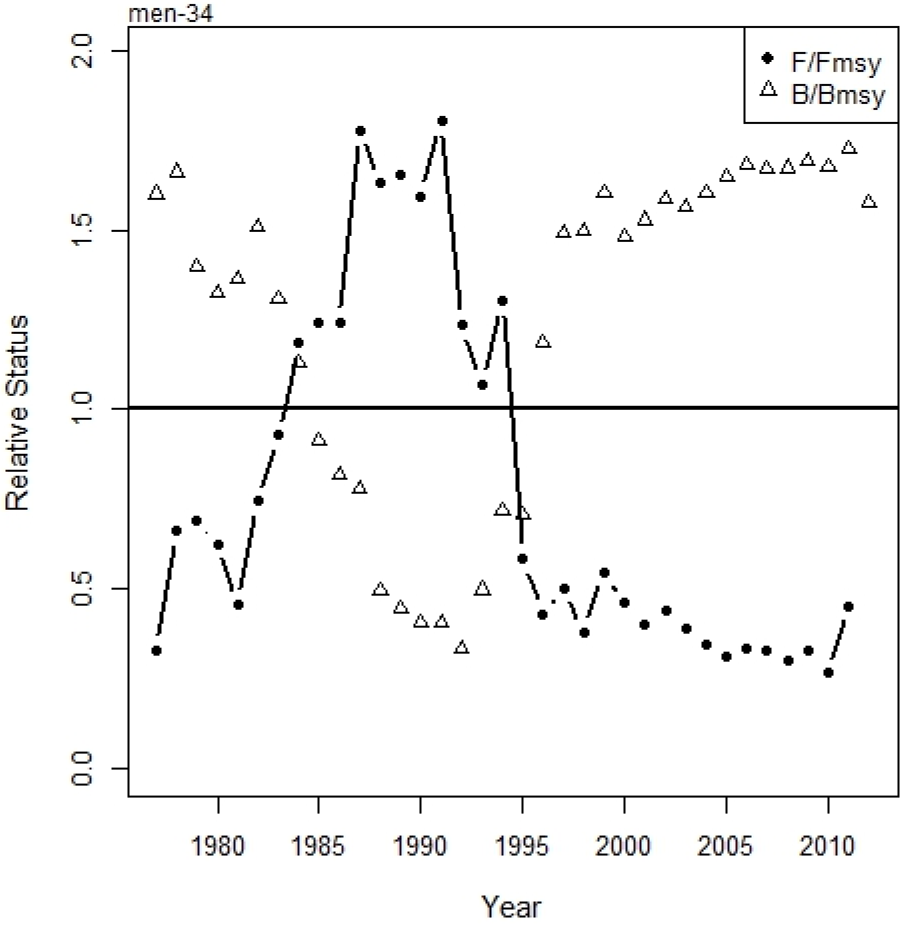


Figure 7.77 Trajectories of relative biomass and fishing mortality estimated from model configuration with recruitment seine index +1 and adult gill net index (men-34).

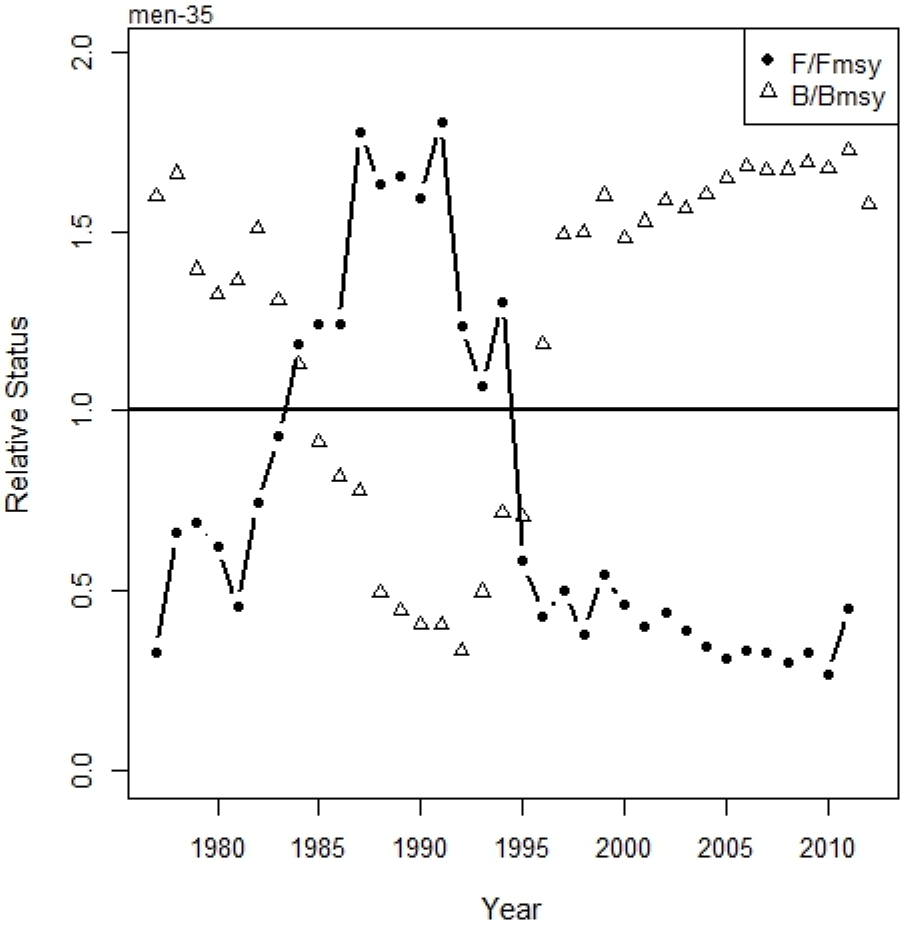


Figure 7.78 Trajectories of relative biomass and fishing mortality estimated from model configuration with recruitment seine index +2 and adult gill net index (men-35).

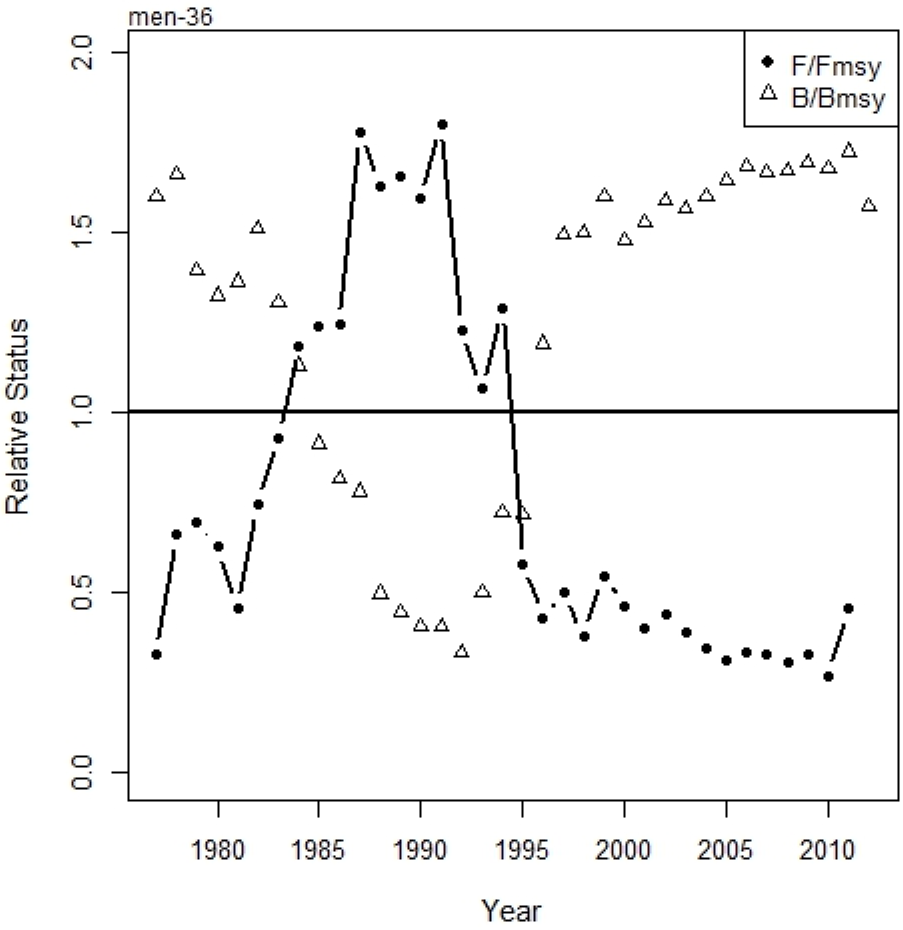


Figure 7.79 Trajectories of relative biomass and fishing mortality estimated from model configuration with recruitment seine index +2, recruitment index +2 and adult gill net index (men-36).

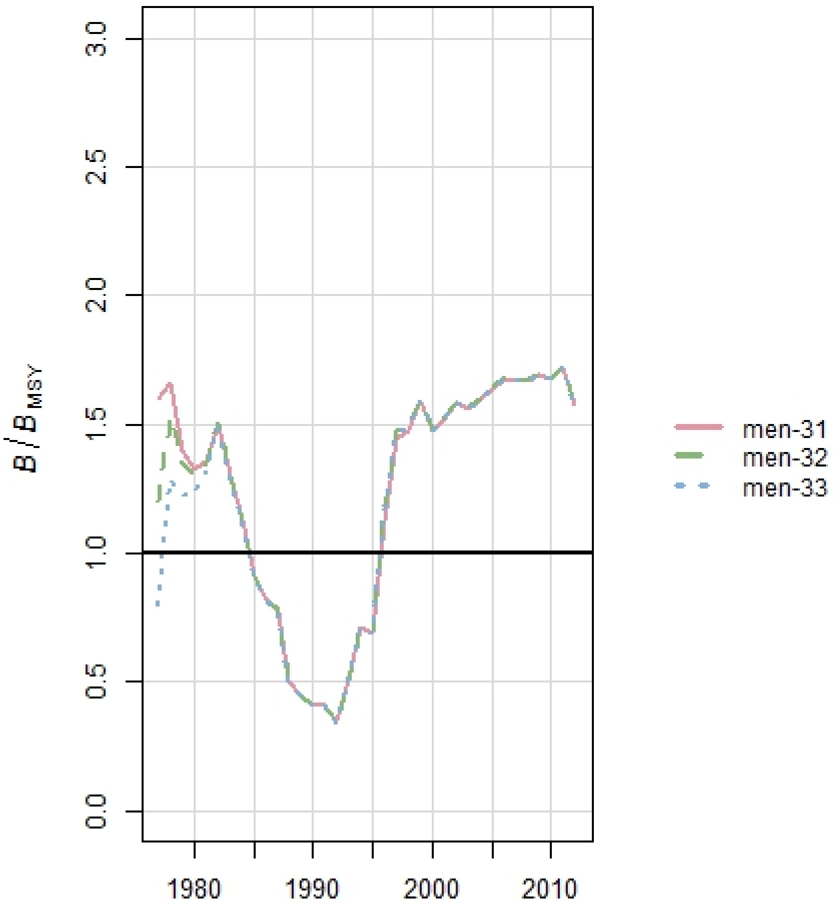


Figure 7.80 Time trajectory of stock-status estimates. Sensitivity of production model to assumed initial conditions. Run men-31 is the primary configuration, B_1 = 0.80K. Runs min-32 and men-33 are sensitivity runs and assume B_1 = 0.60K and B_1 = 0.40K, respectively.

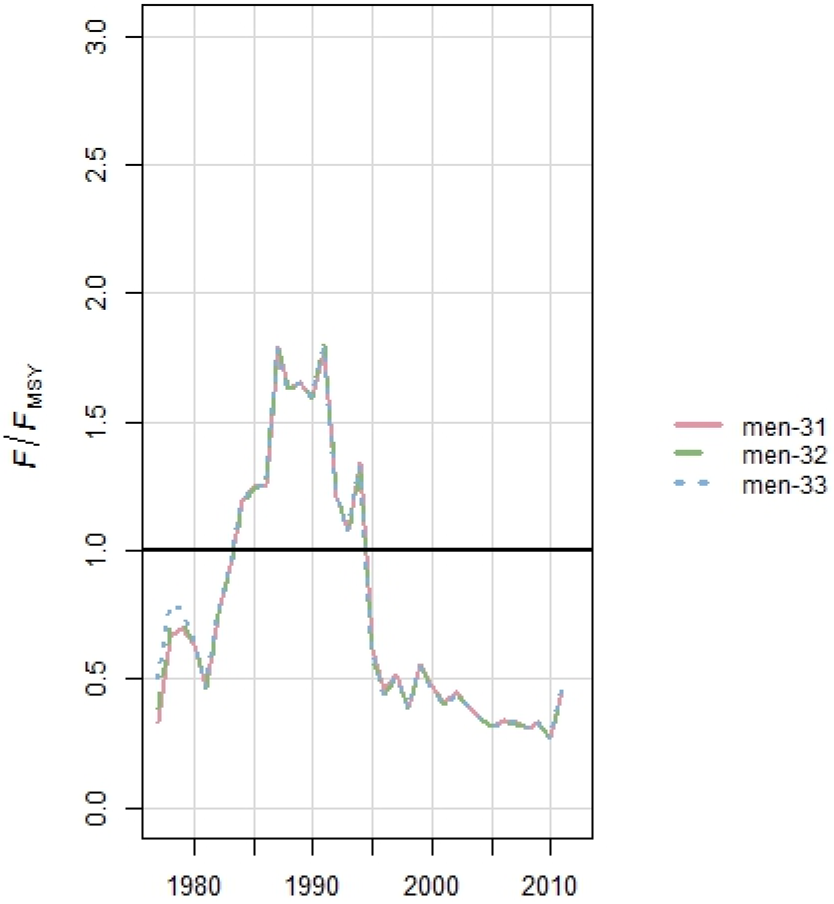


Figure 7.81 Time trajectory of fishing-status estimates. Sensitivity of production model to assumed initial conditions. Run men-31 is the primary configuration, B_1 = 0.80*K*. Runs min-32 and men-33 are sensitivity runs and assume B_1 = 0.60*K* and B_1 = 0.40*K*, respectively.

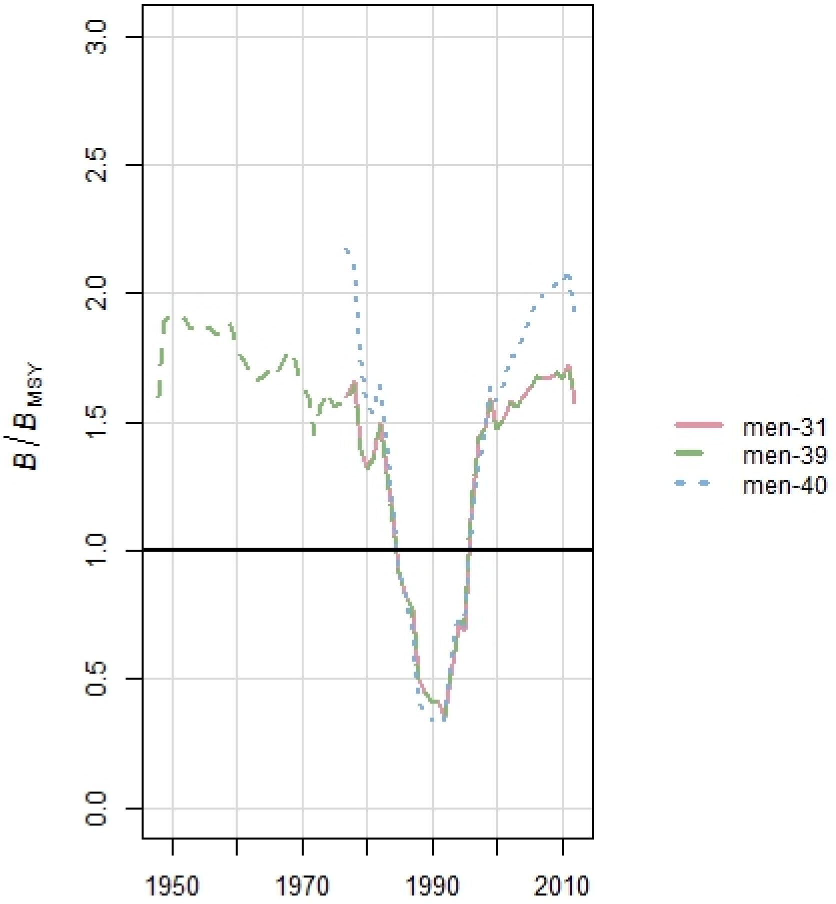


Figure 7.82 Time trajectory of stock-status estimates. Sensitivity of production model to alternative model shape and extended landings time series. Run men-31 is the primary configuration, Runs min-39 and men-40 are sensitivity runs using the extended landings (start 1948) and Fox model shape, respectively.

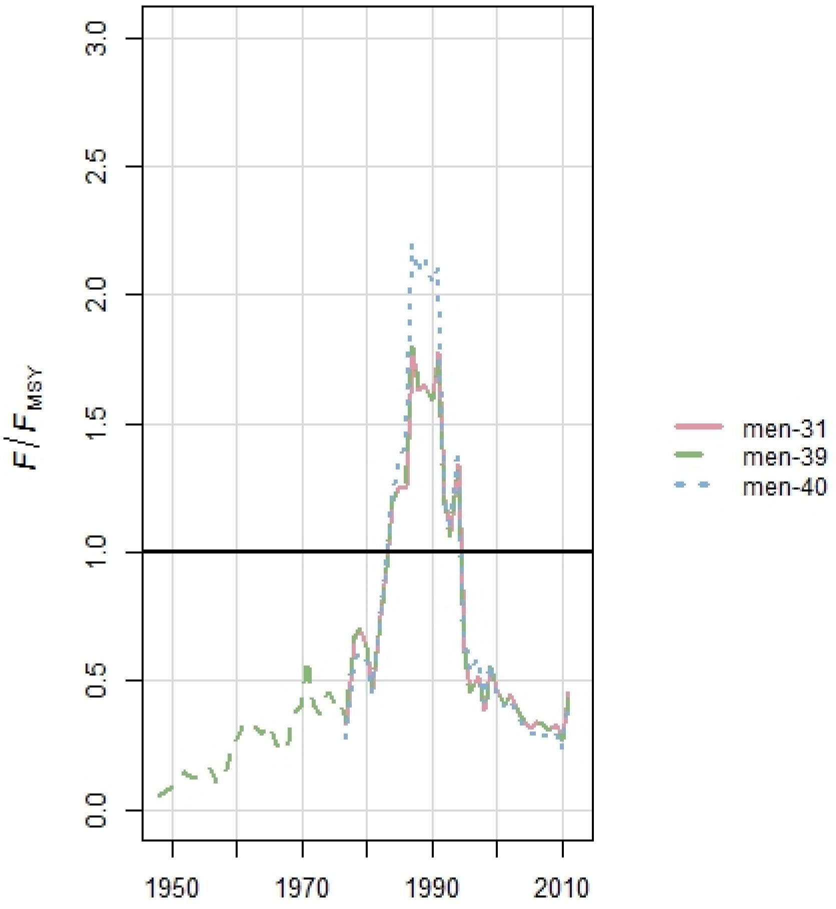


Figure 7.83 Time trajectory of fishing-status estimates. Sensitivity of production model to alternative model shape and extended landings time series. Run men-31 is the primary configuration, Runs min-39 and men-40 are sensitivity runs using the extended landings (start 1948) and Fox model shape, respectively.

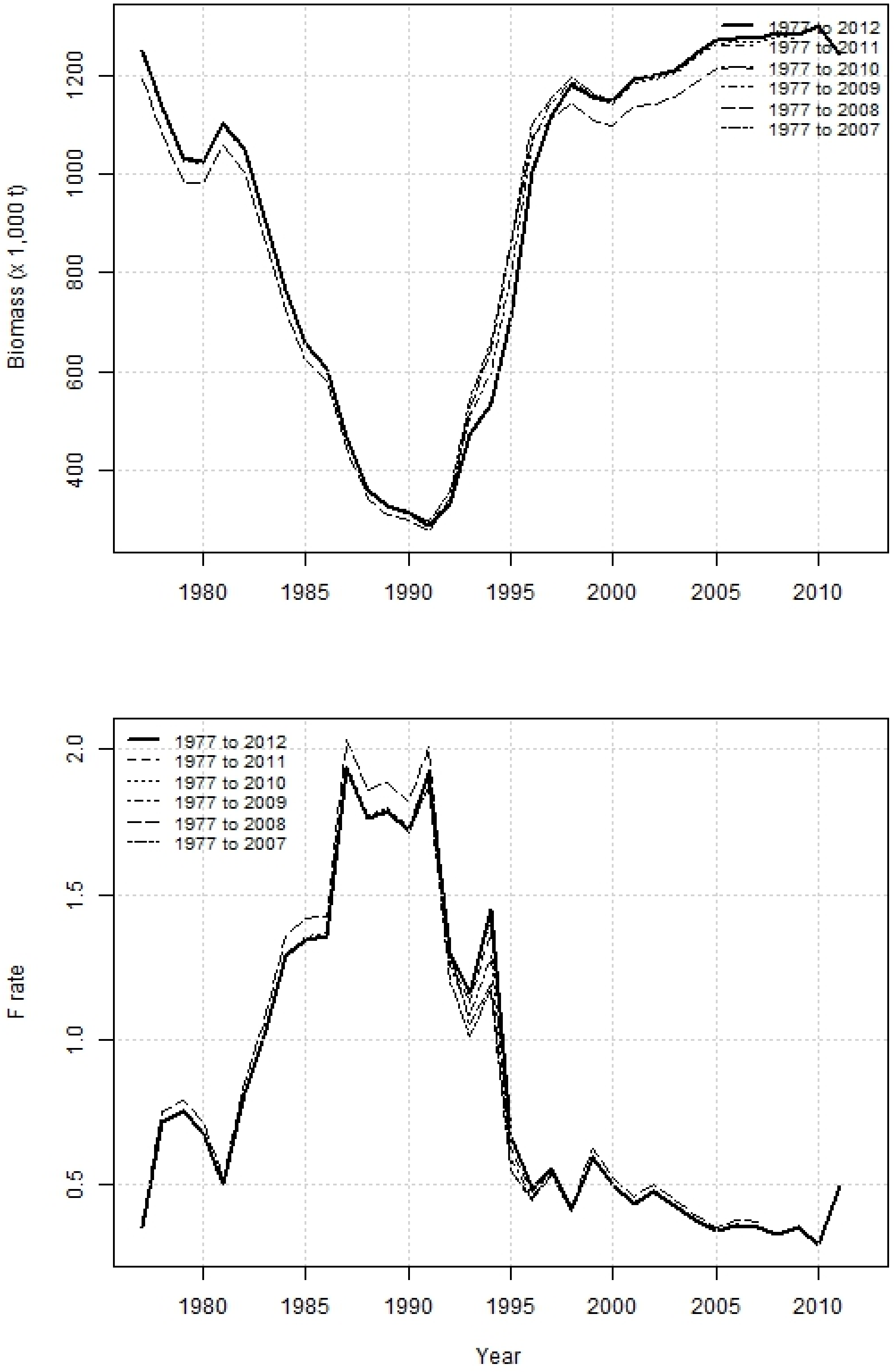


Figure 7.84 Retrospective analysis for adult biomass (top pane) and fishing rate (bottom pane).

8.0 Stock Status

Limit reference points (limits) are the basis for determining stock status (i.e., whether overfishing is occurring or a stock is overfished). When the fishing mortality rate (*F*) exceeds the fishing mortality limit (F_{limit}), then overfishing is occurring; the rate of removal of fish by the fishery exceeds the ability of the stock to replenish itself. When the reproductive output [measured as spawning stock biomass (*SSB*) or population fecundity (*FEC*)] falls below the SSB_{limit}, then the stock is overfished, meaning there is insufficient mature female biomass (*SSB*) or egg production (*FEC*) to replenish the stock.

The Magnuson-Stevens Reauthorization of 1997 (Restrepo et al. 1998) suggests that management measures define both a sustainability limit, as well as a target level for the stock. However, no formally adopted benchmarks are available for Gulf menhaden, and a suite of options were presented in Section 7.1.6. The suite of options are provided and used in order to make a general statement about the likely stock status for Gulf menhaden. In the meantime, managers are working to define the goals for the fishery and to specify objectives for the fishery. Once that has been completed, appropriate benchmarks can be discussed and formally adopted. Thus, below general stock status declarations have been made based on a suite of benchmark options.

8.1 Current Overfishing, Overfished/Depleted Definitions

None currently, but are being discussed along with goals and objectives for the stock.

8.2 Discussion of Alternate Reference Points

8.2.1 F_{MSY} Concept

On the federal level, preference has been given to managing U.S. fisheries using *MSY* derived reference points such as B_{MSY}, F_{MSY}, etc, even though direct estimation of B_{MSY} and F_{MSY} is often not possible or reliable. Such reference points can be incorporated into control rules, which may then call for reductions in fishing effort or landings when a stock falls below an optimal population size (such as SSB_{MSY}) or fishing mortality goes above what is sustainable in the long-term (such as F_{MSY}). For many species setting harvest at some precautionary fraction of *MSY* allows managers to set long term sustainable harvest based on a long-term sustainable population size.

Implicit in that assumption of a long-term harvest being sustainable for a long-term population size (and vice versa), is that the stock recruitment relationship is well known and unchanging. For many species which exhibit a high degree of recruitment variability, setting reference points based around *MSY* may lead to rapid fluctuations in stock status. The greatest concern would be sharp population declines under *MSY*-level removals during periods of low recruitment, although the opposite is also possible. Such difficulties are more apparent when the species examined is short lived, as recruitment is a result of only a few age classes. In those cases, lower recruitment results in lower *SSB* within a few short years, further lowering the possibility for future recruitment. Management may not have time to react to such changes before complete stock collapse. Moreover, *MSY*-based reference points require equilibrium conditions, an assumption which is difficult to make for a forage species. As a result, many have called for the complete removal of *MSY*-based reference points all together (Larkin 1977, Gulland 1978, Barber 1988).

