# SEDAR

Southeast Data, Assessment, and Review

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## SEDAR 27

## Stock Assessment Report

# Gulf of Mexico Menhaden

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# SEDAR 27:
# Gulf Menhaden Stock Assessment Report

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## Terms of Reference

1. Evaluate precision and accuracy of fishery-dependent and fishery-independent data used in the assessment:
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    b. Report metrics of precision for data inputs and use them to inform the model as appropriate.
    c. Describe and justify index standardization methods.
    d. Justify weighting or elimination of available data sources.

2. Evaluate models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points.
    a. Did the model have difficulty finding a stable solution?
    b. Were sensitivity analyses for starting parameter values, priors, etc. and other model diagnostics performed?
    c. Have the model strengths and limitations been clearly and thoroughly explained?
    d. Have the models been used in other peer reviewed assessments? If not, has new model code been verified with simulated data?
    e. Compare and discuss differences among alternative models.

3. State and evaluate assumptions made for all models and explain the likely effects of assumption violations on model outputs, including:
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    d. Choice of a plus group for age-structured species.
    e. Constant or variable ecosystem (e.g., abiotic) conditions.
    f. Choice of stock-recruitment function.
    g. Choice of reference points (e.g. equilibrium assumptions).

4. Evaluate uncertainty of model estimates and biological or empirical reference points.
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5. Perform retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., *F*, *SSB*), reference points, and/or management measures.

6. Recommend stock status as related to reference points.

7. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

# 1.0 Introduction

## 1.1 Definition of the Fishery

The reduction 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 reduction purse-seine fishery (Ahrenholz 1981).

## 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 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 1958-61 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 which he cited 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, then increased during 1989-90 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 2010, 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 41 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 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 studies suggest a single unit stock of gulf menhaden in the northern Gulf of Mexico. In the western Gulf, a single population of *B. patronus* has been identified using mtDNA (Anderson 2007). Anderson and McDonald (2007) noted that despite the similarities between *B. patronus* and *B. gunteri*, the two sympatric species may hybridize occasionally; however, the evidence is limited to a single individual sampled from Texas waters showing introgression. In the eastern Gulf, results from Anderson and Karel (2007) indicate that unidirectional gene flow has occurred between *B. patronus* and Atlantic menhaden (*B. tyrannus*), with flow coming from the southeastern Gulf into the Atlantic and reaching as far north as the Indian River Lagoon. Gene flow in the reverse direction has not been found, and *B. tyrannus* genes have not been found in the Gulf of Mexico population.

*Bycatch considerations and the management unit:* The majority of the management unit is the relatively homogeneous population of *B. patronus*. There is 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 proposed an east-west classification of the bycatch. They noted that the bycatch in Mississippi/eastern Louisiana is characterized by high numbers of species and by the predominance of striped mullet and sciaenids; whereas, in western Louisiana/Texas, the bycatch is characterized by low numbers of species and by the predominance of clupeids and Atlantic bumper (*Chloroscombrus chrysurus*). 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

### 1.4 Regulatory History

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 is one of the most detailed and data-rich fisheries currently operating in the Gulf of Mexico.

The NMFS port samplers have had access to the catch at each of the plants for biostatistical and stock assessment purpose since 1964, and the menhaden companies report daily vessel unloads to the NMFS on a monthly basis throughout the fishing season. Vessel captains provide a daily log of each vessel’s activities including catch estimates, fishing location, set duration, and weather conditions for each and every set. These logs, or Captain’s Daily Fishing Reports (CDFRs), are verified against each plant’s pump-out records and provided to NMFS on a regular basis for compilation. The NMFS continues to publish monthly menhaden landings in the form of a status memo, which are available on the NOAA’s Fishery Market News (NOAA Fisheries Website).

*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 extends 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.

Florida is the only state with a regulation restricting fishing to only weekdays during the 28-week season; although it is generally accepted and practiced that the industry will not make net sets on weekends or on holidays Gulf-wide.

*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), there is a quota of 1.0 million pounds for commercial harvest of menhaden by all gears combined. The quota applies to closing the inside waters of Escambia and Santa Rosa counties only, not any offshore fishery. Purse seines are not allowed for harvesting 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 the Panhandle.

Louisiana’s extended bait season 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, and early bait season begins on April 1 (about three weeks before the reduction season opens).

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 per year, which was set at the approximate five-year average of Texas catches during 2002-2006 (with penalties for overages). This regulation was heralded as precautionary management, capping removals at recent levels with an eye toward minimizing bycatch.

*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/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.

*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, bluefish, Spanish mackerel, king mackerel, dolphinfish, pompano, cobia, or jack crevalle.

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 provides 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 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 (1964-2002) 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 juvenile abundance 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 of Doubleday (1976) as the primary assessment methodology through 2000. The most recently 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 juvenile abundance 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.

Status of stock based on the terminal year (2004) estimates relative to their corresponding limits (or threshold) was compared. 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.

## 1.6 Historical Retrospective

Historical retrospective can be investigated using annual 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 separable VPA 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 juvenile abundance 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 of these assessments:

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 analyses were compared as a series of figures (Figure 1.2 – Figure 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 ages 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.

## 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).

## 3.0 Life History

### 3.1 Stock Definition and 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.

Two independent studies have addressed genetic stock structure in gulf menhaden. Lynch et al. (2010) focused on Atlantic menhaden, but also assessed gulf menhaden with two samples from the northern Gulf of Mexico (Galveston Bay, Texas, and Cameron, Louisiana). This study found no evidence for independent populations, however the focus of the study (Atlantic menhaden) was such that the specimen sampling was not adequate to fully assess stock structure across the species range. Anderson (2006) also measured genetic stock structure with extensive sampling across the range of the fishery. Anderson (2006) also 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 previous focus study on gulf menhaden genetics (Anderson 2006) 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 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.

### 3.2 Menhaden Feeding Habits

Gulf menhaden represent a pivotal mid-trophic level link between primary production and higher level piscivores. Hence, the questions of “what eats menhaden” and “what menhaden eat” are fundamental regarding the true ecosystem role of menhaden because they are a pivotal mid-trophic level linkage between primary production and higher level piscivores. If menhaden are a significant prey item for important top predators, then changes in the abundance of menhaden may influence abundance of these other species. The second question regarding what menhaden eat is more complex, but represents critical information because the two dominant planktonic prey groups (phytoplankton and zooplankton) are at different trophic levels and the ecosystem role of menhaden is very different depending on which one is more important. Obtaining these data by traditional means, such as diet analysis, is difficult and usually biased. A comprehensive examination of the menhaden diet would require a more detailed and direct examination of menhaden feeding behavior, as well as diet analysis using biochemical techniques.

Adult and juvenile menhaden are filter feeders that remove food resources from the water column via their gill rakers while swimming. The filtration efficiency of menhaden is largely a function of branchio-spicule spacing of the gill rakers, which changes allometrically as menhaden grow (Friedland et al. 2006). Recent morphological studies combined with laboratory experiments suggest that filtration efficiency of adult Atlantic menhaden (150-300 mm FL) is optimized for objects 40-50 µm equivalent spherical diameter (ESD) and drops rapidly below 20 µm ESD (Friedland et al. 2006). Friedland et al (2006) also contradicted an earlier study (Friedland 1985) in stating that juvenile menhaden (50-150 mm FL) are capable of filtering particles as small as 10 µm. Adult menhaden may feed on medium to larger celled phytoplankton such as diatoms, as well as small zooplankton such as nauplii and copepodites, and aggregated particulate organic matter. The digestive system of both Atlantic and gulf menhaden are characteristic of animals evolved to consume and digest plant cells including a gizzard thought capable of breaking down particulate detritus (Castillo-Rivera et al. 1996). However, Durbin and Durbin (1983) based on a bioenergetic analyses of Atlantic menhaden in Narragansett Bay, RI, concluded that the standing stock of phytoplankton was not sufficient to support total estimated menhaden production suggesting zooplankton may also be an important component of menhaden diet. For gulf menhaden, little data are currently available on either feeding behavior or diet. However, in a comparison of gulf menhaden to finescale menhaden (*B. gunteri*), Castillio-Rivera et al. (1996) reported the diet of gulf menhaden to be 70-72% phytoplankton. Several studies are currently underway to further elucidate the diet and trophic level of gulf menhaden.

## 3.3 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.

*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 discernable 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.

*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 (see S27DW02, Figure 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. 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 0.041 at age-0 and increased to maximum of 0.54 for fish age-6 (see S27DW02, Figure 3). The coefficient of variation was a curve which increased from 0.041 at age 0 to 0.17 at age 2, and then decreased to 0.09 at age-6. 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 -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.

*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 seven age-6 individuals have been sampled (in 1981 [2], 1982 [2], 1990 [1], 1992 [1], and 1993[1]) from almost 510,000 fish processed from 1964 to 2010. Gulf menhaden older than age-4 are uncommon in the landings, including eighty-two age-5 gulf menhaden and the seven age-6 gulf menhaden already mentioned.

Over 513,300 gulf menhaden were aged between 1964 to 2010. These data were summarized in the form of an age-length key based on 10 mm FL intervals (Table 3.3). Only eighty-three age-5 and seven age-6 gulf menhaden were recorded. As noted elsewhere, most gulf menhaden landed in the reduction fishery were either age-1 or age-2, representing 57% and 38%, 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 3.4).

Maximum fork length of gulf menhaden as recorded in the NMFS biostatistical data bases is about 341 mm FL (n=538,393); maximum weight of gulf menhaden from the same data bases is about 610 grams (n=538,393). 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 2010 port samples of gulf menhaden are shown in Figure 3.2.

## 3.4 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. The differences in the correlations between these two alignments suggest that the relationship is stronger when aligned by cohort for lengths, but not for weights.

During the Data Workshop it became clear that states use standard and total length measurements for their surveys, while NMFS uses fork lengths in their biostatistical data base. The need for statistical regressions to transform among the different length measurements became evident. It was agreed that the each state would collect and measure lengths [fork length (FL), standard length (SL), and total length (TL)] for several hundred fish in late March and early April to remedy this situation. These fish would include both juveniles and adults. The intent of these collections was to get a broad range of sizes and geographic location.

Soon after the Data Workshop, 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 fish). Subsequently 927 fish lengths were collected by the individual states in spring 2011 for which all three lengths were measured. Sample size by state is summarized in Table 3.8. Separate regressions were then conducted relating FL with SL and with TL for direct use in 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:

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

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.

Because of the increased significance in correlations among lengths at age when aligned by cohort rather than annually, we investigated an alternate set of von Bertalanffy fits with the size at age data aligned by cohort (year class). Parameters can be found in Table 7 of S27DW02. We compared the estimated fork lengths at ages-1 and -2 (at mid-year) from the two series of fits to the von Bertalanffy growth equation (Figure 3.3). Based on the similarity of these comparisons and no need to fill in for missing values at the beginning and end of the time series, the Data Workshop participants suggested using the annual growth fits for describing size at age in the model.

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

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

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

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

Annual estimates for parameters *a* and *b*, along with sample size and root MSE, are summarized in Table 3.9. For purposes of representing recent length and weight at age, parameters from regressions for (1) and (3) were averaged for the most recent ten years (2000-2009) and used to calculate lengths and weight at age at the middle of the fishing year (age+0.5; Table 3.10). 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.

Based on the annual von Bertalanffy growth fits, matrices of weight at ages-0 to -6 for 1964-2010 were developed from equations (1) and (3) to represent 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 use in population modeling (Table 3.11). Age-0 weights are included in Table 3.12.

## 3.5 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 ten 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). A sensitivity run was added to the last stock assessment with 20% of the age 1 fish assumed to be mature (Vaughan et al. 2007).

*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

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

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 3.4 illustrates the difference in perspective between using egg production and spawning stock biomass. Assuming a 1:1 sex ratio, annual fecundity at age was calculated and summarized in Tables 3.13 as determined from von Bertalanffy growth equation parameters summarized in Tables 3.9.

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 that 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 3.5).

## 3.6 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 material found in the SEDAR 27 Data Workshop report S27DW03 and discusses decisions made at the Data Workshop. 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 ($K$, $L_\infty$), or as an inverse function of size at age, so consideration of growth of gulf menhaden is relevant to this section.

### 3.6.1 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 ($t_{max}$), von Bertalanffy growth parameters ($K$, $L_\infty$), and average water temperature ($T^oC$).

The maximum age used in calculations was age-6. Mean environmental temperature ($T^oC$) was the mean annual water temperature where fish were caught. Quinn and Deriso (1999) have converted Pauly’s equation from base 10 to natural logarithms as presented above. 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.

| **Source** | **Equation** |
|---|---|
| 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) | $M = 1.5 * K$ |
| Pauly (1980) | $M = exp(-0.0152+0.6543 * ln(K)-0.279 * ln(L_{\infty}$, cm) $+0.4634 * ln(\mathrm{T^{o}C}))$ |
| “Rule of thumb” (Hewitt and Hoenig 2005) | $M = 3/t_{max}$ |

At the SEDAR 27 Data Workshop, the participants agreed that a constant value for natural mortality over ages 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 estimates of *M* (Peterson and Wroblewski 1984, Boudreau and Dickie 1989, Lorenzen 1996). 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 ½ a year (6 months), was added to each age in the von Bertalanffy growth equation to calculate corresponding length on July 1, then converted to weight using a 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).

During the SEDAR 27 Data Workshop, all age-varying approaches were discussed, 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 (S27-DW03). The Data Workshop participants suggested scaling the Lorenzen curve to the Hoenig-based estimate of *M* to be used by the SEDAR 27 Assessment Workshop as a sensitivity run (Table 3.14). The Hoenig-based estimate of *M* is 0.70, and the Lorenzen curve was scaled to 0.70 at age-2, which is the bulk of the adults in the population.

### 3.6.2 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. The mean *M* for 1969 was 0.91, and the mean *M* for 1971 was 1.27. 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 participants at the SEDAR 27 Data Workshop decided that the estimates of natural mortality from the comprehensive tagging study completed by Ahrenholz likely gave an indication of the scale of natural mortality for gulf menhaden in the Gulf of Mexico. 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 3.15). 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 vectors, which were scaled, was scaled using age-2 as the anchor age. The uncertainty surrounding natural mortality was 0.91-1.27 and was based on the mean of *M* for 1969 and 1971, respectively. These values were suggested as potential sensitivity runs (Table 3.15).

Finally, to explore time- and age-varying *M* the Lorenzen curve was fit to weight at age for each year 1964-2010 (Table 3.16), and then each year was scaled using a proportional deviation from the overall *M* (Table 3.17; Figure 3.6). The Data Workshop participants suggested using the time- and age-varying natural mortality matrix as a sensitivity analysis.

### 3.6.3 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). During the SEDAR 27 Data Workshop, all approaches were discussed; however, an 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.

## 3.7 Environmental Factors

Environmental factors that affect recruitment are generally viewed as density independent. These factors include physical processes, for example transport mechanisms, water temperature, DO, 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: 1) a recurring hypoxic zone that forms along the northern Gulf of Mexico and (2) the BP Deep Water Horizon (DWH) oil spill in 2010.

### 3.7.1 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. William Schaaf later conducted a retest in the mid-1980s (referred to in Myers (1998)). Because one value (1958 year class) had high statistical leverage in the original analysis, the addition of more years 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 *B. patronus* 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 Louisiana gulf menhaden harvest. 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-2's in 2011) and 2010 (age-1's in 2011) year classes.

The mean 2010 January TEMP temperature of 12.4 °C was below the long-term mean of 13.6 °C. The 2009 January TEMP 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 March 2010 Mississippi River discharge 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 later in the Fishery Independent section (Section 5). 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 3.18 while several predictive models used for forecasting Louisiana menhaden catches are summarized in Table 3.19.

*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 3.7) 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-year 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 3.8). 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.

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.

Historically, the menhaden fishing season frequently reflects the tropical activities during a particular year (Figure 3.9). 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’ 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 Nino/La Nina events.

### 3.7.2 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 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.

### 3.7.3 Hypoxia Zone

Extensive areas of low dissolved oxygen (<2 ppm) occur in offshore waters along the Louisiana and Texas coasts during summer (Rabalais et al. 1999; Figure 3.10). 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 dissolved oxygen 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.

### 3.7.4 BP Deep Water Horizon Oil Spill in 2010

The 2010 gulf menhaden fishing season opened on Monday, April 19th. The BP Deep Water Horizon (DWH) oil rig exploded and sank on Tuesday, April 20th (Figure 3.11). Beginning about two weeks after the DWH event, 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 spill), the winds in the Gulf of Mexico shifted to 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 for Abbeville, LA. In early May, the NMFS closed the EEZ east of the Mississippi River and the Louisiana Department of Wildlife and Fisheries (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 3.20).

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.

## 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 fishing activities occurring in Louisiana (91% based on the last four-year average) and smaller contributions from Mississippi 5.6%, Texas 2.5%, 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. Landings of gulf menhaden prior to this date can be found intermittently from a series of historical publications to be described in the next two subsections. See SEDAR Data Workshop Report S27DW04 for more detail.

#### 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 2000 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” 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 was 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 1948-2010. 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 started to rise 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 stock reduction analysis (SRA) and surplus production (ASPIC) modeling described later in Section 6.

## 4.2 Commercial Reduction Fishery (1948-2010)

### 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. The gulf menhaden purse-seine fishery is almost exclusively a single species fishery for gulf menhaden, *B. patronus*. Small and relatively insignificant amounts of other menhaden species, i.e., yellowfin menhaden, *B. smithi*, or finescale menhaden, *B. gunteri*, 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 the port of Empire, Louisiana.

Official commercial landings of gulf menhaden from the reduction purse-seine fleet have been maintained by the Beaufort Laboratory of the National Marine Fisheries Service (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 (January 1 through December 31 of the same 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 to 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 to 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 2006, the fleet has been reasonably stable at about 41 vessels.

A recent innovation to the gulf menhaden fleet (since about 2000) has been the use of carry vessels or ‘run boats’. These 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 most successfully at Moss Point, where on average about two of these vessels have operated each fishing season in recent years.

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 2010. Contemporary landings data are supplied to the Beaufort Laboratory by the menhaden industry on a monthly 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 2010, and represent one of the longest and most complete time series of fishery data sets in the nation. The 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 2010.

### 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 abolished 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 became 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 to present, the LDWF has been assigned the contracts to process the fish samples from Empire, Abbeville, and Cameron. Port samples from Moss Point, Mississippi, since about 1995 have been 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 (see Table 3 in Nicholson 1978). 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 2010, landings averaged 479,600 mt annually, a decline of 13% 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 (DWH Oil Spill) to 579,300 mt in 2000.

Tropical weather systems in the northern Gulf have played a major role in depressing landings in recent years (Figure 3.11). 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 Oil Spill forced major closures to traditional menhaden fishing grounds (Figure 3.13).

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 on a monthly basis. Daily vessel unloads are provided in thousands of standard fish (1,000 standard fish = 670 lbs), which are converted to kilograms. Between 2008 and 2010 the reduction fleet (ca. 41 vessels) unloaded an average of 1,977 times during each fishing year; the average unload per vessel was 214 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 caught, 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 4.3). 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 4,800 gulf menhaden from the reduction fishery have been processed annually for size and age composition over the past three fishing seasons, 2008-10 (Table 4.3). 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. 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 47-year period that the NMFS has collected fishery-dependent data from the gulf menhaden fishery (1964-2010), 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. 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" in which hypoxic waters of the Gulf may have on the distribution of gulf menhaden (Smith 2000).

### 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 capture 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 (one vessel fishing at least one day of a given week times its net tonnage - VTW) 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 (vessel-ton-week) is statistically significant ($r^2 = 0.79$ for 1948-2010). 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. Estimates of nominal fishing effort have not been used in menhaden stock assessments for reasons outlined below.

#### 4.2.5.2 CPUEs for the Menhaden Fisheries

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. 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 4.5.

#### 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. 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), we investigated using catch per trip as an alternate unit of CPUE for the Atlantic menhaden purse-seine fishery. Here, 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 4.6). 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, catch per unit effort 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 4.7 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 three years, age-2 gulf menhaden have comprised 68% (2008) and 73% (2009) of the total numbers of fish landed (Table 4.4). However, in 2010 the age composition of the coastwide landings was more evenly distributed with 49% of the catch age-1s and 41% age-2s. Mean fork lengths of age-1 gulf menhaden sampled over the past three years have been 157, 165, and 153 mm, respectively; mean weights of age-1 fish have been 78, 90, and 73 grams. Mean fork lengths of age-2 gulf menhaden sampled over the past three years have been 183, 184, and 181 mm, respectively; mean weights of age-2 fish have been 129, 125, and 121 grams.

### 4.2.7 Potential Biases, Uncertainty, and Measures of Precision

When the menhaden program began in the early 1950s at Beaufort, 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 the plant based on the number of dumps (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). Reduction landings since 1948 are believed to be both accurate and precise compared to most other fisheries.

Development of catch matrices depended on three data sources, including the landings, sampling for weight, and age determination. 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.

*Uncertainty associated with ageing:* During the early decades of the Menhaden Program at NOAA's 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 employee, Mrs. Ethel A. Hall, has been reading menhaden scales for the Beaufort Laboratory from 1969 to the present. Two in-house ageing error analyses were conducted at Beaufort and described in Section 3.3. 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).

### 4.3 Commercial Bait Fishery (1950-2009)

The bait fishery for menhaden has historically accounted for only a minute portion of the total landings of gulf menhaden (see S27DW04). 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 4.8). 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 4.8). 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 (1950-2009), particularly for 1950-1961 prior to availability of data from the NMFS ALS for 1962-2009. The ALS data were provided by NOAA Southeast Fisheries Science Center staff in Miami, Florida on 14 February 2011. Two gears (codes 100 and 125) are associated with reduction landings, while the remaining gear codes are associated with bait landings (see S27DW04).

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 (64.0%). Gill nets and haul seines also were important gears for landing gulf menhaden for bait (24.5% for various gill net codes and 4.8% for haul seines). The remaining 6.7% of bait landings were caught with a variety of gears. We provided estimates of gulf menhaden bait landings by major gears for 1950-2010 (Table 4.8). An annual plot of these landings by gear demonstrates a period between 1986 and 2000 when purse seines dominated the bait landings (Figure 4.7). 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 4.8.

The Data Workshop participants recommended using average bait landings for 1950-1959 (9 mt) for 1948-1949 and average bait landings for 2005-2009 (192 mt) for 2010. Note that the reduction landings averaged 91,000 mt during 1948-1949 and were 379,700 mt in 2010. For the recent period 2000-2009, bait landings average 388.3 mt or 0.08% of the average of 489,622 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 Discards/Bycatch

During the SEDAR 27 Data Workshop in Houston, the question was raised about discarding of gulf menhaden from the shrimp trawl fishery prosecuted across the northern Gulf of Mexico. Because this topic was raised relatively late in the SEDAR process, it was agreed that the scope of this topic would be investigated to the extent that reasonable estimates could be derived for use in a potential sensitivity run of the base and alternate models.

First, Dr. Walter Ingram (NMFS Pascagoula) was contacted. He developed a gulf menhaden CPUE from the SEAMAP program for the period 1987 – 2010. These results (catch of gulf menhaden in numbers per trawl hour) are summarized in Table 4.9 with a few caveats. First, the data are only from summer and fall seasons. Second, they do not include data from the nearshore waters off Texas, because SEAMAP cruises operate beyond depths 5 – 10 fathoms of the coast of Texas (typically tows in this area [zones 18-21] are covered by smaller Texas vessels). Zone locations can be found in Figure 4.9.

Concurrently, Drs. James Nance and Elizabeth Scott-Denton (NMFS Galveston) were contacted about access to shrimp fishery data. They 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 was used in conjunction with CPUE to obtain estimates of gulf menhaden discards. Effort data are summarized in Table 4.10 by area (zone groupings) for 1987-2009. Because effort data were available at the area level (not the zone level), zone-specific CPUE in Table 4.9 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 4.10 presents the CPUE for these areas 2-4. Based on these caveats above, estimated gulf menhaden discards are summarized in Table 4.11 and Figure 4.11.

In general, these discards are thought to be mostly age-0 gulf menhaden. Under that assumption, the estimated number of discards in number can be converted to weight in metric tons based on the mean weight of age-0 menhaden at mid-year (Table 3.9) and summarized in Table 4.11. Alternatively, if we assume 90% are age-0 and the remaining 10% are age-1, then a similar calculation can be made to represent these discards in weight in metric tons (Table 4.11).

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 age-0 catch at age (or alternatively to age-0 and age-1 based on some preferred ratio). For ASPIC and SRA, the additional biomass can be added to the biomass stream based on reduction, bait, and recreational landings.

### 4.3.4 Commercial Bait Catch Rates (CPUE)

In general, catch rates from the commercial bait fishery are unavailable. That said, CPUE was developed above (Table 4.9) for gulf menhaden discarded by the shrimp trawl fishery.

### 4.3.5 Commercial Bait Catch-At-Age

The small amount of bait landings was combined with reduction landings to produce a single landings stream for 1948-2010 and a single catch at age matrix for use in stock assessment models for 1964-2010 (Table 4.12).

### 4.3.6 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.

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 for nearshore waters (0-10 fm).

## 4.4 Recreational Fishery (1981-2009)

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

### 4.4.1 Data Collection Methods

Data from the MRFSS were downloaded from: http://www.st.nmfs.noaa.gov/st1/recreational/queries/index.html using the Custom Query option. Data from the TPWCS were requested directly from staff. See 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 Data Workshop participants 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 (120 g) was applied by region to total harvest (A+B1+B2) in numbers to obtain harvest in weight. Recreational landings for 1981-2009 are summarized in Table 4.2 (see S27DW04 for more detail). Similar to filling in missing values for matching landings from reduction fishery for 1948-2010, average values were obtained from 1981-1990 for the earlier years 1946-1980 and average values for 2005-2009 for 2010.

To put these removals into perspective, for 2000-2009, reduction landings have averaged 489,622 mt, bait landings have average about 388.3 mt, and recreational landings have averaged about 76.6 mt. In general, the recreational landings represent about 0.02% of the reduction landings and about 20% 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 4.8. 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 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%.

# 5.0 Fishery-Independent Data

## 5.1 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. Gillnet data were available from each state except Florida to calculate an adult index of abundance. Each state conducts separate surveys, which collect gulf menhaden, but gulf menhaden are not the target species. Below is a brief description of the data for each state. In addition, SEAMAP plankton and trawl data were considered for creation of an index.

### 5.1.1 Texas

#### 5.1.1.1 Survey Methods

Texas Parks and Wildlife's fishery-independent data are collected as a stratified cluster sampling design; each bay system and Gulf area serves as non-overlapping strata with a fixed number of samples per month (or season, for gill nets; Figure 5.1). A cluster sample is a type of probability sample where each sample unit is a collection, or cluster, of elements. Specifically, locations are sampled and include every organism encountered at that location as part of the sample. Sample locations are drawn independently and without replacement for each combination of gear, stratum, and month (season). Gill net and 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 sites selection since September 1984. Prior to September 1984, sites for setting gill nets were randomly selected from 100 fixed stations in each bay system. Beginning September 1984, random sites were adopted.

Gill nets, bag seines, and trawls 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. Bag seines are pulled along the shoreline and target juvenile fish and invertebrates. Trawls are towed in open water and target juvenile and subadult fish and invertebrates.

For gulf menhaden, bag seines and monofilament gill nets 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. Monofilament 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. Bay trawls are used in all estuarine systems except Cedar Lakes. Gulf trawls, identical to those used in the bays, are used in the Texas Territorial Sea (TTS) <16.7 km from shore, in five Gulf areas 24.1 km either side of Sabine Pass, Bolivar Roads, Matagorda jetties, Aransas Pass, and 48.2 km north from Brazos-Santiago Pass.

Gill net sets are conducted overnight during each spring and fall season. The spring season begins with the 2nd full week in April and extends for 10 weeks. The fall season begins with the 2nd 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 overnight sets are made during each week, and Cedar Lakes, where only one overnight 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 overnight 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 h before sunset and retrieved within 4 h after the following sunrise. Total fishing time is recorded (nearest 0.1 h).

Bag seines are pulled parallel to the shoreline for 15.2 m. The area swept (0.03 ha) is determined using distance pulled and width of the bag seine. 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.

Bay trawl sample locations are randomly selected from grids (1-minute latitude by 1-minute longitude) 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. In East Matagorda Bay, all water is designated as Zone 1; in Sabine Lake and the upper and lower Laguna Madre all water is designated as Zone 2. 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 motion near the center of each grid. All tow times are 10 minutes in duration. No grid is sampled more than once per month. Trawls have been employed in three bays since January 1982 and seven bays since May 1982; trawls were employed in Sabine Lake beginning January 1986, and East Matagorda beginning April 1987. Since inception, samples sizes have been 10 trawls/month/zone.

Gulf trawl sample locations are randomly selected from grids (1-minute latitude X 1-minute longitude) in the TTS that contain water >1.8 m deep in at least ⅓ of the grid, and are known to be free of obstructions.  One half of the samples in each area are collected during each half (days 1-15 and 16-31) of the month to ensure good temporal distribution of samples.  Trawls are towed linearly, parallel to the fathom curve; direction of tow (north or south) is randomly chosen for the initial tow and alternated on subsequent tows.  All tow times are 10 minutes in duration.  No grid is sampled more than once per month.  Trawls have been employed in four Gulf areas within the TTS since August 1985 and five areas since July 1986, with 16 trawls/month/area since inception.

#### 5.1.1.2 Biological and Physical Sampling Methods

Lengths [total (TL) or standard (SL)] of organisms caught are recorded.  In gill nets, up to 19 individuals of each species are measured within each mesh size, on each sampling day.  For all other gears, up to 19 specimens are measured for each species in each sample collected. Standard lengths are converted to total length with a SL-TL equation (Table 3.8).

Mean TL of individual species in gill nets are calculated for each of the four mesh sizes.  Mean lengths for the combined meshes are calculated by weighting individual species mean lengths in each mesh by the number of each species caught in each mesh.  For all other gears, mean lengths of individual species are calculated from individuals measured in each sample.  Coastwide total mean lengths for each species in all gears are weighted according to the catch rate in each bay system, and by bay specific and gear specific weighting factors used for coastwide catch rates.

Surface salinity (ppt), water temperature ($^{o}$C), dissolved oxygen (ppm) and turbidity [Nephelometric Units (NTU)] are measured at the set and pickup for each gill net and prior to each bag seine sample.  Bottom salinity, water temperature, dissolved oxygen and turbidity were measured prior to each trawl sample.

#### 5.1.1.3 Ageing Methods

TPWD does not age gulf menhaden samples collected during fishery-independent monitoring.

#### 5.1.1.4 Use for an index

Bay trawl, seine, and gillnet fishery independent data from Texas were combined with the data from other states to create indices for use in the base run. See Sections 5.2 and 5.3 for more information. Fishery independent Gulf trawl data were considered, but not put forth for use in the assessment model. The Gulf trawl data were collected at depths and locations thought to be outside the main range of gulf menhaden, and thus were thought not to be as useful as other data sources.

### 5.1.2 Louisiana

#### 5.1.2.1 Survey Methods

The sampling design for Louisiana data consists of fixed stations selected by coastal study areas to target areas known to have fish/shellfish when the sampling programs started.

> *Coastal Study Area (CSA) 1* is bordered on the east by the Mississippi River state line and on the south by Bayou Terre aux Boeufs, including such major water bodies as Chandeleur and Mississippi Sounds, and Lake Borgne, Pontchartrain, and Maurepas (Figure 5.2).
>
> *CSA 2* is bisected by the Mississippi River with Bay Terre aux Boeufs on the east, extending to Grand Bayou on the west. Some major water bodies found on the eastern side of the Mississippi River include Breton Sound, Black Bay, Bay Gardene, Little Lake, Bay Craba, American Bay, California Bay, Quarantine Bay and Grand Bay. Bay Adams, Bay Jacques, Skipjack Bay, Sandy Point Bay and Bay Lanaux are found on the western side of the Mississippi River.

*CSA 3* includes Barataria and Caminada Bays and Little Lake. Grand Bayou is the eastern boundary and Bayou Lafourche is the western boundary.

*CSA 4* is the Timbalier and Terrebonne Bay complex along with Lake Pelto. It is bounded on the east by Bayou Lafourche and on the west by Bayou Sale.

*CSA 5* is defined by Bayou Sale on the east and Atchafalaya River/Point au Fer Island on the west. Large water bodies in this area are Caillou Bay, Caillou Lake, Lake Mechant, Lake Decade and Four League Bay.

*CSA 6* extends from Atchafalaya River on the east to Freshwater Bayou on the west. Large water bodies in this area include Vermilion Bay, West Cote Blanche Bay, East Cote Blanche Bay and Atchafalaya Bay.

*CSA 7* encompasses the region from Freshwater Bayou, located in Vermilion Parish, westward to the Louisiana/Texas state line. Estuaries located within CSA 7 include the Rockefeller Wildlife Refuge complex, the Mermentau River Basin, Calcasieu Lake, Lake Charles, Prien Lake and Sabine Lake.

At some 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 2010, new stations were added for each gear. These stations were excluded from the analysis because they are not long-term stations.

The survey period for the 16-ft trawl data is 1967-2010, for the seine data it is 1986-2010, and for the gill net data the survey period is 1986-2010. Gear specifications for the trawls, seines, and gillnets can be found in Tables 5.1, 5.2, and 5.3.

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. The 50-ft bag seine is used to sample juvenile finfish, shellfish, and other marine organisms to monitor relative abundance, size distribution, and seasonal/long term trends. A 750-ft experimental monofilament gill net is used to sample finfish to obtain indices of abundance, size distribution, and ancillary life history information on selected species.

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. The seine samples are carried out monthly during January-August, then semi-monthly during September-December. The gill net sampling is done monthly during October-March, then semi-monthly April-September.

The trawl body is constructed of ¾ in bar mesh No. 9 nylon mesh while the tail is constructed of ¼ in bar mesh knotted 35 lb tensile strength nylon and is 54-60 in long. The trawl is hung on ⅜ in PDP rope with four 3 in by 1½ in spongex floats on the corkline and with a minimum of 3½ 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 ¾ 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 ⅜ in by 2 in, flat iron bar. The 16-ft trawl is attached to a ½ 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.

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 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 ¼ in bar. A lead and float line runs the entire length of the seine. 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 90° 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. The catch in the wings of the net is shaken down to the bag, and removed.

The experimental gill nets are 750 ft long, 8 ft deep, and comprised of five 150 ft panels of 1, $1\frac{1}{4}$, $1\frac{1}{2}$, $1\frac{3}{4}$, and 2 in bar mesh or 2.0, 2.5, 3, 3.5, and 4.0 in stretch mesh. The float line is $\frac{3}{8}$ in diameter hollow braided polypropylene and the lead line is #60 75 lead core, $\frac{5}{16}$ in diameter lead core line. For the gill nets, large floats and anchor weights are attached to the 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.

### 5.1.2.2 Biological and Physical Sampling Methods

All organisms collected in trawls are identified by species, counted, and up to 50 of each species measured in 5mm intervals. 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. All organisms captured in the gillnets 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 (total length in mm); 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 age gulf menhaden samples collected during fishery-independent monitoring.

#### 5.1.2.4 Use for an index

Trawl, seine, and gillnet fishery independent data from Louisiana were combined with the data from other states to create indices for use in the base run.  See Sections 5.2 and 5.3 for more information.

### 5.1.3 Mississippi

#### 5.1.3.1 Survey Methods

Mississippi Department of Marine Resources (MDMR) and the Gulf Coast Research Laboratory (GCRL) collects fishery-independent data using trawls, seines, gillnets, and beam plankton nets. Trawl data have been collected from January 1974 to the present, seine data have been collected from January 1974 to the present, beam plankton net data have been collected from January 1974 to the present, and gillnet data have been collected from October 2005 to the present.

Trawls are run at fixed stations (Figure 5.3) and do not target any specific species.  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: 1½ in stretch mesh #9 thread body, 1⅜ in stretch mesh #18 thread cod end (80x100 deep) fully rigged with 2 in O.D. nylon net rings for purse rope, and no layzline.  Head and footropes of ⅜ in diameter poly-dac net rope with legs extended 3 ft 6 in and rope thimbles spliced in at each end. Six 1½ x 2½ in sponge floats spaced evenly on bosom of headrope with ⅛ 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 ⅜ in stretch mesh #63 knotless nylon netting inserted and hogtied in cod end to hold small specimens.

Seines are sampled at fixed stations (Figure 5.3) and do not target any specific species. Seines are 50 ft bag seines with $\frac{1}{4}$ in bar mesh. Bag seines are set by hand and pulled at various distances from the shoreline depending on the topography of the bottom each station. No changes in methodology have occurred over time.

Beam plankton nets are sampled at fixed stations (Figure 5.3) and do not target any specific species. The wing mesh size is $\frac{1}{16}$ in and the cod-end is 750 microns. An aluminum beam (about 6 feet long) was constructed which the net attaches to. The wings are about 5 ft wide which tapers down like a regular trawl and 28 inches deep, and the cod-end is about 3 ft long tapering down to a PVC tube with screened holes at the bottom. The net is pulled by hand for 50 m parallel to the shoreline, then turning around and pulling the net outside the previous track to the starting point. No changes in methodology have occurred over time.

Gillnets have been sampled at fixed stations (Figure 5.4), but random stations have also been added since May of 2008. Gillnet sampling does not target any specific species. The gillnets are 750 ft long nets consisting of five panels measuring 150 ft apiece. Mesh sizes include 2, $2\frac{1}{2}$, 3, $3\frac{1}{2}$, and 4 in stretch mesh. Gillnets 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 gillnet 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. Data was combined with fixed station data in the database.

### 5.1.3.2 Biological and Physical Sampling Methods

All fish sampled in trawls, seines, beam plankton nets, and gillnets are brought back to the lab for processing. All finfish captured in gillnets are separated by mesh size and bagged for future analysis. All menhaden lengths are total length (TL) recorded 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.

#### 5.1.3.3 Ageing Methods

MDMR does not age gulf menhaden samples collected during fishery-independent monitoring.

#### 5.1.3.4 Use for an Index

Trawl, seine, and gillnet fishery independent data from Mississippi were combined with the data from other states to create indices for use in the base run. See Sections 5.2 and 5.3 for more information. Fishery independent beam plankton net data were considered, but not put forth for use in the assessment model because most states did not collect this type of data consistently.

### 5.1.4 Alabama

#### 5.1.4.1 Survey Methods (Including Coverage, Intensity)

Trawls have been towed at fixed stations by the Alabama Marine Resources Division (AMRD) from 1981 to the present. The trawl gear has not changed over time. Trawls are 16 ft, flat two seam 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. Changes in the stations sampled have occurred over time with some stations being added and others dropped.

Seines have been used at fixed stations from 1981 to the present. 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, 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, otherwise no particular species was targeted.

Beam plankton and larvae (BPL) nets have been implemented from 1981 to the present. The BPL gear has not changed over time. Beam plankton and larvae nets have a 1.8 m aluminum beam with 0.5 mm mesh. The opening is 150 cm by 83.8 cm, and the back of the net is 40 cm in diameter. Net depth is 100 cm in the center and 116 cm on the sides. The bag is detachable and has a 40 cm diameter opening. The bag is 100 cm deep and has a 9 cm opening for the cod end. The cod end is 3 in PVC with a 3 in cap with 16 holes of 0.5 mm screen. The beam plankton and larvae net is towed perpendicular to shore for 426 ft, and sampling does not target any specific species. Sampling occurs at fixed stations. Some stations have been added or dropped from sampling over time, but some long running stations are consistent throughout the time series.

A gillnet survey has been implemented from 2001 to the present. Gillnets used for sampling in Alabama were either small mesh gillnets or large mesh gillnets. The small mesh gillnet is composed of five panels (8 by 150 ft) of graduated mesh sizes (750 ft total). Mesh sizes begin with a 2 in stretch mesh and increase by ½ 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 gillnet is composed of four panels (8 by 150 ft) of graduated mesh sizes (600 ft total). Mesh sizes begin with a 4.5 in stretch mesh and increase by ½ 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 in 2005 when a 4 in mesh was dropped. Nets are soaked for a period of one hour and do not target any specific species. Stations are selected using stratified random sampling with sampling sites being allocated based on variation in samples. Essentially this minimized samples in cold months and areas that did not catch fish, while maintaining a target of 240 sets per year.

#### 5.1.4.2 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 entails measuring up to 50 individuals in mm SL and obtaining the weight of the entire species catch on a bench scale.  Water temperature, salinity, and dissolved oxygen were sampled at each station during each sample taken.

Samples taken during seine sampling are preserved in 5% formalin solution until processing. Large adults if caught are measured for appropriate length, weighed using a spring scale, and released.  Lab processing entails measuring up to 50 individuals in mm SL and obtaining the weight of the entire species catch on a bench scale.  Water temperature, salinity, and dissolved oxygen are sampled at each station during each sample taken.

Samples taken during beam plankton and larvae sampling are preserved in 5% formalin solution until processing.  Lab processing entails measuring up to 50 individuals in mm SL and obtaining the weight of the entire species catch on a bench scale.  Water temperature, salinity, and dissolved oxygen are sampled at each station during each sample taken.

Samples taken during gillnet sampling are placed on ice until processing.  Field processing entails measuring up to 10 individuals in mm FL from each mesh size per species and obtaining a total count by mesh size.  Species of interest are bagged, labeled, and are returned for lab processing.  Lab processing includes measuring length, weight, and ovary weight; sexing; and otolith extraction.  Water temperature, salinity, and dissolved oxygen are sampled at each station during each sample taken.

#### 5.1.4.3 Ageing Methods

The AMRD does not age gulf menhaden samples collected during fishery-independent monitoring.

#### 5.1.4.4 Use for an Index

Trawl, seine, and gillnet fishery independent data from Alabama were combined with the data from other states to create indices for use in the base run.  See Sections 5.2 and 5.3 for more information.  Fishery independent BPL data were considered, but not put forth for use in the assessment model. BPL data are not consistently collected in all states and thus were thought not be as useful as other data sources.

### 5.1.5 Florida

#### 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 seines and trawls. Given the range of gulf menhaden and that other bay systems sampled likely contained other menhaden species, only those samples collected in Apalachicola Bay were used for creation of the indices.

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. Depth identifies the gear types (trawl and/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/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/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 and/or seines) that can be used to sample each microgrid. At some field labs, the seines are further stratified by the presence/absence of overhanging vegetation within the microgrid. Rivers may also be stratified into subzones to ensure that the river's entire salinity gradient 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 (~69 ft), 1.8-m deep center bag seine 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.

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.

#### 5.1.5.2 Biological and Physical Sampling Methods

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 (>1000) 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.

#### 5.1.5.3 Ageing Methods

FFWCC does not age gulf menhaden samples collected during fishery-independent monitoring.

#### 5.1.5.4 Use for an Index

Trawl and seine fishery independent data from Florida were combined with the data from other states to create indices for use in the base run. See Sections 5.2 and 5.3 for more information. Fishery independent data from other gears were considered, but not put forth for use in the assessment model. The other fishery independent data collected by Florida did not have long time series, and thus were thought not be as useful as other data sources.

### 5.1.6 SEAMAP Trawl Survey

#### 5.1.6.1 Survey Methods (Including Coverage and Intensity)

SEAMAP (South East Area Monitoring and Assessment Program) surveys use trawl gear to collect fishery independent data (i.e. finfish, shrimp, and other invertebrates). The Summer and Fall Shrimp/Groundfish use the same survey design that has been used from 1987 to 2009. National Marine Fisheries Service (NMFS) in 2009 changed protocol from stations that were collected across a fathom stratum to a 30 minute fixed tow time; additionally, the designation of “day” and “night” stations was removed. State partners made this switch in 2010. Currently all

SEAMAP trawls follow the same 30-minute tow time survey design. 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 and cost-efficient program. Texas participates in the trawl survey; see Section 5.1.1.1 for more information on their gear.

SEAMAP sampling stations are chosen using a random design with proportional allocation by bottom area within shrimp statistical zones (Figure 4.9). Stations are sampled 24-hours a day, with a tow time (bottom time) of 30 minutes per station. A 42-foot SEAMAP trawl with $1\frac{5}{8}$ in stretched mesh is lowered to depth at each station and the towline is set at a 5:1 cable length water depth ratio. The desired vessel speed while towing is 2.5-3.0 knots.

#### 5.1.6.2 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 is also recorded. Up to 20 individuals of a species are measured for length with the appropriate measurement being used depending upon the species.

#### 5.1.6.3 Ageing Methods

SEAMAP does not age gulf menhaden samples collected during fishery-independent monitoring.

#### 5.1.6.4 Use for an index

SEAMAP trawl data were not used for an index of abundance because data workshop participants thought that the samples were not representative of the range of gulf menhaden given the depth at which most samples had been taken.

### 5.1.7 SEAMAP ichthyoplankton survey

#### 5.1.7.1 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 conduct plankton sampling 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 sites (i.e. SEAMAP 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 gear using during resource surveys (bongo and neuston nets) are described in detail in the SEAMAP Field Operations manual (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 primary (standard) gear employed and it 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 1983 (in part) a flow meter was placed in 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.

### 5.1.7.2 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), St. Petersburg, FL. 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.

### 5.1.7.3 Ageing Methods

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

### 5.1.7.4 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 data workshop participants felt that larvae would likely be more inshore during the spring months, when sampling was most regular. Finally, the data workshop participants 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.

## 5.2 Data Compilation for Use in an Index

Seine data from Texas, Louisiana, Mississippi, Alabama, and Florida were used to calculate a juvenile abundance index for use in the base run. These data reflect juvenile abundance throughout the range of gulf menhaden in the Gulf of Mexico. The lengths sampled were mainly below 100 mm TL, which was the length below which individual gulf menhaden would be age-0 according to the fishery dependent age data and the data workshop participants. The size and age range of fish captured by seines is juvenile or age-0 fish, thus the selectivity curve for the index should be fully selected at age-0 and not selected after age-0.

Trawl data from Texas, Louisiana, Mississippi, Alabama, and Florida were used to calculate a juvenile abundance index for use in the base run. These data reflect juvenile abundance throughout the range of gulf menhaden in the Gulf of Mexico. 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 TL, which was the length below which individuals were determined to be juveniles. If lengths were not measured in TL, then a conversion was used to convert the lengths to TL. The size and age range of fish captured by trawls is juvenile or age-0 fish, thus the selectivity curve for the index should be fully selected at age-0 and not selected after age-0.

Gillnet data from Texas, Louisiana, Mississippi, and Alabama were used to calculate an adult gulf menhaden abundance index for use in the base run. These data were felt to reflect adult abundance throughout the range of gulf menhaden in the Gulf of Mexico. This data set did not include Florida, but it was felt that the data still represented the population as a whole because Florida is at the edge of the range for gulf menhaden. The selectivity for this index will depend on the length composition data available for these samples (provided in Section 5.5) and the age-length key created (Table 3.3).

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.

## 5.3 Methods

### 5.3.1 Seine

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 size and deployment. The gears across the states were relatively similar, thus the seine index has been put forth as an index to be used in the base run.

Different states have different numbers of years of data available. The seine index was limited to the years 1977-2010 based on having more than one state in the index (given that the state at the center of the range, Louisiana, did not start collecting seine data until 1986), sample size, and residual patterns.

#### 5.3.1.1 Response and explanatory variables

*CPUE* – Catch per unit effort (CPUE) has units of catch/area and was calculated as the number of gulf menhaden caught divided by the area swept by a seine haul. The area was estimated for each state separately.

*YEAR* – A summary of the total number of trips per year is provided in Table 5.4, 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 (Texas, Louisiana, Mississippi, Alabama, or Florida). The total number of trips by year and state is provided in Table 5.4, and the total number of trips with gulf menhaden catches by year and region is provided in Table 5.5.

*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.

#### 5.3.1.2 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 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).

<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 did not remove any predictor variables. Recognizable patterns were not apparent in the residuals by state or month; however, the residuals by year were noticeably different in the earliest years (Figure 5.5). This difference supported the decision of eliminating the earliest three years of this index.

<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 both the temperature and salinity variables for the lognormal distribution, and the model did not converge for the gamma distribution. Standard model diagnostics appeared reasonable for the positive component of the model using raw residuals (Dunn and Smyth 1996).

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, state, month, temperature, and salinity, and the factors included for the positive CPUE submodel included year, state, and month.

### 5.3.2 Trawl

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. The gears across the states were relatively similar, thus the trawl index has been put forth as an index to be used in the base run.

Different states have different numbers of years of data available. The trawl index included all years of data available from 1967-2010 based on having the key state at the center of the range, Louisiana.

#### 5.3.2.1 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 5.6, and a summary of the total number of trips with positive gulf menhaden catch per year is provided in Table 5.7.

*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 5.6, and the total number of trips with gulf menhaden catches by year and region is provided in Table 5.7.

*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.

*DEPTH* – Depth was a continuous environmental factor that was thought to have an influence on juvenile gulf menhaden catches.

#### 5.3.2.2 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. Jackknife estimates of variance were computed using the 'leave one out' estimator (Dick 2004). Because of the number of records and limits on memory size in R, jackknifing was done for 20% of the records and then scaled up using a scalar developed from running jackknifing for the seine records both completely and at 20%. All analyses were performed in the R programming language, with much of the code adapted from Dick (2004).

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 the salinity variable. Recognizable patterns were not apparent in the residuals by state, month, or year.

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 eliminated the temperature variable for the lognormal distribution, and the model did not converge for the gamma distribution. Standard model diagnostics appeared reasonable for the positive component of the model using raw residuals (Dunn and Smyth 1996).

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, state, month, temperature, and depth, and the factors included for the positive CPUE submodel included year, state, month, salinity, and depth.

### 5.3.3 Gillnet

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 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 gillnet index has been put forth as an index to be used in the base run.

Different states have different numbers of years of data available. The gillnet index was limited to the years 1986 to 2010 based on residual patterns and having more than one state in the index and including the state at the center of the range of gulf menhaden, specifically Louisiana.

#### 5.3.3.1 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 gillnet set. Louisiana gillnets were assumed to have a soak time of 30 minutes because they are strike nets, meaning that the gillnets are set and then retrieved with little to no soak time. Given that state is also a factor in the analysis, the variability associated with soak time and the assumption of soak time is probably partially captured by the state factor.

*YEAR* – A summary of the total number of trips per year is provided in Table 5.8, and a summary of the total number of trips with positive gulf menhaden catch per year is provided in Table 5.9.

*STATE* – State was defined as the state where the survey occurred (Texas, Louisiana, Mississippi, or Alabama). The total number of trips by year and state is provided in Table 5.8, and the total number of trips with gulf menhaden catches by year and state is provided in Table 5.9.

*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.

*MESH SIZE* – Mesh size was a factor that was thought to have an influence on juvenile gulf menhaden catches and varied by state. This factor accounted for differences in catch due to differences in gear between states.

*DAY/NIGHT* – Gillnets were set during the day and at night. Thus, this factor was included to determine if catches were different between day and night time sets.

#### 5.3.3.2 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. Jackknife estimates of variance were computed using the ‘leave one out’ estimator (Dick 2004). Because of the number of records and limits on memory size in R, jackknifing was done for 20% of the records and then scaled up using a scalar developed from running jackknifing for the seine records both completely and at 20%. All analyses were performed in the R programming language, with much of the code adapted from Dick (2004).

<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 day/night predictor variable. Recognizable patterns were not apparent in the residuals by state or month; however, the residuals by year were noticeably different in the earliest years (Figure 5.6). This difference supported the decision of eliminating the earliest years of this index.

<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 both the temperature and day/night variables for the lognormal distribution, and the model did not converge for the gamma distribution. Standard model diagnostics appeared reasonable for the positive component of the model using raw residuals (Dunn and Smyth 1996).

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, state, month, temperature, salinity, and mesh size, and the factors included for the positive CPUE submodel included year, state, month, salinity, and mesh size.

## 5.4 Indices of Abundance

The seine index showed large year classes of juveniles in 1984, 1986, and 2010 (Figure 5.7, Table 5.10). The trawl index showed large year classes of juveniles in 1968, 1977, 1984, and 2010 (Figure 5.8, Table 5.10). The two juvenile abundance indices were positively correlated (Figure 5.9). The correlation for the entire time series was 0.53. The correlation improved in the most recent years with a correlation of 0.76 for 1990-2010 and 0.94 for 2000-2010. The gillnet index showed a decreasing number of adults until 1993 and then an increasing trend in adult abundance (Figure 5.10, Table 5.10). The uncertainty surrounding each index decreased over time (Table 5.10, Figure 5.7, Figure 5.8, Figure 5.10).

Based on the ability to represent juvenile abundance, the data workshop participants prioritized the indices of juvenile abundance with the 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.

## 5.5 Length Compositions

All lengths sampled during gillnet 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 (Table 5.11, Figure 5.11).

## 6.0 Changes Made to Data Inputs at the Assessment Workshop

### 6.1 Gillnet index

During the Assessment Workshop concerns arose over the gillnet index because of differences in gear specifications and methodology used by the states. The ability to standardize the effort across states was also in question because Louisiana uses a gillnet as a strike net, where the net is deployed and immediately retrieved. Some panelists were also concerned that the gillnet index did not correlate with seine or trawl indices when using a lag. In addition, combining length compositions from multiple states led to questions on how to combine the data, especially since different states have different mesh sizes and catch gulf menhaden at different rates. Because of these concerns, the assessment panelists decided to use only data from Louisiana for the gillnet index, which would allow for effort to be standardized easily and would allow for direct estimation of length compositions. The assessment workshop panelists, many of whom were also data workshop panelists, felt that the index based only on Louisiana would still represent the fluctuations in abundance in the population of gulf menhaden, and would therefore be a good index of abundance for older age classes. See Section 6.6 for further discussion of the indices.

#### 6.1.1 Response and Explanatory Variables

*CPUE* – Catch per unit effort (CPUE) has units of catch/net set and was calculated as the number of gulf menhaden caught divided by one (for each net set).

*YEAR* – Louisiana has sampled using gillnets from 1986-2010.

*MONTH* – Month was used as a factor as catches may be different among 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 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.

#### 6.1.1.1 Standardization

CPUE was modeled using the delta-GLM approach (cf., Lo et al. 1992, Dick 2004, Maunder and Punt 2004). In particular, a lognormal distribution was used for positive CPUE, and the combination of predictor variables best explained CPUE patterns (both for positive CPUE and 0/1 CPUE) was examined. Bootstrapping was used to get estimates of CVs because of the efficiency of bootstrapping when compared to jackknifing. One thousand bootstraps were completed, and this method provided similar estimates of CVs to the jackknifing used above.

<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 did not remove any of the factors. Recognizable patterns were not apparent in the residuals by year or month.

<u>POSITIVE CPUE SUBMODEL</u>: Then, to determine predictor variables important for predicting positive CPUE, the positive portion of the model with all main effects was fitted using the lognormal distribution. 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 factors. Standard model diagnostics appeared reasonable for the positive component of the model using raw residuals (Dunn and Smyth 1996).

Finally, 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 and positive CPUE submodels included year, month, temperature, salinity, and mesh size.

### 6.1.2 Index of Abundance

The gillnet index showed a relatively flat abundance trend with the exception of the years 2008 and 2009, which were high abundance years (Figure 6.1, Table 6.1). The uncertainty surrounding each index was relatively stable over time (Table 6.1, Figure 6.1).

## 6.2 Gillnet Length Compositions

All lengths sampled during gillnet sampling were standardized to fork length using the length-length conversions in Section 3.4. Yearly length compositions from Louisiana were provided as the proportion in each length class for a given year (Table 6.2, Figure 6.2).

## 6.3 Ageing Error Matrix

The ageing error matrix needed to be redone because the assessment panelists decided to use age-0-4+. This decision was made because of the small sample size of age-5 and age-6 individuals in the age compositions. The new ageing error matrix for the otolith:scale comparison can be found in Table 6.3.

## 6.4 Weight at Age and Fecundity

Because the model was extended back until 1948, the years from 1948-1963 did not have any weight at age or fecundity at age data. Thus, the average weight at age and fecundity at age from 1964-1966 was used as the weight at age and fecundity at age for 1948-1963 (Table 6.4, Table 6.5, Table 6.6).

## 6.5 Abundance Index from CPUE in the Commercial Reduction Fishery

A fishery-dependent index of adult abundance was introduced in an Assessment Workshop working document. Prager and Vaughan (2011) developed this index from CPUE in the reduction fishery. Reduction fishery landings are tabulated in the Data Workshop report, along with several measures of fishing effort. Because vessel tonnage has increased over the years, Prager and Vaughan chose vessel-ton-weeks (VTW) as the most stable measure of fishing effort of those given. A nominal abundance index was computed as annual reduction landings divided by annual fishing effort in VTW.

Like most fisheries, the gulf menhaden reduction fishery has experienced fishing-power increases from various factors beyond vessel tonnage. Considerable increases would be expected, e.g., from improvements in netting materials, change from wooden to steel hulls, and use of stern ramps rather than davits for launching purse boats (J. Smith pers. comm.). In an attempt to reduce the effect of such factors, and thus arrive at a measure of effort whose units are consistent, a fishing-power adjustment (assumed annual increase in fishing power) $\gamma$ is often applied to CPUE series derived from commercial fisheries.

Ideally, the value of $\gamma$ would be based on observational data, but when studies have not been made, a constant around $\gamma = 2\%\ \mathrm{yr}^{-1}$ is often used. That value reflects estimates of 1% to 4.5% per year in studied fisheries (e.g., Skjold et al. 1996, Stefansson 1998, Jin et al. 2002, Hannesson 2007). In the gulf menhaden reduction fishery, the unit of effort (VTW) already accounts for part of the fishing-power increase. Therefore, the Assessment Workshop panel agreed with the choice of Prager and Vaughan (2011) to use the lower end of the range, $\gamma = 1\%\ \mathrm{yr}^{-1}$, in this assessment.

There is no straightforward way to derive the variance of the resulting abundance index. Its main components are recorded rather precisely, which argues for a small *CV*. Nonetheless, because of the use of spotter planes in the fishery - among other biological and operational factors - substantial variance may be present in the index's relationship to actual relative abundance. Using a heuristic approach, Prager and Vaughan (2011) doubled the reported *CV* of the reduction landings, which was estimated as 4% by Vaughan et al. (2007), and assumed a constant 8% *CV* for this index.

## 6.6 Index Discussion

At the Assessment Workshop, considerable discussion centered on which indices to use, the credibility of the indices, and how they correlate with one another. Four indices were included in the discussion 1) commercial reduction index, 2) gillnet index based on data from Louisiana only, 3) seine juvenile abundance index, and 4) trawl juvenile abundance index (Table 6.7). In the end, the fishery-independent gillnet index and seine index were chosen for the base run of the assessment. The fishery-independent gillnet index was chosen because it was thought to be an indicator of adult population abundance and because Louisiana is the center of the range for gulf menhaden. The fishery-independent seine index was chosen as it was thought to be the best indicator of juvenile abundance (see Section 5 above for further discussion).

The commercial reduction index correlates well with the seine juvenile abundance index with a one year lag (Table 6.8). Because of this correlation, panelists felt that the commercial reduction index, which was a fishery-dependent index, was a suitable adult abundance index. However, a fishery dependent index based on a purse-seine fishery is troubling because of hyperstability (Hilborn and Walters 1992). Specifically, hyperstability is a concern because fish school and are easily targeted, especially by a fishery which uses spotter planes, meaning that catch per unit of effort can remain high even though abundance may be declining (Clark and Mangel 1979, Hilborn and Walters 1992). Because a fishery-independent adult index was available and because of the concerns regarding the fishery-dependent index, the commercial reduction index was not included in the base run of the assessment models.

The gillnet index went through several iterations before a decision was made as to which version should be used in the base run of the assessment models. The gillnet indices under consideration included: 1) using all states and all mesh sizes, 2) using all states and only the three inch mesh size, and 3) using only the Louisiana data, but including all mesh sizes (Figure 6.3). Several concerns over the gillnet index arose including gear differences among states, gear deployment differences among states, how to combine length composition data, and the lack of a correlation between the gillnet index and any of the other indices, even with a year lag. The ability to standardize the effort across states was also in question because Louisiana fishes gillnets as strike nets. The panelists thoroughly discussed the variation of the gillnet gears among the states. Concerns centered on how to combine the gillnet length compositions from each state to provide overall length compositions for the model. In an effort to circumvent this problem, the panelists felt that the 3-inch mesh size, which was standard for Texas, Louisiana, Mississippi, and Alabama, would provide the best index and length compositions. Using the 3-inch mesh only, the panelists felt that the model would estimate gillnet selectivity more accurately since size ranges at capture were ‘narrowed’, thus removing some of the variation in the data. It was agreed that the index should be based on the 3-inch mesh for all states. However, the 3-inch mesh gillnet index was later discarded in favor of Louisiana’s gillnet index which included all mesh sizes. With the use of Louisiana’s data only, the standardization of effort and combination of gillnet length compositions were simplified and improved. In addition, the assessment workshop panelists, many of whom were also data workshop panelists, felt that the Louisiana index would: 1) represent the fluctuations in abundance in the population of gulf menhaden, 2) represent gulf menhaden in the center of their geographic range, and 3) would be a good index of abundance for older age classes.

Some panelists were also concerned that the gillnet index did not correlate well with the seine or trawl indices when using a lag. This concern arose given the thought that the fishery was expected to be a recruitment-driven fishery, and therefore, there was some expectation that the adult gillnet index should correlate with the juvenile abundance indices with a lag. However, this last statement applies to the fishery, not necessarily the population as a whole, which is what the gillnet index was meant to reflect. Additionally, 2008 and 2009 were high points in the gillnet index and have caused some concern, but these two high points were reflected in the commercial reduction fishery age composition data with a higher proportion of age-2 individuals in those years compared to other years. This shows that the increase in older fish, as reflected in the gillnet index, was apparent in more than one data source.

## 7.0 Methods

## 7.1 Assessment Model Descriptions

In this section, we identify three modeling approaches that were considered as potential base models during the Data and Assessment Workshops. These modeling approaches include: (1) Beaufort Assessment Model (BAM), (2) Surplus Production Model (ASPIC), and (3) Stock Reduction Analysis (SRA). During the Assessment Workshop, the pros-and-cons of these approaches were discussed in detail and summarized in Table 7.1. 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 two approaches (ASPIC and SRA approaches) because of their different model assumptions and to explore possible ranges in stock status relative to benchmarks ($B_{MSY}$ and $F_{MSY}$) given their longer history of stock exploitation.

### 7.1.1 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 in 2003 and SEDAR Update 2005), South Atlantic snowy grouper and tilefish (SEDAR 4 - 2004), South Atlantic red snapper (SEDAR 15 – 2008 and 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.

### 7.1.2 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. We also fit two configurations using the Fox model shape. This modeling approach has been used in many SEDAR assessments as an alternate/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 gillnet 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.

### 7.1.3 Stock Reduction Analysis (SRA)

Stock reduction analysis (SRA) was used, as a complementary model to the Beaufort Assessment Model (BAM), to provide historical evaluation of stock productivity and measure of uncertainties associated with the gulf menhaden stock and recruitment dynamics. Similar modeling approaches were conducted in the SEDAR assessments for the Gulf of Mexico red snapper, gag grouper, and red grouper. The SRA uses historical landings time series to determine how large the stock and recruitment needed to be to have produced the time series of observed landings and the current stock status. A longer historical perspective can be informative in developing measure of uncertainty associated with stock and recruitment and estimation of management reference points.

For this analysis, we used the stochastic version of the SRA (stochastic SRA) developed by Carl Walters (Walters et al. 2006). Unlike earlier versions of the stochastic SRA that estimated uncertainty for recruitment compensation (recK) and unfished population recruitment ($R_0$), the new model estimates the uncertainty about population dynamic parameters that are of interest to managers, i.e. maximum sustainable yield (*MSY*) and the fishing mortality associated with this level of yield ($F_{MSY}$) but expressed as an exploitation rate ($U_{MSY}$). The stochastic SRA is parameterized by taking $U_{MSY}$ (annual exploitation rate producing MSY at equilibrium) and *MSY* as leading parameters, then calculating the Beverton-Holt stock-recruit parameters ($R_0$ and $E_0$, the unfished population recruitment and egg production; and recK, the compensation ratio) from these and from per-recruit fished and unfished eggs and exploitable biomass. Under this parameterization, the model assumes a uniform Bayes prior for $U_{MSY}$ and *MSY*, rather than a uniform prior for the stock-recruitment parameters. In stochastic SRA, recruitment is assumed to have had log-normally distributed annual anomalies. This is accomplished by making a large number of simulation runs with anomaly sequences chosen from normal prior distributions (with or without autocorrelation).

At each iteration, a pair of *MSY* and $U_{MSY}$ values are randomly chosen from the prior, then parameter recK is estimated from these and estimates of $EPR_{F=0}$ (eggs per recruit for an unfished population), $EPR_{Fmsy}$ (eggs per recruit for a population fished at the chosen $U_{MSY}$ ), and $BPR_{Fmsy}$ (exploitable biomass per recruit for a population fished at the chosen $U_{MSY}$) (equation 1). The equilibrium egg per recruit and exploitable biomass per recruit estimates are derived from the Botsford “incidence” functions, which simultaneously capture the effects of fishing and natural mortality on fish as they age (Walters and Martell 2004):

$$recK = \frac{EPR_{F=0}}{EPR_{Fmsy}} - U_{MSY} BPR_{Fmsy} \frac{\dfrac{\sum_{a=1}^{a=ages} Fec_a \, dl_a / da}{EPR_{F=0}}}{\left(\dfrac{EPR_{F=0}}{EPR_{Fmsy}}\right)^2 (BPR_{Fmsy} + U_{MSY} \sum_{a=1}^{a=ages} W_a v_a \, dl_a / da)} \quad (1),$$

where $Fec_a$, $W_a$, and $v_a$ are the fecundity, weight, and vulnerability at age a, respectively, and $dl_a/da$ is the change in survival at age a with respect to age under the rate of fishing, $U_{MSY}$.

The estimate for $R_0$ follows (equation 2) given the choice of $MSY$, $U_{MSY}$, and an estimate of recK as:

$$R_0 = MSY / (U_{MSY} \; BPR_{Fmsy}) \left( \frac{recK - 1}{(recK - 1) EPR_{F=0} / EPR_{Fmsy}} \right) \quad (2),$$

and, $E_0$ can be determined based on equation (3) using the unfished eggs per recruit ratio and an estimate of $R_0$:

$$E_0 = R_0 EPR_{F=0} \quad (3)$$

From estimates of the stock and recruitment parameters $R_0$ and $E_0$ (the unfished population recruitment and egg production) and recK(the compensation ratio), recruitment at time $t$ can be calculated as:

$$R_t = \frac{recK (R_0 / E_0) E_t}{1 + \dfrac{(recK - 1)}{E_0} E_t} \quad (4)$$

Given a spawner-recruit relation, an initial population age structure, and a lognormal set of recruitment anomalies, an age-structured population model is simulated forward in time from the start of the fishery (1873 in this analysis) removing historical catches along the way while adding and subtracting estimates of recruitment and mortality. This is repeated many, many times so that a set of $U_{MSY}$ and $MSY$ pairs are determined that do not lead the population to extinction over the course of the projection, while supporting the observed annual catches and fitting a series of recent abundance indices. The exploitation rate is calculated each year from observed catch divided by modeled exploitable population (sum of vulnerabilities at age multiplied by modeled numbers at age). Model fits the relative abundance (CPUE) data using a maximum likelihood function. The resulting sample of possible historical stock trajectories is resampled using importance resampling (SIR), or a large sample is taken using Monte Carlo-Markov Chain (MCMC) to generate posterior distribution for $MSY$ and $U_{MSY}$. Summing frequencies of occurrence of different values of leading population parameter values over this sample amounts to solving the full state-space estimation problem for the leading parameters (i.e. find marginal probability distribution for the leading population parameters integrated over the probability distribution of historical state trajectories implied by recruitment process errors and by the likelihood of observed population trend indices). For more detail on model formulations see Walters et al (2006), Forest et al. (2008), and Forest and Walters (2009).

## 7.2 Model Configuration for Base and Alternate Approaches

### 7.2.1 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).

#### 7.2.1.1 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 juvenile abundance index and the gillnet 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 1948-2010. The 1948 starting year reflected the first year of landings data, was near the beginning of the fishery, which started near the end of World War II, and was close to unfished conditions for gulf menhaden.

#### 7.2.1.2 Selection and Treatment of Indices

As mentioned above two sources of information were used for abundance indices in the BAM model. Fishery-independent gillnet data were used to develop a CPUE adult abundance index. The gillnet index sampling presumably catches age-1 to 4+ gulf menhaden, with the majority of them presumed to be age-2. The index was derived for Louisiana, which is the center of the stock distribution. The gillnet index was treated in the model as a representation of the coastwide stock, following the estimated age-specific selectivity vector. This assumed age-specific selectivity schedule was as follows: 0.0 for age-0 and 1.0 for age-2. Selectivity for ages one, three, and four were estimated in the model. The level of error in this index was determined by the bootstrapping analysis done on the gillnet 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 gillnet 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 a survey that was not designed to capture gulf menhaden. However, the seine index was a juvenile gulf menhaden index, 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 juvenile abundance index (JAI) was treated as an age-0 CPUE recruitment index, by fitting the product of the model estimated annual age-0 numbers at the beginning of the year and a single catchability parameter to the computed index values. The error in the JAI index was assumed to follow a lognormal distribution. Sensitivity runs (see below) were used to explore alternate methods for deriving the JAI, including the use of a trawl index instead of the seine index.

### 7.2.1.3 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 7.2. The formulation's major characteristics 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 population size because of fishing and natural mortality processes.
- **Growth/Sex Ratio/Maturity/Fecundity:** Size, ratio of males to females, percent of females mature, and fecundity were fixed in the model. The von Bertalanffy growth parameters ($L_\infty$, $K$, and $t_0$) were fixed in the model to estimated values using all of the data available for the entire time series. The weight at age for each year during spawning and during the middle of the fishery were input into the model and were based on yearly 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, but was variable across years and was based on function of length (Lewis and Roithmayr 1981).

- **Recruitment:** 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.
- **Biological benchmarks:** The maximum sustainable yield (*MSY*) benchmarks were used for the gulf menhaden assessment. Overfishing was defined as $F/F_{MSY}$ greater than one. Overfished was defined as $SSB_{2010}/(0.5*SSB_{MSY})$ less than one. These benchmarks are based on the system that has been adopted at the federal level under the Magnuson-Stevenson Act and are discussed below more thoroughly.
- **Fishing:** One fishery was explicitly modeled, the commercial reduction fishery. Fishing mortality rates and selectivity-at-age patterns were estimated for each year.
- **Selectivity functions:** Selectivity for the commercial reduction fishery was estimated using a parameter for each age for each year, although some parameters were fixed values. Selectivity was dome-shaped for the commercial reduction fishery in the earliest years (1948-1979). One reason for allowing dome-shaped selectivity was that a separable VPA showed dome-shaped selectivity for the earliest years (Vaughan et al. 2000). Dome-shaped selectivity was set up such that age-0 selectivity was 0.0, age-2 selectivity was 1.0, and ages-1, 3, and 4 were estimated parameters. Selectivity for 1948-1963 was assumed to be the average selectivity from 1964-1966 because age composition data were unavailable for 1948-1963. Priors were needed to estimate selectivity parameters for 1964-1979. The normally distributed priors were relatively uninformative (ie, large variance) with mean equal to zero. From 1980-2010, selectivity was assumed to be flat-topped with age-0 selectivity assumed 0.0, age-2, 3, and 4 selectivity assumed 1.0, and age-1 selectivity being estimated for each year. The assumption of flat-

topped selectivity was discussed and examined during the assessment workshop, and based on knowledge of the fishery and the age composition data, the participants agreed that the use of flat-topped selectivity was warranted. 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 juvenile abundance index. Selectivity for the gillnet index was age varying, but constant over time. The gillnet index selectivity was allowed to be dome-shaped and was assumed to be 0.0 for age-0, 1.0 for age-2, and was estimated for the other ages. Priors were also needed to estimate selectivity parameters for the gillnet index. The normally distributed priors were relatively uninformative (ie, large variance) with mean equal to 0.5 for age-1 and 1.0 for ages three and four.

- **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 juvenile (age-0) index series (1977-2010; seine index) and an adult index series (1986-2010; gillnet 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.
- **Effective sample size:** Effective sample size was a maximum of 200 for the age compositions from the commercial reduction fishery and for the length compositions from the fishery independent gillnet survey used to create the gillnet index. For 1964-1976, the sample size for the commercial reduction age compositions was set to 10. Sample size was reduced in the earliest years because the only information in the model was from the age composition data, which was creating an unrealistic trend in the fishing mortality of the fishery given the knowledge of the fishery. If sample size was less than 100 for the gillnet length compositions, then the model did not fit that year and did not use that year for

estimation of selectivity. Limiting samples sizes to 100 or greater was done because the length compositions in years with smaller sample sizes were not sufficient to provide a complete distribution of the size of the fish captured in the gillnet survey.

- **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 gillnet index, and the patterns of the abundance indices (both seine and gillnet indices) were fit based on the assumed statistical error distribution and the level of assumed or measured error (see Section 7.2.1.4 below).
- **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.

#### 7.2.1.4 Weighting of Likelihoods

The likelihood components in the BAM model include reduction landings, reduction catch-at-age, a gillnet CPUE index, a seine juvenile abundance index, and gillnet 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 value equal to 0.04 |
| Reduction Catch-at-Age | Multinomial | Annual number of trips sampled was 393 to 1,680, but effective sample size was fixed at 10 for |

|  |  |  |
|---|---|---|
|  |  | 1964-1976 and capped at 200 for all other years |
| Gillnet Index Length Compositions | Multinomial | Annual number of net sets sampled was 4 to 461, but effective sample size was capped at 200 for all years and had a minimum value of 100 for use in model fitting |
| Gillnet Adult Abundance Index | Lognormal | Annual CV value from 0.06 to 0.09 |
| Seine Juvenile Abundance Index | Lognormal | Annual CV values from 0.10 to 0.48 |

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). Then, the panelists agreed to modify the weights in order to get the best model fit and to follow guidance in Francis (2011). First, the indices were given equal weight to one another and the weights were increased to one because the fit to the indices could be improved (Francis 2011). Second, the weight on the gillnet length compositions increased in order for the model to be able to estimate steepness, improve length composition fits, and maintain estimates of F in a reasonable realm. The final gillnet length composition weight was 0.5. Third, the weight on the commercial reduction fishery age compositions was decreased. Reducing the weight in the commercial age compositions allowed for the model to more freely fit the other data components and improved model stability. The final weight for the age composition data was 0.25.

#### 7.2.1.5 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 4,000 bootstrap iterations included landings, gillnet index, seine index, natural mortality, gillnet length compositions, commercial reduction age compositions, and age-1 maturity. The landings, gillnet index, and seine index were all re-sampled using multiplicative lognormal error using the *CV*s 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 $\sigma^2_{s,y}$. 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 CVs in arithmetic space:

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

The gillnet 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 0.18. 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.

#### 7.2.1.6 Sensitivity Analyses

A total of 16 sensitivity runs were completed with the BAM model. These sensitivity runs are represented by those involving input data and those involving changes to the model configuration.

#### 7.2.1.6.1 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 |
|---|---|
| gmenhad-065 | Natural mortality scaled to upper bound of tagging data estimate |
| gmenhad-066 | Natural mortality scaled to lower bound of tagging data estimate |
| gmenhad-067 | Age and time varying natural mortality |
| gmenhad-069 | Gillnet index using data from all meshes and all states |
| gmenhad-070 | Age-1 maturity was set to 0.25 |
| gmenhad-071 | Used Mississippi River flow as an environmental component on the stock-recruitment relationship |
| gmenhad-073 | Trawl index replace seine index as the juvenile abundance index |
| gmenhad-074 | Commercial reduction index replaced the gillnet index. Commercial reduction index had a 1% increase in catchability. |
| gmenhad-080 | Shrimp trawl by-catch included in landings data |
| gmenhad-081 | Added in the trawl index |

Natural mortality is almost always a source of uncertainty in stock assessments. To test the sensitivity of the model output to assumptions about natural mortality, sensitivity run numbers gmenhad-065, gmenhad-066, and gmenhad-067 were completed. In these sensitivity runs, natural mortality values were scaled such that age-2 mortality was the upper bound based on the tagging data (gmenhad-065; Ahrenholz 1981), and age-2 mortality was the lower bound based on the tagging data (gmenhad-066). Additionally, age and year specific values of natural mortality were also input into BAM (gmenhad-067).

The maturity for age-1 individuals in the base BAM model was assumed to be 0.0. Run gmenhad-070 tested a higher (0.25) maturity value. Run gmenhad-080 included increased landings due to shrimp trawl by-catch of gulf menhaden, although the increase in landings was small when compared to commercial reduction landings.

An improved fit of the stock-recruitment curve has been shown for gulf menhaden with the incorporation of Mississippi River flow as an environmental variable (Vaughan et al. 2011). Thus, a sensitivity run (gmenhad-071) was run incorporating Mississippi River flow as an environmental variable on the Beverton-Holt stock-recruitment curve.

A sensitivity run was examined using an alternate juvenile abundance index based on the trawl index (gmenhad-073). Another sensitivity analysis explored the result of the addition of the trawl index to the base run (gmenhad-081). For both of these runs, the weight of the trawl index was 1.0 so that all of the indices had the same weight.

The gillnet index used in the base run was based on data from Louisiana only. For a sensitivity run (gmenhad-069), the gillnet index estimated using all data from all states and mesh sizes replaced the gillnet index in the base run. Lastly, a sensitivity run with the adult gillnet index replaced with the commercial reduction index was completed (gmenhad-074). The commercial reduction index was modified with a 1% increase in catchability. For this run to converge and for the Hessian to invert, a loose prior centered on the value estimated in the base run needed to be included on the steepness parameter of the stock-recruitment relationship.

#### 7.2.1.6.1 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 |
|---|---|
| gmenhad-063 | All weight equal to 1.0 for data components |
| gmenhad-068 | Allowed dome-shaped selectivity for commercial reduction fishery |
| gmenhad-072 | Estimated underlying Ricker stock and recruitment curve |
| gmenhad-082 | Likelihood weight for age composition was 0.5 |
| gmenhad-083 | Likelihood weight for age composition was 0.75 |
| gmenhad-084 | Likelihood weight for age composition was 0.05 |
| gmenhad-085 | Likelihood weight for age composition was 1.0 |

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 (gmenhad-063).