In the case of Gulf menhaden, the stock-recruitment relationship was not well defined because of the use of a fixed value of steepness. Because of the fixed steepness for the stock-recruitment curve, the fact that Gulf menhaden are short lived, and the infinite value of F_{MSY} as discussed in Section 7.1.6, the panel did not propose using the F_{MSY} based benchmarks for management decisions.

8.2.2 F_{MSY} Proxies

The assessment panel also considered *MSY* proxies based on per recruit analyses (e.g., $F_{35\%}$). The values of $F_{X\%}$ are defined as those F values corresponding to $X\%$ spawning potential ratio, i.e., spawners (population fecundity) per recruit relative to that at the unfished level. These quantities may serve as proxies for F_{MSY}, if the spawner-recruit relationship cannot be estimated reliably. Mace (1994) recommended $F_{40\%}$ as a proxy; however, later studies have found that $F_{40\%}$ is too high a fishing rate across many life-history strategies (Williams and Shertzer 2003; Brooks et al. 2009) and can lead to undesirably low levels of biomass and recruitment (Clark 2002).

Given that the fishery managers are still discussing appropriate goals and objectives for the stock, these F_{MSY} proxies were presented as part of the suite of options under consideration, as discussed in Section 7.1.6.

8.2.3 F_{MED} Concept

The concept of F_{MED} was investigated by Mace and Sissenwine (1993) and compared to the percent of the maximum spawning potential (referred to as either *%MSP* and *%SPR*) that corresponds to F_{MED}, thus maintaining population replacement. Mace and Sissenewine (1993) reported that most of the stocks require at least 20-30% of maximum spawning potential to be maintained for population replacement. Among 83 populations analyzed, they estimated replacement *%MSP* for 19 stocks of clupeids, 9 of them being Atlantic herring (slower growing and larger maximum age). The percent corresponding to replacement ranged between 7% and 65%, with a median value of 37%. This variability in percent replacement may result from differences in the range of observed *SSB* values (if the stock is heavily exploited through the entire time series, the range of *SSB* is not as a large as that of a lightly exploited stock, which is likely to affect the F_{MED} estimates).

Given that the fishery managers are still discussing appropriate goals and objectives for the stock, F_{MED} is presented as part of the suite of options under consideration, as discussed in Section 7.1.6.

8.2.4 Ecosytem-Based Reference Points

Reference points are typically defined only for fishery removals that allow for ‘natural’ removals through a separate mortality term. The natural mortality term (*M*) is often constant but is sometimes allowed to vary with age and time when data are sufficient. Reference points based on *MSY* treat this natural mortality term as 'lost yield' in that fishing mortality is typically increased in populations with a high *M* and decreased in population with a low *M*. The difficulty with this approach is that it does not consider the value of natural mortality to the ecosystem in the form of prey biomass for other stocks (e.g., large predators). Awareness of the issue of accounting for the role of Gulf menhaden as a prey resource has increased in recent years due in part to changes in the status of Atlantic menhaden (ASMFC 2010) and a general increase in both public and regulatory awareness of the importance of ecosystem issues. The assessment panel discussed factors necessary to adequately account for ecosystem value of Gulf menhaden in defining fishery reference points and concluded that data and techniques are insufficient at present to incorporate them into the assessment. Nonetheless, the panel had some recommendations regarding future efforts to define more balanced reference points for this stock. The primary issue is to separate predatory mortality from 'lost' yield in assessments and to consider this mortality source more as a component of the fishery with a more complete accounting of necessary allocation of yield to ecosystem services.

8.3 Stock Status Determination

Even though no formal benchmarks have been adopted, based on the suite of benchmarks provided in Section 7.1.6, the assessment panel decided to make general statements on the status of the Gulf menhaden stock in the Gulf of Mexico.

8.3.1 Overfishing Status

The base BAM model estimates for the suite of benchmark options presented and terminal year values are indicated in Table 7.8. This table also indicates the values for some per-recruit-based benchmarks of $F_{40\%}$ and $F_{30\%}$ and benchmarks based on F_{MED}. Based on the suite of benchmarks presented in this section, the results suggest that generally the current stock status is that overfishing is not occurring (Table 7.8). Because no benchmarks have been defined, the stock status relative to targets could not be provided.

The entire time series of estimates of full fishing mortality over F_{MED} is shown in Figure 7.55. Additionally, time series of $F/F_{30\%}$ and $F/F_{40\%}$ are shown in Figures 7.61 and 7.65. The history of fishing mortality rates in these figures suggests that overfishing likely occurred in the 1980s, but generally, overfishing is unlikely to be occurring in the present. The results for the 2011 fishing mortality rate suggests that the base run estimate is below F_{MED} with none of the bootstrap runs exceeding F_{MED} in the most recent years (Figures 7.55 and 7.60).

8.3.2 Overfished Status

The base BAM model estimates for the suite of benchmark options presented and terminal year values are indicated in Table 7.8. This table also indicates the values for some per-recruit-based benchmarks of $SSB_{40\%}$, $SSB_{35\%}$, and $SSB_{30\%}$ and benchmarks based on $SSB_{MED.thresh}$. Based on the suite of benchmarks presented in this section, the results suggest that generally the current stock status is not overfished (Table 7.8). Because no benchmarks have been defined, the stock status relative to targets could not be provided.

The entire time series of estimates of SSB/SSB_{MED} are shown in Figure 7.56. Additionally, time series of $SSB/SSB_{30\%}$ and $SSB/SSB_{40\%}$ are also shown in Figures 7.62 and 7.66. The history of *SSB* in these figures suggests that the population may have been considered overfished in the past, depending upon the benchmark considered. The results indicate that the fecundity estimates for the terminal year are well above $SSB_{MED.thresh}$, with not a single bootstrap estimate falling below 1.0 (Figure 7.56 and 7.60).

8.3.3 Control Rules

As management goals and objectives have not been defined, and therefore, formal benchmarks have not been adopted, only the phase plot of status variables relative to F_{MED} based benchmarks is shown for illustrative purposes (Figure 7.57). In the most recent years, full *F* has not exceeded F_{MED}, thus overfishing is not a concern. A phase plot for the terminal year based on 4,068 bootstrapped experiments demonstrates the uncertainty relative to these control rules in the terminal year (Figure 7.60).

8.3.4 Uncertainty

Uncertainty of the status of the stock relative to the suite of potential benchmarks was investigated using several approaches in line with the recommendations of the SEADAR Uncertainty workshop report (SEDAR 2010). First sensitivity runs were made to explore the effect on benchmarks from changes in assumptions from the base run (Table 7.6). Next sensitivity of the estimates was investigated based on a bootstrapped analysis within the BAM model. Additionally, we used the ASPIC surplus production model, based on a different approach with different assumptions, to interpret the status of Gulf menhaden. ASPIC resulted in the same status determinations as did the BAM model; however, ASPIC stock status determinations used F_{MSY} based benchmarks.

9.0 Research Recommendations

Thoughout the course of the DW and AW, a number of items were identified as important research topics for future stock assessments. The assessment panel evaluated the various items and developed a consensus priority list.

DATA ELEMENT	RECOMMENDATION	PRIORITY
FISHERY-INDEPENDENT ADULT INDEX	Collect Gulf menhaden ageing structures (scales and otoliths) from alternate fishing gears (e.g., gill nets and trawls) to determine gear selectivity. Need to expand efforts to age menhaden by state agencies. Determine readability of whole versus sectioned otoliths.	**Very High**
FISHERY-INDEPENDENT ADULT INDEX	Improve species identifications at the periphery of the Gulf menhaden's range in Texas and Alabama/Florida waters.	**Very High**
GENETICS AND STOCK STRUCTURE	Identification of menhaden-specific nuclear DNA markers (preferably microsatellites or SNP's) using a lab-based DNA library screening techniques. Evaluation of these markers for use in genetic studies of Gulf menhaden	**Very High**
FISHERY-DEPENDENT SURVEYS	A Gulf-wide aerial survey would be a useful tool to measure adult gulf menhaden abundance; "ground-truthing" for fish size and age and school size, would be a necessary adjunct to the survey	**High**
FISHERY-DEPENDENT SURVEYS	Additional sampling needs to be conducted to address the homogeneity of the catch in the hold of the reduction fishery vessels at the four Gulf menhaden factories. Supplemental samples must be pulled from throughout the fish hold during the pumpout process to determine if the assumption that the traditional 'last set of the trip' accurately represents the age composition for the catch for the given port-week	**High**
FECUNDITY/MATURITY	The seminal study on fecundity and sexual maturity of Gulf menhaden was published thirty years ago (Lewis and Roithmayr 1981) with data from the late 1970s. It is recommended that a study should be initiated to re-examine the reproductive biology of gulf menhaden in the northern Gulf of Mexico, which includes updating fecundity estimates, maturity schedules (GSI), and sex ratios. Any study needs to reinvestigate whether gulf menhaden are determinant or indeterminant spawners. Survey necessarily needs to include spawning from winter collections.	**High**
FISHERY-INDEPENDENT JUVENILE INDEX	Improve species identifications at the periphery of the Gulf menhaden's range in Texas and Alabama/Florida waters.	**High**
GENETICS AND STOCK STRUCTURE	Identification in the Clupeid literature of potential new heterologous nuclear DNA markers (preferably microsatellites or SNP's) which will potentially enhance genetic sampling in Gulf menhaden.	**High**
GENETICS AND STOCK STRUCTURE	Reassessment of Gulf menhaden throughout its range using a larger, more informative genetic panel of markers than that described in Anderson (2006).	**High**

DATA ELEMENT	RECOMMENDATION	PRIORITY
FISHERY-INDEPENDENT JUVENILE INDEX	Design and implement a survey dedicated to determining menhaden recruitment in the coastal rivers and upper bays of the northern Gulf of Mexico.	**Med/High**
FISHERY-INDEPENDENT ADULT INDEX	Need to develop/expand menhaden sampling protocols for gill nets and trawls in inshore waters Standardize protocols and gears across states.	**Med/High**
MODELING	Benchmarks – Develop procedures to establish assessment benchmarks (e.g., Fmsy or proxies) that account for the multiple priorities of ecosystem management; such as an alteration of the calculation of Fmsy that includes predation mortality as a component of ecological yield separate from other forms of natural mortality.	**Med/High**
FISHERY-DEPENDENT SURVEYS	Develop fish spotter plane survey to estimate relative abundance of adult gulf menhaden; incorporate search time/flight path into survey as potential survet effort value	**Medium**
TAGGING STUDY	Re-visit the historical Gulf menhaden tag/recovery study. Replicate the study using 21st century tag/recapture technology. Potential products include better estimates of natural mortality, migration, growth, etc which are inputs for the stock assessment.	**Medium**
FISHERY-INDEPENDENT ADULT INDEX	Develop side-by-side gear comparisons among the states for standardization (trawls and gill net/strike nets).	**Low/Med**
PREDATOR/PREY	Expand the diet and stable isotope database to determine the trophic role of Gulf menhaden in the GOM. Investigate fatty acids profiles as an additional more specific indicator of important prey items of Gulf menhaden.	**Low/Med**
PREDATOR/PREY	Need to initiate food habits of major predator species in the northern GOM to determine the importance of menhaden in the diets of fish, seabirds, and marine mammals.	**Low/Med**
FISHERY-INDEPENDENT JUVENILE INDEX	Expand state independent sampling to include more sites in under-represented areas (Perdido Bay, Florida Panhandle, Mississippi Sound) on a monthly schedule.	**Low**
FISHERY-INDEPENDENT JUVENILE INDEX	Develop side-by-side gear comparisons between the states for standardization (seines and trawls).	**Low**
MODELING	Additional research into simulation models such an MSVPAs, ECO-SIM, EcoPath, etc.; results could produce better estimates of natural mortality as well as other fishery parameters.	**Low**
MODELING	Develop a habitat index to examine the potential shift in the Gulf menhaden population to more inshore waters as marsh converts to open water from coastal land loss.	**Low**

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Appendix A1

```
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##
//##  SEDAR 32A Gulf menhaden assessment August 2013
//##
//##  NMFS, Beaufort Lab, Sustainable Fisheries Branch
//##
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
DATA_SECTION

!!cout << "Starting Beaufort Assessment Model" << endl;
!!cout << endl;
!!cout << "               BAM!" << endl;
!!cout << endl;

//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
//-- BAM DATA_SECTION: set-up section
//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>

// Starting and ending year of the model (year data starts)
init_int styr;
init_int endyr;

//Starting year to estimate recruitment deviation from S-R curve
init_int styr_rec_dev;
//Ending year to estimate recruitment deviation from S-R curve
init_int endyr_rec_dev;
//possible 3 phases of constraints on recruitment deviations
init_int endyr_rec_phase1;
init_int endyr_rec_phase2;

// ending year for first selectivity period
init_int endyr_period1;
init_int endyr_period2;

//Total number of ages
init_int nages;

// Vector of ages for age bins
init_vector agebins(1,nages);

//number assessment years
number nyrs;
number nyrs_rec;
//this section MUST BE INDENTED!!!
 LOCAL_CALCS
   nyrs=endyr-styr+1.;
   nyrs_rec=endyr_rec_dev-styr_rec_dev+1.;
 END_CALCS

//Total number of length bins for each matrix and length bins used to compute mass in largest bin (plus group)
init_int nlenbins;       //used to match data
init_int nlenbins_plus;  //used to compute density of largest bin (plus group)
```

```
//Vector of lengths for length bins (mm)(midpoint) and bins used in computation of plus group
init_ivector lenbins(1,nlenbins);
init_ivector lenbins_plus(1,nlenbins_plus);

int nlenbins_all;    //largest size class used to compute average lengths and weights
//this section MUST BE INDENTED!!!
 LOCAL_CALCS
   nlenbins_all=nlenbins+nlenbins_plus;
 END_CALCS

//Max F used in spr and msy calcs
init_number max_F_spr_msy;
//Total number of iterations for spr calcs
init_int n_iter_spr;
//Total number of iterations for msy calcs
init_int n_iter_msy;
//Number years at end of time series over which to average sector F's, for weighted selectivities
init_int selpar_n_yrs_wgted;
//bias correction (set to 1.0 for no bias correction or a negative value to compute from rec variance)
init_number set_BiasCor;
//exclude these years from end of time series for computing bias correction
init_number BiasCor_exclude_yrs;

!!cout << "max_F_spr_msy" << max_F_spr_msy  << endl;

//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
//-- BAM DATA_SECTION: observed data section
//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>

//####################Commercial Reduction fishery #########################

// Landings  (1000 mt)
init_int styr_cR_L;
init_int endyr_cR_L;
init_vector obs_cR_L(styr_cR_L,endyr_cR_L);   //vector of observed landings by year
init_vector cR_L_cv(styr_cR_L,endyr_cR_L);    //vector of CV of landings by year

// Age Compositions
init_int nyr_cR_agec;
init_ivector yrs_cR_agec(1,nyr_cR_agec);
init_vector nsamp_cR_agec(1,nyr_cR_agec);
init_vector nfish_cR_agec(1,nyr_cR_agec);
init_matrix obs_cR_agec(1,nyr_cR_agec,1,nages);

//########################## LA gill net index #######################################

//CPUE
 init_int styr_gill_cpue;
 init_int endyr_gill_cpue;
 init_vector obs_gill_cpue(styr_gill_cpue,endyr_gill_cpue);
 init_vector gill_cpue_cv(styr_gill_cpue,endyr_gill_cpue);

// Length Compositions (3 cm bins)
```

```
init_int nyr_gill_lenc;
init_ivector yrs_gill_lenc(1,nyr_gill_lenc);
init_vector nsamp_gill_lenc(1,nyr_gill_lenc);
init_vector nfish_gill_lenc(1,nyr_gill_lenc);
init_matrix obs_gill_lenc(1,nyr_gill_lenc,1,nlenbins);

!!cout << "start year gill net index" << styr_gill_cpue  << endl;

//########################## seine survey index ###################################
//CPUE
 init_int styr_seine_cpue;
 init_int endyr_seine_cpue;
 init_vector obs_seine_cpue(styr_seine_cpue,endyr_seine_cpue);
 init_vector seine_cpue_cv(styr_seine_cpue,endyr_seine_cpue);



//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
//-- BAM DATA_SECTION: parameter section
//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
//####################Single Parameter values and initial guesses #####################################
// Von Bert parameters in TL mm all fish
init_vector set_Linf(1,7);
init_vector set_K(1,7);
init_vector set_t0(1,7);
//CV of length at age and its standard error all fish
init_vector set_len_cv(1,7);
//age-independent: used only for MSST and to scale age dependent M, prior if M is estimated
init_vector set_M_constant(1,7);
//Spawner-recruit parameters (Initial guesses or fixed values)
init_vector set_steep(1,7);         //recruitment steepness
init_vector set_log_R0(1,7);        //recruitment R0
init_vector set_R_autocorr(1,7);    //recruitment autocorrelation
init_vector set_rec_sigma(1,7);     //recruitment standard deviation in log space
//Initial guesses or fixed values of estimated selectivity parameters
//reduction fishery
init_vector set_selpar_L50_cR(1,7);
init_vector set_selpar_slope_cR(1,7);
init_vector set_selpar_L502_cR(1,7);   //for double logistic selectivity
init_vector set_selpar_slope2_cR(1,7); //for double logistic selectivity

init_vector set_sel_age0_cR(1,7); //input in logit space by age
init_vector set_sel_age1_cR(1,7);
init_vector set_sel_age2_cR(1,7);
init_vector set_sel_age3_cR(1,7);
init_vector set_sel_age4_cR(1,7);

init_vector set_sel_age0_cR2(1,7); //input in logit space by age-period 2
init_vector set_sel_age1_cR2(1,7);
init_vector set_sel_age2_cR2(1,7);
init_vector set_sel_age3_cR2(1,7);
init_vector set_sel_age4_cR2(1,7);

//gill net survey
```

```
init_vector set_selpar_L50_gill(1,7);
init_vector set_selpar_slope_gill(1,7);

//////--index catchability---------------------------------------------------------------------------------
init_vector set_log_q_gill(1,7);    //catchability coefficient (log) for gill net index
init_vector set_log_q_seine(1,7);      //catchability coefficient (log) SC charterboat logbook cpue index

////--F's---------------------------------
init_vector set_log_avg_F_cR(1,7);

//##################Dev Vector Parameter values (vals) and bounds ##################################
//--F vectors----------------------------
init_vector set_log_F_dev_cR(1,3);
init_vector set_log_rec_dev(1,3);
init_vector set_M_dev(1,3);
init_vector set_log_N_dev(1,3);

init_vector set_log_F_dev_cR_vals(styr_cR_L,endyr_cR_L);
init_vector set_log_rec_dev_vals(styr_rec_dev,endyr_rec_dev);
init_vector set_M_dev_vals(styr_seine_cpue,endyr_seine_cpue);
init_vector set_log_N_dev_vals(2,nages);


!!cout << "set_log_rec_dev" << set_log_rec_dev << endl;
//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
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//-- BAM DATA_SECTION: likelihood weights section
//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>

init_number set_w_L;
init_number set_w_lc_gill;
init_number set_w_ac_cR;
init_number set_w_I_gill;          //weight for gill net index
init_number set_w_I_seine;         //weight for seine index
init_number set_w_M_dev;           //weight on M dev constraint
init_number set_w_rec;             //for fitting S-R curve
init_number set_w_rec_early;       //additional constraint on early years recruitment
init_number set_w_rec_end;         //additional constraint on ending years recruitment
init_number set_w_fullF;           //penalty for any Fapex>3(removed in final phase of optimization)
init_number set_w_Ftune;           //weight applied to tuning F (removed in final phase of optimization)
//init_number set_w_cvlen_dev;         //penalty on cv deviations at age
//init_number set_w_cvlen_diff;       //penalty on first difference of cv deviations at age

!!cout << "set_w_I_seine" << set_w_I_seine  << endl;
//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
//-- BAM DATA_SECTION: miscellaneous stuff section
//--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>

//FL(mm)-weight(whole weight in g) relationship: W=aL^b
init_number wgtpar_a;
init_number wgtpar_b;

//Female maturity and proportion female at age
```

```
init_vector maturity_f_obs(1,nages);           //proportion females mature at age
init_vector prop_f_obs(1,nages);               //proportion female at age
init_vector fec_at_age(1,nages);               //fecundity at age

//weights at start and middle of the year
init_vector wgt_spawn(1,nages);      //weights based on cR fishery
init_vector wgt_start(1,nages);      //weights based on cR fishery

init_number spawn_time_frac; //time of year of peak spawning, as a fraction of the year

// Natural mortality
init_vector set_M(1,nages);     //age-dependent: used in model
init_number max_obs_age;        //max observed age, used to scale M

//Spawner-recruit parameters (Initial guesses or fixed values)
init_number SR_switch;

//rate of increase on q
init_int set_q_rate_phase;  //value sets estimation phase of rate increase, negative value turns it off
init_number set_q_rate;
//density dependence on fishery q's
init_int set_q_DD_phase;      //value sets estimation phase of random walk, negative value turns it off
init_number set_q_DD_beta;    //value of 0.0 is density indepenent
init_number set_q_DD_beta_se;
init_int set_q_DD_stage;      //age to begin counting biomass, should be near full exploitation

//random walk on fishery q's
init_int set_q_RW_phase;        //value sets estimation phase of random walk, negative value turns it off
init_number set_q_RW_mrip_var;    //assumed variance of RW q
init_number set_q_RW_gill_var;    //assumed variance of RW q
init_number set_q_RW_seine_var;    //assumed variance of RW q

//Tune Fapex (tuning removed in final year of optimization)
init_number set_Ftune;
init_int set_Ftune_yr;

//threshold sample sizes for length comps
init_number minSS_gill_lenc;

//threshold sample sizes for age comps
init_number minSS_cR_agec;

//ageing error matrix (columns are true ages, rows are ages as read for age comps: columns should sum to one)
init_matrix age_error(1,nages,1,nages);

// #######Indexing integers for year(iyear), age(iage),length(ilen) ###############
int iyear;
int iage;
int ilen;
int ff;
int quant_whole;

number sqrt2pi;
number g2mt;                   //conversion of grams to metric tons
number g2kg;                   //conversion of grams to kg
number g2klb;                  //conversion of grams to 1000 lb
```

```
number mt2klb;                 //conversion of metric tons to 1000 lb
number mt2lb;                  //conversion of metric tons to lb
number dzero;                  //small additive constant to prevent division by zero
number huge_number;            //huge number, to avoid irregular parameter space

init_number end_of_data_file;
//this section MUST BE INDENTED!!!
 LOCAL_CALCS
   if(end_of_data_file!=999)
   {
       cout << "*** WARNING: Data File NOT READ CORRECTLY ****" << endl;
       exit(0);  //KWS
   }
   else
   {
    cout << "Data File read correctly" << endl;
   }
 END_CALCS


PARAMETER_SECTION

 LOCAL_CALCS
  const double Linf_LO=set_Linf(2); const double Linf_HI=set_Linf(3); const double Linf_PH=set_Linf(4);
  const double K_LO=set_K(2); const double K_HI=set_K(3); const double K_PH=set_K(4);
  const double t0_LO=set_t0(2); const double t0_HI=set_t0(3); const double t0_PH=set_t0(4);
  const double len_cv_LO=set_len_cv(2); const double len_cv_HI=set_len_cv(3); const double
len_cv_PH=set_len_cv(4);
  const double M_constant_LO=set_M_constant(2); const double M_constant_HI=set_M_constant(3); const double
M_constant_PH=set_M_constant(4);
  const double steep_LO=set_steep(2); const double steep_HI=set_steep(3); const double steep_PH=set_steep(4);
  const double log_R0_LO=set_log_R0(2); const double log_R0_HI=set_log_R0(3); const double
log_R0_PH=set_log_R0(4);
  const double R_autocorr_LO=set_R_autocorr(2); const double R_autocorr_HI=set_R_autocorr(3); const double
R_autocorr_PH=set_R_autocorr(4);
  const double rec_sigma_LO=set_rec_sigma(2); const double rec_sigma_HI=set_rec_sigma(3); const double
rec_sigma_PH=set_rec_sigma(4);
  const double selpar_L50_cR_LO=set_selpar_L50_cR(2); const double selpar_L50_cR_HI=set_selpar_L50_cR(3);
const double selpar_L50_cR_PH=set_selpar_L50_cR(4);
  const double selpar_slope_cR_LO=set_selpar_slope_cR(2); const double
selpar_slope_cR_HI=set_selpar_slope_cR(3); const double selpar_slope_cR_PH=set_selpar_slope_cR(4);
  const double selpar_L502_cR_LO=set_selpar_L502_cR(2); const double
selpar_L502_cR_HI=set_selpar_L502_cR(3); const double selpar_L502_cR_PH=set_selpar_L502_cR(4);
  const double selpar_slope2_cR_LO=set_selpar_slope2_cR(2); const double
selpar_slope2_cR_HI=set_selpar_slope2_cR(3); const double selpar_slope2_cR_PH=set_selpar_slope2_cR(4);
  const double selpar_age0_cR_LO=set_sel_age0_cR(2); const double selpar_age0_cR_HI=set_sel_age0_cR(3);
const double selpar_age0_cR_PH=set_sel_age0_cR(4);
  const double selpar_age1_cR_LO=set_sel_age1_cR(2); const double selpar_age1_cR_HI=set_sel_age1_cR(3);
const double selpar_age1_cR_PH=set_sel_age1_cR(4);
  const double selpar_age2_cR_LO=set_sel_age2_cR(2); const double selpar_age2_cR_HI=set_sel_age2_cR(3);
const double selpar_age2_cR_PH=set_sel_age2_cR(4);
  const double selpar_age3_cR_LO=set_sel_age3_cR(2); const double selpar_age3_cR_HI=set_sel_age3_cR(3);
const double selpar_age3_cR_PH=set_sel_age3_cR(4);
  const double selpar_age4_cR_LO=set_sel_age4_cR(2); const double selpar_age4_cR_HI=set_sel_age4_cR(3);
const double selpar_age4_cR_PH=set_sel_age4_cR(4);
  const double selpar_age0_cR2_LO=set_sel_age0_cR2(2); const double
```

```
selpar_age0_cR2_HI=set_sel_age0_cR2(3); const double selpar_age0_cR2_PH=set_sel_age0_cR2(4);
  const double selpar_age1_cR2_LO=set_sel_age1_cR2(2); const double
selpar_age1_cR2_HI=set_sel_age1_cR2(3); const double selpar_age1_cR2_PH=set_sel_age1_cR2(4);
  const double selpar_age2_cR2_LO=set_sel_age2_cR2(2); const double
selpar_age2_cR2_HI=set_sel_age2_cR2(3); const double selpar_age2_cR2_PH=set_sel_age2_cR2(4);
  const double selpar_age3_cR2_LO=set_sel_age3_cR2(2); const double
selpar_age3_cR2_HI=set_sel_age3_cR2(3); const double selpar_age3_cR2_PH=set_sel_age3_cR2(4);
  const double selpar_age4_cR2_LO=set_sel_age4_cR2(2); const double
selpar_age4_cR2_HI=set_sel_age4_cR2(3); const double selpar_age4_cR2_PH=set_sel_age4_cR2(4);
  const double selpar_L50_gill_LO=set_selpar_L50_gill(2); const double
selpar_L50_gill_HI=set_selpar_L50_gill(3); const double selpar_L50_gill_PH=set_selpar_L50_gill(4);
  const double selpar_slope_gill_LO=set_selpar_slope_gill(2); const double
selpar_slope_gill_HI=set_selpar_slope_gill(3); const double selpar_slope_gill_PH=set_selpar_slope_gill(4);
  const double log_q_gill_LO=set_log_q_gill(2); const double log_q_gill_HI=set_log_q_gill(3); const double
log_q_gill_PH=set_log_q_gill(4);
  const double log_q_seine_LO=set_log_q_seine(2); const double log_q_seine_HI=set_log_q_seine(3); const double
log_q_seine_PH=set_log_q_seine(4);
  const double log_avg_F_cR_LO=set_log_avg_F_cR(2); const double log_avg_F_cR_HI=set_log_avg_F_cR(3);
const double log_avg_F_cR_PH=set_log_avg_F_cR(4);
  //-dev vectors-----------------------------------------------------------------------------------------------------
  const double log_F_dev_cR_LO=set_log_F_dev_cR(1); const double log_F_dev_cR_HI=set_log_F_dev_cR(2);
const double log_F_dev_cR_PH=set_log_F_dev_cR(3);
  const double log_rec_dev_LO=set_log_rec_dev(1); const double log_rec_dev_HI=set_log_rec_dev(2); const
double log_rec_dev_PH=set_log_rec_dev(3);
  const double M_dev_LO=set_M_dev(1);const double M_dev_HI=set_M_dev(2);const double
M_dev_PH=set_M_dev(3);
  const double N_dev_LO=set_log_N_dev(1);const double N_dev_HI=set_log_N_dev(2);const double
N_dev_PH=set_log_N_dev(3);

 END_CALCS

////--------------Growth--------------------------------------------------------------------------
  init_bounded_number Linf(Linf_LO,Linf_HI,Linf_PH);
  init_bounded_number K(K_LO,K_HI,K_PH);
  init_bounded_number t0(t0_LO,t0_HI,t0_PH);
  init_bounded_number len_cv_val(len_cv_LO,len_cv_HI,len_cv_PH);
  vector Linf_out(1,8);
  vector K_out(1,8);
  vector t0_out(1,8);
  vector len_cv_val_out(1,8);

  vector meanlen_FL(1,nages);   //mean fork length (mm) at age all fish
  vector wgt_fish_mt(1,nages);  //wgt in mt
  vector wgt_spawn_mt(1,nages); //wgt in mt

  matrix wholewgt_cR_mt(styr,endyr,1,nages);    //whole wgt of cR landings in mt

  vector lbins(1,nlenbins);

  matrix lenprob(1,nages,1,nlenbins);           //distn of size at age (age-length key, 1 cm bins) in population
  matrix lenprob_plus(1,nages,1,nlenbins_plus); //used to compute mass in last length bin (a plus group)
  matrix lenprob_all(1,nages,1,nlenbins_all);   //extended lenprob
  vector lenbins_all(1,nlenbins_all);

  //matrices below are used to match length comps
  matrix lenprob_gill(1,nages,1,nlenbins);     //distn of size at age in gill nets
```

```
  //matrices below pertain to the popn at large, used to compute mean weights
  matrix lenprob_gill_all(1,nages,1,nlenbins_all);     //distn of size at age in gill

//  //init_bounded_dev_vector log_len_cv_dev(1,nages,-2,2,3)
//  number log_len_cv
  vector len_sd(1,nages);
  vector len_cv(1,nages); //for fishgraph

////----Predicted length and age compositions
  matrix pred_gill_lenc(1,nyr_gill_lenc,1,nlenbins);
  matrix pred_cR_agec(1,nyr_cR_agec,1,nages);
  matrix ErrorFree_cR_agec(1,nyr_cR_agec,1,nages);


//effective sample size applied in multinomial distributions
  vector nsamp_gill_lenc_allyr(styr,endyr);
  vector nsamp_cR_agec_allyr(styr,endyr);

//Nfish used in MCB analysis (not used in fitting)
  vector nfish_gill_lenc_allyr(styr,endyr);
  vector nfish_cR_agec_allyr(styr,endyr);

//Computed effective sample size for output (not used in fitting)
  vector neff_gill_lenc_allyr_out(styr,endyr);
  vector neff_cR_agec_allyr_out(styr,endyr);

//-----Population-----------------------------------------------------------------------------------
  matrix N(styr,endyr+1,1,nages);           //Population numbers by year and age at start of yr
  matrix N_mdyr(styr,endyr,1,nages);        //Population numbers by year and age at mdpt of yr: used for comps and
cpue
  matrix N_spawn(styr,endyr,1,nages);       //Population numbers by year and age at peaking spawning: used for SSB
  //vector log_Nage_dev(2,nages);
  init_bounded_dev_vector log_Nage_dev(2,nages,N_dev_LO,N_dev_HI,N_dev_PH);
  vector log_Nage_dev_output(2,nages);      //used in output. equals zero for first age
  matrix B(styr,endyr+1,1,nages);           //Population biomass by year and age at start of yr
  vector totB(styr,endyr+1);                //Total biomass by year
  vector totN(styr,endyr+1);                //Total abundance by year
  vector SSB(styr,endyr+1);                   //Total spawning biomass by year (fecundity in mature ova)
  vector rec(styr,endyr+1);                 //Recruits by year
  vector pred_SPR(styr,endyr);                //spawning biomass-per-recruit (lagged) for Fmed calcs
  vector prop_f(1,nages);                   //Proportion female by age
  vector maturity_f(1,nages);                 //Proportion of female mature at age
  vector reprod(1,nages);                   //vector used to compute spawning biomass (fecundity)
  matrix SSBatage(styr,endyr,1,nages);

////---Stock-Recruit Function (Beverton-Holt, steepness parameterization)----------
  init_bounded_number log_R0(log_R0_LO,log_R0_HI,log_R0_PH);   //log(virgin Recruitment)
  vector log_R0_out(1,8);
  number R0;                //virgin recruitment

  init_bounded_number steep(steep_LO,steep_HI,steep_PH); //steepness
  vector steep_out(1,8);
  init_bounded_number rec_sigma(rec_sigma_LO,rec_sigma_HI,rec_sigma_PH);  //sd recruitment residuals
  vector rec_sigma_out(1,8);
```

```
  number rec_sigma_sq;                        //square of rec_sigma
  number rec_logL_add;                        //additive term in -logL term

  init_bounded_dev_vector
log_rec_dev(styr_rec_dev,endyr_rec_dev,log_rec_dev_LO,log_rec_dev_HI,log_rec_dev_PH);  //log recruitment
deviations
  vector log_rec_dev_output(styr,endyr+1);           //used in output. equals zero except for yrs in log_rec_dev

  number var_rec_dev;                              //variance of log recruitment deviations, from yrs with unconstrainted S-R
  number sigma_rec_dev;                              //sample SD of log residuals (may not equal rec_sigma)

  number BiasCor;                              //Bias correction in equilibrium recruits
  init_bounded_number R_autocorr(R_autocorr_LO,R_autocorr_HI,R_autocorr_PH);
  vector R_autocorr_out(1,8);

  number S0;                                //equal to spr_F0*R0 = virgin SSB
  number B0;                                //equal to bpr_F0*R0 = virgin B
  number R1;                                //Recruits in styr
  number R_virgin;                              //unfished recruitment with bias correction
  vector SdS0(styr,endyr+1);                       //SSB / virgin SSB


//-----------------------------------------------------------------------------------------------------------------------------------------
-----
////---Selectivity-------------------------------------------------------------------------

//Commercial Reduction-------------------------------------------------
  matrix sel_cR(styr,endyr,1,nages);
  init_bounded_number selpar_L50_cR(selpar_L50_cR_LO,selpar_L50_cR_HI,selpar_L50_cR_PH);
  init_bounded_number selpar_slope_cR(selpar_slope_cR_LO,selpar_slope_cR_HI,selpar_slope_cR_PH);
  init_bounded_number selpar_L502_cR(selpar_L502_cR_LO,selpar_L502_cR_HI,selpar_L502_cR_PH);
  init_bounded_number selpar_slope2_cR(selpar_slope2_cR_LO,selpar_slope2_cR_HI,selpar_slope2_cR_PH);
  vector selpar_L50_cR_out(1,8);
  vector selpar_slope_cR_out(1,8);
  vector selpar_L502_cR_out(1,8);
  vector selpar_slope2_cR_out(1,8);

  init_bounded_number sel_age0_cR_logit(selpar_age0_cR_LO,selpar_age0_cR_HI,selpar_age0_cR_PH);  //cR
selectivity at age in logit space
  init_bounded_number sel_age1_cR_logit(selpar_age1_cR_LO,selpar_age1_cR_HI,selpar_age1_cR_PH);
  init_bounded_number sel_age2_cR_logit(selpar_age2_cR_LO,selpar_age2_cR_HI,selpar_age2_cR_PH);
  init_bounded_number sel_age3_cR_logit(selpar_age3_cR_LO,selpar_age3_cR_HI,selpar_age3_cR_PH);
  init_bounded_number sel_age4_cR_logit(selpar_age4_cR_LO,selpar_age4_cR_HI,selpar_age4_cR_PH);
  vector sel_age_cR_vec(1,nages);
  number selpar_age0_cR;
  number selpar_age1_cR;
  number selpar_age2_cR;
  number selpar_age3_cR;
  number selpar_age4_cR;
  vector selpar_age0_cR_out(1,8);
  vector selpar_age1_cR_out(1,8);
  vector selpar_age2_cR_out(1,8);
  vector selpar_age3_cR_out(1,8);
  vector selpar_age4_cR_out(1,8);

  init_bounded_number sel_age0_cR2_logit(selpar_age0_cR2_LO,selpar_age0_cR2_HI,selpar_age0_cR2_PH);
```

```
//cR selectivity at age in logit space-period 2
  init_bounded_number sel_age1_cR2_logit(selpar_age1_cR2_LO,selpar_age1_cR2_HI,selpar_age1_cR2_PH);
  init_bounded_number sel_age2_cR2_logit(selpar_age2_cR2_LO,selpar_age2_cR2_HI,selpar_age2_cR2_PH);
  init_bounded_number sel_age3_cR2_logit(selpar_age3_cR2_LO,selpar_age3_cR2_HI,selpar_age3_cR2_PH);
  init_bounded_number sel_age4_cR2_logit(selpar_age4_cR2_LO,selpar_age4_cR2_HI,selpar_age4_cR2_PH);
  vector sel_age_cR2_vec(1,nages);
  number selpar_age0_cR2;
  number selpar_age1_cR2;
  number selpar_age2_cR2;
  number selpar_age3_cR2;
  number selpar_age4_cR2;
  vector selpar_age0_cR2_out(1,8);
  vector selpar_age1_cR2_out(1,8);
  vector selpar_age2_cR2_out(1,8);
  vector selpar_age3_cR2_out(1,8);
  vector selpar_age4_cR2_out(1,8);

//Gill net survey selectivity
  matrix sel_gill(styr_gill_cpue,endyr_gill_cpue,1,nages);
  init_bounded_number selpar_L50_gill(selpar_L50_gill_LO,selpar_L50_gill_HI,selpar_L50_gill_PH);
  init_bounded_number selpar_slope_gill(selpar_slope_gill_LO,selpar_slope_gill_HI,selpar_slope_gill_PH);
  vector selpar_L50_gill_out(1,8);
  vector selpar_slope_gill_out(1,8);

//Weighted total selectivity--------------------------------------------
  //effort-weighted, recent selectivities
  vector sel_wgted_L(1,nages);  //toward landings
  vector sel_wgted_tot(1,nages);

//-------------------------------------------------------------------------------------------------------------------------------------------
-----
//-------CPUE Predictions--------------------------------
  vector pred_gill_cpue(styr_gill_cpue,endyr_gill_cpue);     //predicted gill net U
  matrix N_gill(styr_gill_cpue,endyr_gill_cpue,1,nages);     //used to compute gill net index
  vector pred_seine_cpue(styr_seine_cpue,endyr_seine_cpue);  //predicted seine index
  vector N_seine(styr_seine_cpue,endyr_seine_cpue);          //used to compute seine index

//---Catchability (CPUE q's)----------------------------------------------------------
  init_bounded_number log_q_gill(log_q_gill_LO,log_q_gill_HI,log_q_gill_PH);
  init_bounded_number log_q_seine(log_q_seine_LO,log_q_seine_HI,log_q_seine_PH);
  vector log_q_gill_out(1,8);
  vector log_q_seine_out(1,8);

  //init_bounded_number q_rate(0.001,0.1,set_q_rate_phase);
  number q_rate;
  vector q_rate_fcn_gill(styr_gill_cpue,endyr_gill_cpue);     //increase due to technology creep (saturates in 2003)
  vector q_rate_fcn_seine(styr_seine_cpue,endyr_seine_cpue);  //increase due to technology creep (saturates in 2003)

  //init_bounded_number q_DD_beta(0.1,0.9,set_q_DD_phase);
  number q_DD_beta;
  vector q_DD_fcn(styr,endyr);    //density dependent function as a multiple of q (scaled a la Katsukawa and
Matsuda. 2003)
  number B0_q_DD;                //B0 of ages q_DD_age plus
  vector B_q_DD(styr,endyr);      //annual biomass of ages q_DD_age plus

  vector q_RW_log_dev_gill(styr_gill_cpue,endyr_gill_cpue-1);
```

```
  vector q_RW_log_dev_seine(styr_seine_cpue,endyr_seine_cpue-1);

  vector q_gill(styr_gill_cpue,endyr_gill_cpue); //number q_gill;
  vector q_seine(styr_seine_cpue,endyr_seine_cpue); //number q_seine;

//--------------------------------------------------------------------------------------------------------------------------------
-----
//---Landings in numbers (total or 1000 fish) and in wgt (1000s mt)------------------------------------------------
  matrix L_cR_num(styr,endyr,1,nages);  //landings (numbers) at age
  matrix L_cR_mt(styr,endyr,1,nages);   //landings (mt) at age
  vector pred_cR_L_knum(styr,endyr);    //yearly landings in 1000 fish summed over ages
  vector pred_cR_L_mt(styr,endyr);      //yearly landings in 1000s mt summed over ages

  matrix L_total_num(styr,endyr,1,nages); //total landings in number at age
  matrix L_total_mt(styr,endyr,1,nages);  //landings in mt at age
  vector L_total_knum_yr(styr,endyr);     //total landings in 1000 fish by yr summed over ages
  vector L_total_mt_yr(styr,endyr);       //total landings (1000s mt) by yr summed over ages

////---MSY calcs----------------------------------------------------------------------------
  number F_cR_prop;       //proportion of F_sum attributable to cR
  number F_temp_sum;      //sum of geom mean Fsum's in last X yrs, used to compute F_fishery_prop

  vector F_end(1,nages);
  vector F_end_L(1,nages);
  number F_end_apex;

  number SSB_msy_out;           //SSB (total fecundity) at msy
  number F_msy_out;             //F at msy
  number msy_mt_out;            //max sustainable yield (1000s mt)
  number msy_knum_out;          //max sustainable yield (1000 fish)
  number B_msy_out;             //total biomass at MSY
  number R_msy_out;             //equilibrium recruitment at F=Fmsy
  number spr_msy_out;           //spr at F=Fmsy

  vector N_age_msy(1,nages);         //numbers at age for MSY calculations: beginning of yr
  vector N_age_msy_mdyr(1,nages);    //numbers at age for MSY calculations: mdpt of yr
  vector L_age_msy(1,nages);         //catch at age for MSY calculations
  vector Z_age_msy(1,nages);         //total mortality at age for MSY calculations
  vector F_L_age_msy(1,nages);       //fishing mortality landings (not discards) at age for MSY calculations
  vector F_msy(1,n_iter_msy);        //values of full F to be used in equilibrium calculations
  vector spr_msy(1,n_iter_msy);      //reproductive capacity-per-recruit values corresponding to F values in F_msy
  vector R_eq(1,n_iter_msy);         //equilibrium recruitment values corresponding to F values in F_msy
  vector L_eq_mt(1,n_iter_msy);      //equilibrium landings(1000s mt) values corresponding to F values in F_msy
  vector L_eq_knum(1,n_iter_msy);    //equilibrium landings(1000 fish) values corresponding to F values in F_msy
  vector SSB_eq(1,n_iter_msy);       //equilibrium reproductive capacity (fecundity) values corresponding to F values
in F_msy
  vector B_eq(1,n_iter_msy);         //equilibrium biomass values corresponding to F values in F_msy

  vector FdF_msy(styr,endyr);
  vector SdSSB_msy(styr,endyr+1);
  number SdSSB_msy_end;
  number FdF_msy_end;
  number FdF_msy_end_mean;          //geometric mean of last 3 yrs

  vector wgt_wgted_L_mt(1,nages);  //fishery-weighted average weight at age of landings
  number wgt_wgted_L_denom;         //used in intermediate calculations
```

```
  number iter_inc_msy;               //increments used to compute msy, equals 1/(n_iter_msy-1)


////---Fmed calcs------------------------------------------------------------------------------
  number quant_decimal;
  number quant_diff;
  number quant_result;

  number R_med;                           //median recruitment for chosen benchmark years
  vector R_temp(styr,endyr);
  vector R_sort(styr,endyr);
  number SPR_med;                           //median SSB/R (R = SSB year+1) for chosen SSB years
  number SPR_75th;
  vector SPR_temp(styr,endyr);
  vector SPR_sort(styr,endyr);
  number SSB_med;                          //SSB corresponding to SSB/R median and R median
  number SSB_med_thresh;                   //SSB threshold
  vector SPR_diff(1,n_iter_spr);
  number SPR_diff_min;
  number F_med;                           //Fmed benchmark
  number F_med_target;
  number F_med_age2plus;                    //Fmed benchmark
  number F_med_target_age2plus;
  number L_med;
  number L_med_target;


////--------Mortality------------------------------------------------------------------

  //Stuff immediately below used only if M is estimated
  //init_bounded_number M_constant(0.1,0.2,1);   //age-indpendent: used only for MSST
  //vector Mscale_ages(1,max_obs_age);
  //vector Mscale_len(1,max_obs_age);
  //vector Mscale_wgt_g(1,max_obs_age);
  //vector M_lorenzen(1,max_obs_age);
  //number cum_surv_1plus;

  vector M(1,nages);                 //age-dependent natural mortality
  init_bounded_number M_constant(M_constant_LO,M_constant_HI,M_constant_PH);   //age-indpendent: used
only for MSST
  vector M_constant_out(1,8);
//---------------set up for M at age-1 to be estimated
  init_bounded_dev_vector M_dev(styr_seine_cpue,endyr_seine_cpue,M_dev_LO,M_dev_HI,M_dev_PH);  //M
devs deviations
  vector M_dev_output(styr_seine_cpue,endyr_seine_cpue);

  matrix F(styr,endyr,1,nages);
  vector Fsum(styr,endyr);                  //Full fishing mortality rate by year
  vector Fapex(styr,endyr);                 //Max across ages, fishing mortality rate by year (may differ from Fsum bc of
dome-shaped sel)
  //sdreport_vector fullF_sd(styr,endyr);
  matrix Z(styr,endyr,1,nages);

  init_bounded_number log_avg_F_cR(log_avg_F_cR_LO,log_avg_F_cR_HI,log_avg_F_cR_PH);
  vector log_avg_F_cR_out(1,8);
```

```
  init_bounded_dev_vector
log_F_dev_cR(styr_cR_L,endyr_cR_L,log_F_dev_cR_LO,log_F_dev_cR_HI,log_F_dev_cR_PH);
  vector log_F_dev_cR_out(styr_cR_L,endyr_cR_L);
  matrix F_cR(styr,endyr,1,nages);
  vector F_cR_out(styr,endyr); //used for intermediate calculations in fcn get_mortality
  number log_F_dev_init_cR;
  number log_F_dev_end_cR;

  vector sel_initial(1,nages);      //initial selectivity (commercial selectivity)

//---Per-recruit stuff----------------------------------------------------------------------------------
  vector N_age_spr(1,nages);         //numbers at age for SPR calculations: beginning of year
  vector N_age_spr_mdyr(1,nages);    //numbers at age for SPR calculations: midyear
  vector L_age_spr(1,nages);         //catch at age for SPR calculations
  vector Z_age_spr(1,nages);         //total mortality at age for SPR calculations
  vector spr_static(styr,endyr);     //vector of static SPR values by year
  vector F_L_age_spr(1,nages);       //fishing mortality of landings (not discards) at age for SPR calculations
  vector F_spr(1,n_iter_spr);        //values of full F to be used in per-recruit calculations
  vector spr_spr(1,n_iter_spr);      //reproductive capacity-per-recruit values corresponding to F values in F_spr
  vector L_spr(1,n_iter_spr);        //landings(mt)-per-recruit (ypr) values corresponding to F values in F_spr

  vector N_spr_F0(1,nages);          //Used to compute spr at F=0: at time of peak spawning
  vector N_bpr_F0(1,nages);          //Used to compute bpr at F=0: at start of year
  vector N_spr_initial(1,nages);     //Initial spawners per recruit at age given initial F
  vector N_initial_eq(1,nages);      //Initial equilibrium abundance at age
  vector F_initial(1,nages);         //initial F at age
  vector Z_initial(1,nages);         //initial Z at age
  number spr_initial;                //initial spawners per recruit
  number spr_F0;                     //Spawning biomass per recruit at F=0
  number bpr_F0;                     //Biomass per recruit at F=0

  number iter_inc_spr;               //increments used to compute msy, equals max_F_spr_msy/(n_iter_spr-1)

////-------SDNR output-----------------------------------------------------------------------------

  number sdnr_lc_gill;

  number sdnr_ac_cR;

  number sdnr_I_gill;
  number sdnr_I_seine;

////-------Objective function components-----------------------------------------------------------------------------
  number w_L;

  number w_lc_gill;

  number w_ac_cR;

  number w_I_gill;
  number w_I_seine;

  number w_M_dev;
  number w_rec;
  number w_rec_early;
  number w_rec_end;
```

```
  number w_fullF;
  number w_Ftune;
  //number w_cvlen_dev;
  //number w_cvlen_diff;

  number f_gill_cpue;
  number f_seine_cpue;

  number f_cR_L;

  number f_gill_lenc;

  number f_cR_agec;

  number f_gill_RW_cpue;   //random walk component of indices
  number f_seine_RW_cpue;   //random walk component of indices


  //Penalties and constraints. Not all are used.
  number f_M_dev;                 //likelihood component constraint for annual M devs
  number f_rec_dev;               //weight on recruitment deviations to fit S-R curve
  number f_rec_dev_early;         //extra weight on deviations in first recruitment stanza
  number f_rec_dev_end;           //extra weight on deviations in first recruitment stanza
  number f_rec_historic_dev;      //extra weight on deviations in first recruitment stanza
  number f_Ftune;                 //penalty for tuning F in Ftune yr.  Not applied in final optimization phase.
  number f_fullF_constraint;      //penalty for Fapex>X
  //number f_cvlen_dev_constraint; //deviation penalty on cv's of length at age
  //number f_cvlen_diff_constraint;//first diff penalty on cv's of length at age
  number f_priors;                //prior information on parameters

  objective_function_value fval;
  number fval_data;

//--Dummy variables ----
  number denom;                   //denominator used in some calculations
  number numer;                   //numerator used in some calculations

//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
INITIALIZATION_SECTION


//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
GLOBALS_SECTION
  #include "admodel.h"          // Include AD class definitions
  #include "admb2r.cpp"    // Include S-compatible output functions (needs preceding)
  #include <time.h>
	time_t start,finish;
	long hour,minute,second;
	double elapsed_time;

//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
RUNTIME_SECTION
 maximum_function_evaluations 1000, 2000,3000, 10000;
 convergence_criteria 1e-2, 1e-2,1e-3, 1e-4;
```

```
//##-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>
//##-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>-->><>
PRELIMINARY_CALCS_SECTION

// Set values of fixed parameters or set initial guess of estimated parameters
 Linf=set_Linf(1);
 K=set_K(1);
 t0=set_t0(1);
 len_cv_val=set_len_cv(1);

 M=set_M;
 M_constant=set_M_constant(1);
 M_dev=set_M_dev_vals;
 //for (iage=1;iage<=max_obs_age;iage++){Mscale_ages(iage)=iage;}

 log_R0=set_log_R0(1);
 steep=set_steep(1);
 R_autocorr=set_R_autocorr(1);
 rec_sigma=set_rec_sigma(1);

 log_q_gill=set_log_q_gill(1);
 log_q_seine=set_log_q_seine(1);

 q_rate=set_q_rate;
 q_rate_fcn_gill=1.0;
 q_rate_fcn_seine=1.0;
 q_DD_beta=set_q_DD_beta;
 q_DD_fcn=1.0;
 q_RW_log_dev_gill.initialize();
 q_RW_log_dev_seine.initialize();


 if (set_q_rate_phase<0 & q_rate!=0.0)
 {

    for (iyear=styr_gill_cpue; iyear<=endyr_gill_cpue; iyear++)
    {   if (iyear>styr_gill_cpue & iyear <=2003)
        {//q_rate_fcn_gill(iyear)=(1.0+q_rate)*q_rate_fcn_gill(iyear-1); //compound
          q_rate_fcn_gill(iyear)=(1.0+(iyear-styr_gill_cpue)*q_rate)*q_rate_fcn_gill(styr_gill_cpue);  //linear
        }
        if (iyear>2003) {q_rate_fcn_gill(iyear)=q_rate_fcn_gill(iyear-1);}
    }

    for (iyear=styr_seine_cpue; iyear<=endyr_seine_cpue; iyear++)
    {   if (iyear>styr_seine_cpue & iyear <=2003)
        {//q_rate_fcn_seine(iyear)=(1.0+q_rate)*q_rate_fcn_seine(iyear-1); //compound
          q_rate_fcn_seine(iyear)=(1.0+(iyear-styr_seine_cpue)*q_rate)*q_rate_fcn_seine(styr_seine_cpue);  //linear
        }
        if (iyear>2003) {q_rate_fcn_seine(iyear)=q_rate_fcn_seine(iyear-1);}
    }

 } //end q_rate conditional

 w_L=set_w_L;
```

```
w_lc_gill=set_w_lc_gill;

w_ac_cR=set_w_ac_cR;

w_I_gill=set_w_I_gill;
w_I_seine=set_w_I_seine;

w_M_dev=set_w_M_dev;
w_rec=set_w_rec;
w_fullF=set_w_fullF;
w_rec_early=set_w_rec_early;
w_rec_end=set_w_rec_end;
w_Ftune=set_w_Ftune;
//w_cvlen_dev=set_w_cvlen_dev;
//w_cvlen_diff=set_w_cvlen_diff;

log_avg_F_cR=set_log_avg_F_cR(1);
log_F_dev_cR=set_log_F_dev_cR_vals;
log_Nage_dev=set_log_N_dev_vals;

selpar_L50_cR=set_selpar_L50_cR(1);
selpar_slope_cR=set_selpar_slope_cR(1);
selpar_L502_cR=set_selpar_L502_cR(1);
selpar_slope2_cR=set_selpar_slope2_cR(1);
selpar_L50_gill=set_selpar_L50_gill(1);
selpar_slope_gill=set_selpar_slope_gill(1);

sel_age0_cR_logit=set_sel_age0_cR(1);  //setting cR selectivity at age in logit space
sel_age1_cR_logit=set_sel_age1_cR(1);
sel_age2_cR_logit=set_sel_age2_cR(1);
sel_age3_cR_logit=set_sel_age3_cR(1);
sel_age4_cR_logit=set_sel_age4_cR(1);

sel_age0_cR2_logit=set_sel_age0_cR2(1);  //setting cR selectivity at age in logit space
sel_age1_cR2_logit=set_sel_age1_cR2(1);
sel_age2_cR2_logit=set_sel_age2_cR2(1);
sel_age3_cR2_logit=set_sel_age3_cR2(1);
sel_age4_cR2_logit=set_sel_age4_cR2(1);

sqrt2pi=sqrt(2.*3.14159265);
g2mt=0.000001;          //conversion of grams to metric tons
g2kg=0.001;             //conversion of grams to kg
mt2klb=2.20462;         //conversion of metric tons to 1000 lb
mt2lb=mt2klb*1000.0;   //conversion of metric tons to lb
g2klb=g2mt*mt2klb;     //conversion of grams to 1000 lb
dzero=0.00001;
huge_number=1.0e+10;

SSB_msy_out=0.0;

iter_inc_msy=max_F_spr_msy/(n_iter_msy-1);
iter_inc_spr=max_F_spr_msy/(n_iter_spr-1);

maturity_f=maturity_f_obs;
prop_f=prop_f_obs;
```

```
  lbins=lenbins;

  lenbins_all(1,nlenbins)=lenbins(1,nlenbins);
  for (iyear=1;iyear<=nlenbins_plus; iyear++) {lenbins_all(nlenbins+iyear)=lenbins_plus(iyear);}

  //Fill in sample sizes of comps, possibly sampled in nonconsec yrs
  //Used primarily for output in R object

      nsamp_gill_lenc_allyr=missing;//"missing" defined in admb2r.cpp
      nsamp_cR_agec_allyr=missing;

      nfish_gill_lenc_allyr=missing;//"missing" defined in admb2r.cpp
      nfish_cR_agec_allyr=missing;

      for (iyear=1; iyear<=nyr_gill_lenc; iyear++)
         {if (nsamp_gill_lenc(iyear)>=minSS_gill_lenc)
            {nsamp_gill_lenc_allyr(yrs_gill_lenc(iyear))=nsamp_gill_lenc(iyear);
             nfish_gill_lenc_allyr(yrs_gill_lenc(iyear))=nfish_gill_lenc(iyear);}}

      for (iyear=1; iyear<=nyr_cR_agec; iyear++)
         {if (nsamp_cR_agec(iyear)>=minSS_cR_agec)
           {nsamp_cR_agec_allyr(yrs_cR_agec(iyear))=nsamp_cR_agec(iyear);
            nfish_cR_agec_allyr(yrs_cR_agec(iyear))=nfish_cR_agec(iyear);}}



//fill in Fs for msy and per-recruit analyses
  F_msy(1)=0.0;
  for (ff=2;ff<=n_iter_msy;ff++)
  {
    F_msy(ff)=F_msy(ff-1)+iter_inc_msy;
  }
  F_spr(1)=0.0;
  for (ff=2;ff<=n_iter_spr;ff++)
  {
    F_spr(ff)=F_spr(ff-1)+iter_inc_spr;
  }


//fill in F's, Catch matrices, and log rec dev with zero's
  F_cR.initialize();
  L_cR_num.initialize();

  F_cR_out.initialize();

  sel_cR.initialize();
  sel_gill.initialize();

  log_rec_dev_output.initialize();
  log_Nage_dev_output.initialize();
  log_rec_dev=set_log_rec_dev_vals;

  log_Nage_dev.initialize();
  M_dev_output.initialize();
```

```
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
TOP_OF_MAIN_SECTION
  time(&start);
  arrmblsize=20000000;
  gradient_structure::set_MAX_NVAR_OFFSET(1600);
  gradient_structure::set_GRADSTACK_BUFFER_SIZE(2000000);
  gradient_structure::set_CMPDIF_BUFFER_SIZE(2000000);
  gradient_structure::set_NUM_DEPENDENT_VARIABLES(10000);

//>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
PROCEDURE_SECTION

 R0=mfexp(log_R0);

 //cout<<"start"<<endl;

 get_length_weight_at_age();
 //cout << "got length, weight, fecundity transitions" <<endl;
 get_reprod();
 //cout << "got repro stuff" << endl;
 get_length_at_age_dist();
 //cout<< "got predicted length at age distribution"<<endl;
 get_weight_at_age_landings();
 //cout<< "got weight at age of landings"<<endl;
 get_spr_F0();
 //cout << "got F0 spr" << endl;
 get_selectivity();
 //cout << "got selectivity" << endl;
 get_mortality();
 //cout << "got mortalities" << endl;
 get_bias_corr();
 //cout<< "got recruitment bias correction" << endl;
 get_numbers_at_age();
 //cout << "got numbers at age" << endl;
 //exit(0);
 get_landings_numbers();
 //cout << "got catch at age" << endl;
 get_landings_wgt();
 //cout << "got landings" << endl;
 get_catchability_fcns();
 //cout << "got catchability_fcns" << endl;
 get_indices();
 //cout << "got indices" << endl;
 get_length_comps();
 //cout<< "got length comps"<< endl;
 get_age_comps();
 //cout<< "got age comps"<< endl;
 evaluate_objective_function();
 //cout << "objective function calculations complete" << endl;



FUNCTION get_length_weight_at_age
  //compute mean length (mm FL) and weight (whole) at age
```

```
    meanlen_FL=Linf*(1.0-mfexp(-K*(agebins-t0+0.5)));    //fork length in mm
    wgt_fish_mt=g2mt*wgt_start; //wgt in mt
    wgt_spawn_mt=g2mt*wgt_spawn;   //mt of whole wgt


FUNCTION get_reprod
   //for reproductive capacity calcs
   //product of sex ratio, maturity, and fecundity for gulf menhaden
   reprod=elem_prod(elem_prod(prop_f,maturity_f),fec_at_age);


FUNCTION get_length_at_age_dist
  //compute matrix of length at age, based on the normal distribution

  for (iage=1;iage<=nages;iage++)
  {
    //len_cv(iage)=mfexp(log_len_cv+log_len_cv_dev(iage));
    len_cv(iage)=len_cv_val;
    len_sd(iage)=meanlen_FL(iage)*len_cv(iage);

    //len_cv(iage)=len_cv_max-(len_cv_max-len_sd)/(1.0+mfexp(-len_cv_slope*(iage-len_cv_a50)));
    for (ilen=1;ilen<=nlenbins_all;ilen++)
     { lenprob_all(iage,ilen)=(mfexp(-(square(lenbins_all(ilen)-meanlen_FL(iage))/
       (2.*square(len_sd(iage)))))/(sqrt2pi*len_sd(iage)));
     }

    lenprob_all(iage)/=sum(lenprob_all(iage)); //standardize to approximate integration and to account for truncated
normal (i.e., no sizes<smallest)

    for (ilen=1;ilen<=nlenbins;ilen++) {lenprob(iage,ilen)=lenprob_all(iage,ilen);
    }
    for
(ilen=nlenbins+1;ilen<=nlenbins_all;ilen++){lenprob(iage)(nlenbins)=lenprob(iage)(nlenbins)+lenprob_all(iage)(ile
n);
    } //plus group
  }
  //fishery specific length probs
  lenprob_gill=lenprob;

  lenprob_gill_all=lenprob_all;


FUNCTION get_weight_at_age_landings

  for (iyear=styr; iyear<=endyr; iyear++)
  {
    wholewgt_cR_mt(iyear)=wgt_fish_mt;  //whole weight in mt

  }

FUNCTION get_spr_F0
  //at mdyr, apply half this yr's mortality, half next yr's
  N_spr_F0(1)=1.0*mfexp(-1.0*M(1)*spawn_time_frac); //at peak spawning time
  N_bpr_F0(1)=1.0;      //at start of year
  for (iage=2; iage<=nages; iage++)
  {
```

```
    N_spr_F0(iage)=N_spr_F0(iage-1)*mfexp(-1.0*(M(iage-1)*(1.0-spawn_time_frac) +
M(iage)*spawn_time_frac));
    N_bpr_F0(iage)=N_bpr_F0(iage-1)*mfexp(-1.0*(M(iage-1)));
  }
  N_spr_F0(nages)=N_spr_F0(nages)/(1.0-mfexp(-1.0*M(nages))); //plus group (sum of geometric series)
  N_bpr_F0(nages)=N_bpr_F0(nages)/(1.0-mfexp(-1.0*M(nages)));

  spr_F0=sum(elem_prod(N_spr_F0,reprod));
  bpr_F0=sum(elem_prod(N_bpr_F0,wgt_spawn_mt));

FUNCTION get_selectivity
  selpar_age0_cR=1.0/(1.0+mfexp(-sel_age0_cR_logit));