A sensitivity run was completed to allow for dome-shaped selectivity in the most recent time period (1980-2010) by allowing age-3 and age-4 selectivity to be estimated as opposed to fixed at 1.0 in the base run (gmenhad-068). This sensitivity run was completed because of concerns regarding spatial distribution of different age classes and therefore availability to the fishery.

A sensitivity run was completed with an underlying Ricker stock-recruit curve (gmenhad-072). 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.

A series of sensitivity runs were completed across a range of weights on the age composition likelihood component (gmenhad-082 to gmenhad-085). This set of sensitivity runs was completed because of discussion relating to reduction in influence in the model for the age composition data. The BAM uses age composition data, while SRA and ASPIC do not. Reducing the weight of the age compositions does not, however, result in a non-age structured model, but did allow for improved fits elsewhere (as discussed in Section 7.2.1.4 above).

### 7.2.1.7 Retrospective Analyses

Retrospective analyses were completed by running the BAM model in a series of runs sequentially omitting years 2010 to 2006, as indicated below:

| **Run Number** | **Sensitivity Examined** |
|---|---|
| gmenhad-079 | Retrospective analysis with modeling ending in 2009 |
| gmenhad-078 | Retrospective analysis with modeling ending in 2008 |
| gmenhad-077 | Retrospective analysis with modeling ending in 2007 |
| gmenhad-076 | Retrospective analysis with modeling ending in 2006 |
| gmenhad-075 | Retrospective analysis with modeling ending in 2005 |

### 7.2.1.8 Reference Point Estimation – Parameterization, Uncertainty, and Sensitivity Analysis

The current gulf menhaden stock assessment used maximum sustainable yield (*MSY*) based benchmarks based on a Beverton-Holt stock recruitment model with a bias correction, which is in contrast to former assessments for this species. The quantities $F_{MSY}$, $SSB_{MSY}$, $B_{MSY}$, and *MSY* were estimated by the method of Shepherd (1982). *MSY* based benchmarks are commonly used in the federal management system and maximize equilibrium landings. 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 assessment workshop panel chose to present the commonly used *MSY* based benchmarks. $F_{MSY}$ was specified as the limit reference point and was estimated using the weighted natural mortality, selectivity, and fecundity per recruit for 1964-2010. The $F_{Target}$ was not specified by the panel, and instead, a range of values was provided such that managers will be able to choose. The $F_{\text{Target}}$ provided included 0.65 $F_{MSY}$, 0.75 $F_{MSY}$, and 0.85 $F_{MSY}$.

The equilibrium fecundity per recruit calculations were based upon average selectivity, *M*-at-age (which was constant), weight-at-age, and fecundity-at-age for all years in the model where data besides total landings were available (1964-2010).

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. The target for *FEC*, or $SSB_{MSY}$, was the spawning stock biomass in number of maturing ova associated with a population at $F_{MSY}$. The *FEC* threshold (limit) was assumed to be 50% of this value. Uncertainty estimates for these benchmarks are derived from the bootstrap method mentioned in Section 7.2.1.5.

### 7.2.2 Alternative Assessment Model — Production Model — ASPIC

A production model was used as one alternate model in this assessment. Data were analyzed primarily with a logistic (Schaefer) production model (Schaefer 1954 and 1957, Pella 1967, Prager 1994), as implemented by the ASPIC software, version 5.44 (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. We did not attempt to estimate model shape, as in the Pella–Tomlinson model, but instead used the Schaefer form, except for one sensitivity run using the Fox (1970) model shape.

In many cases, it is difficult to estimate the year-1 biomass (either absolutely or relative to carrying capacity *K*) from a production model. This is especially common when the indices are not well correlated, as here. To avoid that difficulty, we fixed year-1 biomass at 85% of carrying capacity ($B_1 = 0.85K$), an assumption consistent with low exploitation levels in 1948 and earlier.

All runs were conditioned on catch. This reflects the almost certain situation that observed catches are known more accurately and precisely than the abundance indices.

#### 7.2.2.1 Spatial and Temporal Coverage

The spatial and temporal coverage of this model were the same as those of the base model (BAM), as the same data series were used. A sensitivity run was attempted with the landing series extended back to 1920.

#### 7.2.2.2 Selection and Treatment of Indices

Four abundance indices were considered for or used in these analyses (Figure 8.36). Selection of indices was made by the Assessment Workshop panel. Pairwise correlations between indices used in production modeling are illustrated in Figure 8.37. These correlations vary from those in the BAM application, because of the time offset introduced when the indices were used in production modeling (see next section).

##### 7.2.2.2.1 Juvenile Abundance Indices

Two juvenile abundance indices (JAIs) are tabulated in this report, one from seine sampling off Texas, Louisiana, Mississippi, Alabama, and Florida, the other from trawling off Texas, Louisiana, Mississippi, Alabama, and Florida. Following the base BAM configuration, the seine index was used in the base production-model configuration. The trawl index was substituted for it in one sensitivity run.

When used in production modeling, the juvenile indices were adjusted in time for better correspondence with data on removals and with the adult abundance indices. The year value associated with each juvenile index datum was increased by one, under the assumption that an indicator of age-0 abundance in any given year should be an indicator of age-1 abundance in the following year. Landings are mainly age-1 and age-2 fish. The indices as adjusted are shown in Figure 8.36.

The coefficients of variation (*CV*s) for the two JAIs were increased from the values used in the BAM application. Here, the juvenile index was assumed proportional to unobserved fishable abundance in the following year. Clearly, that relationship adds variance, through variability in survival and in age composition of the fishable stock. To address that added variance in an admittedly heuristic way, tabulated *CV*s were doubled for use in production modeling.

#### 7.2.2.2.2 Adult Abundance Indices

The adult abundance index (AAI) derived from fishery-independent gillnet sampling off Louisiana was used as the main AAI in production modeling, as it was in BAM. The Assessment Workshop panel, after extensive discussion, decided to discard the data from Texas, Mississippi, and Alabama when computing the index. *CV*s were used as tabulated.

The AAI derived from reduction CPUE was used in one sensitivity run. The *CV*s as described in Section 6.5 were used with it. Both AAIs indices are plotted in Figure 8.36.

#### 7.2.2.3 Parameterization

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 $qi$, $i = 1 \ldots m$, where $m$ is the number of abundance indices used. From the leading parameters, many other quantities of management interest can be computed. For more detail, see Prager (1994), Quinn and Deriso (1999), or Haddon (2001).

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, a procedure that markedly reduces variance by removing the uncertainty in catchability (Prager 1994).

#### 7.2.2.4 Weighting of Likelihoods

Annual inverse-variance weighting was used, based on the *CV*s of indices described above. The error in each index was assumed lognormally distributed.

### 7.2.2.5 Estimating Precision

A bootstrap with 1,000 realizations was used to quantify uncertainty in model estimates for the base run and to provide a set of starting values for stock projections. 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; e. g., on $B_{2011}/B_{MSY}$. The bootstrap has the advantage of requiring few parametric assumptions.

In the bootstrapping method employed by ASPIC, estimated abundance indices and residuals from the original fit are saved. 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.

### 7.2.2.6 Sensitivity Analyses

Sensitivity run configurations and estimates are summarized in Table 8.9. These configurations are described in the balance of Section 7.2.2.6. Results are summarized in Section 8.2.

#### 7.2.2.6.1 Sensitivity to Input Data

Sensitivity to input data was assessed through two configurations (runs 109, 110) in which other indices were substituted for those used in the base run (Table 8.9).

#### 7.2.2.6.2 Sensitivity to Model Configuration

Two sets of sensitivity runs examined sensitivity to model configuration. The first was a single run (run 108) 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 119, 120) examining sensitivity to the assumption $B_1 = 0.85K$ used in the base run. Both runs were similar to the base production model run, except that one assumed $B_1 = 0.75K$ and the other assumed $B_1 = 0.95K$.

#### 7.2.2.7 Retrospective Analyses

A retrospective analysis (runs 114–118) compared the base run to runs with 1, 2, 3, 4, or 5 years of data omitted from the end of the data.

#### 7.2.2.8 Reference Point Estimation—Parameterization, Uncertainty, & Sensitivity Analysis

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

### 7.2.3 Alternative Assessment Model — Stock Reduction Analysis - SRA

Stock reduction analysis (SRA) was used, as a complementary model to the Beaufort Assessment Model (BAM), to provide historical evaluation of stock productivity and measure of uncertainties associated with the gulf menhaden stock and recruitment dynamics. The SRA uses historical landings time series to determine how large the stock and recruitment needed to be to have produced the time series of observed landings and the current stock status. A longer historical perspective can be informative in developing measure of uncertainty associated with stock and recruitment and estimation of management reference points. The stochastic SRA is parameterized by taking $U_{MSY}$ (annual exploitation rate producing $MSY$ at equilibrium) and $MSY$ as leading parameters, then calculating the Beverton-Holt stock-recruit parameters from these and from per-recruit fished and unfished eggs and exploitable biomasses. Given a spawner-recruit relationship, an initial population age structure, and a lognormal set of recruitment anomalies, an age-structured population model is simulated forward in time from the start of the fishery removing historical catches along the way while adding and subtracting estimates of recruitment and mortality. This is repeated many times so that a set of $U_{MSY}$ and $MSY$ pairs are determined that do not lead the population to extinction over the course of the projection. The resulting sample of possible historical stock trajectories is resampled using Monte Carlo-Markov Chain (MCMC) to generate posterior distributions for $MSY$ and $U_{MSY}$.

### 7.2.3.1 Spatial and Temporal Coverage

The SRA assumes the same spatial coverage used in the BAM model--one coastal population of gulf menhaden from Texas to Florida (Panhandle). The stochastic SRA was run with historical landings extended back to 1873 (1873-2010, constructed by Smith and Vaughan, SEDAR 27-DW04).

### 7.2.3.2 Selection and Treatment of Indices

The stochastic SRA formulation allows for one adult index series for tuning. Due to this limitation, two alternate state models based on two different indices were considered: the alternate-1 model, which used the gill net survey (catch rate) series (SEDAR 27-DW02) and the alternate-2 model, which used the reduction fishery catch per vessel-ton-weeks (VTW) series (see Section 6.5). The gill net series (1986-2010) is a coast wide index representing age-1 and -2 gulf menhaden with the bulk of them being age-2 (SEDAR 27-DW02). The reduction fishery index, which has a longer time series (1948-2010) than the gill net index, is strongly correlated with the fishery-independent seine survey index (lagged by one year, $r$=0.51 $F$=0.0023) (see section 6.6). Additional sensitivity runs were made using alternative indices that were available from the trawl survey (1967-2010 catch rate series lagged by one year, SEDAR 27-DW02) and the reduction fishery data (1983-2010 catch-per-set series, SEDAR 27-DW04). The reduction fishery catch-per-set index was strongly correlated with the reduction fishery VTW index ($r$=0.69 $F$=0.0000441), with the fishery- independent seine index ($r$=0.70 $F$=0.0000295), and with the fishery-independent trawl index ($r$=0.67

$F$=0.00011). The variance of adult index in SRA is defaulted to 0.04 ($CV$ on arithmetic scale, which represents a standard deviation of around 0.2.

### 7.2.3.3 Parameterization

The alternate models were run using annual landings series, fisheries vulnerability at age, an adult tuning index, and life history parameters and natural mortality estimates. The historical annual landings (in metric tons (mt)) were available for the period 1873-2010 (SEDAR 27-DW04). The vulnerability-at-age vectors were obtained from the 2011 BAM model (Section 8.1.2.1) for three periods (1873-1979, 1980-1993 and 1994-2010). The life history parameters estimates included: the von Bertalanffy growth parameters $L_{\infty}$= 23.8 cm FL, $K$ = 0.44 $yr^{-1}$, and $t_0$ = -0.808 years; the coefficient of variation for length at age = 0.1; maximum weight = 0.27 kg; and 50% size at maturity= 18.3 cm. Natural mortality rate ($M$), which was age dependent (Lorenzen approach), was determined from annual survival rates ($S=e^{-M}$).

The recruitment variability was modeled using log-normally distributed error with the standard deviation set at 0.5 in both alternate models. This value is within the range of 0.3 to 0.6 typical of fish populations (Walters et al. 2006). The alternate models assumed no autocorrelation among recruitment estimates (rho=0.0).

The stochastic SRA requires an input parameter estimate for current exploitation rate (U). Given the uncertainty associated with the estimate of $U$ (e.g., lack of estimates of U or biomass from recent tagging studies and/or surveys), we examined four simulation runs for each alternate model based on four potential values of $U$, including: $U$=0.3 $yr^{-1}$ (or $F$=0.64 $yr^{-1}$ based on $M$=1.1 $yr^{-1}$); $U$=0.4 $yr^{-1}$ ( or $F$=0.95 $yr^{-1}$ based on $M$=1.1 $yr^{-1}$): $U$=0.5 $yr^{-1}$ (or $F$=1.35 $yr^{-1}$ based on $M$=1.1 $yr^{-1}$), and $U$=0.6 $yr^{-1}$ (or $F$=1.9 $yr^{-1}$ based on $M$=1.1 $yr^{-1}$). These values reflected estimates of exploitation and fishing mortality rates reported from historical tagging studies and stock assessment reports for gulf menhaden. The estimates of U from old tagging studies (1969-1971) varied between 0.39 and 0.54 $yr^{-1}$ (or $F$ of 0.93-1.2 $yr^{-1}$ based on $M$ of 0.69-1.2 $yr^{-1}$, Ahrenholz 1981). The fishing mortality rate estimates from stock assessment reports varied between 0.5 and $F > 2.5$ (Vaughan 1987, Vaughan and Merriner 1991, Vaughan et al 1996, Vaughan et al. 2000, Vaughan et al. 2007).

The MCMC computations were based on 100,000 prior samples sampled from a wide range of values for $MSY$ (100,000- 2,000,000 mt), $U_{MSY}$ (0.1- 0.9 $yr^{-1}$), and $S$ (survival from natural mortality, 0.3-0.45 or $M$= 0.8-1.2). The MCMC was allowed to run for a long time until a convergence was obtained.

### 7.2.3.4 Weighting of Likelihood

Weighting was not used in the stochastic SRA.

### 7.2.3.5 Estimating Precision (e.g., ASEs, Likelihood Profiling, MCMC)

In stochastic SRA, recruitment was assumed to have had lognormally distributed annual anomalies. To account for these anomalies, a very large number of simulation runs was made with anomaly sequences chosen from normal prior distributions. The resulting sample of possible historical stock trajectories was re-sampled using Monte Carlo-Markov Chain (MCMC), generating posterior distributions for leading parameters ($MSY$ and $U_{MSY}$). This was employed so that the choice of each new pair of $U_{MSY}$ and $MSY$ values is effected by the likelihood that these values will result in a fit to the index of abundance (as measured in all earlier trials). This way the relative distribution of these 'accepted' pairs describe the marginal posterior distributions for $U_{MSY}$ and $MSY$.

The MCMC convergence diagnostics were examined using the BOA routine (Bayseian Output Analysis program for MCMC) in R (R package version 2.13). Visual inspections were made to evaluate how well the MCMC chain was mixed. The visual plot inspections included: autocorrelation plot-- to assess the autocorrelation between the draws of Marko chain; trace and density plots --to examine whether the Markov chain was stuck in certain areas of the parameter space; and running mean plot--to inspect plots of iterations against the mean of the draws up to each iteration. After model convergence, samples from the conditional distributions were used to summarize the posterior distribution of important management parameters, i.e., $MSY$, $U_{MSY}$, $S$, $U_{2010}/U_{MSY}$, *and* $E_{2010}/E_0$. The marginal posterior distributions, posterior means, posterior standard deviations, and posterior quintiles were generated for each parameter.

### 7.2.3.6 Sensitivity Analyses

Sensitivity runs involved selected parameters estimates and model configurations. Sensitivity runs were made concerning $CV$ values associated with the recruitment parameter and the index of abundance. The standard deviation ($SD$) for recruitment anomalies was assumed at 0.5 in the alternate models. This is within the range of 0.3 to 0.6 typical of fish populations (Walters et al. 2006); however, sensitivity runs were made with the recruitment $SD$ values of 0.25 and 0.75. The variance associated with the index of abundance was set at 0.04 (log scaled default value representing a $CV$ of around 0.2) in both alternate models. To explore the impact of a larger variance associated with the index of abundance, a sensitivity run was conducted with the variance set at 0.1—reflecting a noisy index, which allows for a wider parameter space in the MCMC computations.

The sensitivity analysis associated with model configuration included model runs using the trawl survey catch rate (lagged by one year) and the reduction fishery catch-per-set series as alternative tuning indices.

### 7.2.3.7 Retrospective Analyses

Not applicable to the SRA methodology.

### 7.2.3.8 Reference Point Estimation – Parameterization, and Uncertainty

The stochastic SRA is essentially an exploratory tool used to derive likely estimates of important management parameters, e.g. $U_{MSY}$ and $MSY$ under an assumption that maximum sustainable yield is the reference point against which the gulf menhaden status is determined. For fish populations in which most individuals vulnerable to the fishing gear have already had the opportunity to spawn, $U_{MSY}$ must approach unity. Alternatively, harvesting a population at an age before most individuals have spawned, results in lower sustainable harvest rate. In this analysis, the posterior distributions for $MSY$ and $U_{MSY}$ were estimated using MCMC routine. The measure of uncertainty associated with current stock condition ($E_{2010}/E_0$) and exploitation rate ($U_{2010}/U_{MSY}$) was determined from the marginal posterior distributions generated from the alternate-1 and alternate-2 simulation runs.

## 8.0 Base and Alternate Assessment Model Results

## 8.1 Results of Base BAM Model

### 8.1.1 Goodness of Fit

Goodness-of-fit was governed in the BAM assessment model by the likelihood components in the objective function (Table 7.2). The relative fit among the likelihood components was governed by the weighting terms and the assumed error levels for each data source (see Section 7.2.1.4). 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 (1948–2010; Figure 8.1) 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 8.2) indicate a good overall model fit to the observed data. The bubble plot for the reduction fishery (Figure 8.3) indicates that the model fit underestimates age-2 and overestimates ages-3 in the more recent years.

Observed and predicted coastwide juvenile abundance seine indices were compared for the base model run (1977–2010; Figure 8.4). The residual pattern suggests that the JAI index data did not fit well in the early 1990s and mid-2000s. The residual pattern also suggests that the model had a difficult time fitting high recruitment years. Visual examination of the fit suggests that the overall pattern fit reasonably well, with the BAM model capturing the some of the lows and highs observed in the index values.

The observed and predicted gillnet index (1986–2010; Figure 8.5) values appear to fit as well as the JAI index values. The pattern of fit is similar in that the general patterns are captured. The model has a more difficult time fitting estimates to observed values in the early to mid-1990s and for the last three years. The last two years of the gillnet index happen to be the highest values and the model has a difficult time fitting those extreme values. Patterns in the annual comparisons of observed and predicted proportion gillnet measurements at length for the gillnet index (Figure 8.6) indicate a good overall model fit to the observed data. The bubble plot for the gillnet index length compositions (Figure 8.7) indicates that the model fit underestimates the lower and higher ranges of lengths and overestimates the middle range of lengths.

### 8.1.2 Parameter Estimates (Include Precision of Estimates)

#### 8.1.2.1 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 over time were compared graphically in Figures 8.8, 8.9, and 8.10 for the time periods 1948-1979, 1980-1993, and 1994 to 2010, respectively. Selectivity parameters were estimated for ages one, three, and four for the earliest time period and for age-1 in the two more recent time periods. Priors were used for estimation of the selectivity parameters in the earliest years. Priors were changed to extreme high and low values, but had little influence on the model biological reference point estimates. Therefore, the model was robust to prior specifications. The big differences between the two time periods with logistic or flat-topped selectivity are in the amount of age-1 fish that are selected from year to year with the most recent years selecting age-1 individuals with a lower proportion.

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 JAI abundance index and gillnet adult abundance 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 -5.30 (0.005 back transformed) for the seine index with a standard error of 0.053, while the log-catchability of the gillnet index was -2.55 (0.078 back transformed) with a standard error of 0.107.

#### 8.1.2.2 Exploitation Rates

Total fishing mortality rates on ages-2 to -4+ (referred to as *F* age-2+) were calculated as the weighted average of age-specific *F*s for those ages and population number-at-age (Figure 8.11). Highly variable fishing mortalities were noted throughout the entire time series, with a steady increase in fishing mortality until the 1980s, fishing mortality at its highest in the 1980s, then a slight decline in fishing mortality, stabilizing for most of the 1990s to early 2000s, with a decline in the most recent few years. In the most recent decade, the weighted average fishing mortality rate on ages 2-4+ has generally been below 1.0 and has been below 0.5 in the three most recent years (Table 8.1). The estimate of fishing mortality rate for 2010 is 0.26 (Table 8.1).

The annual trend in full *F* by age classes is analogous to the one described for the average weighted *F* (Figure 8.12). However, *F* rates can vary substantially among age groups (Table 8.2). Selectivity on age-0 was assumed to be 0.0, while age-2 was fully selected in all years.

Average exploitation rate, defined as the proportion of the population removed annually by the fishery

$$\hat{C}_{ij}/\widehat{N}_{ij}$$

where $i$ = age and $j$ = year,

over the last decade was 4% for age-1, 26% for age-2, and 27-28% for age-3 and older.

### 8.1.2.3 Abundance, Fecundity, and Recruitment Estimates

The base BAM model estimated population numbers-at-age (ages 0-4+) for 1948–2010 (Figure 8.13 and Table 8.3). 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 high in the late 1940s and throughout the 1950s, declined to the lowest level in the 1980s, and has generally increased since then (Figure 8.14 and Table 8.4). The largest values of population fecundity were present in the 1940s, 1950s, and in 2009. The time period 1948-2010 produced a median population fecundity of 160 x $10^{12}$ ova with a minimum of 73 x $10^{12}$ and a maximum of 248 x $10^{12}$ and an interquartile range of 115 x $10^{12}$ to 193 x $10^{12}$. The estimate for population fecundity in 2010 was 187 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 8.15).

Age-0 recruits of gulf menhaden (Figure 8.16 and Table 8.5) were high during the late 1940s, the 1950s, and occurred randomly in later years, including the largest year-classes of 1984, 2007, and 2010. The annual estimated recruitment values relative to the median are shown in Figure 8.17. The most recent estimate for 2010 is quite high and likely will be modified in the future as more data from the cohort (age-1 in 2011, age-2 in 2012, etc.) are added to the analysis. The current estimate of recruits to age-0 in 2010 (293.6 billion) is above the 95th percentile and is the second 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 8.18).

### 8.1.3 Sensitivity Analyses

The results of the sensitivity runs suggest that the base BAM model is fairly robust to some of the induced changes (Figures 8.19-8.22). The sensitivity run (gmenhad-070) that modified age-1 maturity had an effect on the overall scale of the fecundity of the population, otherwise the model was robust to changes in age-1 maturity (Figure 8.21). Sensitivity run (gmenhad-068), which allowed the commercial reduction fishery selectivity to be dome-shaped, had an effect on the population fecundity and a very slight effect on R (Figures 8.21 and 8.20), with estimates of $F$ being fairly robust to the selectivity change.

The results of the sensitivity runs suggest that the base BAM model outputs could be scaled with some of the induced changes (Figures 8.19-8.22). The sensitivity runs that modified the natural mortality inputs (gmenhad-065 and gmenhad-066) resulted in different scales of the outputs for full $F$, recruitment, and fecundity, which in turn affected estimates of $F_{MSY}$ and the resulting $F/F_{MSY}$. Natural mortality having a scaling effect on the overall results was expected because of trade-offs with respect to how much of the total mortality is attributed to natural versus fishing mortality. Another group of sensitivity runs that had an effect on the scale of the outputs was the set with differing likelihood weights (both the sensitivity with all weights being equal, gmenhad-063, and the set of sensitivities changing the weight on the age composition data, gmenhad-082 to gmenhad-085; Figures 8.19-8.21). The effect that the weights had on the overall outputs of the model was not surprising because the weights give different data components more emphasis, so changing emphasis on one component allows for greater emphasis on other components, which the model is also trying to fit. The weights did have an effect on the estimate of $F_{MSY}$ as well, which in turn affected $F/F_{MSY}$ (Figure 8.22).

The results of some of the sensitivity runs resulted in changes in the overall trends of outputs when compared to the base run of the BAM model (Figures 8.19-8.22). The sensitivity runs including the trawl juvenile abundance index (gmenhad-073 and gmenhad-081) resulted in changes to the recruitment and fecundity of the population during the late 1960s and 1970s (Figures 8.20 and 8.21). Because of the additional years of data on recruitment, it was expected that the model would predict differences in recruitment and fecundity in the 1960s and 1970s. In addition, the use of the trawl index led to problems estimating $F_{MSY}$ (Table 8.6). The addition of the commercial reduction fishery-dependent index also led to changes in the trends of full F and led to difficulty in estimating $F_{MSY}$ (Figures 8.19 and 8.22). The sensitivity run using the Ricker version of the stock-recruitment curve also led to different trends in recruitment and fecundity over time (Figures 8.20 and 8.21). With the Ricker stock-recruitment curve, the model wanted to start with a low abundance and biomass and then increase from there; however, this is an unrealistic trajectory for the population given that we know the fishery started around the end of World War II. In addition, the sensitivity run with the Ricker stock-recruitment curve was unable to estimate $F_{MSY}$. Finally, the sensitivity run, which used the version of the gillnet index that included all states and all mesh sizes, led to different trends in full $F$, fecundity, and recruitment over time, and had difficulty estimating $F_{MSY}$.

Even with the differences in the sensitivity runs, for those that estimated $F_{MSY}$, none of the runs resulted in overfishing or overfished conditions with respect to stock status (Table 8.6).

### 8.1.4 Retrospective Analyses

No major patterns or biases in the results of a retrospective analysis over time were present (Figures 8.23-8.25). The results indicate that the terminal full fishing mortality rate is fairly stable (Figure 8.23). The resulting recruitment and fecundity do not show consistent biases or patterns (Figures 8.24 and 8.25; Table 8.6). However, the magnitude of stock status outcomes varies considerably in this set of retrospective model runs. In particular, the ratio of full fishing mortality to fishing mortality at $MSY$ ($F/F_{MSY}$) in the terminal year showed large year-to-year variations (Figure 8.26). When 2008 or 2009 were the terminal year, the model could not estimated $F_{MSY}$, and for other years, $F_{MSY}$ was estimated much higher than in the base run ending in 2010.

### 8.1.5 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 8.1.3 and 8.1.4), and by using a Monte Carlo bootstrap procedure. The parametric bootstrap procedure was run for 4,000 iterations. For some iterations, $F_{MSY}$ was not estimable; if this was true, then that particular iteration was not included in the results. About 15% of runs did not estimate $F_{MSY}$ and were not included in the analysis of the results. The resulting estimates from these runs, which were described above, have been summarized in Figures 8.14, 8.16 and 8.27 and Tables 8.4, 8.5, and 8.7, showing the 95% confidence region. In general, the bootstrap results are not symmetrical distributions about the base run results because the some of the uncertainty specifications were not symmetrical.

### 8.1.6 Reference Point Results – Parameter Estimates and Sensitivity

Fecundity-per-recruit and yield-per-recruit (mt) estimates as a function of full fishing mortality rates are shown in Figures 8.28 and 8.29. These plots are offered as a reference for other fishing mortality rates. For example, the terminal year fishing mortality rate estimate ($F_{2010}$) of 0.257 is equivalent to an $F_{74\%}$ mortality rate, and the $F_{MSY}$ estimate of 1.46 from the base BAM model is equivalent to an $F_{31\%}$ mortality rate (Figure 8.28).

The base BAM model estimates for the benchmarks and terminal year values are indicated in Table 8.8. This table also indicates the values for some per-recruit-based benchmarks of $F_{40\%}$, $F_{30\%}$, and $F_{25\%}$. The base BAM model estimated the stock status based on the $F_{MSY}$ estimators. The results suggest that the current stock status is not overfished ($\mathrm{SSB}_{2010} > 0.5*\mathrm{SSB}_{MSY}$ or $FEC_{2010} > 0.5*FEC_{MSY}$) and overfishing is not occurring (geometric mean of $F_{2008\text{-}2010}/F_{MSY} < 1.0$; Table 8.8). Additionally, the $SSB_{2010}/SSB_{MSY} > 1.0$ meaning that the population fecundity is above the target.

The entire time series of estimates of full fishing mortality over $F_{MSY}$ and $\mathrm{SSB}/\mathrm{SSB}_{\mathrm{MSY}}$ are shown in Figures 8.30 and 8.31, and a phase plot of the last 27 years of estimates is shown in Figure 8.32. The history of fishing mortality rates in Figures 8.30 and 8.32 suggests that overfishing may have occurred in the 1980s. The population has never been considered overfished and has not been below $0.5*SSB_{MSY}$ during the entire time series.

The uncertainty in the terminal year stock status indicators were expressed using the results of the 4,000 bootstrap runs of the base BAM model, although about 15% of runs were excluded because of difficulty estimating $F_{MSY}$. The results indicate that the fecundity estimates for the terminal year are well above the limit and target, with not a single bootstrap estimate falling below 1.0 (Figures 8.33-8.35). The results for the 2010 fishing mortality rate suggests that the base run estimate is below the limit of $F_{MSY}$ with none of the bootstrap runs exceeding the $F_{MSY}$ limit in the most recent years (Figures 8.33-8.35).

The estimation of $F_{MSY}$ was not stable and relied heavily on the 2008 and 2009 data points for estimation in the retrospective analyses. In addition, $F_{MSY}$ could not be estimated for about 15% of bootstrap runs. In the MCB runs, the stock-recruitment parameters, in particular steepness, often hit a bound, which led to the inability to estimate $F_{MSY}$. Even with the difficulty in estimating $F_{MSY}$ for some runs, the panel decided to use $F_{MSY}$ based benchmarks for the assessment because the majority of the runs estimated $F_{MSY}$, using the $F_{MSY}$ based benchmarks reflects the federal standard, and the stock-recruitment curve was well defined.

## 8.2 Results of Alternate Model (Production Model — ASPIC)

### 8.2.1 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.

Fit to the base model (Figure 8.38) reflects a compromise between fitting the two indices. The high points (2008 and 2009) in the gillnet index appear to be influential in generating an increasing trend in estimated abundance at the end of the time series. In contrast, the two high points in the seine index (in the mid-1980s) are less well fit for two reasons: their position in the center of the series gives them less leverage, and the higher *CV*s of the seine index gives it less influence on the overall fit.

Fit to the Fox model (not shown) was quite similar to fit to the base run. The objective function (weighted SSE) from the Fox model was marginally higher than that from the base run (4.20 vs. 4.16); i.e., the fit was slightly worse.

Fit to the sensitivity run with trawl, rather than seine, juvenile index was not markedly different from the base run (Figure 8.39). The two objective function values are not directly comparable because of the different lengths of the JAIs.

Fit to the sensitivity run with reduction, rather than gillnet, adult index (Figure 8.40) was quite different from the base run, in large part because the pattern of abundance in the reduction index is quite different from that in the gillnet index. Again, objective function values are not directly comparable because of the different series lengths.

### 8.2.2 Parameter Estimates

The parameter estimates of most interest from base and sensitivity runs are listed in Table 8.9. Estimates from the base run are given along with estimated precision in Table 8.10.

***Analyst's comments:*** Estimates of $F_{MSY}$ are smaller than one might expect for a species with rapid growth and maturity. Partly, that is because estimates are not full F in numbers (as in BAM), but ponderal *F* averaged over the population. Nonetheless, it appears that the production model had a difficult time scaling the population. This is not unusual when indices do not agree completely or do not have sufficient contrast.

The bootstrap appears to underestimate uncertainty in this application. The reason for that is not clear.

#### 8.2.2.1 Catchability Estimates

Catchability estimates appear in Table 8.10. They are directly influenced by the scaling issue mentioned in the preceding paragraph.

#### 8.2.2.2 Biomass and Fishing-Mortality Estimates

Estimates of relative biomass and fishing mortality (i.e., stock and fishery status) are emphasized, because they sidestep the scaling issue by integrating out the uncertainty in catchability. Also, they are of direct management interest.

For the base run, time trajectories are given graphically in Figure 8.41. Tables of results can be found in the ASPIC output files.

Most sensitivity runs estimated status trajectories very similar to those from the base run. The sensitivity run most different was the one using the reduction CPUE index instead of the gillnet adult abundance index (Figure 8.42).

Estimated status trajectories were insensitive to assumption about starting biomass relative to *K* (Figure 8.43). In comparing sensitivity runs 108–110, a few patterns were apparent (Figure 8.44). Because the starting assumption was based on the ratio *B*/*K*, but the plots were based on the ratio

$B/B_{MSY}$, the Fox model appears to start at a higher level than the others (Figure 8.44, top, triangles). As noted previously, run 110 (which used the reduction index) was the most different from other runs, and was markedly less optimistic about biomass status and fishery status (Figure 8.44, '×' symbols). Otherwise, estimated trajectories were relatively insensitive to the factors considered.

### 8.2.4 Retrospective Analyses

Results of the retrospective analysis are given in Figure 8.45.

### 8.2.5 Reference Point Results – Parameter Estimates and Sensitivity

See Tables 8.9 and 8.10.

## 8.3 Results of Alternate SRA Model

### 8.3.1 Goodness of Fit

The estimated trends in exploitable biomass were contrasted with the observed catch rates from the gill net and reduction fishery indices to help estimate the likely management parameters $U_{MSY}$ and MSY. Fits of the estimated exploitable biomass to the gill net index (alternate-1 model runs, left panel in Figure 8.46 and to the reduction fishery index (alternate-2 model runs, right panel in Figure 8.46 reflected the patterns observed in these indices.

The MCMC visual diagnostic showed no evidence that the parameters estimated did not converge in any of the simulation runs. The diagnostic results for one of the four simulation runs (e.g., the model run with $U$ input parameter set at 0.4) from each alternate model are presented in Appendices B.1. and B.2.

### 8.3.2 Exploitation Rates and Abundance (Biomass) Estimates

The trajectories of exploitation rate (*U*) and exploitable biomass (*vul_B*) from the two alternate models are shown in Figure 8.47. The exploitation rate estimates increased gradually during 1948-1994 with peak values during 1985-1994 in both models. This was followed by a sharp decline in *U* during 1995-2008 in the alternate-1 model runs and a slower decline in *U* during the same period in the alternate-2 model runs. Both models showed a slight increase in *U* during 2009-2010. Exploitation rates were estimated at low levels (an annual average of <0.05) prior to 1948 in both models. The *U* increased slowly during 1950's, 1960's, and 1970's with estimates between 0.06 and 0.2 $yr^{-1}$ based on the alternate-1 model runs and estimates between 0.09 and 0.4 $yr^{-1}$ based on the alternate-2 model runs. The *U* increased rapidly during 1980's and 1990's, reaching average values between 0.52 and 0.66 $yr^{-1}$ based the alternate-1 model runs and average values between 0.35 and 0.55 $yr^{-1}$ based on the alternate-2 model runs. After 1995, all trajectories showed a gradual decline in *U* to average values between 0.28 and 0.38 $yr^{-1}$ based on the alternate-1 model runs and average values between 0.29 and 0.46 based on the alternate-2 model runs.

The estimated trends in exploitable biomass were different from the two alternate models, especially for recent years (Figure 8.47). The estimates of exploitable biomass were high in the early period in both models varying between 2 to 2.5 million mt during 1873-1980 based on the alternate-1 model runs and between 1.9 and 2.6 million mt during 1873-1960 based on the alternate-2 model. The trajectories from the alternate-1 model showed a gradual decline in biomass during 1980's and 1990's, reaching low biomass levels (0.8-0.9 million mt) in the mid- 1990's. Similarly, the trajectories from the alternate-2 model runs showed a decline in biomass from the mid-1960s to mid-1990s. The exploitable biomass estimates since the mid-1990s show an increasing trend based on the alternate-1 model runs and a flat trend based on the alternate-2 model runs (Figure 8.47, left panels). The estimates of exploitable biomass and exploitation rates from the SRA model runs (alternate-1 and alternate-2), BAM model runs (base run and sensitivity runs using the coast-wide gill net index and the reduction fishery index), and ASPIC model runs (sensitivity runs based on the coast wide gill net index and the reduction fishery index) are shown in Figures 8.48 and 8.49.

### 8.3.3 Sensitivity Analyses

Model results from the alternate-1 and alternate-2 simulation runs were fairly robust to the choices of the standard deviation values associated with the recruitment parameter (Figures 8.50 and 8.51) or the CVs associated with the tuning indices (Figures 8.52 and 8.53). The exploitable biomass trajectories generated from the sensitivity runs using alternative tuning indices are shown in Figure 8.54. The simulations run using the gill net index (alternate-1 model) showed an increasing trend in biomass for recent years while the biomass trends have been generally flat from the simulation runs based on the reduction fishery catch per vessel-ton-weeks (alternate-2) index, or the reduction fishery catch-per-set index, or the trawl survey index. Despite the differences in the trends and magnitude of exploitable biomass from these sensitivity runs, the management parameters estimates, i.e., $MSY$, $U_{MSY}$, $E_{2010}/E_0$, and $U_{2010}/U_{MSY}$, were fairly robust to the choices of the tuning index (Tables 8.11 and 8.12).

### 8.3.4 Retrospective Analyses

Not applicable to the SRA.

### 8.3.5 Reference Point Results and Uncertainty Analysis

The MCMC posterior mean and quantile estimates generated from the alternate-1 and alternate-2 simulations runs for important management parameters ($U_{MSY}$, $MSY$, $U_{2010}/U_{MSY}$, and $E_{2010}/E_0$) are illustrated in Tables 8.11 and 8.12. The estimates of $U_{MSY}$ were high from both alternate model runs, with posterior mean values estimated between 0.70 $\text{yr}^{-1}$ and 0.76 $\text{yr}^{-1}$. This may reflect the life history attributes of gulf menhaden (i.e., short-lived, early maturity, fast growth, and high natural mortality), which tend to predispose gulf menhaden toward high values of $F_{MSY}$ ($U_{MSY}$). The MCMC posterior sample distributions for $MSY$ estimated from the two alternate model runs are shown in Figures 8.55 and 8.56. The uncertainty associated with $MSY$ and $U_{MSY}$ was generally larger for model runs parameterized with lower values of current exploitation rate. The posterior mean estimates for *MSY* varied between 750,000 and 870,000 mt based on the alternate-1 model runs and varied between 690,000 and 900,000 mt based on the alternate-2 model runs (Tables 8.11 and 8.12). The annual landings in recent years (dotted line in Figures 8.55 and 8.56, left panels) have been below the MSY values estimated from the alternate-1 and alternate-2 simulations runs. The MCMC posterior distributions for $U_{2010}/U_{MSY}$ and $E_{2010}/E_0$ generated from the two alternate model runs are shown in Figures 8.57 and 8.58. The posterior mean estimates varied between 0.4 and 0.66 for $U_{2010}/U_{MSY}$ and varied between 0.39 and 0.76 for $E_{2010}/E_0$ based on alternate-1 and alternate-2 simulation runs (Tables 8.11 and 8.12). The control plot (MCMC posterior distributions of $E_{2010}/E_0$ vs $U_{2010}/U_{MSY}$) indicated that the gulf menhaden stock would not be considered overfished and not undergoing overfishing (Figure 8.59).

## 9.0 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. The biomass limit for an overfished menhaden stock has previously been proposed as 0.5*SS$B_{MSY}$ (Vaughan et al. 2007). The suggested target for spawning biomass (or $FEC$) should be near $B_{MSY}$ (or its proxy). The target level chosen for fishing mortality is less clear, other than the stipulation that $F_{target}$ be sufficiently below the $F_{limit}$.

## 9.1 Current Overfishing, Overfished/Depleted Definitions

None currently, but were proposed in Vaughan et al. (2007).

## 9.2 Discussion of Alternate Reference Points

### 9.2.1 $F_{MSY}$ 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 is as well defined as many other stocks. In addition, the relatvely small, consolidated nature of the fishing fleet makes management more responsive to current conditions than is typical for exploited stocks and will reduce the lag between detected recruitment reductions and management response. Because of the well defined stock-recruitment curve, even though gulf menhaden are short lived, and the nature of the fishery, the panel proposed using the $F_{MSY}$ based benchmarks for management decisions.

### 9.2.2 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 popualtions 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.

## 9.3 Stock Status Determination

### 9.3.1 Overfishing Status

Full $F/F_{MSY}$ for the terminal year was less than 1 (Figure 8.30). Hence, based on this criterion, overfishing is not occurring. A range of $F/F_{MSY}$ values are shown based on the sensitivity runs (Table 8.6), with none suggesting overfishing. Additionally, none of the MCB runs resulted in a status determination of overfishing (Figure 8.30).

### 9.3.2 Overfished Status

$SSB/SSB_{limit}$ and $SSB/SSB_{target}$ for the terminal year were greater than 1 (Figure 8.31). Hence, based on this criterion, the stock is not overfished. The terminal year value is well above the target (ratio of 3.35). The bootstrapped values of $SSB$ fall completely in the region that is considered not to be overfished. None of the sensitivity runs suggest the stock is overfished (Table 8.6).

### 9.3.3 Control Rules

The phase plot shows the recent history of status variables relative to their benchmarks (Figure 8.32). In the most recent 23 years, full $F$ has not exceeded $F_{MSY}$, thus overfishing is not a concern. A phase plot for the terminal year based on 4,000 bootstrapped experiments demonstrates the uncertainty relative to these control rules in the terminal year (Figure 8.35). The stock has never been below $SSB_{\text{target}}$. A $F_{target}$ has not been defined for this fishery, but $F$ values associated with a few options have been provided in Table 8.8. An $F_{target}$ of $0.75*F_{MSY}$ was shown in Figures 8.31 and 8.35 as an example of a possible target value.

### 9.3.4 Uncertainty

Uncertainty of the status of the stock relative to the two benchmarks was investigated using several approaches in line with the recommdations 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 8.6). Next sensitivity of the estimates was investigated based on a bootstrapped analysis within the BAM model. Additionally, we used the stochastic SRA model and ASPIC surplus production model, based on different approaches, to interpret the status of gulf menhaden. Both stochastic SRA (although SRA used a different gillnet index) and ASPIC resulted in the same status determinations as did the BAM model (Figure 9.1 is a comparison of ASPIC and BAM).

## 10.0 Research Recommendations

Research recommendations are divided into two categories: data and modeling.

### 10.1 Data Needs

*Collection of structures from gillnet surveys* – Need to start collecting scales from gulf menhaden captured during the state gillnet surveys. Collection of scales would allow for the age of individuals to be determined in order to provide gillnet survey age composition data for the stock assessment.

*Adult Monitoring Survey* - Need to expand existing sampling protocols or develop additional protocols to monitor adult populations that specifically target adult menhaden inshore. Aerial surveys may be useful tools with ground-truthing for size and age.

*Standardized Juvenile Index Sampling* - Design and implement a survey dedicated to determining menhaden recruitment in the rivers and upper bays of the northern Gulf of Mexico.

*Maturity and Fecundity* - 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, and sex ratios. Any study needs to reinvestigate whether gulf menhaden are determinant or indeterminant spawners.

*Understanding Predator/Prey Relations* - Expand the diet and stable isotope database to determine the trophic role of gulf menhaden in the northern Gulf of Mexico. Investigate fatty acids profiles as an additional more specific indicator of important prey items of gulf menhaden.

Most data available for *Brevoortia spp*. feeding behavior is based on examination of Atlantic menhaden (*B. tyrannus*). One key research need is that data on gulf menhaden feeding be collected to improve the specificity of ecosystem models. This includes direct analysis of diet, as well as examinations of feeding behavior, in response to key prey items. Direct diet enumeration is difficult due to the planktonic nature of the prey, but biochemical techniques such as analysis of stable isotope ratios (Litvin and Weinstein 2004, Rooker et al. 2006) and fatty acid profiles (Rooker et al. 1998), provide valuable tools for diet analysis of filter feeders. These techniques can also be used to examine the role of gulf menhaden as a prey item for higher trophic level piscivores, which will allow for a more precise inclusion of menhaden in food web models of the Gulf of Mexico. An emphasis on quantifying the trophic role of menhaden in the Gulf of Mexico is an important step in the move towards ecosystem-based management.

*Genetics* - There is a need for further research on gulf menhaden stock structure, with an emphasis on increased genetic sampling (i.e. larger nuclear DNA marker data sets). More specifically, priority areas should include:

1. 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.

2. Identification of menhaden-specific nuclear DNA markers (preferably microsatellites or SNP's) using a lab-based DNA library screening technique.

3. Evaluation of the markers identified in (1) and (2) for appropriateness in population genetic studies of gulf menhaden.

4. Reassessment of gulf menhaden samples throughout the range of the species using a larger, more informative genetic panel of markers than that described in Anderson (2006).

*Tagging Studies* - Re-institute the gulf menhaden tag/recovery study. Many more tools exist today to simplify tag/recapture of fishes, and an updated tag/recapture study would allow for the estimation of natural mortality. Generally, natural mortality is one of the most difficult values in a stock assessment to determine, thus empirical evidence of the natural mortality rate would be beneficial. In addition, redoing the natural mortality study of Ahrenholz (1981) would provide information on whether or not the natural mortality rate is changing through time and whether it is increasing or decreasing.

## 10.2 Further Analyses and Modeling Approaches

*Fishery-independent data* – Further evaluation of the available fishery-independent data and exploration of ways to combine the data from each state in order to provide a single coastwide index would benefit the stock assessment by providing information on trends in abundance over time.

*Environmental factors* – Exploration of environmental factors that play a crucial role in gulf menhaden recruitment dynamics and catchability (both fishery-dependent and fishery-independent) would be beneficial. Relationships related to recruitment could be applied to the stock-recruitment curve in the model to better define the number of recruits produced each year. The effects that environmental factors have on catchability of different fishery-independent and fishery-dependent gears would provide information to the model on if catchability is changing over time and how, which will lead to better estimates of abundance and trajectory over time.

Establish additional research of simulation models to incorporate the fishery into ecological scenarios which may include MSVPAs, ECO-SIM, EcoPath, etc. to get better estimates of natural mortality, which would account for predator-prey dynamics.

## 11.0 Minority Opinion (if applicable)

### 11.1 Description of Minority Opinion

### 11.2 Justification from Majority (on why not adopted)

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## 13.0 Tables

**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 (EC)** |
|---|---|---|
| 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

**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, 1964-2010. Intervals represent their mid-point.

| Fork Length (mm) | Age | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | Total |
| 55 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 65 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 5 |
| 75 | 6 | 17 | 0 | 0 | 0 | 0 | 0 | 23 |
| 85 | 54 | 99 | 1 | 0 | 0 | 0 | 0 | 154 |
| 95 | 107 | 554 | 0 | 0 | 0 | 0 | 0 | 661 |
| 105 | 182 | 1,541 | 1 | 0 | 0 | 0 | 0 | 1,724 |
| 115 | 239 | 4,334 | 2 | 0 | 0 | 0 | 0 | 4,575 |
| 125 | 289 | 11,695 | 16 | 2 | 1 | 0 | 0 | 12,003 |
| 135 | 148 | 28,334 | 19 | 0 | 0 | 0 | 0 | 28,501 |
| 145 | 18 | 58,788 | 86 | 0 | 0 | 0 | 0 | 58,892 |
| 155 | 0 | 85,294 | 2,137 | 3 | 0 | 0 | 0 | 87,434 |
| 165 | 0 | 68,449 | 22,201 | 12 | 0 | 0 | 0 | 90,662 |
| 175 | 0 | 29,017 | 53,274 | 122 | 2 | 0 | 0 | 82,415 |
| 185 | 0 | 6,282 | 63,683 | 1,003 | 8 | 0 | 0 | 70,976 |
| 195 | 0 | 566 | 39,676 | 5,771 | 85 | 1 | 0 | 46,099 |
| 205 | 0 | 21 | 11,632 | 8,558 | 490 | 6 | 0 | 20,707 |
| 215 | 0 | 7 | 1,865 | 3,936 | 620 | 32 | 0 | 6,460 |
| 225 | 0 | 1 | 226 | 1,038 | 320 | 28 | 3 | 1,616 |
| 235 | 0 | 0 | 25 | 208 | 75 | 12 | 3 | 323 |
| 245 | 0 | 0 | 7 | 38 | 12 | 1 | 1 | 59 |
| 255 | 0 | 0 | 3 | 9 | 5 | 3 | 0 | 20 |
| 265 | 0 | 0 | 1 | 4 | 1 | 0 | 0 | 6 |
| 275 | 0 | 1 | 1 | 3 | 0 | 0 | 0 | 5 |
| 285 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 3 |
| 295 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 3 |
| 305 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 2 |
| Total | 1,047 | 295,002 | 194,857 | 20,714 | 1,619 | 83 | 7 | 513,329 |
| Percent | 0.20% | 57.47% | 37.96% | 4.04% | 0.32% | 0.02% | 0.00% | 100.00% |

**Table 3.4** Statistics for gulf menhaden fork length at age, 1964 – 2010.

| Age | N | Obs FL (mm) | SD (mm) | CV = SD/P | Pred FL (mm) |
|---|---|---|---|---|---|
| **0.5** | 1,047 | 110.3 | 15.0 | 0.126 | 119 |
| **1** | 295,002 | 148.9 | 15.0 | 0.098 | 152 |
| **2** | 194,857 | 178.2 | 11.7 | 0.064 | 183 |
| **3** | 20,714 | 199.4 | 10.5 | 0.052 | 203 |
| **4** | 1,619 | 209.0 | 10.6 | 0.049 | 215 |
| **5** | 83 | 217.1 | 11.1 | 0.050 | 223 |
| **6** | 7 | 232.0 | 7.9 | 0.034 | 229 |
| **Sum/ Average** | 513329 | | 11.7 | 0.062 | |

**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 | | |

**Table 3.5** (cont.)

| **Year** | **0** | **1** | **2** | **3** | **4** | **5** | **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 | |

**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 | | |

**Table 3.6** (cont.)

| **Year** | **0** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|---|
| 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 | |

**Table 3.7** Correlation analysis (Pearson correlation coefficients) of 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.

| Source | Relationship | Years | Gears | FL (mm) | SL (mm) | TL (mm) | N | $R^2$ | Intercept | Slope |
|---|---|---|---|---|---|---|---|---|---|---|
| **Alabama** | TL = f(SL) | 2011 | Gillnet, Trawl, BPL | - | 21-201 | 25-258 | 90 | 0.9994 | -3.270 | 1.299 |
| **Louisiana** | TL = f(SL) | 2011 | Gillnet, Trawl, Seine | - | 23-192 | 27-247 | 409 | 0.9962 | -1.389 | 1.298 |
| **Mississippi** | TL = f(SL) | 2011 | Gillnet, Trawl, BPL | - | 19-246 | 23-296 | 235 | 0.9983 | 1.049 | 1.237 |
| **Texas** | TL = f(SL) | 1975-1978 & 2011 | Gillnet, 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 | Gillnet, Trawl, BPL | 23-222 | 21-201 | - | 90 | 0.9996 | -0.956 | 1.109 |
| **Louisiana** | FL = f(SL) | 2011 | Gillnet, Trawl, Seine | 26-206 | 23-192 | - | 409 | 0.9964 | 0.378 | 1.088 |
| **Mississippi** | FL = f(SL) | 2011 | Gillnet, 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 | Gillnet, Trawl, BPL | 23-222 | - | 25-258 | 90 | 0.9996 | 1.869 | 0.854 |
| **Louisiana** | FL = f(TL) | 2011 | Gillnet, Trawl, Seine | 26-206 | - | 27-247 | 410 | 0.9974 | 1.571 | 0.838 |
| **Mississippi** | FL = f(TL) | 2011 | Gillnet, 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 and annual estimated parameters obtained from weight-length and length at age regressions from biological sampling of gulf menhaden, 1964-2010.

| **Year** | **Weight-Length** | | | | **Von Bertalanffy Curve** | | | |
|---|---|---|---|---|---|---|---|---|
| | **n** | **a** | **b** | **RMSE** | **n** | $L_\infty$ | ***K*** | $t_0$ |
| 1964 | 12376 | -12.695 | 3.365 | 0.0095 | 12260 | 236.9 | 0.429 | -0.958 |
| 1965 | 15673 | -12.481 | 3.329 | 0.0081 | 15185 | 427.8 | 0.128 | -1.790 |
| 1966 | 12705 | -11.592 | 3.157 | 0.0070 | 12429 | 284.2 | 0.269 | -1.303 |
| 1967 | 14401 | -11.270 | 3.085 | 0.0083 | 14065 | 234.2 | 0.506 | -0.516 |
| 1968 | 15831 | -11.668 | 3.167 | 0.0076 | 15273 | 284.1 | 0.316 | -0.911 |
| 1969 | 15044 | -11.374 | 3.107 | 0.0087 | 14764 | 426.4 | 0.121 | -2.148 |
| 1970 | 10531 | -11.959 | 3.224 | 0.0056 | 10402 | 231.3 | 0.537 | -0.535 |
| 1971 | 7848 | -12.192 | 3.269 | 0.0080 | 7654 | 239.5 | 0.474 | -0.691 |
| 1972 | 9975 | -11.756 | 3.180 | 0.0080 | 9886 | 222.5 | 0.674 | -0.372 |
| 1973 | 8954 | -11.663 | 3.181 | 0.0078 | 8953 | 343.2 | 0.198 | -1.592 |
| 1974 | 10085 | -10.793 | 2.995 | 0.0097 | 10086 | 227.9 | 0.800 | -0.066 |
| 1975 | 9528 | -11.562 | 3.144 | 0.0078 | 9527 | 565.7 | 0.092 | -2.022 |
| 1976 | 13532 | -10.791 | 2.988 | 0.0077 | 13389 | 335.8 | 0.233 | -1.102 |
| 1977 | 14910 | -11.382 | 3.098 | 0.0060 | 14897 | 374.7 | 0.167 | -1.448 |
| 1978 | 12983 | -12.052 | 3.239 | 0.0058 | 12944 | 409.8 | 0.122 | -2.336 |
| 1979 | 11618 | -12.238 | 3.268 | 0.0053 | 11121 | 243.4 | 0.392 | -1.149 |
| 1980 | 9948 | -13.045 | 3.427 | 0.0229 | 9883 | 234.3 | 0.606 | -0.095 |
| 1981 | 10405 | -11.682 | 3.166 | 0.0100 | 10273 | 240.1 | 0.435 | -0.636 |
| 1982 | 10678 | -12.669 | 3.361 | 0.0110 | 10341 | 282.4 | 0.230 | -1.845 |
| 1983 | 14837 | -12.256 | 3.280 | 0.0082 | 14523 | 232.8 | 0.509 | -0.572 |
| 1984 | 15955 | -11.906 | 3.215 | 0.0072 | 15936 | 232.2 | 0.542 | -0.336 |
| 1985 | 13227 | -11.531 | 3.131 | 0.0075 | 13225 | 232.0 | 0.533 | -0.391 |
| 1986 | 16495 | -11.782 | 3.194 | 0.0061 | 16494 | 235.5 | 0.480 | -0.339 |
| 1987 | 16458 | -11.707 | 3.173 | 0.0056 | 16458 | 258.7 | 0.285 | -1.370 |
| 1988 | 12403 | -11.363 | 3.110 | 0.0113 | 12402 | 222.5 | 0.552 | -0.345 |
| 1989 | 13951 | -11.819 | 3.202 | 0.0072 | 13950 | 247.8 | 0.347 | -1.051 |
| 1990 | 11500 | -11.707 | 3.184 | 0.0117 | 11456 | 232.3 | 0.481 | -0.600 |
| 1991 | 11637 | -12.178 | 3.274 | 0.0082 | 11378 | 239.6 | 0.383 | -1.269 |
| 1992 | 15231 | -10.408 | 2.932 | 0.0095 | 14214 | 234.1 | 0.443 | -0.920 |
| 1993 | 15347 | -11.308 | 3.111 | 0.0116 | 14576 | 243.5 | 0.364 | -1.280 |
| 1994 | 16785 | -10.976 | 3.030 | 0.0072 | 16062 | 238.5 | 0.456 | -0.741 |
| 1995 | 14275 | -12.036 | 3.248 | 0.0077 | 13489 | 238.3 | 0.416 | -1.060 |
| 1996 | 13052 | -12.576 | 3.339 | 0.0177 | 12115 | 243.8 | 0.393 | -1.004 |
| 1997 | 10634 | -11.640 | 3.162 | 0.0058 | 9923 | 224.7 | 0.568 | -0.481 |
| 1998 | 10034 | -10.969 | 3.034 | 0.0053 | 9043 | 230.4 | 0.466 | -0.834 |
| 1999 | 11774 | -11.701 | 3.177 | 0.0057 | 10641 | 242.4 | 0.354 | -1.565 |

**Table 3.9** (Cont.)

| Year | Weight-Length | | | | Von Bertalanffy Curve | | | |
|---|---|---|---|---|---|---|---|---|
| | **n** | **a** | **b** | **RMSE** | **n** | $L_\infty$ | $K$ | $t_0$ |
| 2000 | 9588 | -10.027 | 2.833 | 0.0118 | 8383 | 230.1 | 0.466 | -0.851 |
| 2001 | 7351 | -10.896 | 3.027 | 0.0085 | 6222 | 247.7 | 0.301 | -2.184 |
| 2002 | 6611 | -11.339 | 3.097 | 0.0054 | 5597 | 227.3 | 0.520 | -0.736 |
| 2003 | 9239 | -11.142 | 3.056 | 0.0048 | 7839 | 238.1 | 0.420 | -0.795 |
| 2004 | 7655 | -11.850 | 3.204 | 0.0055 | 6644 | 224.0 | 0.450 | -0.908 |
| 2005 | 7202 | -11.041 | 3.046 | 0.0087 | 6206 | 244.9 | 0.278 | -2.042 |
| 2006 | 5763 | -11.359 | 3.105 | 0.0061 | 4698 | 210.7 | 0.577 | -0.631 |
| 2007 | 5151 | -11.782 | 3.192 | 0.0056 | 3989 | 218.5 | 0.506 | -0.829 |
| 2008 | 5877 | -12.256 | 3.284 | 0.0057 | 4663 | 210.6 | 0.644 | -0.643 |
| 2009 | 7419 | -10.871 | 3.007 | 0.0064 | 6193 | 251.8 | 0.253 | -2.569 |
| 2010 | 4530 | -11.065 | 3.048 | 0.0067 | 3678 | 212.2 | 0.689 | -0.313 |

**Table 3.10** Estimated fork lengths and weights for gulf menhaden calculated at middle of fishing year averaged over 2000-2010 (annual estimates), and female maturity at age from Lewis and Roithmayr (1981).

| Year | FL (mm) | Weight (g) | Maturity (%) |
|---|---|---|---|
| 0 | 118.7 | 31.9 | 0 |
| 1 | 152.4 | 70.4 | 0 |
| 2 | 183.1 | 126.1 | 100 |
| 3 | 202.8 | 174.6 | 100 |
| 4 | 215.5 | 211.8 | 100 |
| 5 | 223.7 | 238.4 | 100 |
| 6 | 229.0 | 256.7 | 100 |

**Table 3.11** Weight (g) at ages 1-6 on January 1 (start of fishing year) estimated from annual von Bertalanffy growth parameters presented in Table 3.9.

| Year | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1964 | 45.0 | 99.3 | 152.7 | 196.7 | 229.7 | 253.2 |
| 1965 | 39.8 | 90.5 | 162.7 | 253.1 | 357.7 | 471.9 |
| 1966 | 45.2 | 97.2 | 157.3 | 217.5 | 272.8 | 321.1 |
| 1967 | 38.1 | 94.9 | 147.8 | 187.8 | 215.1 | 232.8 |
| 1968 | 41.4 | 101.4 | 171.0 | 238.6 | 298.0 | 347.2 |
| 1969 | 47.6 | 94.2 | 155.5 | 228.7 | 310.4 | 397.8 |
| 1970 | 41.8 | 103.4 | 159.2 | 200.0 | 226.9 | 243.8 |
| 1971 | 43.6 | 104.6 | 163.4 | 209.9 | 243.0 | 265.4 |
| 1972 | 46.0 | 111.8 | 162.3 | 193.3 | 210.5 | 219.6 |
| 1973 | 54.9 | 116.8 | 194.3 | 279.7 | 366.6 | 450.5 |
| 1974 | 45.1 | 125.9 | 181.8 | 211.5 | 225.8 | 232.5 |
| 1975 | 50.7 | 108.6 | 190.7 | 295.4 | 420.2 | 561.5 |
| 1976 | 42.9 | 100.3 | 171.2 | 246.6 | 319.9 | 387.3 |
| 1977 | 36.3 | 82.7 | 144.6 | 216.9 | 294.6 | 373.5 |
| 1978 | 48.8 | 95.0 | 155.7 | 228.1 | 309.3 | 396.1 |
| 1979 | 48.4 | 99.2 | 149.2 | 191.5 | 224.4 | 248.8 |
| 1980 | 24.2 | 93.3 | 163.3 | 214.2 | 246.2 | 265.0 |
| 1981 | 34.4 | 87.0 | 140.8 | 185.7 | 219.4 | 243.3 |
| 1982 | 46.5 | 91.2 | 143.6 | 198.1 | 250.5 | 298.7 |
| 1983 | 39.2 | 98.7 | 155.0 | 197.9 | 227.3 | 246.4 |
| 1984 | 32.4 | 94.2 | 153.7 | 198.1 | 227.7 | 246.2 |
| 1985 | 33.1 | 90.0 | 143.4 | 183.0 | 209.4 | 226.1 |
| 1986 | 26.6 | 82.0 | 140.7 | 188.7 | 223.4 | 247.0 |
| 1987 | 39.0 | 80.6 | 127.0 | 172.0 | 212.4 | 246.7 |
| 1988 | 31.3 | 86.1 | 136.7 | 173.4 | 197.3 | 212.0 |
| 1989 | 39.4 | 87.5 | 139.1 | 186.2 | 225.3 | 256.2 |
| 1990 | 39.0 | 96.6 | 152.1 | 195.6 | 226.4 | 247.0 |
| 1991 | 53.9 | 106.0 | 156.9 | 200.0 | 233.7 | 258.8 |
| 1992 | 52.3 | 104.7 | 152.0 | 188.7 | 215.1 | 233.3 |
| 1993 | 55.3 | 106.8 | 157.3 | 200.6 | 235.1 | 261.3 |
| 1994 | 44.4 | 98.8 | 149.6 | 189.6 | 218.3 | 237.9 |
| 1995 | 52.0 | 107.7 | 161.3 | 205.2 | 238.4 | 262.2 |
| 1996 | 42.9 | 95.5 | 149.7 | 196.6 | 233.6 | 261.1 |
| 1997 | 40.5 | 99.3 | 150.4 | 186.1 | 208.6 | 222.2 |
| 1998 | 47.4 | 99.2 | 145.8 | 181.6 | 206.7 | 223.6 |
| 1999 | 60.7 | 108.8 | 154.9 | 194.2 | 225.6 | 249.6 |
| 2000 | 46.1 | 91.2 | 130.4 | 159.8 | 180.2 | 193.9 |
| 2001 | 75.9 | 119.5 | 160.8 | 196.9 | 226.8 | 250.8 |
| 2002 | 47.3 | 100.9 | 146.8 | 179.9 | 201.9 | 215.7 |
| 2003 | 38.1 | 86.0 | 133.0 | 171.9 | 201.2 | 222.2 |
| 2004 | 41.4 | 88.3 | 132.2 | 167.0 | 192.2 | 209.5 |
| 2005 | 55.3 | 92.1 | 128.9 | 162.6 | 191.7 | 216.0 |
| 2006 | 41.3 | 89.0 | 127.6 | 153.6 | 169.7 | 179.2 |
| 2007 | 44.9 | 94.1 | 136.9 | 168.3 | 189.4 | 203.0 |
| 2008 | 50.3 | 105.2 | 146.4 | 171.9 | 186.5 | 194.5 |
| 2009 | 66.3 | 101.5 | 136.2 | 168.0 | 195.9 | 219.5 |
| 2010 | 39.9 | 97.1 | 139.8 | 165.3 | 179.2 | 186.5 |

**Table 3.12** Weight (mm) at ages 1-6 on July 1 (middle of fishing year) estimated from annual von Bertalanffy growth parameters presented in Table 3.9.

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1964 | 33.3 | 71.4 | 126.9 | 176.1 | 214.6 | 242.5 | 262.0 |
| 1965 | 30.6 | 62.4 | 124.1 | 205.8 | 303.9 | 413.9 | 531.4 |
| 1966 | 34.6 | 69.6 | 126.8 | 187.8 | 245.9 | 297.9 | 342.3 |
| 1967 | 26.0 | 65.8 | 122.8 | 169.5 | 202.9 | 224.9 | 239.0 |
| 1968 | 29.8 | 69.3 | 135.9 | 205.6 | 269.5 | 323.9 | 368.0 |
| 1969 | 38.4 | 68.9 | 123.2 | 190.8 | 268.7 | 353.6 | 442.7 |
| 1970 | 28.5 | 72.0 | 133.0 | 181.5 | 215.0 | 236.4 | 249.5 |
| 1971 | 30.6 | 73.1 | 135.2 | 188.4 | 228.0 | 255.3 | 273.5 |
| 1972 | 30.5 | 79.6 | 139.7 | 179.9 | 203.2 | 215.8 | 222.4 |
| 1973 | 42.7 | 83.4 | 154.1 | 236.5 | 323.3 | 409.1 | 490.3 |
| 1974 | 26.3 | 86.9 | 157.7 | 199.2 | 220.0 | 229.8 | 234.3 |
| 1975 | 40.0 | 76.6 | 146.7 | 240.4 | 355.5 | 489.0 | 637.3 |
| 1976 | 31.8 | 69.3 | 134.7 | 208.8 | 283.8 | 354.5 | 418.2 |
| 1977 | 27.6 | 57.3 | 112.1 | 179.8 | 255.4 | 334.1 | 412.4 |
| 1978 | 39.7 | 69.9 | 123.7 | 190.6 | 267.8 | 352.1 | 440.7 |
| 1979 | 37.1 | 73.1 | 124.9 | 171.5 | 209.1 | 237.6 | 258.2 |
| 1980 | 12.6 | 56.0 | 130.2 | 191.4 | 232.2 | 256.9 | 271.1 |
| 1981 | 23.8 | 59.5 | 114.6 | 164.6 | 203.9 | 232.4 | 252.3 |
| 1982 | 37.2 | 67.5 | 116.9 | 170.9 | 224.7 | 275.3 | 320.7 |
| 1983 | 26.7 | 68.0 | 128.2 | 178.3 | 214.1 | 237.9 | 253.1 |
| 1984 | 20.2 | 62.0 | 125.5 | 178.0 | 214.5 | 238.0 | 252.5 |
| 1985 | 21.5 | 60.6 | 118.2 | 165.0 | 197.7 | 218.8 | 231.8 |
| 1986 | 16.3 | 52.4 | 112.2 | 166.3 | 207.6 | 236.4 | 255.5 |
| 1987 | 30.3 | 58.7 | 103.7 | 150.0 | 192.9 | 230.3 | 261.5 |
| 1988 | 20.0 | 57.9 | 112.9 | 156.8 | 186.7 | 205.6 | 217.0 |
| 1989 | 29.4 | 62.3 | 113.5 | 163.5 | 206.8 | 241.8 | 268.8 |
| 1990 | 26.9 | 66.9 | 125.6 | 175.6 | 212.5 | 237.8 | 254.4 |
| 1991 | 42.1 | 79.4 | 132.1 | 179.6 | 218.0 | 247.2 | 268.6 |
| 1992 | 40.0 | 78.5 | 129.5 | 171.7 | 203.1 | 225.1 | 240.1 |
| 1993 | 43.6 | 80.5 | 132.7 | 180.1 | 219.0 | 249.1 | 271.7 |
| 1994 | 32.3 | 71.1 | 125.3 | 171.1 | 205.2 | 229.0 | 245.0 |
| 1995 | 39.6 | 79.3 | 135.4 | 184.6 | 223.1 | 251.3 | 271.3 |
| 1996 | 31.7 | 68.1 | 123.2 | 174.4 | 216.3 | 248.4 | 271.8 |
| 1997 | 27.4 | 69.6 | 126.7 | 170.1 | 198.7 | 216.3 | 226.8 |
| 1998 | 35.4 | 73.1 | 123.7 | 165.1 | 195.3 | 216.1 | 229.8 |
| 1999 | 49.5 | 84.5 | 132.5 | 175.5 | 210.9 | 238.5 | 259.2 |
| 2000 | 35.3 | 68.8 | 112.0 | 146.3 | 171.0 | 187.7 | 198.8 |
| 2001 | 65.3 | 97.7 | 140.7 | 179.6 | 212.6 | 239.5 | 260.8 |
| 2002 | 34.8 | 74.2 | 125.4 | 165.0 | 192.1 | 209.6 | 220.5 |
| 2003 | 27.8 | 61.3 | 110.3 | 153.7 | 187.7 | 212.6 | 230.1 |
| 2004 | 30.9 | 64.5 | 111.2 | 150.9 | 180.7 | 201.7 | 215.9 |
| 2005 | 46.6 | 73.4 | 110.7 | 146.3 | 177.8 | 204.4 | 226.3 |
| 2006 | 29.8 | 65.5 | 109.9 | 142.0 | 162.7 | 175.1 | 182.3 |
| 2007 | 33.4 | 69.5 | 116.8 | 154.0 | 180.0 | 197.0 | 207.7 |
| 2008 | 36.5 | 78.7 | 127.9 | 160.8 | 180.3 | 191.1 | 197.0 |
| 2009 | 57.8 | 83.8 | 119.1 | 152.6 | 182.5 | 208.2 | 229.8 |
| 2010 | 26.3 | 69.2 | 120.8 | 154.3 | 173.3 | 183.5 | 188.7 |

**Table 3.13** Overall and annual estimates of fecundity (no. of maturing or ripe ova in billions) at ages 1-6 on January 1 (start of fishing year) by applying Eq. (4) to fork lengths at age on January 1.

| Year | Eggs per Ages for Female Gulf Menhaden | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| 1964 | 9,310 | 23,161 | 38,020 | 50,894 | 60,852 | 68,067 |
| 1965 | 7,720 | 20,105 | 39,791 | 66,601 | 99,636 | 137,605 |
| 1966 | 8,448 | 21,657 | 39,110 | 58,210 | 76,903 | 93,932 |
| 1967 | 7,075 | 22,273 | 38,862 | 52,492 | 62,257 | 68,759 |
| 1968 | 7,855 | 23,500 | 44,562 | 66,991 | 87,952 | 106,037 |
| 1969 | 9,294 | 21,812 | 40,772 | 65,957 | 96,602 | 131,641 |
| 1970 | 8,074 | 24,020 | 40,373 | 53,114 | 61,822 | 67,380 |
| 1971 | 8,615 | 24,348 | 41,351 | 55,631 | 66,195 | 73,483 |
| 1972 | 9,188 | 27,162 | 42,783 | 52,917 | 58,718 | 61,851 |
| 1973 | 10,122 | 25,417 | 47,259 | 73,668 | 102,448 | 131,694 |
| 1974 | 8,302 | 31,388 | 50,499 | 61,438 | 66,887 | 69,449 |
| 1975 | 10,185 | 26,047 | 52,154 | 89,510 | 138,212 | 197,648 |
| 1976 | 8,135 | 24,503 | 49,053 | 78,743 | 110,383 | 141,465 |
| 1977 | 7,080 | 19,862 | 39,982 | 66,398 | 97,379 | 131,056 |
| 1978 | 9,954 | 22,119 | 39,955 | 63,125 | 90,862 | 122,174 |
| 1979 | 10,391 | 24,331 | 39,507 | 53,133 | 64,133 | 72,468 |
| 1980 | 4,816 | 22,174 | 41,800 | 56,802 | 66,500 | 72,282 |
| 1981 | 6,401 | 19,909 | 35,899 | 50,373 | 61,802 | 70,159 |
| 1982 | 9,570 | 20,845 | 35,182 | 50,972 | 66,853 | 81,877 |
| 1983 | 7,692 | 22,931 | 39,107 | 52,201 | 61,492 | 67,638 |
| 1984 | 5,874 | 21,289 | 38,409 | 52,161 | 61,675 | 67,769 |
| 1985 | 6,243 | 21,518 | 38,301 | 51,818 | 61,236 | 67,321 |
| 1986 | 4,489 | 17,635 | 33,953 | 48,483 | 59,524 | 67,232 |
| 1987 | 7,392 | 17,956 | 31,283 | 45,328 | 58,633 | 70,406 |
| 1988 | 5,324 | 18,838 | 33,512 | 45,084 | 52,962 | 57,937 |
| 1989 | 7,230 | 18,982 | 33,275 | 47,351 | 59,674 | 69,717 |
| 1990 | 6,904 | 20,835 | 36,215 | 49,185 | 58,758 | 65,328 |
| 1991 | 10,585 | 23,594 | 37,548 | 50,055 | 60,193 | 67,925 |
| 1992 | 9,136 | 22,873 | 37,426 | 49,828 | 59,258 | 65,977 |
| 1993 | 10,052 | 22,850 | 37,031 | 50,148 | 61,099 | 69,688 |
| 1994 | 8,296 | 23,083 | 39,286 | 53,176 | 63,683 | 71,092 |
| 1995 | 10,001 | 23,829 | 38,581 | 51,452 | 61,526 | 68,927 |
| 1996 | 8,830 | 22,398 | 37,748 | 51,799 | 63,263 | 72,001 |
| 1997 | 7,601 | 22,869 | 38,026 | 49,370 | 56,817 | 61,389 |
| 1998 | 8,730 | 22,434 | 36,724 | 48,589 | 57,354 | 63,419 |
| 1999 | 12,299 | 25,058 | 38,570 | 50,845 | 61,040 | 69,049 |
| 2000 | 8,846 | 22,503 | 36,686 | 48,445 | 57,127 | 63,135 |
| 2001 | 15,164 | 27,114 | 39,653 | 51,381 | 61,585 | 70,052 |
| 2002 | 9,419 | 24,290 | 38,868 | 50,145 | 57,907 | 62,926 |
| 2003 | 7,201 | 20,208 | 35,159 | 48,665 | 59,421 | 67,389 |
| 2004 | 7,877 | 19,700 | 32,115 | 42,592 | 50,483 | 56,052 |
| 2005 | 10,773 | 20,634 | 31,671 | 42,563 | 52,493 | 61,083 |
| 2006 | 7,744 | 20,214 | 31,712 | 39,984 | 45,281 | 48,475 |
| 2007 | 8,597 | 21,106 | 33,281 | 42,765 | 49,371 | 53,703 |
| 2008 | 10,110 | 24,183 | 35,707 | 43,176 | 47,531 | 49,944 |
| 2009 | 14,042 | 24,338 | 35,553 | 46,606 | 56,803 | 65,796 |
| 2010 | 7,259 | 22,489 | 35,755 | 44,264 | 49,063 | 51,613 |

**Table 3.14** The unscaled Lorenzen age-specific estimates of *M* (Lorenzen 1996), and the Lorenzen scaled to the Hoenig estimate of *M* using the average weight at age from the entire time series. The Data Workshop participants suggested using the Lorenzen scaled to the Hoenig estimate of M as a sensitivity analysis run.

| Age | Lorenzen | Scaled to Hoenig |
|---|---|---|
| 0 | 1.28 | 1.07 |
| 1 | 1.01 | 0.84 |
| 2 | 0.84 | 0.70 |
| 3 | 0.76 | 0.64 |
| 4 | 0.72 | 0.60 |
| 5 | 0.70 | 0.58 |
| 6 | 0.68 | 0.57 |

**Table 3.15** 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 Data Workshop participants. The Data Workshop 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 | 1.67 | 1.38 | 1.93 |
| 1 | 1.31 | 1.09 | 1.52 |
| 2 | 1.10 | 0.91 | 1.27 |
| 3 | 1.00 | 0.82 | 1.15 |
| 4 | 0.94 | 0.78 | 1.09 |
| 5 | 0.91 | 0.75 | 1.05 |
| 6 | 0.89 | 0.73 | 1.02 |

**Table 3.16** Lorenzen age-specific estimates of *M* from 1964 to 2010 based on weight at age from year to year. These are the unscaled values.

| **Year** | **0** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|---|
| 1964 | 1.27 | 1.00 | 0.84 | 0.76 | 0.72 | 0.69 | 0.68 |
| 1965 | 1.30 | 1.05 | 0.85 | 0.73 | 0.65 | 0.59 | 0.54 |
| 1966 | 1.25 | 1.01 | 0.84 | 0.75 | 0.69 | 0.65 | 0.62 |
| 1967 | 1.37 | 1.03 | 0.85 | 0.77 | 0.73 | 0.71 | 0.69 |
| 1968 | 1.31 | 1.01 | 0.82 | 0.73 | 0.67 | 0.63 | 0.61 |
| 1969 | 1.21 | 1.01 | 0.85 | 0.74 | 0.67 | 0.62 | 0.58 |
| 1970 | 1.33 | 1.00 | 0.83 | 0.76 | 0.72 | 0.70 | 0.69 |
| 1971 | 1.30 | 1.00 | 0.83 | 0.75 | 0.70 | 0.68 | 0.67 |
| 1972 | 1.30 | 0.97 | 0.82 | 0.76 | 0.73 | 0.72 | 0.71 |
| 1973 | 1.17 | 0.96 | 0.79 | 0.70 | 0.63 | 0.59 | 0.56 |
| 1974 | 1.36 | 0.95 | 0.79 | 0.73 | 0.71 | 0.70 | 0.70 |
| 1975 | 1.20 | 0.98 | 0.81 | 0.69 | 0.62 | 0.56 | 0.51 |
| 1976 | 1.28 | 1.01 | 0.83 | 0.72 | 0.66 | 0.62 | 0.59 |
| 1977 | 1.34 | 1.07 | 0.87 | 0.76 | 0.68 | 0.63 | 0.59 |
| 1978 | 1.20 | 1.01 | 0.85 | 0.74 | 0.67 | 0.62 | 0.58 |
| 1979 | 1.23 | 1.00 | 0.85 | 0.77 | 0.72 | 0.70 | 0.68 |
| 1980 | 1.70 | 1.08 | 0.84 | 0.74 | 0.70 | 0.68 | 0.67 |
| 1981 | 1.40 | 1.06 | 0.87 | 0.78 | 0.73 | 0.70 | 0.68 |
| 1982 | 1.22 | 1.02 | 0.86 | 0.77 | 0.71 | 0.67 | 0.63 |
| 1983 | 1.36 | 1.02 | 0.84 | 0.76 | 0.72 | 0.70 | 0.68 |
| 1984 | 1.48 | 1.05 | 0.85 | 0.76 | 0.72 | 0.70 | 0.68 |
| 1985 | 1.45 | 1.06 | 0.86 | 0.78 | 0.74 | 0.71 | 0.70 |
| 1986 | 1.58 | 1.10 | 0.87 | 0.78 | 0.72 | 0.70 | 0.68 |
| 1987 | 1.30 | 1.07 | 0.90 | 0.80 | 0.74 | 0.70 | 0.68 |
| 1988 | 1.48 | 1.07 | 0.87 | 0.79 | 0.75 | 0.73 | 0.72 |
| 1989 | 1.32 | 1.05 | 0.87 | 0.78 | 0.73 | 0.69 | 0.67 |
| 1990 | 1.35 | 1.02 | 0.84 | 0.76 | 0.72 | 0.70 | 0.68 |
| 1991 | 1.18 | 0.97 | 0.83 | 0.76 | 0.71 | 0.69 | 0.67 |
| 1992 | 1.20 | 0.98 | 0.84 | 0.77 | 0.73 | 0.71 | 0.69 |
| 1993 | 1.17 | 0.97 | 0.83 | 0.76 | 0.71 | 0.69 | 0.67 |
| 1994 | 1.28 | 1.01 | 0.85 | 0.77 | 0.73 | 0.70 | 0.69 |
| 1995 | 1.20 | 0.97 | 0.83 | 0.75 | 0.71 | 0.68 | 0.67 |