  selpar_age1_cR=1.0/(1.0+mfexp(-sel_age1_cR_logit));
  //selpar_age2_cR=1.0/(1.0+mfexp(-sel_age2_cR_logit));
  selpar_age2_cR=1.0;
  //selpar_age3_cR=1.0/(1.0+mfexp(-sel_age3_cR_logit));
  selpar_age3_cR=0.35;
  //selpar_age4_cR=1.0/(1.0+mfexp(-sel_age3_cR_logit));
  selpar_age4_cR=0.35;
  sel_age_cR_vec(1)=selpar_age0_cR;
  sel_age_cR_vec(2)=selpar_age1_cR;
  sel_age_cR_vec(3)=selpar_age2_cR;
  sel_age_cR_vec(4)=selpar_age3_cR;
  sel_age_cR_vec(5)=selpar_age4_cR;

  selpar_age0_cR2=1.0/(1.0+mfexp(-sel_age0_cR2_logit));
  selpar_age1_cR2=1.0/(1.0+mfexp(-sel_age1_cR2_logit));
  //selpar_age2_cR2=1.0/(1.0+mfexp(-sel_age2_cR2_logit));
  selpar_age2_cR2=1.0;
  //selpar_age3_cR2=1.0/(1.0+mfexp(-sel_age3_cR_logit));
  selpar_age3_cR2=0.35;
  //selpar_age4_cR2=1.0/(1.0+mfexp(-sel_age3_cR_logit));
  selpar_age4_cR2=0.35;
  sel_age_cR2_vec(1)=selpar_age0_cR2;
  sel_age_cR2_vec(2)=selpar_age1_cR2;
  sel_age_cR2_vec(3)=selpar_age2_cR2;
  sel_age_cR2_vec(4)=selpar_age3_cR2;
  sel_age_cR2_vec(5)=selpar_age4_cR2;

  for (iyear=styr; iyear<=endyr_period1; iyear++)
  {
    //sel_cR(iyear)=logistic(agebins, selpar_L50_cR, selpar_slope_cR);
    //sel_cR(iyear)=logistic_double(agebins, selpar_L50_cR, selpar_slope_cR, selpar_L502_cR, selpar_slope2_cR);
    sel_cR(iyear)=sel_age_cR_vec;
  }

  for (iyear=(endyr_period1+1); iyear<=endyr_period2; iyear++)
  {
    //sel_cR(iyear)=logistic(agebins, selpar_L50_cR, selpar_slope_cR);
    //sel_cR(iyear)=logistic_double(agebins, selpar_L50_cR, selpar_slope_cR, selpar_L502_cR, selpar_slope2_cR);
    //sel_cR(iyear)=sel_age_cR2_vec;
    sel_cR(iyear)=sel_age_cR_vec;
  }

  for (iyear=styr_gill_cpue; iyear<=endyr_gill_cpue; iyear++)
  {
```

```
    sel_gill(iyear)=logistic(agebins,selpar_L50_gill,selpar_slope_gill);
  }

  sel_initial=sel_cR(styr);

FUNCTION get_mortality
  Fsum.initialize();
  Fapex.initialize();
  F.initialize();

  //initialization F is avg from first 3 yrs of observed landings
  log_F_dev_init_cR=sum(log_F_dev_cR(styr_cR_L,(styr_cR_L+2)))/3.0;

  for (iyear=styr; iyear<=endyr; iyear++)
  {
    if(iyear>=styr_cR_L & iyear<=endyr_cR_L)
    {  F_cR_out(iyear)=mfexp(log_avg_F_cR+log_F_dev_cR(iyear));
       F_cR(iyear)=sel_cR(iyear)*F_cR_out(iyear);
       Fsum(iyear)+=F_cR_out(iyear);
    }

    //Total F at age
    F(iyear)=F_cR(iyear); //first in additive series (NO +=)

    Fapex(iyear)=max(F(iyear));
    Z(iyear)=M+F(iyear);

    if(iyear>=styr_seine_cpue & iyear<=endyr_seine_cpue)
    { Z(iyear,2)=M(2)+M_dev(iyear)+F(iyear,2); //adds deviations in age-1 M
    }

  }  //end iyear


FUNCTION get_bias_corr
  var_rec_dev=norm2(log_rec_dev(styr_rec_dev,endyr_rec_dev)-
              sum(log_rec_dev(styr_rec_dev,endyr_rec_dev))/nyrs_rec)
              /(nyrs_rec-1.0);

  rec_sigma_sq=square(rec_sigma);
  if (set_BiasCor <= 0.0) {BiasCor=mfexp(rec_sigma_sq/2.0);}   //bias correction
  else {BiasCor=set_BiasCor;}

FUNCTION get_numbers_at_age
//Initialization

  S0=spr_F0*R0;  //virgin SSB

  R_virgin=SR_eq_func(R0, steep, spr_F0, spr_F0, BiasCor, SR_switch);

  B0=bpr_F0*R_virgin*1000000;  //virgin biomass
  B0_q_DD=R_virgin*sum(elem_prod(N_bpr_F0(set_q_DD_stage,nages),wgt_fish_mt(set_q_DD_stage,nages)));

  F_initial=sel_cR(styr)*mfexp(log_avg_F_cR+log_F_dev_init_cR);
  Z_initial=M+F_initial;
```

```
//Initial equilibrium age structure
  N_spr_initial(1)=1.0*mfexp(-1.0*Z_initial(1)*spawn_time_frac); //at peak spawning time;
  for (iage=2; iage<=nages; iage++)
    {
      N_spr_initial(iage)=N_spr_initial(iage-1)*
                   mfexp(-1.0*(Z_initial(iage-1)*(1.0-spawn_time_frac) + Z_initial(iage)*spawn_time_frac));
    }
  N_spr_initial(nages)=N_spr_initial(nages)/(1.0-mfexp(-1.0*Z_initial(nages))); //plus group

  spr_initial=sum(elem_prod(N_spr_initial,reprod)); //initial ssb for s-r curve

  R1=SR_eq_func(R0, steep, spr_F0, spr_initial, BiasCor, SR_switch)*mfexp(log_rec_dev(styr_rec_dev));
  //R1=SR_eq_func(R0, steep, spr_F0, spr_initial, BiasCor, SR_switch);
  if(R1<0.0) {R1=1.0;} //Avoid negative popn sizes during search algorithm



//Compute equilibrium age structure for first year
  N_initial_eq(1)=R1;
  for (iage=2; iage<=nages; iage++)
  {
    N_initial_eq(iage)=N_initial_eq(iage-1)*
        mfexp(-1.0*(Z_initial(iage-1)));
  }
  //plus group calculation
  N_initial_eq(nages)=N_initial_eq(nages)/(1.0-mfexp(-1.0*Z_initial(nages))); //plus group

//Add deviations to initial equilibrium N
  N(styr)(2,nages)=elem_prod(N_initial_eq(2,nages),mfexp(log_Nage_dev));

  //if (styr==styr_rec_dev) {N(styr,1)=N_initial_eq(1)*mfexp(log_rec_dev(styr_rec_dev));}
  //else {N(styr,1)=N_initial_eq(1);}
  N(styr,1)=N_initial_eq(1);

  N_mdyr(styr)(1,nages)=elem_prod(N(styr)(1,nages),(mfexp(-1.*(Z_initial(1,nages))*0.5))); //mid year
  N_spawn(styr)(1,nages)=elem_prod(N(styr)(1,nages),(mfexp(-1.*(Z_initial(1,nages))*spawn_time_frac))); //peak
spawning time

  SSB(styr)=sum(elem_prod(N_spawn(styr),reprod));
  B_q_DD(styr)=sum(elem_prod(N(styr)(set_q_DD_stage,nages),wgt_fish_mt(set_q_DD_stage,nages)));


//Rest of years
  for (iyear=styr; iyear<endyr; iyear++)
  {
    if(iyear<(styr_rec_dev-1)||iyear>(endyr_rec_dev-1)) //recruitment follows S-R curve exactly
    {
        //N(iyear+1,1)=BiasCor*SR_func(R0, steep, spr_F0, SSB(iyear),SR_switch);
        N(iyear+1)(2,nages)=++elem_prod(N(iyear)(1,nages-1),(mfexp(-1.*Z(iyear)(1,nages-1))));
        N(iyear+1,nages)+=N(iyear,nages)*mfexp(-1.*Z(iyear,nages));//plus group
        //N_mdyr(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-1.*(Z(iyear+1)(1,nages))*0.5)));
        N_spawn(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-
1.*(Z(iyear+1)(1,nages))*spawn_time_frac))); //peak spawning time
        SSB(iyear+1)=sum(elem_prod(N_spawn(iyear+1),reprod));

B_q_DD(iyear+1)=sum(elem_prod(N(iyear+1)(set_q_DD_stage,nages),wgt_fish_mt(set_q_DD_stage,nages)));
```

```
        N(iyear+1,1)=BiasCor*SR_func(R0, steep, spr_F0, SSB(iyear+1),SR_switch);
        N_mdyr(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-1.*(Z(iyear+1)(1,nages))*0.5)));
    }
    else   //recruitment follows S-R curve with lognormal deviation
    {
        N(iyear+1)(2,nages)=++elem_prod(N(iyear)(1,nages-1),(mfexp(-1.*Z(iyear)(1,nages-1))));
        N(iyear+1,nages)+=N(iyear,nages)*mfexp(-1.*Z(iyear,nages));//plus group
        N_spawn(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-
1.*(Z(iyear+1)(1,nages))*spawn_time_frac))); //peak spawning time
        SSB(iyear+1)=sum(elem_prod(N_spawn(iyear+1),reprod));

B_q_DD(iyear+1)=sum(elem_prod(N(iyear+1)(set_q_DD_stage,nages),wgt_fish_mt(set_q_DD_stage,nages)));

        N(iyear+1,1)=BiasCor*SR_func(R0, steep, spr_F0, SSB(iyear+1),SR_switch)*mfexp(log_rec_dev(iyear+1));
        N_mdyr(iyear+1)(1,nages)=elem_prod(N(iyear+1)(1,nages),(mfexp(-1.*(Z(iyear+1)(1,nages))*0.5)));
    }
  }

    //values for projections
    N(endyr+1)(2,nages)=++elem_prod(N(endyr)(1,nages-1),(mfexp(-1.*Z(endyr)(1,nages-1))));
    N(endyr+1,nages)+=N(endyr,nages)*mfexp(-1.*Z(endyr,nages));//plus group
    SSB(endyr+1)=sum(elem_prod(N(endyr+1),reprod));
    N(endyr+1,1)=BiasCor*SR_func(R0, steep, spr_F0, SSB(endyr+1),SR_switch);

//Time series of interest
  rec=column(N,1);
  SdS0=SSB/S0;

 for (iyear=styr; iyear<=endyr; iyear++)
  {
    pred_SPR(iyear)=SSB(iyear)/rec(iyear);
  }

FUNCTION get_landings_numbers //Baranov catch eqn
  for (iyear=styr; iyear<=endyr; iyear++)
  {
    for (iage=1; iage<=nages; iage++)
    {
      L_cR_num(iyear,iage)=N(iyear,iage)*F_cR(iyear,iage)*
        (1.-mfexp(-1.*Z(iyear,iage)))/Z(iyear,iage);

    }
    pred_cR_L_knum(iyear)=sum(L_cR_num(iyear));//landings already being estimated in 1000s

  }


FUNCTION get_landings_wgt

////---Predicted landings------------------------
  for (iyear=styr; iyear<=endyr; iyear++)
  {
    L_cR_mt(iyear)=elem_prod(L_cR_num(iyear),wholewgt_cR_mt(iyear))*1000000; //in 1000 mt

    pred_cR_L_mt(iyear)=sum(L_cR_mt(iyear));
```

```
 }


FUNCTION get_catchability_fcns
 //Get rate increase if estimated, otherwise fixed above
  if (set_q_rate_phase>0.0)
  {

      for (iyear=styr_gill_cpue; iyear<=endyr_gill_cpue; iyear++)
      {   if (iyear>styr_gill_cpue & iyear <=2003)
          {//q_rate_fcn_gill(iyear)=(1.0+q_rate)*q_rate_fcn_gill(iyear-1); //compound
            q_rate_fcn_gill(iyear)=(1.0+(iyear-styr_gill_cpue)*q_rate)*q_rate_fcn_gill(styr_gill_cpue);  //linear
          }
          if (iyear>2003) {q_rate_fcn_gill(iyear)=q_rate_fcn_gill(iyear-1);}
      }

      for (iyear=styr_seine_cpue; iyear<=endyr_seine_cpue; iyear++)
      {   if (iyear>styr_seine_cpue & iyear <=2003)
          {//q_rate_fcn_seine(iyear)=(1.0+q_rate)*q_rate_fcn_seine(iyear-1); //compound
            q_rate_fcn_seine(iyear)=(1.0+(iyear-styr_seine_cpue)*q_rate)*q_rate_fcn_seine(styr_seine_cpue);  //linear
          }
          if (iyear>2003) {q_rate_fcn_seine(iyear)=q_rate_fcn_seine(iyear-1);}
      }


  } //end q_rate conditional

 //Get density dependence scalar (=1.0 if density independent model is used)
  if (q_DD_beta>0.0)
  {
    B_q_DD+=dzero;
    for (iyear=styr;iyear<=endyr;iyear++)
        {q_DD_fcn(iyear)=pow(B0_q_DD,q_DD_beta)*pow(B_q_DD(iyear),-q_DD_beta);}
          //{q_DD_fcn(iyear)=1.0+4.0/(1.0+mfexp(0.75*(B_q_DD(iyear)-0.1*B0_q_DD))); }
  }


FUNCTION get_indices
//---Predicted CPUEs------------------------

  //Gill net index
  q_gill(styr_gill_cpue)=mfexp(log_q_gill);
  for (iyear=styr_gill_cpue; iyear<=endyr_gill_cpue; iyear++)
  {   N_gill(iyear)=elem_prod(N_mdyr(iyear),sel_gill(iyear));
      pred_gill_cpue(iyear)=q_gill(iyear)*q_rate_fcn_gill(iyear)*q_DD_fcn(iyear)*sum(N_gill(iyear));
      if (iyear<endyr_gill_cpue){q_gill(iyear+1)=q_gill(iyear)*mfexp(q_RW_log_dev_gill(iyear));}
  }

 //seine index
  q_seine(styr_seine_cpue)=mfexp(log_q_seine);
  for (iyear=styr_seine_cpue; iyear<=endyr_seine_cpue; iyear++)
  {   N_seine(iyear)=N(iyear,1)*mfexp(-1.*(Z(iyear)(1)*0.25));//matching seine index with April 1 (1/4 of the year
completed)
      pred_seine_cpue(iyear)=q_seine(iyear)*q_rate_fcn_seine(iyear)*q_DD_fcn(iyear)*N_seine(iyear);
      if (iyear<endyr_seine_cpue){q_seine(iyear+1)=q_seine(iyear)*mfexp(q_RW_log_dev_seine(iyear));}
  }
```

```
FUNCTION get_length_comps

 //gill net survey
  for (iyear=1;iyear<=nyr_gill_lenc;iyear++)
  {
        pred_gill_lenc(iyear)=(N_gill(yrs_gill_lenc(iyear))*lenprob_gill)
                        /sum(N_gill(yrs_gill_lenc(iyear)));
  }


FUNCTION get_age_comps

 //Commerical reduction
 for (iyear=1;iyear<=nyr_cR_agec;iyear++)
  {
    ErrorFree_cR_agec(iyear)=L_cR_num(yrs_cR_agec(iyear))/sum(L_cR_num(yrs_cR_agec(iyear)));
    pred_cR_agec(iyear)=age_error*ErrorFree_cR_agec(iyear);
  }



////-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
FUNCTION get_weighted_current
  F_temp_sum=0.0;
  F_temp_sum+=mfexp((selpar_n_yrs_wgted*log_avg_F_cR+
        sum(log_F_dev_cR((endyr-selpar_n_yrs_wgted+1),endyr)))/selpar_n_yrs_wgted);

  F_cR_prop=mfexp((selpar_n_yrs_wgted*log_avg_F_cR+
        sum(log_F_dev_cR((endyr-selpar_n_yrs_wgted+1),endyr)))/selpar_n_yrs_wgted)/F_temp_sum;

  log_F_dev_end_cR=sum(log_F_dev_cR((endyr-selpar_n_yrs_wgted+1),endyr))/selpar_n_yrs_wgted;

  F_end_L=sel_cR(endyr)*mfexp(log_avg_F_cR+log_F_dev_end_cR);

  F_end=F_end_L;
  F_end_apex=max(F_end);

  sel_wgted_tot=F_end/F_end_apex;
  sel_wgted_L=elem_prod(sel_wgted_tot, elem_div(F_end_L,F_end));

  wgt_wgted_L_denom=F_cR_prop;
  wgt_wgted_L_mt=F_cR_prop/wgt_wgted_L_denom*wholewgt_cR_mt(endyr)*1000; //to scale to 1000s mt

FUNCTION get_msy

  //compute values as functions of F
  for(ff=1; ff<=n_iter_msy; ff++)
  {
    //uses fishery-weighted F's
    Z_age_msy=0.0;
    F_L_age_msy=0.0;

    F_L_age_msy=F_msy(ff)*sel_wgted_L;
```

```
    Z_age_msy=M+F_L_age_msy;

    N_age_msy(1)=1.0;
    for (iage=2; iage<=nages; iage++)
    {
      N_age_msy(iage)=N_age_msy(iage-1)*mfexp(-1.*Z_age_msy(iage-1));
    }
    N_age_msy(nages)=N_age_msy(nages)/(1.0-mfexp(-1.*Z_age_msy(nages)));
    N_age_msy_mdyr(1,(nages-1))=elem_prod(N_age_msy(1,(nages-1)),
                              mfexp((-1.*Z_age_msy(1,(nages-1)))*spawn_time_frac));
    N_age_msy_mdyr(nages)=(N_age_msy_mdyr(nages-1)*
                         (mfexp(-1.*(Z_age_msy(nages-1)*(1.0-spawn_time_frac) +
                          Z_age_msy(nages)*spawn_time_frac) )))
                          /(1.0-mfexp(-1.*Z_age_msy(nages)));

    spr_msy(ff)=sum(elem_prod(N_age_msy_mdyr,reprod));


    //Compute equilibrium values of R (including bias correction), SSB and Yield at each F
    R_eq(ff)=SR_eq_func(R0, steep, spr_msy(1), spr_msy(ff), BiasCor, SR_switch);


    if (R_eq(ff)<dzero) {R_eq(ff)=dzero;}
    N_age_msy*=R_eq(ff);
    N_age_msy_mdyr*=R_eq(ff);

    for (iage=1; iage<=nages; iage++)
    {
      L_age_msy(iage)=N_age_msy(iage)*(F_L_age_msy(iage)/Z_age_msy(iage))*
                     (1.-mfexp(-1.*Z_age_msy(iage)));
    }

    SSB_eq(ff)=sum(elem_prod(N_age_msy_mdyr,reprod));
    B_eq(ff)=sum(elem_prod(N_age_msy,wgt_spawn_mt))*1000000;//to scale to 1000s mt and catch in 1000s
    L_eq_mt(ff)=sum(elem_prod(L_age_msy,wgt_wgted_L_mt))*1000;//to scale to catch in 1000s,
wgt_wgted_L_mt is already scaled to 1000s mt
    L_eq_knum(ff)=sum(L_age_msy)/1000.0;
  }

  msy_mt_out=max(L_eq_mt);

  for(ff=1; ff<=n_iter_msy; ff++)
  {
   if(L_eq_mt(ff) == msy_mt_out)
      {
        SSB_msy_out=SSB_eq(ff);
        B_msy_out=B_eq(ff);
        R_msy_out=R_eq(ff);
        msy_knum_out=L_eq_knum(ff);
        F_msy_out=F_msy(ff);
        spr_msy_out=spr_msy(ff);
      }
  }

//-----------------------------------------------------------------------------------------------------------------------------------
---------------------------------------------------
```

```
FUNCTION get_miscellaneous_stuff

//switch here if var_rec_dev <=dzero
  if(var_rec_dev>0.0)
   {sigma_rec_dev=sqrt(var_rec_dev);} //pow(var_rec_dev,0.5);  //sample SD of predicted residuals (may not equal
rec_sigma)
   else{sigma_rec_dev=0.0;}

  len_cv=elem_div(len_sd,meanlen_FL);

  //compute total landings-at-age in 1000 fish and 1000s mt
  L_total_num.initialize();
  L_total_mt.initialize();
  L_total_knum_yr.initialize();
  L_total_mt_yr.initialize();

  for(iyear=styr; iyear<=endyr; iyear++)
  {
        L_total_mt_yr(iyear)=pred_cR_L_mt(iyear);
        L_total_knum_yr(iyear)=pred_cR_L_knum(iyear);

        B(iyear)=elem_prod(N(iyear),wgt_spawn_mt)*1000000;//scale to 1000s mt and 1000s fish landed
        totN(iyear)=sum(N(iyear));  //in 1000s of fish
        totB(iyear)=sum(B(iyear));  //in 1000s of mt
        SSBatage(iyear)=elem_prod(N(iyear),reprod);
  }

  L_total_num=L_cR_num;   //landings at age in 1000s fish
  L_total_mt=L_cR_mt;   //landings at age in 1000s mt whole weight

  B(endyr+1)=elem_prod(N(endyr+1),wgt_spawn_mt)*1000000;//scale to 1000s mt and 1000s fish
  totN(endyr+1)=sum(N(endyr+1));//in 1000s of fish
  totB(endyr+1)=sum(B(endyr+1));//in 1000s of mt


  if(F_msy_out>0)
    {
      FdF_msy=Fapex/F_msy_out;
      FdF_msy_end=FdF_msy(endyr);
      FdF_msy_end_mean=pow((FdF_msy(endyr)*FdF_msy(endyr-1)*FdF_msy(endyr-2)),(1.0/3.0));
    }
  if(SSB_msy_out>0)
    {
      SdSSB_msy=SSB/SSB_msy_out;
      SdSSB_msy_end=SdSSB_msy(endyr);
    }

   //fill in log recruitment deviations for yrs they are nonzero
   for(iyear=styr_rec_dev; iyear<=endyr_rec_dev; iyear++)
     {log_rec_dev_output(iyear)=log_rec_dev(iyear);}

   //fill in log Nage deviations for ages they are nonzero (ages2+)
   for(iage=2; iage<=nages; iage++)
   {
    log_Nage_dev_output(iage)=log_Nage_dev(iage);
   }
```

```
//-----------------------------------------------------------------------------------------------------------------------------------
-----------------------------------------------
FUNCTION get_per_recruit_stuff

  //static per-recruit stuff

  for(iyear=styr; iyear<=endyr; iyear++)
  {
    N_age_spr(1)=1.0;
    for(iage=2; iage<=nages; iage++)
    {
      N_age_spr(iage)=N_age_spr(iage-1)*mfexp(-1.*Z(iyear,iage-1));
    }
    N_age_spr(nages)=N_age_spr(nages)/(1.0-mfexp(-1.*Z(iyear,nages)));
    N_age_spr_mdyr(1,(nages-1))=elem_prod(N_age_spr(1,(nages-1)),
                            mfexp(-1.*Z(iyear)(1,(nages-1))*spawn_time_frac));
    N_age_spr_mdyr(nages)=(N_age_spr_mdyr(nages-1)*
                      (mfexp(-1.*(Z(iyear)(nages-1)*(1.0-spawn_time_frac) + Z(iyear)(nages)*spawn_time_frac) )))
                      /(1.0-mfexp(-1.*Z(iyear)(nages)));
    spr_static(iyear)=sum(elem_prod(N_age_spr_mdyr,reprod))/spr_F0;
  }


  //compute SSB/R and YPR as functions of F
  for(ff=1; ff<=n_iter_spr; ff++)
  {
    //uses fishery-weighted F's, same as in MSY calculations
    Z_age_spr=0.0;
    F_L_age_spr=0.0;

    F_L_age_spr=F_spr(ff)*sel_wgted_L;

    Z_age_spr=M+F_L_age_spr;

    N_age_spr(1)=1.0;
    for (iage=2; iage<=nages; iage++)
    {
      N_age_spr(iage)=N_age_spr(iage-1)*mfexp(-1.*Z_age_spr(iage-1));
    }
    N_age_spr(nages)=N_age_spr(nages)/(1-mfexp(-1.*Z_age_spr(nages)));
    N_age_spr_mdyr(1,(nages-1))=elem_prod(N_age_spr(1,(nages-1)),
                               mfexp((-1.*Z_age_spr(1,(nages-1)))*spawn_time_frac));
    N_age_spr_mdyr(nages)=(N_age_spr_mdyr(nages-1)*
                      (mfexp(-1.*(Z_age_spr(nages-1)*(1.0-spawn_time_frac) + Z_age_spr(nages)*spawn_time_frac) )))
                      /(1.0-mfexp(-1.*Z_age_spr(nages)));

    spr_spr(ff)=sum(elem_prod(N_age_spr_mdyr,reprod));
    L_spr(ff)=0.0;
    for (iage=1; iage<=nages; iage++)
    {
      L_age_spr(iage)=N_age_spr(iage)*(F_L_age_spr(iage)/Z_age_spr(iage))*
                   (1.-mfexp(-1.*Z_age_spr(iage)));
      L_spr(ff)+=L_age_spr(iage)*wgt_wgted_L_mt(iage)*1000; //already scaled to 1000s mt, but need to scale to
1000s fish
```

```
    }
  }

FUNCTION get_effective_sample_sizes

      neff_gill_lenc_allyr_out=missing;//"missing" defined in admb2r.cpp
      neff_cR_agec_allyr_out=missing;


      for (iyear=1; iyear<=nyr_gill_lenc; iyear++)
         {if (nsamp_gill_lenc(iyear)>=minSS_gill_lenc)

{neff_gill_lenc_allyr_out(yrs_gill_lenc(iyear))=multinom_eff_N(pred_gill_lenc(iyear),obs_gill_lenc(iyear));}
          else {neff_gill_lenc_allyr_out(yrs_gill_lenc(iyear))=-99;}
         }

      for (iyear=1; iyear<=nyr_cR_agec; iyear++)
         {if (nsamp_cR_agec(iyear)>=minSS_cR_agec)

{neff_cR_agec_allyr_out(yrs_cR_agec(iyear))=multinom_eff_N(pred_cR_agec(iyear),obs_cR_agec(iyear));}
          else {neff_cR_agec_allyr_out(yrs_cR_agec(iyear))=-99;}
         }


FUNCTION get_Fmed_benchmarks

  //sorting function for recruitment and SPR values (slow algorithm, but works)
  R_temp=rec(styr,endyr);
  SPR_temp=pred_SPR(styr,endyr);
  for(int jyear=endyr; jyear>=styr; jyear--)
  {
    R_sort(jyear)=max(R_temp);
    SPR_sort(jyear)=max(SPR_temp);
    for(iyear=styr; iyear<=endyr; iyear++)
    {
      if(R_temp(iyear)==R_sort(jyear))
      {
        R_temp(iyear)=0.0;
      }
      if(SPR_temp(iyear)==SPR_sort(jyear))
      {
        SPR_temp(iyear)=0.0;
      }
    }
  }

  // compute the quantile using quant_whole (declared in the data section)
  // which computes the floor integer of a decimal number
  //median
  quant_decimal=(endyr-styr)*0.5;
  quant_whole=(endyr-styr)*0.5;
  quant_diff=quant_decimal-quant_whole;
  R_med=R_sort(styr+quant_whole)*(1-quant_diff)+R_sort(styr+quant_whole+1)*(quant_diff);
  SPR_med=SPR_sort(styr+quant_whole)*(1-quant_diff)+SPR_sort(styr+quant_whole+1)*(quant_diff);
  //cout << "quant_decimal = " << quant_decimal << endl;
  //cout << "quant_whole = " << quant_whole << endl;
```

```
  //cout << "quant_diff = " << quant_diff << endl;
  //cout << "result = " << quant_whole*(1-quant_diff)+(quant_whole+1)*quant_diff << endl;
  //cout << "R_med = " << R_med << endl;
  //cout << "R_sort = " << R_sort << endl;
  //cout << "R = " << R_temp << endl;

  //75th quantile
  quant_decimal=(endyr-styr)*0.75;
  quant_whole=(endyr-styr)*0.75;
  quant_diff=quant_decimal-quant_whole;
  SPR_75th=SPR_sort(styr+quant_whole)*(1-quant_diff)+SPR_sort(styr+quant_whole+1)*(quant_diff);
  //cout << "quant_decimal = " << quant_decimal << endl;
  //cout << "quant_whole = " << quant_whole << endl;
  //cout << "quant_diff = " << quant_diff << endl;
  //cout << "result = " << quant_whole*(1-quant_diff)+(quant_whole+1)*quant_diff << endl;

  //find F that matches SPR_med = F_med
  SPR_diff=square(spr_spr-SPR_med);
  SPR_diff_min=min(SPR_diff);
  for(ff=1; ff<=n_iter_spr; ff++)
  {
    if(SPR_diff(ff)==SPR_diff_min)
    {
      F_med=F_spr(ff);
      //F_med_age2plus=F_spr_age2plus(ff);
      L_med=L_spr(ff)*R_med;
    }
  }
  SSB_med=SPR_med*R_med;
  SSB_med_thresh=SSB_med*0.5;

  //get the target that corresponds to Fmed, based on 75th quantile of SPR scatter
  SPR_diff=square(spr_spr-SPR_75th);
  SPR_diff_min=min(SPR_diff);
  for(ff=1; ff<=n_iter_spr; ff++)
  {
    if(SPR_diff(ff)==SPR_diff_min)
    {
      F_med_target=F_spr(ff);
      //F_med_target_age2plus=F_spr_age2plus(ff);
      L_med_target=L_spr(ff)*R_med;
    }
  }



//--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------


FUNCTION evaluate_objective_function
  fval=0.0;
  fval_data=0.0;
//---likelihoods---------------------------

//---Indices-------------------------------
```

```
  f_gill_cpue=0.0;
  f_gill_cpue=lk_lognormal(pred_gill_cpue, obs_gill_cpue, gill_cpue_cv, w_I_gill);
  fval+=f_gill_cpue;
  fval_data+=f_gill_cpue;

  f_seine_cpue=0.0;
  f_seine_cpue=lk_lognormal(pred_seine_cpue, obs_seine_cpue, seine_cpue_cv, w_I_seine);
  fval+=f_seine_cpue;
  fval_data+=f_seine_cpue;

////---Landings-------------------------------

  //f_cR_L in 1000s mt
  f_cR_L=lk_lognormal(pred_cR_L_mt, obs_cR_L, cR_L_cv, w_L);

  fval+=f_cR_L;
  fval_data+=f_cR_L;


//---Length comps-------------------------------

  //f_gill_lenc
  f_gill_lenc=lk_robust_multinomial(nsamp_gill_lenc, pred_gill_lenc, obs_gill_lenc, nyr_gill_lenc,
double(nlenbins), minSS_gill_lenc, w_lc_gill);
  //f_gill_lenc=lk_multinomial(nsamp_gill_lenc, pred_gill_lenc, obs_gill_lenc, nyr_gill_lenc, minSS_gill_lenc,
w_lc_gill);
  fval+=f_gill_lenc;
  fval_data+=f_gill_lenc;



//////---Age comps-------------------------------

  //f_cR_agec
  f_cR_agec=lk_robust_multinomial(nsamp_cR_agec, pred_cR_agec, obs_cR_agec, nyr_cR_agec, double(nages),
minSS_cR_agec, w_ac_cR);
  //f_cR_agec=lk_multinomial(nsamp_cR_agec, pred_cR_agec, obs_cR_agec, nyr_cR_agec, minSS_cR_agec,
w_ac_cR);
  fval+=f_cR_agec;
  fval_data+=f_cR_agec;


////-----------Constraints and penalties-------------------------------
  f_M_dev=0.0;
  f_M_dev=norm2(M_dev);
  fval+=w_M_dev*f_M_dev;



  f_rec_dev=0.0;
  //rec_sigma_sq=square(rec_sigma);
  rec_logL_add=nyrs_rec*log(rec_sigma);
  f_rec_dev=(square(log_rec_dev(styr_rec_dev) + rec_sigma_sq/2.0)/(2.0*rec_sigma_sq));
  for(iyear=(styr_rec_dev+1); iyear<=endyr_rec_dev; iyear++)
    {f_rec_dev+=(square(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1) + rec_sigma_sq/2.0)/
```

```
            (2.0*rec_sigma_sq));}
  f_rec_dev+=rec_logL_add;
  fval+=w_rec*f_rec_dev;

  f_rec_dev_early=0.0; //possible extra constraint on early rec deviations
  if (w_rec_early>0.0)
    { if (styr_rec_dev<endyr_rec_phase1)
        {
         for(iyear=styr_rec_dev; iyear<=endyr_rec_phase1; iyear++)
         //{f_rec_dev_early+=(square(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1) + rec_sigma_sq/2.0)/
         //                (2.0*rec_sigma_sq)) + rec_logL_add;}
         {f_rec_dev_early+=square(log_rec_dev(iyear));}
        }
  fval+=w_rec_early*f_rec_dev_early;
  }

  f_rec_dev_end=0.0; //possible extra constraint on ending rec deviations
  if (w_rec_end>0.0)
  { if (endyr_rec_phase2<endyr)
        {
         for(iyear=(endyr_rec_phase2+1); iyear<=endyr; iyear++)
         //{f_rec_dev_end+=(square(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1) + rec_sigma_sq/2.0)/
         //               (2.0*rec_sigma_sq)) + rec_logL_add;}
         {f_rec_dev_end+=square(log_rec_dev(iyear));}
        }
     fval+=w_rec_end*f_rec_dev_end;
   }


  //fval+=norm2(log_Nage_dev); //applies if initial age structure is estimated


  //Random walk components of fishery dependent indices

  //f_gill_RW_cpue=0.0;
  //for (iyear=styr_gill_cpue; iyear<endyr_gill_cpue; iyear++)
  //    {f_gill_RW_cpue+=square(q_RW_log_dev_gill(iyear))/(2.0*set_q_RW_gill_var);}
  //fval+=f_gill_RW_cpue;

  //f_seine_RW_cpue=0.0;
  //for (iyear=styr_seine_cpue; iyear<endyr_seine_cpue; iyear++)
  //    {f_seine_RW_cpue+=square(q_RW_log_dev_seine(iyear))/(2.0*set_q_RW_seine_var);}
  //fval+=f_seine_RW_cpue;


//---Priors---------------------------------------------------
//neg_log_prior arguments: estimate, prior mean, prior var/-CV, pdf type
//Variance input as a negative value is considered to be CV in arithmetic space (CV=-1 implies loose prior)
//pdf type 1=none, 2=lognormal, 3=normal, 4=beta
  f_priors=0.0;
  //f_priors+=neg_log_prior(Linf,set_Linf(5),set_Linf(6),set_Linf(7));
  //f_priors+=neg_log_prior(K,set_K(5),set_K(6),set_K(7));
  //f_priors+=neg_log_prior(t0,set_t0(5),set_t0(6),set_t0(7));
  //f_priors+=neg_log_prior(len_cv_val,set_len_cv(5),set_len_cv(6),set_len_cv(7));
  //f_priors+=neg_log_prior(M_constant,set_M_constant(5),set_M_constant(6),set_M_constant(7));
```

```
  //f_priors+=neg_log_prior(steep,set_steep(5),set_log_R0(6),set_log_R0(7));
  //f_priors+=neg_log_prior(log_R0,set_log_R0(5),set_log_R0(6),set_log_R0(7));
  //f_priors+=neg_log_prior(R_autocorr,set_R_autocorr(5),set_R_autocorr(6),set_R_autocorr(7));
  //f_priors+=neg_log_prior(rec_sigma,set_rec_sigma(5),set_rec_sigma(6),set_rec_sigma(7));

  //f_priors+=neg_log_prior(selpar_L50_cR,set_selpar_L50_cR(5),set_selpar_L50_cR(6), set_selpar_L50_cR(7));
  //f_priors+=neg_log_prior(selpar_slope_cR,set_selpar_slope_cR(5),set_selpar_slope_cR(6),
set_selpar_slope_cR(7));
  //f_priors+=neg_log_prior(selpar_L502_cR,set_selpar_L502_cR(5),set_selpar_L502_cR(6),
set_selpar_L502_cR(7));
  //f_priors+=neg_log_prior(selpar_slope2_cR,set_selpar_slope2_cR(5),set_selpar_slope2_cR(6),
set_selpar_slope2_cR(7));
  //f_priors+=neg_log_prior(sel_age1_cR_logit,set_sel_age1_cR(5),set_sel_age1_cR(6), set_sel_age1_cR(7));
  //f_priors+=neg_log_prior(sel_age3_cR_logit,set_sel_age3_cR(5),set_sel_age3_cR(6), set_sel_age3_cR(7));
  //f_priors+=neg_log_prior(sel_age4_cR_logit,set_sel_age4_cR(5),set_sel_age4_cR(6), set_sel_age4_cR(7));

  //f_priors+=neg_log_prior(selpar_L50_gill,set_selpar_L50_gill(5),set_selpar_L50_gill(6), set_selpar_L50_gill(7));
  //f_priors+=neg_log_prior(selpar_slope_gill,set_selpar_slope_gill(5),set_selpar_slope_gill(6),
set_selpar_slope_gill(7));

  //f_priors+=neg_log_prior(log_q_gill,set_log_q_gill(5),set_log_q_gill(6),set_log_q_gill(7));
  //f_priors+=neg_log_prior(log_q_seine,set_log_q_seine(5),set_log_q_seine(6),set_log_q_seine(7));

  //f_priors+=neg_log_prior(log_avg_F_cR,set_log_avg_F_cR(5),set_log_avg_F_cR(6),set_log_avg_F_cR(7));


  fval+=f_priors;

  //cout << "fval = " << fval << "  fval_data = " << fval_data << endl;
  //cout << endl;

//---------------------------------------------------------------------------------------
//Logistic function: 2 parameters
FUNCTION dvar_vector logistic(const dvar_vector& ages, const dvariable& L50, const dvariable& slope)
  //ages=vector of ages, L50=age at 50% selectivity, slope=rate of increase
  RETURN_ARRAYS_INCREMENT();
  dvar_vector Sel_Tmp(ages.indexmin(),ages.indexmax());
  Sel_Tmp=1./(1.+mfexp(-1.*slope*(ages-L50))); //logistic;
  RETURN_ARRAYS_DECREMENT();
  return Sel_Tmp;

//----------------------------------------------------------------------------------------
//Logistic function: 4 parameters
FUNCTION dvar_vector logistic_double(const dvar_vector& ages, const dvariable& L501, const dvariable&
slope1, const dvariable& L502, const dvariable& slope2)
  //ages=vector of ages, L50=age at 50% selectivity, slope=rate of increase, L502=age at 50% decrease additive to
L501, slope2=slope of decrease
  RETURN_ARRAYS_INCREMENT();
  dvar_vector Sel_Tmp(ages.indexmin(),ages.indexmax());
  Sel_Tmp=elem_prod( (1./(1.+mfexp(-1.*slope1*(ages-L501)))),(1.-(1./(1.+mfexp(-1.*slope2*(ages-
(L501+L502)))))) );
  Sel_Tmp=Sel_Tmp/max(Sel_Tmp);
  RETURN_ARRAYS_DECREMENT();
  return Sel_Tmp;

//----------------------------------------------------------------------------------------
```

```
//Jointed logistic function: 6 parameters (increasing and decreasing logistics joined at peak selectivity)
FUNCTION dvar_vector logistic_joint(const dvar_vector& ages, const dvariable& L501, const dvariable& slope1, const dvariable& L502, const dvariable& slope2, const dvariable& satval, const dvariable& joint)
  //ages=vector of ages, L501=age at 50% sel (ascending limb), slope1=rate of increase,L502=age at 50% sel (descending), slope1=rate of increase (ascending),
  //satval=saturation value of descending limb, joint=location in age vector to join curves (may equal age or age + 1 if age-0 is included)
  RETURN_ARRAYS_INCREMENT();
  dvar_vector Sel_Tmp(ages.indexmin(),ages.indexmax());
  Sel_Tmp=1.0;
  for (iage=1; iage<=nages; iage++)
  {
   if (double(iage)<joint) {Sel_Tmp(iage)=1./(1.+mfexp(-1.*slope1*(ages(iage)-L501)));}
   if (double(iage)>joint){Sel_Tmp(iage)=1.0-(1.0-satval)/(1.+mfexp(-1.*slope2*(ages(iage)-L502)));}
  }
  Sel_Tmp=Sel_Tmp/max(Sel_Tmp);
  RETURN_ARRAYS_DECREMENT();
  return Sel_Tmp;

//-----------------------------------------------------------------------------------
//Double Gaussian function: 6 parameters (as in SS3)
FUNCTION dvar_vector gaussian_double(const dvar_vector& ages, const dvariable& peak, const dvariable& top, const dvariable& ascwid, const dvariable& deswid, const dvariable& init, const dvariable& final)
  //ages=vector of ages, peak=ascending inflection location (as logistic), top=width of plateau, ascwid=ascent width (as log(width))
  //deswid=descent width (as log(width))
  RETURN_ARRAYS_INCREMENT();
  dvar_vector Sel_Tmp(ages.indexmin(),ages.indexmax());
  dvar_vector sel_step1(ages.indexmin(),ages.indexmax());
  dvar_vector sel_step2(ages.indexmin(),ages.indexmax());
  dvar_vector sel_step3(ages.indexmin(),ages.indexmax());
  dvar_vector sel_step4(ages.indexmin(),ages.indexmax());
  dvar_vector sel_step5(ages.indexmin(),ages.indexmax());
  dvar_vector sel_step6(ages.indexmin(),ages.indexmax());
  dvar_vector pars_tmp(1,6); dvar_vector sel_tmp_iq(1,2);

  pars_tmp(1)=peak;
  pars_tmp(2)=peak+1.0+(0.99*ages(nages)-peak-1.0)/(1.0+mfexp(-top));
  pars_tmp(3)=mfexp(ascwid);
  pars_tmp(4)=mfexp(deswid);
  pars_tmp(5)=1.0/(1.0+mfexp(-init));
  pars_tmp(6)=1.0/(1.0+mfexp(-final));

  sel_tmp_iq(1)=mfexp(-(square(ages(1)-pars_tmp(1))/pars_tmp(3)));
  sel_tmp_iq(2)=mfexp(-(square(ages(nages)-pars_tmp(2))/pars_tmp(4)));

  sel_step1=mfexp(-(square(ages-pars_tmp(1))/pars_tmp(3)));
  sel_step2=pars_tmp(5)+(1.0-pars_tmp(5))*(sel_step1-sel_tmp_iq(1))/(1.0-sel_tmp_iq(1));
  sel_step3=mfexp(-(square(ages-pars_tmp(2))/pars_tmp(4)));
  sel_step4=1.0+(pars_tmp(6)-1.0)*(sel_step3-1.0)/(sel_tmp_iq(2)-1.0);
  sel_step5=1.0/ (1.0+mfexp(-(20.0* elem_div((ages-pars_tmp(1)), (1.0+sfabs(ages-pars_tmp(1)))) )));
  sel_step6=1.0/(1.0+mfexp(-(20.0*elem_div((ages-pars_tmp(2)),(1.0+sfabs(ages-pars_tmp(2)))) )));

  Sel_Tmp=elem_prod(sel_step2,(1.0-sel_step5))+
        elem_prod(sel_step5,((1.0-sel_step6)+ elem_prod(sel_step4,sel_step6)) );
```

```
  Sel_Tmp=Sel_Tmp/max(Sel_Tmp);
  RETURN_ARRAYS_DECREMENT();
  return Sel_Tmp;

//----------------------------------------------------------------------------------
//Spawner-recruit function (Beverton-Holt or Ricker)
FUNCTION dvariable SR_func(const dvariable& R0, const dvariable& h, const dvariable& spr_F0, const
dvariable& SSB, int func)
  //R0=virgin recruitment, h=steepness, spr_F0=spawners per recruit @ F=0, SSB=spawning biomass
  //func=1 for Beverton-Holt, 2 for Ricker
  RETURN_ARRAYS_INCREMENT();
  dvariable Recruits_Tmp;
  switch(func) {
    case 1: //Beverton-Holt
      Recruits_Tmp=((0.8*R0*h*SSB)/(0.2*R0*spr_F0*(1.0-h)+(h-0.2)*SSB));
    break;
    case 2: //Ricker
      Recruits_Tmp=((SSB/spr_F0)*mfexp(h*(1-SSB/(R0*spr_F0))));
    break;
  }
  RETURN_ARRAYS_DECREMENT();
  return Recruits_Tmp;

//----------------------------------------------------------------------------------
//Spawner-recruit equilibrium function (Beverton-Holt or Ricker)
FUNCTION dvariable SR_eq_func(const dvariable& R0, const dvariable& h, const dvariable& spr_F0, const
dvariable& spr_F, const dvariable& BC, int func)
  //R0=virgin recruitment, h=steepness, spr_F0=spawners per recruit @ F=0, spr_F=spawners per recruit @ F,
BC=bias correction
  //func=1 for Beverton-Holt, 2 for Ricker
  RETURN_ARRAYS_INCREMENT();
  dvariable Recruits_Tmp;
  switch(func) {
    case 1: //Beverton-Holt
      Recruits_Tmp=(R0/((5.0*h-1.0)*spr_F))*(BC*4.0*h*spr_F-spr_F0*(1.0-h));
    break;
    case 2: //Ricker
      Recruits_Tmp=R0/(spr_F/spr_F0)*(1.0+log(BC*spr_F/spr_F0)/h);
    break;
  }
  RETURN_ARRAYS_DECREMENT();
  return Recruits_Tmp;


//----------------------------------------------------------------------------------
//compute multinomial effective sample size for a single yr
FUNCTION dvariable multinom_eff_N(const dvar_vector& pred_comp, const dvar_vector& obs_comp)
  //pred_comp=vector of predicted comps, obscomp=vector of observed comps
  dvariable EffN_Tmp; dvariable numer; dvariable denom;
  RETURN_ARRAYS_INCREMENT();
  numer=sum( elem_prod(pred_comp,(1.0-pred_comp)) );
  denom=sum( square(obs_comp-pred_comp) );
  if (denom>0.0) {EffN_Tmp=numer/denom;}
  else {EffN_Tmp=-missing;}
  RETURN_ARRAYS_DECREMENT();
  return EffN_Tmp;
```

```
//--------------------------------------------------------------------------------------
//Likelihood contribution: lognormal
FUNCTION dvariable lk_lognormal(const dvar_vector& pred, const dvar_vector& obs, const dvar_vector& cv,
const dvariable& wgt_dat)
  //pred=vector of predicted vals, obs=vector of observed vals, cv=vector of CVs in arithmetic space,
wgt_dat=constant scaling of CVs
  //small_number is small value to avoid log(0) during search
  RETURN_ARRAYS_INCREMENT();
  dvariable LkvalTmp;
  dvariable small_number=0.00001;
  dvar_vector var(cv.indexmin(),cv.indexmax()); //variance in log space
  var=log(1.0+square(cv/wgt_dat));   // convert cv in arithmetic space to variance in log space
  LkvalTmp=sum(0.5*elem_div(square(log(elem_div((pred+small_number),(obs+small_number)))),var) );
  RETURN_ARRAYS_DECREMENT();
  return LkvalTmp;

//--------------------------------------------------------------------------------------
//Likelihood contribution: multinomial
FUNCTION dvariable lk_multinomial(const dvar_vector& nsamp, const dvar_matrix& pred_comp, const
dvar_matrix& obs_comp, const double& ncomp, const double& minSS, const dvariable& wgt_dat)
  //nsamp=vector of N's, pred_comp=matrix of predicted comps, obs_comp=matrix of observed comps, ncomp =
number of yrs in matrix, minSS=min N threshold, wgt_dat=scaling of N's
  RETURN_ARRAYS_INCREMENT();
  dvariable LkvalTmp;
  dvariable small_number=0.00001;
  LkvalTmp=0.0;
  for (int ii=1; ii<=ncomp; ii++)
  {if (nsamp(ii)>=minSS)
    {LkvalTmp-=wgt_dat*nsamp(ii)*sum(elem_prod((obs_comp(ii)+small_number),
              log(elem_div((pred_comp(ii)+small_number), (obs_comp(ii)+small_number)))));
    }
  }
  RETURN_ARRAYS_DECREMENT();
  return LkvalTmp;


//--------------------------------------------------------------------------------------
//Likelihood contribution: multinomial
FUNCTION dvariable lk_robust_multinomial(const dvar_vector& nsamp, const dvar_matrix& pred_comp, const
dvar_matrix& obs_comp, const double& ncomp, const dvariable& mbin, const double& minSS, const dvariable&
wgt_dat)
  //nsamp=vector of N's, pred_comp=matrix of predicted comps, obs_comp=matrix of observed comps, ncomp =
number of yrs in matrix, mbin=number of bins, minSS=min N threshold, wgt_dat=scaling of N's
  RETURN_ARRAYS_INCREMENT();
  dvariable LkvalTmp;
  dvariable small_number=0.00001;
  LkvalTmp=0.0;
  dvar_matrix Eprime=elem_prod((1.0-obs_comp), obs_comp)+0.1/mbin; //E' of Francis 2011, p.1131
  dvar_vector nsamp_wgt=nsamp*wgt_dat;
  //cout<<nsamp_wgt<<endl;
  for (int ii=1; ii<=ncomp; ii++)
  {if (nsamp(ii)>=minSS)
    {LkvalTmp+= sum(0.5*log(Eprime(ii))-log(small_number+mfexp(elem_div((-square(obs_comp(ii)-
pred_comp(ii))) , (Eprime(ii)*2.0/nsamp_wgt(ii)) ))) );
    }
```

```
 }
 RETURN_ARRAYS_DECREMENT();
 return LkvalTmp;


//--------------------------------------------------------------------------------
//--------------------------------------------------------------------------------
//Likelihood contribution: priors
FUNCTION  dvariable neg_log_prior(dvariable pred, const double& prior, dvariable var, int pdf)
 //prior=prior point estimate, var=variance (if negative, treated as CV in arithmetic space), pred=predicted value,
pdf=prior type (1=none, 2=lognormal, 3=normal, 4=beta)
   dvariable LkvalTmp;
   dvariable alpha, beta, ab_iq;
   dvariable big_number=1e10;
   LkvalTmp=0.0;
   // compute generic pdf's
   switch(pdf) {
      case 1: //option to turn off prior
        LkvalTmp=0.0;
        break;
      case 2: // lognormal
        if(prior<=0.0) cout << "YIKES: Don't use a lognormal distn for a negative prior" << endl;
        else if(pred<=0) LkvalTmp=big_number=1e10;
        else {
          if(var<0.0) var=log(1.0+var*var) ;      // convert cv to variance on log scale
          LkvalTmp= 0.5*( square(log(pred/prior))/var + log(var) );
        }
      break;
      case 3: // normal
        if(var<0.0 && prior!=0.0) var=square(var*prior);       // convert cv to variance on observation scale
        else if(var<0.0 && prior==0.0) var=-var;               // cv not really appropriate if prior value equals zero
        LkvalTmp= 0.5*( square(pred-prior)/var + log(var) );
        break;
      case 4: // beta
        if(var<0.0) var=square(var*prior);          // convert cv to variance on observation scale
        if(prior<=0.0 || prior>=1.0) cout << "YIKES: Don't use a beta distn for a prior outside (0,1)" << endl;
        ab_iq=prior*(1.0-prior)/var - 1.0; alpha=prior*ab_iq; beta=(1.0-prior)*ab_iq;
        if(pred>=0 && pred<=1) LkvalTmp= (1.0-alpha)*log(pred)+(1.0-beta)*log(1.0-pred)-
gammln(alpha+beta)+gammln(alpha)+gammln(beta);
        else LkvalTmp=big_number;
        break;
      default: // no such prior pdf currently available
        cout << "The prior must be either 1(lognormal), 2(normal), or 3(beta)." << endl;
        cout << "Presently it is " << pdf << endl;
        exit(0);
   }
   return LkvalTmp;

//--------------------------------------------------------------------------------
//SDNR: age comp likelihood (assumes fits are done with the robust multinomial function)
FUNCTION dvariable sdnr_multinomial(const double& ncomp, const dvar_vector& ages, const dvar_vector&
nsamp,
                                   const dvar_matrix& pred_comp, const dvar_matrix& obs_comp, const dvariable& wgt_dat)
 //ncomp=number of years of data, ages=vector of ages, nsamp=vector of N's,
 //pred_comp=matrix of predicted comps, obs_comp=matrix of observed comps, wgt_dat=likelihood weight for
data source
```

```
  RETURN_ARRAYS_INCREMENT();
  dvariable SdnrTmp;
  dvar_vector o(1,ncomp);
  dvar_vector p(1,ncomp);
  dvar_vector ose(1,ncomp);
  dvar_vector res(1,ncomp);
  SdnrTmp=0.0;
  for (int ii=1; ii<=ncomp; ii++)
  {
    o(ii)=sum(elem_prod(ages,obs_comp(ii)));
    p(ii)=sum(elem_prod(ages,pred_comp(ii)));
    ose(ii)=sqrt((sum(elem_prod(square(ages),pred_comp(ii)))-square(p(ii)))/(nsamp(ii)*wgt_dat));
  }
  res=elem_div((o-p),ose);
  SdnrTmp=sqrt(sum(square(res-(sum(res)/ncomp))/(ncomp-1.0)));
  RETURN_ARRAYS_DECREMENT();
  return SdnrTmp;


//--------------------------------------------------------------------------------
//SDNR: lognormal likelihood
FUNCTION dvariable sdnr_lognormal(const dvar_vector& pred, const dvar_vector& obs, const dvar_vector& cv, const dvariable& wgt_dat)
  //nyr=number of years of data, pred=vector of predicted data, obs=vector of observed data, cv=vector of cv's, wgt_dat=likelihood weight for data source
  RETURN_ARRAYS_INCREMENT();
  dvariable SdnrTmp;
  dvariable small_number=0.00001;
  dvariable n;
  dvar_vector res(cv.indexmin(),cv.indexmax());
  SdnrTmp=0.0;
  res=elem_div(log(elem_div(obs+small_number,pred+small_number)),sqrt(log(1+square(cv/wgt_dat))));
  n=cv.indexmax()-cv.indexmin()+1;
  SdnrTmp=sqrt(sum(square(res-(sum(res)/n))/(n-1.0)));
  RETURN_ARRAYS_DECREMENT();
  return SdnrTmp;

//--------------------------------------------------------------------------------
REPORT_SECTION

  if (last_phase())
  {
      // cout<<"start report"<<endl;
      get_weighted_current();
      //cout<<"got weighted"<<endl;
      get_msy();
      //cout<<"got msy"<<endl;
      get_miscellaneous_stuff();
      //cout<<"got misc stuff"<<endl;
      get_per_recruit_stuff();
      //cout<<"got per recruit"<<endl;
      get_effective_sample_sizes();
      get_Fmed_benchmarks();
      cout << "got Fmed benchmarks" << endl;

      time(&finish);
```

```
		elapsed_time=difftime(finish,start);
		hour=long(elapsed_time)/3600;
		minute=long(elapsed_time)%3600/60;
		second=(long(elapsed_time)%3600)%60;
		cout<<endl<<endl<<"************************************************"<<endl;
		cout<<"--Start time: "<<ctime(&start)<<endl;
		cout<<"--Finish time: "<<ctime(&finish)<<endl;
		cout<<"--Runtime: ";
		cout<<hour<<" hours, "<<minute<<" minutes, "<<second<<" seconds"<<endl;
		cout<<"************************************************"<<endl;

   cout <<endl;
   cout << "><>--><>--><>--><>--><>--><>--><>--><>--><>--><>"  <<endl;
   cout << "BC Fmsy=" << F_msy_out<< "   BC SSBmsy=" << SSB_msy_out <<endl;
   cout <<"F status="<<FdF_msy_end<<endl;
   cout <<"Pop status="<<SdSSB_msy_end<<endl;
   cout << "h="<<steep<<"   R0="<<R0<<endl;
   cout << "><>--><>--><>--><>--><>--><>--><>--><>--><>--><>"  <<endl;


   report << "TotalLikelihood " << fval << endl;
   report << "N" << endl;
   report << N<<endl;
   report << "F" << endl;
   report << F <<endl;

   sdnr_lc_gill=sdnr_multinomial(nyr_gill_lenc, lbins, nsamp_gill_lenc, pred_gill_lenc, obs_gill_lenc, w_lc_gill);

   sdnr_ac_cR=sdnr_multinomial(nyr_cR_agec, agebins, nsamp_cR_agec, pred_cR_agec, obs_cR_agec,
w_ac_cR);

   sdnr_I_gill=sdnr_lognormal(pred_gill_cpue, obs_gill_cpue, gill_cpue_cv, w_I_gill);
   sdnr_I_seine=sdnr_lognormal(pred_seine_cpue, obs_seine_cpue, seine_cpue_cv, w_I_seine);



//##########################################################################################
#####
   //##  Passing parameters to vector for bounds check plotting

//##########################################################################################
#####
    Linf_out(8)=Linf; Linf_out(1,7)=set_Linf;
    K_out(8)=K; K_out(1,7)=set_K;
    t0_out(8)=t0; t0_out(1,7)=set_t0;
    len_cv_val_out(8)=len_cv_val; len_cv_val_out(1,7)=set_len_cv;
    log_R0_out(8)=log_R0; log_R0_out(1,7)=set_log_R0;
    steep_out(8)=steep; steep_out(1,7)=set_steep;
    rec_sigma_out(8)=rec_sigma; rec_sigma_out(1,7)=set_rec_sigma;
    R_autocorr_out(8)=R_autocorr; R_autocorr_out(1,7)=set_R_autocorr;
    selpar_L50_cR_out(8)=selpar_L50_cR; selpar_L50_cR_out(1,7)=set_selpar_L50_cR;
    selpar_slope_cR_out(8)=selpar_slope_cR; selpar_slope_cR_out(1,7)=set_selpar_slope_cR;
    selpar_L502_cR_out(8)=selpar_L502_cR; selpar_L502_cR_out(1,7)=set_selpar_L502_cR;
    selpar_slope2_cR_out(8)=selpar_slope2_cR; selpar_slope2_cR_out(1,7)=set_selpar_slope2_cR;
    selpar_age0_cR_out(8)=sel_age0_cR_logit; selpar_age0_cR_out(1,7)=set_sel_age0_cR;
    selpar_age1_cR_out(8)=sel_age1_cR_logit; selpar_age1_cR_out(1,7)=set_sel_age1_cR;
```

```
    selpar_age2_cR_out(8)=sel_age2_cR_logit; selpar_age2_cR_out(1,7)=set_sel_age2_cR;
    selpar_age3_cR_out(8)=sel_age3_cR_logit; selpar_age3_cR_out(1,7)=set_sel_age3_cR;
    selpar_age4_cR_out(8)=sel_age4_cR_logit; selpar_age4_cR_out(1,7)=set_sel_age4_cR;
    selpar_age0_cR2_out(8)=sel_age0_cR2_logit; selpar_age0_cR2_out(1,7)=set_sel_age0_cR2;
    selpar_age1_cR2_out(8)=sel_age1_cR2_logit; selpar_age1_cR2_out(1,7)=set_sel_age1_cR2;
    selpar_age2_cR2_out(8)=sel_age2_cR2_logit; selpar_age2_cR2_out(1,7)=set_sel_age2_cR2;
    selpar_age3_cR2_out(8)=sel_age3_cR2_logit; selpar_age3_cR2_out(1,7)=set_sel_age3_cR2;
    selpar_age4_cR2_out(8)=sel_age4_cR2_logit; selpar_age4_cR2_out(1,7)=set_sel_age4_cR2;
    selpar_L50_gill_out(8)=selpar_L50_gill; selpar_L50_gill_out(1,7)=set_selpar_L50_gill;
    selpar_slope_gill_out(8)=selpar_slope_gill; selpar_slope_gill_out(1,7)=set_selpar_slope_gill;
    log_q_gill_out(8)=log_q_gill; log_q_gill_out(1,7)=set_log_q_gill;
    log_q_seine_out(8)=log_q_seine; log_q_seine_out(1,7)=set_log_q_seine;
    M_constant_out(8)=M_constant; M_constant_out(1,7)=set_M_constant;
    log_avg_F_cR_out(8)=log_avg_F_cR; log_avg_F_cR_out(1,7)=set_log_avg_F_cR;

    log_rec_dev_output(styr_rec_dev,endyr_rec_dev)=log_rec_dev;
    log_F_dev_cR_out(styr_cR_L,endyr_cR_L)=log_F_dev_cR;
    M_dev_output(styr_seine_cpue,endyr_seine_cpue)=M_dev;
    log_Nage_dev_output(2,nages)=log_Nage_dev;

  #include "gm_make_Robject-001.cxx"   // write the S-compatible report

} //endl last phase loop
```