**Table 3.16** (cont.)

| **Year** | **0** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|---|
| 1996 | 1.29 | 1.02 | 0.85 | 0.76 | 0.72 | 0.69 | 0.67 |
| 1997 | 1.34 | 1.01 | 0.84 | 0.77 | 0.73 | 0.72 | 0.71 |
| 1998 | 1.24 | 1.00 | 0.85 | 0.78 | 0.74 | 0.72 | 0.70 |
| 1999 | 1.12 | 0.95 | 0.83 | 0.76 | 0.72 | 0.69 | 0.68 |
| 2000 | 1.24 | 1.02 | 0.88 | 0.81 | 0.77 | 0.75 | 0.73 |
| 2001 | 1.03 | 0.91 | 0.82 | 0.76 | 0.72 | 0.69 | 0.68 |
| 2002 | 1.25 | 0.99 | 0.85 | 0.78 | 0.74 | 0.72 | 0.71 |
| 2003 | 1.34 | 1.05 | 0.88 | 0.79 | 0.75 | 0.72 | 0.70 |
| 2004 | 1.30 | 1.04 | 0.88 | 0.80 | 0.76 | 0.73 | 0.72 |
| 2005 | 1.14 | 1.00 | 0.88 | 0.81 | 0.76 | 0.73 | 0.71 |
| 2006 | 1.31 | 1.03 | 0.88 | 0.81 | 0.78 | 0.76 | 0.75 |
| 2007 | 1.27 | 1.01 | 0.86 | 0.79 | 0.76 | 0.74 | 0.72 |
| 2008 | 1.23 | 0.97 | 0.84 | 0.78 | 0.76 | 0.74 | 0.74 |
| 2009 | 1.07 | 0.96 | 0.86 | 0.80 | 0.75 | 0.72 | 0.70 |
| 2010 | 1.36 | 1.01 | 0.86 | 0.79 | 0.77 | 0.75 | 0.75 |

**Table 3.17** Lorenzen age-specific estimates of *M* from 1964 to 2010 based on weight at age from year to year. These are the values scaled to 1.10, the estimate of *M* from the tagging study, for each year.

| **Year** | **0** | **1** | **2** | **3** | **4** | **5** | **6** |
|---|---|---|---|---|---|---|---|
| 1964 | 1.65 | 1.31 | 1.10 | 0.99 | 0.94 | 0.90 | 0.88 |
| 1965 | 1.69 | 1.36 | 1.11 | 0.94 | 0.83 | 0.74 | 0.66 |
| 1966 | 1.63 | 1.32 | 1.10 | 0.97 | 0.89 | 0.84 | 0.80 |
| 1967 | 1.77 | 1.34 | 1.11 | 1.00 | 0.95 | 0.92 | 0.90 |
| 1968 | 1.71 | 1.32 | 1.07 | 0.94 | 0.87 | 0.82 | 0.78 |
| 1969 | 1.58 | 1.32 | 1.11 | 0.97 | 0.87 | 0.79 | 0.72 |
| 1970 | 1.73 | 1.30 | 1.08 | 0.98 | 0.93 | 0.91 | 0.89 |
| 1971 | 1.69 | 1.30 | 1.08 | 0.97 | 0.92 | 0.89 | 0.87 |
| 1972 | 1.70 | 1.26 | 1.06 | 0.99 | 0.95 | 0.93 | 0.92 |
| 1973 | 1.52 | 1.24 | 1.03 | 0.90 | 0.81 | 0.74 | 0.69 |
| 1974 | 1.77 | 1.23 | 1.02 | 0.95 | 0.93 | 0.92 | 0.91 |
| 1975 | 1.55 | 1.28 | 1.05 | 0.89 | 0.78 | 0.68 | 0.60 |
| 1976 | 1.67 | 1.32 | 1.08 | 0.94 | 0.85 | 0.79 | 0.74 |
| 1977 | 1.74 | 1.39 | 1.14 | 0.99 | 0.88 | 0.81 | 0.75 |
| 1978 | 1.56 | 1.32 | 1.11 | 0.97 | 0.87 | 0.79 | 0.73 |
| 1979 | 1.59 | 1.30 | 1.10 | 1.00 | 0.94 | 0.91 | 0.88 |
| 1980 | 2.09 | 1.40 | 1.09 | 0.97 | 0.91 | 0.88 | 0.87 |
| 1981 | 1.82 | 1.38 | 1.13 | 1.01 | 0.95 | 0.91 | 0.89 |
| 1982 | 1.59 | 1.33 | 1.12 | 1.00 | 0.92 | 0.86 | 0.82 |
| 1983 | 1.76 | 1.33 | 1.09 | 0.99 | 0.94 | 0.91 | 0.89 |
| 1984 | 1.89 | 1.36 | 1.10 | 0.99 | 0.94 | 0.91 | 0.89 |
| 1985 | 1.86 | 1.37 | 1.12 | 1.01 | 0.96 | 0.93 | 0.91 |
| 1986 | 1.98 | 1.43 | 1.14 | 1.01 | 0.94 | 0.91 | 0.89 |
| 1987 | 1.70 | 1.38 | 1.16 | 1.04 | 0.97 | 0.92 | 0.88 |
| 1988 | 1.89 | 1.39 | 1.14 | 1.03 | 0.97 | 0.95 | 0.93 |
| 1989 | 1.71 | 1.36 | 1.13 | 1.02 | 0.95 | 0.90 | 0.87 |
| 1990 | 1.76 | 1.33 | 1.10 | 0.99 | 0.94 | 0.91 | 0.89 |
| 1991 | 1.52 | 1.26 | 1.08 | 0.99 | 0.93 | 0.90 | 0.87 |
| 1992 | 1.55 | 1.27 | 1.09 | 1.00 | 0.95 | 0.92 | 0.90 |
| 1993 | 1.51 | 1.26 | 1.08 | 0.99 | 0.93 | 0.89 | 0.87 |
| 1994 | 1.67 | 1.31 | 1.10 | 1.00 | 0.95 | 0.92 | 0.90 |
| 1995 | 1.56 | 1.27 | 1.08 | 0.98 | 0.92 | 0.89 | 0.87 |

**Table 3.17** (cont.)

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| 1996 | 1.68 | 1.33 | 1.11 | 1.00 | 0.93 | 0.89 | 0.87 |
| 1997 | 1.75 | 1.32 | 1.10 | 1.00 | 0.96 | 0.93 | 0.92 |
| 1998 | 1.62 | 1.30 | 1.11 | 1.01 | 0.96 | 0.93 | 0.91 |
| 1999 | 1.43 | 1.24 | 1.08 | 0.99 | 0.94 | 0.91 | 0.88 |
| 2000 | 1.62 | 1.32 | 1.14 | 1.05 | 1.00 | 0.97 | 0.95 |
| 2001 | 1.26 | 1.18 | 1.06 | 0.99 | 0.94 | 0.90 | 0.88 |
| 2002 | 1.63 | 1.29 | 1.10 | 1.01 | 0.97 | 0.94 | 0.93 |
| 2003 | 1.74 | 1.37 | 1.14 | 1.03 | 0.97 | 0.94 | 0.91 |
| 2004 | 1.69 | 1.35 | 1.14 | 1.04 | 0.98 | 0.95 | 0.93 |
| 2005 | 1.47 | 1.30 | 1.14 | 1.05 | 0.99 | 0.95 | 0.92 |
| 2006 | 1.71 | 1.34 | 1.14 | 1.06 | 1.01 | 0.99 | 0.97 |
| 2007 | 1.65 | 1.32 | 1.13 | 1.03 | 0.98 | 0.96 | 0.94 |
| 2008 | 1.60 | 1.27 | 1.09 | 1.02 | 0.98 | 0.96 | 0.95 |
| 2009 | 1.34 | 1.24 | 1.12 | 1.04 | 0.98 | 0.94 | 0.91 |
| 2010 | 1.77 | 1.32 | 1.11 | 1.03 | 0.99 | 0.98 | 0.97 |

**Table 3.18** 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 3.19** Predictive models used for forecasting Louisiana menhaden catches. Total harvest by number in 1,000,000 fish, total harvest by weight (X1,000 mt), and effort (X1,000 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 3.20** Cumulative monthly purse-seine landings of gulf menhaden for reduction in 2010, 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% |

**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 | x | x | x | x | x | x | x | | x | x | x | x | | | | | | 11 |
| 1965 | x | x | x | x | x | | x | | x | x | | x | x | x | x | | | 12 |
| 1966 | x | x | x | x | x | | x | x | x | x | x | x | x | x | | | | 13 |
| 1967 | x | x | x | x | x | | x | | x | x | x | x | x | x | | x | | 13 |
| 1968 | x | x | x | x | x | | x | x | x | x | x | x | x | x | | x | | 14 |
| 1969 | x | x | x | x | x | | | x | x | x | x | x | x | x | | x | | 13 |
| 1970 | x | x | x | x | x | | x | | x | x | x | x | x | x | | x | | 13 |
| 1971 | x | x | x | x | x | | x | | x | x | x | x | x | x | | x | | 13 |
| 1972 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1973 | | x | x | x | x | | | | x | x | x | | x | x | | x | | 10 |
| 1974 | | x | x | x | x | | | | x | x | x | | x | x | | x | | 10 |
| 1975 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1976 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1977 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1978 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1979 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1980 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1981 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1982 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1983 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1984 | x | x | x | x | x | | | | x | x | x | | x | x | | x | | 11 |
| 1985 | | x | x | x | | | | | | | x | | x | x | | x | | 7 |
| 1986 | | x | x | x | x | | | | | | x | | x | x | | x | | 8 |
| 1987 | | x | x | x | x | | | | | | x | | x | x | | x | | 8 |
| 1988 | | x | x | x | x | | | | | | x | | x | x | | x | | 8 |
| 1989 | | x | x | x | x | | | | | | x | | x | x | | x | x | 9 |
| 1990 | | x | x | x | x | | | | | | x | | x | x | | x | x | 9 |
| 1991 | | | x | x | x | | | | | | | | x | x | | x | x | 7 |
| 1992 | | | x | | x | | | | | | | | x | x | | x | x | 6 |
| 1993 | | | x | | x | | | | | | | | x | x | | x | x | 6 |
| 1994 | | | x | | x | | | | | | | | x | x | | x | x | 6 |
| 1995 | | | x | | x | | | | | | | | x | x | | x | x | 6 |
| 1996 | | | x | | x | | | | | | | | x | | | x | x | 5 |
| 1997 | | | x | | x | | | | | | | | x | | | x | x | 5 |
| 1998 | | | x | | x | | | | | | | | x | | | x | x | 5 |
| 1999 | | | x | | x | | | | | | | | x | | | x | x | 5 |
| 2000 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2001 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2002 | | | x | | x | | | | | | | | x | | | x | | 4 |

**Table 4.1.** (cont.)

| Year | Plant | | | | | | | | | | | | | | | | | Total Plants |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **54** | **55** | **56** | **57** | **58** | **59** | **60** | **61** | **62** | **63** | **64** | **65** | **68** | **69** | **70** | **71** | **72** | |
| 2003 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2004 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2005 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2006 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2007 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2008 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2009 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2010 | | | x | | x | | | | | | | | x | | | x | | 4 |
| 2011 | | | x | | x | | | | | | | | x | | | x | | 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, effort (vessel-ton-weeks, vtw), and CPUE from the reduction purse-seine fishery, 1948-2010, landings from the bait fisheries, 1950-2009, landings estimated from the recreational fishery (MRFSS), 1981-2009, 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, and prior 5-yr average for 2010.

| Year | Reduction Landings (1000 mt) | Reduction Effort (vtw) | CPUE | Bait Landings (1000 mt) | Recreational Catches (1000 mt) | Combined Total Landings (1000 mt) |
|---|---|---|---|---|---|---|
| 1948 | 74.6 | 40.7 | 1.833 | 0.009 | 0.210 | 74.8 |
| 1949 | 107.4 | 66.2 | 1.622 | 0.009 | 0.210 | 107.6 |
| 1950 | 147.2 | 82.2 | 1.791 | 0.000 | 0.210 | 147.4 |
| 1951 | 154.8 | 94.2 | 1.643 | 0.003 | 0.210 | 155.0 |
| 1952 | 227.1 | 113.3 | 2.004 | 0.004 | 0.210 | 227.3 |
| 1953 | 195.7 | 104.7 | 1.869 | 0.001 | 0.210 | 195.9 |
| 1954 | 181.2 | 113.0 | 1.604 | 0.001 | 0.210 | 181.4 |
| 1955 | 213.3 | 122.9 | 1.736 | 0.011 | 0.210 | 213.5 |
| 1956 | 244.0 | 155.1 | 1.573 | 0.014 | 0.210 | 244.2 |
| 1957 | 159.3 | 155.2 | 1.026 | 0.003 | 0.210 | 159.5 |
| 1958 | 196.2 | 202.8 | 0.967 | 0.040 | 0.210 | 196.4 |
| 1959 | 325.9 | 205.8 | 1.584 | 0.009 | 0.210 | 326.1 |
| 1960 | 376.8 | 211.7 | 1.780 | 0.005 | 0.210 | 377.0 |
| 1961 | 455.9 | 241.6 | 1.887 | 0.011 | 0.210 | 456.1 |
| 1962 | 479.0 | 289.0 | 1.657 | 0.009 | 0.210 | 479.2 |
| 1963 | 437.5 | 277.3 | 1.578 | 0.020 | 0.210 | 437.7 |
| 1964 | 407.8 | 272.9 | 1.494 | 0.038 | 0.210 | 408.0 |
| 1965 | 461.2 | 335.6 | 1.374 | 0.196 | 0.210 | 461.5 |
| 1966 | 357.6 | 381.3 | 0.938 | 0.254 | 0.210 | 358.0 |
| 1967 | 316.1 | 404.7 | 0.781 | 0.058 | 0.210 | 316.3 |
| 1968 | 371.9 | 382.8 | 0.972 | 0.207 | 0.210 | 372.3 |
| 1969 | 521.5 | 411.0 | 1.269 | 0.137 | 0.210 | 521.8 |
| 1970 | 545.9 | 400.0 | 1.365 | 0.280 | 0.210 | 546.3 |
| 1971 | 728.5 | 472.9 | 1.540 | 0.366 | 0.210 | 729.0 |
| 1972 | 501.9 | 447.5 | 1.122 | 0.292 | 0.210 | 502.3 |
| 1973 | 486.4 | 426.2 | 1.141 | 0.446 | 0.210 | 487.0 |
| 1974 | 587.4 | 485.5 | 1.210 | 0.319 | 0.210 | 587.8 |
| 1975 | 542.6 | 538.0 | 1.009 | 0.211 | 0.210 | 543.0 |
| 1976 | 561.2 | 575.8 | 0.975 | 0.328 | 0.210 | 561.7 |
| 1977 | 447.1 | 532.7 | 0.839 | 0.298 | 0.210 | 447.6 |
| 1978 | 820.0 | 574.3 | 1.428 | 0.404 | 0.210 | 820.6 |
| 1979 | 777.9 | 533.9 | 1.457 | 1.727 | 0.210 | 779.8 |
| 1980 | 701.3 | 627.6 | 1.117 | 0.999 | 0.210 | 702.5 |

**Table 4.2** (cont.)

| Year | Reduction Landings (1000 mt) | Reduction Effort (vtw) | CPUE | Bait Landings (1000 mt) | Recreational Catches (1000 mt) | Combined Total Landings (1000 mt) |
|---|---|---|---|---|---|---|
| 1981 | 552.6 | 623.0 | 0.887 | 1.074 | 0.038 | 553.7 |
| 1982 | 853.9 | 653.8 | 1.306 | 1.577 | 0.054 | 855.5 |
| 1983 | 923.5 | 655.8 | 1.408 | 1.739 | 0.024 | 925.3 |
| 1984 | 982.8 | 645.9 | 1.522 | 2.317 | 0.005 | 985.1 |
| 1985 | 881.1 | 560.6 | 1.572 | 2.998 | 0.449 | 884.5 |
| 1986 | 822.1 | 606.5 | 1.355 | 8.521 | 0.258 | 830.9 |
| 1987 | 894.2 | 604.2 | 1.480 | 17.261 | 0.209 | 911.7 |
| 1988 | 623.7 | 594.1 | 1.050 | 16.019 | 0.488 | 640.2 |
| 1989 | 569.6 | 555.3 | 1.026 | 13.503 | 0.440 | 583.5 |
| 1990 | 528.3 | 563.1 | 0.938 | 11.085 | 0.135 | 539.5 |
| 1991 | 544.3 | 472.3 | 1.152 | 8.629 | 0.051 | 553.0 |
| 1992 | 421.4 | 408.0 | 1.033 | 11.269 | 0.138 | 432.8 |
| 1993 | 539.2 | 455.2 | 1.185 | 12.182 | 0.170 | 551.6 |
| 1994 | 761.6 | 472.0 | 1.614 | 13.135 | 0.189 | 774.9 |
| 1995 | 463.9 | 417.0 | 1.112 | 8.068 | 0.056 | 472.0 |
| 1996 | 479.4 | 451.7 | 1.061 | 12.270 | 0.082 | 491.8 |
| 1997 | 611.2 | 430.2 | 1.421 | 11.927 | 0.020 | 623.1 |
| 1998 | 486.2 | 409.3 | 1.188 | 0.914 | 0.047 | 487.2 |
| 1999 | 684.3 | 414.5 | 1.651 | 1.025 | 0.051 | 685.4 |
| 2000 | 579.3 | 417.6 | 1.387 | 0.788 | 0.207 | 580.3 |
| 2001 | 521.3 | 400.6 | 1.301 | 0.751 | 0.048 | 522.1 |
| 2002 | 574.5 | 386.7 | 1.486 | 0.472 | 0.108 | 575.1 |
| 2003 | 517.1 | 363.2 | 1.424 | 0.489 | 0.118 | 517.7 |
| 2004 | 468.7 | 390.5 | 1.200 | 0.421 | 0.064 | 469.2 |
| 2005 | 433.8 | 326.0 | 1.331 | 0.281 | 0.048 | 434.1 |
| 2006 | 464.4 | 367.2 | 1.265 | 0.174 | 0.055 | 464.6 |
| 2007 | 453.8 | 369.2 | 1.229 | 0.251 | 0.030 | 454.1 |
| 2008 | 425.4 | 355.8 | 1.196 | 0.139 | 0.028 | 425.6 |
| 2009 | 457.5 | 377.8 | 1.211 | 0.128 | 0.061 | 457.7 |
| 2010 | 379.7 | 320.3 | 1.185 | 0.195 | 0.044 | 379.9 |

**Table 4.3** 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, 1964-2010.

| Year | Sample Size (N Fish) | Sample Size (N Sets) | Landings | | Mean Weight (g) |
|---|---|---|---|---|---|
| | | | (millions) | (1000 mt) | |
| 1964 | 12260 | 625 | 4949.6 | 407.8 | 82.4 |
| 1965 | 15185 | 790 | 6232.4 | 461.2 | 74.0 |
| 1966 | 12429 | 640 | 4244.1 | 357.6 | 84.3 |
| 1967 | 14065 | 721 | 4640.8 | 316.1 | 68.1 |
| 1968 | 15273 | 795 | 4579.5 | 371.9 | 81.2 |
| 1969 | 14764 | 759 | 7413.8 | 521.5 | 70.3 |
| 1970 | 10402 | 527 | 5646.1 | 545.9 | 96.7 |
| 1971 | 7654 | 393 | 7924.1 | 728.5 | 91.9 |
| 1972 | 9886 | 998 | 4893.0 | 501.9 | 102.6 |
| 1973 | 8953 | 896 | 4290.8 | 486.4 | 113.4 |
| 1974 | 10086 | 1009 | 5378.9 | 587.4 | 109.2 |
| 1975 | 9527 | 953 | 4510.5 | 542.6 | 120.3 |
| 1976 | 13389 | 1355 | 6169.3 | 561.2 | 91.0 |
| 1977 | 14897 | 1492 | 6107.7 | 447.1 | 73.2 |
| 1978 | 12944 | 1300 | 9587.4 | 820.0 | 85.5 |
| 1979 | 11121 | 1163 | 7922.4 | 777.9 | 98.2 |
| 1980 | 9883 | 1014 | 7220.4 | 701.3 | 97.1 |
| 1981 | 10273 | 1042 | 7539.1 | 552.6 | 73.3 |
| 1982 | 10341 | 1076 | 9014.5 | 853.9 | 94.7 |
| 1983 | 14523 | 1485 | 8902.7 | 923.5 | 103.7 |
| 1984 | 15936 | 1599 | 11119.2 | 982.8 | 88.4 |
| 1985 | 13225 | 1324 | 11451.6 | 881.1 | 76.9 |
| 1986 | 16494 | 1652 | 9369.7 | 822.1 | 87.7 |
| 1987 | 16458 | 1647 | 11115.3 | 894.2 | 80.4 |
| 1988 | 12402 | 1240 | 8088.5 | 623.7 | 77.1 |
| 1989 | 13950 | 1392 | 7241.5 | 569.6 | 78.7 |
| 1990 | 11456 | 1152 | 5824.4 | 528.3 | 90.7 |
| 1991 | 11378 | 1164 | 4803.7 | 544.3 | 113.3 |
| 1992 | 14214 | 1524 | 3916.2 | 421.4 | 107.6 |
| 1993 | 14576 | 1537 | 5237.9 | 539.2 | 102.9 |
| 1994 | 16062 | 1680 | 7317.0 | 761.6 | 104.1 |
| 1995 | 13489 | 1470 | 3896.3 | 463.9 | 119.1 |
| 1996 | 12115 | 1506 | 4566.8 | 479.4 | 105.0 |
| 1997 | 9923 | 1121 | 5950.0 | 611.2 | 102.7 |
| 1998 | 9043 | 1072 | 4598.4 | 486.2 | 105.7 |
| 1999 | 10641 | 1183 | 6198.3 | 684.3 | 110.4 |
| 2000 | 8383 | 964 | 5607.9 | 579.3 | 103.3 |
| 2001 | 6222 | 740 | 3951.7 | 521.3 | 131.9 |
| 2002 | 5597 | 836 | 4999.8 | 574.5 | 114.9 |
| 2003 | 7839 | 1066 | 5274.7 | 517.1 | 98.0 |
| 2004 | 6644 | 942 | 5001.3 | 468.7 | 93.7 |
| 2005 | 6206 | 895 | 4398.3 | 433.8 | 98.6 |
| 2006 | 4698 | 594 | 4895.1 | 464.4 | 94.9 |
| 2007 | 3989 | 657 | 4750.1 | 453.8 | 95.5 |
| 2008 | 4663 | 593 | 3608.2 | 425.4 | 117.9 |
| 2009 | 6193 | 748 | 3603.3 | 457.5 | 127.0 |
| 2010 | 3678 | 461 | 3891.6 | 379.7 | 97.6 |

**Table 4.4** Estimated reduction landings of gulf menhaden in numbers by age (in millions), 1964-2010.

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | Total |
|---|---|---|---|---|---|---|---|---|
| 1964 | 2.8 | 3329.3 | 1495.2 | 118.1 | 4.4 | 0.0 | 0.0 | 4949.6 |
| 1965 | 43.4 | 5031.4 | 1076.6 | 80.3 | 0.7 | 0.0 | 0.0 | 6232.4 |
| 1966 | 30.5 | 3314.4 | 865.2 | 33.8 | 0.3 | 0.0 | 0.0 | 4244.1 |
| 1967 | 22.4 | 4267.7 | 337.7 | 13.0 | 0.0 | 0.0 | 0.0 | 4640.8 |
| 1968 | 65.1 | 3475.2 | 1001.3 | 37.5 | 0.5 | 0.0 | 0.0 | 4579.5 |
| 1969 | 20.8 | 6075.0 | 1286.3 | 31.7 | 0.0 | 0.0 | 0.0 | 7413.8 |
| 1970 | 50.2 | 3279.9 | 2280.0 | 36.1 | 0.0 | 0.0 | 0.0 | 5646.1 |
| 1971 | 21.6 | 5761.1 | 1955.5 | 181.8 | 4.1 | 0.0 | 0.0 | 7924.1 |
| 1972 | 19.1 | 3047.7 | 1733.5 | 88.5 | 4.0 | 0.0 | 0.0 | 4893.0 |
| 1973 | 49.9 | 3033.0 | 1107.0 | 99.6 | 1.3 | 0.0 | 0.0 | 4290.8 |
| 1974 | 1.4 | 3846.8 | 1471.7 | 59.1 | 0.0 | 0.0 | 0.0 | 5378.9 |
| 1975 | 108.8 | 2440.5 | 1499.2 | 461.8 | 0.2 | 0.0 | 0.0 | 4510.5 |
| 1976 | 0.0 | 4591.4 | 1373.9 | 203.9 | 0.0 | 0.0 | 0.0 | 6169.3 |
| 1977 | 0.0 | 4660.0 | 1331.7 | 110.4 | 5.6 | 0.0 | 0.0 | 6107.7 |
| 1978 | 0.0 | 6787.4 | 2742.0 | 52.7 | 5.2 | 0.0 | 0.0 | 9587.4 |
| 1979 | 0.0 | 4701.2 | 2877.2 | 337.2 | 6.1 | 0.8 | 0.0 | 7922.4 |
| 1980 | 65.9 | 3409.4 | 3261.1 | 436.2 | 46.3 | 1.6 | 0.0 | 7220.4 |
| 1981 | 0.0 | 5750.5 | 1424.9 | 329.4 | 29.7 | 3.3 | 1.2 | 7539.1 |
| 1982 | 0.0 | 5146.7 | 3302.0 | 503.5 | 58.5 | 2.1 | 1.7 | 9014.5 |
| 1983 | 0.0 | 4685.7 | 3809.2 | 382.6 | 23.8 | 1.3 | 0.0 | 8902.7 |
| 1984 | 0.0 | 7749.6 | 2881.5 | 438.4 | 49.0 | 0.7 | 0.0 | 11119.2 |
| 1985 | 0.0 | 8682.7 | 2498.6 | 233.7 | 36.5 | 0.0 | 0.0 | 11451.6 |
| 1986 | 0.0 | 4276.0 | 4892.0 | 174.9 | 25.8 | 1.0 | 0.0 | 9369.7 |
| 1987 | 0.0 | 6699.5 | 3975.6 | 427.8 | 12.5 | 0.0 | 0.0 | 11115.3 |
| 1988 | 0.0 | 5337.7 | 2581.4 | 151.5 | 18.0 | 0.0 | 0.0 | 8088.5 |
| 1989 | 0.0 | 5550.4 | 1622.0 | 67.0 | 2.1 | 0.0 | 0.0 | 7241.5 |
| 1990 | 0.0 | 3889.2 | 1785.0 | 136.2 | 13.1 | 0.3 | 0.4 | 5824.4 |
| 1991 | 0.0 | 2217.5 | 2339.9 | 215.6 | 28.2 | 2.5 | 0.0 | 4803.7 |
| 1992 | 0.0 | 2187.3 | 1505.8 | 197.1 | 24.2 | 1.7 | 0.2 | 3916.2 |
| 1993 | 0.0 | 3492.8 | 1532.9 | 193.5 | 15.7 | 2.8 | 0.2 | 5237.9 |
| 1994 | 0.0 | 3627.6 | 3195.6 | 441.2 | 49.0 | 3.7 | 0.0 | 7317.0 |
| 1995 | 0.0 | 1369.2 | 2423.4 | 99.7 | 3.9 | 0.2 | 0.0 | 3896.3 |
| 1996 | 0.0 | 1784.2 | 2513.7 | 251.1 | 16.8 | 0.9 | 0.0 | 4566.8 |
| 1997 | 0.0 | 3235.6 | 2398.8 | 276.1 | 38.2 | 1.3 | 0.0 | 5950.0 |
| 1998 | 0.0 | 1804.8 | 2587.1 | 189.7 | 15.2 | 1.6 | 0.0 | 4598.4 |
| 1999 | 0.0 | 3368.8 | 2393.0 | 416.9 | 19.7 | 0.0 | 0.0 | 6198.3 |
| 2000 | 0.0 | 2029.8 | 3164.5 | 347.7 | 62.5 | 3.4 | 0.0 | 5607.9 |
| 2001 | 0.0 | 987.7 | 2654.2 | 290.2 | 18.9 | 0.8 | 0.0 | 3951.7 |
| 2002 | 0.0 | 1585.6 | 2863.1 | 534.0 | 17.1 | 0.0 | 0.0 | 4999.8 |
| 2003 | 0.0 | 1910.1 | 3011.7 | 339.6 | 13.4 | 0.0 | 0.0 | 5274.7 |
| 2004 | 0.0 | 2799.4 | 1764.0 | 400.3 | 37.6 | 0.0 | 0.0 | 5001.3 |
| 2005 | 82.0 | 1731.9 | 2381.0 | 189.0 | 13.6 | 0.0 | 0.8 | 4398.3 |
| 2006 | 0.0 | 2246.5 | 2301.3 | 317.8 | 29.6 | 0.0 | 0.0 | 4895.1 |
| 2007 | 0.0 | 2199.7 | 2421.4 | 111.8 | 13.3 | 3.9 | 0.0 | 4750.1 |
| 2008 | 0.0 | 960.6 | 2465.7 | 160.3 | 21.7 | 0.0 | 0.0 | 3608.2 |
| 2009 | 0.0 | 455.0 | 2633.4 | 466.6 | 47.9 | 0.4 | 0.0 | 3603.3 |
| 2010 | 0.0 | 2057.6 | 1572.3 | 238.8 | 22.5 | 0.4 | 0.0 | 3891.6 |

**Table 4.5** Nominal fishing effort information for the gulf menhaden fishery from CDFRs, 1983-2010. ***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 |

**Table 4.6** Number of fishing trips, catch per trips, and standard error of mean catch per trip by the gulf menhaden reduction fleet, 1964-2010. Note that trip information is incomplete (*) for 1983 and 1984.

| Year | All Data | | |
|---|---|---|---|
| | N | Catch (mt) | SE (mt) |
| 1964 | 4692 | 87.3 | 1.186 |
| 1965 | 4235 | 109.4 | 2.508 |
| 1966 | 3617 | 99.3 | 1.617 |
| 1967 | 3221 | 98.6 | 1.521 |
| 1968 | 3176 | 117.6 | 1.736 |
| 1969 | 3638 | 144.0 | 1.840 |
| 1970 | 3769 | 145.5 | 1.854 |
| 1971 | 4453 | 163.6 | 1.755 |
| 1972 | 3659 | 137.2 | 1.609 |
| 1973 | 3437 | 141.5 | 1.654 |
| 1974 | 3943 | 149.0 | 1.676 |
| 1975 | 3987 | 136.1 | 1.515 |
| 1976 | 4066 | 138.0 | 1.576 |
| 1977 | 3724 | 120.1 | 1.417 |
| 1978 | 4474 | 183.3 | 1.727 |
| 1979 | 4078 | 190.8 | 1.880 |
| 1980 | 4186 | 167.5 | 1.717 |
| 1981 | 3811 | 145.0 | 1.566 |
| 1982 | 4695 | 181.9 | 1.712 |
| 1983 | 1218* | 151.0 | 3.280 |
| 1984 | 2128* | 190.6 | 2.487 |
| 1985 | 3343 | 263.6 | 2.139 |
| 1986 | 4028 | 204.1 | 1.793 |
| 1987 | 4427 | 202.0 | 1.694 |
| 1988 | 3629 | 171.9 | 1.757 |
| 1989 | 3618 | 157.4 | 1.743 |
| 1990 | 3557 | 148.5 | 1.657 |
| 1991 | 2977 | 182.8 | 2.060 |
| 1992 | 2468 | 170.8 | 1.955 |
| 1993 | 2928 | 184.2 | 1.952 |
| 1994 | 3238 | 235.2 | 2.137 |
| 1995 | 2587 | 179.3 | 2.135 |
| 1996 | 2693 | 178.0 | 2.090 |
| 1997 | 2831 | 215.9 | 2.222 |
| 1998 | 2447 | 198.7 | 2.307 |
| 1999 | 2811 | 243.4 | 2.339 |
| 2000 | 2600 | 222.8 | 2.622 |
| 2001 | 2434 | 214.2 | 2.613 |
| 2002 | 2552 | 225.1 | 2.533 |
| 2003 | 2370 | 218.2 | 2.666 |
| 2004 | 2371 | 197.7 | 2.499 |
| 2005 | 2083 | 208.3 | 2.675 |
| 2006 | 2088 | 222.4 | 2.807 |
| 2007 | 2193 | 206.9 | 2.731 |
| 2008 | 1896 | 224.4 | 3.041 |
| 2009 | 2280 | 200.6 | 2.579 |
| 2010 | 1755 | 216.4 | 3.223 |

**Table 4.7** 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 |
| 2010 | 354 | 40 | 187-453 |

**Table 4.8** Gulf menhaden bait landings (mt) by gear from NOAA Fisheries S&T and ALS data bases, 1950-2009.

| 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 | 1726.8 |
| 1980 | 502.9 | 22.9 | 472.8 | 0.1 | 998.7 |
| 1981 | 544.6 | 21.4 | 507.0 | 0.0 | 1073.0 |
| 1982 | 797.6 | 40.0 | 739.1 | 0.0 | 1576.7 |
| 1983 | 883.4 | 36.3 | 819.5 | 0.0 | 1739.2 |
| 1984 | 1167.3 | 72.7 | 1077.3 | 0.0 | 2317.4 |
| 1985 | 1447.5 | 359.3 | 1063.0 | 0.2 | 2870.0 |
| 1986 | 251.3 | 1353.5 | 70.5 | 0.1 | 1675.4 |
| 1987 | 8567.7 | 2931.3 | 155.9 | 5.6 | 11660.5 |
| 1988 | 8485.8 | 1594.9 | 205.5 | 1.0 | 10287.2 |
| 1989 | 11226.7 | 894.3 | 79.6 | 0.2 | 12200.8 |

**Table 4.8** (cont.)

| Year | Gear | | | | Total Bait |
|---|---|---|---|---|---|
| | Purse | Gill | Haul | Other | |
| 1990 | 9996.4 | 178.7 | 2.0 | 32.5 | 10209.6 |
| 1991 | 4958.6 | 91.6 | 272.4 | 2.4 | 5325.0 |
| 1992 | 6503.1 | 1295.0 | 57.0 | 47.3 | 7902.4 |
| 1993 | 6470.1 | 836.8 | 46.6 | 1954.4 | 9308.0 |
| 1994 | 7320.8 | 670.3 | 0.1 | 1995.8 | 9987.1 |
| 1995 | 5828.3 | 1276.1 | 0.0 | 963.7 | 8068.0 |
| 1996 | 10758.4 | 1500.2 | 0.0 | 11.5 | 12270.1 |
| 1997 | 10349.4 | 1559.0 | 9.6 | 8.7 | 11926.8 |
| 1998 | 6505.3 | 892.0 | 0.0 | 5.4 | 7402.8 |
| 1999 | 7210.4 | 914.7 | 0.1 | 11.5 | 8136.5 |
| 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 |

**Table 4.9** Catch in numbers per trawl hour from SEAMAP database for zones 10-21, 1987-2010. 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.

| | Shrimp Statistical Zone | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **Total Yearly CPUE** |
| **1987** | 0.00 | 0.00 | | 1.24 | 1.29 | 2.92 | 0.80 | 13.15 | 0.53 | 1.58 | 0.15 | 0.00 | 1.97 |
| **1988** | 0.00 | 0.00 | | 5.13 | 3.70 | 2.26 | 3.11 | 3.04 | 0.96 | 0.77 | 0.00 | 6.28 | 2.29 |
| **1989** | 0.00 | 4.21 | 0.00 | 1.16 | 5.48 | 3.89 | 73.76 | 2.92 | 4.89 | 4.76 | 8.05 | 0.19 | 9.11 |
| **1990** | | 0.71 | | 5.64 | 9.04 | 0.36 | 1.64 | 7.53 | 0.26 | 8.03 | 0.17 | 0.00 | 3.34 |
| **1991** | | 0.02 | | 3.78 | 0.29 | 0.11 | 5.57 | 0.23 | 0.24 | 6.81 | 0.25 | 0.00 | 1.73 |
| **1992** | 0.00 | 0.00 | | 5.07 | 1.74 | 0.27 | 2.28 | 11.06 | 0.17 | 6.54 | 0.00 | 0.95 | 2.55 |
| **1993** | | 0.76 | | 6.87 | 0.78 | 14.49 | 0.58 | 77.61 | 0.23 | 1.68 | 0.21 | 0.54 | 10.37 |
| **1994** | | 0.07 | | 0.14 | 1.52 | 3.45 | 5.16 | 4.04 | 0.76 | 1.15 | 0.29 | 0.14 | 1.67 |
| **1995** | | 0.19 | | 102.34 | 3.54 | 0.09 | 70.71 | 5.27 | 0.95 | 19.50 | 2.12 | 4.28 | 20.90 |
| **1996** | | 1.15 | | 2.72 | 2.04 | 3.19 | 3.85 | 2.03 | 1.84 | 2.83 | 2.43 | 0.05 | 2.21 |
| **1997** | | 3.90 | | 2.49 | 2.55 | 1.68 | 7.33 | 2.73 | 0.00 | 27.41 | 24.67 | 55.37 | 12.81 |
| **1998** | | 1.14 | 0.00 | 8.64 | 5.37 | 0.11 | 7.22 | 0.77 | 2.14 | 24.81 | 2.15 | 2.21 | 4.96 |
| **1999** | | 0.02 | 9.23 | 11.86 | 1.57 | 1.53 | 33.30 | 2.08 | 2.76 | 4.00 | 8.75 | 0.93 | 6.91 |
| **2000** | | 13.74 | | 6.25 | 0.24 | 1.41 | 0.40 | 14.58 | 142.23 | 1.84 | 0.60 | 3.00 | 18.43 |
| **2001** | | 0.05 | | 0.17 | 0.19 | 0.26 | 0.32 | 1.07 | 0.57 | 7.13 | 0.10 | 0.00 | 0.98 |
| **2002** | 0.00 | 2.78 | | 17.41 | 0.14 | 0.56 | 22.78 | 0.39 | 10.69 | 23.01 | 6.07 | 1.68 | 7.77 |
| **2003** | 0.00 | 0.64 | | 1.18 | 15.26 | 3.07 | 2.47 | 1.77 | 0.49 | 5.25 | 6.18 | 0.00 | 3.30 |
| **2004** | | 0.27 | | 0.00 | 1.22 | 3.18 | 0.82 | 14.19 | 0.58 | 1.19 | 0.43 | 0.13 | 2.20 |
| **2005** | | 0.86 | | 15.04 | 3.71 | 1.17 | 38.66 | 23.16 | 0.00 | 12.53 | 0.08 | 15.46 | 11.07 |
| **2006** | 0.00 | 0.27 | | 47.59 | 14.94 | 0.25 | 1.61 | 0.87 | 6.34 | 9.01 | 5.16 | 7.96 | 8.55 |
| **2007** | | 0.26 | | 0.69 | 5.55 | 0.16 | 1.56 | 8.15 | 8.02 | 10.86 | 2.32 | 0.00 | 3.76 |
| **2008** | 0.00 | 0.26 | | 0.00 | 0.00 | 0.13 | 0.18 | 0.70 | 0.33 | 2.10 | 0.07 | 0.25 | 0.24 |
| **2009** | 0.00 | 0.14 | | 4.43 | 3.27 | 2.50 | 0.20 | 1.64 | 1.04 | 0.06 | 0.00 | 0.27 | 0.80 |
| **2010** | 0.07 | 0.00 | 0.00 | 2.63 | 0.00 | 0.09 | 8.48 | 3.10 | 2.88 | 0.04 | 0.00 | 0.00 | 0.91 |

**Table 4.10** 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 4.9).

| Year | Sum of Effort By Area (Zone) | | | |
|---|---|---|---|---|
| | **2 (10-12)** | **3 (13-17)** | **4 (18-21)** | **Grand Total** |
| 1987 | 52779 | 153796 | 104341 | 310916 |
| 1988 | 52790 | 142829 | 88978 | 284597 |
| 1989 | 44121 | 148045 | 86598 | 278765 |
| 1990 | 45751 | 139685 | 100036 | 285472 |
| 1991 | 35091 | 150185 | 96059 | 281336 |
| 1992 | 33723 | 160294 | 100990 | 295007 |
| 1993 | 36821 | 136715 | 95463 | 269000 |
| 1994 | 33100 | 141131 | 98938 | 273169 |
| 1995 | 35717 | 111258 | 72739 | 219714 |
| 1996 | 24489 | 109163 | 79784 | 213436 |
| 1997 | 31258 | 131275 | 91072 | 253605 |
| 1998 | 29359 | 126038 | 81801 | 237198 |
| 1999 | 37284 | 138093 | 70252 | 245629 |
| 2000 | 32134 | 133308 | 74777 | 240219 |
| 2001 | 34477 | 143353 | 77466 | 255297 |
| 2002 | 42650 | 164588 | 69012 | 276249 |
| 2003 | 30109 | 147386 | 53208 | 230702 |
| 2004 | 23870 | 115109 | 53314 | 192293 |
| 2005 | 15094 | 80896 | 37027 | 133017 |
| 2006 | 13530 | 89035 | 25514 | 128078 |
| 2007 | 19374 | 75427 | 24051 | 118853 |
| 2008 | 21120 | 59282 | 21659 | 102061 |
| 2009 | 21028 | 78035 | 22342 | 121405 |
| 2010* | 20507 | 70915 | 22684 | 114106 |

* Average effort for 2007-2009 used for 2010.

**Table 4.11** Estimates discards of gulf menhaden from the U.S. shrimp trawl fishery in the northern Gulf of Mexico, 1987 – 2010. Estimates are given in numbers and metric tons. To alternative hypotheses are represented: 1) all discards are age 0, and 2) discards are 90% age 0 and 10% age 1. Estimates based on CPUE and Effort given in Tables 4.9 and 4.10.

| **Year** | **In Numbers** | **Age-0 Only (mt)** | **Age-0 and -1 (mt)** |
|---|---|---|---|
| 1987 | 14,911,366 | 451.7 | 494.1 |
| 1988 | 19,203,000 | 383.1 | 455.9 |
| 1989 | 70,300,354 | 2068.8 | 2299.9 |
| 1990 | 36,870,504 | 991.6 | 1139.1 |
| 1991 | 24,121,800 | 1015.2 | 1105.2 |
| 1992 | 31,102,905 | 1244.9 | 1364.5 |
| 1993 | 38,997,097 | 1698.4 | 1842.6 |
| 1994 | 11,133,500 | 359.6 | 402.8 |
| 1995 | 134,976,420 | 5342.7 | 5879.1 |
| 1996 | 17,940,674 | 569.0 | 634.4 |
| 1997 | 149,974,181 | 4113.4 | 4746.6 |
| 1998 | 84,892,444 | 3007.6 | 3327.8 |
| 1999 | 53,142,612 | 2628.2 | 2814.4 |
| 2000 | 273,090,245 | 9632.3 | 10549.1 |
| 2001 | 24,451,471 | 1596.7 | 1676.0 |
| 2002 | 113,406,566 | 3943.5 | 4390.5 |
| 2003 | 25,181,744 | 699.6 | 784.1 |
| 2004 | 6,949,853 | 214.5 | 237.9 |
| 2005 | 38,062,773 | 1775.3 | 1877.0 |
| 2006 | 36,685,070 | 1093.6 | 1224.5 |
| 2007 | 21,674,711 | 724.4 | 802.7 |
| 2008 | 2,970,627 | 108.5 | 121.0 |
| 2009 | 2,612,390 | 151.0 | 157.7 |
| 2010 | 3,417,445 | 89.9 | 104.6 |
| **Geometric Mean** | **27,713,690** | **972.4** | **1076.3** |

**Table 4.12** Gulf menhaden catch in numbers (in millions) at age from the reduction, bait and recreational fisheries combined, 1964-2010.

| Year | 0 | 1 | 2 | 3 | 4 | 5 | 6 | Total |
|---|---|---|---|---|---|---|---|---|
| 1964 | 2.76 | 3331.31 | 1496.06 | 118.14 | 4.35 | 0.00 | 0.00 | 4952.62 |
| 1965 | 43.47 | 5035.82 | 1077.58 | 80.34 | 0.70 | 0.00 | 0.00 | 6237.91 |
| 1966 | 30.49 | 3318.72 | 866.28 | 33.80 | 0.26 | 0.00 | 0.00 | 4249.56 |
| 1967 | 22.46 | 4271.27 | 337.95 | 13.01 | 0.00 | 0.00 | 0.00 | 4644.68 |
| 1968 | 65.13 | 3479.13 | 1002.42 | 37.49 | 0.50 | 0.00 | 0.00 | 4584.68 |
| 1969 | 20.81 | 6079.05 | 1287.20 | 31.68 | 0.00 | 0.00 | 0.00 | 7418.74 |
| 1970 | 50.24 | 3282.79 | 2282.03 | 36.11 | 0.00 | 0.00 | 0.00 | 5651.17 |
| 1971 | 21.61 | 5765.68 | 1957.00 | 181.98 | 4.12 | 0.00 | 0.00 | 7930.40 |
| 1972 | 19.13 | 3050.79 | 1735.26 | 88.63 | 4.03 | 0.00 | 0.00 | 4897.85 |
| 1973 | 49.97 | 3037.09 | 1108.47 | 99.75 | 1.27 | 0.00 | 0.00 | 4296.56 |
| 1974 | 1.41 | 3850.21 | 1472.97 | 59.13 | 0.00 | 0.00 | 0.00 | 5383.73 |
| 1975 | 108.85 | 2442.41 | 1500.37 | 462.19 | 0.19 | 0.00 | 0.00 | 4514.01 |
| 1976 | 0.00 | 4595.79 | 1375.26 | 204.12 | 0.00 | 0.00 | 0.00 | 6175.16 |
| 1977 | 0.00 | 4665.24 | 1333.23 | 110.50 | 5.64 | 0.00 | 0.00 | 6114.61 |
| 1978 | 0.00 | 6792.52 | 2744.06 | 52.71 | 5.24 | 0.00 | 0.00 | 9594.54 |
| 1979 | 0.00 | 4712.93 | 2884.32 | 338.04 | 6.08 | 0.75 | 0.00 | 7942.12 |
| 1980 | 65.97 | 3415.29 | 3266.73 | 436.90 | 46.38 | 1.56 | 0.00 | 7232.84 |
| 1981 | 0.00 | 5762.11 | 1427.81 | 330.06 | 29.72 | 3.35 | 1.22 | 7554.27 |
| 1982 | 0.00 | 5156.57 | 3308.27 | 504.50 | 58.58 | 2.05 | 1.74 | 9031.71 |
| 1983 | 0.00 | 4694.68 | 3816.50 | 383.34 | 23.82 | 1.33 | 0.00 | 8919.67 |
| 1984 | 0.00 | 7767.86 | 2888.30 | 439.40 | 49.15 | 0.72 | 0.00 | 11145.42 |
| 1985 | 0.00 | 8716.66 | 2508.39 | 234.62 | 36.66 | 0.00 | 0.00 | 11496.35 |
| 1986 | 0.00 | 4321.65 | 4944.28 | 176.79 | 26.10 | 0.97 | 0.00 | 9469.79 |
| 1987 | 0.00 | 6830.36 | 4053.23 | 436.13 | 12.69 | 0.00 | 0.00 | 11332.41 |
| 1988 | 0.00 | 5478.97 | 2649.72 | 155.48 | 18.45 | 0.00 | 0.00 | 8302.61 |
| 1989 | 0.00 | 5686.31 | 1661.73 | 68.62 | 2.11 | 0.00 | 0.00 | 7418.77 |
| 1990 | 0.00 | 3971.82 | 1822.92 | 139.10 | 13.42 | 0.35 | 0.44 | 5948.05 |
| 1991 | 0.00 | 2252.87 | 2377.23 | 219.06 | 28.61 | 2.58 | 0.00 | 4880.35 |
| 1992 | 0.00 | 2246.49 | 1546.51 | 202.46 | 24.88 | 1.75 | 0.16 | 4022.24 |
| 1993 | 0.00 | 3572.84 | 1568.02 | 197.93 | 16.06 | 2.86 | 0.15 | 5357.86 |
| 1994 | 0.00 | 3691.06 | 3251.52 | 448.88 | 49.82 | 3.71 | 0.00 | 7444.99 |
| 1995 | 0.00 | 1393.14 | 2465.87 | 101.40 | 3.99 | 0.15 | 0.00 | 3964.55 |
| 1996 | 0.00 | 1830.16 | 2578.50 | 257.57 | 17.27 | 0.96 | 0.00 | 4684.46 |
| 1997 | 0.00 | 3298.83 | 2445.72 | 281.50 | 38.97 | 1.33 | 0.00 | 6066.34 |
| 1998 | 0.00 | 1808.39 | 2592.24 | 190.04 | 15.22 | 1.57 | 0.00 | 4607.45 |
| 1999 | 0.00 | 3374.07 | 2396.76 | 417.51 | 19.69 | 0.00 | 0.00 | 6208.02 |
| 2000 | 0.00 | 2033.29 | 3169.96 | 348.27 | 62.62 | 3.39 | 0.00 | 5617.52 |
| 2001 | 0.00 | 989.17 | 2658.24 | 290.60 | 18.88 | 0.84 | 0.00 | 3957.73 |
| 2002 | 0.00 | 1587.23 | 2865.99 | 534.50 | 17.14 | 0.00 | 0.00 | 5004.86 |
| 2003 | 0.00 | 1912.31 | 3015.25 | 339.95 | 13.37 | 0.00 | 0.00 | 5280.88 |
| 2004 | 0.00 | 2802.27 | 1765.86 | 400.73 | 37.61 | 0.00 | 0.00 | 5006.47 |
| 2005 | 82.06 | 1733.25 | 2382.76 | 189.11 | 13.59 | 0.00 | 0.83 | 4401.61 |
| 2006 | 0.00 | 2247.56 | 2302.40 | 317.93 | 29.58 | 0.00 | 0.00 | 4897.47 |
| 2007 | 0.00 | 2201.05 | 2422.88 | 111.82 | 13.34 | 3.90 | 0.00 | 4752.99 |
| 2008 | 0.00 | 960.94 | 2466.62 | 160.38 | 21.72 | 0.00 | 0.00 | 3609.66 |
| 2009 | 0.00 | 455.19 | 2634.45 | 466.80 | 47.94 | 0.38 | 0.00 | 3604.76 |
| 2010 | 0.00 | 2058.94 | 1573.34 | 238.95 | 22.47 | 0.40 | 0.00 | 3894.10 |

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

| | **Texas** | **Louisiana** | **Mississippi** | **Alabama** | **Florida** |
|---|---|---|---|---|---|
| Length | 600 | 750 | 750 | 750 | NA |
| Mesh size/type | 3,4,5,6 | 2,2.5,3,3.5,4 | 2,2.5,3,3.5,4 | 2,2.5,3,3.5,4<br>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 | |
| 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.

| | **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 | |
| Legs length | 60' | 50' | | 50' | |
| Bag dimensions | 1.8 m wide | 6' by 6' | 1.5 $m^3$ | 4'x4'x4' | 1.8 $m^3$ |
| Mesh size | 1/2" | 1/4" bar mesh | 0.6 cm=0.24" | 3/16" 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" | 24" | 36" | 24" | 36" |
| Door Height | 18" | 14" | 18" | 12.5" | 18" |
| Leg length | 1.5' | 1' | | 6' | 4' |
| Net Footrope | | | | 17.8' | 21.5' |
| Net Headrope | 20' | 16' | 16' | 14.2' | 20' |
| Bag Length | | 4.9' | | 2' | 7' |
| Mesh Body/Front | 1.5" stretch | 1.5" stretch | | 1.37" stretch | 1.5" stretch |
| Mesh Cod/Bag | 1.5" stretch | 0.5" stretch | 1/4" knotless bar | 1.75" cover and 3/16" knotless bar liner | 1/8" knotless bar |
| No. of weights | 1 per foot | 1/4" chain along the footrope webbing | | 3/16" chain, 17 links = 1 chain, 7 chains along footrope | 1/4" chain along the footrope webbing |
| Weight size | 2 oz/ weight | | | 7 chains=4 lbs | |
| No. of Floats | | 4 | | 2 | 4 |
| Float Dimensions | | 2.5"x1" | | 3"x3" | 2.5"x1" |
| Tickler Length | none | none | none | none | 24' of ¼” chain |
| Effort | 10 minute tow | 10 minute tow | 10 minute tow | 10 minute tow | timed tow |
| Rough size range | 116-151<br>67-123 | 20-85 | 37-85 | 50-70 | 21-64 |
| length measurement | TL | TL | SL | SL | SL |

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

**Table 5.4**. Number of trips by state and year for the fishery-independent data collected by seines.

| Year | Texas | Louisiana | Mississippi | Alabama | Florida | Total |
|---|---|---|---|---|---|---|
| 1974 | | | 24 | | | 24 |
| 1975 | | | 24 | | | 24 |
| 1976 | 68 | | 18 | | | 86 |
| 1977 | 154 | | 24 | | | 178 |
| 1978 | 462 | | 24 | | | 486 |
| 1979 | 501 | | 24 | | | 525 |
| 1980 | 501 | | 24 | | | 525 |
| 1981 | 588 | | 24 | 78 | | 690 |
| 1982 | 840 | | 23 | 137 | | 1000 |
| 1983 | 949 | | 23 | 127 | | 1099 |
| 1984 | 960 | | 23 | 93 | | 1076 |
| 1985 | 960 | | 22 | 44 | | 1026 |
| 1986 | 1080 | 463 | 23 | 37 | | 1603 |
| 1987 | 1080 | 468 | 24 | 87 | | 1659 |
| 1988 | 1241 | 425 | 22 | 60 | | 1748 |
| 1989 | 1296 | 459 | 24 | 29 | | 1808 |
| 1990 | 1728 | 474 | 23 | 24 | | 2249 |
| 1991 | 1728 | 449 | 23 | 24 | | 2224 |
| 1992 | 2035 | 528 | 23 | 24 | | 2610 |
| 1993 | 2038 | 549 | 24 | 22 | | 2633 |
| 1994 | 2035 | 618 | 23 | 22 | | 2698 |
| 1995 | 2039 | 633 | 24 | 19 | | 2715 |
| 1996 | 2160 | 659 | 24 | 21 | | 2864 |
| 1997 | 2160 | 680 | 24 | 21 | | 2885 |
| 1998 | 2156 | 681 | 24 | 16 | 76 | 2953 |
| 1999 | 2158 | 693 | 24 | 6 | 96 | 2977 |
| 2000 | 2160 | 684 | 24 | 22 | 138 | 3028 |
| 2001 | 2160 | 697 | 23 | 83 | 408 | 3371 |
| 2002 | 2159 | 676 | 23 | 81 | 408 | 3347 |
| 2003 | 2159 | 690 | 24 | 84 | 396 | 3353 |
| 2004 | 2157 | 701 | 24 | 81 | 396 | 3359 |
| 2005 | 2160 | 636 | 24 | 71 | 396 | 3287 |
| 2006 | 2160 | 647 | 24 | 75 | 396 | 3302 |
| 2007 | 2159 | 669 | 24 | 84 | 395 | 3331 |
| 2008 | 2156 | 683 | 24 | 72 | 396 | 3331 |
| 2009 | 2154 | 696 | 24 | 68 | 387 | 3329 |
| 2010 | 2157 | 503 | 12 | 66 | 394 | 3132 |

**Table 5.5**. Number of positive trips by state and year for the fishery-independent data collected by seines.

| Year | Texas | Louisiana | Mississippi | Alabama | Florida |
|---|---|---|---|---|---|
| 1974 | | | 14 | | |
| 1975 | | | 13 | | |
| 1976 | 21 | | 9 | | |
| 1977 | 3 | | 14 | | |
| 1978 | 40 | | 11 | | |
| 1979 | 47 | | 9 | | |
| 1980 | 44 | | 12 | | |
| 1981 | 68 | | 10 | 19 | |
| 1982 | 136 | | 13 | 24 | |
| 1983 | 139 | | 7 | 28 | |
| 1984 | 206 | | 9 | 36 | |
| 1985 | 127 | | 7 | 9 | |
| 1986 | 166 | 223 | 8 | 7 | |
| 1987 | 148 | 166 | 5 | 5 | |
| 1988 | 104 | 144 | 4 | 5 | |
| 1989 | 135 | 162 | 8 | 3 | |
| 1990 | 282 | 193 | 9 | 6 | |
| 1991 | 297 | 171 | 12 | 6 | |
| 1992 | 341 | 196 | 9 | 3 | |
| 1993 | 331 | 210 | 10 | 3 | |
| 1994 | 207 | 192 | 12 | 3 | |
| 1995 | 294 | 188 | 17 | 4 | |
| 1996 | 331 | 263 | 16 | 5 | |
| 1997 | 351 | 207 | 16 | 6 | |
| 1998 | 372 | 270 | 15 | 9 | 10 |
| 1999 | 283 | 235 | 13 | 2 | 4 |
| 2000 | 185 | 186 | 11 | 3 | 8 |
| 2001 | 342 | 192 | 10 | 30 | 54 |
| 2002 | 332 | 209 | 11 | 32 | 59 |
| 2003 | 296 | 225 | 15 | 31 | 68 |
| 2004 | 242 | 214 | 16 | 31 | 65 |
| 2005 | 282 | 206 | 15 | 18 | 55 |
| 2006 | 219 | 203 | 7 | 16 | 52 |
| 2007 | 351 | 258 | 8 | 23 | 48 |
| 2008 | 264 | 212 | 8 | 19 | 48 |
| 2009 | 262 | 259 | 13 | 29 | 62 |
| 2010 | 318 | 280 | 9 | 22 | 65 |

**Table 5.6** Number of trips by state and year for the fishery-independent data collected by trawls.

| Year | Texas | Louisiana | Mississippi | Alabama | Florida | Total |
|---|---|---|---|---|---|---|
| 1967 | | 161 | | | | 161 |
| 1968 | | 473 | | | | 473 |
| 1969 | | 254 | | | | 254 |
| 1970 | | 154 | | | | 154 |
| 1971 | | 344 | | | | 344 |
| 1972 | | 745 | | | | 745 |
| 1973 | | 998 | | | | 998 |
| 1974 | | 861 | 47 | | | 908 |
| 1975 | | 558 | 48 | | | 606 |
| 1976 | | 539 | 36 | | | 575 |
| 1977 | | 389 | 48 | | | 437 |
| 1978 | | 332 | 48 | | | 380 |
| 1979 | | 446 | 48 | | | 494 |
| 1980 | | 573 | 48 | | | 621 |
| 1981 | | 695 | 48 | 89 | | 832 |
| 1982 | 1197 | 1055 | 80 | 164 | | 2496 |
| 1983 | 1440 | 1034 | 96 | 175 | | 2745 |
| 1984 | 1428 | 976 | 96 | 188 | | 2688 |
| 1985 | 1440 | 1240 | 96 | 187 | | 2963 |
| 1986 | 1680 | 1014 | 96 | 190 | | 2980 |
| 1987 | 1770 | 1149 | 96 | 215 | | 3230 |
| 1988 | 1790 | 1127 | 96 | 210 | | 3223 |
| 1989 | 1800 | 1065 | 84 | 189 | | 3138 |
| 1990 | 1679 | 1207 | 48 | 204 | | 3138 |
| 1991 | 1680 | 1299 | 48 | 206 | | 3233 |
| 1992 | 1679 | 989 | 48 | 236 | | 2952 |
| 1993 | 1678 | 1137 | 48 | 223 | | 3086 |
| 1994 | 1676 | 1182 | 48 | 227 | | 3133 |
| 1995 | 1680 | 1192 | 48 | 221 | | 3141 |
| 1996 | 1680 | 1283 | 48 | 230 | | 3241 |
| 1997 | 1679 | 1377 | 48 | 219 | | 3323 |
| 1998 | 1680 | 1445 | 48 | 173 | 64 | 3410 |
| 1999 | 1680 | 1499 | 48 | 81 | 96 | 3404 |
| 2000 | 1680 | 1453 | 48 | 112 | 138 | 3431 |
| 2001 | 1680 | 1516 | 48 | 240 | 228 | 3712 |
| 2002 | 1677 | 1480 | 48 | 259 | 228 | 3692 |
| 2003 | 1677 | 1506 | 48 | 239 | 228 | 3698 |
| 2004 | 1664 | 1432 | 48 | 281 | 228 | 3653 |
| 2005 | 1675 | 1392 | 47 | 282 | 228 | 3624 |
| 2006 | 1680 | 1442 | 48 | 275 | 228 | 3673 |
| 2007 | 1678 | 1425 | 48 | 291 | 228 | 3670 |
| 2008 | 1677 | 1492 | 48 | 278 | 226 | 3721 |
| 2009 | 1673 | 1428 | 48 | 270 | 212 | 3631 |
| 2010 | 418 | 1425 | 24 | 295 | 210 | 2372 |

**Table 5.7** Number of positive trips by state and year for the fishery-independent data collected by trawls.

| Year | Texas | Louisiana | Mississippi | Alabama | Florida |
|---|---|---|---|---|---|
| 1967 | | 30 | | | |
| 1968 | | 221 | | | |
| 1969 | | 112 | | | |
| 1970 | | 62 | | | |
| 1971 | | 105 | | | |
| 1972 | | 176 | | | |
| 1973 | | 250 | | | |
| 1974 | | 304 | 17 | | |
| 1975 | | 207 | 21 | | |
| 1976 | | 200 | 17 | | |
| 1977 | | 164 | 22 | | |
| 1978 | | 132 | 21 | | |
| 1979 | | 144 | 17 | | |
| 1980 | | 208 | 18 | | |
| 1981 | | 214 | 21 | 21 | |
| 1982 | 353 | 290 | 22 | 41 | |
| 1983 | 343 | 308 | 32 | 52 | |
| 1984 | 431 | 436 | 44 | 58 | |
| 1985 | 394 | 417 | 34 | 42 | |
| 1986 | 285 | 321 | 30 | 27 | |
| 1987 | 471 | 355 | 30 | 37 | |
| 1988 | 321 | 362 | 36 | 35 | |
| 1989 | 316 | 326 | 26 | 31 | |
| 1990 | 397 | 365 | 15 | 34 | |
| 1991 | 540 | 393 | 22 | 34 | |
| 1992 | 591 | 346 | 15 | 43 | |
| 1993 | 446 | 448 | 22 | 30 | |
| 1994 | 357 | 417 | 20 | 34 | |
| 1995 | 328 | 384 | 19 | 44 | |
| 1996 | 366 | 490 | 22 | 52 | |
| 1997 | 462 | 369 | 12 | 39 | |
| 1998 | 435 | 548 | 19 | 68 | 2 |
| 1999 | 300 | 455 | 20 | 8 | 2 |
| 2000 | 356 | 410 | 12 | 21 | 1 |
| 2001 | 501 | 424 | 12 | 52 | 20 |
| 2002 | 507 | 464 | 14 | 46 | 13 |
| 2003 | 489 | 445 | 13 | 59 | 22 |
| 2004 | 437 | 446 | 18 | 74 | 14 |
| 2005 | 425 | 412 | 13 | 38 | 9 |
| 2006 | 478 | 377 | 17 | 29 | 6 |
| 2007 | 514 | 482 | 11 | 41 | 2 |
| 2008 | 395 | 446 | 15 | 39 | 12 |
| 2009 | 279 | 480 | 16 | 49 | 7 |
| 2010 | 135 | 709 | 4 | 100 | 12 |

**Table 5.8** Number of trips by state and year for the fishery-independent data collected by gillnets.

| Year | Texas | Louisiana | Mississippi | Alabama | Total |
|---|---|---|---|---|---|
| 1975 | 44 | | | | 44 |
| 1976 | 73 | | | | 73 |
| 1977 | 112 | | | | 112 |
| 1978 | 128 | | | | 128 |
| 1979 | 247 | | | | 247 |
| 1980 | 192 | | | | 192 |
| 1981 | 387 | | | | 387 |
| 1982 | 650 | | | | 650 |
| 1983 | 650 | | | | 650 |
| 1984 | 658 | | | | 658 |
| 1985 | 670 | | | | 670 |
| 1986 | 760 | 459 | | | 1219 |
| 1987 | 760 | 819 | | | 1579 |
| 1988 | 760 | 720 | | | 1480 |
| 1989 | 760 | 839 | | | 1599 |
| 1990 | 757 | 941 | | | 1698 |
| 1991 | 755 | 836 | | | 1591 |
| 1992 | 760 | 785 | | | 1545 |
| 1993 | 759 | 670 | | | 1429 |
| 1994 | 758 | 766 | | | 1524 |
| 1995 | 760 | 752 | | | 1512 |
| 1996 | 800 | 746 | | | 1546 |
| 1997 | 800 | 767 | | | 1567 |
| 1998 | 798 | 775 | | | 1573 |
| 1999 | 799 | 793 | | | 1592 |
| 2000 | 780 | 795 | | | 1575 |
| 2001 | 779 | 804 | | 51 | 1634 |
| 2002 | 779 | 790 | | 129 | 1698 |
| 2003 | 779 | 805 | | 131 | 1715 |
| 2004 | 773 | 806 | | 218 | 1797 |
| 2005 | 780 | 751 | 19 | 202 | 1752 |
| 2006 | 778 | 748 | 89 | 204 | 1819 |
| 2007 | 778 | 779 | 97 | 177 | 1831 |
| 2008 | 778 | 766 | 107 | 224 | 1875 |
| 2009 | 779 | 816 | 216 | 208 | 2019 |
| 2010 | 100 | 751 | 200 | 127 | 1178 |

**Table 5.9** Number of positive trips by state and year for the fishery-independent data collected by gillnets.

| Year | Texas | Louisiana | Mississippi | Alabama |
|---|---|---|---|---|
| 1975 | 20 | | | |
| 1976 | 27 | | | |
| 1977 | 38 | | | |
| 1978 | 30 | | | |
| 1979 | 56 | | | |
| 1980 | 34 | | | |
| 1981 | 84 | | | |
| 1982 | 139 | | | |
| 1983 | 136 | | | |
| 1984 | 186 | | | |
| 1985 | 184 | | | |
| 1986 | 189 | 323 | | |
| 1987 | 103 | 199 | | |
| 1988 | 116 | 200 | | |
| 1989 | 121 | 173 | | |
| 1990 | 121 | 195 | | |
| 1991 | 131 | 184 | | |
| 1992 | 120 | 154 | | |
| 1993 | 86 | 132 | | |
| 1994 | 109 | 168 | | |
| 1995 | 134 | 173 | | |
| 1996 | 122 | 191 | | |
| 1997 | 134 | 220 | | |
| 1998 | 134 | 249 | | |
| 1999 | 157 | 232 | | |
| 2000 | 161 | 257 | | |
| 2001 | 190 | 206 | | 13 |
| 2002 | 199 | 251 | | 46 |
| 2003 | 213 | 285 | | 56 |
| 2004 | 190 | 276 | | 61 |
| 2005 | 169 | 272 | 6 | 50 |
| 2006 | 198 | 325 | 23 | 48 |
| 2007 | 189 | 273 | 38 | 26 |
| 2008 | 208 | 313 | 36 | 32 |
| 2009 | 182 | 346 | 59 | 42 |
| 2010 | 19 | 222 | 56 | 23 |

**Table 5.10** Seine, trawl, and gillnet abundance indices and associated coefficient of variation (*CV*) for use in the base run.

| Year | Seine | Seine CV | Trawl | Trawl CV | Gillnet | Gillnet CV |
|---|---|---|---|---|---|---|
| 1967 | | | 0.57 | 0.16 | | |
| 1968 | | | 2.69 | 0.16 | | |
| 1969 | | | 1.24 | 0.21 | | |
| 1970 | | | 1.12 | 0.15 | | |
| 1971 | | | 0.59 | 0.18 | | |
| 1972 | | | 0.35 | 0.16 | | |
| 1973 | | | 0.66 | 0.13 | | |
| 1974 | | | 1.01 | 0.09 | | |
| 1975 | | | 1.52 | 0.16 | | |
| 1976 | | | 1.64 | 0.20 | | |
| 1977 | 0.85 | 0.48 | 2.11 | 0.14 | | |
| 1978 | 0.95 | 0.39 | 1.08 | 0.12 | | |
| 1979 | 0.38 | 0.34 | 0.63 | 0.13 | | |
| 1980 | 0.79 | 0.33 | 1.04 | 0.17 | | |
| 1981 | 0.64 | 0.24 | 0.76 | 0.11 | | |
| 1982 | 1.12 | 0.20 | 0.80 | 0.07 | | |
| 1983 | 0.74 | 0.19 | 0.93 | 0.08 | | |
| 1984 | 2.60 | 0.16 | 1.50 | 0.08 | | |
| 1985 | 0.77 | 0.20 | 0.74 | 0.07 | | |
| 1986 | 2.04 | 0.14 | 0.72 | 0.08 | 1.15 | 0.07 |
| 1987 | 0.72 | 0.15 | 0.75 | 0.07 | 0.59 | 0.08 |
| 1988 | 0.60 | 0.16 | 0.69 | 0.07 | 0.91 | 0.07 |
| 1989 | 0.64 | 0.14 | 0.56 | 0.08 | 0.67 | 0.07 |
| 1990 | 1.16 | 0.12 | 0.88 | 0.08 | 0.80 | 0.07 |
| 1991 | 1.15 | 0.12 | 0.88 | 0.07 | 0.67 | 0.08 |
| 1992 | 1.27 | 0.12 | 1.17 | 0.06 | 0.63 | 0.08 |
| 1993 | 1.64 | 0.11 | 1.17 | 0.07 | 0.52 | 0.08 |
| 1994 | 0.62 | 0.13 | 0.82 | 0.08 | 0.62 | 0.09 |
| 1995 | 0.87 | 0.12 | 0.67 | 0.07 | 0.73 | 0.08 |
| 1996 | 1.44 | 0.11 | 0.99 | 0.07 | 0.66 | 0.08 |
| 1997 | 0.88 | 0.11 | 0.73 | 0.06 | 0.92 | 0.08 |
| 1998 | 1.34 | 0.11 | 1.00 | 0.07 | 0.91 | 0.08 |
| 1999 | 0.87 | 0.12 | 0.70 | 0.08 | 0.97 | 0.07 |
| 2000 | 0.47 | 0.13 | 0.52 | 0.07 | 1.12 | 0.07 |
| 2001 | 1.01 | 0.11 | 1.05 | 0.07 | 1.17 | 0.07 |
| 2002 | 0.87 | 0.11 | 0.95 | 0.06 | 1.12 | 0.07 |
| 2003 | 1.07 | 0.11 | 0.93 | 0.06 | 1.48 | 0.07 |
| 2004 | 0.62 | 0.11 | 0.79 | 0.06 | 1.17 | 0.07 |
| 2005 | 0.71 | 0.11 | 0.75 | 0.07 | 1.34 | 0.07 |
| 2006 | 0.65 | 0.11 | 0.68 | 0.07 | 1.64 | 0.06 |
| 2007 | 0.95 | 0.10 | 1.19 | 0.07 | 1.21 | 0.07 |
| 2008 | 0.60 | 0.11 | 0.62 | 0.07 | 1.71 | 0.06 |
| 2009 | 1.01 | 0.11 | 0.73 | 0.07 | 1.47 | 0.06 |
| 2010 | 1.95 | 0.11 | 3.08 | 0.08 | 0.81 | 0.08 |

**Table 5.11** Yearly length compositions for lengths sampled from gulf menhaden caught in gillnets from 1986-2010.

| Sample size | Year | Yearly Menhaden Length Increments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **(0,10]** | **(10,20]** | **(20,30]** | **(30,40]** | **(40,50]** | **(50,60]** | **(60,70]** | **(70,80]** | **(80,90]** |
| 4601 | 1986 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2379 | 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 932 | 1988 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 774 | 1989 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 987 | 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 788 | 1991 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1769 | 1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2809 | 1993 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3245 | 1994 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3427 | 1995 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 3626 | 1996 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| 4948 | 1997 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5227 | 1998 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5200 | 1999 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6637 | 2000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7009 | 2001 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6973 | 2002 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7664 | 2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6380 | 2004 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 7162 | 2005 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 8740 | 2006 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 6604 | 2007 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 10230 | 2008 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 9522 | 2009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4581 | 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 5.11**. (Cont.)

| Year | Yearly Menhaden Length Increments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **(90,100]** | **(100,110]** | **(110,120]** | **(120,130]** | **(130,140]** | **(140,150]** | **(150,160]** | **(160,170]** | **(170,180]** |
| 1986 | 0.01 | 0.01 | 0.02 | 0.07 | 0.15 | 0.16 | 0.09 | 0.07 | 0.04 |
| 1987 | 0.01 | 0.01 | 0.01 | 0.05 | 0.15 | 0.19 | 0.08 | 0.04 | 0.03 |
| 1988 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.04 | 0.02 | 0.03 | 0.07 |
| 1989 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.01 | 0.01 | 0.03 |
| 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.04 | 0.06 |
| 1991 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.02 |
| 1992 | 0.01 | 0.01 | 0.01 | 0.02 | 0.03 | 0.03 | 0.04 | 0.08 | 0.10 |
| 1993 | 0.00 | 0.00 | 0.00 | 0.02 | 0.07 | 0.09 | 0.06 | 0.10 | 0.13 |
| 1994 | 0.00 | 0.00 | 0.01 | 0.04 | 0.11 | 0.13 | 0.07 | 0.08 | 0.10 |
| 1995 | 0.00 | 0.00 | 0.01 | 0.04 | 0.11 | 0.10 | 0.06 | 0.07 | 0.10 |
| 1996 | 0.01 | 0.01 | 0.01 | 0.05 | 0.11 | 0.12 | 0.07 | 0.08 | 0.09 |
| 1997 | 0.00 | 0.00 | 0.01 | 0.04 | 0.10 | 0.11 | 0.09 | 0.09 | 0.12 |
| 1998 | 0.01 | 0.01 | 0.02 | 0.06 | 0.13 | 0.13 | 0.08 | 0.08 | 0.10 |
| 1999 | 0.00 | 0.01 | 0.02 | 0.05 | 0.11 | 0.09 | 0.06 | 0.07 | 0.09 |
| 2000 | 0.01 | 0.01 | 0.02 | 0.05 | 0.11 | 0.09 | 0.06 | 0.06 | 0.10 |
| 2001 | 0.01 | 0.01 | 0.01 | 0.04 | 0.08 | 0.07 | 0.06 | 0.09 | 0.11 |
| 2002 | 0.01 | 0.01 | 0.02 | 0.04 | 0.10 | 0.10 | 0.06 | 0.06 | 0.08 |
| 2003 | 0.00 | 0.01 | 0.02 | 0.05 | 0.11 | 0.12 | 0.07 | 0.07 | 0.11 |
| 2004 | 0.01 | 0.01 | 0.02 | 0.06 | 0.11 | 0.11 | 0.07 | 0.07 | 0.09 |
| 2005 | 0.01 | 0.01 | 0.02 | 0.05 | 0.11 | 0.13 | 0.09 | 0.09 | 0.11 |
| 2006 | 0.00 | 0.01 | 0.02 | 0.06 | 0.12 | 0.12 | 0.11 | 0.09 | 0.10 |
| 2007 | 0.01 | 0.01 | 0.01 | 0.04 | 0.10 | 0.12 | 0.11 | 0.11 | 0.11 |
| 2008 | 0.00 | 0.01 | 0.01 | 0.03 | 0.11 | 0.12 | 0.08 | 0.10 | 0.13 |
| 2009 | 0.01 | 0.01 | 0.01 | 0.04 | 0.08 | 0.11 | 0.09 | 0.09 | 0.11 |
| 2010 | 0.01 | 0.01 | 0.02 | 0.05 | 0.10 | 0.09 | 0.06 | 0.07 | 0.09 |

**Table 5.11** (Cont.)

| Year | Yearly Menhaden Length Increments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **(180,190]** | **(190,200]** | **(200,210]** | **(210,220]** | **(220,230]** | **(230,240]** | **(240,250]** | **(250,260]** | **(260,270]** |
| 1986 | 0.03 | 0.05 | 0.10 | 0.09 | 0.05 | 0.02 | 0.01 | 0.00 | 0.01 |
| 1987 | 0.04 | 0.06 | 0.12 | 0.10 | 0.06 | 0.03 | 0.01 | 0.01 | 0.01 |
| 1988 | 0.07 | 0.12 | 0.19 | 0.18 | 0.11 | 0.04 | 0.01 | 0.01 | 0.01 |
| 1989 | 0.05 | 0.14 | 0.24 | 0.25 | 0.14 | 0.05 | 0.01 | 0.01 | 0.01 |
| 1990 | 0.09 | 0.14 | 0.22 | 0.18 | 0.09 | 0.04 | 0.03 | 0.02 | 0.03 |
| 1991 | 0.04 | 0.10 | 0.19 | 0.22 | 0.18 | 0.09 | 0.03 | 0.01 | 0.02 |
| 1992 | 0.07 | 0.07 | 0.12 | 0.15 | 0.13 | 0.05 | 0.02 | 0.01 | 0.01 |
| 1993 | 0.08 | 0.07 | 0.09 | 0.10 | 0.07 | 0.04 | 0.02 | 0.01 | 0.01 |
| 1994 | 0.08 | 0.07 | 0.08 | 0.09 | 0.06 | 0.03 | 0.01 | 0.00 | 0.00 |
| 1995 | 0.07 | 0.07 | 0.10 | 0.09 | 0.07 | 0.04 | 0.02 | 0.01 | 0.01 |
| 1996 | 0.08 | 0.06 | 0.08 | 0.09 | 0.06 | 0.03 | 0.01 | 0.00 | 0.00 |
| 1997 | 0.09 | 0.07 | 0.09 | 0.07 | 0.05 | 0.03 | 0.01 | 0.00 | 0.01 |
| 1998 | 0.07 | 0.05 | 0.08 | 0.08 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 |
| 1999 | 0.07 | 0.07 | 0.09 | 0.09 | 0.06 | 0.02 | 0.01 | 0.01 | 0.01 |
| 2000 | 0.10 | 0.09 | 0.10 | 0.09 | 0.05 | 0.02 | 0.01 | 0.00 | 0.00 |
| 2001 | 0.09 | 0.09 | 0.12 | 0.11 | 0.06 | 0.03 | 0.01 | 0.00 | 0.01 |
| 2002 | 0.08 | 0.07 | 0.11 | 0.12 | 0.07 | 0.02 | 0.01 | 0.01 | 0.01 |
| 2003 | 0.07 | 0.05 | 0.09 | 0.10 | 0.06 | 0.02 | 0.01 | 0.00 | 0.00 |
| 2004 | 0.08 | 0.07 | 0.10 | 0.09 | 0.05 | 0.01 | 0.01 | 0.00 | 0.01 |
| 2005 | 0.09 | 0.07 | 0.09 | 0.07 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 |
| 2006 | 0.08 | 0.07 | 0.08 | 0.07 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2007 | 0.08 | 0.06 | 0.09 | 0.07 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2008 | 0.10 | 0.08 | 0.09 | 0.07 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2009 | 0.11 | 0.08 | 0.10 | 0.08 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 |
| 2010 | 0.09 | 0.08 | 0.10 | 0.10 | 0.07 | 0.02 | 0.01 | 0.01 | 0.00 |

**Table 5.11** (Cont.)

| Year | Yearly Menhaden Length Increments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **(270,280]** | **(280,290]** | **(290,300]** | **(300,310]** | **(310,320]** | **(320,330]** | **(330,340]** | **(340,350]** | **(350,360]** |
| 1986 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988 | 0.02 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1989 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1990 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1991 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1992 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1994 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1995 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1996 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1997 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1998 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1999 | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2001 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2002 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2005 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2006 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2007 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2008 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 5.11** (Cont.)

| Year | Yearly Menhaden Length Increments | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (360,370] | (370,380] | (380,390] | (390,400] | (400,410] | (410,420] | (420,430] | (430,440] | (440,450] |
| 1986 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1989 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1991 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1994 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1995 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1996 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1997 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1998 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1999 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2001 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2002 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2005 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2006 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2007 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2008 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 5.11** (Cont.)

| Year | Yearly Menhaden Length Increments | | | | | |
|---|---|---|---|---|---|---|
| | **(450,460]** | **(460,470]** | **(470,480]** | **(480,490]** | **(490,500]** | **(500,770]** |
| 1986 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1989 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1991 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1994 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1995 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1996 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1997 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1998 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1999 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2001 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2002 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2005 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2006 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2007 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2008 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 6.1** The scaled gillnet index over time and associated coefficient of variation using only the Louisiana data. This index was redone at the assessment workshop and is the index in the base run.

| Year | Scaled index | CV |
|---|---|---|
| 1986 | 0.89 | 0.08 |
| 1987 | 0.55 | 0.09 |
| 1988 | 1.05 | 0.07 |
| 1989 | 0.75 | 0.08 |
| 1990 | 0.77 | 0.08 |
| 1991 | 0.79 | 0.08 |
| 1992 | 0.60 | 0.09 |
| 1993 | 0.55 | 0.09 |
| 1994 | 0.84 | 0.09 |
| 1995 | 0.69 | 0.09 |
| 1996 | 0.76 | 0.08 |
| 1997 | 1.11 | 0.08 |
| 1998 | 1.05 | 0.08 |
| 1999 | 0.80 | 0.08 |
| 2000 | 1.03 | 0.07 |
| 2001 | 1.15 | 0.08 |
| 2002 | 1.05 | 0.07 |
| 2003 | 1.04 | 0.07 |
| 2004 | 0.94 | 0.08 |
| 2005 | 1.16 | 0.07 |
| 2006 | 1.13 | 0.07 |
| 2007 | 0.92 | 0.07 |
| 2008 | 2.44 | 0.07 |
| 2009 | 2.09 | 0.06 |
| 2010 | 0.82 | 0.08 |

**Table 6.2** Gillnet length compositions using Louisiana data only for 1986 to 2010. Sample size is the number of net sets that measured lengths of gulf menhaden.

| Sample size | Year | Yearly Menhaden Length Increments for Louisiana Only | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | **(0,10]** | **(10,20]** | **(20,30]** | **(30,40]** | **(40,50]** | **(50,60]** | **(60,70]** | **(70,80]** | **(80,90]** |
| 351 | 1986 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 235 | 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 35 | 1988 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 1989 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 4 | 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5 | 1991 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 82 | 1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 196 | 1993 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 194 | 1994 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 213 | 1995 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 262 | 1996 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| 280 | 1997 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 366 | 1998 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 325 | 1999 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 410 | 2000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 353 | 2001 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 383 | 2002 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 387 | 2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 348 | 2004 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 374 | 2005 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 460 | 2006 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| 375 | 2007 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| 439 | 2008 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 461 | 2009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 287 | 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 6.2** (Cont.)

| Year | Yearly Menhaden Length Increments for Louisiana Only | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **(90,100]** | **(100,110]** | **(110,120]** | **(120,130]** | **(130,140]** | **(140,150]** | **(150,160]** | **(160,170]** | **(170,180]** |
| 1986 | 0.01 | 0.02 | 0.03 | 0.10 | 0.23 | 0.24 | 0.12 | 0.10 | 0.05 |
| 1987 | 0.02 | 0.01 | 0.02 | 0.07 | 0.22 | 0.28 | 0.11 | 0.06 | 0.03 |
| 1988 | 0.00 | 0.01 | 0.00 | 0.03 | 0.06 | 0.16 | 0.10 | 0.12 | 0.24 |
| 1989 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.20 | 0.20 |
| 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 0.08 | 0.15 | 0.00 | 0.08 | 0.08 |
| 1991 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.22 |
| 1992 | 0.01 | 0.01 | 0.03 | 0.03 | 0.06 | 0.07 | 0.08 | 0.16 | 0.19 |
| 1993 | 0.01 | 0.01 | 0.01 | 0.03 | 0.10 | 0.13 | 0.08 | 0.14 | 0.18 |
| 1994 | 0.00 | 0.00 | 0.01 | 0.05 | 0.14 | 0.16 | 0.08 | 0.09 | 0.12 |
| 1995 | 0.00 | 0.01 | 0.01 | 0.06 | 0.16 | 0.14 | 0.09 | 0.10 | 0.13 |
| 1996 | 0.01 | 0.01 | 0.02 | 0.06 | 0.15 | 0.16 | 0.09 | 0.11 | 0.11 |
| 1997 | 0.01 | 0.00 | 0.01 | 0.05 | 0.12 | 0.14 | 0.11 | 0.11 | 0.14 |
| 1998 | 0.01 | 0.01 | 0.03 | 0.07 | 0.17 | 0.17 | 0.11 | 0.10 | 0.12 |
| 1999 | 0.01 | 0.01 | 0.03 | 0.08 | 0.16 | 0.14 | 0.09 | 0.10 | 0.12 |
| 2000 | 0.01 | 0.01 | 0.02 | 0.07 | 0.14 | 0.11 | 0.07 | 0.07 | 0.12 |
| 2001 | 0.01 | 0.01 | 0.01 | 0.05 | 0.11 | 0.10 | 0.08 | 0.11 | 0.13 |
| 2002 | 0.01 | 0.02 | 0.03 | 0.06 | 0.13 | 0.14 | 0.09 | 0.09 | 0.10 |
| 2003 | 0.01 | 0.01 | 0.03 | 0.09 | 0.18 | 0.18 | 0.10 | 0.10 | 0.13 |
| 2004 | 0.01 | 0.02 | 0.04 | 0.11 | 0.17 | 0.17 | 0.10 | 0.10 | 0.09 |
| 2005 | 0.01 | 0.01 | 0.03 | 0.07 | 0.15 | 0.17 | 0.11 | 0.11 | 0.13 |
| 2006 | 0.01 | 0.01 | 0.02 | 0.09 | 0.16 | 0.15 | 0.14 | 0.10 | 0.11 |
| 2007 | 0.01 | 0.01 | 0.02 | 0.05 | 0.14 | 0.17 | 0.14 | 0.14 | 0.13 |
| 2008 | 0.00 | 0.01 | 0.02 | 0.04 | 0.13 | 0.15 | 0.09 | 0.11 | 0.15 |
| 2009 | 0.01 | 0.01 | 0.02 | 0.04 | 0.09 | 0.13 | 0.10 | 0.11 | 0.12 |
| 2010 | 0.01 | 0.01 | 0.02 | 0.07 | 0.14 | 0.12 | 0.08 | 0.10 | 0.11 |

**Table 6.2** (Cont.)

| Year | Yearly Menhaden Length Increments for Louisiana Only | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **(180,190]** | **(190,200]** | **(200,210]** | **(210,220]** | **(220,230]** | **(230,240]** | **(240,250]** | **(250,260]** | **(260,270]** |
| 1986 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1987 | 0.03 | 0.03 | 0.05 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1988 | 0.12 | 0.06 | 0.07 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 |
| 1989 | 0.00 | 0.00 | 0.20 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1990 | 0.00 | 0.15 | 0.00 | 0.15 | 0.00 | 0.15 | 0.08 | 0.00 | 0.08 |
| 1991 | 0.22 | 0.33 | 0.11 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1992 | 0.12 | 0.08 | 0.07 | 0.06 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993 | 0.10 | 0.06 | 0.06 | 0.05 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1994 | 0.09 | 0.08 | 0.07 | 0.06 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1995 | 0.09 | 0.06 | 0.05 | 0.04 | 0.03 | 0.02 | 0.00 | 0.00 | 0.00 |
| 1996 | 0.08 | 0.05 | 0.05 | 0.04 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1997 | 0.10 | 0.07 | 0.06 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1998 | 0.08 | 0.04 | 0.04 | 0.02 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 |
| 1999 | 0.09 | 0.07 | 0.06 | 0.03 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2000 | 0.12 | 0.09 | 0.08 | 0.06 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2001 | 0.10 | 0.08 | 0.08 | 0.06 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 |
| 2002 | 0.08 | 0.06 | 0.07 | 0.05 | 0.04 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2003 | 0.08 | 0.03 | 0.03 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004 | 0.07 | 0.04 | 0.04 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2005 | 0.09 | 0.04 | 0.04 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2006 | 0.08 | 0.05 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2007 | 0.07 | 0.04 | 0.03 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2008 | 0.11 | 0.07 | 0.06 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2009 | 0.12 | 0.08 | 0.08 | 0.05 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 |
| 2010 | 0.10 | 0.07 | 0.06 | 0.05 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 |

**Table 6.2** (Cont.)

| Year | Yearly Menhaden Length Increments for Louisiana Only | | | | | | |
|---|---|---|---|---|---|---|---|
| | **(270,280]** | **(280,290]** | **(290,300]** | **(300,310]** | **(310,320]** | **(320,330]** | **(330,340+]** |
| 1986 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1987 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1988 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1989 | 0.00 | 0.00 | 0.20 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1990 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1991 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1992 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1993 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1994 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1995 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1996 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1997 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1998 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1999 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2001 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2002 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2003 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2004 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2005 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2006 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2007 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2008 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2009 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

**Table 6.3** Ageing error matrix determined for the comparison between otoliths and scales.

| | 0 | 1 | 2 | 3 | 4+ |
|---|---|---|---|---|---|
| 0 | 1.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1 | 0.00 | 1.00 | 0.11 | 0.00 | 0.00 |
| 2 | 0.00 | 0.00 | 0.78 | 0.16 | 0.00 |
| 3 | 0.00 | 0.00 | 0.11 | 0.68 | 0.17 |
| 4+ | 0.00 | 0.00 | 0.00 | 0.16 | 0.83 |

**Table 6.4** Weight (g) at age for gulf menhaden on a January 1 birthday.

| Year | 0 | 1 | 2 | 3 | 4+ |
|---|---|---|---|---|---|
| 1948 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1949 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1950 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1951 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1952 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1953 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1954 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1955 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1956 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1957 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1958 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1959 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1960 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1961 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1962 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1963 | 0.00 | 43.3 | 95.7 | 157.6 | 222.4 |
| 1964 | 0.00 | 45.0 | 99.3 | 152.7 | 196.7 |
| 1965 | 0.00 | 39.8 | 90.5 | 162.7 | 253.1 |
| 1966 | 0.00 | 45.2 | 97.2 | 157.3 | 217.5 |
| 1967 | 0.00 | 38.1 | 94.9 | 147.8 | 187.8 |
| 1968 | 0.00 | 41.4 | 101.4 | 171.0 | 238.6 |
| 1969 | 0.00 | 47.6 | 94.2 | 155.5 | 228.7 |
| 1970 | 0.00 | 41.8 | 103.4 | 159.2 | 200.0 |
| 1971 | 0.00 | 43.6 | 104.6 | 163.4 | 209.9 |
| 1972 | 0.00 | 46.0 | 111.8 | 162.3 | 193.3 |
| 1973 | 0.00 | 54.9 | 116.8 | 194.3 | 279.7 |
| 1974 | 0.00 | 45.1 | 125.9 | 181.8 | 211.5 |
| 1975 | 0.00 | 50.7 | 108.6 | 190.7 | 295.4 |
| 1976 | 0.00 | 42.9 | 100.3 | 171.2 | 246.6 |
| 1977 | 0.00 | 36.3 | 82.7 | 144.6 | 216.9 |
| 1978 | 0.00 | 48.8 | 95.0 | 155.7 | 228.1 |
| 1979 | 0.00 | 48.4 | 99.2 | 149.2 | 191.5 |
| 1980 | 0.00 | 24.2 | 93.3 | 163.3 | 214.2 |
| 1981 | 0.00 | 34.4 | 87.0 | 140.8 | 185.7 |
| 1982 | 0.00 | 46.5 | 91.2 | 143.6 | 198.1 |
| 1983 | 0.00 | 39.2 | 98.7 | 155.0 | 197.9 |
| 1984 | 0.00 | 32.4 | 94.2 | 153.7 | 198.1 |
| 1985 | 0.00 | 33.1 | 90.0 | 143.4 | 183.0 |
| 1986 | 0.00 | 26.6 | 82.0 | 140.7 | 188.7 |
| 1987 | 0.00 | 39.0 | 80.6 | 127.0 | 172.0 |
| 1988 | 0.00 | 31.3 | 86.1 | 136.7 | 173.4 |
| 1989 | 0.00 | 39.4 | 87.5 | 139.1 | 186.2 |
| 1990 | 0.00 | 39.0 | 96.6 | 152.1 | 195.6 |
| 1991 | 0.00 | 53.9 | 106.0 | 156.9 | 200.0 |

**Table 6.4** (Cont.)

| **Year** | **0** | **1** | **2** | **3** | **4+** |
|---|---|---|---|---|---|
| 1992 | 0.00 | 52.3 | 104.7 | 152.0 | 188.7 |
| 1993 | 0.00 | 55.3 | 106.8 | 157.3 | 200.6 |
| 1994 | 0.00 | 44.4 | 98.8 | 149.6 | 189.6 |
| 1995 | 0.00 | 52.0 | 107.7 | 161.3 | 205.2 |
| 1996 | 0.00 | 42.9 | 95.5 | 149.7 | 196.6 |
| 1997 | 0.00 | 40.5 | 99.3 | 150.4 | 186.1 |
| 1998 | 0.00 | 47.4 | 99.2 | 145.8 | 181.6 |
| 1999 | 0.00 | 60.7 | 108.8 | 154.9 | 194.2 |
| 2000 | 0.00 | 46.1 | 91.2 | 130.4 | 159.8 |
| 2001 | 0.00 | 75.9 | 119.5 | 160.8 | 196.9 |
| 2002 | 0.00 | 47.3 | 100.9 | 146.8 | 179.9 |
| 2003 | 0.00 | 38.1 | 86.0 | 133.0 | 171.9 |
| 2004 | 0.00 | 41.4 | 88.3 | 132.2 | 167.0 |
| 2005 | 0.00 | 55.3 | 92.1 | 128.9 | 162.6 |
| 2006 | 0.00 | 41.3 | 89.0 | 127.6 | 153.6 |
| 2007 | 0.00 | 44.9 | 94.1 | 136.9 | 168.3 |
| 2008 | 0.00 | 50.3 | 105.2 | 146.4 | 171.9 |
| 2009 | 0.00 | 66.3 | 101.5 | 136.2 | 168.0 |
| 2010 | 0.00 | 39.9 | 97.1 | 139.8 | 165.3 |

**Table 6.5** Weight (g) at age for the middle of the year, which is also the middle of the fishing year.

| Year | 0 | 1 | 2 | 3 | 4+ |
|---|---|---|---|---|---|
| 1948 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1949 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1950 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1951 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1952 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1953 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1954 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1955 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1956 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1957 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1958 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1959 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1960 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1961 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1962 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1963 | 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 1964 | 33.3 | 71.4 | 126.9 | 176.1 | 214.6 |
| 1965 | 30.6 | 62.4 | 124.1 | 205.8 | 303.9 |
| 1966 | 34.6 | 69.6 | 126.8 | 187.8 | 245.9 |
| 1967 | 26.0 | 65.8 | 122.8 | 169.5 | 202.9 |
| 1968 | 29.8 | 69.3 | 135.9 | 205.6 | 269.5 |
| 1969 | 38.4 | 68.9 | 123.2 | 190.8 | 268.7 |
| 1970 | 28.5 | 72.0 | 133.0 | 181.5 | 215.0 |
| 1971 | 30.6 | 73.1 | 135.2 | 188.4 | 228.0 |
| 1972 | 30.5 | 79.6 | 139.7 | 179.9 | 203.2 |
| 1973 | 42.7 | 83.4 | 154.1 | 236.5 | 323.3 |
| 1974 | 26.3 | 86.9 | 157.7 | 199.2 | 220.0 |
| 1975 | 40.0 | 76.6 | 146.7 | 240.4 | 355.5 |
| 1976 | 31.8 | 69.3 | 134.7 | 208.8 | 283.8 |
| 1977 | 27.6 | 57.3 | 112.1 | 179.8 | 255.4 |
| 1978 | 39.7 | 69.9 | 123.7 | 190.6 | 267.8 |
| 1979 | 37.1 | 73.1 | 124.9 | 171.5 | 209.1 |
| 1980 | 12.6 | 56.0 | 130.2 | 191.4 | 232.2 |
| 1981 | 23.8 | 59.5 | 114.6 | 164.6 | 203.9 |
| 1982 | 37.2 | 67.5 | 116.9 | 170.9 | 224.7 |
| 1983 | 26.7 | 68.0 | 128.2 | 178.3 | 214.1 |
| 1984 | 20.2 | 62.0 | 125.5 | 178.0 | 214.5 |
| 1985 | 21.5 | 60.6 | 118.2 | 165.0 | 197.7 |
| 1986 | 16.3 | 52.4 | 112.2 | 166.3 | 207.6 |
| 1987 | 30.3 | 58.7 | 103.7 | 150.0 | 192.9 |
| 1988 | 20.0 | 57.9 | 112.9 | 156.8 | 186.7 |
| 1989 | 29.4 | 62.3 | 113.5 | 163.5 | 206.8 |
| 1990 | 26.9 | 66.9 | 125.6 | 175.6 | 212.5 |

**Table 6.5** (Cont.)

| **Year** | **0** | **1** | **2** | **3** | **4+** |
|---|---|---|---|---|---|
| 1991 | 42.1 | 79.4 | 132.1 | 179.6 | 218.0 |
| 1992 | 40.0 | 78.5 | 129.5 | 171.7 | 203.1 |
| 1993 | 43.6 | 80.5 | 132.7 | 180.1 | 219.0 |
| 1994 | 32.3 | 71.1 | 125.3 | 171.1 | 205.2 |
| 1995 | 39.6 | 79.3 | 135.4 | 184.6 | 223.1 |
| 1996 | 31.7 | 68.1 | 123.2 | 174.4 | 216.3 |
| 1997 | 27.4 | 69.6 | 126.7 | 170.1 | 198.7 |
| 1998 | 35.4 | 73.1 | 123.7 | 165.1 | 195.3 |
| 1999 | 49.5 | 84.5 | 132.5 | 175.5 | 210.9 |
| 2000 | 35.3 | 68.8 | 112.0 | 146.3 | 171.0 |
| 2001 | 65.3 | 97.7 | 140.7 | 179.6 | 212.6 |
| 2002 | 34.8 | 74.2 | 125.4 | 165.0 | 192.1 |
| 2003 | 27.8 | 61.3 | 110.3 | 153.7 | 187.7 |
| 2004 | 30.9 | 64.5 | 111.2 | 150.9 | 180.7 |
| 2005 | 46.6 | 73.4 | 110.7 | 146.3 | 177.8 |
| 2006 | 29.8 | 65.5 | 109.9 | 142.0 | 162.7 |
| 2007 | 33.4 | 69.5 | 116.8 | 154.0 | 180.0 |
| 2008 | 36.5 | 78.7 | 127.9 | 160.8 | 180.3 |
| 2009 | 57.8 | 83.8 | 119.1 | 152.6 | 182.5 |
| 2010 | 26.3 | 69.2 | 120.8 | 154.3 | 173.3 |

**Table 6.6** Fecundity at age for ages 0 to 4+ for 1948-2010.

| Year | 0 | 1 | 2 | 3 | 4+ |
|---|---|---|---|---|---|
| 1948 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1949 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1950 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1951 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1952 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1953 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1954 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1955 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1956 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1957 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1958 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1959 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1960 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1961 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1962 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1963 | 0.0 | 8493 | 21641 | 38974 | 58568 |
| 1964 | 0.0 | 9310 | 23161 | 38020 | 50894 |
| 1965 | 0.0 | 7720 | 20105 | 39791 | 66601 |
| 1966 | 0.0 | 8448 | 21657 | 39110 | 58210 |
| 1967 | 0.0 | 7075 | 22273 | 38862 | 52492 |
| 1968 | 0.0 | 7855 | 23500 | 44562 | 66991 |
| 1969 | 0.0 | 9294 | 21812 | 40772 | 65957 |
| 1970 | 0.0 | 8074 | 24020 | 40373 | 53114 |
| 1971 | 0.0 | 8615 | 24348 | 41351 | 55631 |
| 1972 | 0.0 | 9188 | 27162 | 42783 | 52917 |
| 1973 | 0.0 | 10122 | 25417 | 47259 | 73668 |
| 1974 | 0.0 | 8302 | 31388 | 50499 | 61438 |
| 1975 | 0.0 | 10185 | 26047 | 52154 | 89510 |
| 1976 | 0.0 | 8135 | 24503 | 49053 | 78743 |
| 1977 | 0.0 | 7080 | 19862 | 39982 | 66398 |
| 1978 | 0.0 | 9954 | 22119 | 39955 | 63125 |
| 1979 | 0.0 | 10391 | 24331 | 39507 | 53133 |
| 1980 | 0.0 | 4816 | 22174 | 41800 | 56802 |
| 1981 | 0.0 | 6401 | 19909 | 35899 | 50373 |
| 1982 | 0.0 | 9570 | 20845 | 35182 | 50972 |
| 1983 | 0.0 | 7692 | 22931 | 39107 | 52201 |
| 1984 | 0.0 | 5874 | 21289 | 38409 | 52161 |
| 1985 | 0.0 | 6243 | 21518 | 38301 | 51818 |
| 1986 | 0.0 | 4489 | 17635 | 33953 | 48483 |
| 1987 | 0.0 | 7392 | 17956 | 31283 | 45328 |
| 1988 | 0.0 | 5324 | 18838 | 33512 | 45084 |
| 1989 | 0.0 | 7230 | 18982 | 33275 | 47351 |
| 1990 | 0.0 | 6904 | 20835 | 36215 | 49185 |
| 1991 | 0.0 | 10585 | 23594 | 37548 | 50055 |

**Table 6.6** (Cont.)

| **Year** | **0** | **1** | **2** | **3** | **4+** |
|---|---|---|---|---|---|
| 1992 | 0.0 | 9136 | 22873 | 37426 | 49828 |
| 1993 | 0.0 | 10052 | 22850 | 37031 | 50148 |
| 1994 | 0.0 | 8296 | 23083 | 39286 | 53176 |
| 1995 | 0.0 | 10001 | 23829 | 38581 | 51452 |
| 1996 | 0.0 | 8830 | 22398 | 37748 | 51799 |
| 1997 | 0.0 | 7601 | 22869 | 38026 | 49370 |
| 1998 | 0.0 | 8730 | 22434 | 36724 | 48589 |
| 1999 | 0.0 | 12299 | 25058 | 38570 | 50845 |
| 2000 | 0.0 | 8846 | 22503 | 36686 | 48445 |
| 2001 | 0.0 | 15164 | 27114 | 39653 | 51381 |
| 2002 | 0.0 | 9419 | 24290 | 38868 | 50145 |
| 2003 | 0.0 | 7201 | 20208 | 35159 | 48665 |
| 2004 | 0.0 | 7877 | 19700 | 32115 | 42592 |
| 2005 | 0.0 | 10773 | 20634 | 31671 | 42563 |
| 2006 | 0.0 | 7744 | 20214 | 31712 | 39984 |
| 2007 | 0.0 | 8597 | 21106 | 33281 | 42765 |
| 2008 | 0.0 | 10110 | 24183 | 35707 | 43176 |
| 2009 | 0.0 | 14042 | 24338 | 35553 | 46606 |
| 2010 | 0.0 | 7259 | 22489 | 35755 | 44264 |

**Table 6.7** Index comparisons for usefulness in the BAM, ASPIC, and SRA models.

| Index | Pros | Cons | Comments |
|---|---|---|---|
| Reduction | Longer Dataset -1948<br>Large sample size<br>VTW with 1% efficiency | Fishing grounds shrinking in recent years, not population range<br>Plant processing/capacity saturation | Correlates well with JAI |
| LA Gillnet | Statistically designed sampling | Doesn't reflect entire population range<br>Short duration (1986-2010)<br>No age data | Not well correlated with other indices.<br>Two very high points (2008, 2009) are questionable. |
| Seine | Statistically designed sampling<br>Includes all states | Short Duration (1977-2010) | Age-0s<br>Highly correlated to trawl |
| Trawl | Statistically designed sampling<br>Includes all states<br>Long duration (1967-2010) | No gear standardization among states | Size cutoff at 100 mm to isolate age-0s<br>Highly correlated to seine |

**Table 6.8** Pairwise correlations between abundance indices of gulf menhaden. The gillnet index is based on Louisiana data only. The commercial reduction index is the raw index with no modifications for catchability changes. When correlating an adult index with a juvenile index, a one-year lag was used.

| | **Adult indices** | | **Juvenile indices** | |
|---|---|---|---|---|
| | **Gillnet** | **Reduction** | **Seine** | **Trawl** |
| Gillnet | 1.00 | 0.02 | -0.30 | 0.10 |
| Reduction | 0.02 | 1.00 | 0.51 | 0.16 |
| Seine | -0.30 | 0.51 | 1.00 | 0.53 |
| Trawl | 0.10 | 0.16 | 0.53 | 1.00 |

**Table 7.1** Model comparisons for use in the gulf menhaden assessment.

| **Criteria** | **BAM** | **ASPIC** | **SRA** |
|---|---|---|---|
| Applicability to mgmt (benchmarks) | Multiple options for benchmark computation | Internally estimated benchmarks | Limited to MSY 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) | Peer reviewed for other species (Gag, red snapper, red and yellowedge grouper, tilefish) |
| Data requirements | All available menhaden data | Less data required (limited to landings, effort, and indices; less than SRA) | Less data required (limited to landings and indices); need prior distributions |
| Model complexity | Moderate | Low | Low |
| Measures of uncertainty | Bootstrap and sensitivity runs | Bootstrap and sensitivity runs | MCMC and sensitivity runs |
| Understanding model properties and operation | Familiar among committee | Familiar among committee | Familiar among committee |
| Appropriateness of model assumptions for menhaden | Very appropriate, flexible relative to MSY benchmarks | Appropriate, MSY benchmarks can be obtained | Appropriate, MSY benchmarks can be obtained |
| Model diagnostics | Many | Moderate | Few |

**Table 7.2** 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: $y = \{1948,..,2010\}$ | $y$ | |
| Age index: $a = \{0,...,4+\}$ | $a$ | |
| Length index: $l = \{5,…,405+\}$ | $l$ | |
| **Input Data** | **Symbol** | **Description/Definition** |
| 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 |
| Maturity at age | $m_a$ | From data workshop |
| Fecundity at age | $\gamma_a$ | From data workshop |
| Observed age-0 CPUE<br>$y = \{1977,...,2010\}$ | $U_{1,y}$ | Based on numbers of age-0 fish from state seine surveys (selected at Assessment Workshop) |
| Observed gillnet CPUE<br>$y = \{1986,...,2010\}$ | $U_{2,y}$ | Based on gillnet survey from Louisiana (selected at Assessment Workshop) |
| Selectivity for $U_2$ | $\hat{s}'_a$ | Fixed at 0 for $a = \{0\}$, 1.0 for $a = \{2\}$, and estimated for $a = \{1,3, \text{and } 4+\}$ (from Assessment Workshop) |
| 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 data workshop |
| Observed natural mortality | $M_a$ | From data workshop, varies with age and is constant across time. Scaled to empirically based value from Arhenholz (1981). |
| **Population Model** | **Symbol** | **Description/Definition** |
| Fishery selectivity | $\hat{s}_{a,y}$ | Estimated for each year (y) 1964-2010. Assumed to be the average of 1964-1966 for 1948-1963. For 1964-1979, age-0 was assumed 0.0, age-2 was assumed 1.0, and ages-1, 3, and 4 were estimated. For 1980-2010, age-0 was assumed 0.0, age-2+ was assumed 1.0, and age-1 was estimated. |
| Fishing mortality (fully selected) | $F_{a,y}$ | $F_{a,y} = \hat{s}_{a,y}\hat{F}_y$ where $s_{a,y}$ and $F_y$ values for each year are estimated parameters |
| Total mortality | $Z_{a,y}$ | $Z_{a,y} = M_a + F_{a,y}$ |

**Table 7.2** (C*ont.*)

| **Population Model** | **Symbol** | **Description/Definition** |
|---|---|---|
| Fecundity per recruit at *F* = 0 | $\phi$ | $\phi = \sum_{a=0}^{4+} N_a m_a \gamma_a 0.5 \Big/ N_0$<br>where $N_{a+1} = N_a \exp(-Z_a)$ and<br>$N_{4+} = N_3 \exp(-Z_3)/[1-\exp(-Z_{4+})]$ and the sex ratio is assumed to be 1:1. |
| Population numbers | $N_{a,y}$ | $N_{0,1948} = \frac{\hat{R}_0 (0.8\varsigma\hat{h} S_{equil} - 0.2\Phi_0 (1-\hat{h}))}{(\hat{h}-0.2) S_{equil}}$<br>$\hat{N}_{1+,1948}$ estimated subject to penalties for deviating from equilibrium conditions.<br>$N_{0,y+1} = \frac{0.8\hat{R}_0 \hat{h} S_{y+1}}{0.2\Phi_0 \hat{R}_0 (1-\hat{h}) + (\hat{h}-0.2) S_{y+1}} \exp(\hat{R}_{y+1})$<br>$N_{a+1,y+1} = N_{a,y} \exp(-Z_{a,y})$<br>$N_{A,y} = N_{A-1,y-1} \frac{\exp(-Z_{A-1,y-1})}{1-\exp(-Z_{A-1,y-1})}$ |
| Population fecundity | $\varepsilon_y$ | $\varepsilon_y = \sum_{a=0}^{4+} N_{a,y} m_a \gamma_a 0.5$ |
| Population biomass | $B_y$ | $B_y = \sum_{a=0}^{4+} N_{a,y} w_a^p$ |
| 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 catchability parameter |
| Predicted gillnet 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 catchability parameter |

**Table 7.2** (Cont.)

| **Population Model** | **Symbol** | **Description/Definition** |
|---|---|---|
| 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* |
| **Negative Log-Likelihood** | **Symbol** | **Description/Definition** |
| Multinomial age composition | $\Lambda_f$ | $\Lambda_f = \lambda_f n_y^a \sum_y \sum_l (p_{l,y} + x) \log\left(\frac{\breve{p}_{l,y} + x}{p_{l,y} + x}\right)$<br>where $\lambda_f$ is a preset weighting factor equal to 0.25 (from Assessment Workshop) and *x* is fixed at an arbitrary value of 0.001. |
| Lognormal indices | $\Lambda_f$ | $\Lambda_f = \lambda_f \sum_y \frac{\left[\log\left(U_{u,y} + x\right) - \log\left(\breve{U}_{u,y} + x\right)\right]^2}{2\sigma_U^2}$<br>where $\lambda_f$ is a preset weighting factor equal to 1.0 for both the seine and gillnet indices, *x* is fixed at an arbitrary value of 0.001, and $\sigma_U = \sqrt{\log(1 + (c_U)^2)}$ . |
| Lognormal landings | $\Lambda_f$ | $\Lambda_f = \lambda_f \sum_y \frac{\left[\log\left(L_y + x\right) - \log\left(\breve{L}_y + x\right)\right]^2}{2\sigma_L^2}$<br>where $\lambda_f$ is a preset weighting factor equal to 1.0, *x* is fixed at an arbitrary value of 0.001, and $\sigma_L = \sqrt{\log(1 + (c_L)^2)}$ . |
| Multinomial length composition | $\Lambda_f$ | $\Lambda_f = \lambda_f n_y^l \sum_y \sum_l (\tau_{l,y} + x) \log\left(\frac{\breve{\tau}_{l,y} + x}{\tau_{l,y} + x}\right)$<br>where $\lambda_f$ is a preset weighting factor equal to 0.5 (from the Assessment Workshop) and *x* is fixed at an arbitrary value of 0.001. |
| Lognormal recruitment deviations | $\Lambda_f$ | $\Lambda_f = \lambda_f \left[ R_{1948}^2 + \sum_{y>1948} \frac{\left[\left(R_y - R_{y-1}\right) + \left(\hat{\sigma}_R^2 / 2\right)\right]^2}{2\hat{\sigma}_R^2} \right]$<br>where $\lambda$ f is a preset weighting factor. |
| Penalty on initial age structure | $\Lambda_f$ | $\Lambda_f = \sum_{a=1}^{A} (\hat{N}_{a,1948} - N_a^{equil})^2$ |
| Prior distributions and penalties | $\Lambda_f$ | $\Lambda_f = \sum 0.5 * \frac{(pred - prior)^2}{prior} + \log(prior)$<br>The sum of all of the priors, which all have the functional form above, where pred is the predicted value and prior is the prior value. The gillnet selectivity and commercial reduction fishery selectivity from 1964-1979 both have priors for ages-1, -3, and -4. |

**Table 8.1** Estimated annual fishing mortality rates: Age2+ *F* (N-weighted over ages 2+) from the base BAM model and full *F*.

| Year | Age2+ *F* | Full *F* |
|---|---|---|
| 1948 | 0.03 | 0.04 |
| 1949 | 0.05 | 0.06 |
| 1950 | 0.07 | 0.08 |
| 1951 | 0.07 | 0.09 |
| 1952 | 0.11 | 0.13 |
| 1953 | 0.09 | 0.11 |
| 1954 | 0.09 | 0.10 |
| 1955 | 0.10 | 0.12 |
| 1956 | 0.12 | 0.14 |
| 1957 | 0.08 | 0.09 |
| 1958 | 0.09 | 0.11 |
| 1959 | 0.16 | 0.19 |
| 1960 | 0.19 | 0.23 |
| 1961 | 0.25 | 0.29 |
| 1962 | 0.27 | 0.32 |
| 1963 | 0.26 | 0.30 |
| 1964 | 0.24 | 0.28 |
| 1965 | 0.28 | 0.32 |
| 1966 | 0.21 | 0.24 |
| 1967 | 0.18 | 0.21 |
| 1968 | 0.20 | 0.23 |
| 1969 | 0.30 | 0.35 |
| 1970 | 0.33 | 0.39 |
| 1971 | 0.45 | 0.52 |
| 1972 | 0.31 | 0.36 |
| 1973 | 0.26 | 0.29 |
| 1974 | 0.31 | 0.35 |
| 1975 | 0.32 | 0.37 |
| 1976 | 0.37 | 0.42 |
| 1977 | 0.33 | 0.38 |
| 1978 | 0.64 | 0.76 |
| 1979 | 0.95 | 1.09 |
| 1980 | 1.15 | 1.15 |
| 1981 | 0.54 | 0.54 |
| 1982 | 1.45 | 1.45 |
| 1983 | 2.18 | 2.18 |
| 1984 | 1.19 | 1.19 |
| 1985 | 0.94 | 0.94 |
| 1986 | 1.67 | 1.67 |
| 1987 | 2.41 | 2.41 |
| 1988 | 0.93 | 0.93 |
| 1989 | 0.51 | 0.51 |
| 1990 | 0.70 | 0.70 |
| 1991 | 0.86 | 0.86 |
| 1992 | 0.43 | 0.43 |
| 1993 | 0.39 | 0.39 |
| 1994 | 0.84 | 0.84 |
| 1995 | 0.60 | 0.60 |
| 1996 | 0.73 | 0.73 |
| 1997 | 0.65 | 0.65 |
| 1998 | 0.53 | 0.53 |
| 1999 | 0.53 | 0.53 |
| 2000 | 0.66 | 0.66 |
| 2001 | 0.53 | 0.53 |
| 2002 | 0.80 | 0.80 |
| 2003 | 0.76 | 0.76 |
| 2004 | 0.56 | 0.56 |
| 2005 | 0.53 | 0.53 |
| 2006 | 0.58 | 0.58 |
| 2007 | 0.51 | 0.51 |
| 2008 | 0.45 | 0.45 |
| 2009 | 0.35 | 0.35 |
| 2010 | 0.26 | 0.26 |

**Table 8.2** Estimated full fishing mortality rates at age from the base BAM model.

| Year | 0 | 1 | 2 | 3 | 4+ |
|---|---|---|---|---|---|
| 1948 | 0.00 | 0.02 | 0.04 | 0.02 | 0.02 |
| 1949 | 0.00 | 0.03 | 0.06 | 0.03 | 0.03 |
| 1950 | 0.00 | 0.04 | 0.08 | 0.04 | 0.04 |
| 1951 | 0.00 | 0.04 | 0.09 | 0.04 | 0.04 |
| 1952 | 0.00 | 0.07 | 0.13 | 0.06 | 0.06 |
| 1953 | 0.00 | 0.06 | 0.11 | 0.06 | 0.06 |
| 1954 | 0.00 | 0.05 | 0.10 | 0.05 | 0.05 |
| 1955 | 0.00 | 0.06 | 0.12 | 0.06 | 0.06 |
| 1956 | 0.00 | 0.07 | 0.14 | 0.07 | 0.07 |
| 1957 | 0.00 | 0.05 | 0.09 | 0.05 | 0.05 |
| 1958 | 0.00 | 0.06 | 0.11 | 0.06 | 0.06 |
| 1959 | 0.00 | 0.10 | 0.19 | 0.09 | 0.09 |
| 1960 | 0.00 | 0.12 | 0.23 | 0.11 | 0.11 |
| 1961 | 0.00 | 0.15 | 0.29 | 0.14 | 0.14 |
| 1962 | 0.00 | 0.17 | 0.32 | 0.16 | 0.16 |
| 1963 | 0.00 | 0.15 | 0.30 | 0.15 | 0.15 |
| 1964 | 0.00 | 0.14 | 0.28 | 0.14 | 0.14 |
| 1965 | 0.00 | 0.17 | 0.32 | 0.16 | 0.16 |
| 1966 | 0.00 | 0.13 | 0.24 | 0.12 | 0.12 |
| 1967 | 0.00 | 0.12 | 0.21 | 0.10 | 0.10 |
| 1968 | 0.00 | 0.12 | 0.23 | 0.11 | 0.11 |
| 1969 | 0.00 | 0.18 | 0.35 | 0.17 | 0.17 |
| 1970 | 0.00 | 0.18 | 0.39 | 0.19 | 0.19 |
| 1971 | 0.00 | 0.26 | 0.52 | 0.26 | 0.26 |
| 1972 | 0.00 | 0.17 | 0.36 | 0.18 | 0.18 |
| 1973 | 0.00 | 0.15 | 0.29 | 0.14 | 0.14 |
| 1974 | 0.00 | 0.18 | 0.35 | 0.17 | 0.18 |
| 1975 | 0.00 | 0.17 | 0.37 | 0.18 | 0.18 |
| 1976 | 0.00 | 0.21 | 0.42 | 0.21 | 0.21 |
| 1977 | 0.00 | 0.23 | 0.38 | 0.15 | 0.16 |
| 1978 | 0.00 | 0.35 | 0.76 | 0.29 | 0.31 |
| 1979 | 0.00 | 0.26 | 1.09 | 0.50 | 0.45 |
| 1980 | 0.00 | 0.18 | 1.15 | 1.15 | 1.15 |
| 1981 | 0.00 | 0.30 | 0.54 | 0.54 | 0.54 |
| 1982 | 0.00 | 0.26 | 1.45 | 1.45 | 1.45 |
| 1983 | 0.00 | 0.21 | 2.18 | 2.18 | 2.18 |
| 1984 | 0.00 | 0.47 | 1.19 | 1.19 | 1.19 |
| 1985 | 0.00 | 0.40 | 0.94 | 0.94 | 0.94 |

**Table 8.2** (Cont.)

| **Year** | **0** | **1** | **2** | **3** | **4+** |
|---|---|---|---|---|---|
| 1986 | 0.00 | 0.21 | 1.67 | 1.67 | 1.67 |
| 1987 | 0.00 | 0.33 | 2.41 | 2.41 | 2.41 |
| 1988 | 0.00 | 0.27 | 0.93 | 0.93 | 0.93 |
| 1989 | 0.00 | 0.40 | 0.51 | 0.51 | 0.51 |
| 1990 | 0.00 | 0.24 | 0.70 | 0.70 | 0.70 |
| 1991 | 0.00 | 0.12 | 0.86 | 0.86 | 0.86 |
| 1992 | 0.00 | 0.15 | 0.43 | 0.43 | 0.43 |
| 1993 | 0.00 | 0.24 | 0.39 | 0.39 | 0.39 |
| 1994 | 0.00 | 0.24 | 0.84 | 0.84 | 0.84 |
| 1995 | 0.00 | 0.08 | 0.60 | 0.60 | 0.60 |
| 1996 | 0.00 | 0.09 | 0.73 | 0.73 | 0.73 |
| 1997 | 0.00 | 0.16 | 0.65 | 0.65 | 0.65 |
| 1998 | 0.00 | 0.08 | 0.53 | 0.53 | 0.53 |
| 1999 | 0.00 | 0.15 | 0.53 | 0.53 | 0.53 |
| 2000 | 0.00 | 0.10 | 0.66 | 0.66 | 0.66 |
| 2001 | 0.00 | 0.05 | 0.53 | 0.53 | 0.53 |
| 2002 | 0.00 | 0.07 | 0.80 | 0.80 | 0.80 |
| 2003 | 0.00 | 0.08 | 0.76 | 0.76 | 0.76 |
| 2004 | 0.00 | 0.12 | 0.56 | 0.56 | 0.56 |
| 2005 | 0.00 | 0.07 | 0.53 | 0.53 | 0.53 |
| 2006 | 0.00 | 0.09 | 0.58 | 0.58 | 0.58 |
| 2007 | 0.00 | 0.08 | 0.51 | 0.51 | 0.51 |
| 2008 | 0.00 | 0.02 | 0.45 | 0.45 | 0.45 |
| 2009 | 0.00 | 0.01 | 0.35 | 0.35 | 0.35 |
| 2010 | 0.00 | 0.10 | 0.26 | 0.26 | 0.26 |

**Table 8.3** Estimated numbers of gulf menhaden (billions) at the start of the fishing year from the base BAM model.

| Year | 0 | 1 | 2 | 3 | 4+ |
|---|---|---|---|---|---|
| 1948 | 204.62 | 38.52 | 10.09 | 3.17 | 1.83 |
| 1949 | 204.88 | 38.52 | 10.18 | 3.22 | 1.84 |
| 1950 | 204.74 | 38.57 | 10.08 | 3.19 | 1.85 |
| 1951 | 204.33 | 38.54 | 9.98 | 3.10 | 1.82 |
| 1952 | 204.02 | 38.46 | 9.95 | 3.05 | 1.77 |
| 1953 | 203.17 | 38.41 | 9.71 | 2.91 | 1.70 |
| 1954 | 202.99 | 38.25 | 9.78 | 2.89 | 1.64 |
| 1955 | 202.99 | 38.21 | 9.78 | 2.93 | 1.62 |
| 1956 | 202.67 | 38.21 | 9.67 | 2.88 | 1.61 |
| 1957 | 202.16 | 38.15 | 9.58 | 2.79 | 1.57 |
| 1958 | 202.66 | 38.06 | 9.81 | 2.91 | 1.57 |
| 1959 | 202.49 | 38.15 | 9.68 | 2.92 | 1.59 |
| 1960 | 200.97 | 38.12 | 9.31 | 2.66 | 1.54 |
| 1961 | 199.29 | 37.83 | 9.12 | 2.46 | 1.41 |
| 1962 | 197.67 | 37.52 | 8.77 | 2.27 | 1.26 |
| 1963 | 195.25 | 37.21 | 8.58 | 2.12 | 1.13 |
| 1964 | 196.48 | 36.75 | 8.60 | 2.12 | 1.06 |
| 1965 | 194.44 | 36.99 | 8.63 | 2.17 | 1.04 |
| 1966 | 196.10 | 36.60 | 8.41 | 2.08 | 1.03 |
| 1967 | 195.95 | 36.91 | 8.70 | 2.20 | 1.04 |
| 1968 | 198.39 | 36.89 | 8.85 | 2.34 | 1.10 |
| 1969 | 195.25 | 37.35 | 8.82 | 2.34 | 1.15 |
| 1970 | 194.88 | 36.75 | 8.38 | 2.07 | 1.10 |
| 1971 | 190.77 | 36.69 | 8.25 | 1.89 | 0.99 |
| 1972 | 187.26 | 35.91 | 7.61 | 1.63 | 0.84 |
| 1973 | 186.18 | 35.25 | 8.16 | 1.77 | 0.78 |
| 1974 | 183.39 | 35.05 | 8.20 | 2.03 | 0.83 |
| 1975 | 179.92 | 34.52 | 7.89 | 1.91 | 0.90 |
| 1976 | 187.03 | 33.87 | 7.84 | 1.82 | 0.88 |
| 1977 | 183.95 | 35.21 | 7.39 | 1.71 | 0.82 |
| 1978 | 185.18 | 34.63 | 7.57 | 1.67 | 0.81 |
| 1979 | 158.67 | 34.86 | 6.59 | 1.18 | 0.69 |
| 1980 | 182.07 | 29.87 | 7.27 | 0.74 | 0.44 |
| 1981 | 173.31 | 34.27 | 6.74 | 0.77 | 0.14 |
| 1982 | 207.76 | 32.62 | 6.83 | 1.31 | 0.20 |
| 1983 | 177.75 | 39.11 | 6.76 | 0.53 | 0.13 |
| 1984 | 254.42 | 33.46 | 8.57 | 0.25 | 0.03 |

**Table 8.3** (Cont.)

| **Year** | **0** | **1** | **2** | **3** | **4+** |
|---|---|---|---|---|---|
| 1985 | 180.58 | 47.89 | 5.66 | 0.87 | 0.03 |
| 1986 | 199.58 | 33.99 | 8.68 | 0.73 | 0.13 |
| 1987 | 197.22 | 37.57 | 7.42 | 0.54 | 0.06 |
| 1988 | 145.68 | 37.12 | 7.31 | 0.22 | 0.02 |
| 1989 | 155.09 | 27.42 | 7.65 | 0.96 | 0.04 |
| 1990 | 170.65 | 29.19 | 4.98 | 1.53 | 0.22 |
| 1991 | 151.53 | 32.12 | 6.23 | 0.82 | 0.32 |
| 1992 | 163.78 | 28.52 | 7.69 | 0.88 | 0.18 |
| 1993 | 200.51 | 30.83 | 6.64 | 1.66 | 0.26 |
| 1994 | 140.88 | 37.74 | 6.54 | 1.50 | 0.48 |
| 1995 | 169.33 | 26.52 | 8.00 | 0.94 | 0.32 |
| 1996 | 219.95 | 31.87 | 6.63 | 1.46 | 0.26 |
| 1997 | 183.67 | 41.40 | 7.86 | 1.06 | 0.31 |
| 1998 | 209.63 | 34.57 | 9.53 | 1.37 | 0.27 |
| 1999 | 196.76 | 39.46 | 8.65 | 1.87 | 0.36 |
| 2000 | 153.21 | 37.04 | 9.13 | 1.69 | 0.48 |
| 2001 | 190.11 | 28.84 | 9.02 | 1.57 | 0.42 |
| 2002 | 176.10 | 35.79 | 7.40 | 1.76 | 0.43 |
| 2003 | 198.20 | 33.15 | 9.01 | 1.10 | 0.37 |
| 2004 | 174.98 | 37.31 | 8.22 | 1.40 | 0.26 |
| 2005 | 189.08 | 32.94 | 8.95 | 1.56 | 0.35 |
| 2006 | 195.49 | 35.59 | 8.27 | 1.75 | 0.42 |
| 2007 | 333.21 | 36.80 | 8.75 | 1.54 | 0.45 |
| 2008 | 182.38 | 62.73 | 9.19 | 1.74 | 0.44 |
| 2009 | 171.88 | 34.33 | 16.56 | 1.95 | 0.52 |
| 2010 | 293.60 | 32.36 | 9.19 | 3.88 | 0.65 |

**Table 8.4** 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 |
|---|---|---|---|---|
| 1948 | 224,395 | 207,461 | 236,548 | 331,468 |
| 1949 | 226,870 | 209,756 | 238,735 | 333,202 |
| 1950 | 225,577 | 208,620 | 237,670 | 332,055 |
| 1951 | 221,726 | 205,031 | 234,243 | 329,902 |
| 1952 | 218,994 | 201,407 | 230,889 | 327,634 |
| 1953 | 211,703 | 193,225 | 223,188 | 320,750 |
| 1954 | 210,233 | 192,548 | 222,272 | 320,370 |
| 1955 | 210,422 | 193,324 | 223,190 | 319,953 |
| 1956 | 207,972 | 191,192 | 220,713 | 317,294 |
| 1957 | 204,176 | 185,895 | 215,636 | 313,784 |
| 1958 | 208,781 | 189,780 | 219,544 | 316,586 |
| 1959 | 208,221 | 190,847 | 219,923 | 315,775 |
| 1960 | 197,749 | 177,956 | 207,989 | 306,631 |
| 1961 | 187,964 | 168,844 | 200,412 | 302,121 |
| 1962 | 176,104 | 156,032 | 188,965 | 292,343 |
| 1963 | 167,408 | 144,946 | 179,598 | 284,543 |
| 1964 | 166,911 | 144,882 | 183,144 | 293,416 |
| 1965 | 164,502 | 144,409 | 176,757 | 272,085 |
| 1966 | 161,714 | 139,343 | 174,296 | 274,895 |
| 1967 | 166,946 | 142,690 | 176,685 | 272,121 |
| 1968 | 192,870 | 172,836 | 206,466 | 306,814 |
| 1969 | 181,761 | 166,335 | 198,039 | 296,537 |
| 1970 | 171,858 | 153,511 | 188,213 | 289,947 |
| 1971 | 167,055 | 142,048 | 181,785 | 287,010 |
| 1972 | 160,337 | 124,809 | 175,673 | 295,706 |
| 1973 | 174,327 | 140,363 | 191,957 | 308,579 |
| 1974 | 205,257 | 166,889 | 221,302 | 344,550 |
| 1975 | 192,860 | 162,099 | 209,990 | 324,848 |
| 1976 | 175,343 | 144,711 | 189,971 | 293,194 |
| 1977 | 134,782 | 105,418 | 145,053 | 232,105 |
| 1978 | 142,735 | 112,767 | 157,211 | 256,506 |
| 1979 | 121,981 | 94,750 | 140,246 | 244,642 |
| 1980 | 108,479 | 75,987 | 114,202 | 203,589 |
| 1981 | 84,317 | 49,787 | 87,542 | 168,964 |
| 1982 | 99,155 | 65,509 | 104,688 | 197,464 |
| 1983 | 91,330 | 64,312 | 101,689 | 198,962 |
| 1984 | 96,837 | 70,753 | 108,461 | 198,831 |

**Table 8.4** (Cont.)

| Year | BAM Base run | 2.5 percentile | 50 percentile | 97.5 percentile |
|---|---|---|---|---|
| 1985 | 78,295 | 51,655 | 92,059 | 178,809 |
| 1986 | 92,121 | 78,485 | 109,710 | 183,534 |
| 1987 | 76,458 | 62,736 | 92,449 | 163,271 |
| 1988 | 73,043 | 47,494 | 86,550 | 165,572 |
| 1989 | 89,399 | 66,978 | 103,659 | 178,723 |
| 1990 | 84,995 | 63,731 | 97,058 | 166,773 |
| 1991 | 96,996 | 75,679 | 118,376 | 209,496 |
| 1992 | 108,884 | 87,870 | 133,333 | 227,733 |
| 1993 | 113,051 | 103,382 | 147,785 | 240,422 |
| 1994 | 117,897 | 107,646 | 148,696 | 237,412 |
| 1995 | 121,703 | 100,397 | 144,215 | 240,989 |
| 1996 | 108,606 | 88,758 | 123,168 | 199,321 |
| 1997 | 117,596 | 89,265 | 127,916 | 213,589 |
| 1998 | 138,622 | 106,339 | 154,416 | 256,321 |
| 1999 | 153,498 | 124,490 | 175,280 | 289,071 |
| 2000 | 145,412 | 111,454 | 154,259 | 251,533 |
| 2001 | 164,144 | 127,278 | 181,100 | 303,253 |
| 2002 | 134,992 | 110,326 | 149,253 | 238,954 |
| 2003 | 119,336 | 88,250 | 124,364 | 204,421 |
| 2004 | 108,827 | 83,067 | 121,280 | 206,282 |
| 2005 | 124,434 | 102,173 | 147,641 | 252,710 |
| 2006 | 119,582 | 100,343 | 139,835 | 229,287 |
| 2007 | 127,558 | 107,970 | 152,020 | 252,779 |
| 2008 | 151,882 | 138,433 | 198,905 | 339,007 |
| 2009 | 248,272 | 199,887 | 275,282 | 446,188 |
| 2010 | 187,042 | 165,561 | 204,637 | 307,901 |

**Table 8.5** 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 |
|---|---|---|---|---|
| 1948 | 204.62 | 69.41 | 232.13 | 903.63 |
| 1949 | 204.88 | 69.42 | 232.36 | 905.23 |
| 1950 | 204.74 | 69.41 | 232.20 | 904.10 |
| 1951 | 204.33 | 69.41 | 231.92 | 901.91 |
| 1952 | 204.02 | 69.41 | 231.54 | 899.56 |
| 1953 | 203.17 | 69.39 | 230.71 | 893.36 |
| 1954 | 202.99 | 69.38 | 230.61 | 892.86 |
| 1955 | 202.99 | 69.37 | 230.64 | 892.11 |
| 1956 | 202.67 | 69.35 | 230.38 | 889.04 |
| 1957 | 202.16 | 69.31 | 229.71 | 885.14 |
| 1958 | 202.66 | 69.26 | 229.98 | 887.94 |
| 1959 | 202.49 | 69.16 | 229.87 | 886.44 |
| 1960 | 200.97 | 68.97 | 228.23 | 876.57 |
| 1961 | 199.29 | 68.70 | 227.02 | 869.60 |
| 1962 | 197.67 | 68.56 | 225.75 | 863.11 |
| 1963 | 195.25 | 68.36 | 222.63 | 849.90 |
| 1964 | 196.48 | 68.81 | 224.78 | 856.96 |
| 1965 | 194.44 | 68.30 | 221.85 | 842.64 |
| 1966 | 196.10 | 69.21 | 224.27 | 852.58 |
| 1967 | 195.95 | 68.67 | 223.31 | 844.44 |
| 1968 | 198.39 | 69.64 | 227.29 | 862.07 |
| 1969 | 195.25 | 67.87 | 222.64 | 840.52 |
| 1970 | 194.88 | 68.23 | 223.26 | 838.91 |
| 1971 | 190.77 | 66.11 | 217.99 | 816.45 |
| 1972 | 187.26 | 65.34 | 215.01 | 798.44 |
| 1973 | 186.18 | 63.83 | 213.34 | 803.76 |
| 1974 | 183.39 | 60.80 | 207.43 | 788.42 |
| 1975 | 179.92 | 60.48 | 205.55 | 787.14 |
| 1976 | 187.03 | 67.81 | 214.94 | 800.68 |
| 1977 | 183.95 | 70.21 | 208.89 | 764.21 |
| 1978 | 185.18 | 69.63 | 212.84 | 793.30 |
| 1979 | 158.67 | 54.92 | 171.71 | 659.97 |
| 1980 | 182.07 | 68.71 | 199.11 | 744.62 |
| 1981 | 173.31 | 67.61 | 193.69 | 693.36 |
| 1982 | 207.76 | 82.67 | 245.03 | 893.00 |
| 1983 | 177.75 | 73.31 | 201.86 | 694.09 |
| 1984 | 254.42 | 117.65 | 310.65 | 1,022.60 |

**Table 8.5** (Cont.)

| Year | BAM Base run | 2.5 percentile | 50 percentile | 97.5 percentile |
|---|---|---|---|---|
| 1985 | 180.58 | 69.83 | 201.47 | 676.47 |
| 1986 | 199.58 | 71.34 | 219.84 | 835.50 |
| 1987 | 197.22 | 84.12 | 235.27 | 800.59 |
| 1988 | 145.68 | 54.24 | 164.43 | 593.67 |
| 1989 | 155.09 | 58.61 | 179.06 | 648.60 |
| 1990 | 170.65 | 67.78 | 216.20 | 795.61 |
| 1991 | 151.53 | 62.31 | 198.51 | 738.43 |
| 1992 | 163.78 | 65.60 | 203.24 | 736.64 |
| 1993 | 200.51 | 75.55 | 232.33 | 844.20 |
| 1994 | 140.88 | 47.14 | 153.48 | 576.98 |
| 1995 | 169.33 | 57.39 | 183.21 | 680.25 |
| 1996 | 219.95 | 84.60 | 263.62 | 990.24 |
| 1997 | 183.67 | 66.29 | 207.69 | 756.15 |
| 1998 | 209.63 | 74.81 | 234.14 | 863.33 |
| 1999 | 196.76 | 70.35 | 223.90 | 841.97 |
| 2000 | 153.21 | 54.02 | 175.62 | 666.88 |
| 2001 | 190.11 | 65.68 | 209.34 | 790.77 |
| 2002 | 176.10 | 62.67 | 198.27 | 763.76 |
| 2003 | 198.20 | 75.53 | 240.65 | 921.20 |
| 2004 | 174.98 | 62.76 | 208.54 | 784.44 |
| 2005 | 189.08 | 71.48 | 227.34 | 886.18 |
| 2006 | 195.49 | 76.28 | 250.37 | 954.31 |
| 2007 | 333.21 | 109.25 | 369.59 | 1,426.64 |
| 2008 | 182.38 | 64.61 | 218.42 | 886.95 |
| 2009 | 171.88 | 56.60 | 185.38 | 718.87 |
| 2010 | 293.60 | 119.35 | 377.48 | 1,424.72 |

**Table 8.6** Estimates of $F_{MSY}$, $MSY$, the geometric mean of the last 3 years (2008-2010) for $F/F_{MSY}$, $SSB_{MSY}$, and $SSB_{2010}/SSB_{MSY}$ from the sensitivity runs and retrospective analysis that were completed. If the value for $F_{MSY}$ is -, then the model could not estimate the value and a bound was hit.

| **BAM model run name** | $F_{MSY}$ | $MSY$ | $F/F_{MSY}$ | $SSB_{MSY}$ | $SSB/SSB_{MSY}$ |
|---|---|---|---|---|---|
| Base run | 1.46 | 826 | 0.24 | 55779 | 3.35 |
| higher *M* | 1.19 | 817 | 0.26 | 78861 | 2.69 |
| lower *M* | 2.41 | 904 | 0.16 | 24092 | 6.94 |
| age and time varying *M* | 0.82 | 703 | 0.35 | 94029 | 2.45 |
| gillnet index all states all meshes | 0.24 | 1140 | 0.27 | 527441 | 1.55 |
| trawl index replace seine index | 1.99 | 1064 | 0.17 | 42584 | 4.37 |
| reduction index replace gillnet index | - | | | | |
| add in trawl index | 5.88 | 1464 | 0.07 | 11312 | 14.00 |
| age-1 maturity | 2.12 | 910 | 0.16 | 67176 | 3.23 |
| Mississippi River flow | 1.46 | 826 | 0.24 | 55779 | 3.35 |
| include shrimp trawl by-catch | 1.45 | 827 | 0.24 | 56216 | 3.34 |
| Ricker stock-recruitment curve | - | | | | |
| dome-shaped selectivity for commercial reduction fishery | 0.97 | 675 | 0.41 | 100224 | 2.03 |
| weights equal | 4.85 | 1113 | 0.09 | 14975 | 9.33 |
| age comp weight=1.0 | 9.23 | 1192 | 0.07 | 4638 | 23.42 |
| age comp weight=0.75 | 8.53 | 1248 | 0.06 | 4863 | 25.05 |
| age comp weight=0.50 | 2.86 | 919 | 0.16 | 28959 | 4.96 |
| age comp weight=0.05 | 0.57 | 709 | 0.38 | 131398 | 2.13 |
| Retrospective 2009 | - | | | | |
| Retrospective 2008 | - | | | | |
| Retrospective 2007 | 7.73 | 1312 | 0.06 | 18797 | 7.27 |
| Retrospective 2006 | 9.05 | 1268 | 0.05 | 17804 | 7.63 |
| Retrospective 2005 | - | | | | |

**Table 8.7** 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** |
|---|---|---|---|---|
| 1948 | 0.04 | 0.02 | 0.04 | 0.05 |
| 1949 | 0.06 | 0.03 | 0.06 | 0.07 |
| 1950 | 0.08 | 0.05 | 0.07 | 0.09 |
| 1951 | 0.09 | 0.05 | 0.08 | 0.10 |
| 1952 | 0.13 | 0.08 | 0.13 | 0.16 |
| 1953 | 0.11 | 0.07 | 0.11 | 0.13 |
| 1954 | 0.10 | 0.06 | 0.10 | 0.12 |
| 1955 | 0.12 | 0.07 | 0.12 | 0.15 |
| 1956 | 0.14 | 0.09 | 0.15 | 0.18 |
| 1957 | 0.09 | 0.06 | 0.10 | 0.12 |
| 1958 | 0.11 | 0.07 | 0.11 | 0.13 |
| 1959 | 0.19 | 0.12 | 0.20 | 0.26 |
| 1960 | 0.23 | 0.13 | 0.22 | 0.28 |
| 1961 | 0.29 | 0.16 | 0.28 | 0.37 |
| 1962 | 0.32 | 0.18 | 0.32 | 0.42 |
| 1963 | 0.30 | 0.16 | 0.27 | 0.36 |
| 1964 | 0.28 | 0.16 | 0.27 | 0.37 |
| 1965 | 0.32 | 0.19 | 0.32 | 0.43 |
| 1966 | 0.24 | 0.14 | 0.25 | 0.34 |
| 1967 | 0.21 | 0.11 | 0.19 | 0.26 |
| 1968 | 0.23 | 0.13 | 0.21 | 0.28 |
| 1969 | 0.35 | 0.19 | 0.31 | 0.42 |
| 1970 | 0.39 | 0.23 | 0.38 | 0.53 |
| 1971 | 0.52 | 0.29 | 0.51 | 0.74 |
| 1972 | 0.36 | 0.19 | 0.33 | 0.50 |
| 1973 | 0.29 | 0.16 | 0.27 | 0.39 |
| 1974 | 0.35 | 0.20 | 0.34 | 0.48 |
| 1975 | 0.37 | 0.20 | 0.33 | 0.47 |
| 1976 | 0.42 | 0.24 | 0.43 | 0.63 |
| 1977 | 0.38 | 0.23 | 0.38 | 0.58 |
| 1978 | 0.76 | 0.43 | 0.72 | 1.06 |
| 1979 | 1.09 | 0.62 | 1.14 | 1.74 |
| 1980 | 1.15 | 0.65 | 1.27 | 2.28 |
| 1981 | 0.54 | 0.34 | 0.65 | 1.11 |
| 1982 | 1.45 | 0.72 | 1.60 | 3.50 |
| 1983 | 2.18 | 0.99 | 2.61 | 18.24 |
| 1984 | 1.19 | 0.60 | 1.19 | 2.18 |

**Table 8.7** (Cont.)

| Year | BAM Base run | 2.5 percentile | 50 percentile | 97.5 percentile |
|---|---|---|---|---|
| 1985 | 0.94 | 0.51 | 0.91 | 1.28 |
| 1986 | 1.67 | 0.77 | 1.35 | 1.83 |
| 1987 | 2.41 | 1.10 | 2.34 | 3.10 |
| 1988 | 0.93 | 0.49 | 0.92 | 1.84 |
| 1989 | 0.51 | 0.28 | 0.46 | 0.71 |
| 1990 | 0.70 | 0.38 | 0.64 | 0.96 |
| 1991 | 0.86 | 0.52 | 0.86 | 1.27 |
| 1992 | 0.43 | 0.25 | 0.37 | 0.49 |
| 1993 | 0.39 | 0.25 | 0.35 | 0.43 |
| 1994 | 0.84 | 0.54 | 0.75 | 0.91 |
| 1995 | 0.60 | 0.34 | 0.53 | 0.71 |
| 1996 | 0.73 | 0.48 | 0.72 | 0.92 |
| 1997 | 0.65 | 0.49 | 0.71 | 0.87 |
| 1998 | 0.53 | 0.32 | 0.49 | 0.65 |
| 1999 | 0.53 | 0.41 | 0.58 | 0.71 |
| 2000 | 0.66 | 0.46 | 0.65 | 0.80 |
| 2001 | 0.53 | 0.36 | 0.52 | 0.65 |
| 2002 | 0.80 | 0.57 | 0.85 | 1.06 |
| 2003 | 0.76 | 0.48 | 0.74 | 0.97 |
| 2004 | 0.56 | 0.35 | 0.54 | 0.73 |
| 2005 | 0.53 | 0.33 | 0.51 | 0.68 |
| 2006 | 0.58 | 0.37 | 0.56 | 0.74 |
| 2007 | 0.51 | 0.29 | 0.44 | 0.56 |
| 2008 | 0.45 | 0.30 | 0.42 | 0.51 |
| 2009 | 0.35 | 0.23 | 0.32 | 0.39 |
| 2010 | 0.26 | 0.17 | 0.24 | 0.28 |

**Table 8.8** Summary of benchmarks and terminal year (2010) values estimated for the base BAM model. Fecundity was used as the metric for *SSB*.

| Benchmarks and Terminal Year Values | Base BAM Model Estimates |
|---|---|
| $R_0$ | 206.5 |
| Y at $F_{MSY}$ | 825,822 mt |
| Limit: $F_{MSY}$ | 1.46 |
| Target options: 65% $F_{MSY}$ | 0.95 |
| 75% $F_{MSY}$ | 1.10 |
| 85% $F_{MSY}$ | 1.24 |
| $F_{2010}$ | 0.26 |
| $F_{2008\text{-}2010}/F_{MSY}$ (geometric mean) | 0.24 |
| $F_{40\%}$ | 1.04 |
| $F_{30\%}$ | 1.54 |
| $F_{25\%}$ | 1.90 |
| Target: $SSB_{MSY}$ | 55779 |
| Limit: 0.5*$SSB_{MSY}$ | 27889 |
| $SSB_{2010}$ | 187041 |
| $SSB_{2010}/SSB_{MSY}$ | 3.35 |

**Table 8.9** 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 2011** | **$F_{MSY}$** | **$MSY$** |
|---|---|---|---|---|---|---|---|
| 107 | Base run | 0.43 | 1.40 | 542 | 866 | 0.22 | 644 |
| 108 | Fox model | 0.42 | 1.49 | 558 | 894 | 0.25 | 623 |
| 109 | Substitute trawl for seine index | 0.43 | 1.41 | 532 | 872 | 0.19 | 641 |
| 110 | Substitute reduction for gillnet index | 0.86 | 0.97 | 453 | 442 | 0.037 | 453 |
| 114 | Retrospective, drop 1 yr | 0.54 | 1.32 | 594 | 838 | 0.26 | 660 |
| 115 | Retrospective, drop 2 yr | 0.53 | 1.27 | 597 | 800 | 0.22 | 646 |
| 116 | Retrospective, drop 3 yr | 0.52 | 1.36 | 566 | 866 | 0.16 | 652 |
| 117 | Retrospective, drop 4 yr | 0.59 | 1.26 | 597 | 785 | 0.18 | 639 |
| 118 | Retrospective, drop 5 yr | 0.58 | 1.21 | 612 | 758 | 0.18 | 639 |
| 119 | $B_1 = 0.75\ K$ | 0.43 | 1.40 | 542 | 866 | 0.22 | 644 |
| 120 | $B_1 = 0.95\ K$ | 0.43 | 1.40 | 542 | 866 | 0.22 | 644 |

**Table 8.10** 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** |
| $B1/K$ | 8.500E-01 | 8.500E-01 | 8.500E-01 | 1.344E-09 | 0.000 |
| $K$ | 5.971E+03 | 5.253E+03 | 7.519E+03 | 1.194E+03 | 0.200 |
| | | | | | |
| q(1) | 3.531E-04 | 2.669E-04 | 4.581E-04 | 9.696E-05 | 0.275 |
| q(2) | 3.239E-04 | 2.263E-04 | 4.264E-04 | 1.038E-04 | 0.321 |
| q2/q1 | 9.171E-01 | 7.514E-01 | 1.054E+00 | 1.551E-01 | 0.169 |
| | | | | | |
| $MSY$ | 6.441E+02 | 6.191E+02 | 6.557E+02 | 2.011E+01 | 0.031 |
| Ye(2011) | 5.421E+02 | 4.878E+02 | 5.935E+02 | 5.210E+01 | 0.096 |
| Y.($F_{MSY}$) | 8.663E+02 | 7.616E+02 | 9.321E+02 | 9.217E+01 | 0.106 |
| | | | | | |
| $B_{MSY}$ | 2.986E+03 | 2.627E+03 | 3.760E+03 | 5.972E+02 | 0.200 |
| $F_{MSY}$ | 2.157E-01 | 1.666E-01 | 2.477E-01 | 4.571E-02 | 0.212 |
| | | | | | |
| $F_{MSY}$(1) | 6.110E+02 | 5.149E+02 | 7.277E+02 | 9.883E+01 | 0.162 |
| $F_{MSY}$(2) | 6.662E+02 | 5.422E+02 | 8.857E+02 | 1.668E+02 | 0.250 |
| | | | | | |
| $B./B_{MSY}$ | 1.398E+00 | 1.248E+00 | 1.503E+00 | 1.326E-01 | 0.095 |
| $F./F_{MSY}$ | 4.307E-01 | 3.927E-01 | 5.000E-01 | 5.673E-02 | 0.132 |
| Ye./$MSY$ | 8.416E-01 | 7.471E-01 | 9.385E-01 | 1.001E-01 | 0.119 |

***Note:*** Ye. is equilibrium yield in 2011. Y.($F_{MSY}$) is yield in the next year (2011) at $F_{MSY}$. $B./B_{MSY}$ is terminal biomass relative to $B_{MSY}$, etc.

**Table 8.11** MCMC posterior mean and quintiles estimates of $E_{2010}/E_0$,*MSY*, S, $U_{2010}/U_{MSY}$ , and $U_{MSY}$, generated from the alternate-1 model runs (Gill net index) with the current exploitation rate parameter set at *U*=0.3, *U*=0.4, *U*=0.5, and *U*=0.6.

| Model Runs | Mean | SD | 0.025 quintile | 0.5 quintile | 0.975 quintile |
|---|---|---|---|---|---|
| **Run1 (*U*=0.3)** | | | | | |
| $E_{2010}/E_0$ | 0.76 | 0.16 | 0.49 | 0.75 | 1.11 |
| *MSY** | 870 | 159 | 583 | 860 | 1209 |
| *S* | 0.37 | 0.04 | 0.31 | 0.37 | 0.44 |
| $U_{2010}/U_{MSY}$ | 0.40 | 0.10 | 0.28 | 0.38 | 0.65 |
| $U_{MSY}$ | 0.71 | 0.13 | 0.43 | 0.73 | 0.89 |
| | | | | | |
| **Run2 (*U*=0.4)** | | | | | |
| $E_{2010}/E_0$ | 0.66 | 0.13 | 0.43 | 0.64 | 0.94 |
| *MSY** | 813 | 138 | 557 | 809 | 1095 |
| *S* | 0.37 | 0.04 | 0.31 | 0.37 | 0.44 |
| $U_{2010}/U_{MSY}$ | 0.50 | 0.11 | 0.34 | 0.47 | 0.77 |
| $U_{MSY}$ | 0.72 | 0.12 | 0.45 | 0.74 | 0.89 |
| | | | | | |
| **Run3 (*U*=0.5)** | | | | | |
| $E_{2010}/E_0$ | 0.61 | 0.13 | 0.38 | 0.60 | 0.87 |
| *MSY** | 786 | 130 | 545 | 780 | 1065 |
| *S* | 0.37 | 0.04 | 0.30 | 0.37 | 0.44 |
| $U_{2010}/U_{MSY}$ | 0.56 | 0.12 | 0.39 | 0.54 | 0.86 |
| $U_{MSY}$ | 0.74 | 0.11 | 0.48 | 0.76 | 0.89 |
| | | | | | |
| **Run4 (*U*=0.6)** | | | | | |
| $E_{2010}/E_0$ | 0.55 | 0.11 | 0.35 | 0.54 | 0.80 |
| *MSY** | 775 | 120 | 546 | 771 | 1023 |
| *S* | 0.37 | 0.04 | 0.30 | 0.37 | 0.44 |
| $U_{2010}/U_{MSY}$ | 0.63 | 0.13 | 0.44 | 0.61 | 0.95 |
| $U_{MSY}$ | 0.75 | 0.11 | 0.49 | 0.77 | 0.89 |

**MSY* x 1000mt

**Table 8.12** MCMC posterior mean and quintiles estimates of $E_{2010}/E_0$,$MSY$, S, $U_{2010}/U_{MSY}$ , and $U_{MSY}$, generated from the alternate-2 model runs (Reduction fishery index) with the current exploitation rate parameter set at $U$=0.3, $U$=0.4, $U$=0.5, and $U$=0.6.

| Model Runs | Mean | SD | 0.025 quintile | 0.5 quintile | 0.975 quintile |
|---|---|---|---|---|---|
| **Run1 (*U*=0.3)** | | | | | |
| $E_{2010}/E_0$ | 0.54 | 0.10 | 0.36 | 0.54 | 0.76 |
| *MSY** | 900 | 185 | 570 | 889 | 1296 |
| *S* | 0.41 | 0.03 | 0.34 | 0.42 | 0.45 |
| $U_{2010}/U_{MSY}$ | 0.42 | 0.11 | 0.28 | 0.40 | 0.71 |
| $U_{MSY}$ | 0.70 | 0.13 | 0.39 | 0.72 | 0.89 |
| | | | | | |
| **Run2 (*U*=0.4)** | | | | | |
| $E_{2010}/E_0$ | 0.47 | 0.09 | 0.32 | 0.47 | 0.66 |
| *MSY** | 793 | 141 | 535 | 783 | 1094 |
| *S* | 0.41 | 0.03 | 0.34 | 0.42 | 0.45 |
| $U_{2010}/U_{MSY}$ | 0.53 | 0.12 | 0.36 | 0.50 | 0.82 |
| $U_{MSY}$ | 0.72 | 0.12 | 0.44 | 0.74 | 0.89 |
| | | | | | |
| **Run3 (*U*=0.5)** | | | | | |
| $E_{2010}/E_0$ | 0.43 | 0.08 | 0.28 | 0.42 | 0.61 |
| *MSY** | 738 | 110 | 531 | 731 | 971 |
| *S* | 0.41 | 0.03 | 0.34 | 0.42 | 0.45 |
| $U_{2010}/U_{MSY}$ | 0.61 | 0.12 | 0.43 | 0.59 | 0.89 |
| $U_{MSY}$ | 0.75 | 0.11 | 0.49 | 0.77 | 0.89 |
| | | | | | |
| **Run4 (*U*=0.6)** | | | | | |
| $E_{2010}/E_0$ | 0.39 | 0.08 | 0.25 | 0.39 | 0.57 |
| *MSY** | 693 | 101 | 513 | 685 | 912 |
| *S* | 0.41 | 0.03 | 0.34 | 0.42 | 0.45 |
| $U_{2010}/U_{MSY}$ | 0.69 | 0.13 | 0.50 | 0.68 | 1.00 |
| $U_{MSY}$ | 0.76 | 0.10 | 0.53 | 0.78 | 0.89 |

**MSY* x 1000mt

## 14.0 Figures

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

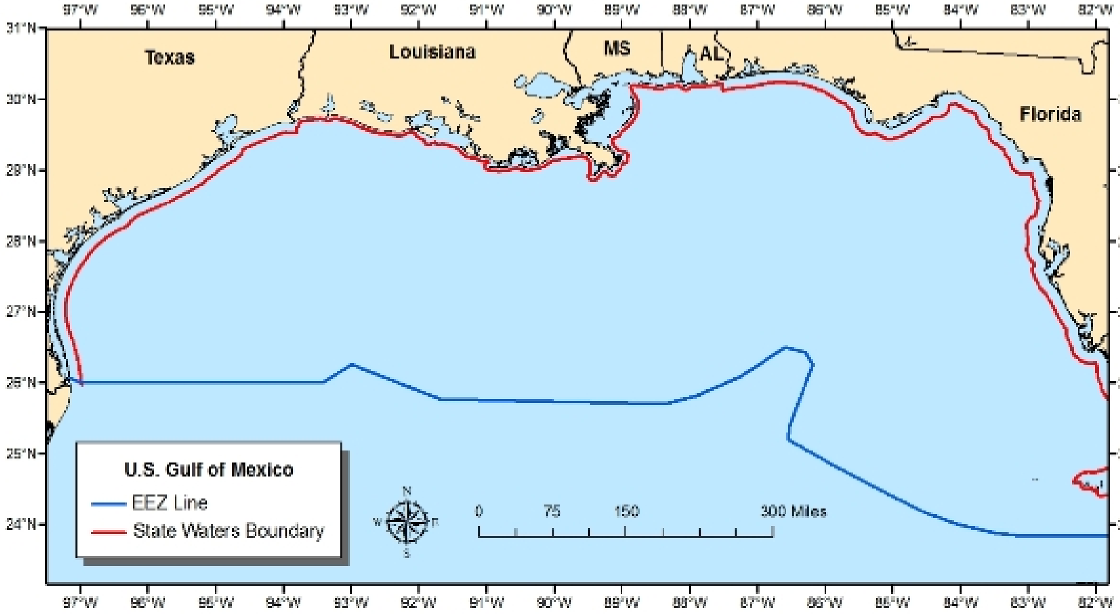


**Figure 1.2** Historical retrospective on fishing mortality (F) from Nelson and Ahrenholz (N&A_1986), Vaughan (V_1987), Vaughan et al (V_1996), Vaughan et al. (V_2000), GSMFC report (SVPA_2007), and Vaughan et al. (ADMB_2007).