Appendix A2

```
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
##
##  Data Input File
##  SEDAR 32A Gulf menhaden assessment August 2013
##
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>

##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
##-- BAM DATA SECTION: set-up section
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>

#Starting and ending year of model
1977
2011

#Starting year to estimate recruitment deviation from S-R curve
1977

#Ending year to estimate recruitment deviation from S-R curve
2011

#3 phases of constraints on recruitment deviations:
#allows possible heavier constraint (weights defined later) in early and late period, with lighter constraint in the
middle
#ending years of recruitment constraint phases
1980
2008

#Ending year for first and second selectivity period
1993
2011

#Number of ages (5 classes is 0,...,4+) //assumes 4-6 is plus group
5
#Vector of agebins, last is a plus group
0.0 1.0 2.0 3.0 4.0

#Number length bins used to match length comps and number used to compute plus group
15
7

#Vector of length bins (mm)(midpoint of bin) used to match length comps and bins used to compute plus group
85      95      105     115     125     135     145     155     165     175     185     195     205
        215     225
235     245     255     265     275     285     295


#Max value of F used in spr and msy calculations
10.0
#Number of iterations in spr calculations
10001
```

```
#Number of iterations in msy calculations
10001
#Number years at end of time series over which to average sector Fs, for weighted selectivities
3
#Multiplicative bias correction of recruitment (may set to 1.0 for none or negative to compute from recruitment
variance)
-1.0
#Number yrs to exclude at end of time series for computing bias correction (end rec devs may have extra constraint)
0



##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
##-- BAM DATA SECTION: observed data section
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>

#######################Commercial Reduction
Landings####################################################################
#Total landings (includes reduction landings + bait and recreational(very small; assumes a 100% discard mortality
rate on rec landings))
#Starting and ending years of landings time series, respectively
1977
2011
#Observed Total removals (1000s of mt) and assumed CVs
447.60  820.60  779.83  702.50  553.71  855.53  925.26  985.12  884.39  824.02  906.06  634.45  582.22
        538.64  549.67  429.43  548.67  771.77  472.02  491.75  623.15  493.65  692.49  580.29  522.11
        575.07  517.70  469.24  434.13  464.65  454.09  425.57  457.69  379.93  613.83
0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04
        0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04
        0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04    0.04

#Number and vector of years of age compositions for commercial reduction fishery
35
1977  1978  1979  1980  1981  1982  1983  1984  1985  1986  1987  1988  1989  1990  1991  1992  1993  1994
1995  1996  1997  1998  1999  2000  2001  2002  2003  2004  2005  2006  2007  2008  2009  2010  2011
###sample sizes of age comps by year (first row observed Nsets, second row Nfish)
1492    1300    1163    1014    1042    1076    1485    1599    1324    1652    1647    1240    1392
        1152    1164    1524    1537    1680    1470    1506    1124    1073    1183    969     740
        836     1066    942     899     594     657     594     748     461     835
14897   12944   11121   9883    10273   10341   14523   15936   13225   16494   16458   12402   13950
        11456   11378   14214   14576   16062   13489   12115   9923    9043    10641   8383    6222
        5597    7839    6644    6206    4698    3989    4663    6193    3678    7254
#age composition samples (year,age) from recreational fishery--combined across gear and unweighted--last age is a
plus group (1 to 12+)
0.000   0.763   0.218   0.018   0.001
0.000   0.708   0.286   0.005   0.001
0.000   0.593   0.363   0.043   0.001
0.009   0.472   0.452   0.060   0.007
0.000   0.763   0.189   0.044   0.005
0.000   0.571   0.366   0.056   0.007
0.000   0.526   0.428   0.043   0.003
0.000   0.697   0.259   0.039   0.004
0.000   0.758   0.218   0.020   0.003
0.000   0.456   0.522   0.019   0.003
```

```
0.000   0.603   0.358   0.038   0.001
0.000   0.660   0.319   0.019   0.002
0.000   0.766   0.224   0.009   0.000
0.000   0.668   0.306   0.023   0.002
0.000   0.462   0.487   0.045   0.006
0.000   0.559   0.384   0.050   0.007
0.001   0.666   0.292   0.037   0.004
0.000   0.496   0.437   0.060   0.007
0.000   0.351   0.622   0.026   0.001
0.000   0.391   0.550   0.055   0.004
0.000   0.544   0.403   0.046   0.007
0.000   0.392   0.563   0.041   0.004
0.000   0.544   0.386   0.067   0.003
0.000   0.362   0.564   0.062   0.012
0.000   0.250   0.672   0.074   0.005
0.000   0.317   0.573   0.107   0.003
0.000   0.362   0.571   0.064   0.003
0.000   0.560   0.353   0.080   0.008
0.019   0.394   0.541   0.043   0.003
0.000   0.459   0.470   0.065   0.006
0.000   0.463   0.510   0.024   0.004
0.000   0.266   0.683   0.044   0.006
0.000   0.126   0.731   0.129   0.013
0.000   0.529   0.404   0.061   0.006
0.007   0.632   0.317   0.037   0.007


########################################LA gill net
index############################################################
#Starting and ending years of LA gill net index
1988
2011
#Observed index and assumed CVs
0.27    0.21    0.24    0.25    0.22    0.41    0.84    0.55    0.67    1.24    0.94    0.80    1.00
        1.34    0.99    1.02    0.90    1.24    1.18    0.86    3.52    2.64    0.75    1.93
0.09    0.10    0.10    0.11    0.13    0.16    0.15    0.15    0.14    0.13    0.13    0.13    0.13
        0.13    0.13    0.13    0.14    0.13    0.12    0.13    0.12    0.11    0.14    0.13

#Number and vector of years of length compositions for gill net survey
16
1996  1997  1998  1999  2000  2001  2002  2003  2004  2005  2006  2007  2008  2009  2010  2011
#sample size of gill net survey length comp data by year (first row observed Ntrips, second row Nfish)
209     236     246     231     266     219     241     247     231     234     297     253     277
        308     193     248
2338    3386    3059    2913    4235    3542    3131    3297    2851    3659    4588    3301    5794
        5782    2377    4222
#gill net length composition samples (year,lengthbin 1 cm)
0.01    0.01    0.01    0.02    0.07    0.15    0.16    0.09    0.11    0.11    0.08    0.05    0.05
        0.04    0.03
0.00    0.01    0.00    0.01    0.06    0.13    0.14    0.11    0.1     0.13    0.09    0.07    0.07
        0.03    0.03
0.00    0.01    0.01    0.02    0.06    0.17    0.19    0.11    0.11    0.12    0.07    0.04    0.03
        0.02    0.02
0.00    0.01    0.01    0.03    0.07    0.16    0.14    0.1     0.11    0.11    0.08    0.06    0.06
        0.03    0.02
```

```
0.00    0.00    0.01    0.02    0.06    0.14    0.11    0.07    0.07    0.12    0.12    0.08    0.08
        0.06    0.04
0.01    0.01    0.01    0.01    0.06    0.13    0.11    0.08    0.13    0.14    0.08    0.06    0.07
        0.05    0.06
0.00    0.01    0.01    0.03    0.06    0.14    0.14    0.08    0.09    0.11    0.09    0.06    0.07
        0.06    0.05
0.00    0.01    0.01    0.03    0.09    0.19    0.19    0.1     0.1     0.13    0.07    0.02    0.02
        0.02    0.01
0.00    0.01    0.02    0.04    0.11    0.18    0.17    0.11    0.1     0.08    0.07    0.04    0.04
        0.02    0.01
0.00    0.01    0.01    0.03    0.06    0.14    0.18    0.12    0.13    0.13    0.08    0.04    0.04
        0.02    0.00
0.01    0.01    0.01    0.02    0.08    0.16    0.16    0.15    0.1     0.1     0.08    0.05    0.04
        0.02    0.01
0.01    0.01    0.01    0.02    0.04    0.13    0.17    0.15    0.14    0.13    0.07    0.04    0.03
        0.02    0.01
0.00    0.01    0.01    0.02    0.04    0.12    0.14    0.1     0.12    0.15    0.11    0.08    0.06
        0.03    0.02
0.00    0.01    0.01    0.02    0.04    0.08    0.13    0.12    0.11    0.13    0.12    0.07    0.07
        0.05    0.03
0.00    0.01    0.01    0.03    0.07    0.14    0.12    0.09    0.09    0.11    0.1     0.08    0.06
        0.05    0.03
0.00    0.01    0.02    0.03    0.09    0.17    0.16    0.09    0.07    0.11    0.1     0.06    0.05
        0.02    0.01


#######################################Seine survey
index##########################################################
#Starting and ending years of the seine survey index
1996
2010
#Observed CPUE and assumed CVs
1.22    0.44    0.98    0.77    0.33    0.67    0.89    1.09    0.72    1.50    0.62    0.76    0.46
        1.56    2.97
0.20    0.19    0.20    0.20    0.23    0.20    0.19    0.18    0.20    0.21    0.21    0.19    0.21
        0.20    0.20



##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
##-- BAM DATA SECTION: parameter section
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
##################Parameter values and initial
guesses##################################################################################
####################################################
##prior PDF (1=none, 2=lognormal, 3=normal, 4=beta)
##############################################################
#initial # lower # upper #       #  prior  # prior   # prior #
# guess  # bound # bound # phase #  mean   # var/-CV #  PDF  #
#--------#-------#-------#-------#---------#---------#-------#
                                           ###### Biological input #####################################
 239.5      150     400      3     239.5    0.087      1     # VonBert Linf (units in mm FL)
 0.40       0.05    0.8      3     0.40     -0.27      1     # VonBert K (units in mm FL)
 -0.78     -4.0     0.0      3     -1.013   -0.28      1     # VonBert t0 (units in mm FL)
```

```
 0.2       0.01    0.5      3     0.08     0.235      1     # CV of length at age
 0.26       0.05    0.65     -3     0.26     0.092      1     # constant M (used only to compute MSST=(1-M)SSBmsy)
                                                    ###### SR parameters ########################################
 0.75      0.21    0.99     -4     0.80     0.0196     1     # SR steepness parameter
 5.3      2.0     10.0      1     5.3     -0.25       1     # SR log_R0 parameter
 0.0      -1.0     1.0      -3     0.0      -0.5       1     # SR recruitment autocorrelation (lag 1)
 0.6       0.2     1.2      -4     0.6      -0.25      1     # s.d. of recruitment in log space
                                                    ###### Selectivity parameters ##############################
 1.25      0.75     10.0     -1    1.25     -0.5       1     # reduction age at 50% selectivity
 4.08      0.5     12.0      -1    4.08     -0.5       1     # reduction slope of ascending limb
 3.75      0.5     10.0      -3    2.75     -0.5       1     # reduction age at 50% selectivity for descending limb
 4.08      0.5     12.0      -3    4.08     -0.5       1     # reduction slope of descending limb

 -9.0    -10.0     10.0     -1     -5.0     -0.5      1     #age-0 cR selectivity in logit space
 0.0      -10.0     10.0      1      0.0     -0.5      1     #age-1 cR selectivity in logit space
 9.0     -10.0     10.0     -1      5.0     -0.5      1     #age-2 cR selectivity in logit space
 -0.6      -15.0     10.0      -1      0.0     -0.5      1     #age-3 cR selectivity in logit space
 0.0      -10.0     10.0      -1      0.0     -0.5      1     #age-4+ cR selectivity in logit space

 -9.0    -10.0     10.0     -1     -5.0     -0.5      1     #age-0 cR selectivity in logit space-period 2
 0.0      -10.0     10.0      -1      0.0     -0.5      1     #age-1 cR selectivity in logit space-period 2
 9.0     -10.0     10.0     -1      5.0     -0.5      1     #age-2 cR selectivity in logit space-period 2
 0.0      -15.0     10.0     -1      0.0     -0.5      1     #age-3 cR selectivity in logit space-period 2
 0.0      -10.0     10.0     -1      0.0     -0.5      1     #age-4+ cR selectivity in logit space-period 2

 1.25      0.25     10.0      2     1.25     -0.5      1     # gill net survey age at 50% selectivity
 4.08      2.5     25.0      2     4.08     -0.5      1     # gill net survey slope of ascending limb
                                                     ###### Index catchability parameters ########################
 -10.0     -15   10.0       1     -10.0    -0.5      1     # gill net index (log q)
 -10.0     -15    0.0       1     -10.0    -0.5      1     # seine index (log q)
                                                    ###### Fishing mortality parameters #########################
 -1.0      -10.0   4.50       1     -1.0     -0.5      1     #cR average log mean F

##### Dev vectors
#######################################################################################
#########################
# lower # upper #       #
# bound # bound # phase #
#-------#-------#-------#
   -5      5       2    # cR F devs
   -5      5      3    # rec devs
   -1.25    2.00     -2    # M devs for age-1
   -30     30       2     #devs for initial N or age structure


# cR F dev initial guesses
0           0           0           0           0           0           0           0           0           0           0           0           0
            0           0           0           0           0           0           0           0           0           0           0           0
            0           0           0           0           0           0           0           0           0           0
#-1.67222403071 -1.59880268257 -1.53003732453 -1.46484809148 -1.40160106482 -1.34187427116 -
1.28539715100 -1.22891896632 -1.17527883036 -1.12406892691 -1.07479213292 -1.00764268639 -
0.943226356126 -0.881225298631 -0.823151703433 -0.769323070393 -0.725474427739 -0.683184460767 -
0.641991128254 -0.602025365775 -0.563094538360 -0.473650736599 -0.389267852103 -0.309515271447 -
0.233393525870 -0.159961456300 -0.154550548593 -0.0791328234758 0.0356805895781 0.144481383977
0.235486666654 -0.305651019223 0.233855678943 -1.78632825332 0.578525524612 1.16274237019
1.74589265057 0.811514203228 0.767052796444 1.02935783431 0.603528796199 0.982571575281
```

```
0.640660306968 -0.0114737927059 -0.0639889764727 0.627562022985 1.04667319986 0.658712387449
0.472369805927 0.637725582852 0.843838689633 0.630488288118 0.116623960627 1.21404034912
1.44450135881 1.54473766355 1.87760512404 1.41542438087 0.871368810487 1.43827272648 1.67875344544
1.01504859156

# rec devs
0         0         0         0         0         0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0         0         0         0         0
          0         0         0         0         0         0         0         0         0     0
#0.194201111886 -1.13978478939 -0.0661388106143 0.165700304946 1.22456944710 -0.444668148641
0.265368070225 1.18726157682 -0.652591080236 -0.705755253699 0.812035361192 -0.612963572894
0.479884734830 -1.31433184136 -0.454881981172 0.865970614135 0.696316486505 -0.202581252128 -
0.213110635976 0.417301422426 -1.27894953389 1.06357468718 0.153222099384 -0.199440583255 -
0.0337988093946 -0.206409623974

# M devs for age-1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

#N devs
0 0 0 0



##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
##-- BAM DATA SECTION: likelihood weights section
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>

##################Likelihood Component
Weighting#################################################################################
##Weights in objective fcn  (commented wgts are those after correcting M vector--did not use)
1.0       #landings
0.132#0.161#0.164#1.0       #gill net length comps
0.021#0.110#0.021#1.0       #commercial age comps
0.615#0.375#0.362#0.354#1.0       #gill net index
0.429#0.508#0.528#1.0       #seine index
0#2.0       #M_devs
1.0           #S-R residuals
0.0           #constraint on early recruitment deviations
0.0           #constraint on ending recruitment deviations
0.0       #penalty if F exceeds 3.0 (reduced by factor of 10 each phase, not applied in final phase of optimization)
fULL F summed over fisheries
0.0           #weight on tuning F (penalty not applied in final phase of optimization)



##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>
##-- BAM DATA SECTION: miscellaneous stuff section
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--
><>

#length-weight (FL-whole wgt) coefficients a and b, W=aL^b, (W in g, FL in mm)--sexes combined
8.17E-6
3.18
```

```
#time-invariant vector of % maturity-at-age for females (ages 0-4+)
0.0  0.0  1.00  1.00  1.00

#time-invariant vector of proportion female (ages 0-4+)--assume 50:50 sex ratio
0.5      0.5      0.5      0.5      0.5

#time-invariant fecundity at age (number of maturing ova per individual)
#0.0   8728      21814   36385   49542
0.0      9153    21234   35341   49118


#time-invariant weight (in grams) at age at spawning
#0.0   45.3      95.9    145.9   187.9
0.0    47.1      93.9    142.5   186.6

#time-invariant weight (in grams) at age at start of fishing year
34.2     69.9    121.6   168.1   205.3

#time of year (as fraction) for spawning: Jan 1 = 0d/365d
0.0

#age-dependent natural mortality at age (ages 0-4+)
1.62     1.30    1.10    1.00    0.94
#Max observed age
7

#Spawner-recruit parameters
# SR function switch (integer 1=Beverton-Holt, 2=Ricker)
1

#rate increase switch: Integer value (choose estimation phase, negative value turns it off)
-1
##annual positive rate of increase on all fishery dependent q's due to technology creep
0.0
# DD q switch: Integer value (choose estimation phase, negative value turns it off)
-1
##density dependent catchability exponent, value of zero is density independent, est range is (0.1,0.9)
0.0
##SE of density dependent catchability exponent (0.128 provides 95% CI in range 0.5)
0.128
#Age to begin counting D-D q (should be age near full exploitation)
2
#Random walk switch:Integer value (choose estimation phase, negative value turns it off)
-3
#Variance (sd^2) of fishery dependent random walk catchabilities (0.03 is near the sd=0.17 of Wilberg and Bence
0.03
0.03
0.03

#Tuning F (not applied in last phase of optimization)
0.2
#Year for tuning F
2011

##threshold sample sizes for length comps (set to 99999.0 if sel is fixed)
```

```
1.0 #gill net

#threshold sample sizes (greater than or equal to) for age comps
1.0 #commerical reduction

#Ageing error matrix (columns are true age 0-4+, rows are ages as read for age comps: columns should sum to one)
1.00    0.00    0.00    0.00    0.00
0.00    1.00    0.11    0.00    0.00
0.00    0.00    0.78    0.16    0.00
0.00    0.00    0.11    0.68    0.17
0.00    0.00    0.00    0.16    0.83

999 #end of data file flag
```

Appendix B1

```
FIT  ## Run type (FIT, BOT, or IRF)
"men-31"
LOGISTIC  YLD    WTDSSE
103  ## Verbosity
1000  90  ## Number of bootstrap trials, <= 1000
0  2000000  ## 0=no MC search, 1=search, 2=repeated srch; N trials
1.0000E-08  ## Convergence crit. for simplex
3.0000E-08  8  ## Convergence crit. for restarts, N restarts
1.0000E-04  24  ## Conv. crit. for F; N steps/yr for gen. model
6.0000  ## Maximum F when cond. on yield
0.0  ## Stat weight for B1>K as residual (usually 0 or 1)
1  ## Number of fisheries (data series)
1.0000E+00    ## Statistical weights for data series
0.80  ## B1/K (starting guess, usually 0 to 1)
6.5000E+02  ## MSY (starting guess)
1.0000E+04  ## K (carrying capacity) (starting guess)
2.1592E-04  ## q (starting guesses -- 1 per data series)
0  1  1  1  1  1    ## Estimate flags (0 or 1) (B1/K,MSY,K,q1...qn)
6.11624E+01  1.22325E+04  ## Min and max constraints -- MSY
6.11624E+02  1.22325E+05  ## Min and max constraints -- K
3921295  ## Random number seed
35 ## Number of years of data in each series
"Gill net"
CC
1977  -1.00 447.5962    0.0000
1978  -1.00 820.6022    0.0000
1979  -1.00 779.8254    0.0000
1980  -1.00 702.4973    0.0000
1981  -1.00 553.7092    0.0000
1982  -1.00 855.5277    0.0000
1983  -1.00 925.2619    0.0000
1984  -1.00 985.1220    0.0000
1985  -1.00 884.3944    0.0000
1986  -1.00 824.0195    0.0000
1987  -1.00 906.0578    0.0000
1988  0.27  634.4488    114.1170
1989  0.21  582.2171    108.9899
1990  0.24  538.6375    95.5576
1991  0.25  549.6734    84.2461
1992  0.22  429.4327    57.5160
1993  0.41  548.6686    41.3194
1994  0.84  771.7658    42.3341
1995  0.55  472.0214    42.7970
1996  0.67  491.7473    50.5909
1997  1.24  623.1455    59.3740
1998  0.94  493.6477    56.9524
1999  0.80  692.4852    56.6173
2000  1.00  580.2887    62.9105
2001  1.34  522.1053    58.5769
2002  0.99  575.0693    62.5758
2003  1.02  517.6982    62.8386
2004  0.90  469.2393    50.1541
2005  1.24  434.1297    59.1004
2006  1.18  464.6525    71.9712
```

```
2007  0.86  454.0934    62.7829
2008  3.52  425.5664    68.6536
2009  2.64  457.6857    79.7198
2010  0.75  379.9259    49.0894
2011  1.93  613.8257    61.3351
```