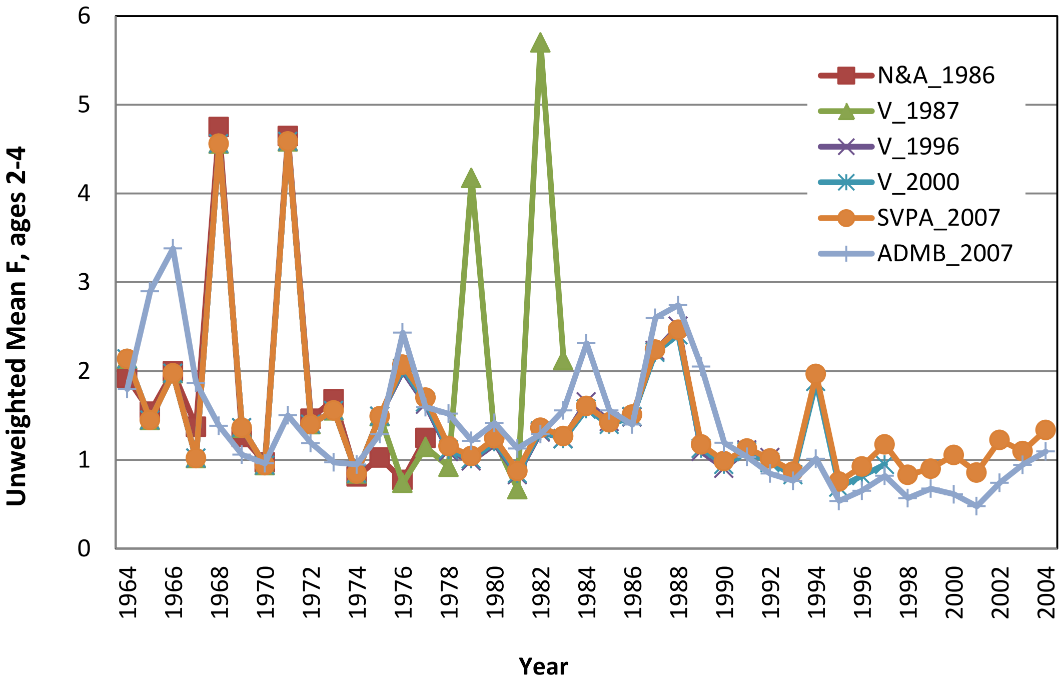


**Figure 1.3** Historical retrospective on spawning stock biomass (*SSB*) from Nelson and Ahrenholz (N&A_1986), Vaughan (V_1987), Vaughan et al (V_1996), Vaughan et al. (V_2000), GSMFC report (SVPA_2007), and Vaughan et al. (ADMB_2007).

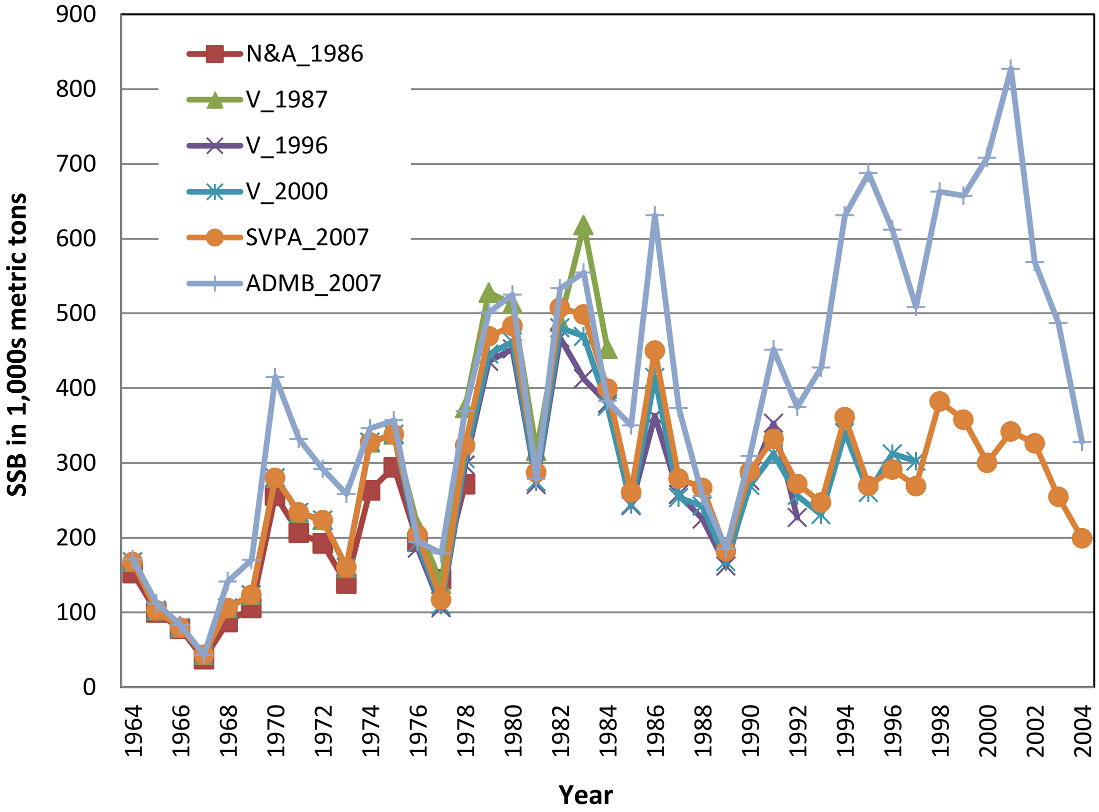


**Figure 1.4** Historical retrospective on recruits to age 1 ($R_1$) from Nelson and Ahrenholz (N&A_1986), Vaughan (V_1987), Vaughan et al (V_1996), Vaughan et al. (V_2000), GSMFC report (SVPA_2007), and Vaughan et al. (ADMB_2007).

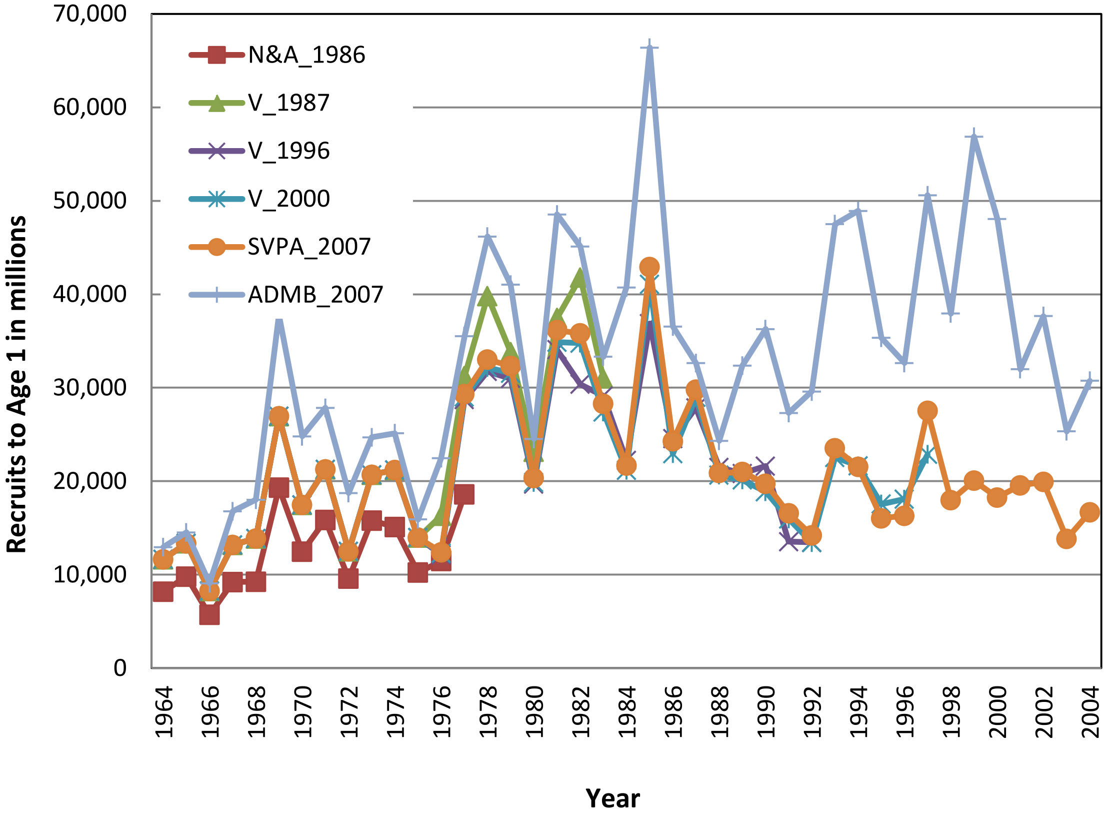


**Figure 3.1** Scale sample from age-2 gulf menhaden.

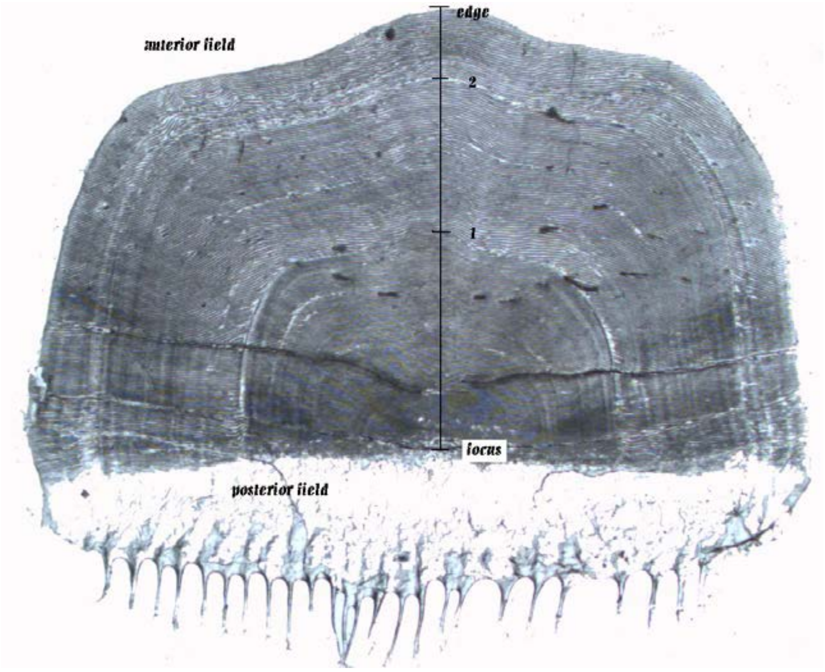


**Figure 3.2** Fork length (cm) frequencies by age of gulf menhaden in the 2010 port samples.

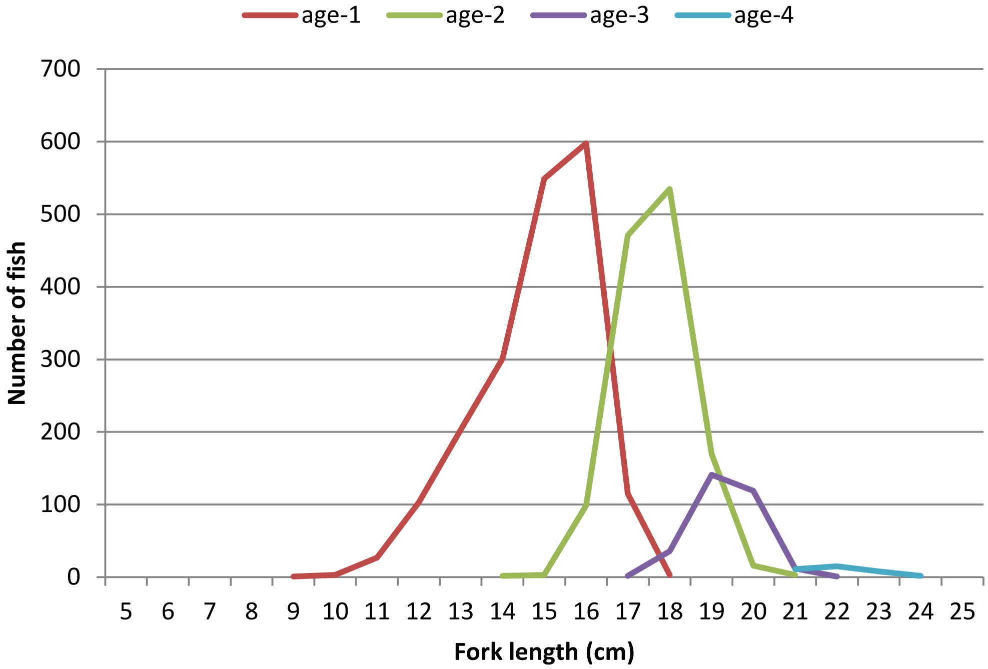
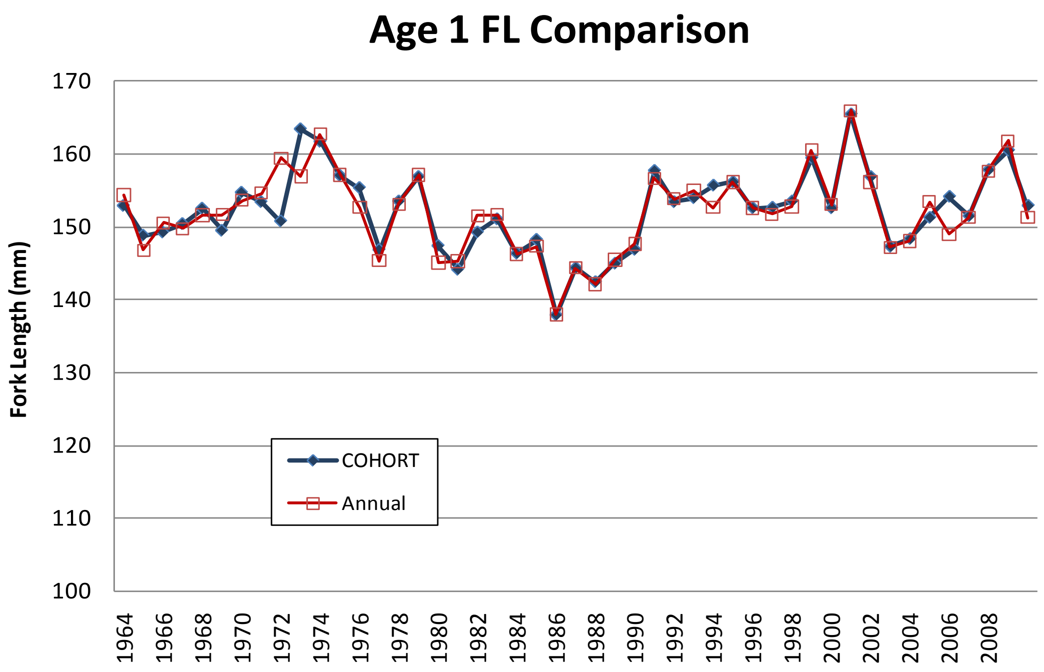


**Figure 3.3** Comparison of predicted lengths at age (ages 1 and 2) between parameters obtained from annual and cohort based von Bertalanffy fits.



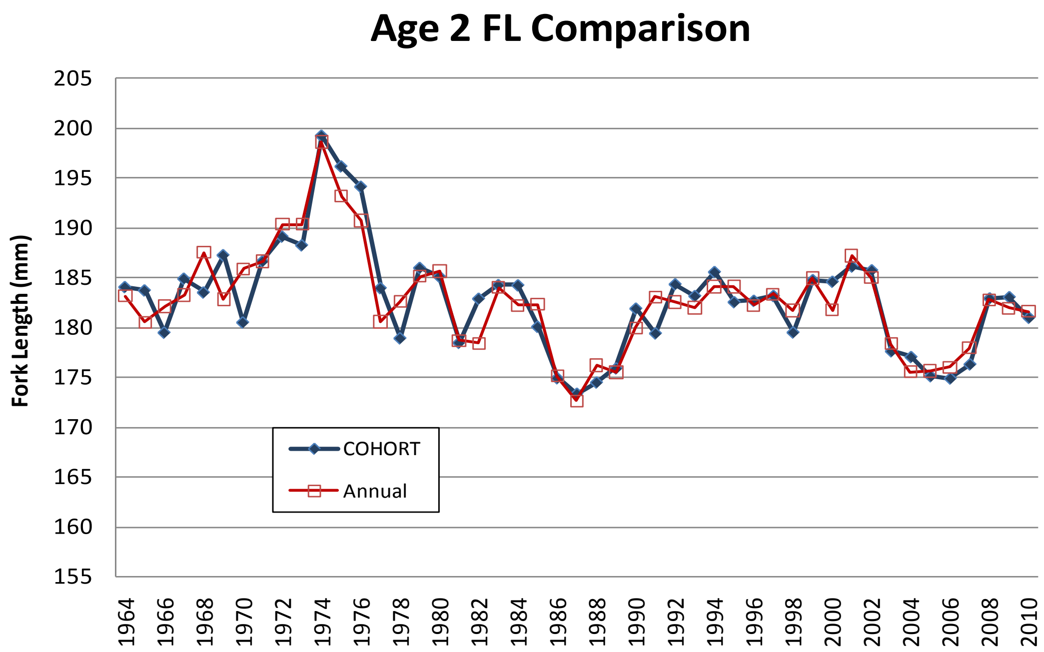


**Figure 3.4** Comparison of female weight and fecundity (no. of maturing or ripe ova) as a function of fork length (mm) for gulf menhaden. Fecundity relationship from Lewis and Roithmayr (1981).

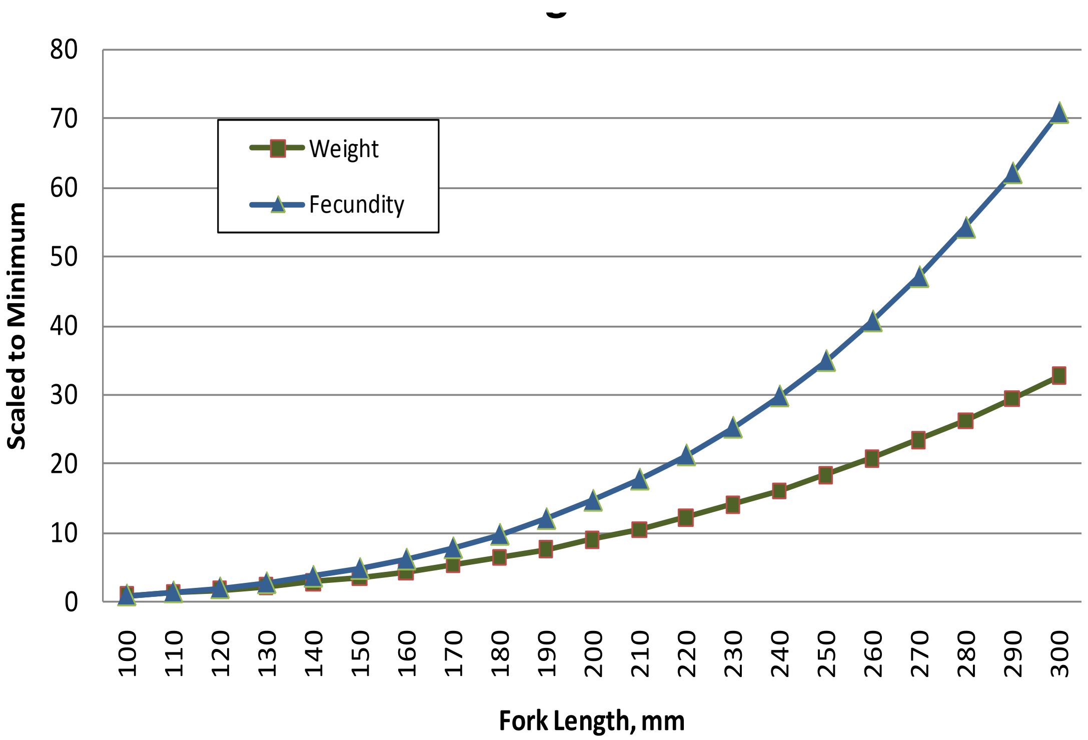


**Figure 3.5** Proportion of eggs from age 2 spawners (first time spawners) to total population egg production as estimated in latest stock assessment (Vaughan et al. 2007), 1964-2004.

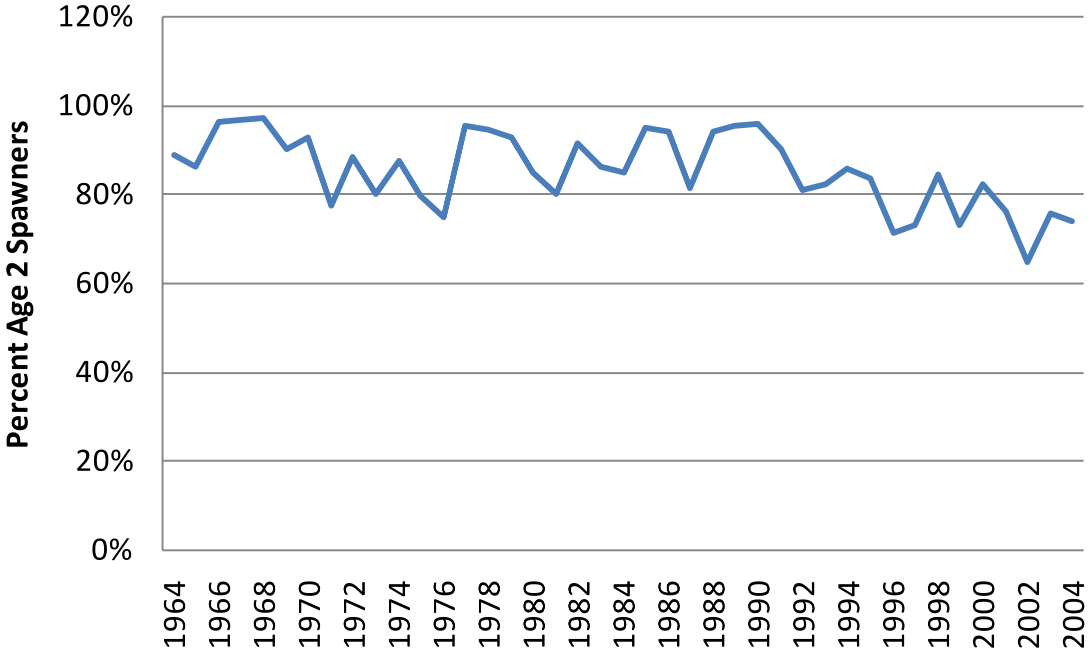


**Figure 3.6** Year- and age-varying *M* using yearly weight at age and the Lorenzen curve with values scaled to 1.10 at age 2 (the mean from Ahrenholz 1981).

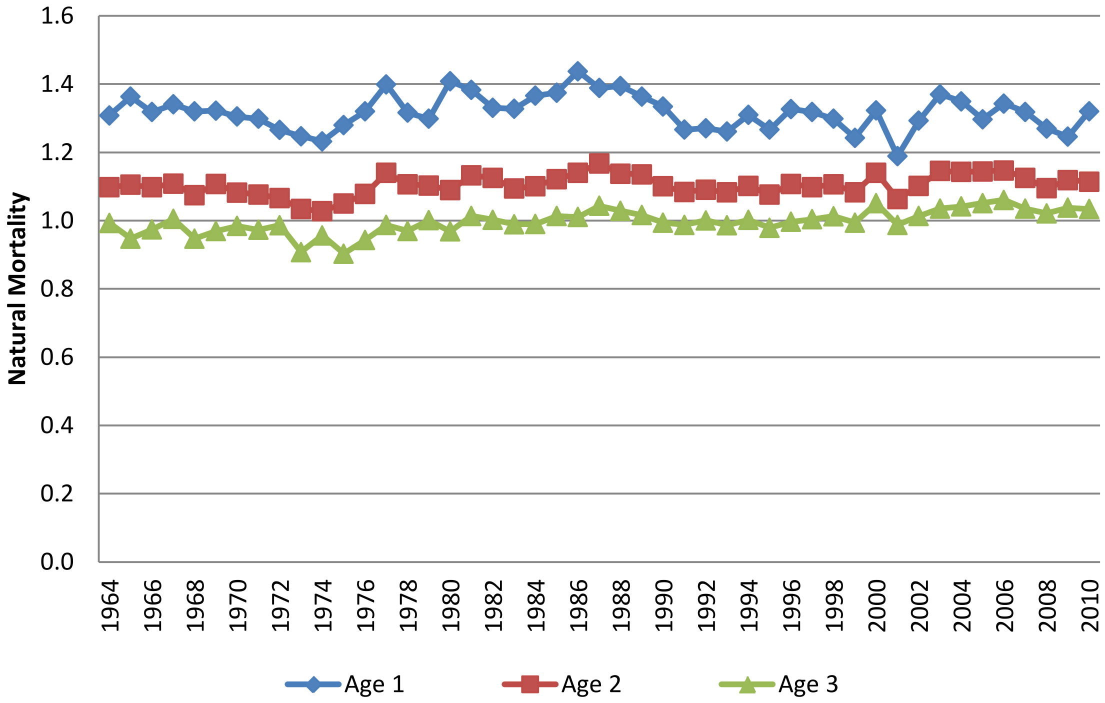


**Figure 3.7** Winter (Nov-Mar) Mississippi River flow measured at two US Corps of Engineers gauges (Simmesport, LA, on the Atchafalaya River and Tarbert Landings, MS, on the Mississippi River).

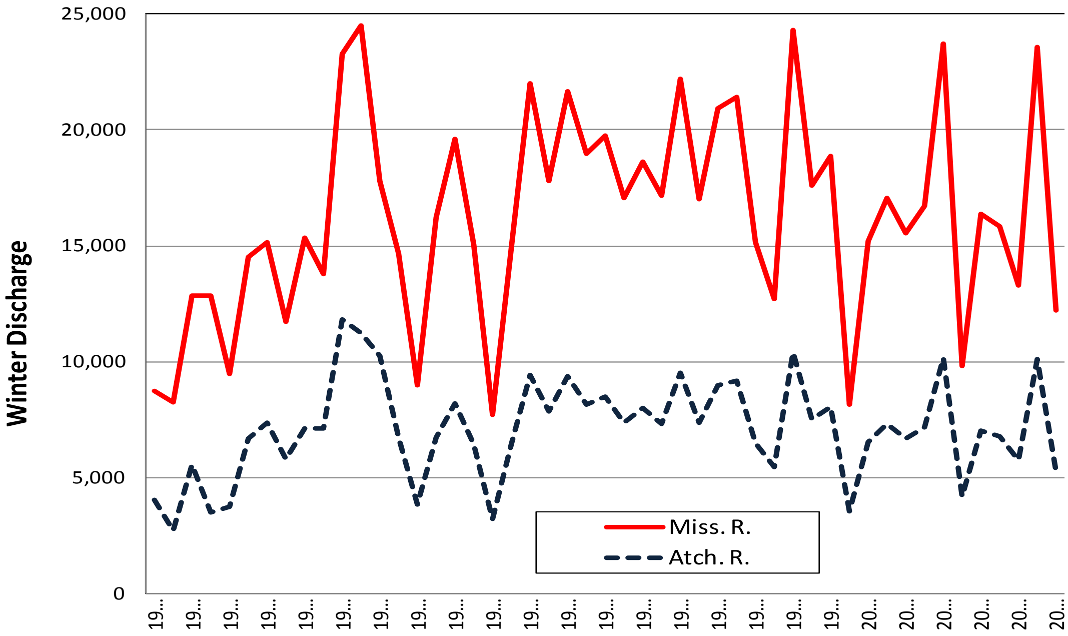


**Figure 3.8** Warm (red) and cold (blue) episodes based on a threshold of +/- 0.5°C for the Oceanic Niño Index (ONI) [each month is 3 month (center month noted) running mean of ERSST.v3b SST anomalies in the Niño 3.4 region (5°N-5°S, 120°-170°W)], based on the 1971-2000 base period. For historical purposes 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.

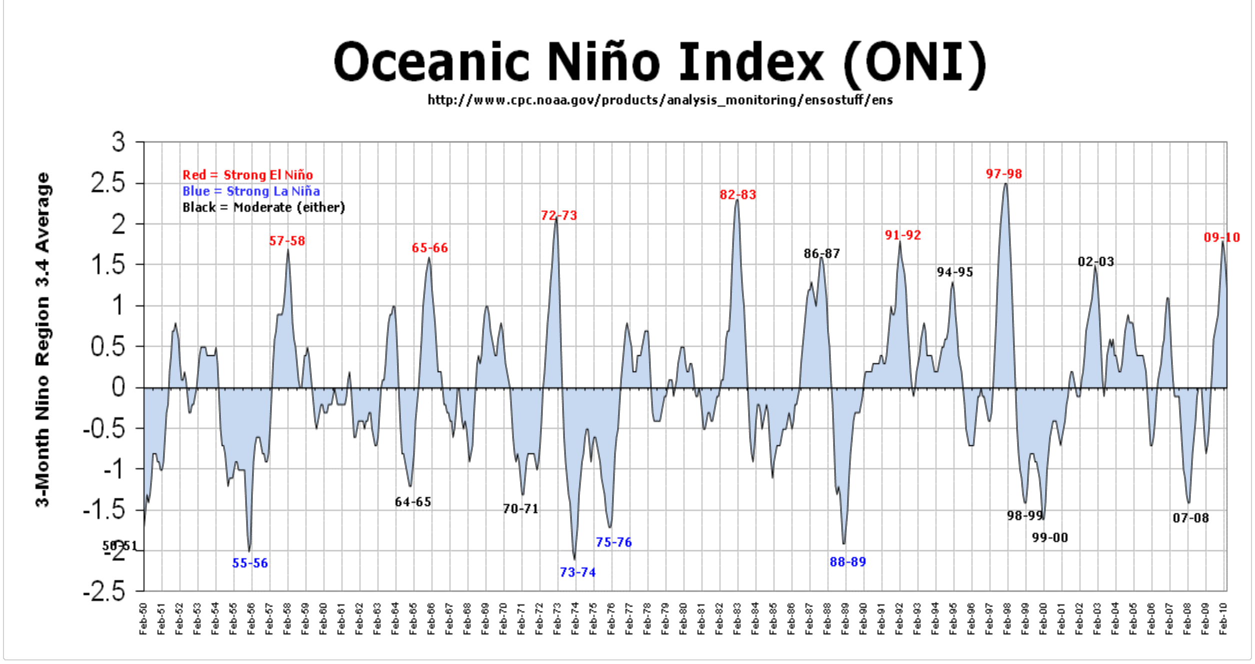


**Figure 3.9** Number of tropical storms and hurricanes in the northern Gulf of Mexico, 1851-2010.

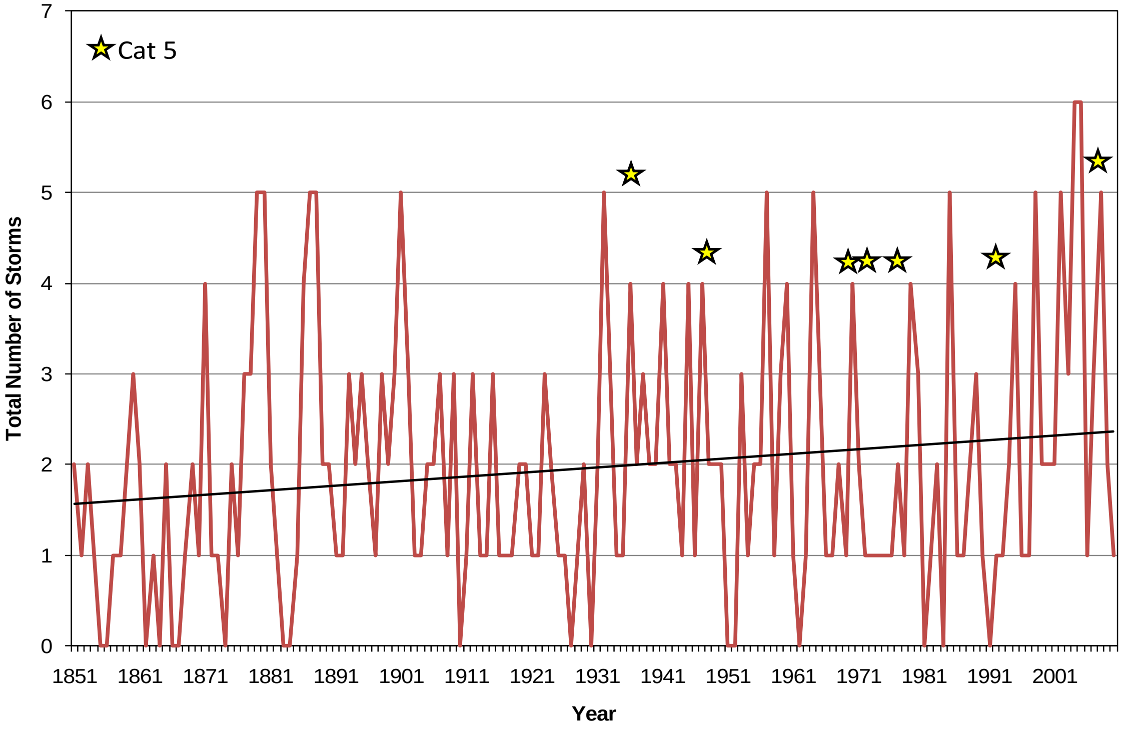


**Figure 3.10** Map of the Gulf of Mexico showing the combined footprint of the Hypoxic Area or "Dead Zone" for the period 1998 to 2004.

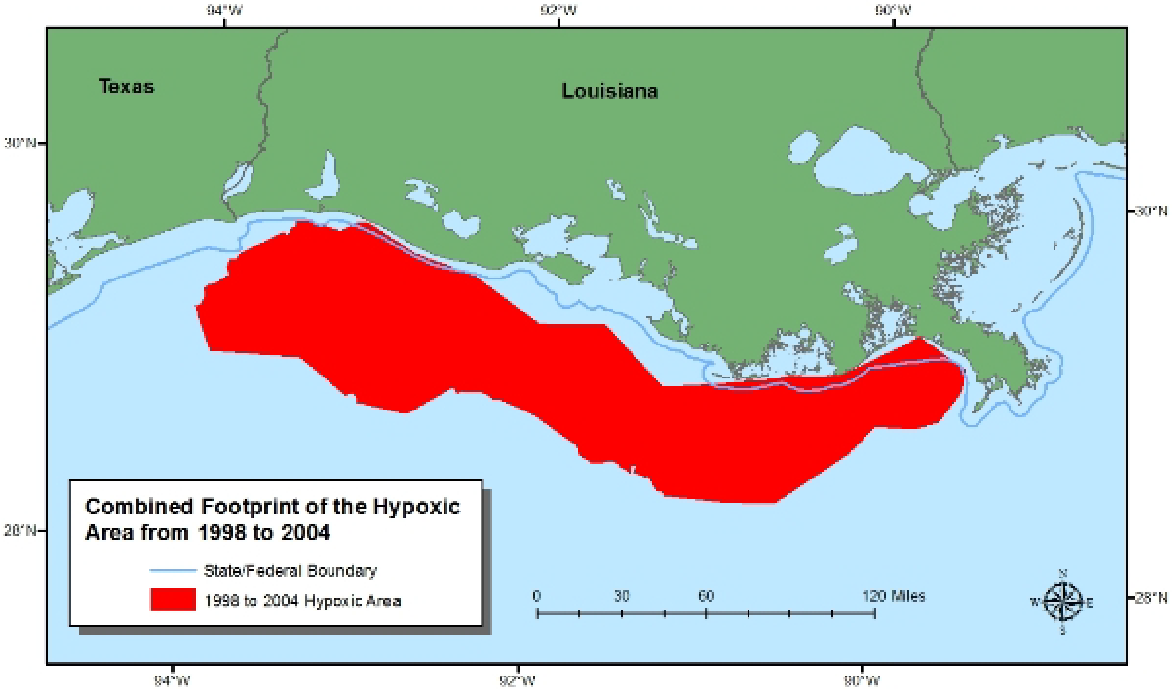


**Figure 3.11** Map of the Gulf of Mexico showing the site of the BP Deepwater Horizon Oil Spill and fishery closure boundary on 13 July 2010 (Source: SERO).

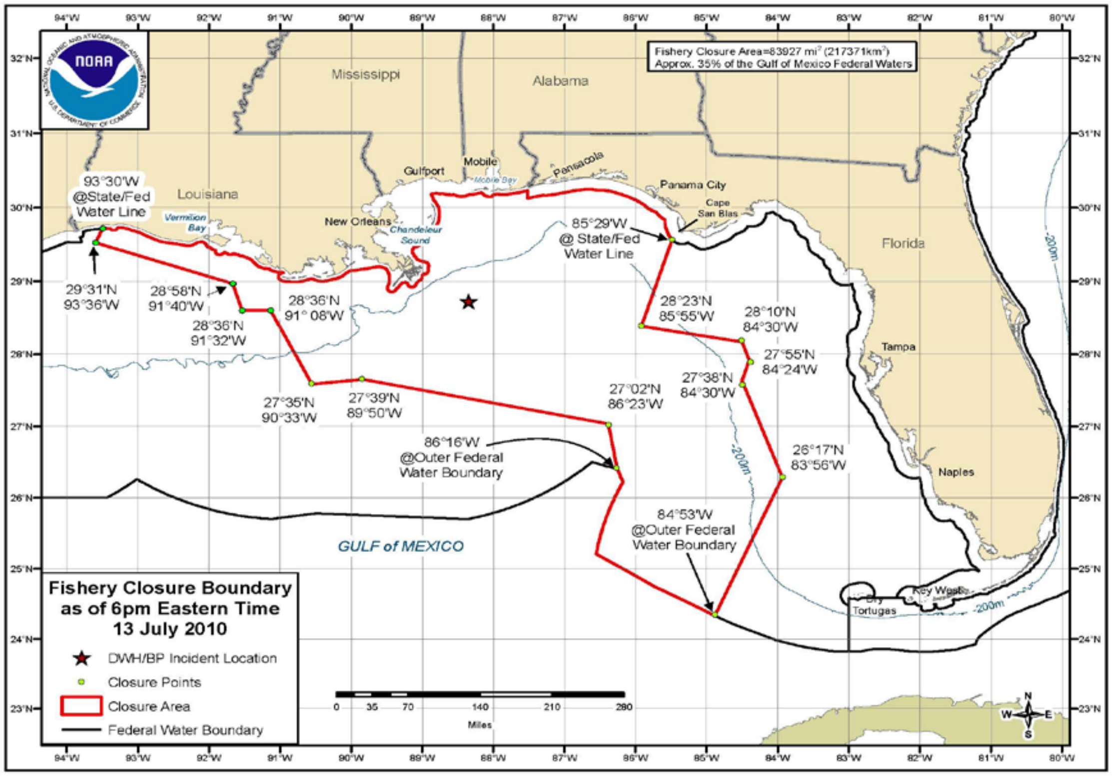


**Figure 4.1** Total gulf menhaden landings along the Gulf of Mexico coast of the U.S., 1873-2010. Reconstructed landings were developed from historical reports for 1873-1947. Reduction landings maintained at NMFS Beaufort are combined with bait and recreational landings for 1948-2010.

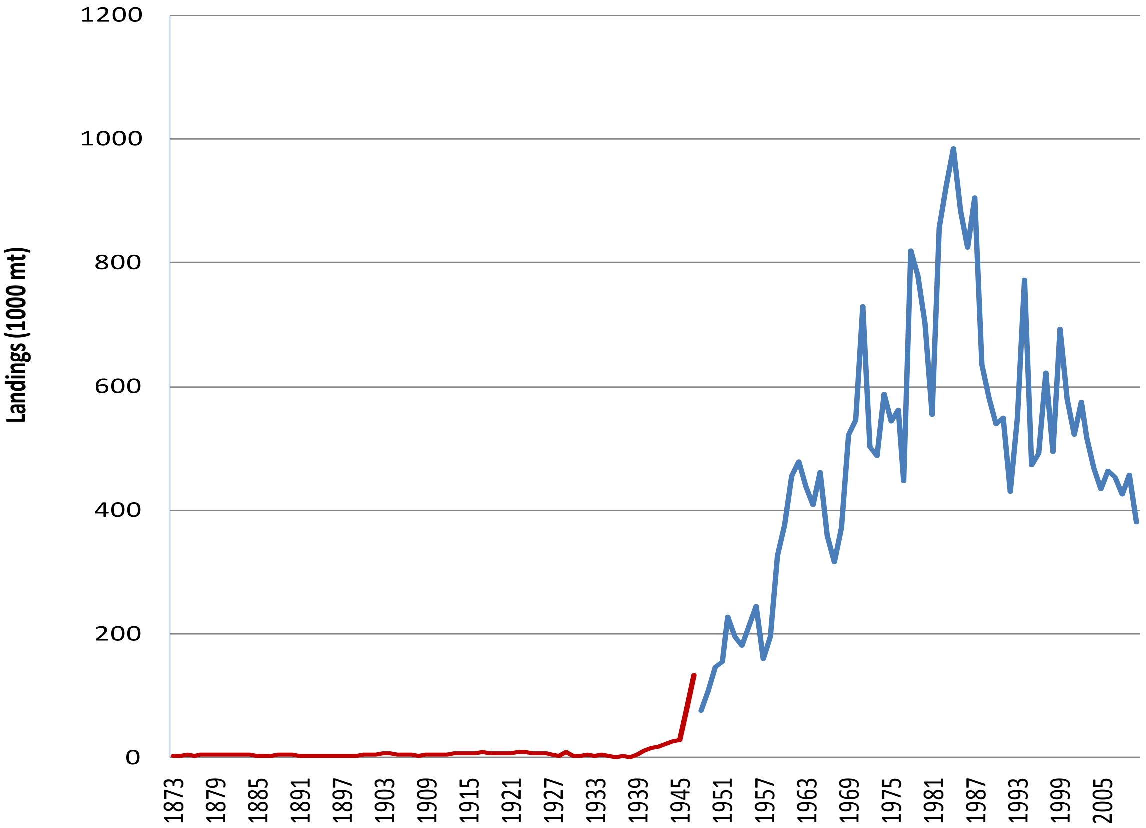


**Figure 4.2** Annual values of gulf menhaden reduction landings (1000 mt) and nominal effort (vessel-ton-week), 1948-2010.

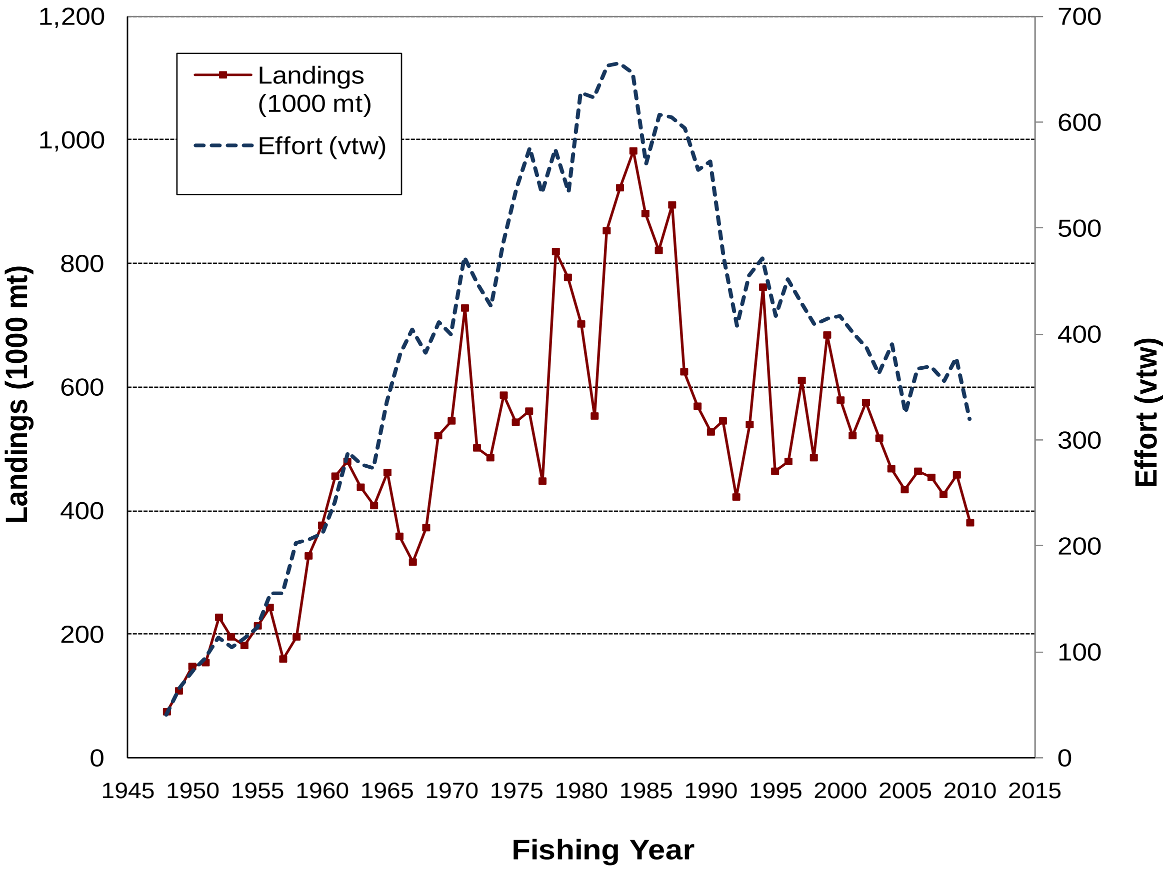


**Figure 4.3** Percent age-1 and age-2 gulf menhaden in the catch-at-age matrix, 1964-2010.

**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.

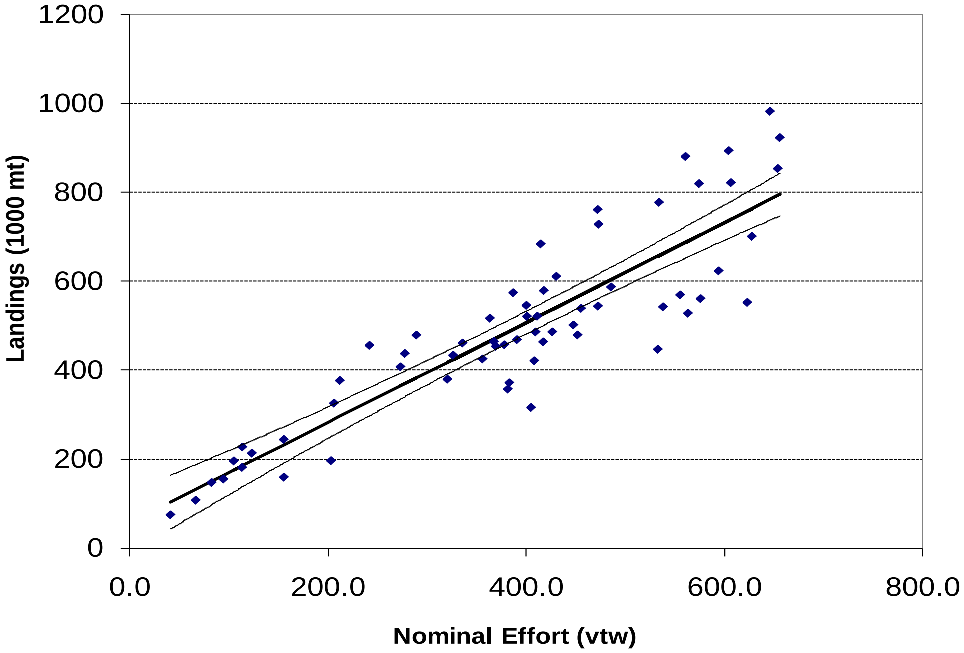


**Figure 4.5** Comparison of nominal fishing effort for gulf menhaden reduction fleet. Effort compared includes: (1) vessel-ton-week, 1948-2010, (2) trips, 1964-2010, and (3) purse-seine sets, 1983-2010. All effort estimates are standardized by dividing by the respective value in 2010 to put them on a common scale. Years with incomplete data (sets in 1992, 1993, and 2005) are left blank.

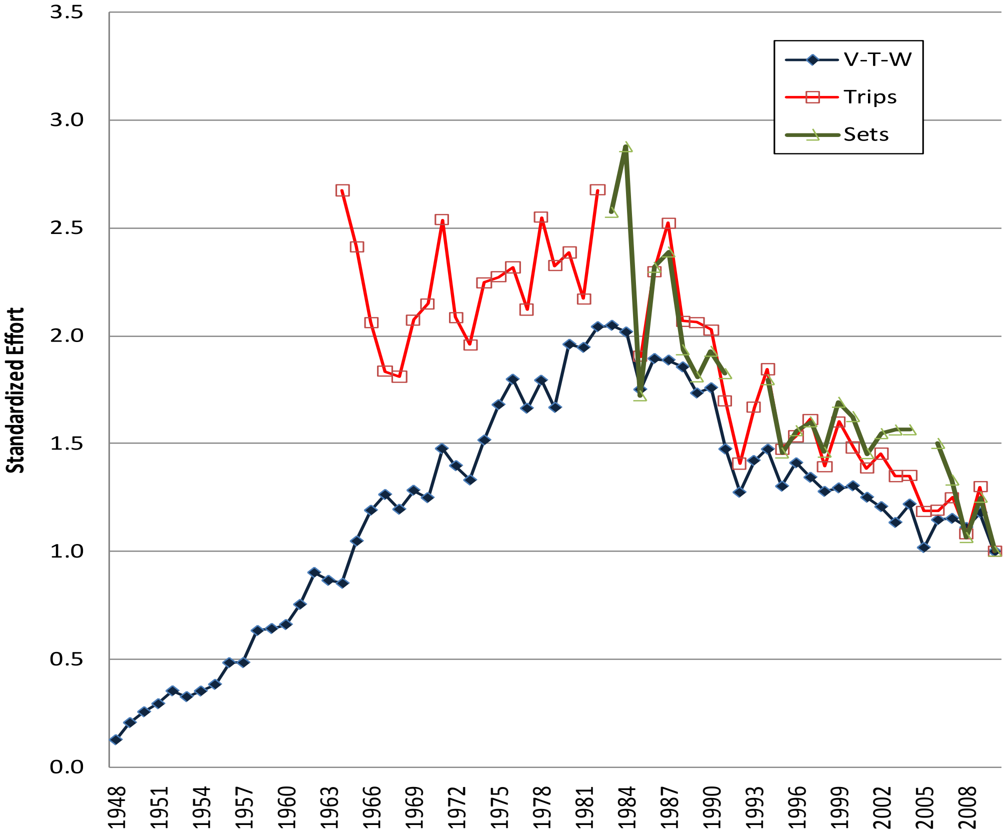


**Figure 4.6** Comparison of calculated CPUE across different measures of fishing effort, including landings per vessel-ton-week (C/VTW), landings per trip (C/Trip) and catch per set.

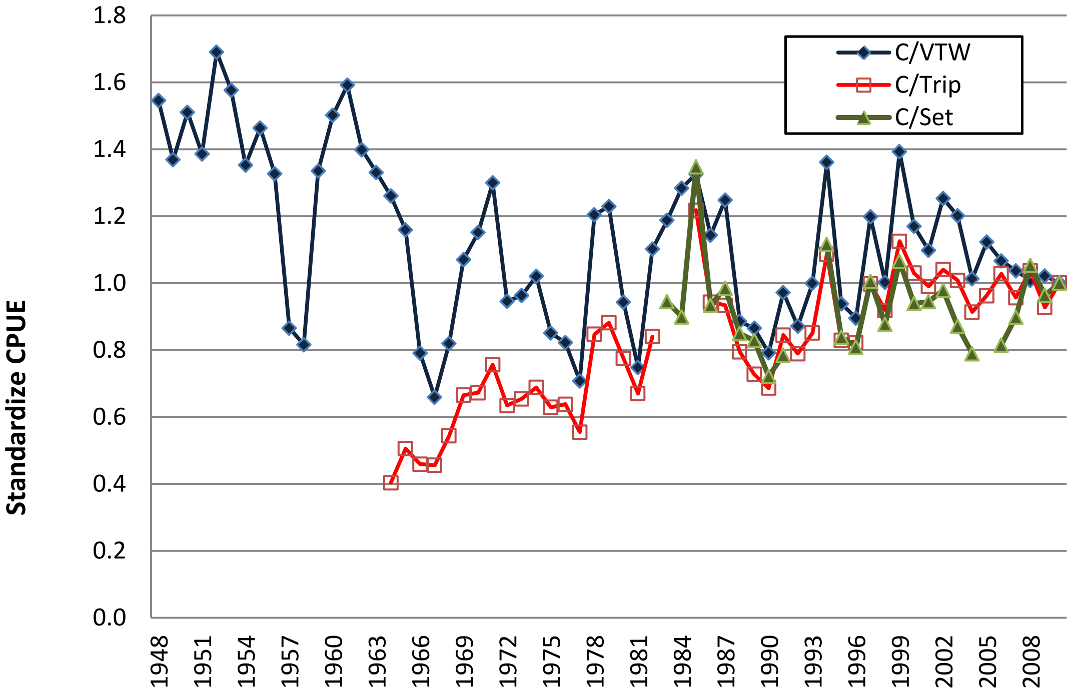


**Figure 4.7** Gulf menhaden bait landings obtained from the NOAA Fisheries Commercial Landings database (ALS), 1950-2010; primarily purse seine, gill nets, haul seines, and other gears.

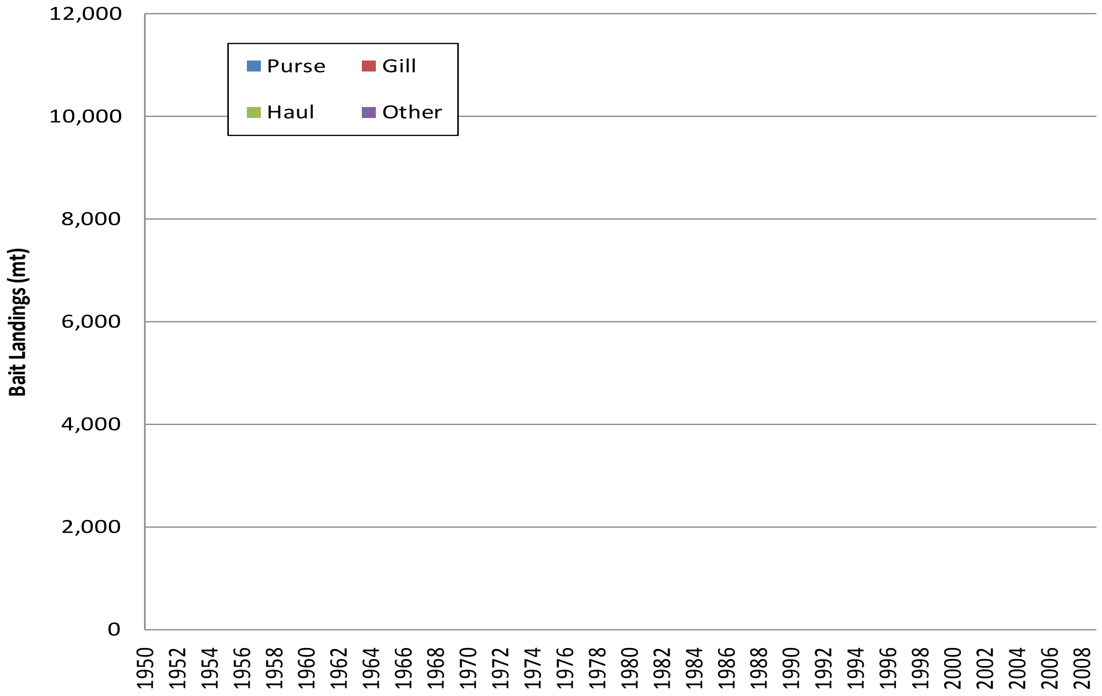


**Figure 4.8** Comparison of reduction fishery with combined bait and recreational fisheries, 1948-2010.

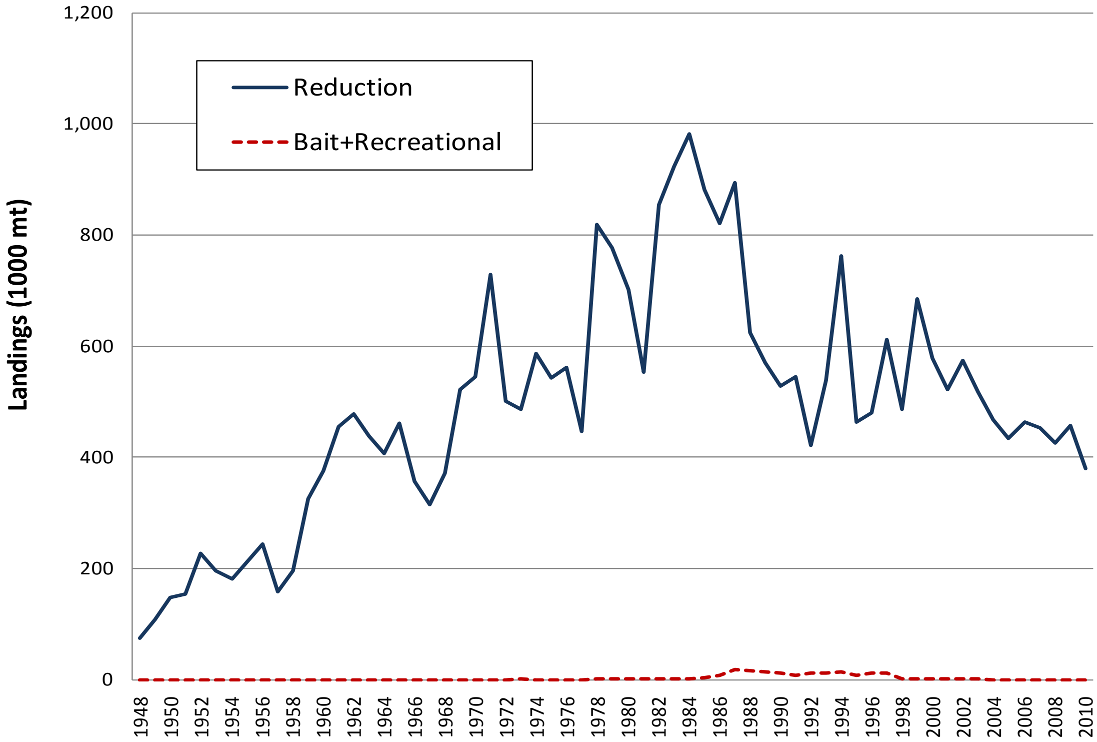
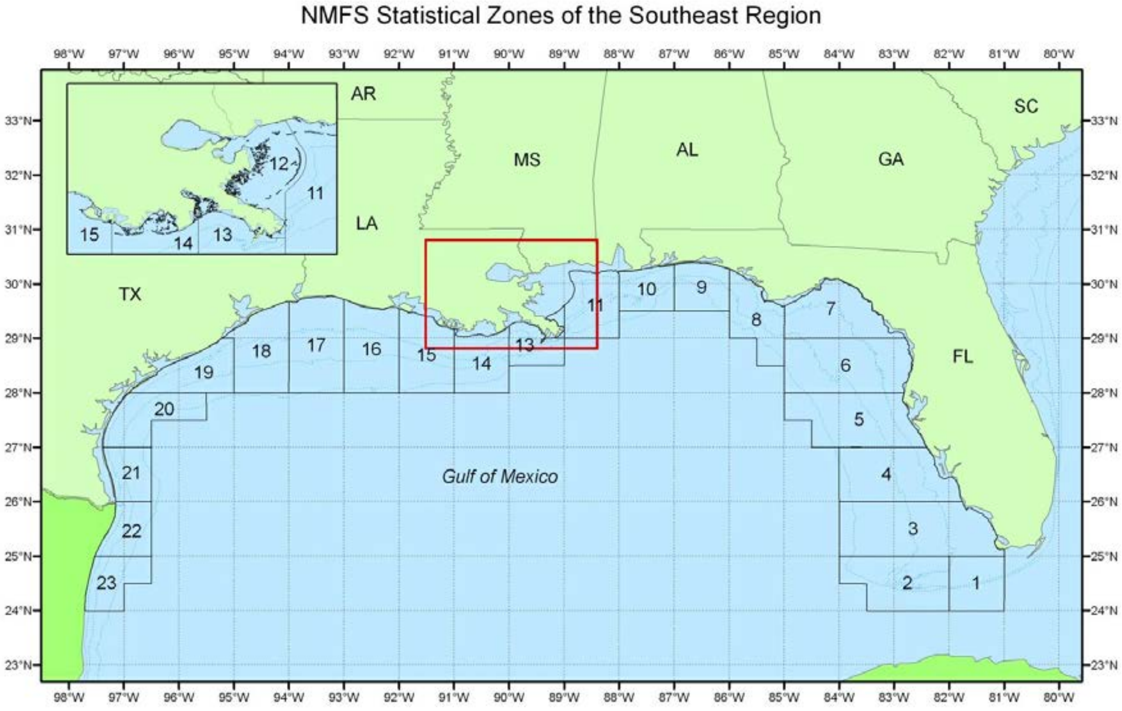


**Figure 4.9** National Marine Fisheries Service Gulf Shrimp Landing Statistical Zones used for SEAMAP sampling with trawls.



Note: Stat zone 12 expands east to include Chandeleur Islands (see inset)

**Figure 4.10** Gulf menhaden CPUE (numbers per trawl hour) from SEAMAP trawls.

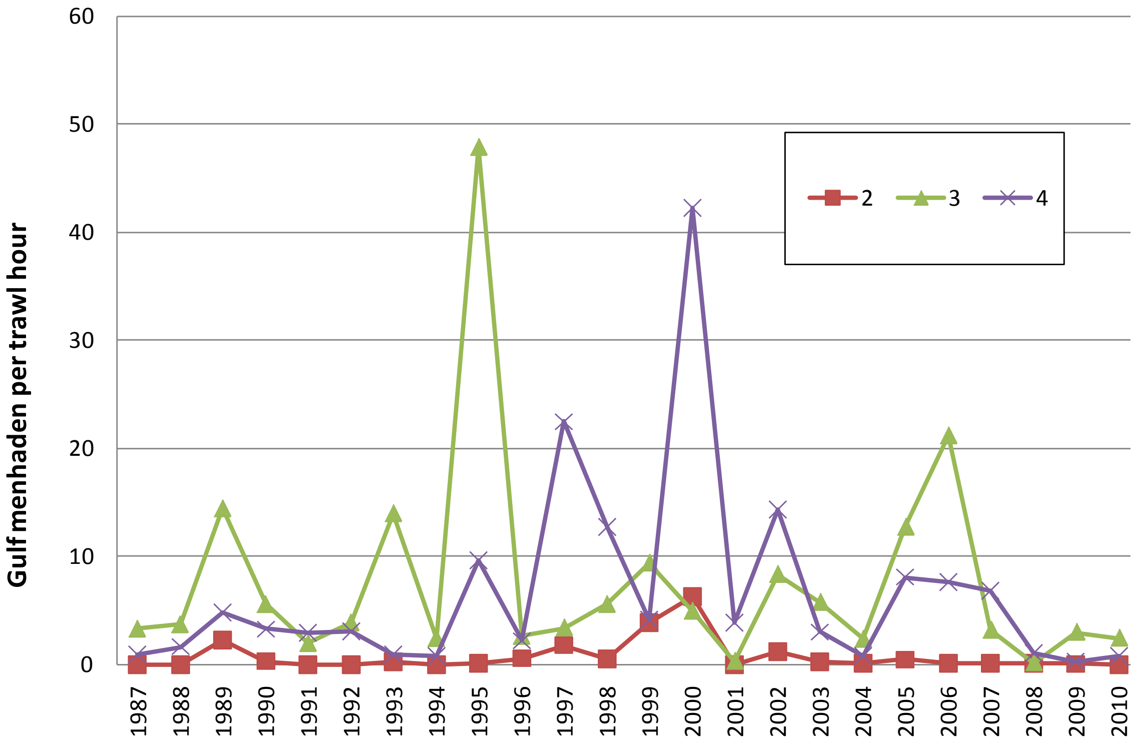


**Figure 4.11** Gulf menhaden discards in numbers from the U.S. shrimp trawl fishery of the northern Gulf of Mexico as estimated from SEAMAP trawl CPUE and shrimp fishery effort.

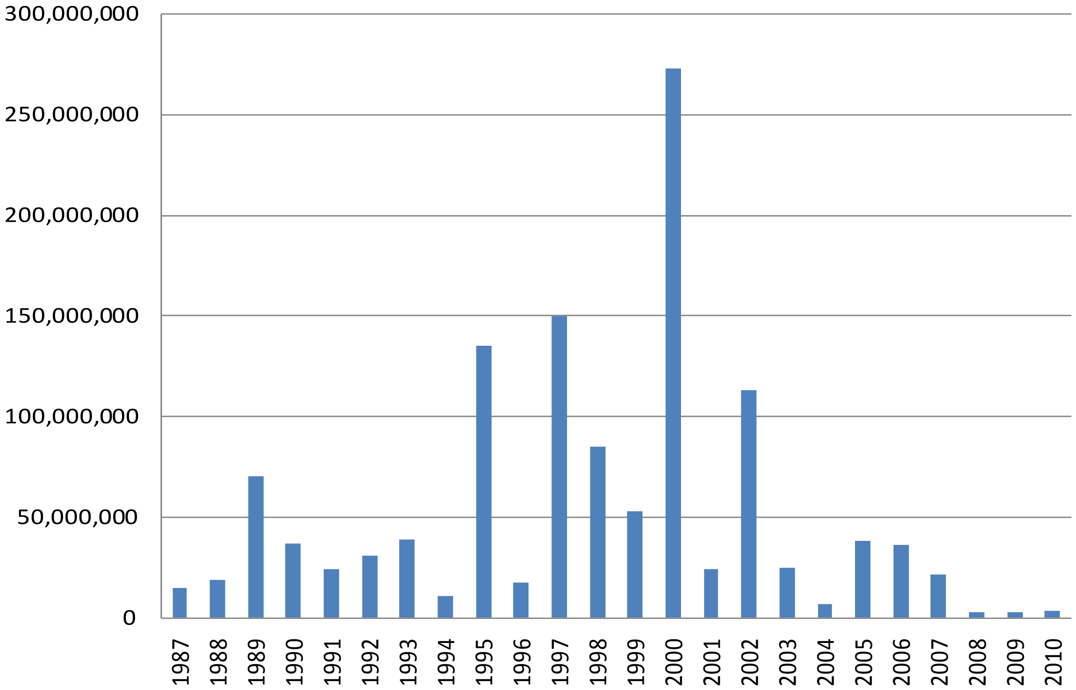


**Figure 5.1** Map of Texas bay systems.

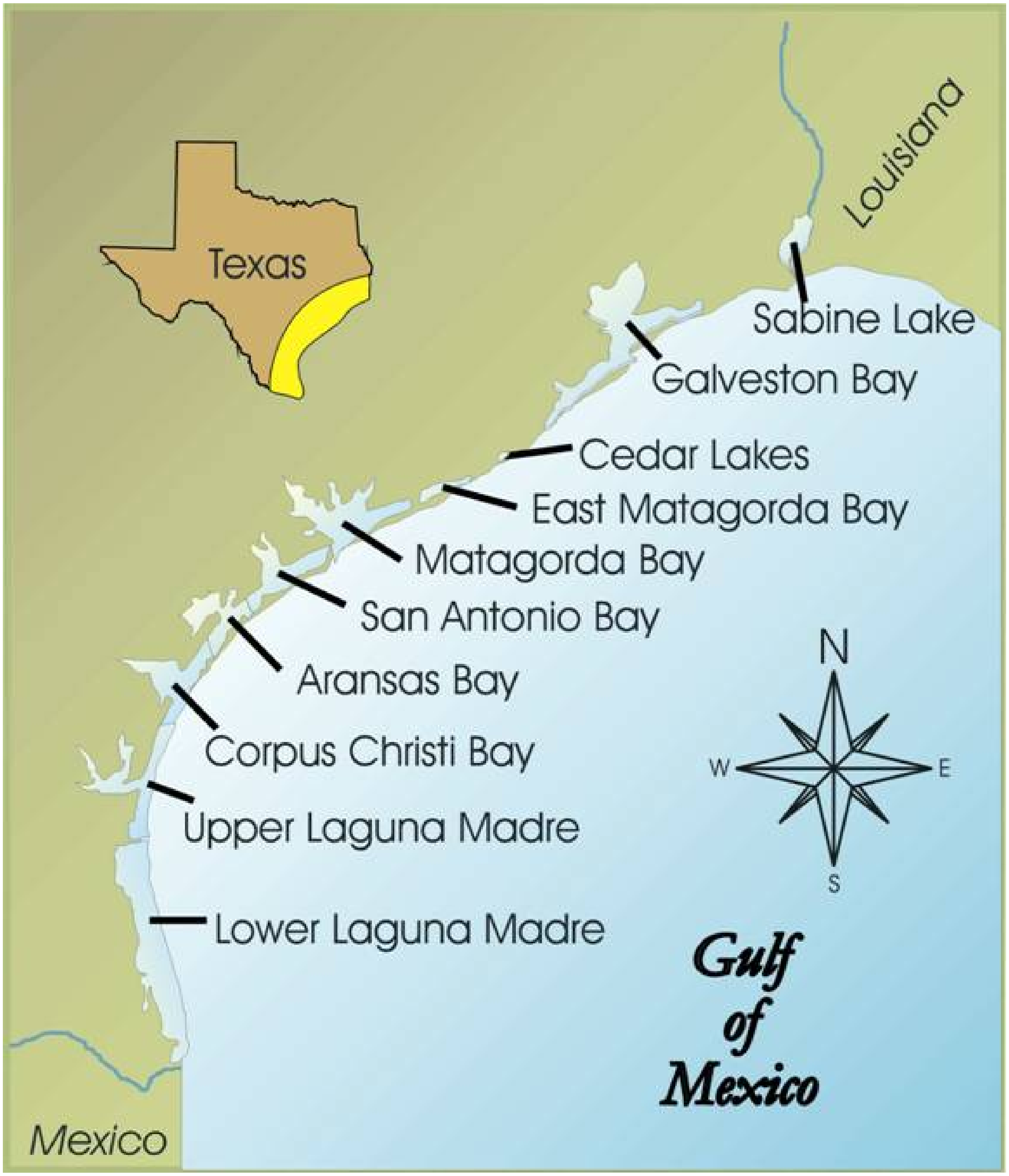


**Figure 5.2** Map showing the boundaries of the 7 coastal study areas (i.e., management units) for Louisiana Department of Wildlife and Fisheries. The boundaries are generally delineated by river basins.

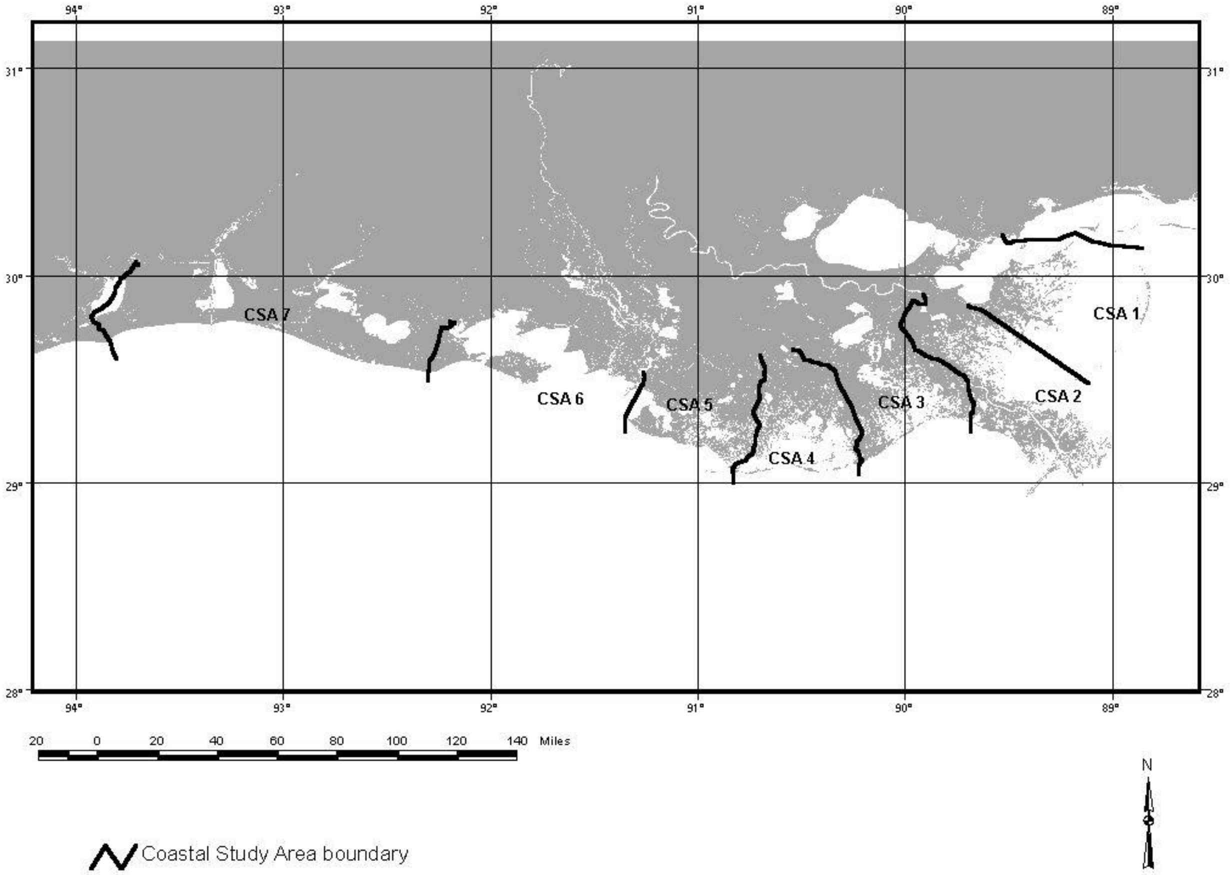


**Figure 5.3** Fixed seine, trawl, and beam plankton net stations for fishery-independent sampling conducted by Mississippi Department of Marine Resources.

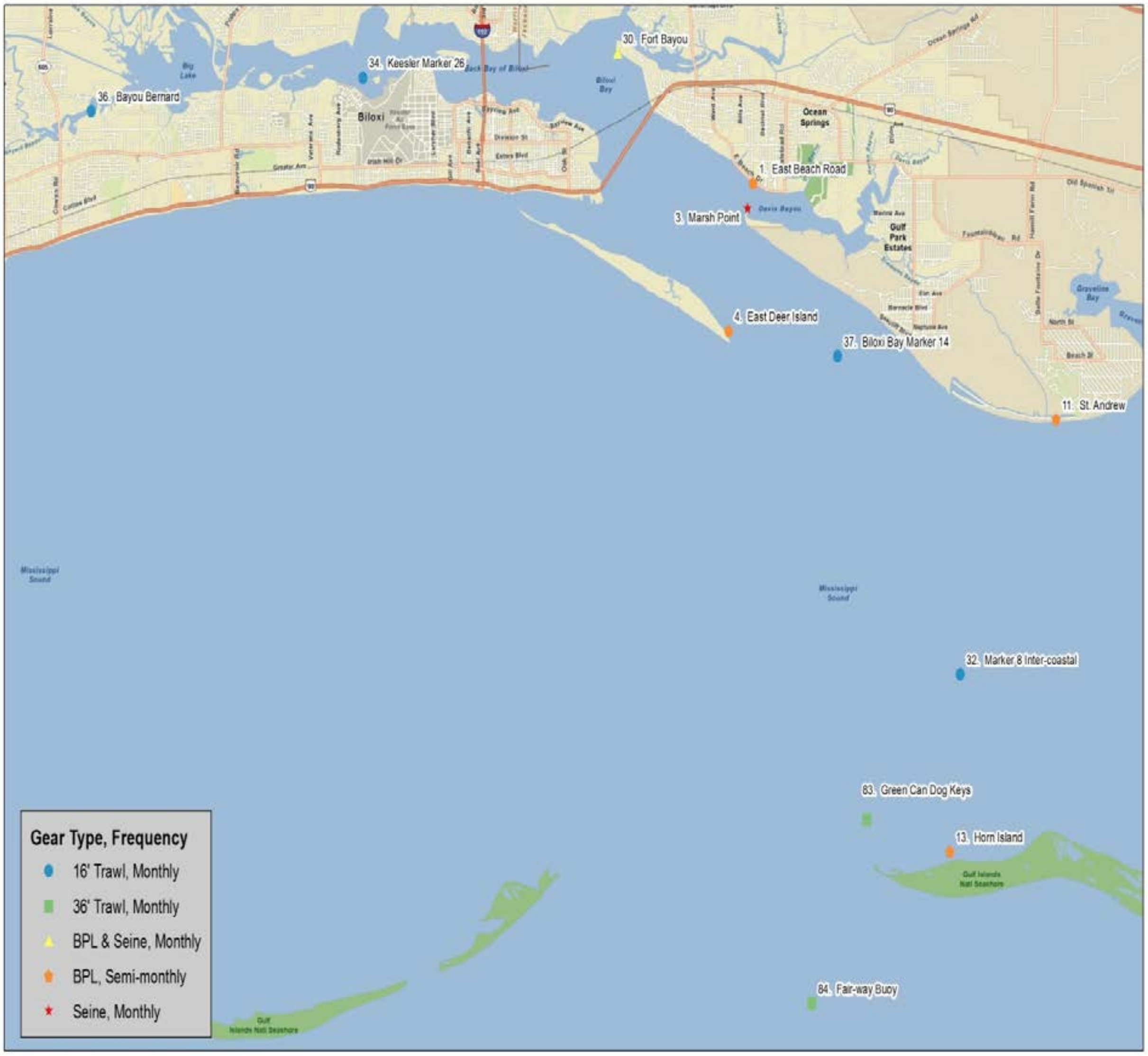
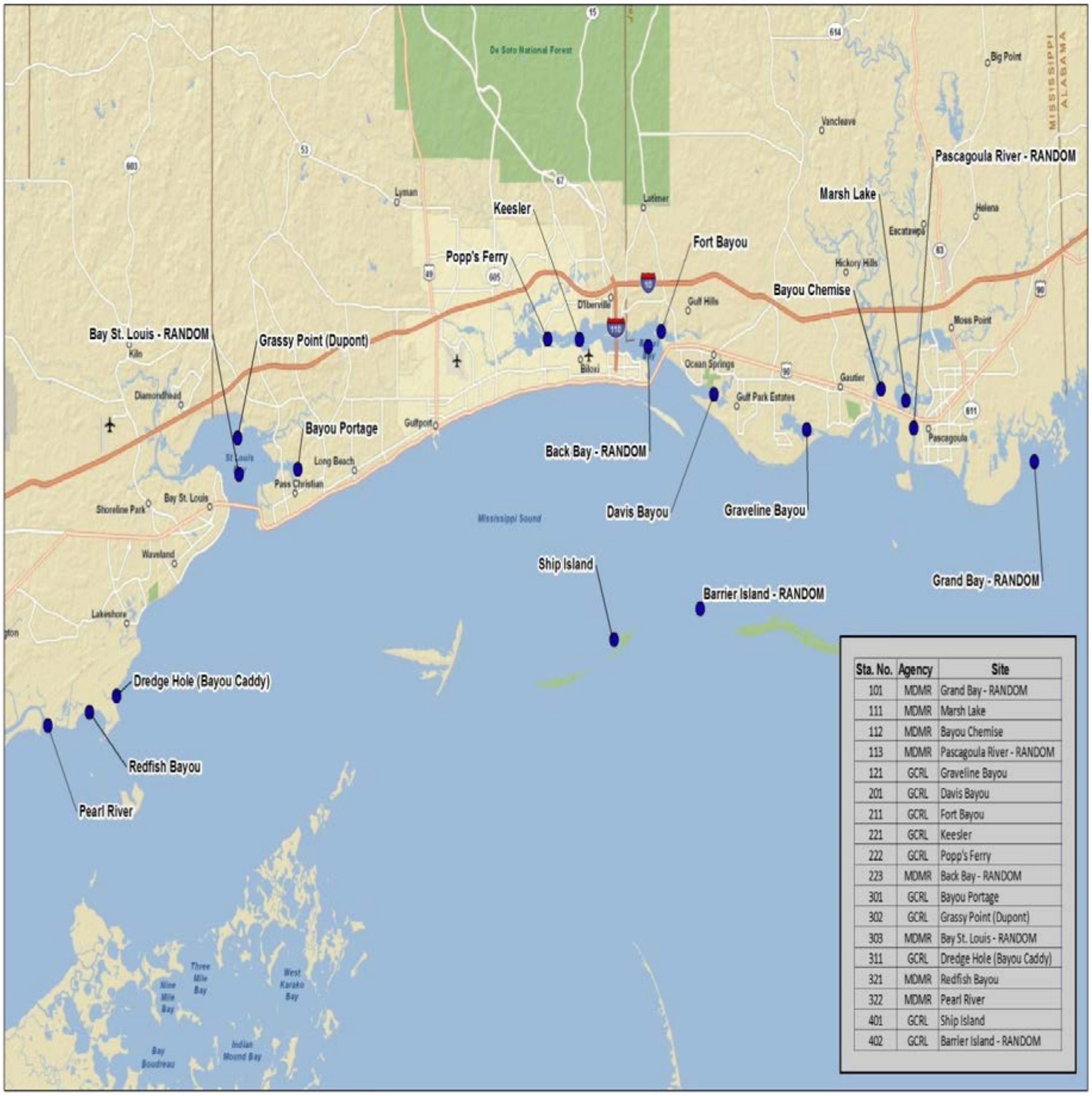


**Figure 5.4** Fixed gillnet stations for fishery-independent sampling conducted by Mississippi Department of Marine Resources.



| Sta. No. | Agency | Site |
|---|---|---|
| 101 | MDMR | Grand Bay - RANDOM |
| 111 | MDMR | Marsh Lake |
| 112 | MDMR | Bayou Chemise |
| 113 | MDMR | Pascagoula River - RANDOM |
| 121 | GCRL | Graveline Bayou |
| 201 | GCRL | Davis Bayou |
| 211 | GCRL | Fort Bayou |
| 221 | GCRL | Keesler |
| 222 | GCRL | Popp's Ferry |
| 223 | MDMR | Back Bay - RANDOM |
| 301 | GCRL | Bayou Portage |
| 302 | GCRL | Grassy Point (Dupont) |
| 303 | MDMR | Bay St. Louis - RANDOM |
| 311 | GCRL | Dredge Hole (Bayou Caddy) |
| 321 | MDMR | Redfish Bayou |
| 322 | MDMR | Pearl River |
| 401 | GCRL | Ship Island |
| 402 | GCRL | Barrier Island - RANDOM |

**Figure 5.5** Residuals by year for the positive portion of the delta-glm model for the seine index for gulf menhaden.

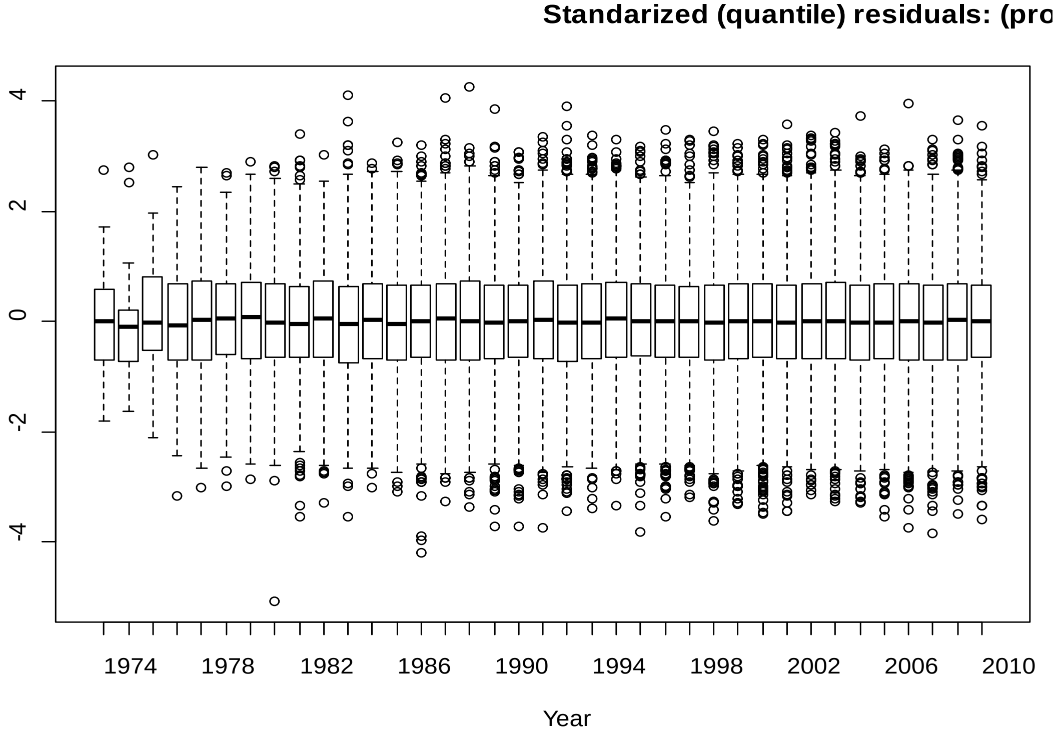


**Figure 5.6** Residuals by year for the positive portion of the delta-glm model for the gillnet index for gulf menhaden.

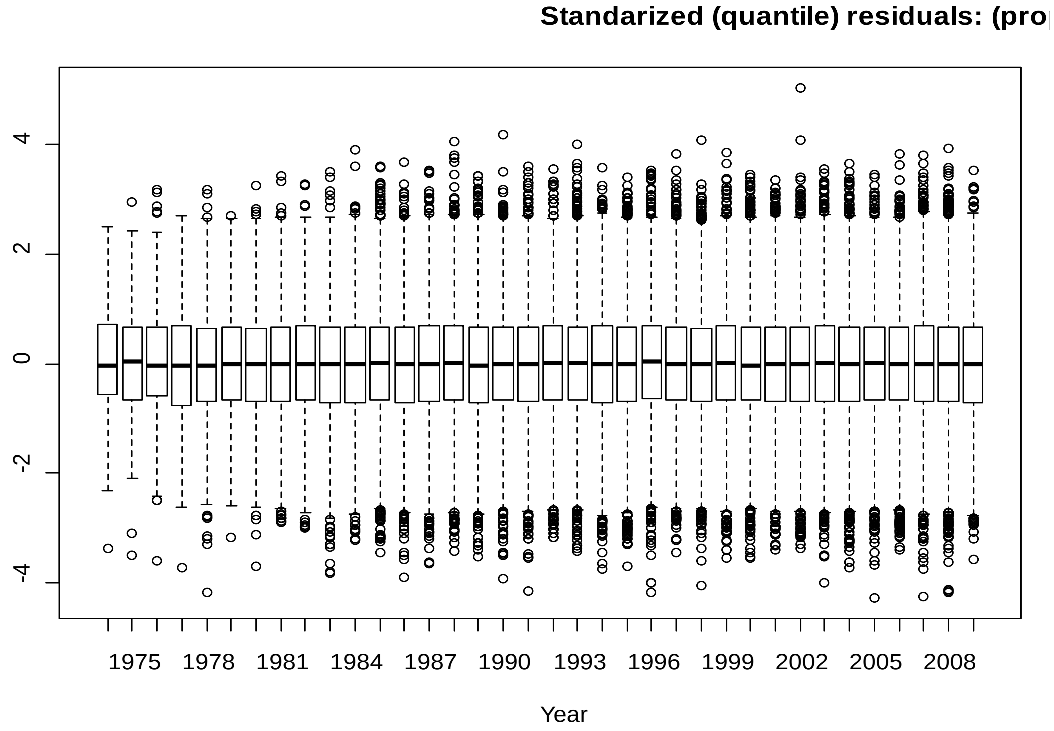


**Figure 5.7** The standardized gulf menhaden seine index for 1977 to 2010 will represent juvenile abundance.

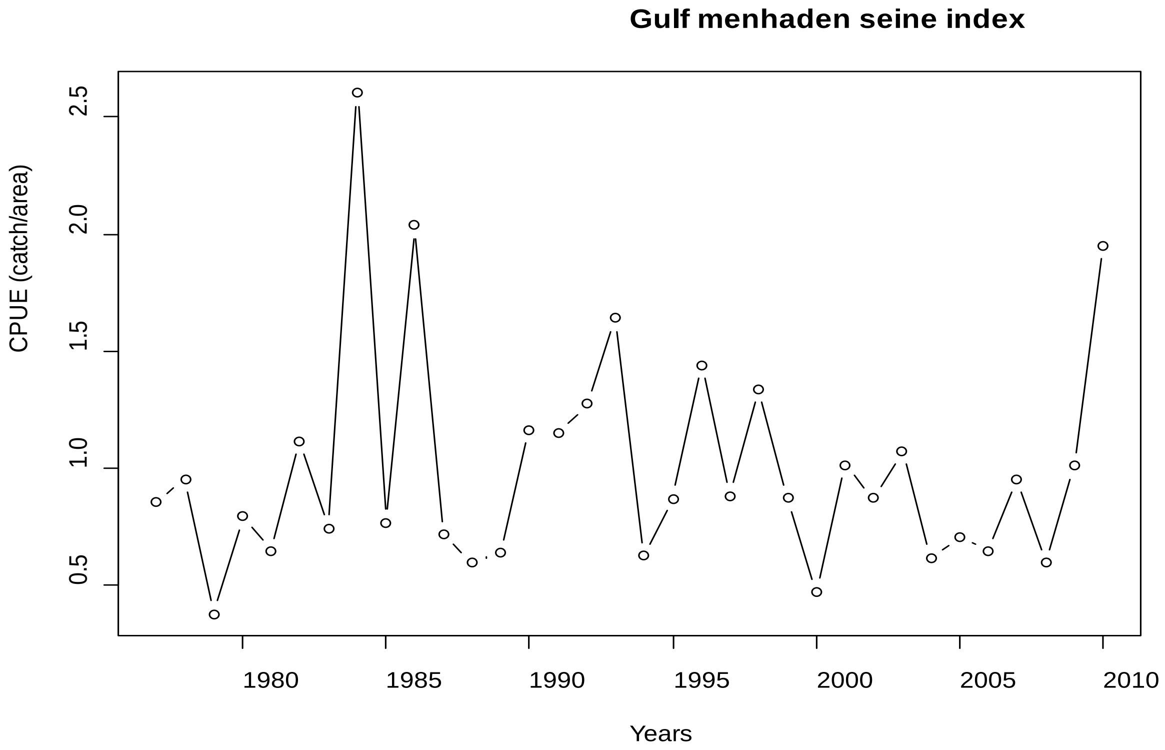


**Figure 5.8** The standardized gulf menhaden trawl index for 1967 to 2010 will represent juvenile abundance.

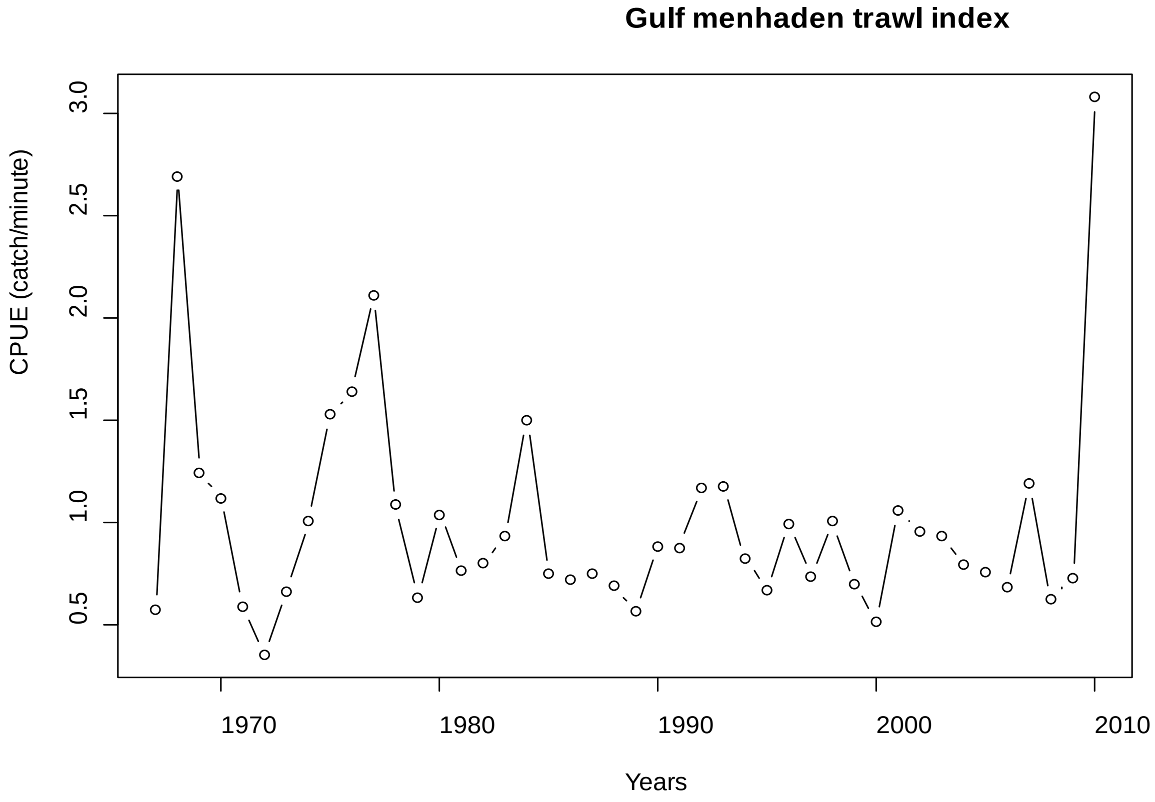


**Figure 5.9** The standardized seine and trawl juvenile abundance indices were positively correlated with a correlation of 0.53 for the years 1977 to 2010.

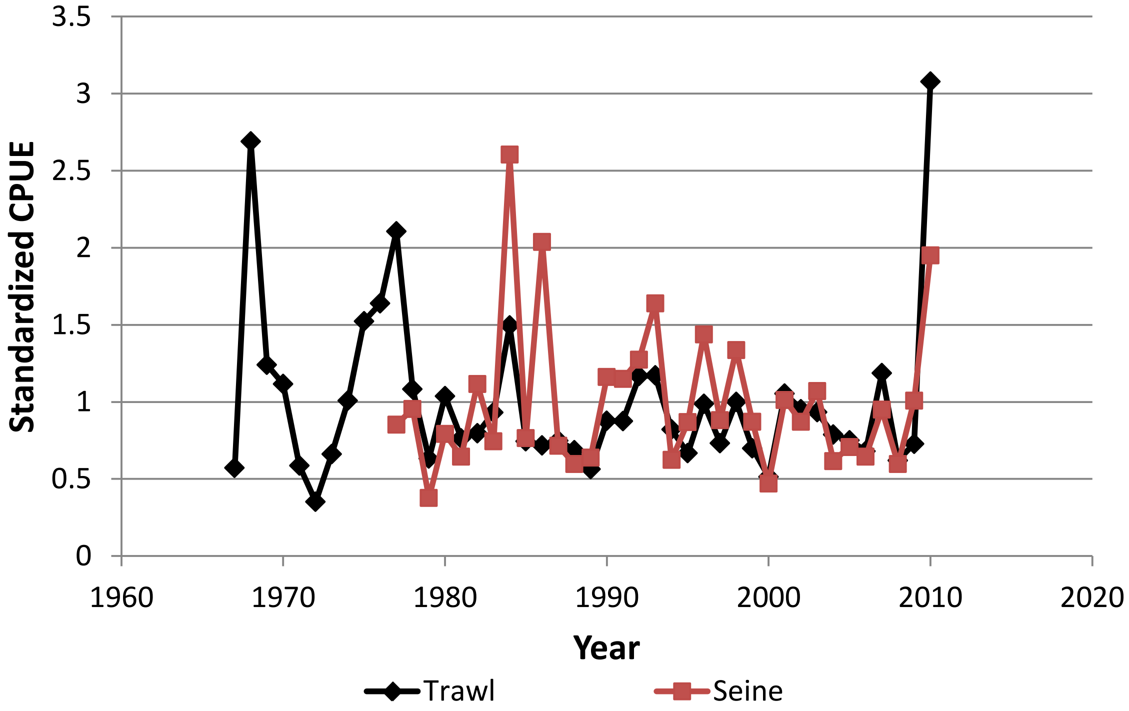


**Figure 5.10** The standardized gulf menhaden gillnet index for 1986 to 2010 will represent adult abundance.

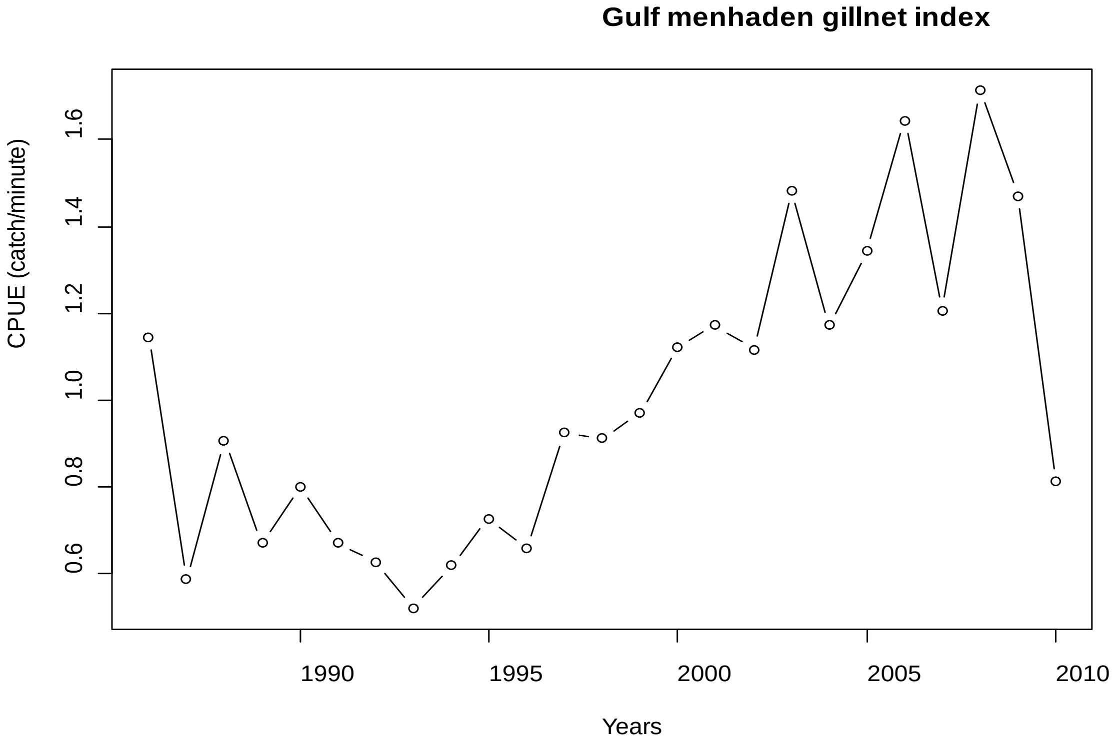


**Figure 6.1** The standardized gulf menhaden gillnet index for 1986 to 2010 using only data from Louisiana. This index was redone at the assessment workshop.

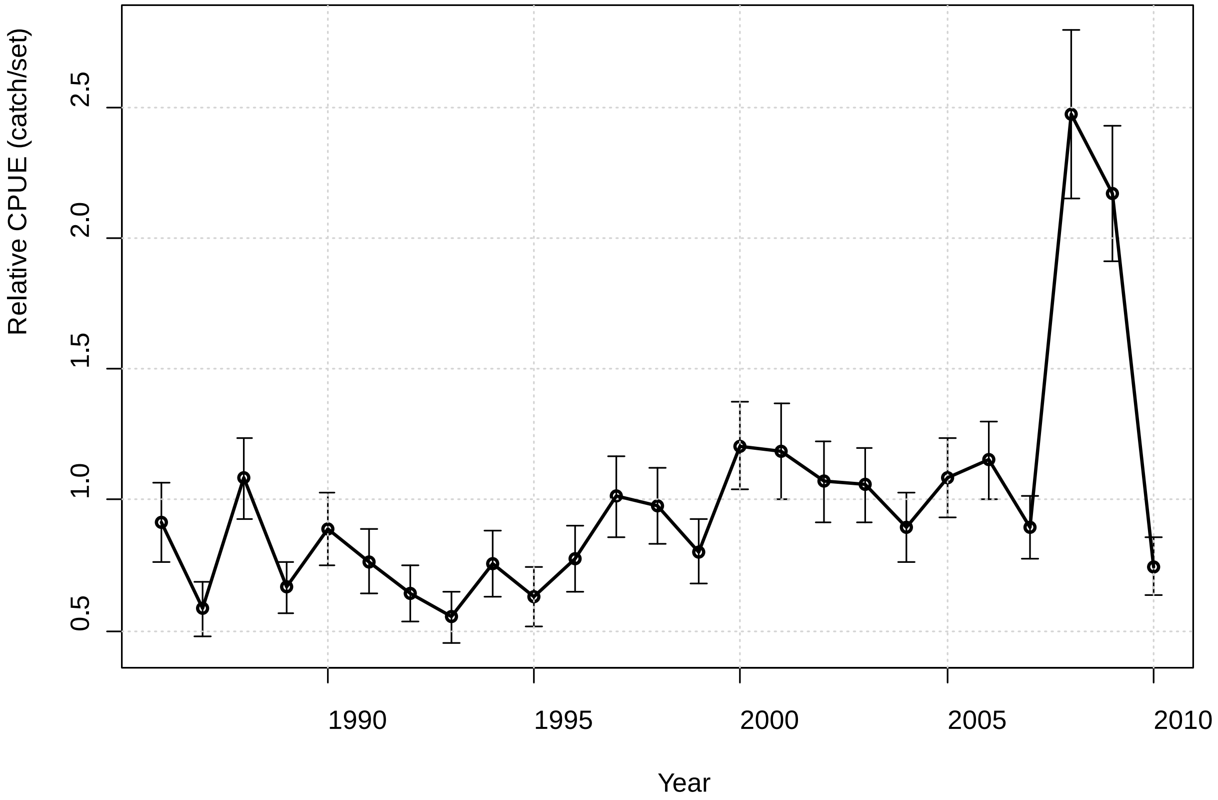


**Figure 6.2** Gillnet index length compositions using on data from Louisiana. Length compositions from 1988 to 1992 were not used in the base run because of the small number of gillnet sets that were used to get length measurements in those years.

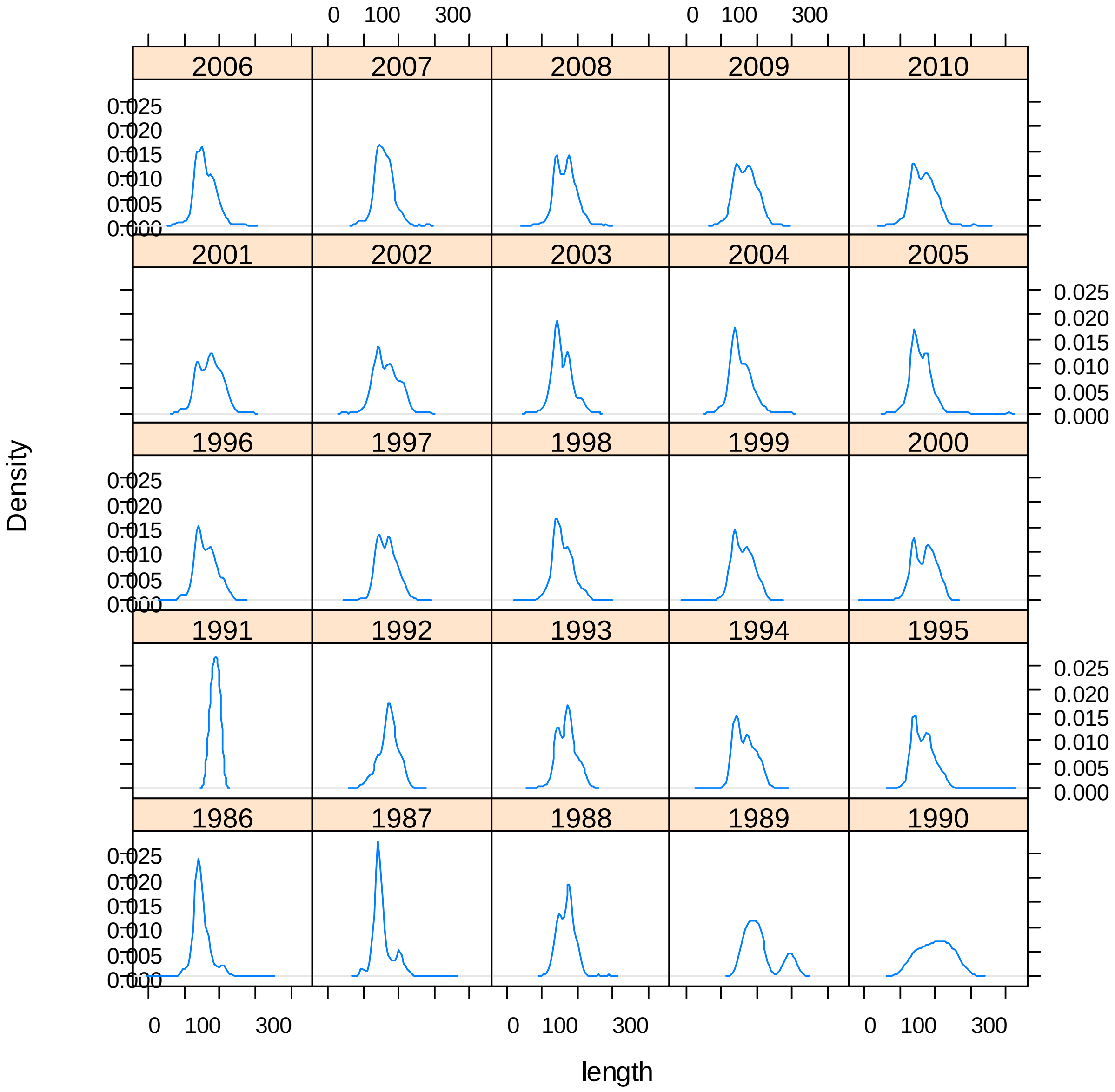


**Figure 6.3** Iterations of the gillnet index discussed by the assessment workshop panelists. The solid line is the gillnet index that was used in the base run of BAM and is an index estimated using only data from Louisiana, but included all mesh sizes. The dotted line is the gillnet index when data from all states and all meshes sizes are used, and the dashed line is the gillnet index when data from all states, but only the 3-inch mesh size was used.

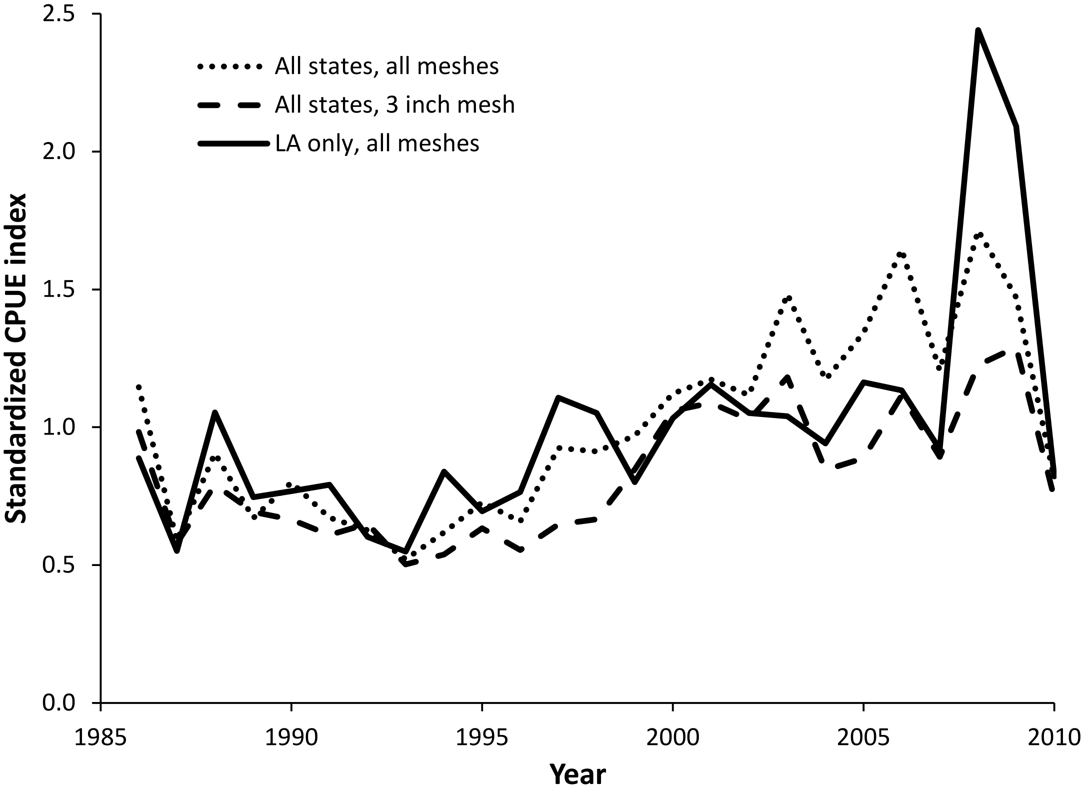


**Figure 8.1** Observed and predicted landings for the commercial reduction fishery from 1948-2010.

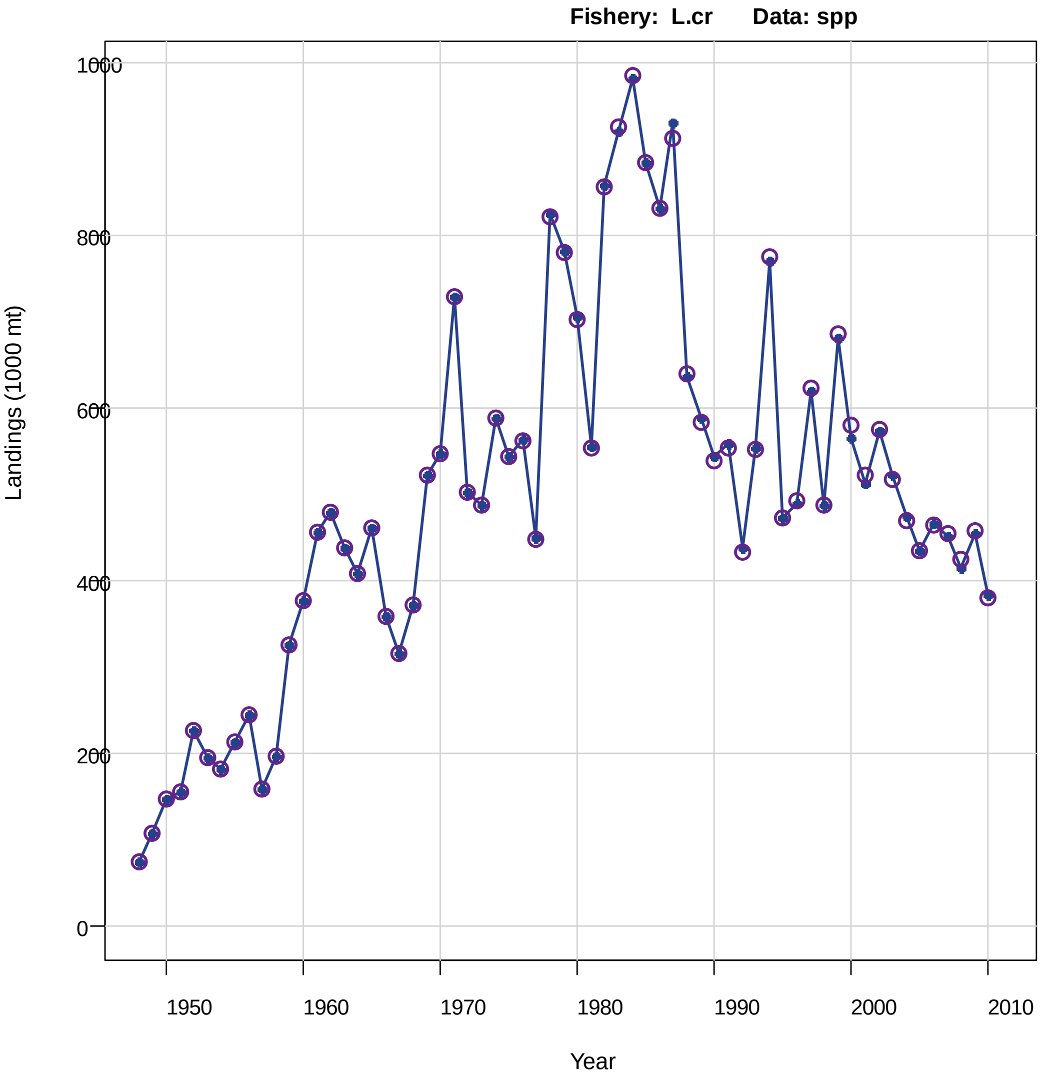


**Figure 8.2** Observed and predicted age compositions for the commercial reduction fishery from 1964-2010. Each panel includes the year and associated sample size in the upper right corner.

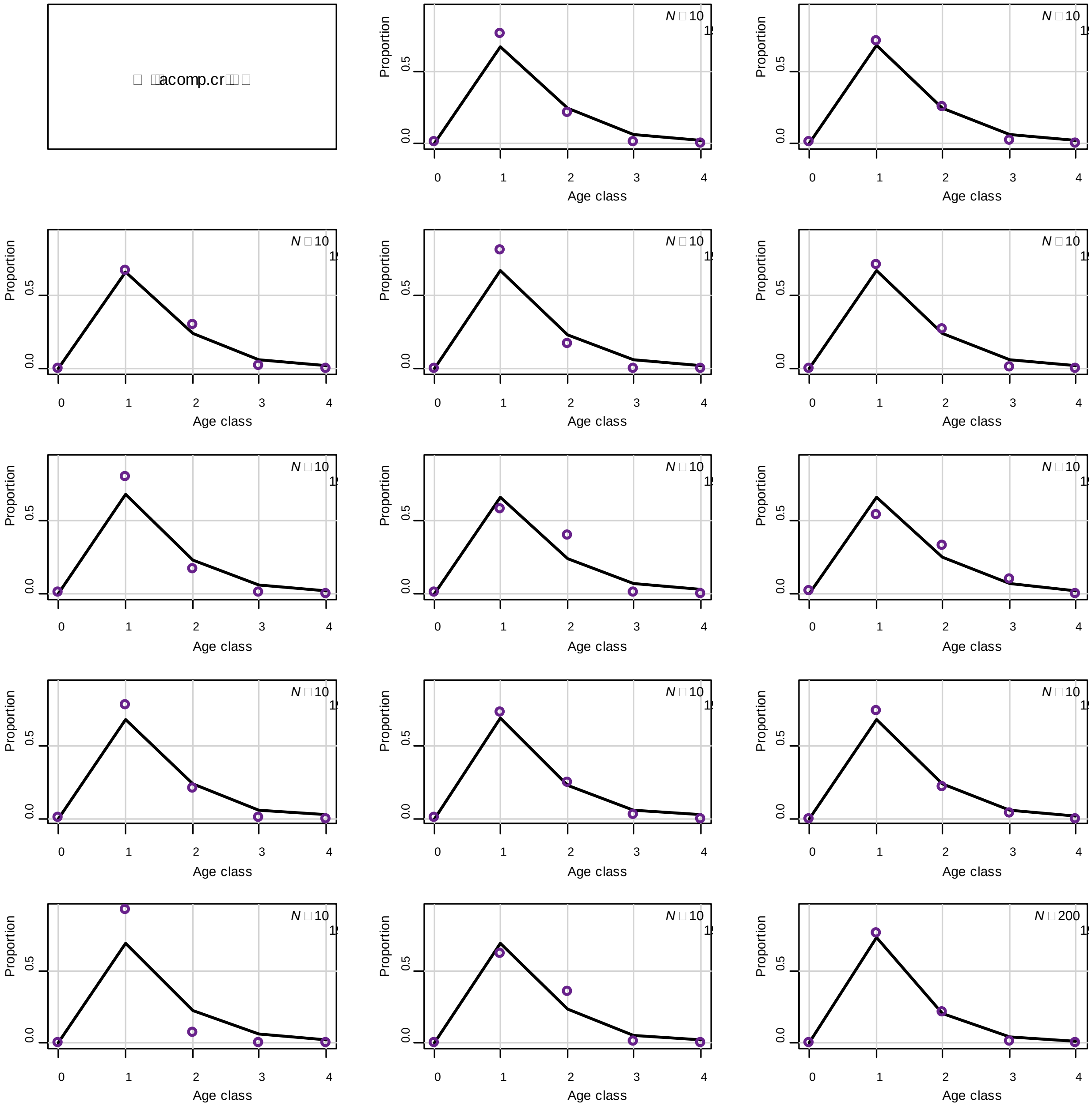


**Figure 8.2** (Cont.)

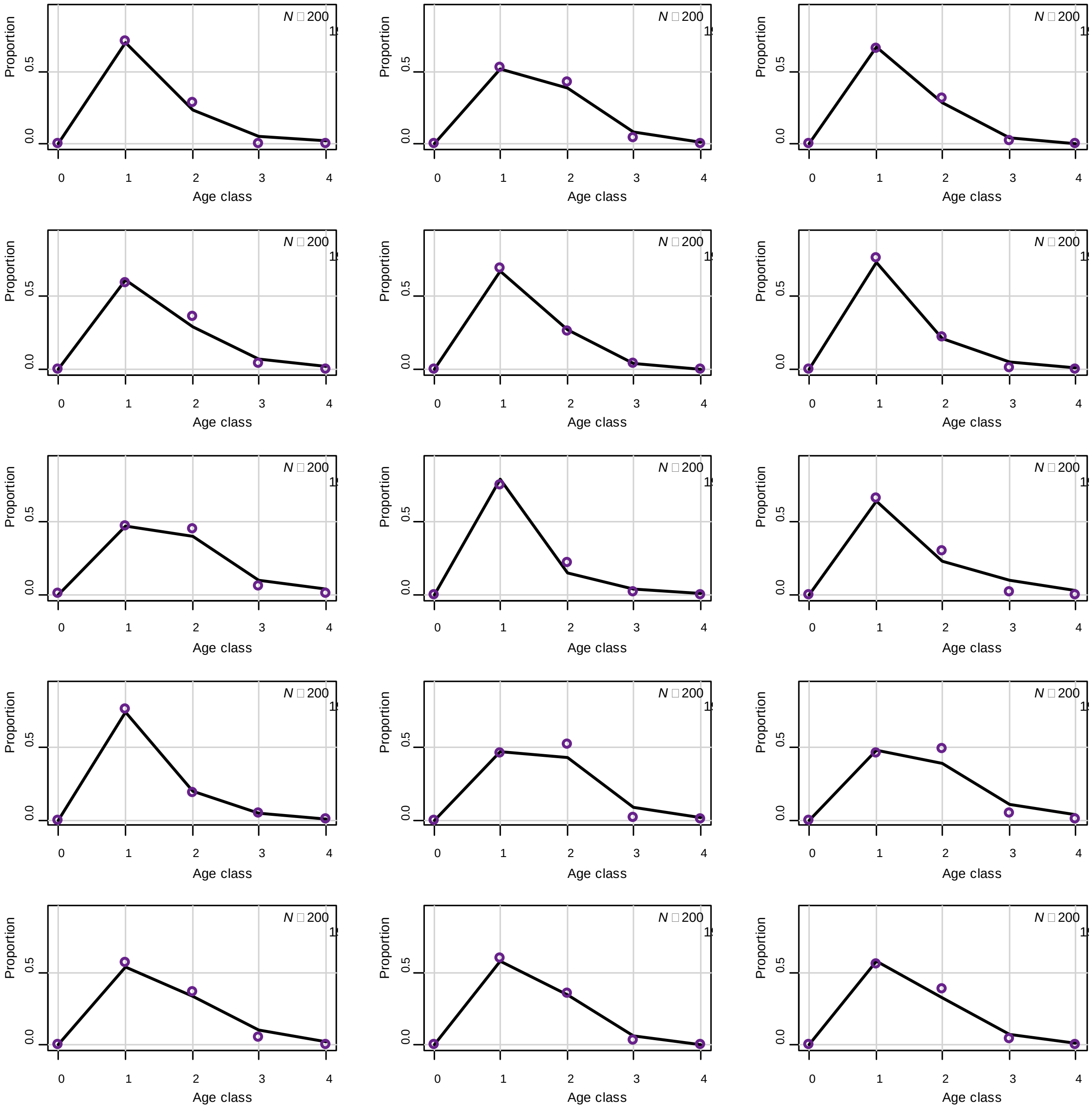


**Figure 8.2** (Cont.)

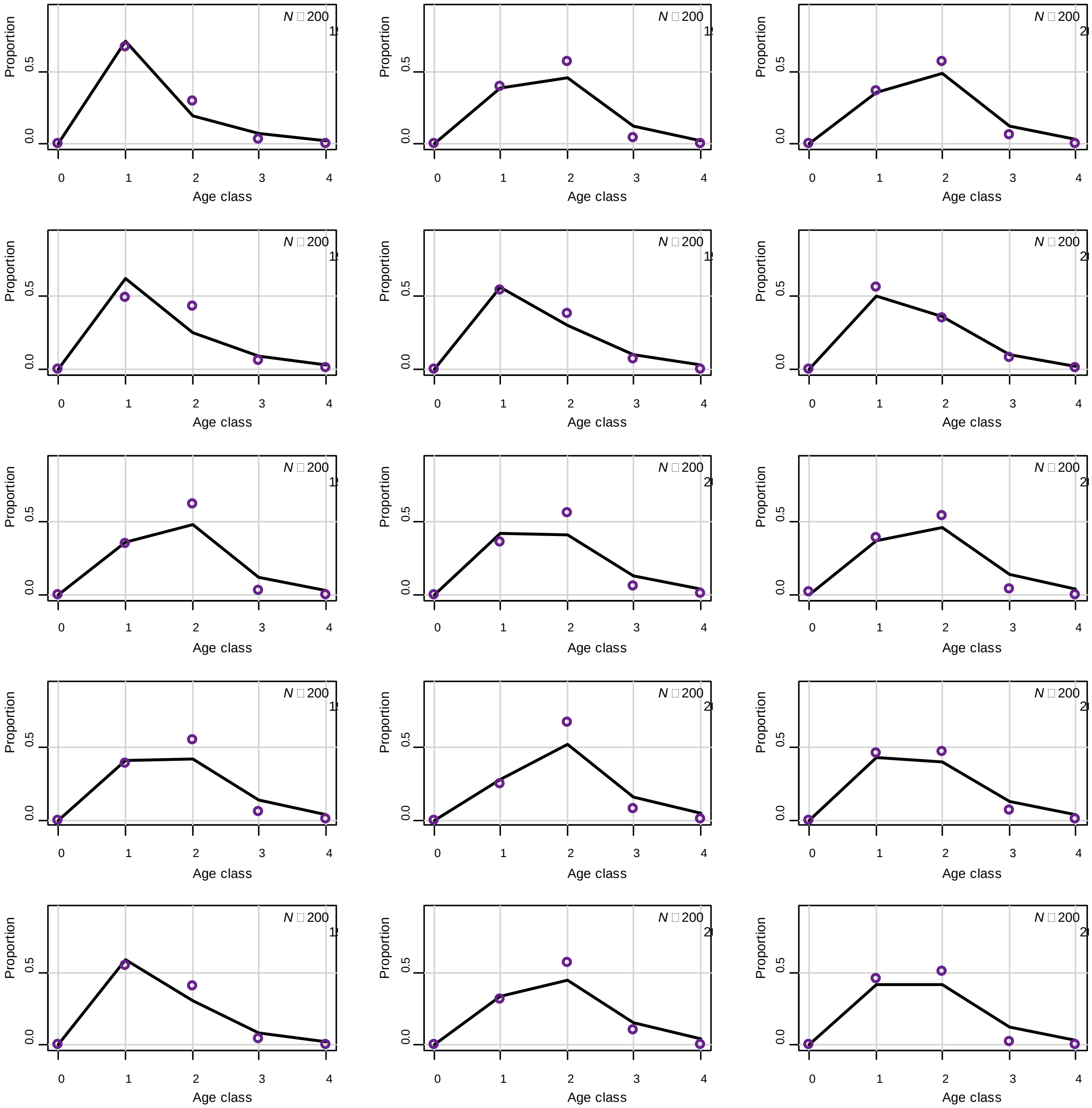


**Figure 8.2** (Cont.)

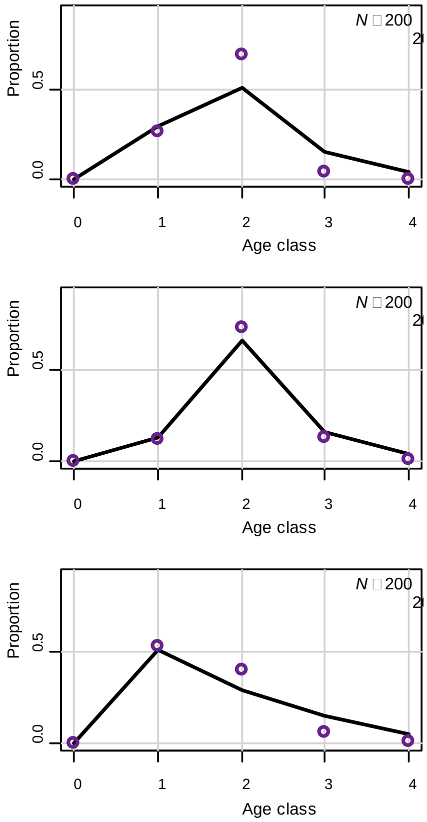


**Figure 8.3** Bubble plot of residuals for the age compositions for the commercial reduction fishery from 1964-2010. Light colored circles are underestimated while dark colored circles are overestimated.

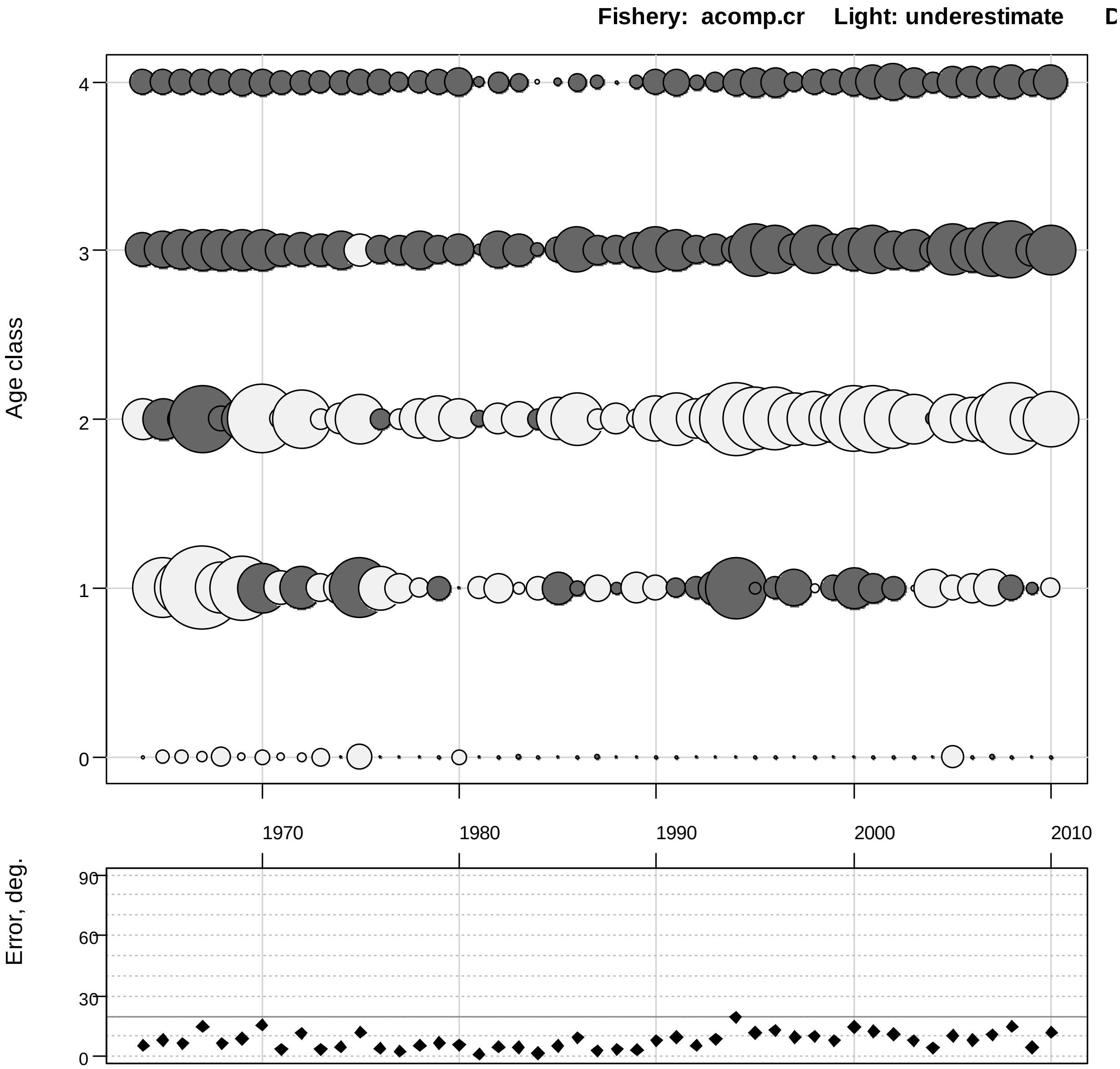


**Figure 8.4** Observed and predicted seine index, which was a juvenile abundance index, for 1977-2010.

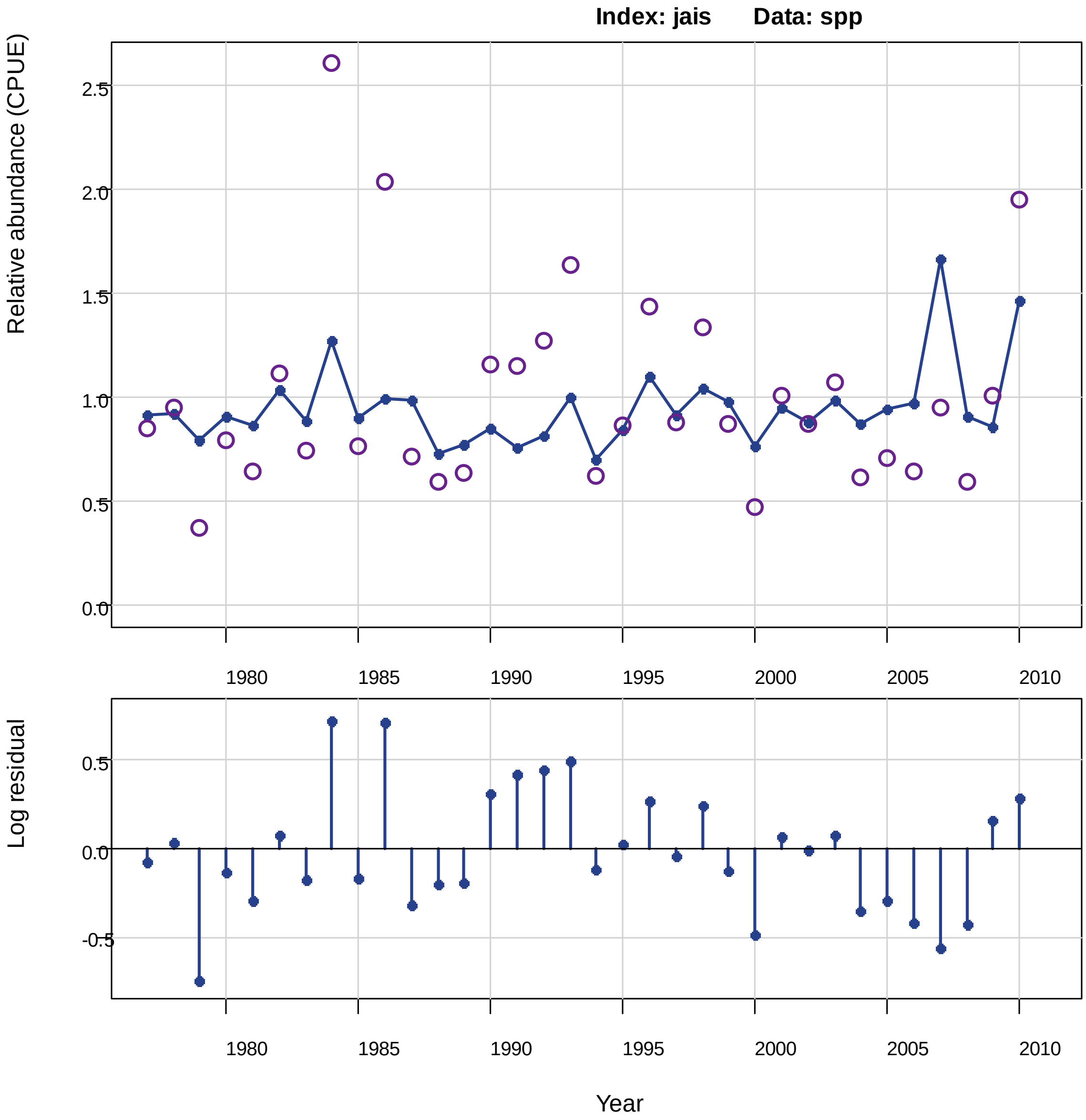


**Figure 8.5** Observed and predicted gillnet index, which was an adult abundance index, for 1986-2010.

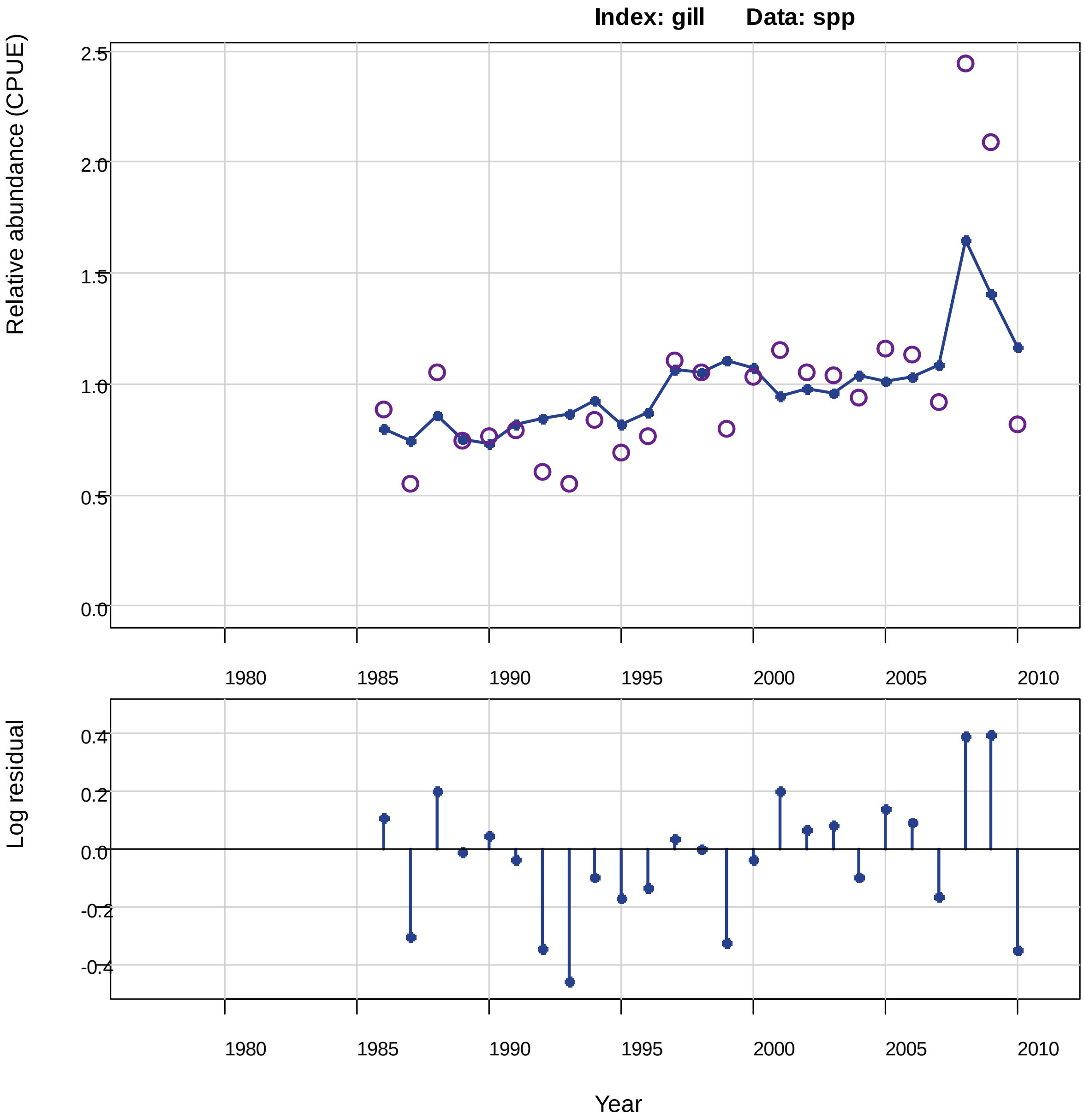


**Figure 8.6** Observed and predicted length compositions for the gillnet index from 1986-2010. Each panel includes the year and associated sample size in the upper right corner. Missing years were not used for fitting the model.

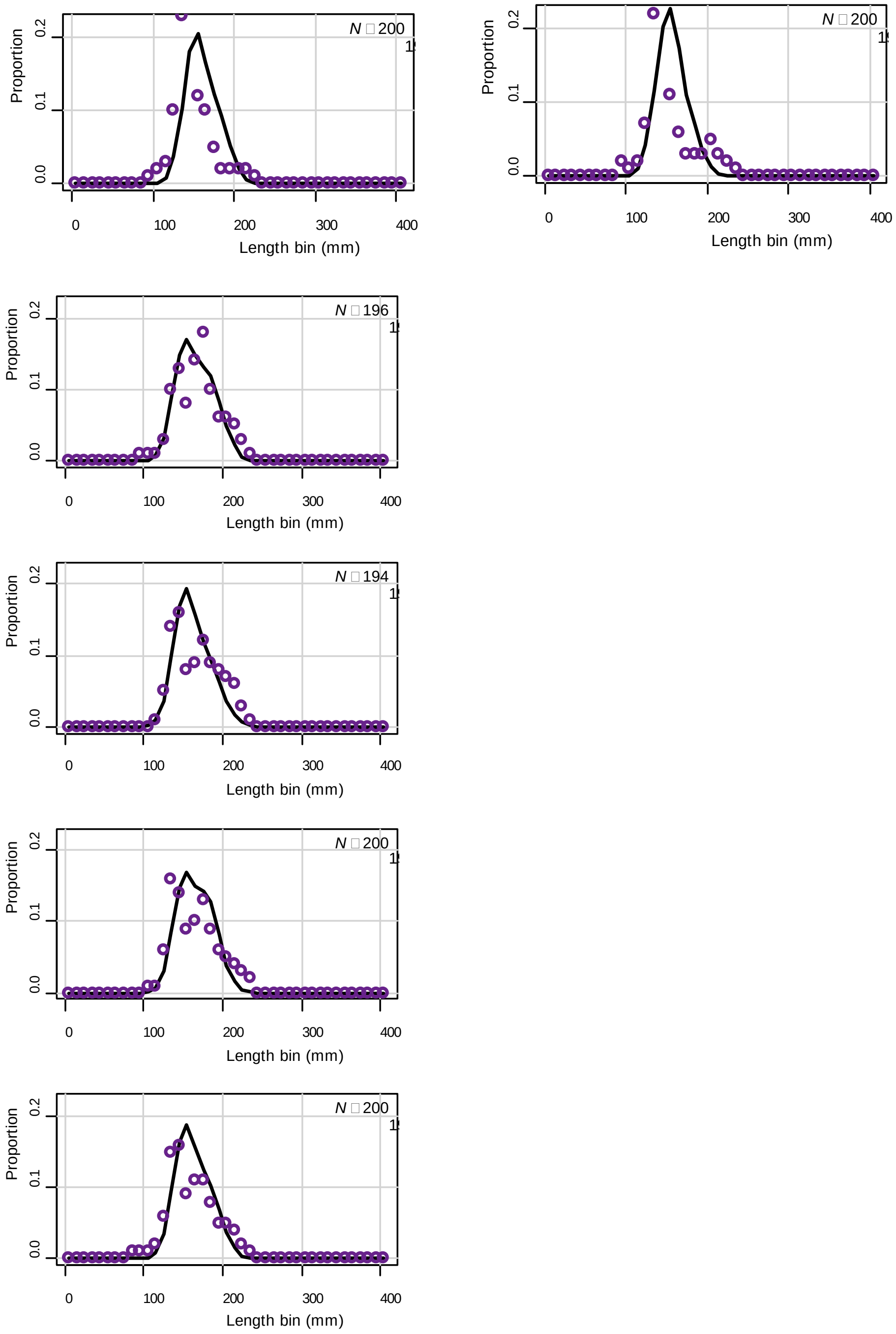


**Figure 8.6** (Cont.)

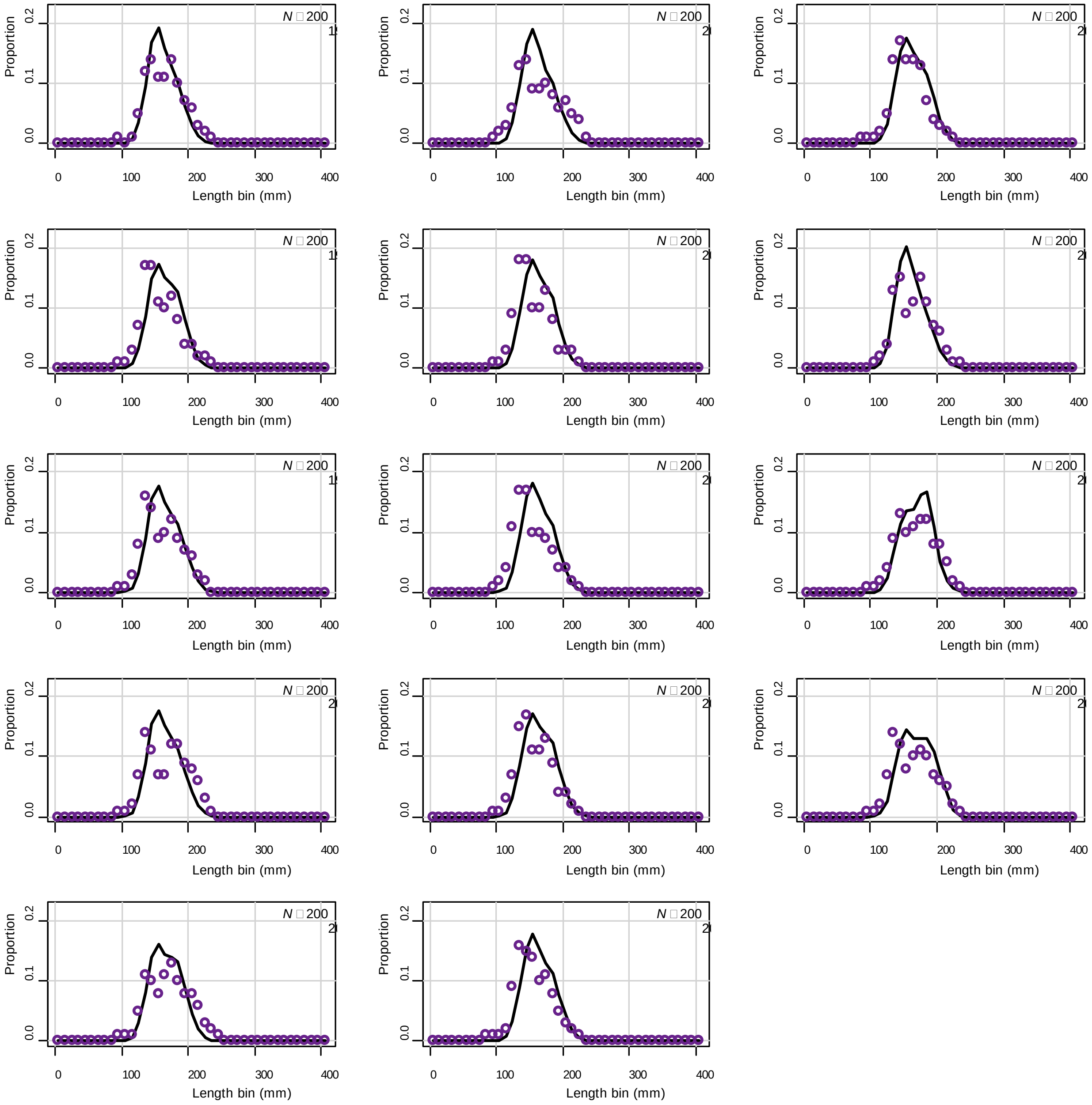


**Figure 8.7** Bubble plot of residuals for the length compositions for the gillnet index from 1986-2010. Light colored circles are underestimated while dark colored circles are overestimated. The years 1988-1992 were not used for model fitting due to small sample sizes, thus the bubble plot for those years show the largest residual errors.

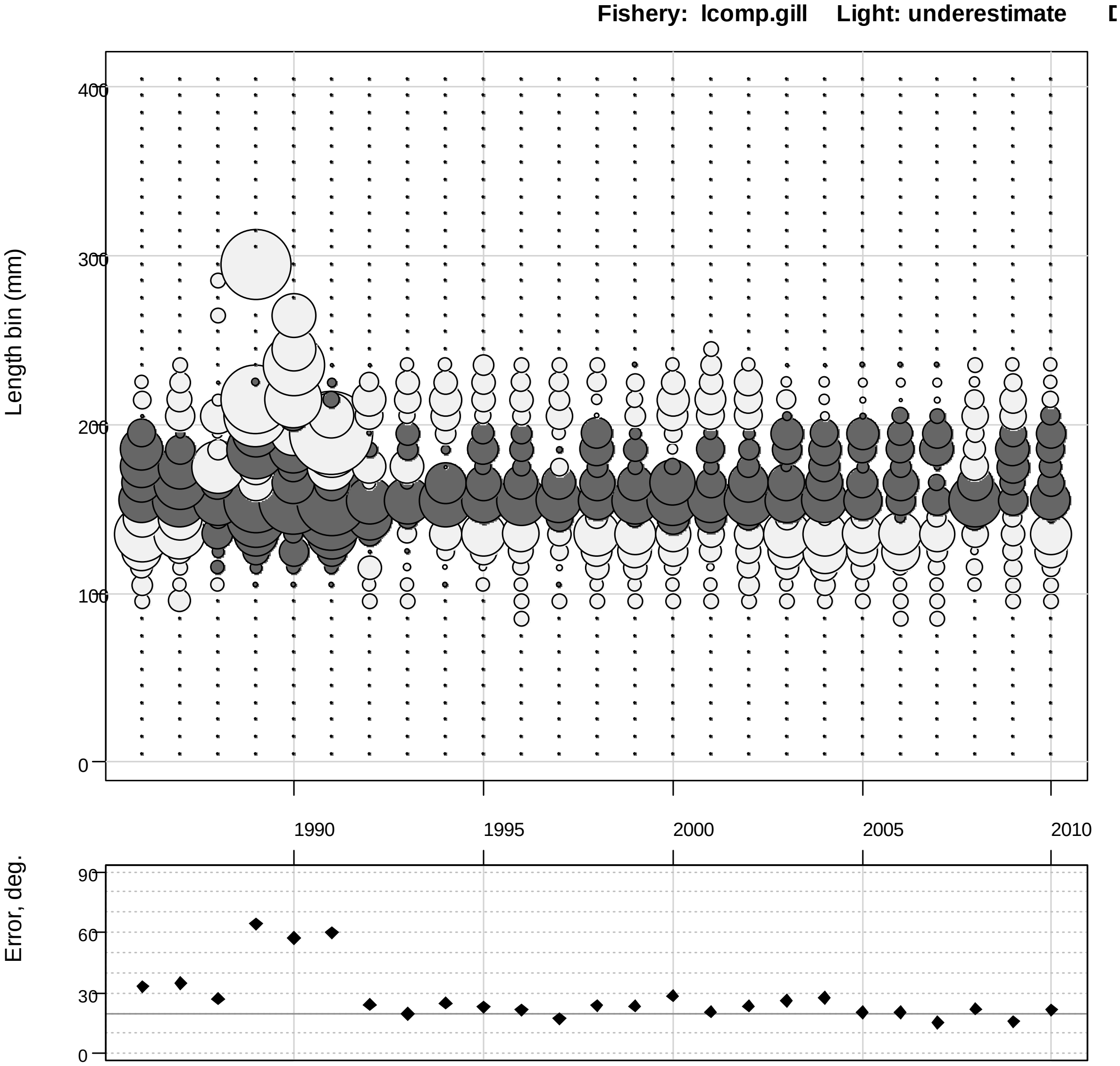


**Figure 8.8** Estimated selectivity for the commercial reduction fishery for ages one, three, and four from 1964-1979. Age-0 was assumed to be 0.0, and age-2 was assumed to be 1.0

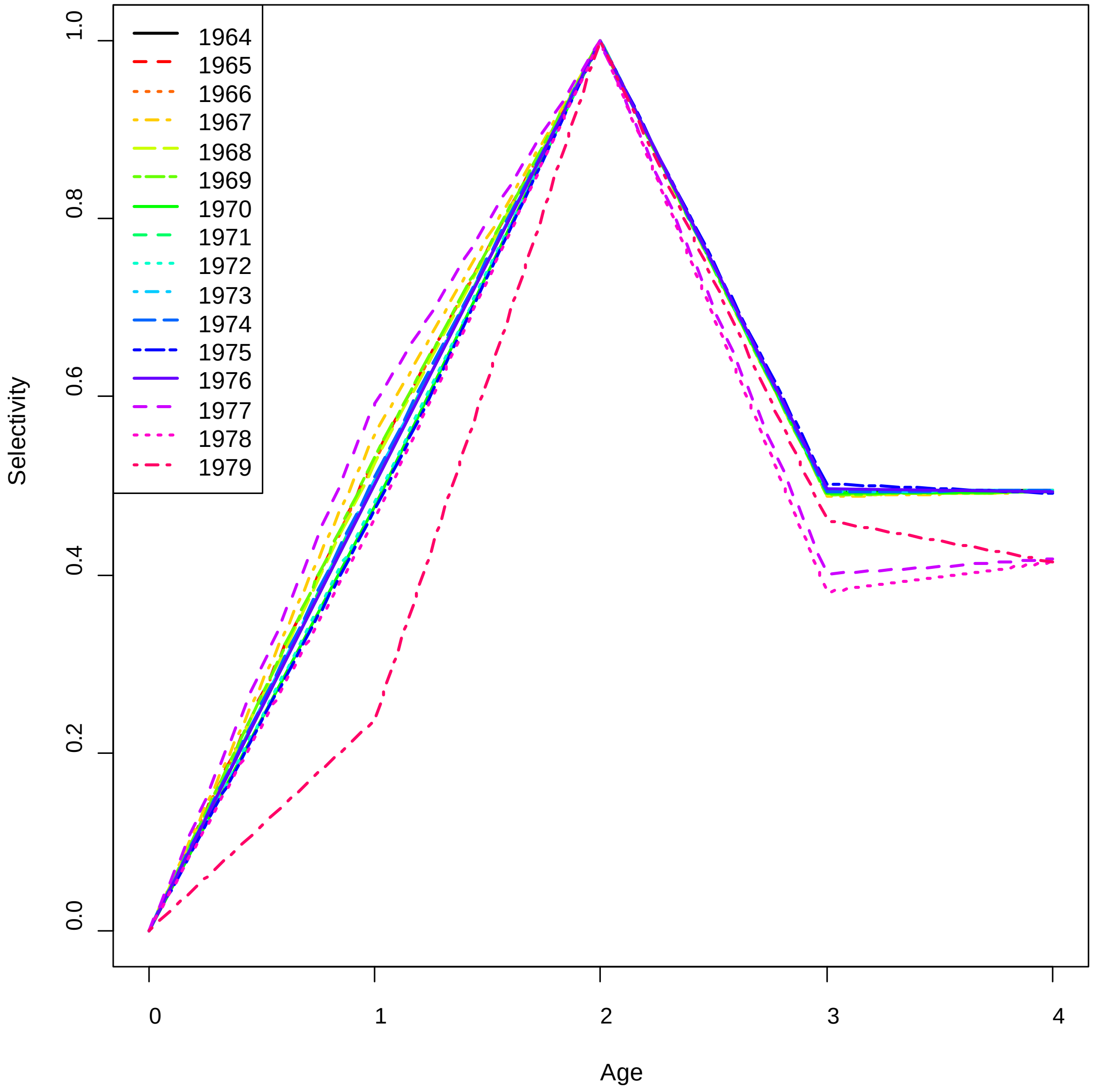


**Figure 8.9** Estimated selectivity for the commercial reduction fishery for age-1 from 1980-1993. Age-0 was assumed to be 0.0, and ages-2+ was assumed to be 1.0.