SEDAR

Southeast Data, Assessment, and Review

SEDAR 32A

Gulf of Mexico Menhaden

SECTION II: Review Workshop Report

September 2013

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

Table of Contents

1. Introduction

1.1 Workshop Time and Place

The SEDAR 32A Review Workshop for Gulf of Mexico menhaden was held August 27-30, 2013 in Morehead City, NC. It was held in conjunction with the Review Workshop for SEDAR 32 for South Atlantic blueline tilefish.

1.2 Terms of Reference

1. Evaluate the data used in the assessment, addressing the following:
   a) Are data decisions made by the Assessment Workshop sound and robust?
   b) Are data uncertainties acknowledged, reported, and within normal or expected levels?
   c) Are data applied properly within the assessment model?
   d) Are input data series reliable and sufficient to support the assessment approach and findings?

2. Evaluate the methods used to assess the stock, taking into account the available data.
   a) Are methods scientifically sound and robust?
   b) Are assessment models configured properly and used consistent with standard practices?
   c) Are the methods appropriate for the available data?

3. Evaluate the assessment findings with respect to the following:
   a) Are abundance, exploitation, and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?
   b) Is the stock overfished? What information helps you reach this conclusion?
   c) Is the stock undergoing overfishing? What information helps you reach this conclusion?
   d) Is there an informative stock recruitment relationship? Is the stock recruitment curve reliable and useful for evaluation of productivity and future stock conditions?
   e) Are the quantitative estimates of the status determination criteria for this stock reliable? If not, are there other indicators that may be used to inform managers about stock trends and conditions?

4. Consider how uncertainties in the assessment, and their potential consequences, are addressed.
   - Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods.
   - Ensure that the implications of uncertainty in technical conclusions are clearly stated.

5. Consider the research recommendations provided by the Data and Assessment workshops and make any additional recommendations or prioritizations warranted.
    - Clearly denote research and monitoring that could improve the reliability of, and information provided by, future assessments.
    - Provide recommendations on possible ways to improve the SEDAR process.

6. Provide guidance on key improvements in data or modeling approaches which should be considered when scheduling the next assessment.

7. Prepare a Peer Review Summary summarizing the Panel's evaluation of the stock assessment and addressing each Term of Reference. Develop a list of tasks to be completed following the workshop. Complete and submit the Peer Review Summary Report in accordance with the project guidelines.

The panel shall ensure that corrected estimates are provided by addenda to the assessment report in the event corrections are made in the assessment, alternative model configurations are recommended, or additional analyses are prepared as a result of review panel findings regarding the TORs above.

1.3 List of Participants

Review Workshop Panelists

Steve Cadrin	Review Panel Chair	SAFMC SSC
Churchhill Grimes	Reviewer	SAFMC SSC
Will Patterson	Reviewer	GSMFC Appointee
Gary Melvin	Reviewer	CIE
Stephen Smith	Reviewer	CIE
Kevin Stokes	Reviewer	CIE

Analytical Team

Kevin Craig	Lead analyst, SA BLT	NMFS Beaufort
Amy Scheuller	Lead analyst, GoM menhaden	NMFS Beaufort
Kyle Shertzer	Assessment Team	NMFS Beaufort
Erik Williams	Assessment Team	NMFS Beaufort
Katie Andrews	Assessment Team	NMFS Beaufort
Rob Cheshire	Assessment Team	NMFS Beaufort
Robert Leaf	Assessment Team	USM

Observers

Dewey Hemilright	Fishing Industry	Commercial, NC
Robert Johnson	Fishing Industry	Charter/Headboat, FL

GSMFC Menhaden Advisory Committee

John Mareska, ADCNR-MRD
Behzad Mahmoudi, FL FWC
Jerry Mambretti, TPWD
Borden Wallace, Daybrook Fisheries
Ron Lukens, Omega Protein, Inc.
Matt Hill, MDMR
Harry Blanchet, LDWF

Council Representative

Michelle Duval	Council Member	SAFMC

Council and Agency Staff

Julia Byrd	SEDAR Coordinator	SEDAR
Julie O'Dell	Admin.	SEDAR/SAFMC
Michael Errigo	Fishery Biologist	SAFMC Staff
Steve VanderKooy	IJF Program Coordinator	GSMFC
Jessica Stephen	Fishery Biologist	SERO
Brian Langseth	Observer	SEFSC Beaufort
Joe Smith	Fishery Biologist	SEFSC Beaufort

Data workshop observers

Tony Austin
Robert O'Boyle
Mike Prager
Doug Vaughan

1.4 List of Background Documents and Review Workshop Working Papers

Gulf of Mexico menhaden review workshop document list.

Document #	Title
SEDAR32A - **1.1**	2012 Dec 07 SEDAR32 Analyst CC summary (file type: Word)
SEDAR32A - **1.2**	2012 Dec 07 SEAMAP INDEX presentation 1 (file type: PowerPoint)
SEDAR32A - **1.3**	2012 Dec 07 Revised CDFR CPUE Index (file type: PowerPoint)
SEDAR32A - **1.4**	2012 Dec 07 Gillnet index (file type: PowerPoint)
SEDAR32A - **2.1**	2012 Dec 11 SEDAR32A Analyst CC summary (file type: Word)
SEDAR32A - **2.2**	2012 Dec 11 Langseth SEAMAP INDEX presentation 1 (file type: PowerPoint)
SEDAR32A - **3.1**	2013 Feb 05 SEDAR32A Analyst CC summary (file type: Word)
SEDAR32A - **3.2**	2013 Feb 05 Seine Index02-2013 (file type: PowerPoint)
SEDAR32A - **3.3**	2013 Feb 05 SEAMAP INDEX presentation 4 (file type: PowerPoint)
SEDAR32A - **3.4**	2013 Feb 05 Gillnet index and other data (file type: PowerPoint)

SEDAR32A - **4.1**	2013 March 8 SEDAR32A CC summary (file type: Word)
SEDAR32A - **4.2**	2013 March 8 Data webinar_draft (file type: PowerPoint)
SEDAR32A - **4.3**	2013 March 8 SEAMAP INDEX presentation 5 (file type: PowerPoint)
SEDAR32A - **5.1**	2013 March 26 SEDAR32A CC summary (file type: Word)
SEDAR32A - **5.2**	2013 March 26 Data webinar_final (file type: PowerPoint)
SEDAR32A - **6.1**	2013 May 9 SEDAR32A Conf Call Summary (file type: Word)
SEDAR32A - **6.2**	2013 May 9 BAM AW_webinar 1 (file type: PowerPoint)
SEDAR32A - **7.1**	2013 June 4 SEDAR32A Conf Call Summary (file type: Word)
SEDAR32A - **7.2**	2013 June 4 BAM AW_webinar 2 (file type: PowerPoint)
SEDAR32A - **7.3**	2013 June 4 Surplus production models for Gulf menhaden (file type: PowerPoint)
SEDAR32A - **8.0**	SEDAR32A AW Summary (file type: PDF)
SEDAR32A – **RW01**	The Beaufort Assessment Model (BAM) with application to Gulf menhaden: mathematical description, implementation details, and computer code (file type: PDF)
SEDAR32A - **RW02**	Benchmarks in Excel (file type: Excel)

2. Review Panel Report

Executive Summary

The Review Panel (RP) was presented the data inputs, modeling framework, and outputs of the SEDAR 32A Gulf of Mexico menhaden stock assessment. The base assessment model was the Beaufort Assessment Model (BAM), a highly flexible, integrated analysis, statistical catch-at-age model. However, surplus production model results computed with ASPIC were presented as complimentary information. The RP concluded that the data used in the assessment were generally sound and robust. Likewise, data generally were applied properly and uncertainty in data inputs was appropriately acknowledged. Numerous sensitivity analyses and exploration of alternative scenarios also were presented during the Assessment Workshop (AW), and additional model exploration and sensitivity runs were requested during the Review Workshop (RW). The RP was impressed with the performance of the Analytical Team (AT) and the level of documentation that accompanied the assessment. Unfortunately, it was not possible for the RP to conclude whether Gulf menhaden is overfished or undergoing overfishing because stock status benchmarks had not been set by the Gulf States Marine Fisheries Commission at the time of the RW. That said, given benchmarks commonly applied in the region, such as a threshold spawning stock biomass (SSB) of 30-40% spawning potential ratio (SPR) and associated limit fishing mortality (F) rates, it is unlikely the stock is either overfished or undergoing overfishing.

2.1 Statements Addressing Each ToR

1. *Evaluate the data used in the assessment, addressing the following:*

    - *Are data decisions made by the Data and Assessment Workshops sound and robust?*
    - *Are data uncertainties acknowledged, reported and within normal or expected levels?*
    - *Are data applied properly within the assessment model?*
    - *Are input data series reliable and sufficient to support the assessment approach and findings?*

Data decisions made by the Data and Assessment Workshop Panels generally were sound and robust. Likewise, data generally were applied properly and uncertainty in data inputs was appropriately acknowledged. Cases in which the RW had additional questions or concerns with respect to data inputs are described below.

Stock Structure:

Gulf menhaden range from western Florida through the northern Gulf of Mexico (GOM) to Campeche, Mexico, but their abundance is greatest in the north central GOM. The RP agreed with the conclusion that no evidence exists to contradict the assumption that the population in the north central GOM constitutes a unit stock. However, there was some uncertainty as to whether population trends and demographics were similar in eastern and western portions of the species' range.

Landings:

Landings estimates were judged to be accurate as the reduction fishery is responsible for nearly all landings and there has been a logbook system in place since 1964 for that fishery, including daily catch records. Cooperation by industry in supplying information to NMFS is impressive (weekly electronic reporting, 100% participation in voluntary program, access for port sampling and provision of freezer space for samples). The decision to start the landings time series in 1977 was quite reasonable given concerns about data quality for age composition data prior to 1977, inexplicable truncated age distributions in the early 1970s, and other issues with early data as noted in past stock assessments. However, sensitivity analyses were conducted with the longer times series of age composition included.