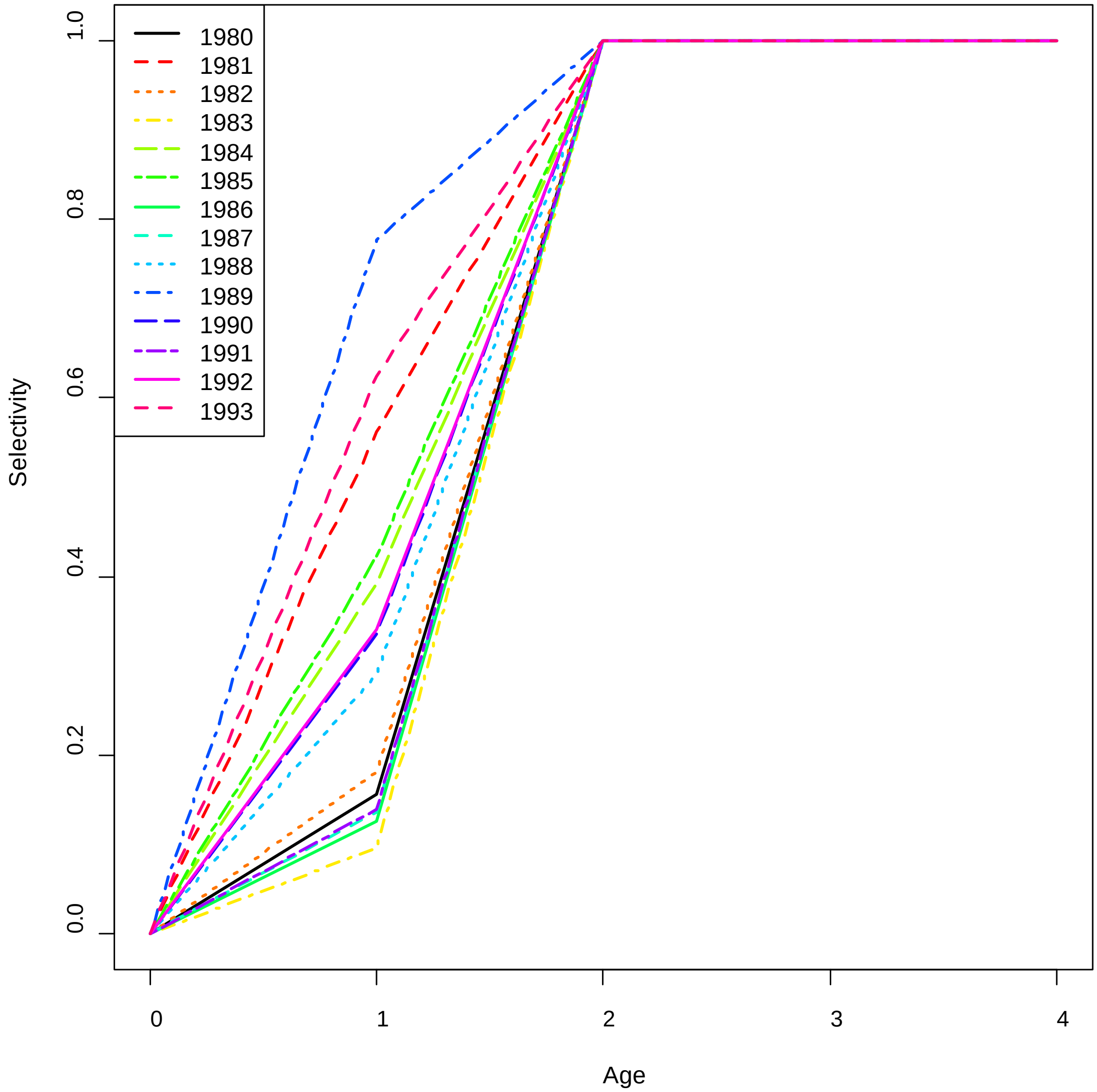


**Figure 8.10** Estimated selectivity for the commercial reduction fishery for age-1 from 1994-2010. Age-0 was assumed to be 0.0, and ages-2+ was assumed to be 1.0.

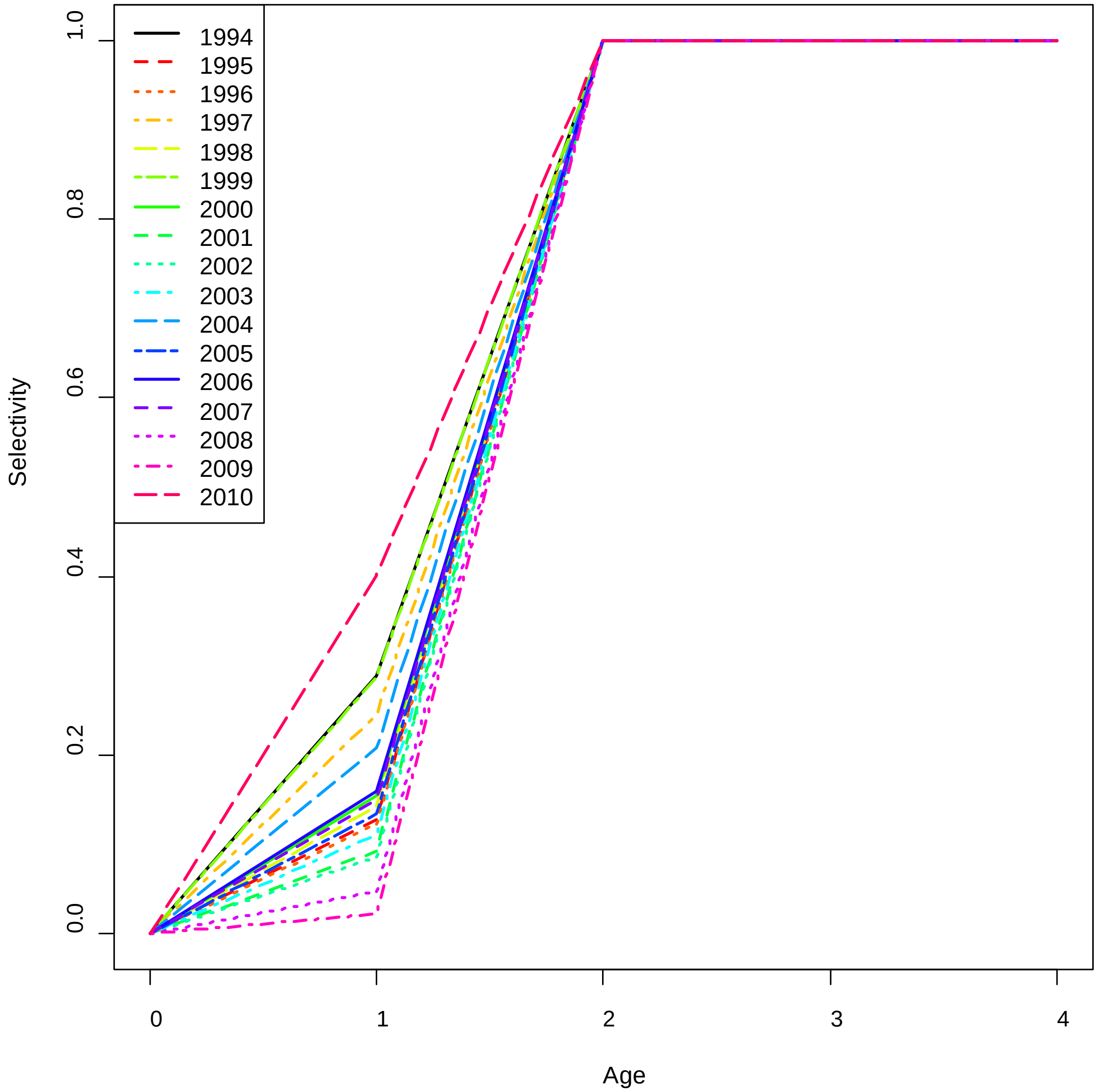


**Figure 8.11** Estimated age-2+ fishing mortality rate for the commercial reduction fishery from 1948-2010.

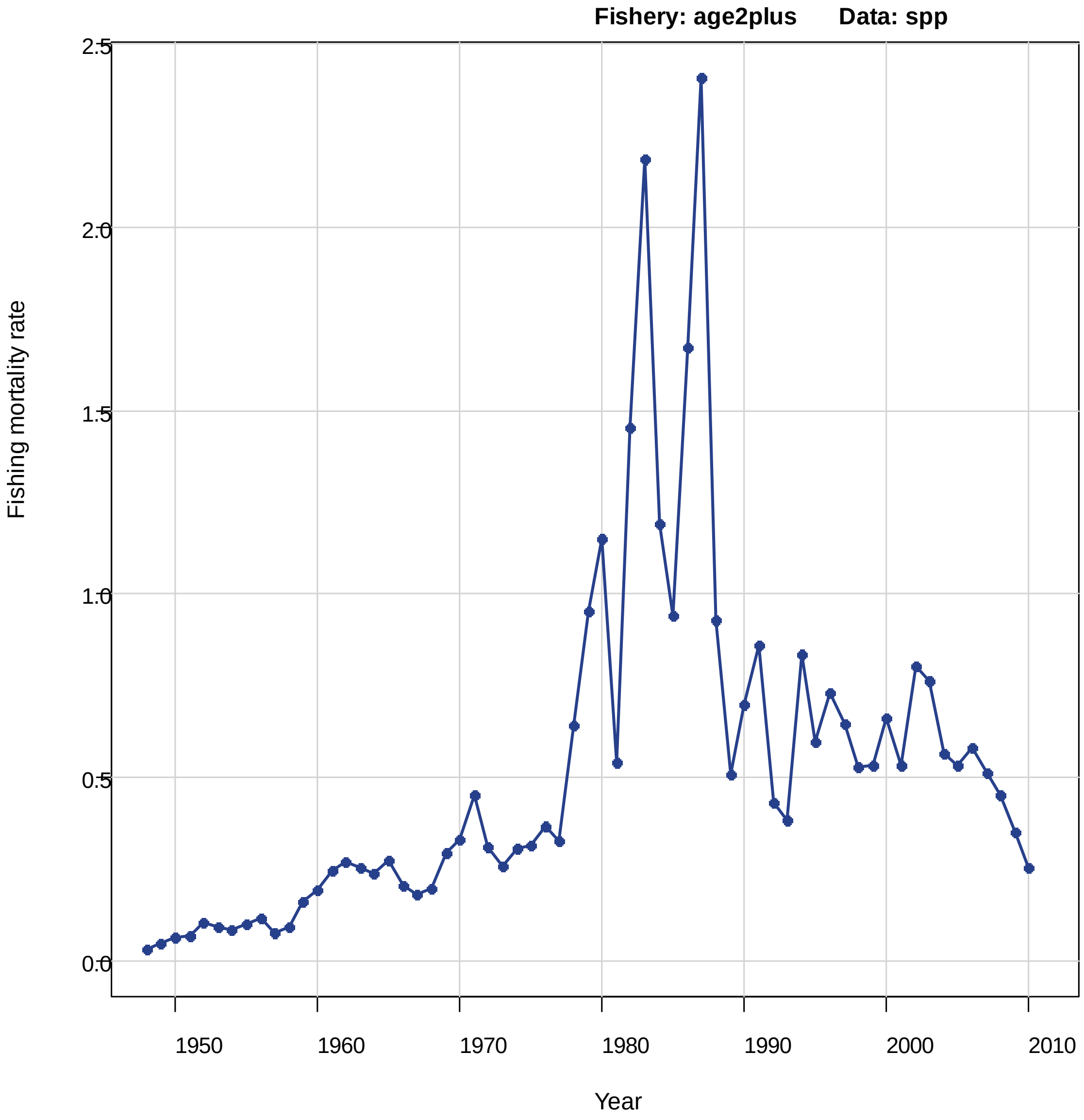


**Figure 8.12** Estimated full fishing mortality rate for the commercial reduction fishery from 1948-2010.

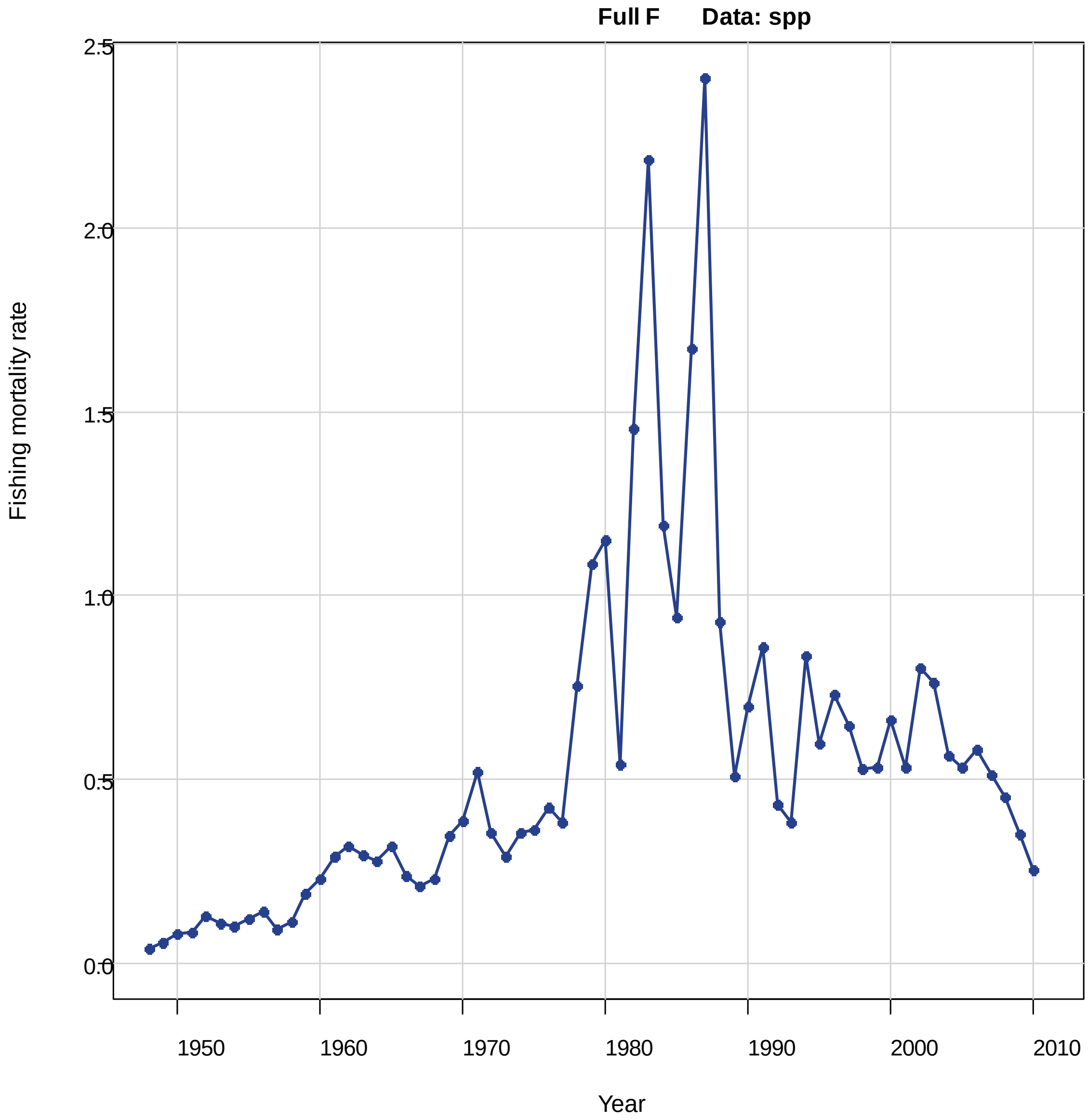


**Figure 8.13** Estimated numbers at age of gulf menhaden (billions) at the start of the fishing year from the base BAM model.

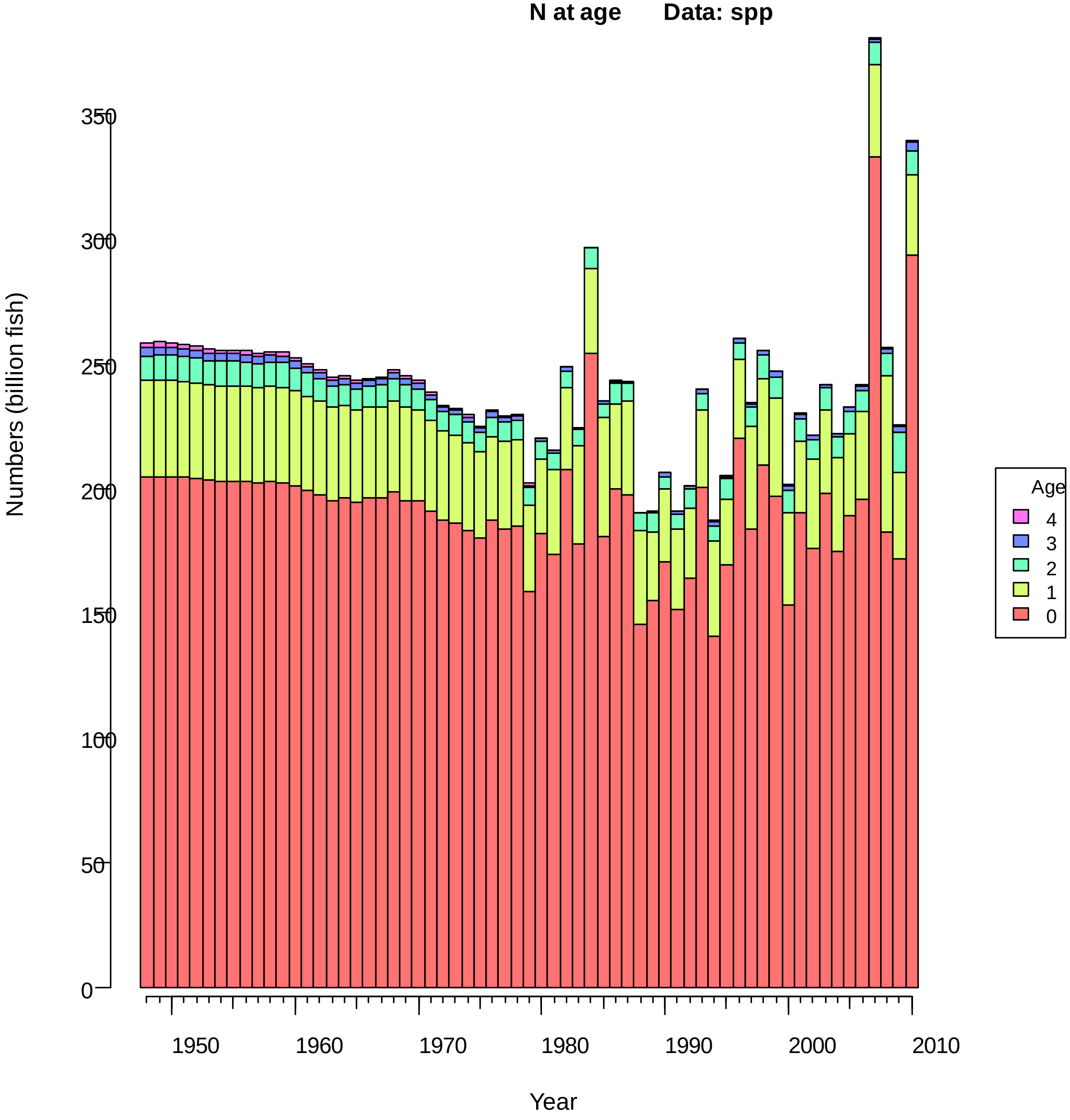


**Figure 8.14** Estimated annual fecundity (billions of eggs) from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs after runs were eliminated that were not able to estimate $F_{MSY}$.

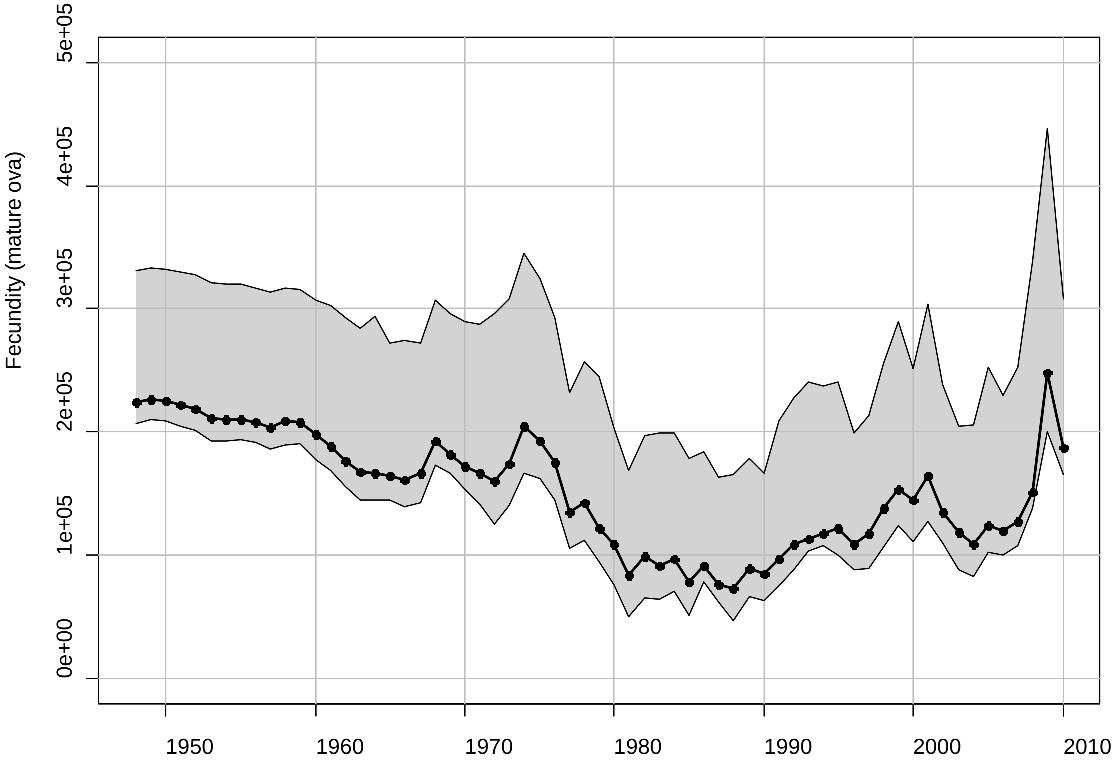


**Figure 8.15** Estimated total fecundity (billions of mature ova) at age for gulf menhaden at the start of the fishing year from the base run of BAM.

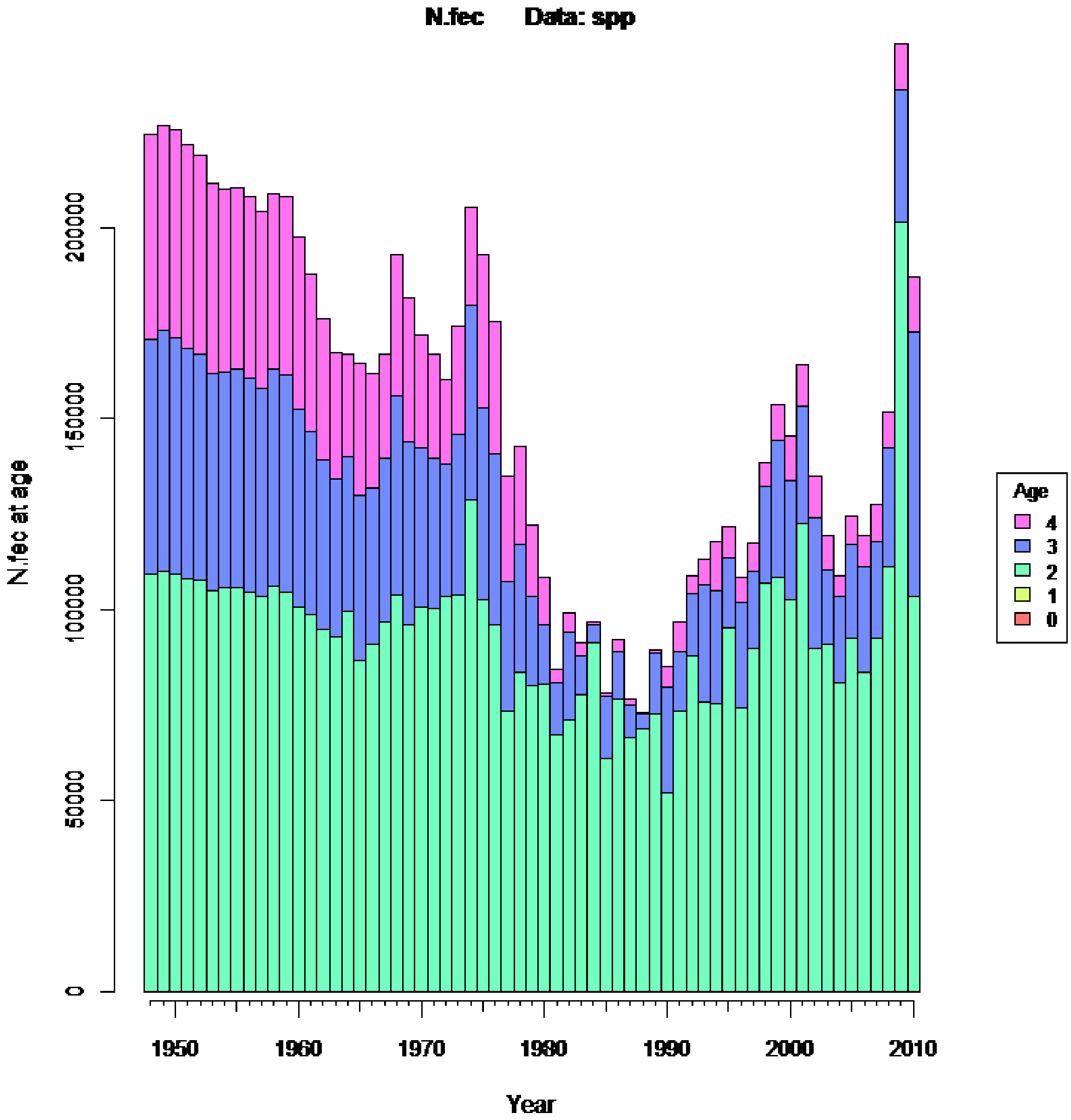


**Figure 8.16** Estimated annual recruitment to age-0 (billions) from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs after runs were eliminated that were not able to estimate $F_{MSY}$.

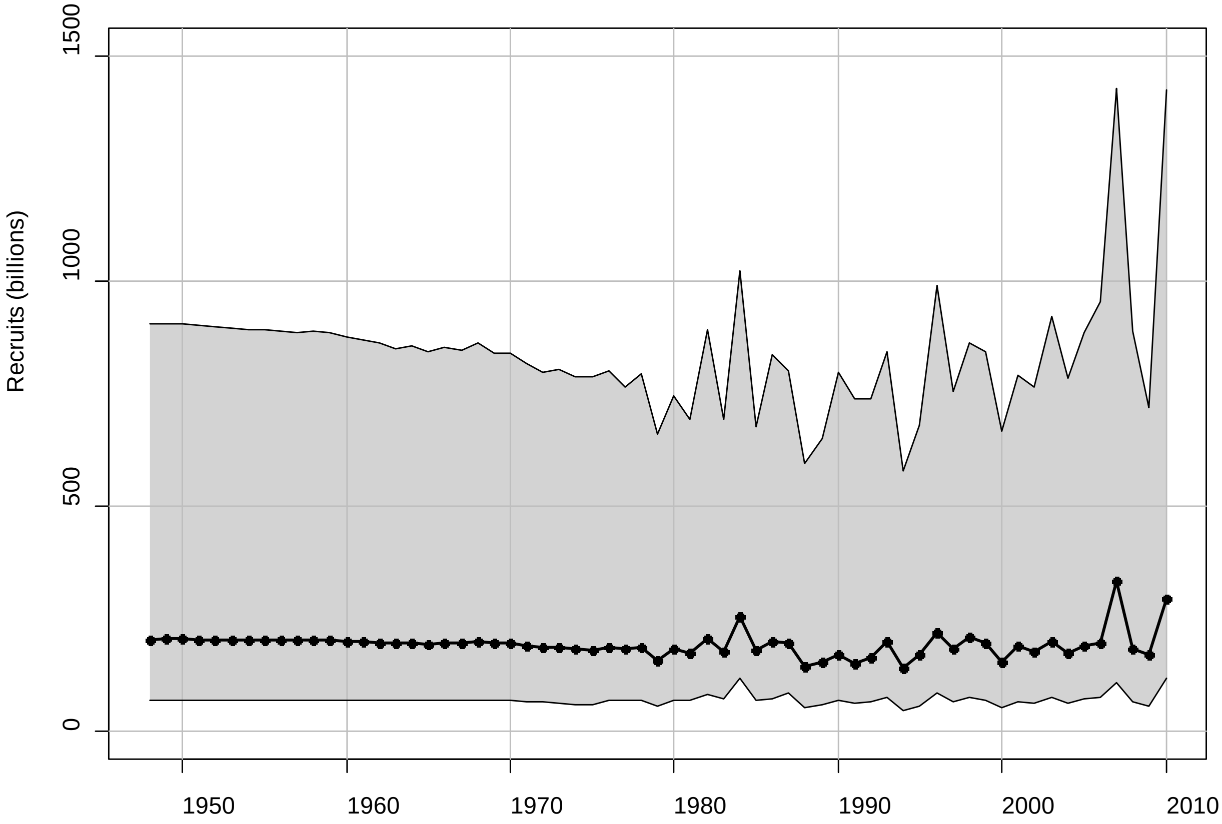


**Figure 8.17** Estimated annual recruitment to age-0 (billions) from the base BAM model (connected points). The dashed line represents the median recruitment from the entire time series.

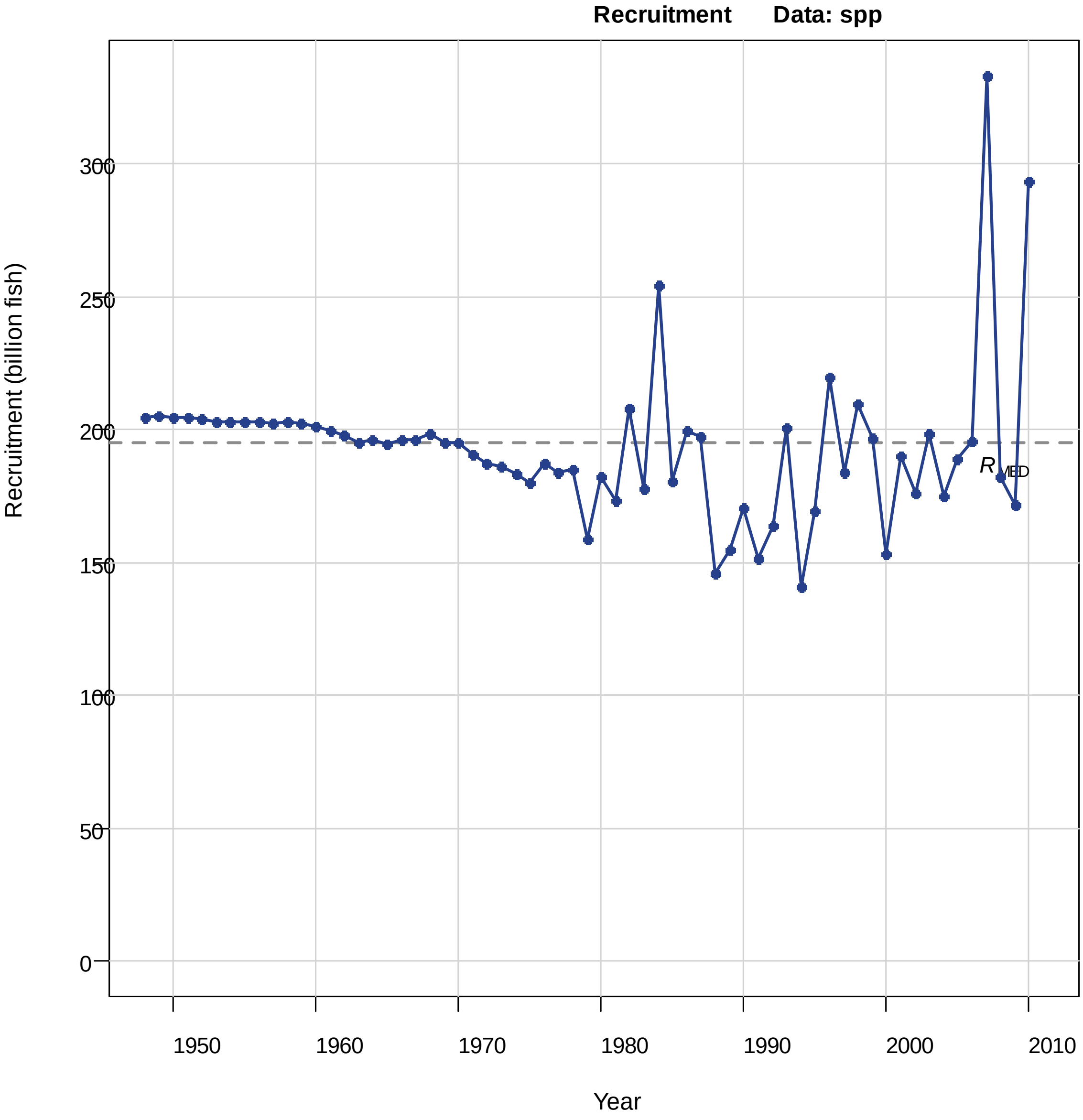


**Figure 8.18** Estimated spawning stock (billions of mature ova) and recruitment (billions of age-0 fish) from the base BAM model (points). Lines indicate the median recruitment (horizontal) and the 50th and 75th percentile of spawners-per-recruit.

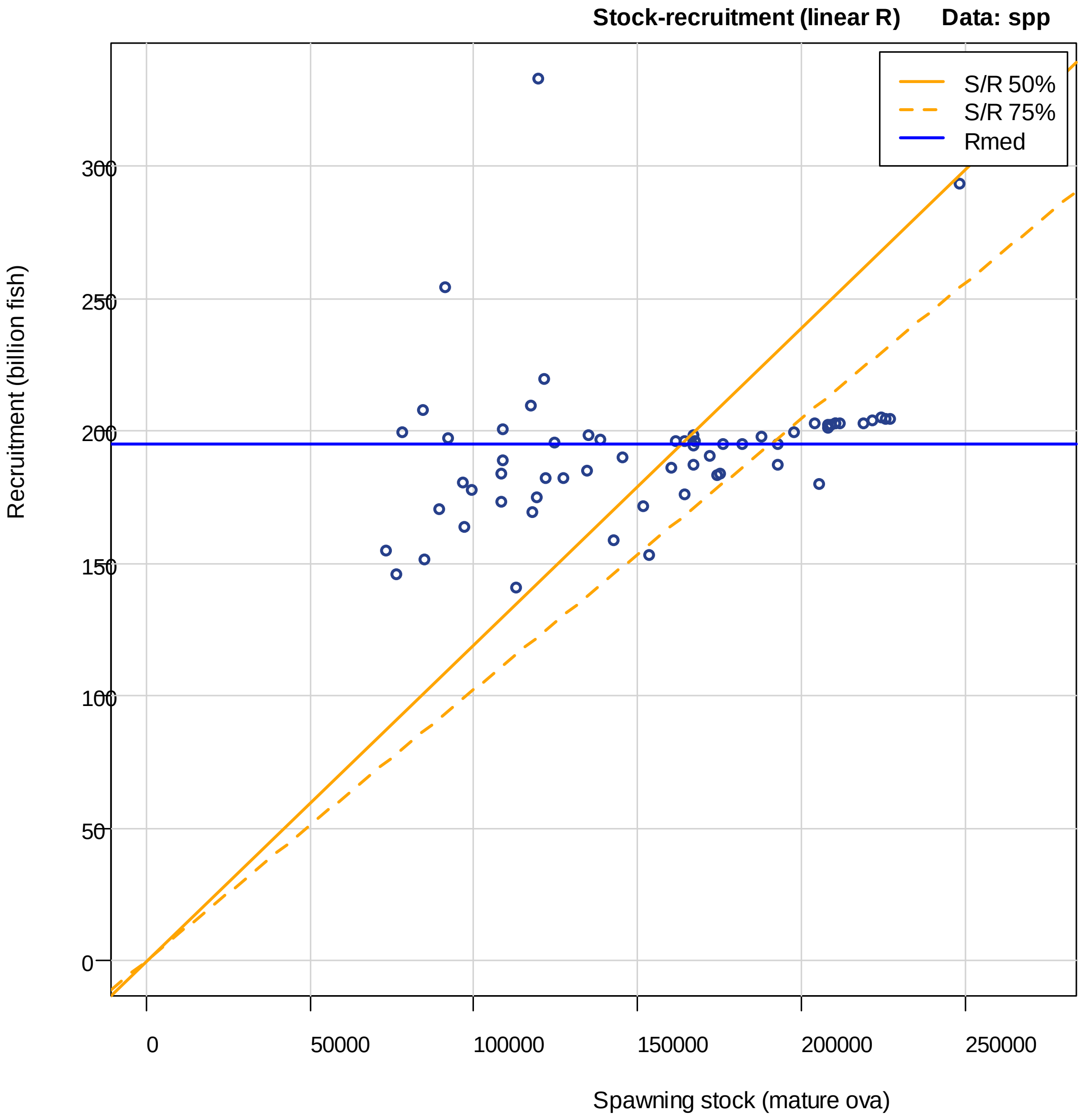


**Figure 8.19** Estimated fishing mortality rate for sensitivity runs related to changes in the input natural mortality rate (panel 1), to changes in the input indices (panel 2), to changes in other model components (panel 3), and to changes in the age composition likelihood weight.

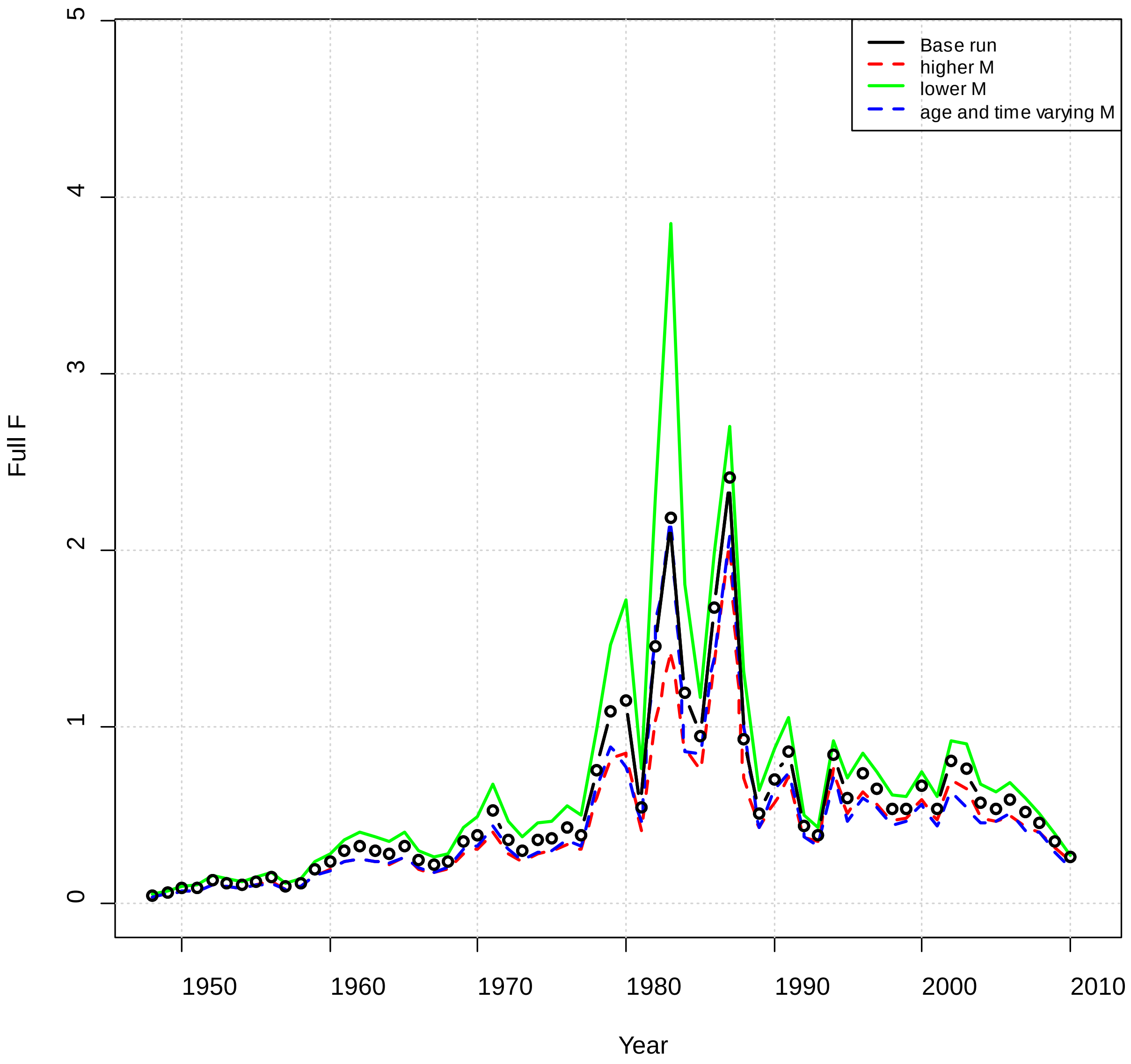
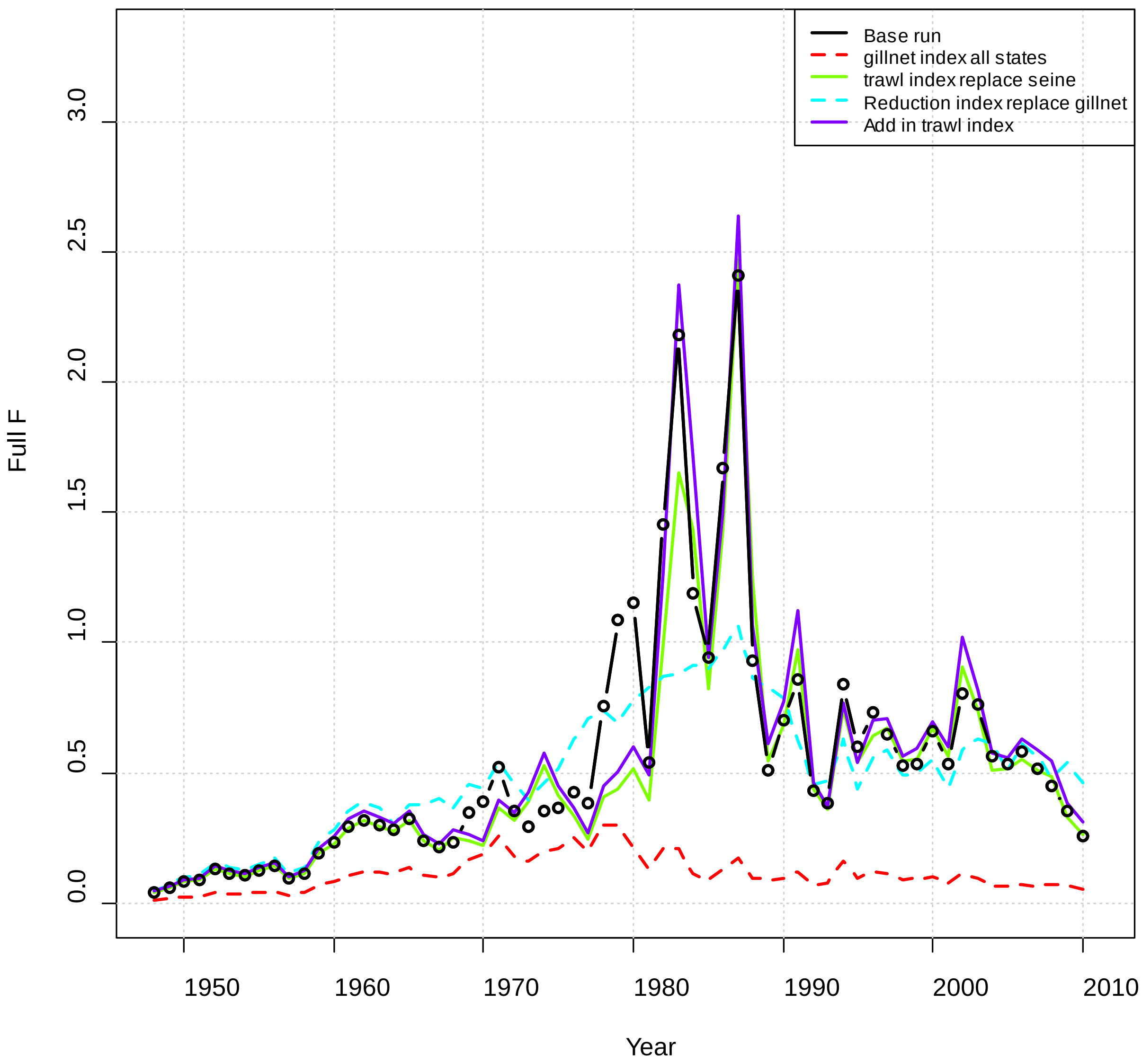


**Figure 8.19** (Cont.)



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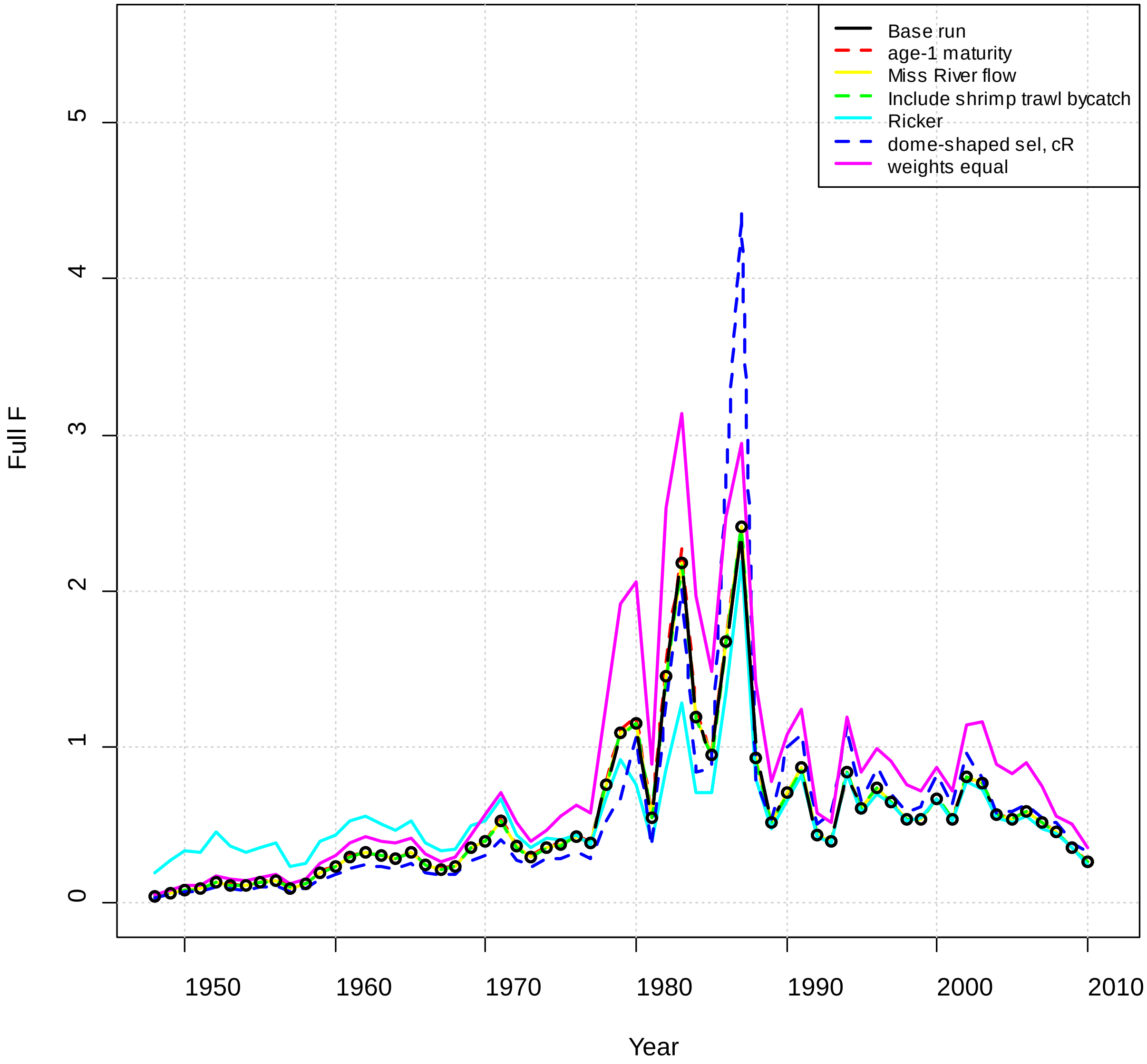

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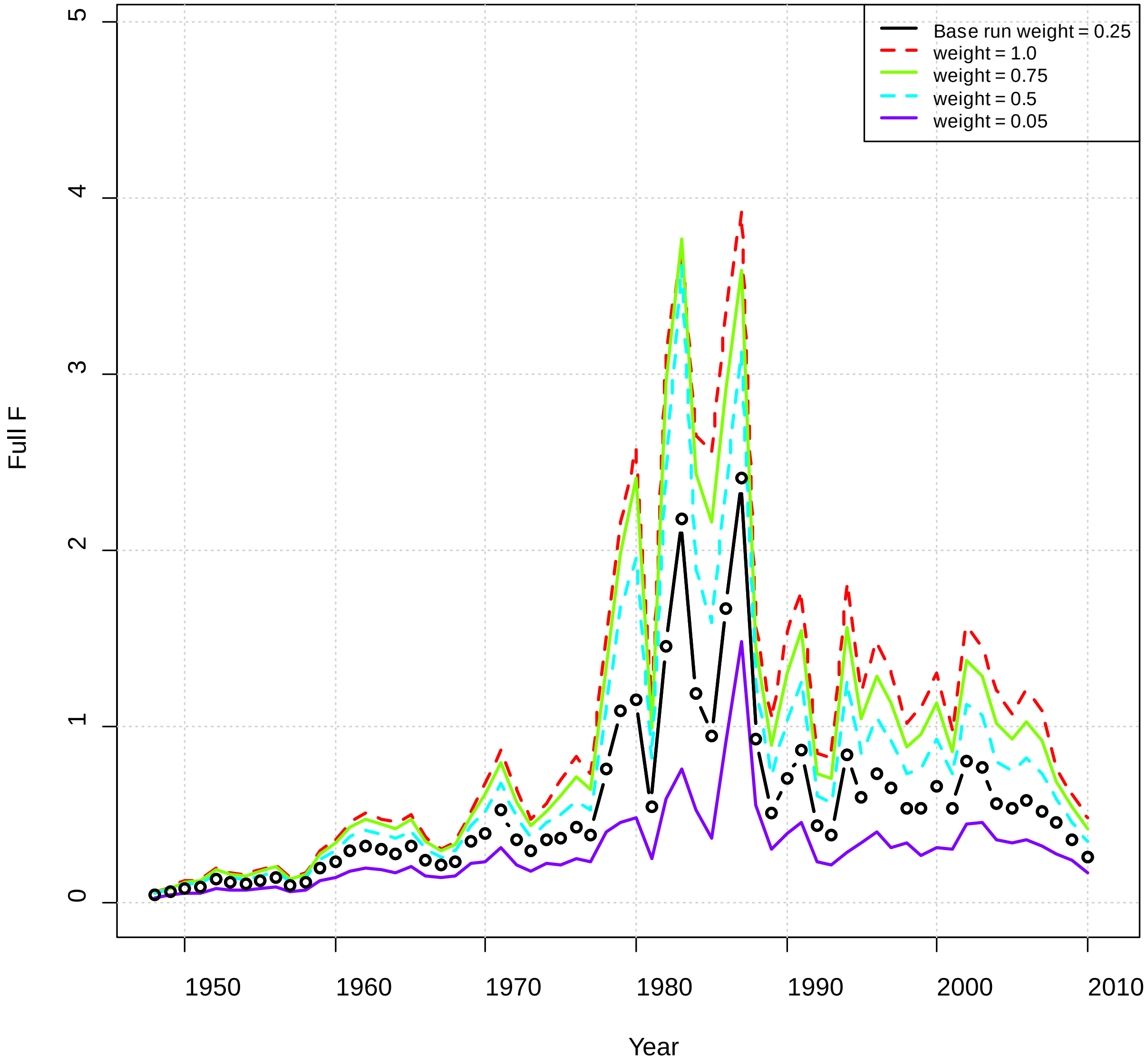
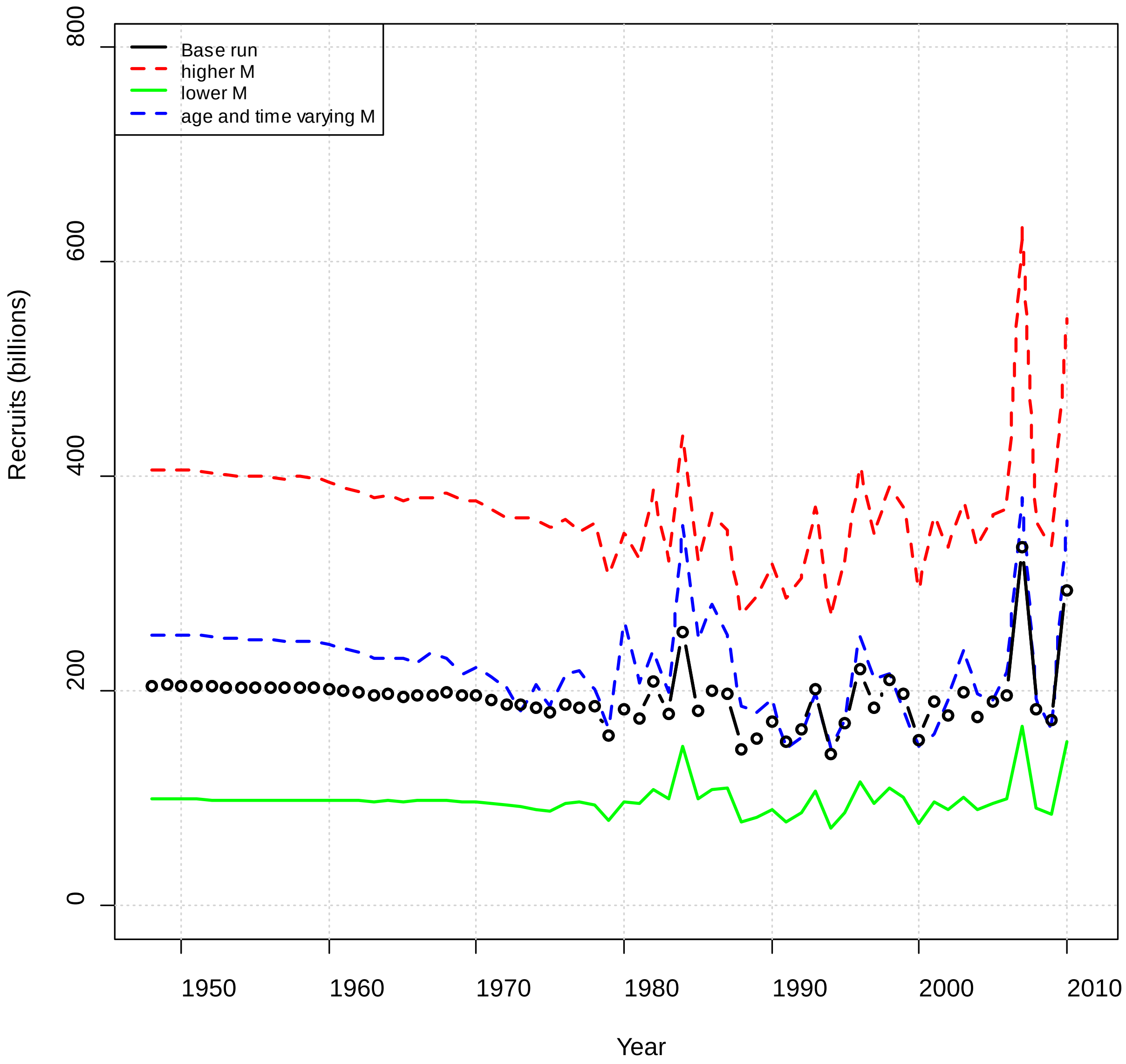


**Figure 8.20** Estimated recruitment for sensitivity runs related to changes in the input natural mortality rate (panel 1), to changes in the input indices (panel 2), to changes in other model components (panel 3), and to changes in the age composition likelihood weight.



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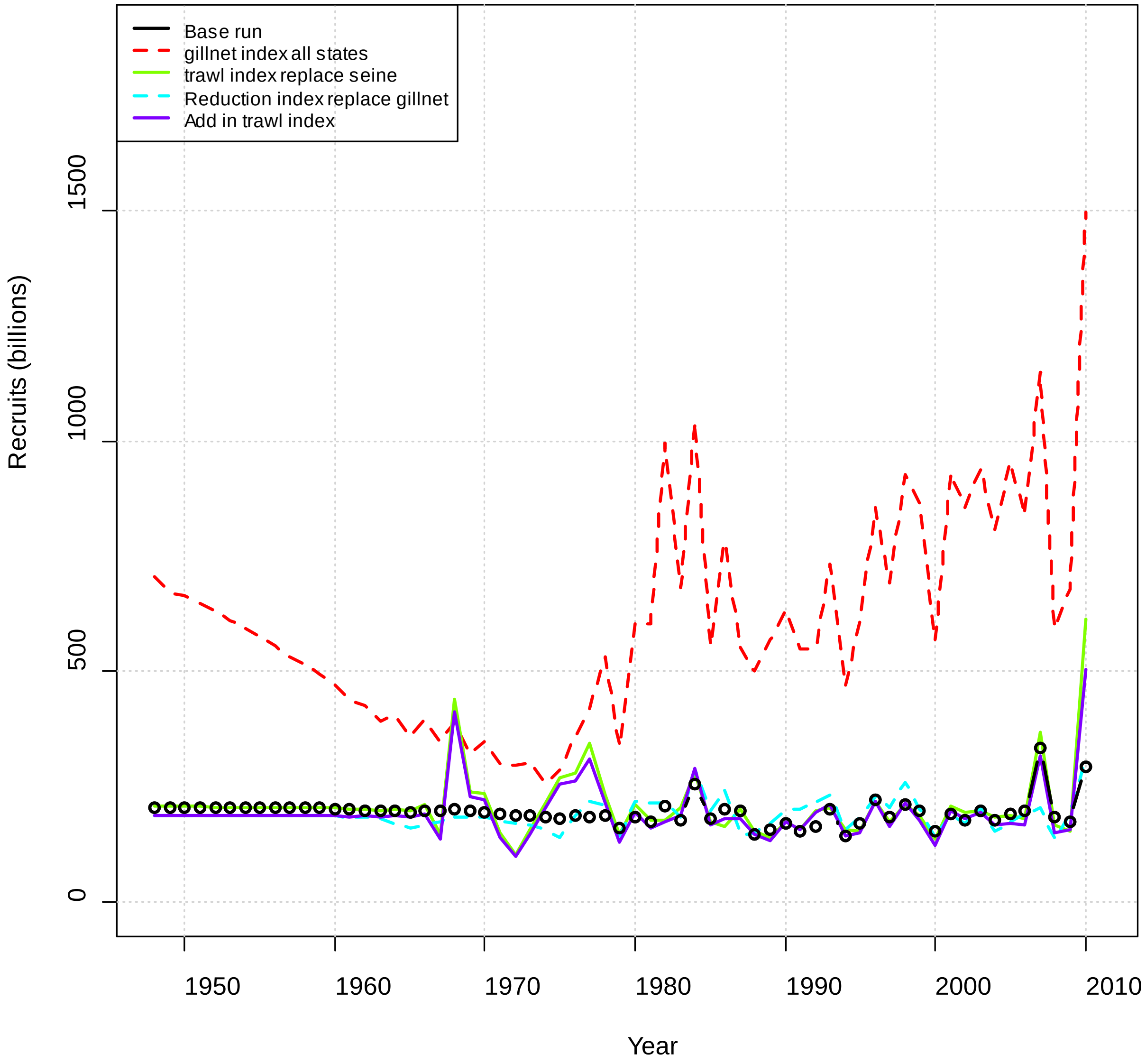
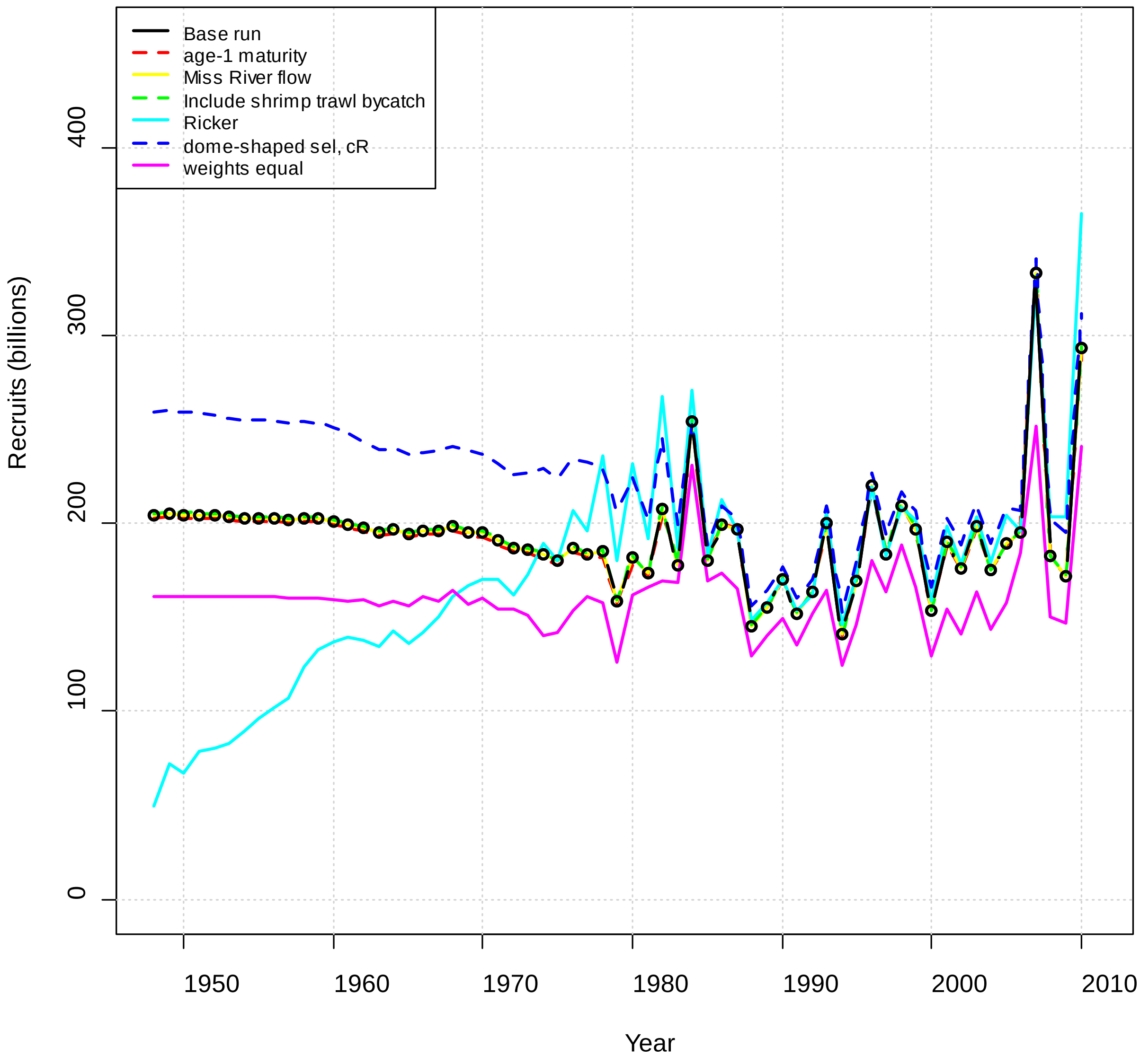


**Figure 8.20** (Cont.)



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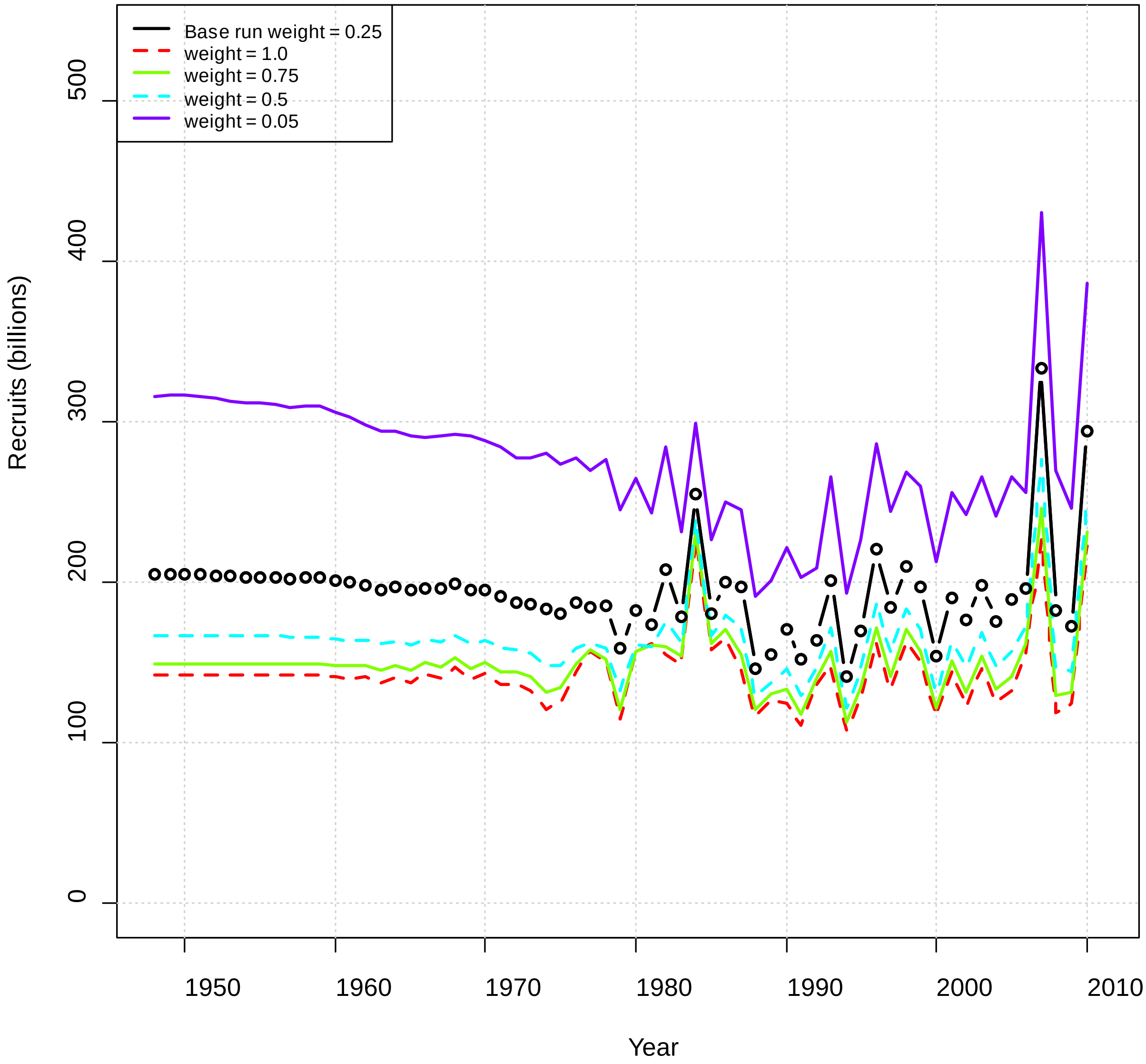
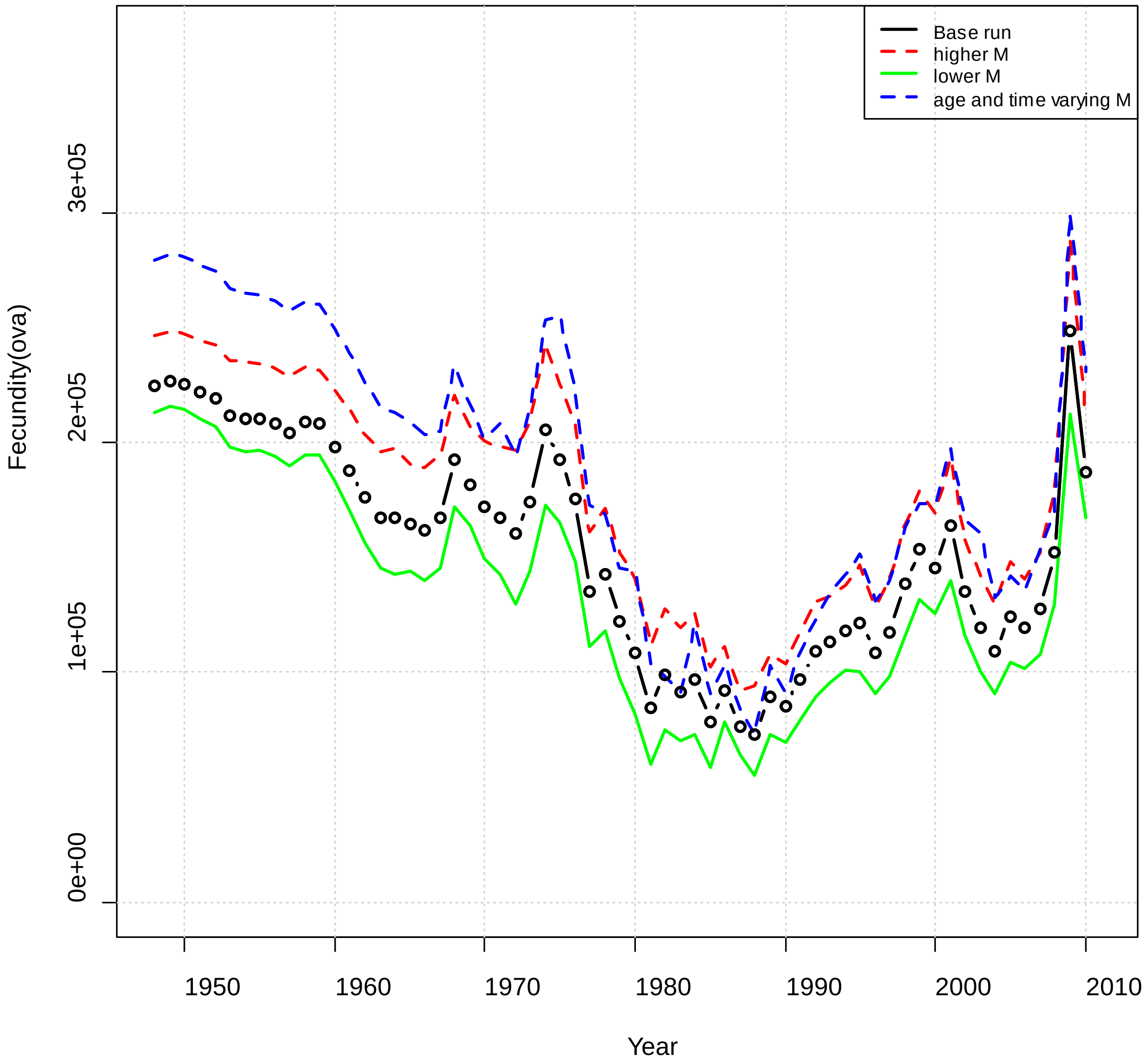


**Figure 8.21** Estimated fecundity for sensitivity runs related to changes in the input natural mortality rate (panel 1), to changes in the input indices (panel 2), to changes in other model components (panel 3), and to changes in the age composition likelihood weight.



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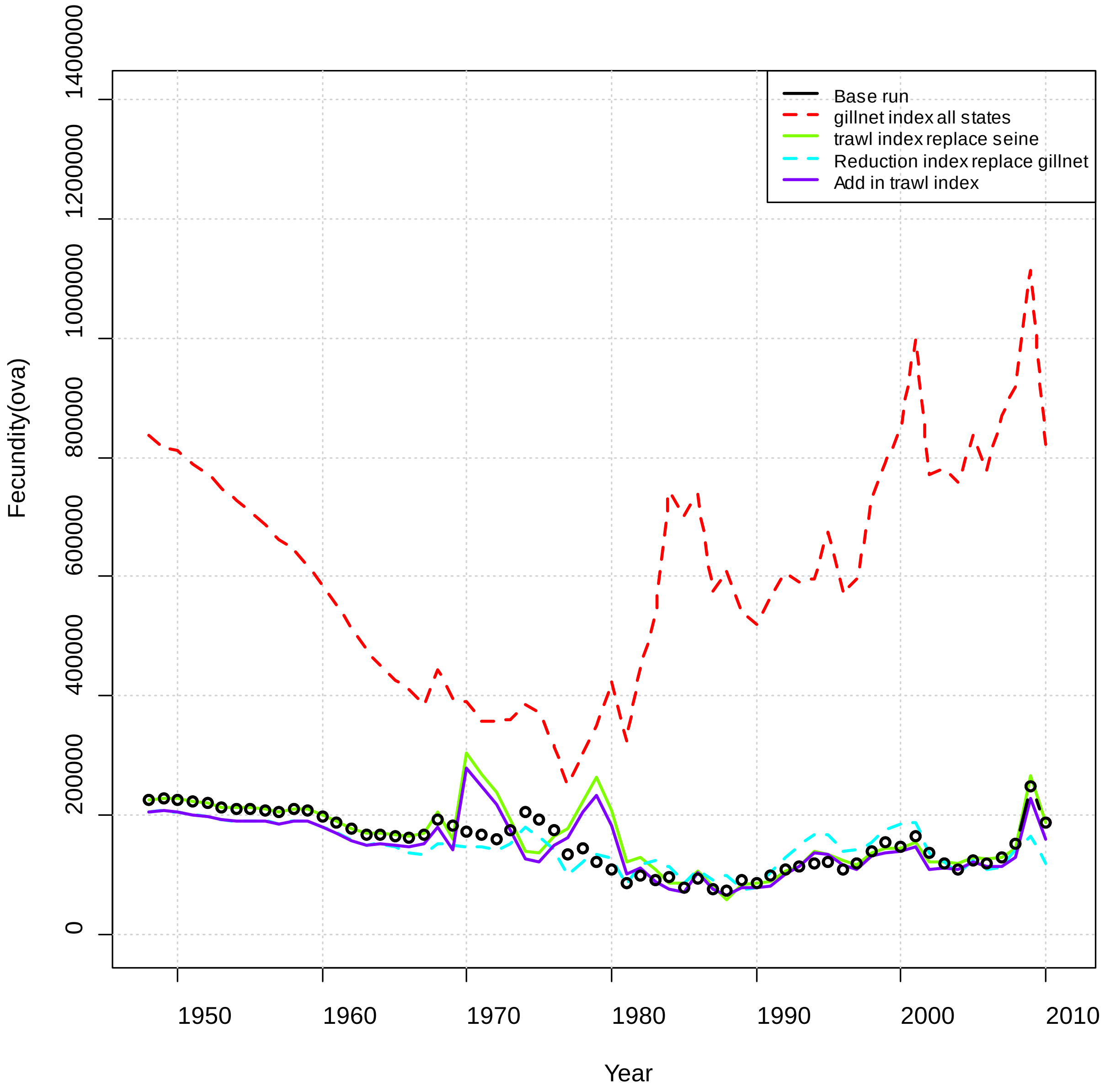

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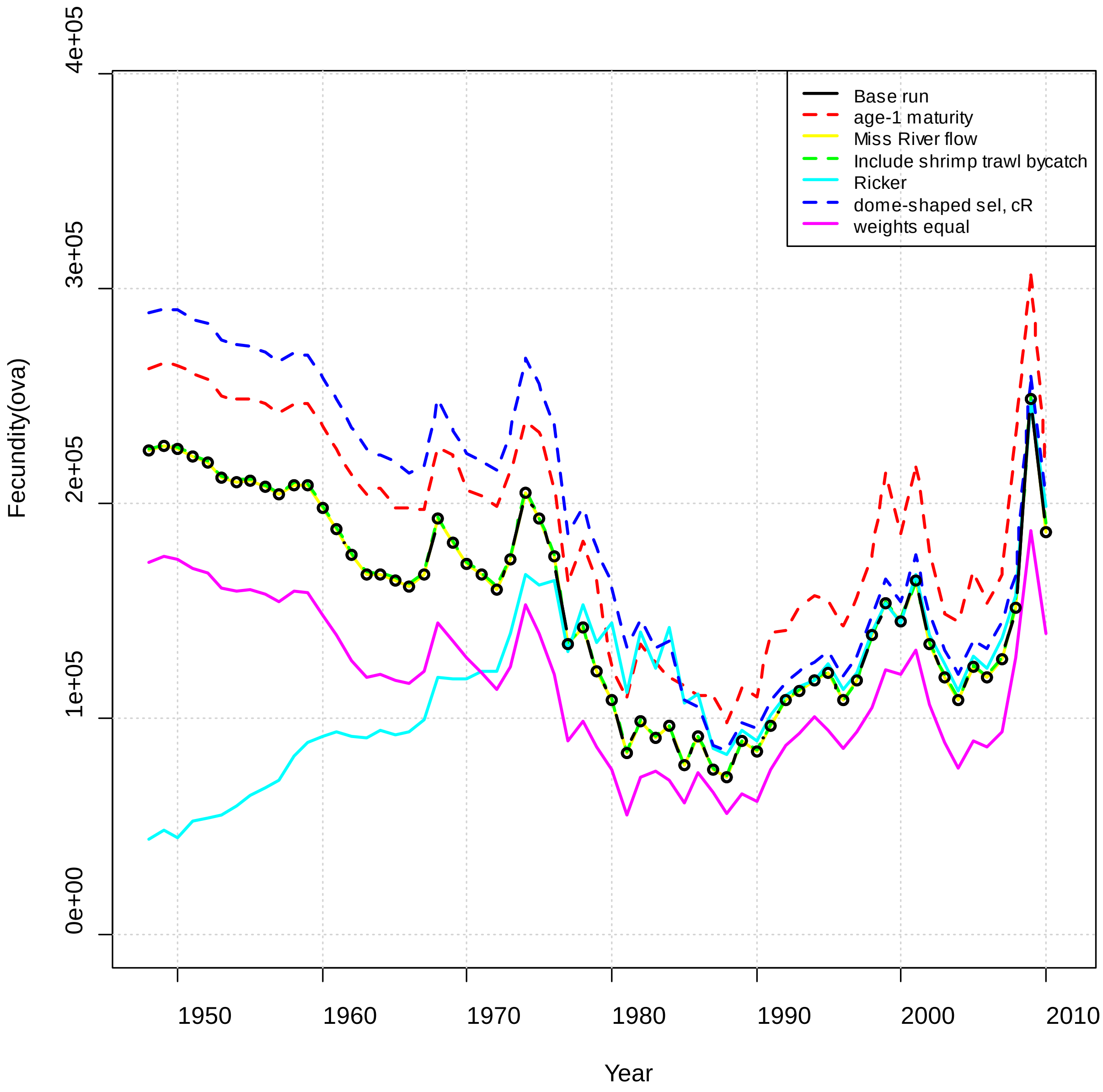


**Figure 8.21** (Cont.)

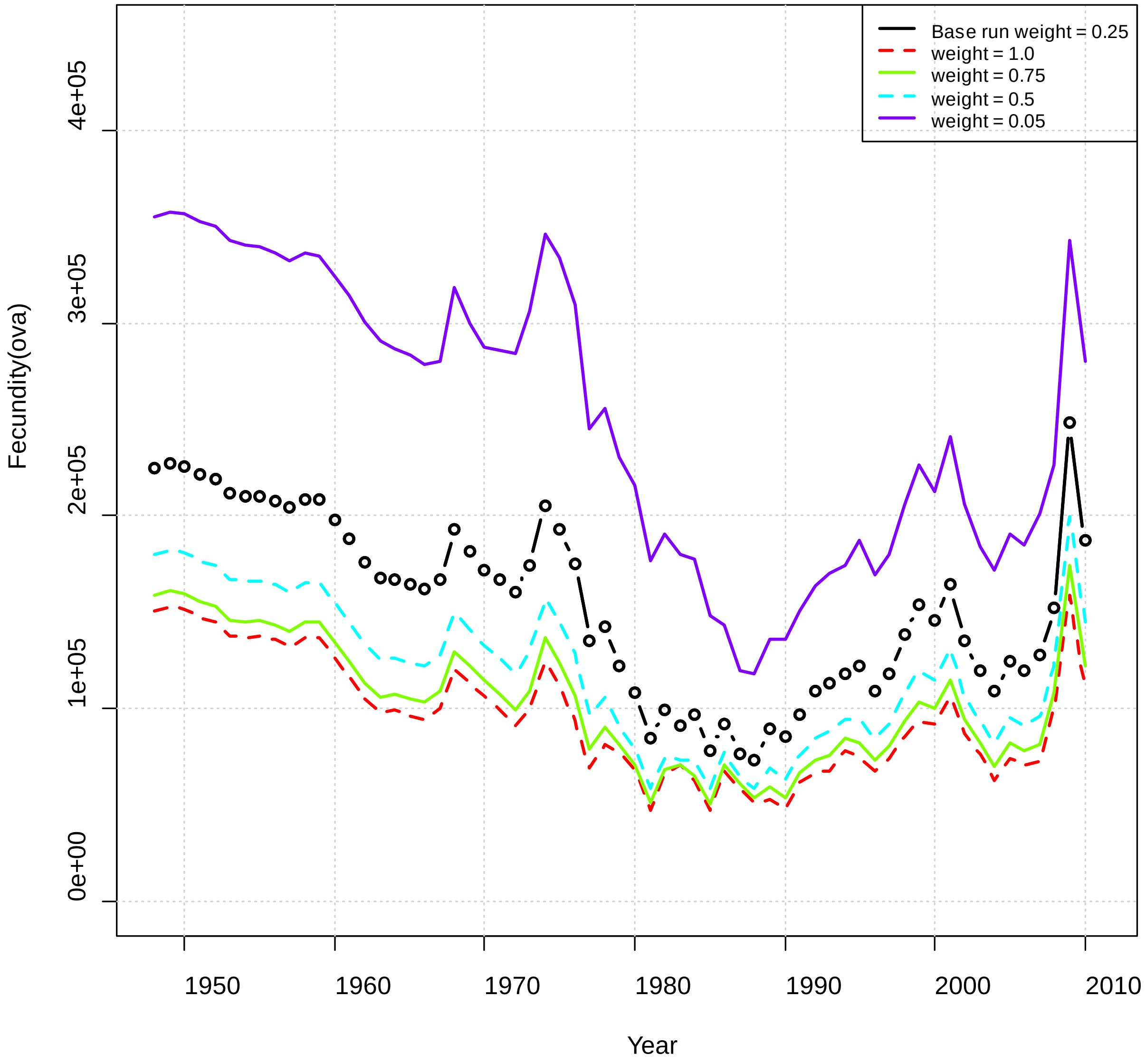


**Figure 8.22** Fishing mortality rate over fishing mortality rate at MSY for sensitivity runs related to changes in the input natural mortality rate (panel 1), to changes in the input indices (panel 2), to changes in other model components (panel 3), and to changes in the age composition likelihood weight.