The protocol for sampling menhaden to estimate length and age composition of the reduction fishery landings involves taking a haphazard sample from the top of a given boat's hold. Members of the RP questioned if such a method provided a sample representative of the catch. Results from a 2012 study involving alternative sampling protocols suggest that sampling only from the top of a hold provides a poor representation of the catch [Assessment Panel (AP) Report Fig 4.8], specifically underestimating numbers of older fish in the catch. For example, age-3 fish constituted less than 3% of the catch when sampled with the traditional method, while they were approximately 20% of samples taken from the start, middle, or end of hold pump-out. No age-4 fish were present in samples taken with the traditional method, but they constituted approximately 5% of landings sampled during the start or middle of pump-out.

There was some discussion about the lack of older fish in the estimated catch-at-age being due to older fish being less vulnerable to the fishery if the spatial distribution of fish is age-specific. The major grounds for the fishery are within 10 miles of the coast, but the species is estimated to occur out to 60 miles. Therefore, if older fish are found farther offshore or in smaller, non-targeted schools, then they may not be vulnerable to the fishery, which would conflict with an assumption of a logistic selectivity function for the reduction fishery. However, based on early-season catches that are generally taken farther offshore (10-20 miles), older fish do not appear to be farther offshore during the fishing months.

More information on the spatial distribution of the fishery was requested. The analysis presented on fishery hotspots composited for 2008, 2009 and 2011 fishing years was informative, but a longer time series of year-specific hotspots would have provided information on the spatial overlap between fishery- and fishery-independent indices of abundance used in the assessment. Plotting these hotspots may provide insight into the potential distribution of older fish off of western Louisiana, as well as to the east of Alabama/Mississippi, areas not covered by either the seine or gillnet survey indices used in the assessment.

Reproductive Biology:

The use of fecundity as a metric of reproductive potential to compute a proxy for spawning stock biomass was discussed. A relationship produced in the early 1980s relating numbers of eggs to female length was used in this assessment to estimate length-specific fecundity in the model, thus larger older fish are estimated to produce more eggs per capita than younger fish. Ovarian egg number may be a reliable index of SSB if all the ovary samples were at the same stage of reproductive development, but that would seem unlikely for existing menhaden fecundity data. Furthermore, Gulf menhaden has a protracted spawning season and is assumed to be an indeterminate batch spawner. If older fish produce more batches or higher quality eggs, then their contribution to stock-specific fecundity would be underestimated using the current approach. Lastly, it was noted that while fecundity is a common metric of reproductive potential in the region, it is not specified in the management plan as part of stock status determination criteria.

Aging:

Several issues exist with the aging protocols. Multiple scale readers aged fish in the 1960s to early 1970s, but only a single reader has aged fish consistently since the 1970s. No formal protocol for aging appears to exist. Three informal analyses of aging accuracy or repeatability produced questionable results (e.g., 71% agreement between otolith and scale derived age estimates; 82% agreement between age estimates from scales aged in 2005 and again in 2012; and, substantial disagreement in age estimates from the 1970s versus contemporary re-ageing of those samples). Given the short-lived nature of the fish, reader error of even one year can cause substantial bias in an age-based assessment. While the computed aging error matrix did not indicate directional bias, the assumption that the error was symmetric about ages precluded any other error pattern from being estimated. In most fishes, age of older individuals tends to be underestimated by scales as annuli pack at the scale margin and become difficult to discern. In fact, the assessment team conveyed that aging older menhaden (>2 yrs) with scales is more difficult than aging younger fish.

There was evidence of a shift in the estimated age composition of landings from mostly age-1 fish in the1960s-80s to mostly age-2 fish in more recent decades. Several hypotheses for the shift are discussed in the AW Report (e.g., habitat alteration affecting recruitment of juvenile fish in estuaries, decreased fishing mortality, recent contractions in the spatial distribution of the fishery, changing spatial distribution of age-1 menhaden, or the influence of hypoxic habitats on spatial distribution). However, re-aging of a sub-sample of scales from three years among each decade from 1970s to the 2000s indicated ages of fish sampled in the early portion of the time series when multiple scale readers existed may have been underestimated. Therefore, the AW Panel removed the earliest years of the time series. No other bias was identified.

Natural Mortality:

Data from an extensive tagging study conducted in the early 1970s were used to estimate natural mortality, M. The resultant estimate of M (1.22 y^{-1}) was then scaled with the Lorenzen (1996) function to estimate declining M with age. The RW concluded this approach was sound.

Indices of Abundance:

A number of available abundance indices were excluded from being used in the model. A juvenile trawl index which was highly correlated with the seine index was included in the SEDAR 27 assessment model, but dismissed here because it was judged that bottom trawls are not efficient for pelagic species, the spatial extent of the survey was not appropriate for the resource, and the western portion of the survey has species identification problems. A research recommendation was included in the AW report for genetic sampling by size to solve the species identification problem. The gillnet index was limited to the Louisiana series. Data from the western and eastern portions of the resource area were excluded because of mixed species catches and species identification problems. A larval survey was not used because of poor winter coverage, complex recruitment dynamics from larvae to fishery recruitment, and problems with species identification. Members of the Review Panel questioned why some of these indices were excluded prior to assessing their impact on model fit, such as through likelihood profiling.

A question arose about whether there could be a cryptic biomass of older (>3 years) that is not encountered by the fishery. Amy Schueller responded that older fish are captured in the gillnet survey. Further, if fish school by size or age, then small schools of larger, older fish may not be targeted by purse seiners.

2. *Evaluate the methods used to assess the stock, taking into account the available data.*

- *Are methods scientifically sound and robust?*
- *Are assessment models configured properly and used consistent with standard practices?*
- *Are the methods appropriate for the available data?*

The Beaufort Assessment Model (BAM) was used as the principal assessment tool. The BAM, implemented in AD Model Builder software (Fournier et al. 2012), is structured to allow implementation of forward projecting, statistical catch-at-age assessment models. Use of the

BAM permitted the inclusion of all available data types, including total annual removals from the commercial fleets (and the very small recreational catches), age and length compositions, and indices of biomass abundance, with appropriate error distributions and use of priors on parameters. Decisions on *a priori* data inclusion and exclusion are considered above under ToR-1. The specified assessment model used standard approaches to predicting landings and modelling recruitment, and the BAM allowed an exploration of catchability and selectivity options.

The base case model and rationale for modelling decisions are well described in the AW report and were further explored during the RW. The base case run included commercial and recreational landings, age and length composition data and two indices of abundance, one each representing age 1 and age 2 fish. Natural mortality was estimated from tagging data, assumed to be constant through time, and was scaled among ages based on the method of Lorenzen (1996). Steepness of the Beverton-Holt spawner recruit (S-R) relationship was fixed at 0.7. Selectivities and catchabilities were all estimated as constant for the full assessment period (1977-2011).

The model was fit to the data using appropriate methods, consistent with standard practice. Analysis included iterative reweighting using the method of Francis (2011) and exploration of a variety of data configurations and parameterizations. The modelling processes and decision making that resulted in a proposed base case run and sensitivity testing are well described in the AW Report, which includes information on Likelihood components, weighting, SDNRs by data component and weight, likelihood profiles, etc. Further diagnostics were made available and elaborated during the RW.

The treatment of the data and the relative importance given to the various components were well explored by the AW and at the RW and appear appropriate. The model structure is adequate to capture the main patterns in the data, thus the modelling procedures adopted appear to be robust. Landings and indices were fit using lognormal likelihoods. Age composition data were fit using robust multinomial likelihoods. Landings were fit closely by the model, as were age composition data. Trends in abundance indices were generally fit by the model, but greater residuals existed for extreme index values that were not as closely fit by the model.

Residual patterns of the recruitment index (seine survey) do not fit well for extreme year-class (large of small) but there are no major residual patterns to cause concern. The gillnet survey is fit well but the model cannot fit the high observed values of 2008 and 2009.

In addition to the catch-at-age primary assessment, an age-aggregated biomass dynamics stock assessment was carried out using the ASPIC software. The biomass dynamics models was considered as a complementary rather than an alternative analysis because the catch-at-age model makes fuller use of composition data and represents a more detailed investigation of population dynamics, hence is better able to capture higher frequency changes in indices (e.g., recent high indices and catches). The biomass dynamics model provides a useful comparison with the catch-at-age model, which it broadly supports without capturing recent population changes. A number of sensitivity tests were carried out on the biomass dynamics model which demonstrated the robustness of conclusions based upon it. The biomass dynamics model used, implemented with ASPIC, is well known and used. The methods were appropriately configured and implemented.

Monte Carlo Bootstrapping (MCB) was used to portray uncertainty around model outputs, including status estimates. MCB combines parametric bootstrapping to landings and indices data and resampling from age composition data. The Monte Carlo component entails drawing values of M and steepness from specified pdf's. Outputs provided are the quantiles of the distribution resulting from application of the MCB simulations. Each simulation applies a single BAM model using the weights developed for the vase case run. No reweighting procedures are used for individual realisations.

The MCB generates a stochastic version of the BAM model by introducing process error to the model components of natural mortality and steepness. Means of management quantities (MSY, BMSY, FMSY) from the MCB runs do not equal estimates from the base run. The direction of the differences observed between the MCB based estimates and those of the base run are in the direction predicted by Bousquet et al (2008). FMSY from the MCB runs will be less than the deterministic estimates from the BAM base run, estimates of MSY will be slightly higher and those for BMSY slightly lower. The size of the differences will be a function of the amount of stochastic error in the model. Of course, these differences may not be apparent when looking only at ratio benchmarks.

3. Evaluate the assessment findings with respect to the following:

- *Are abundance, exploitation, and biomass estimates reliable, consistent with input data and population biological characteristics, and useful to support status inferences?*
- *Is the stock overfished? What information helps you reach this conclusion?*
- *Is the stock undergoing overfishing? What information helps you reach this conclusion?*
- *Is there an informative stock recruitment relationship? Is the stock recruitment curve reliable and useful for evaluation of productivity and future stock conditions?*
- *Are the quantitative estimates of the status determination criteria for this stock reliable? If not, are there other indicators that may be used to inform managers about stock trends and conditions?*

The RW Panel examined the consistency of input data and population biological characteristics with abundance estimates, exploitation, and biomass estimates. Panelists felt the base BAM parameterization chosen by the AW view provided the best representation of stock status and felt the usage of MCB for projection estimates was appropriate.

According to current sampling, the fishery landings are dominated by age-2 fish with fishing occurring later in the year, after this age group has spawned. However, the selectivity pattern for the reduction fishery was flat topped, and there is uncertainty about the presence of older fish (age-3 and older) in fishery-independent gillnet catches versus reduction fishery landings.

Very high F estimates were estimated during time series considered, especially during the 1980s. Fishing mortality has subsequently declined to range between 1.0 and 3.5 y^{-1}. The 2011 fully selected F was 2.36, with older age F's. Older ages were much lower.

Currently there are no formal benchmarks established for Gulf menhaden to evaluate stock status. The AT presented a suite of potential options for the RW Panel to evaluate. Values of SSB_{2011}/SSB_{MED}, $SSB_{2011}/SSB_{30\%SPR}$, $SSB_{2011}/SSB_{35\%SPR}$, $SSB_{2011}/SSB_{40\%SPR}$ from the BAM base run all exceeded 1.0. Results from the surplus production model also estimated SSB_{2011}/SSB_{MSY} to be much greater than 1.0. Therefore, it is unlikely the Gulf menhaden stock would be evaluated to be overfished given commonly applied benchmarks in the region.

F_{MSY} was defined as infinite because of the stock population dynamics and the nature of the fishery. This assumption is valid as long as the fishery selectivity remains as assumed and estimated. The surplus production model produced results relative to estimates of MSY with no indication of exceeding the criteria typically used to evaluate overfishing. The review panel agrees with the AW Panel's general statement that it is unlikely the Gulf menhaden stock is experiencing overfishing given commonly applied benchmarks in the region

Managers are currently defining the goals and objectives for the Gulf menhaden fishery, as well as establishing biomass and F benchmarks. Without established thresholds, it is not possible to provide quantitative estimates of stock status.

4. Consider how uncertainties in the assessment, and their potential consequences, are addressed.

- *Comment on the degree to which methods used to evaluate uncertainty reflect and capture the significant sources of uncertainty in the population, data sources, and assessment methods.*

- *Ensure that the implications of uncertainty in technical conclusions are clearly stated.*

Uncertainty was explored in the assessment modelling using extensive sensitivity runs and likelihood profiling, retrospective analyses, and Monte Carlo Bootstrapping (MCB). All of the methods used are standard and widely used. The AW reported on the various analyses and more materials were provided and used in discussion at the RW. The application of methods appears to be comprehensive and appropriately focused. Sensitivity runs as variants of the base case run are numerous and good information was provided on the impacts on fits (through detailed likelihood components and also weighting diagnostics, SDNRs, likelihood profiles, etc.). Such runs can only look at what the model structure accommodates and cannot consider structural uncertainties such as alternative stock structures. No such structural uncertainties were identified for menhaden and the assessment and its outputs have been appropriately and comprehensively considered.

Issues considered in sensitivity runs include scaling and the form of M, S-R steepness and form, adjustment of model weights and exclusion of each series of indices, alternative selectivity assumptions for the commercial reduction fishery, start year, inclusion/exclusion of indices, alternative weightings, and alternative growth specification.

The MCB is alluded to above under ToR-2. A total of 5,000 realizations were made using M and h values drawn from specified probability density functions (PDFs) and with the landings, indices, and composition data bootstrapped. A total of 4,068 realizations were used to compile the final MCB quantile plots with realizations discarded if they did not converge or showed other poor behavior. The process for discarding realizations was not discussed in detail. Each realization of the BAM model was run using the iteratively reweighted weights from the base case (it would have been impossible to automate this process for each of the 3,200 realizations). It should be noted that reweighting can have major implications for fitting and parameter estimation and that each realization may not be feasible, possibly explaining why some realizations did not converge. The degree to which this may or may not matter is model- and data-specific. As all realizations are afforded equal weight in determining distributions of outputs there is in general need for care in interpreting MCB results. For menhaden, the SDNRs for all sensitivity tests are surprisingly good (except for one case) when runs are made using the base case weights. However, this is no guarantee that for specific M and h combinations drawn from the PDFs, which may be incompatible, the base case weights would necessarily be appropriate. Notwithstanding this concern, the RW was comfortable that the AW had fully explored uncertainty to the extent possible and that the characterization of benchmark trajectories and hence stock status (ToR-3) and projections (ToR-4) are suitable for informing management decisions.

5. Consider the research recommendations provided by the Assessment workshop and make any additional recommendations or prioritizations warranted.

- *Clearly denote research and monitoring that could improve the reliability of, and information provided by, future assessments.*

- *Provide recommendations on possible ways to improve the SEDAR process.*

The RW panel suggested there should be evaluation of the utility of using ovarian egg number as a proxy for SSB and notes that this will depend not only on biological considerations but also on ageing validation and errors, and selectivity determination. Ultimately, the utility of egg numbers versus SSB will depend on how status benchmarks and control rules are determined.

The Louisiana gillnet survey used in the menhaden assessment has a number of different mesh sizes and concern was expressed about developing a single index over these different mesh sizes, especially given the length frequencies presented in the assessment (AW Report, Fig. 5.44). The RW panel recommends evaluating the efficacy of developing separate indices by mesh or accounting for the different mesh sizes within the same index.

The panel did not see value in undertaking genetic studies to further elucidate Gulf menhaden population structure given the fishery operates in the center of the species distribution and it is unlikely that information gained would justify the expense of additional analyses. However, the RW panel did see considerable benefit in using simpler genetic techniques, such as DNA barcoding, to aid species identification, which is currently problematic in fishery-independent surveys conducted in peripheral range areas in Texas, Alabama, and Florida.

Throughout the course of the DW and AW, a number of items were identified as important research topics for future stock assessments. The RW Panel evaluated the various items in those lists and developed a consensus priority list.

DATA ELEMENT	RECOMMENDATION	PRIORITY
FISHERY-INDEPENDENT ADULT INDEX	Collect Gulf menhaden ageing structures (scales and otoliths) from alternate fishing gears (e.g., gillnets and trawls) to determine gear selectivity. Need to expand efforts to age menhaden by state agencies. Determine readability of whole versus sectioned otoliths.	**Very High**
FISHERY-INDEPENDENT ADULT INDEX	Improve species identifications at the periphery of the Gulf menhaden's range in Texas and Alabama/Florida waters.	**Very High**
FISHERY-DEPENDENTSURVEYS	A Gulf-wide aerial survey may be a useful tool to measure adult Gulf menhaden abundance; "groundtruthing" for fish size and age and school size, would be a necessary adjunct to the survey.	**High**
FISHERY-DEPENDENTSURVEYS	Additional sampling needs to be conducted to address the homogeneity of the catch in the hold of the reduction fishery vessels at the four	**High**

	Gulf menhaden factories. Supplemental samples must be pulled from throughout the fishhold during the pumpout process to determine if the assumption that the traditional 'last set of the trip' accurately represents the age composition for the catch for the given port-week	
FISHERY-INDEPENDENTJUVENILE INDEX	Improve species identifications at the periphery of the Gulf menhaden's range in Texas and Alabama/Florida waters.	**High**
FECUNDITY/MATURITY	The seminal study on fecundity and sexual maturity of Gulf menhaden was published thirty years ago (Lewis and Roithmayr 1981) with data from the late 1970s. It is recommended that a study should be initiated to re-examine the reproductive biology of gulf menhaden in the northern Gulf of Mexico,which includes updating fecundity estimates, maturity schedules(GSI), and sex ratios. Any study needs to reinvestigate whether gulf menhaden are determinant or indeterminant spawners. Survey necessarily needs to include spawning from winter collections.	**High**
GENETICS AND STOCKSTRUCTURE	Identification of menhaden-specific nuclear DNA markers (preferably microsatellites or SNP's) using a lab-based DNA library screening techniques. Evaluation of these markers for use in genetic studies of Gulf menhaden	**Low**
GENETICS AND STOCK STRUCTURE	Identification in the Clupeid literature of potential new heterologous nuclear DNA markers (preferably microsatellites or SNP's) which will potentially enhance genetic sampling in Gulf menhaden.	**Low**
GENETICS AND STOCKSTRUCTURE	Reassessment of Gulf menhaden throughout its range using a larger,more informative genetic panel of markers than that described in Anderson (2006).	**Low**

The panel provided the following comments on the research recommendations that given in the assessment documents.

Several issues were identified with ageing for menhaden including the lack of formal protocols for inter-reader comparisons and calibration/reference data sets. Given the short-lived nature of the fish, reader error of even one year can cause substantial bias in an age-based assessment. Given the pending retirement of the single ager, assessment of the accuracy of ageing and the establishment of formal protocols should be done as soon as possible.

It was not apparent to the panel that stock structure was an issue in the stock assessment and the panel did not see value in undertaking genetic studies on stock structure. However, the panel did see considerable benefit in using simpler genetic techniques such as DNA barcoding to aid species identification, which is currently problematic in peripheral range areas as sampled in the Texas, Alabama, and Florida surveys. Resolution of species identification and any other measures to ensure more consistency across the many state surveys that were excluded from the assessment could provide a more representative basis for monitoring abundance.

The recommendation to consider an aerial survey should be pursued, although the turbid waters close to the Mississippi may limit detectability of fish schools. This kind of survey offers an opportunity to form a partnership between the states, federal government and the fishing industry in a monitoring program to ensure sustainability.

The panel recommended that addressing the sampling of the catch throughout the holds of the reduction fishery vessels be rated as very high priority given concerns about the selectivity of larger fish to the catch. The 2012 study indicated that sampling only the top of the hold may underestimate the proportion of older fish in the catch and given the use of fecundity for spawning stock biomass result in an underestimate of productivity (see below).

While the studies proposed to update knowledge about the reproductive biology of Gulf menhaden would be nice to do, the panel felt that the current approach is adequate for now and more priority should be given to resolving the selectivity pattern of older fish to the fishery so that their reproductive contribution to the population can be better accounted for.

6. Provide guidance on key improvements in data or modeling approaches which should be considered when scheduling the next assessment.

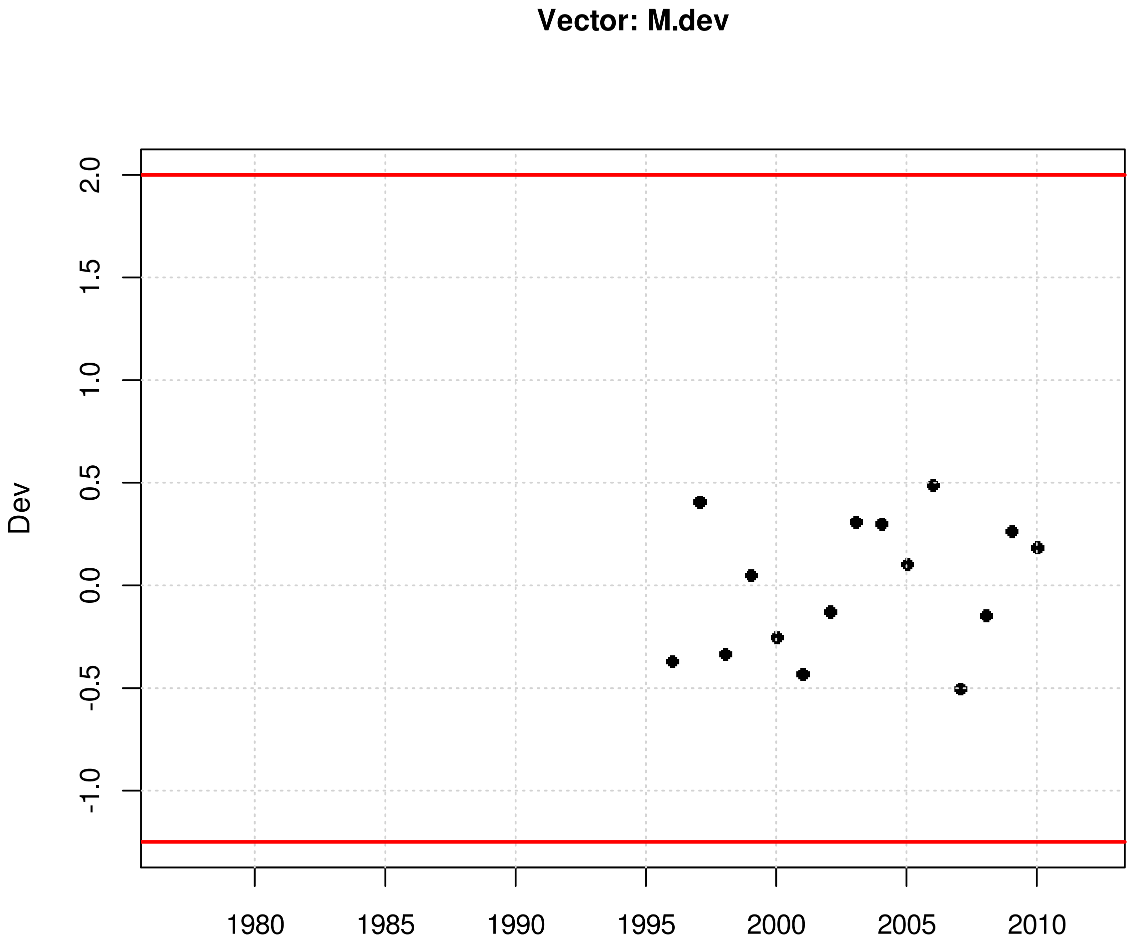
The Review panel expressed some concern about the selectivity associated with the Louisiana gillnet survey used as an index of adult abundance for the assessment model. Probability density functions of length samples depict an expected distribution pattern for the smaller mesh sizes; however, the larger mesh sizes show a broad size distribution uncharacteristic of this gear type. The gillnet index also samples larger, and presumed older, fish than the commercial reduction fishery. This implies that the large fish are not being captured by the fishery and supports the dome shaped reduction fishery selectivity of 0.35 for ages 3 and 4 in the BAM base run assessment parameterization. However, a recent study to investigate sampling protocols in the reduction fishery, albeit small, suggests that the traditional reduction fishery sampling method may be missing larger fish when samples are only collected from the top of the hold.

The index is used to characterize the coast-wide stock following the age specific selectivity vector within the model. Understanding of the gillnet selectivity and reduction fishery sampling could resolve several fitting problems with the index and uncertainties in the model and should be considered for the next scheduled assessment.

7. Prepare a Peer Review Summary summarizing the Panel's evaluation of the stock assessment and addressing each Term of Reference. Develop a list of tasks to be completed following the workshop. Complete and submit the Peer Review Summary report in accordance with the project guidelines.

2.2 Summary Results of Analytical Requests

The Review Panel requested the results from the exploratory analysis that allowed time-varying natural mortality to see if there was any indication of increasing M from increasing predator populations. The results (figure below) do not suggest an increase in M.



The Review Panel was concerned that the poor fit to gillnet length composition resulted from inappropriate selectivity assumptions. Two alternative approaches to modeling gillnet survey selectivity were attempted:

1) assuming age-0 selectivity=0, estimating age-1 selectivity, and assuming age-2+ selectivity=1; and
2) assuming age-0 selectivity=0, estimating age-1 and age-2 selectivity, and assuming age-3+ selectivity=1.

Both alternatives had the nearly identical estimates of age-1 selectivity and a similar residual pattern. Therefore, the Panel concluded that a more the extensive analysis is required, possibly disaggregating the survey into multiple indices from different mesh-size panels

Several peculiar results from sensitivity and retrospective analyses were inspected. The 2008 retrospective analysis had extremely high estimate of catchability (q) for the gillnet survey (19). When the q estimate was constrained to be similar to the estimates from other analyses, solutions were similar to pre-2010 retrospective analyses. Fixing the q at 0.22 produced a worse fit to gillnet index, and a lower value of q resulted in a greater estimate of R0. Despite the problems in fitting to the gillnet survey, the Panel cannot justify excluding or downweighting indices.

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