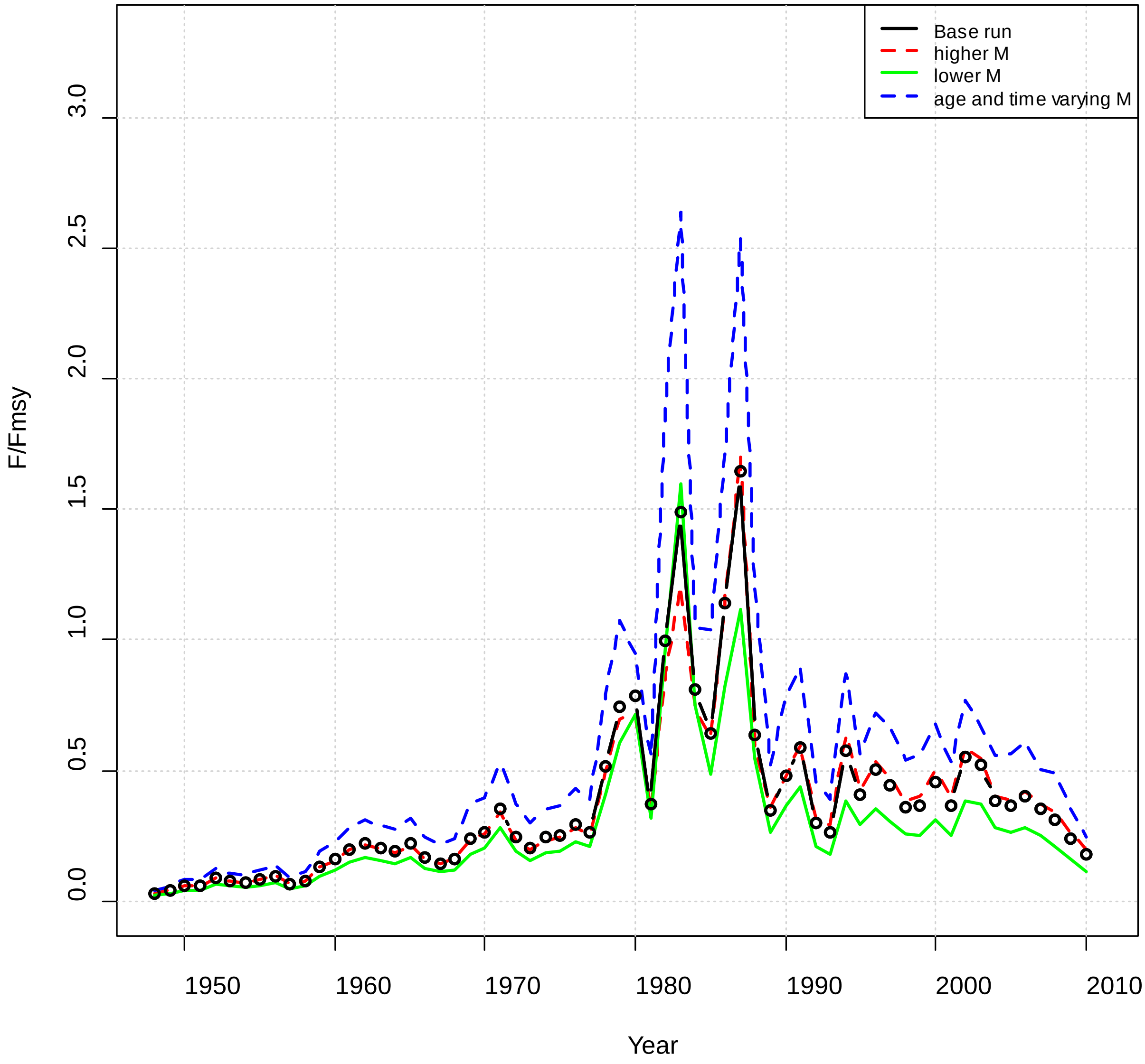


**Figure 8.22** (Cont.)

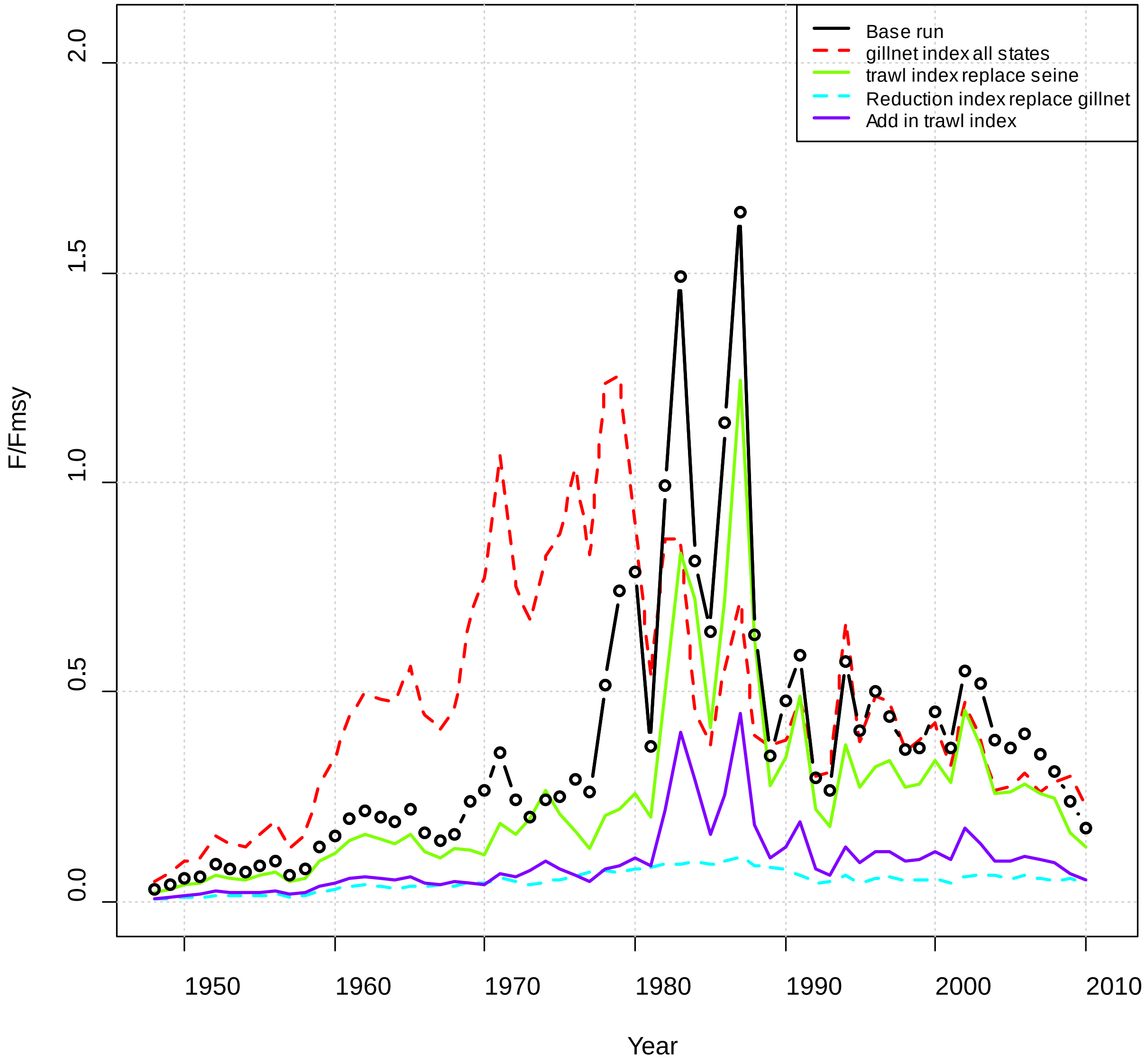
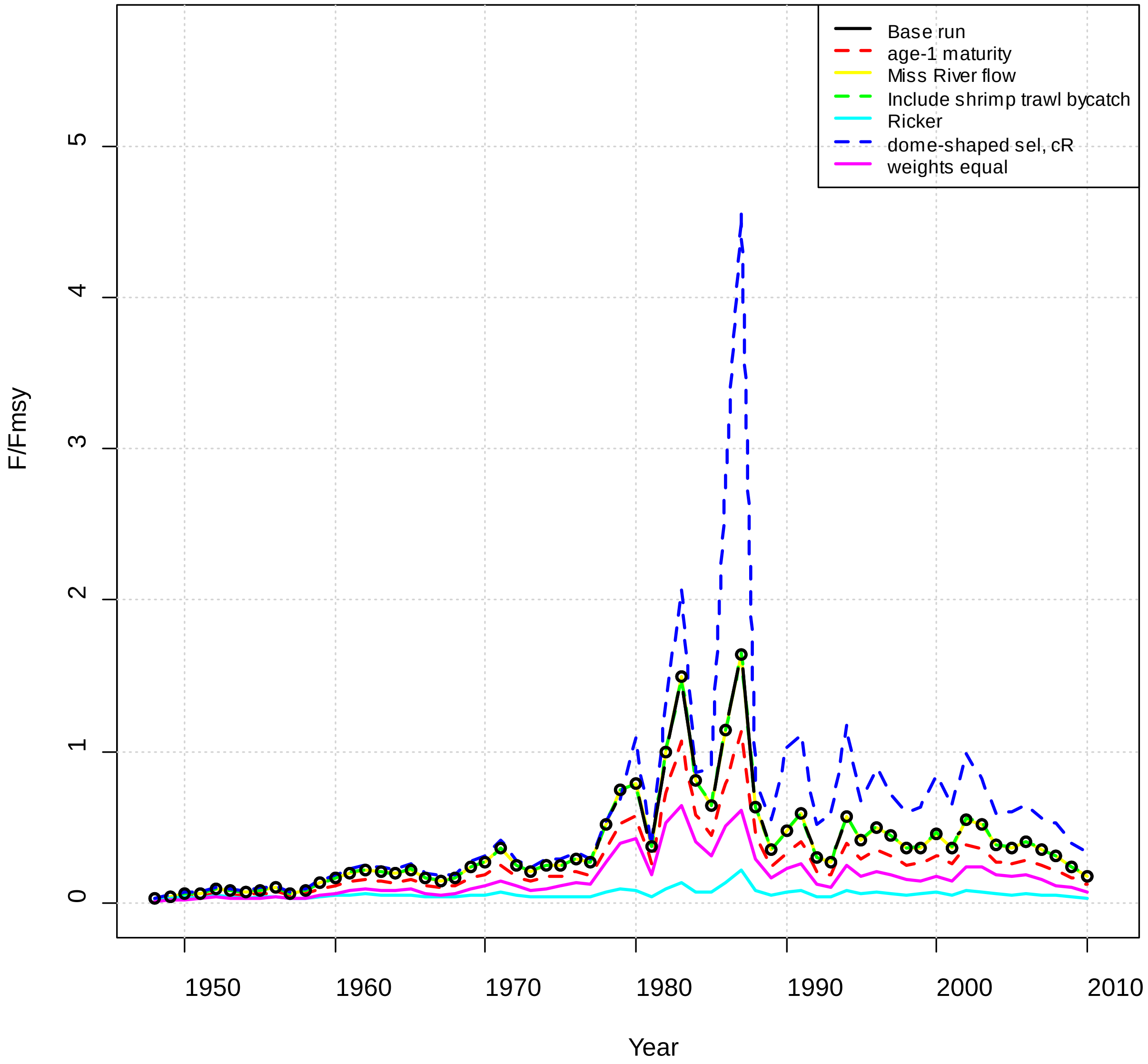


**Figure 8.22** (Cont.)



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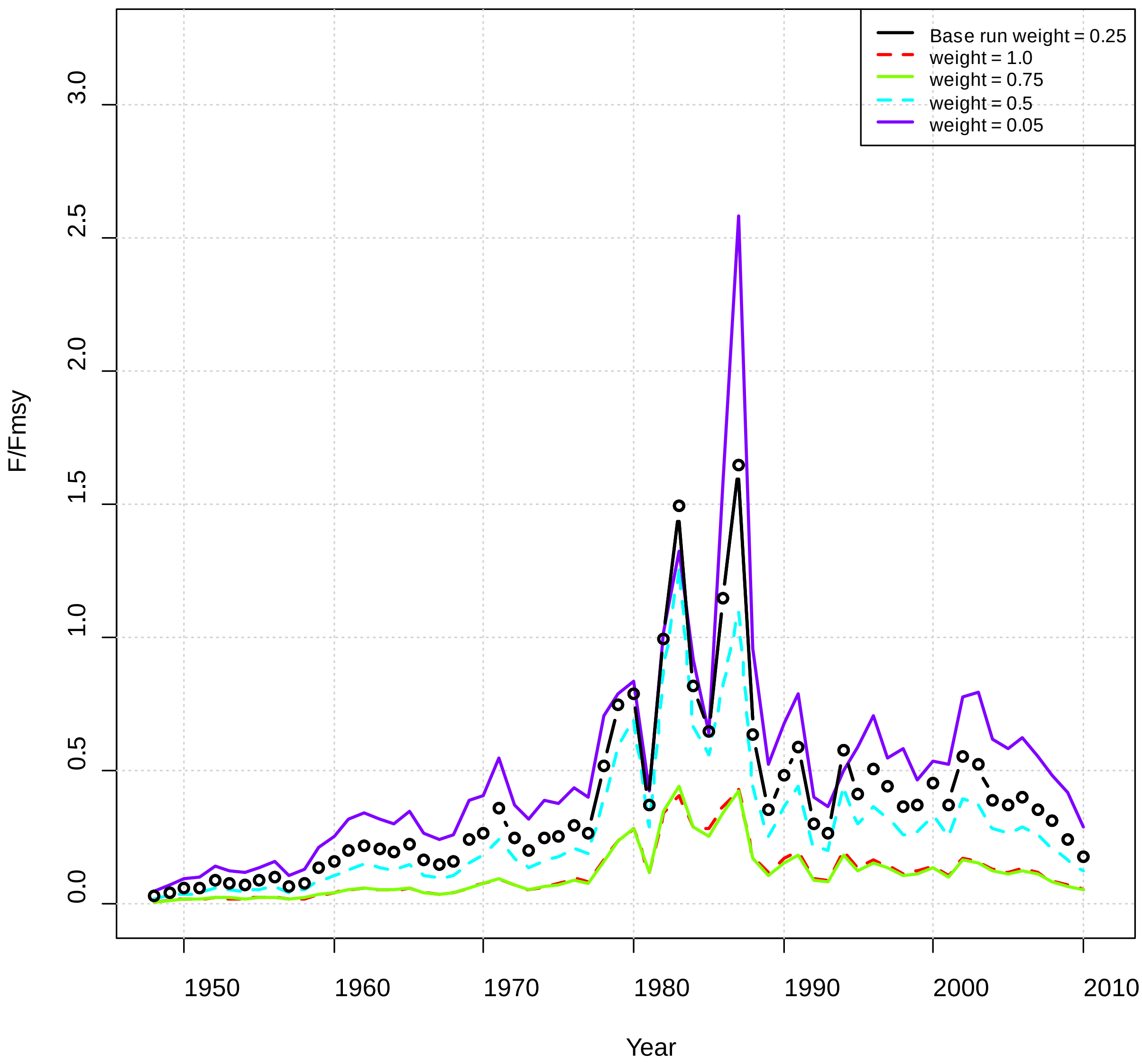


**Figure 8.23** Full fishing mortality rate over time for the retrospective analysis.

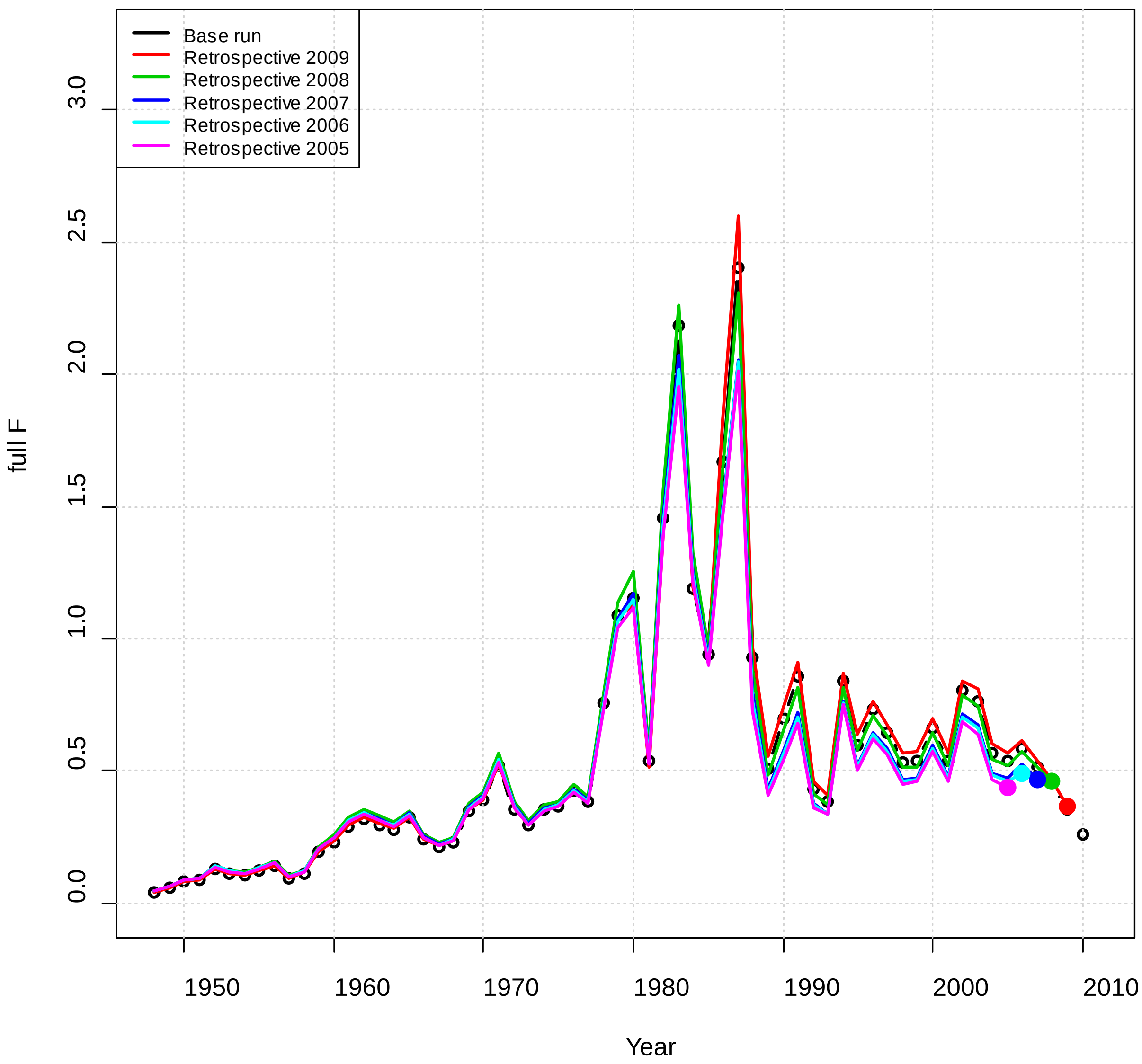


**Figure 8.24** Annual recruitments estimated in the base run of BAM and for the retrospective analysis.

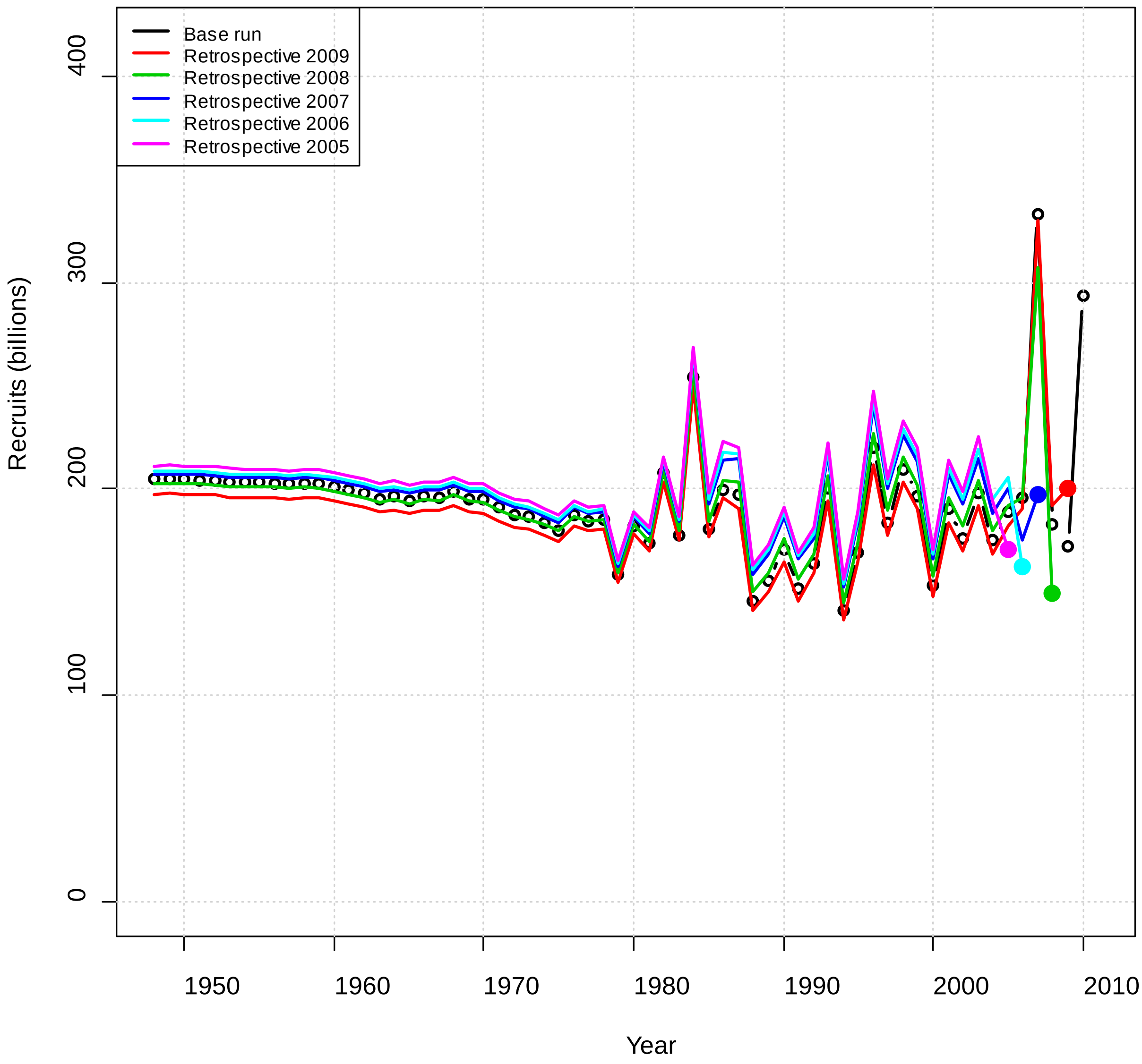


**Figure 8.25** Annual fecundity estimated in the base run of BAM and for the retrospective analysis.

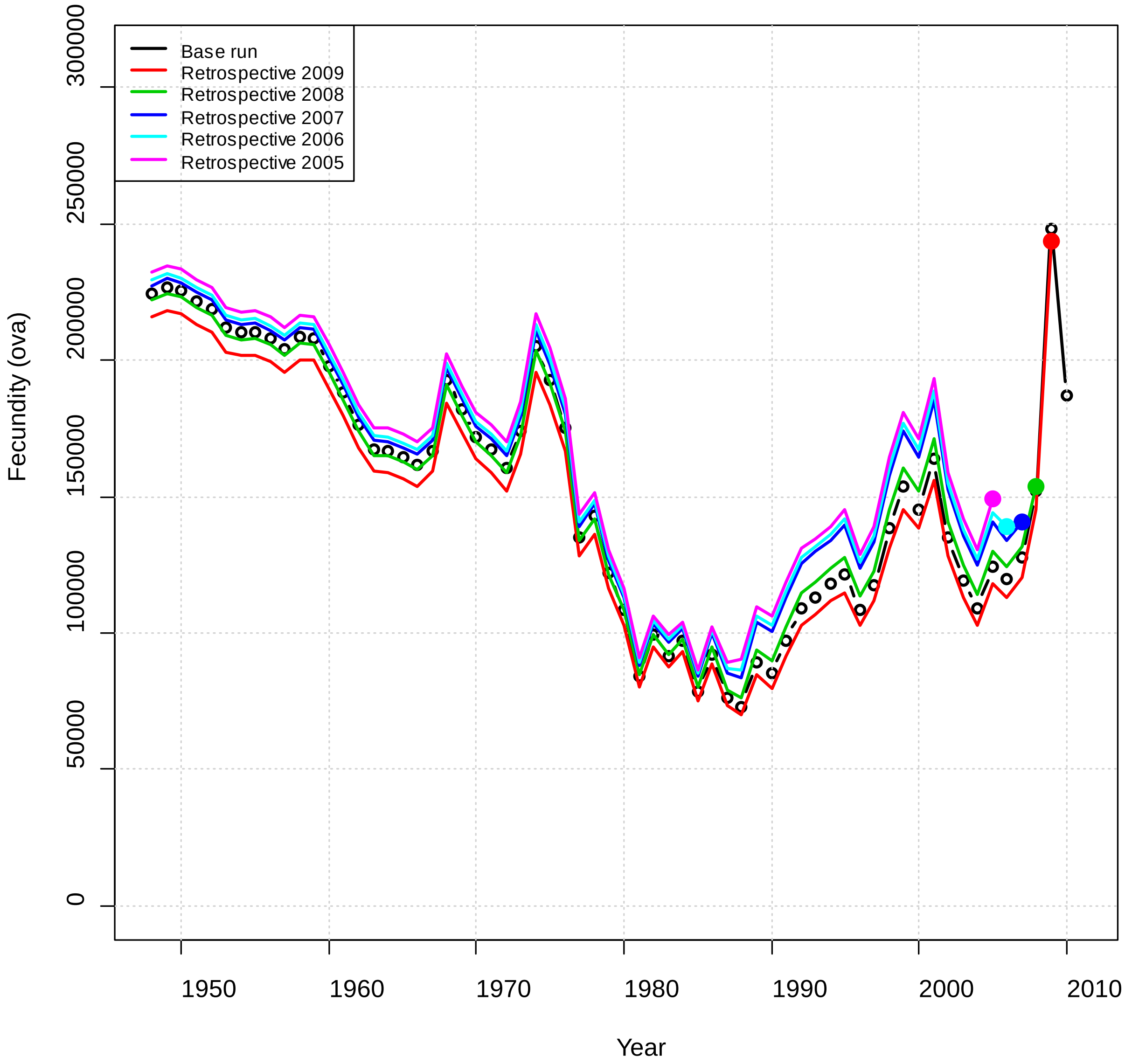


**Figure 8.26** Fishing mortality rate over $F_{MSY}$ for the retrospective analysis.

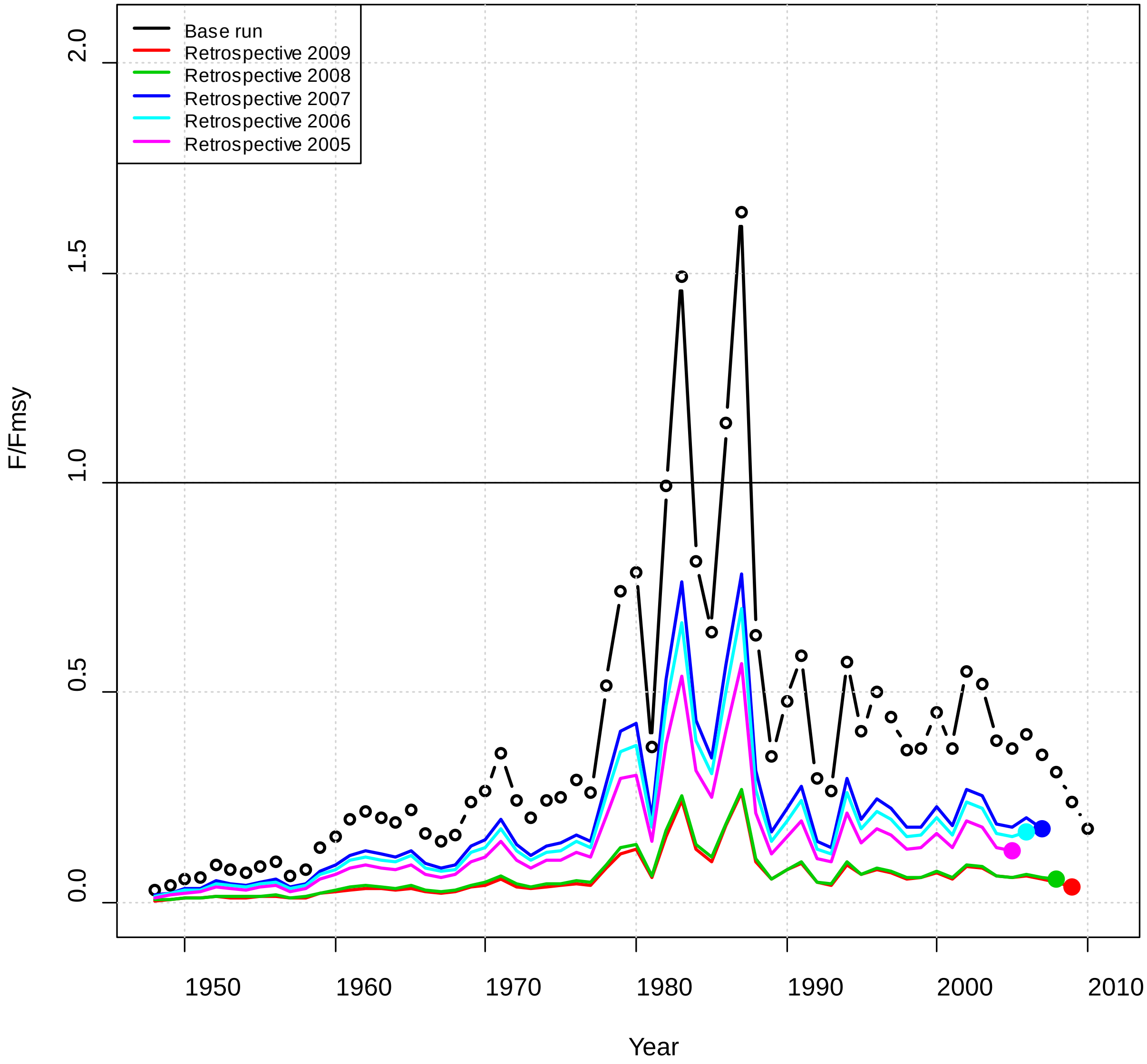


**Figure 8.27** Estimated annual full F from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs after runs were eliminated that were not able to estimate $F_{MSY}$.

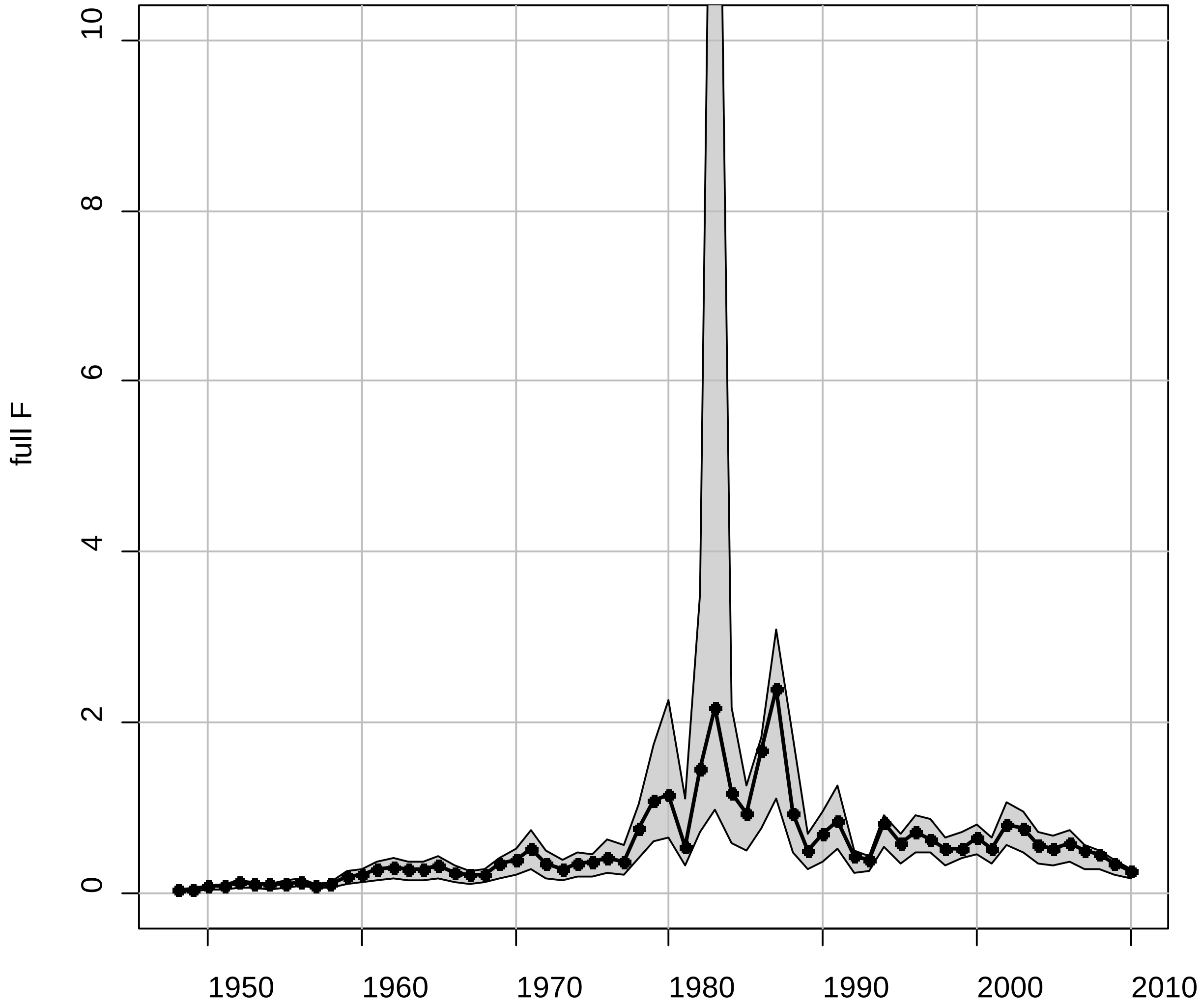


**Figure 8.28** Estimates of the proportional (re-scaled to max of 1.0) fecundity-per-recruit as a function of the full fishing mortality rate from the base BAM model.

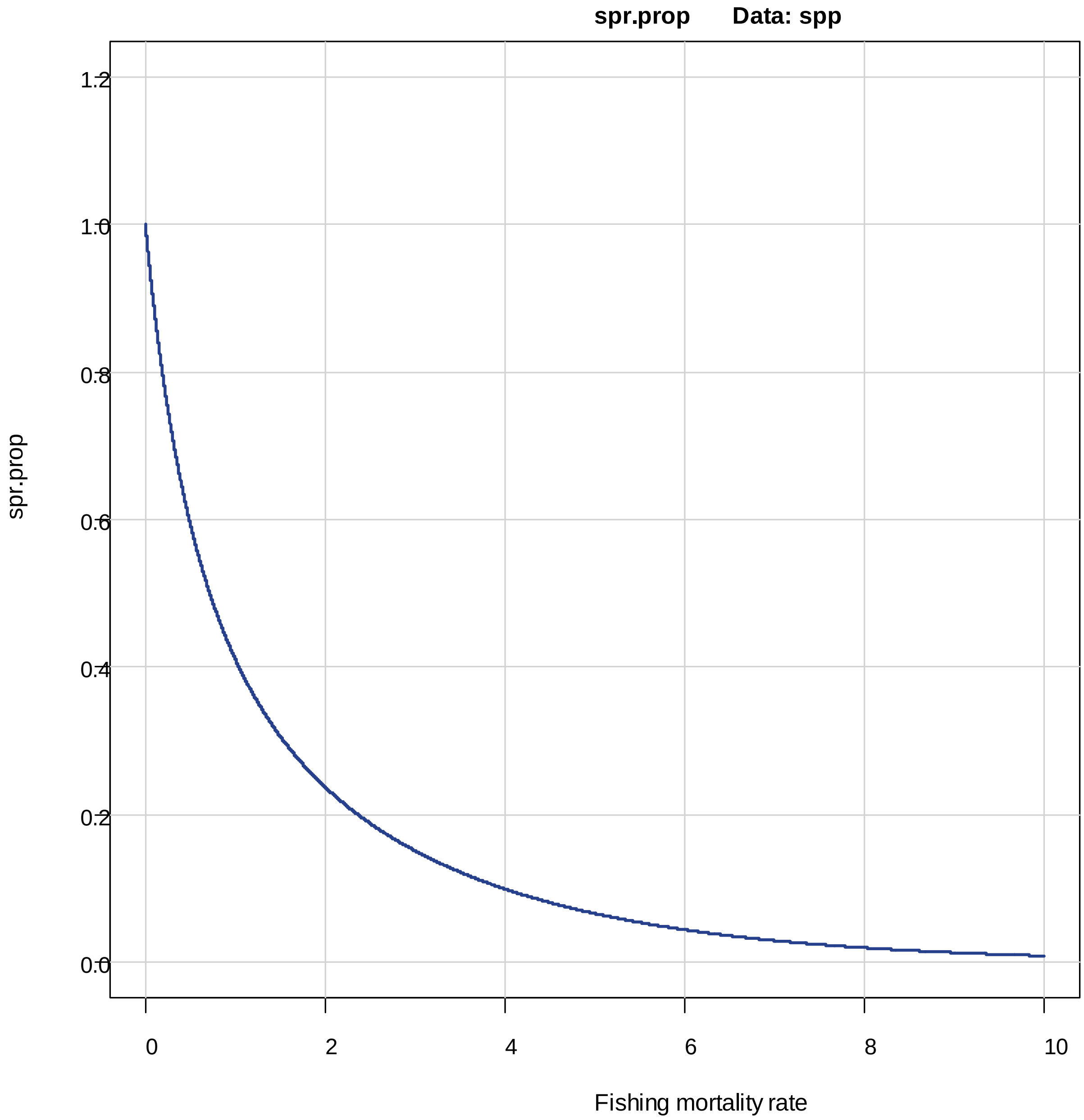


**Figure 8.29** Estimates of the yield-per-recruit (mt/million) as a function of the full fishing mortality rate from the base BAM model.

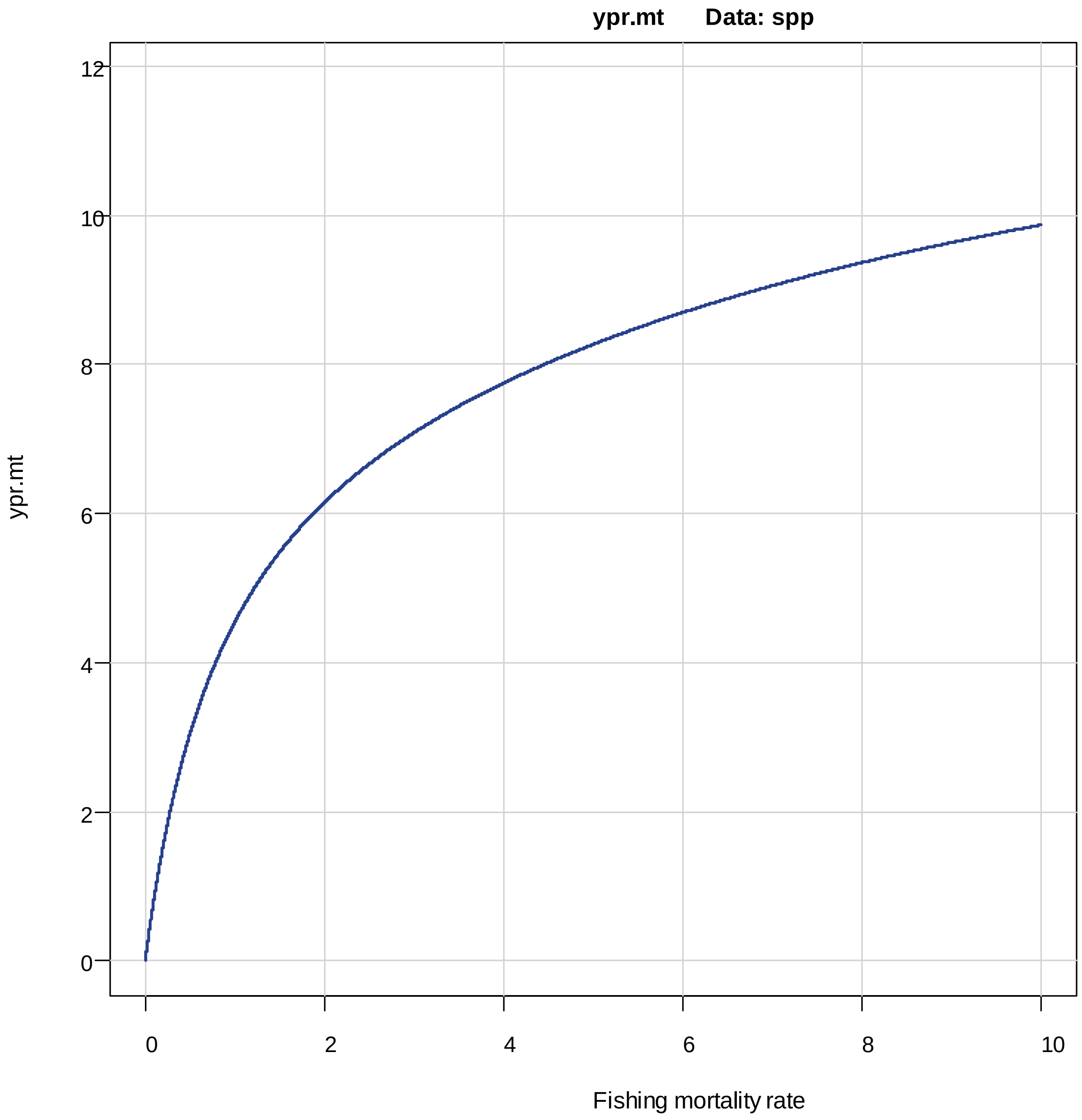


**Figure 8.30** Estimates of the full fishing mortality rate relative to the $F_{MSY}$ benchmark (fishing limit value) from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs.

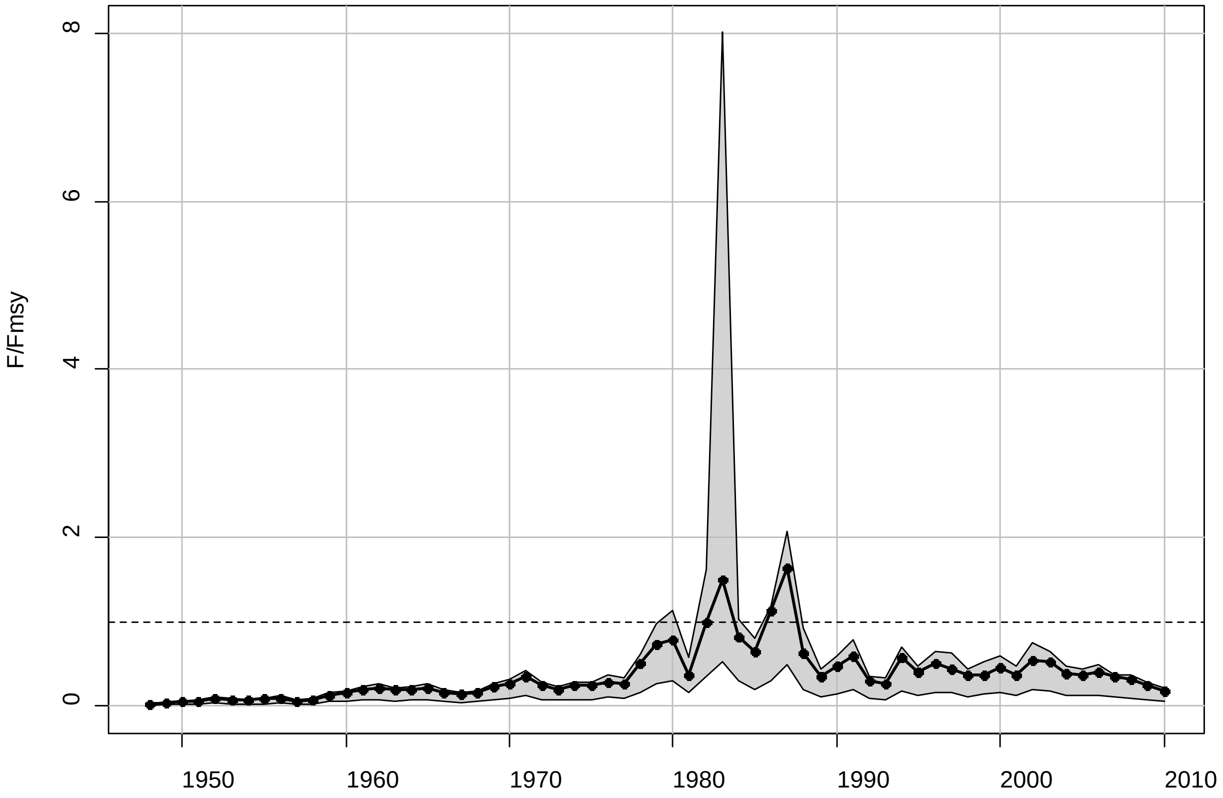


**Figure 8.31** Estimates of the population fecundity (*SSB*) relative to the target benchmark (*SSB*$_{MSY}$) from the base BAM model (connected points). Shaded area represents the 95% confidence interval of the bootstrap runs.

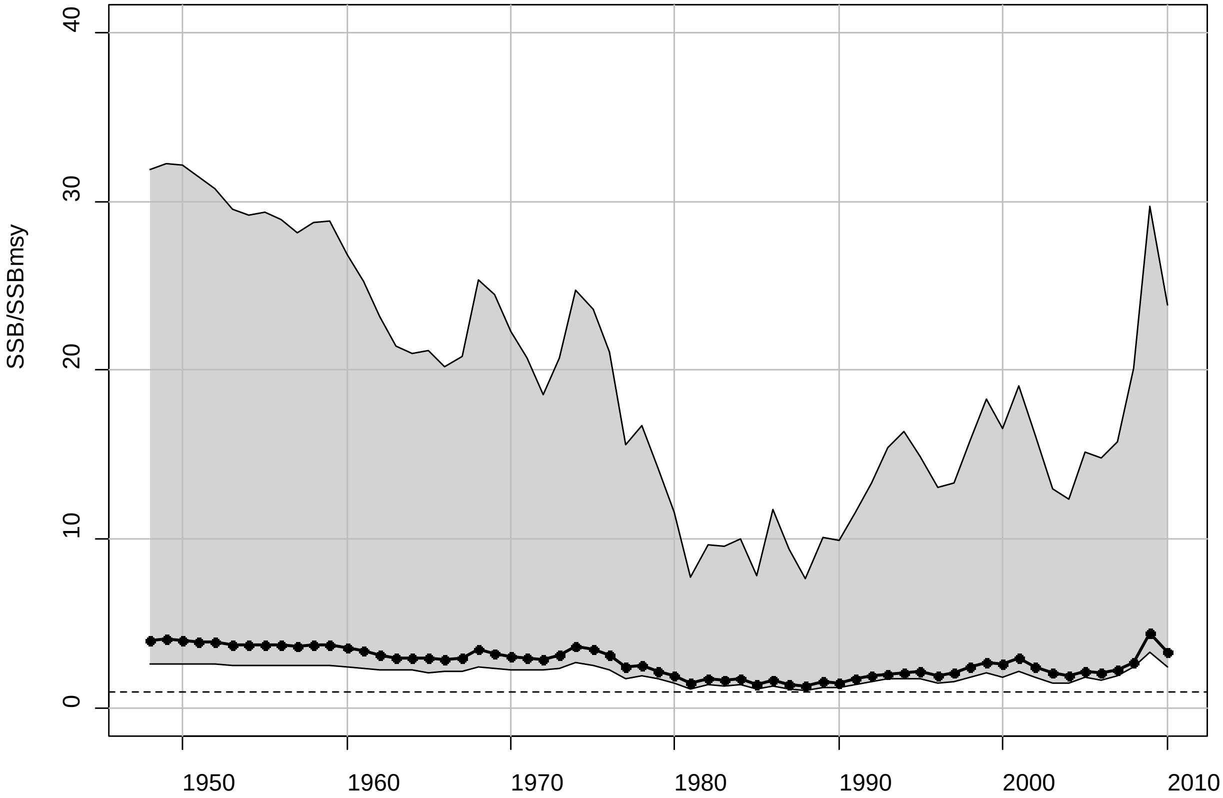


**Figure 8.32** Phase plot of recent estimates of the population fecundity (mature ova in billions) and full fishing mortality rate from the base BAM model. Solid vertical and horizontal lines indicate the targets and limits for each respective axis. For this phase plot the $F_{target}$ displayed is 0.75 $F_{MSY}$; 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).

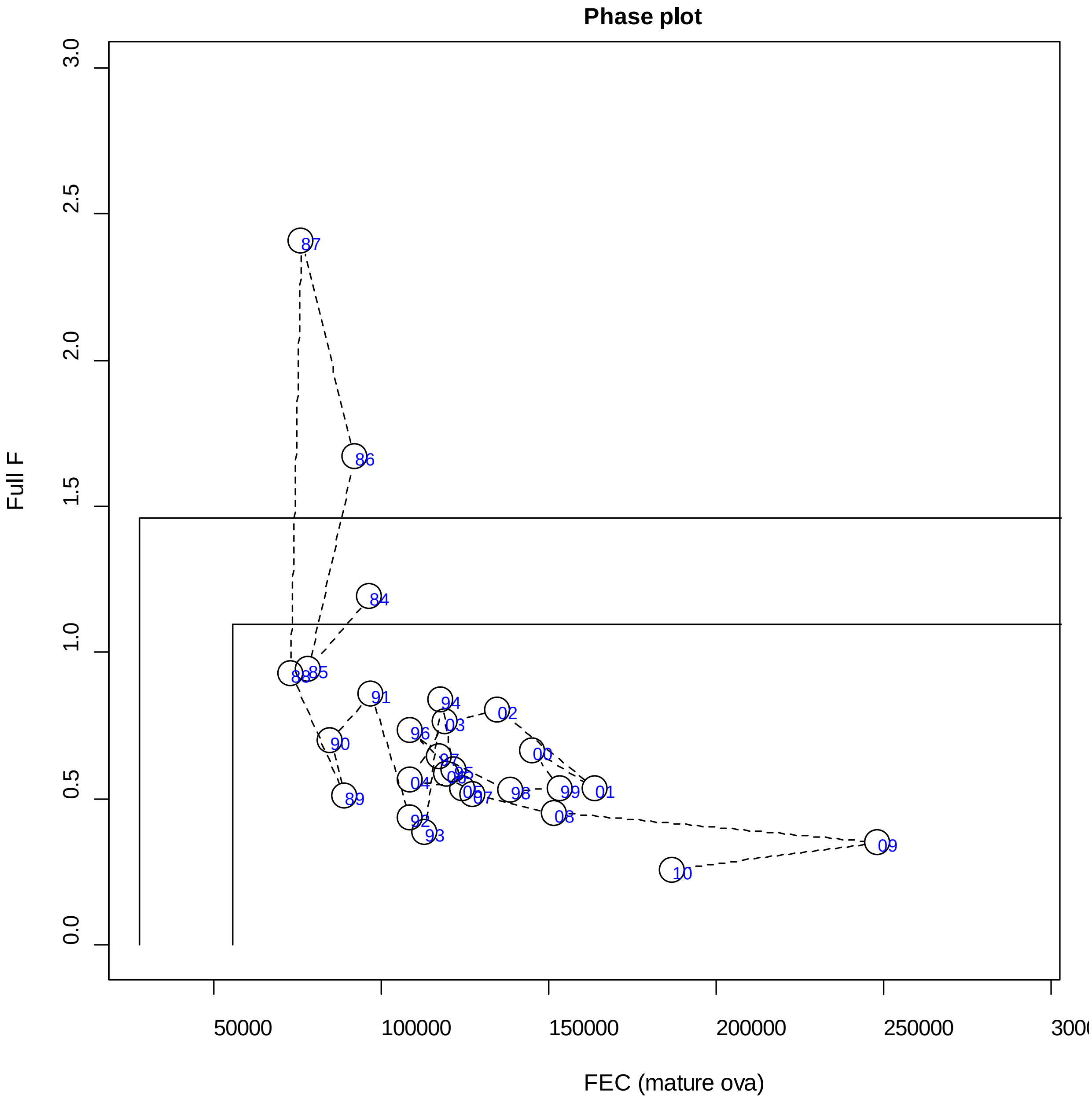


**Figure 8.33** Cumulative probability density distribution of the full fishing mortality rate in 2010 relative to the fishing limit value ($F_{MSY}$) from the bootstrap estimates from the base BAM model.

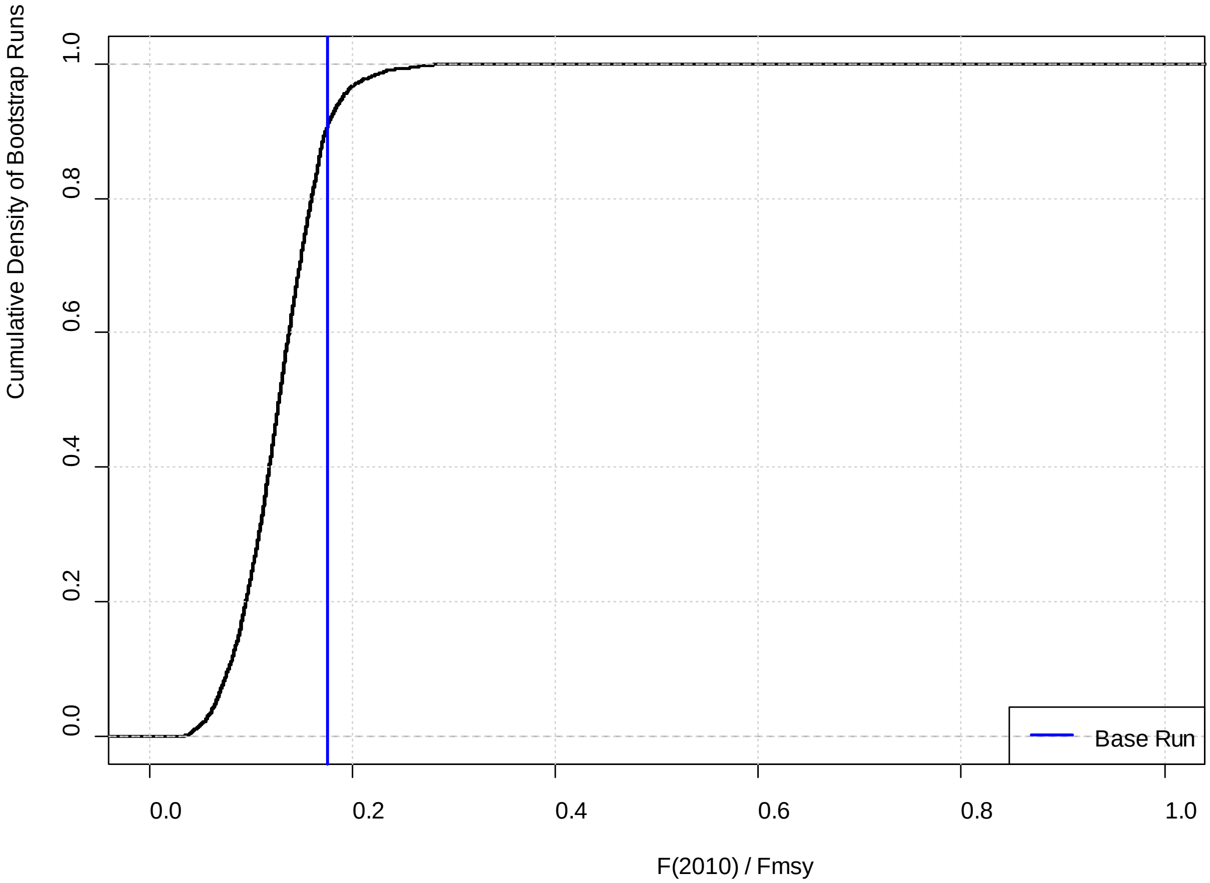


**Figure 8.34** Cumulative probability density distribution of the population fecundity in 2010 relative to the target value from the bootstrap estimates from the base BAM model.

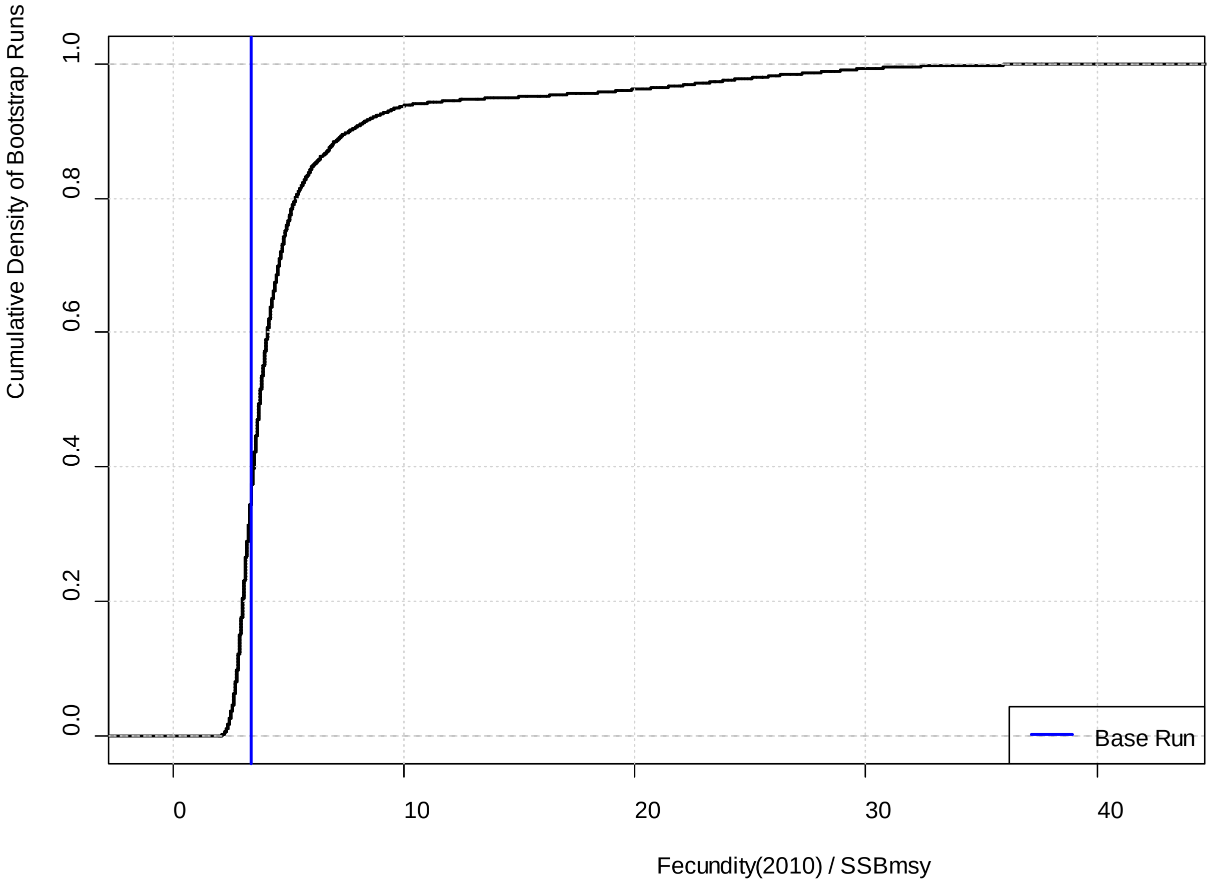


**Figure 8.35** Scatter plot of the 2010 estimates relative to the limit benchmark of $F_{MSY}$ and the target $SSB_{MSY}$ from the 4,000 bootstrap estimates (excluding those that were unable to estimate $F_{MSY}$) from the base BAM model.

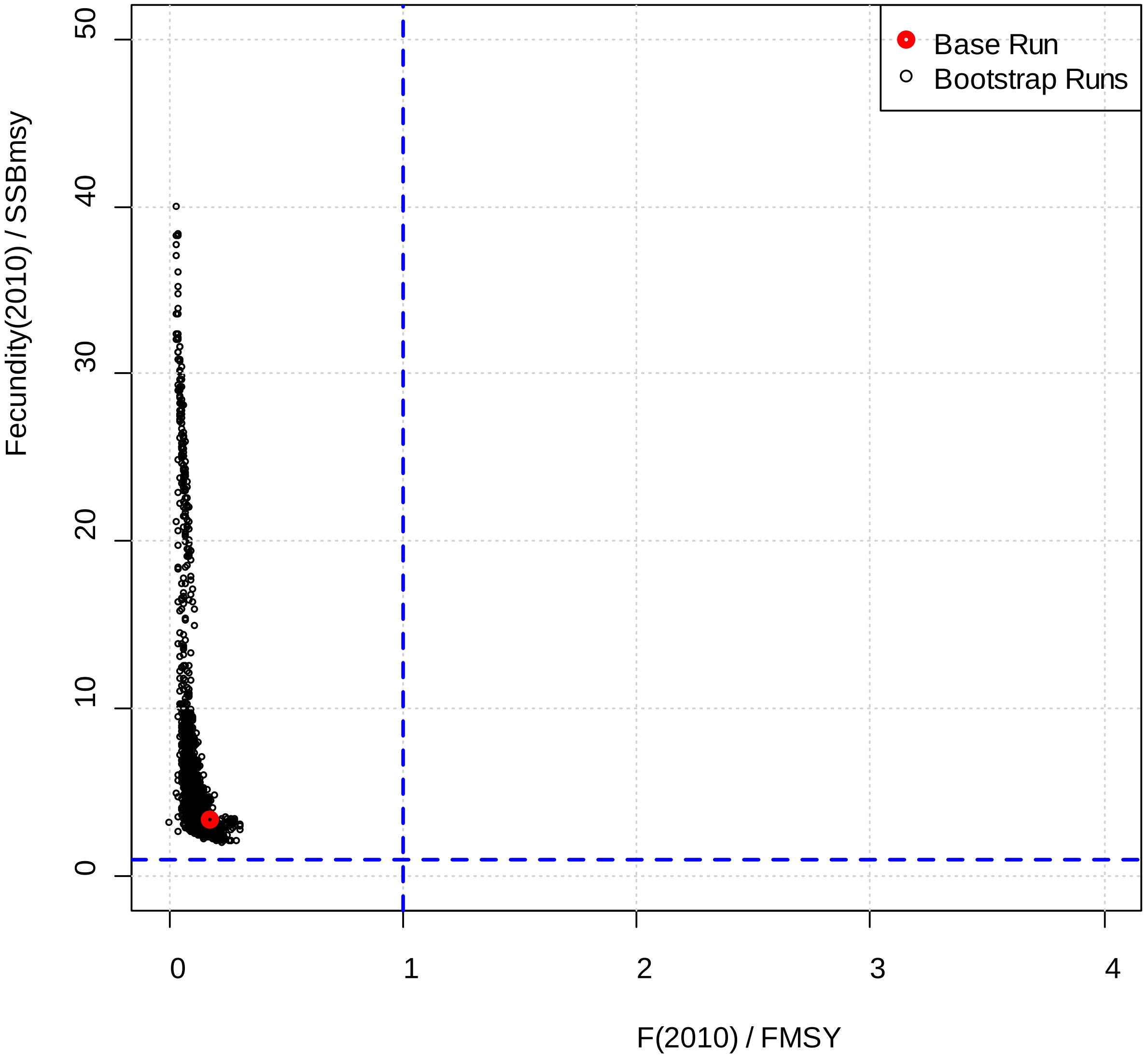
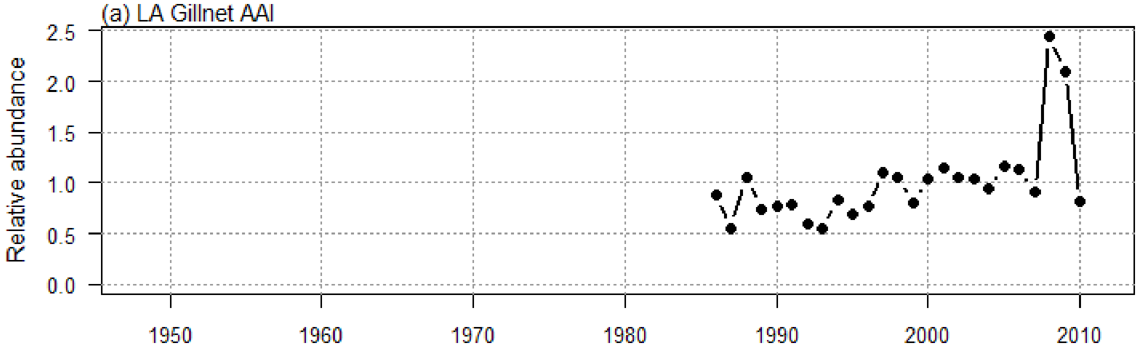
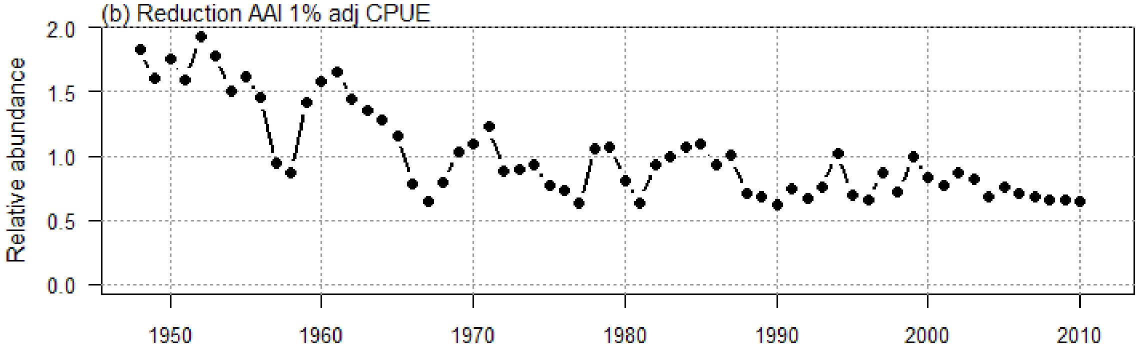


**Figure 8.36** Abundance indices used in production modeling of gulf menhaden.

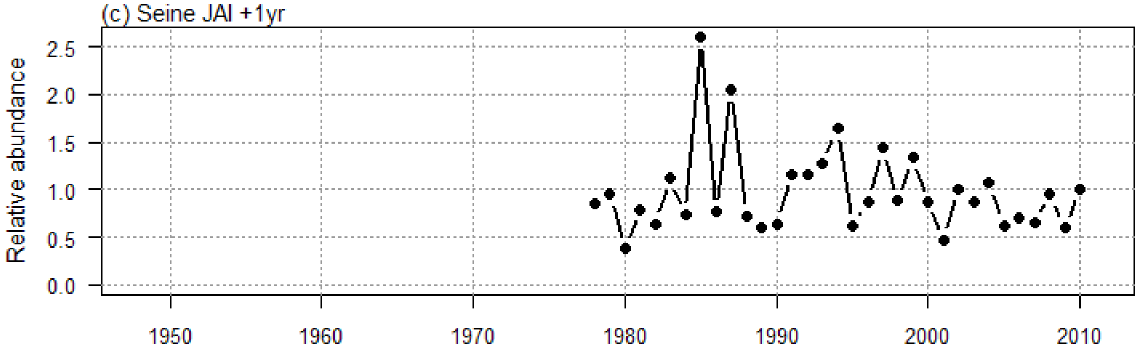
(a) LA Gillnet AAI



(b) Reduction AAI 1% adj CPUE



(c) Seine JAI +1yr



(d) Trawl JAI +1yr

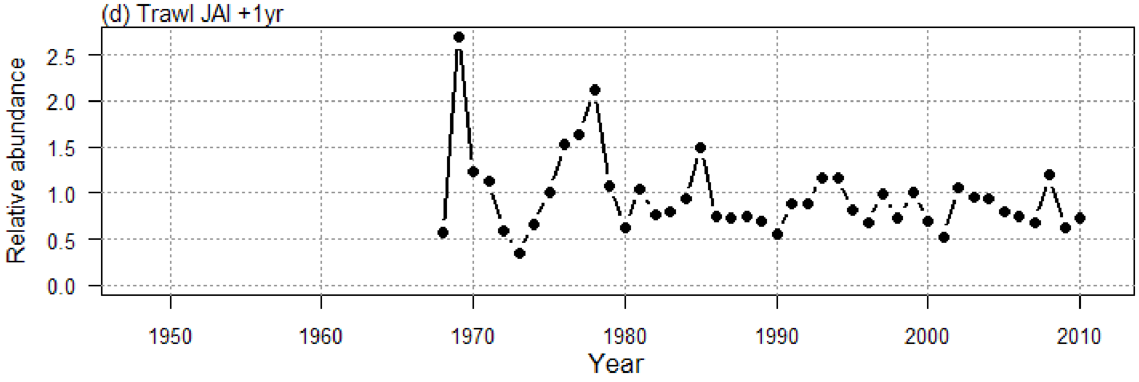


**Figure 8.37** Pairs plot of correlations between indices used in production modeling of gulf menhaden.

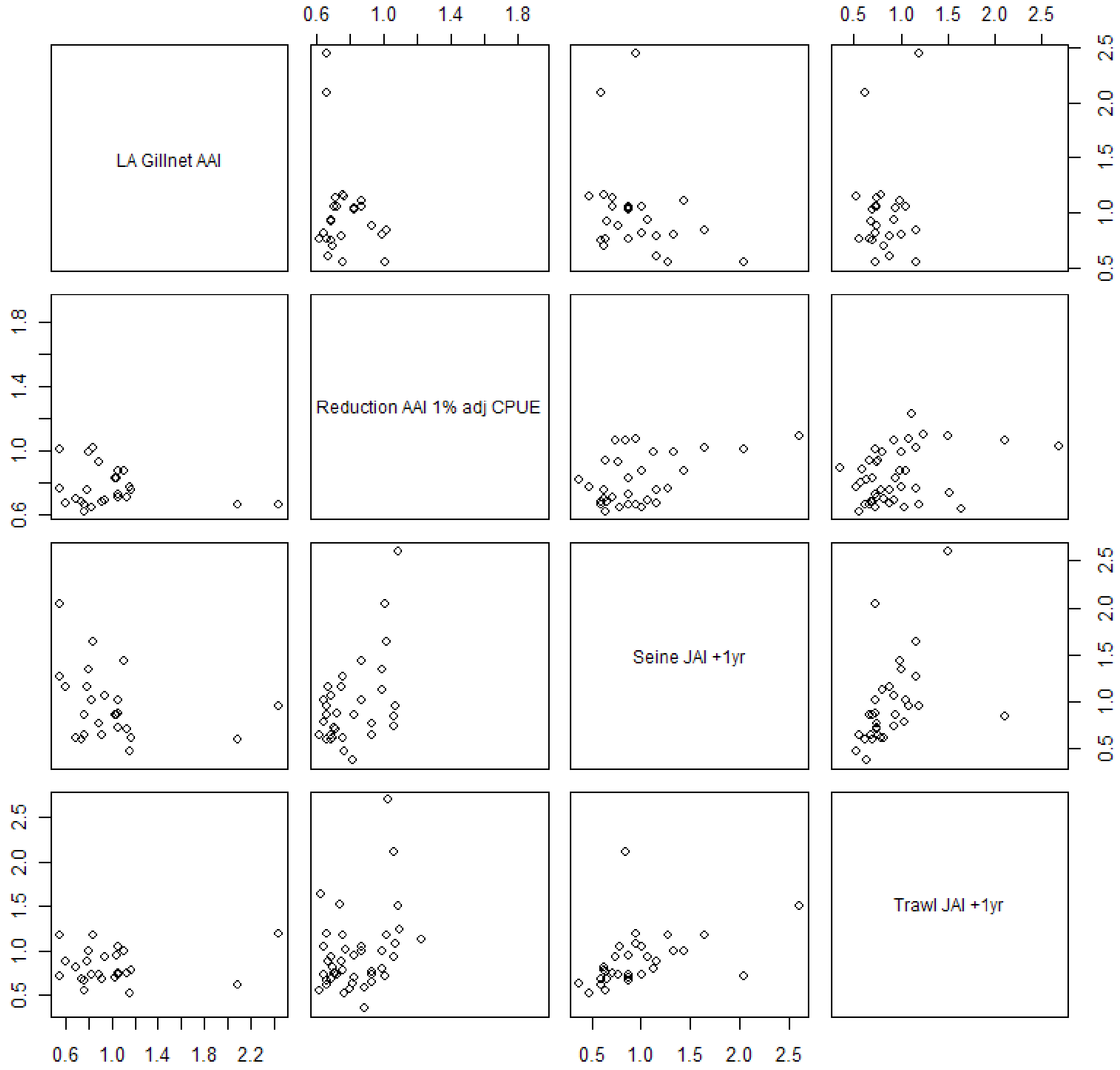


**Figure 8.38** Fit of base production model (run 107). Top, fit to gillnet index; bottom, to seine index.

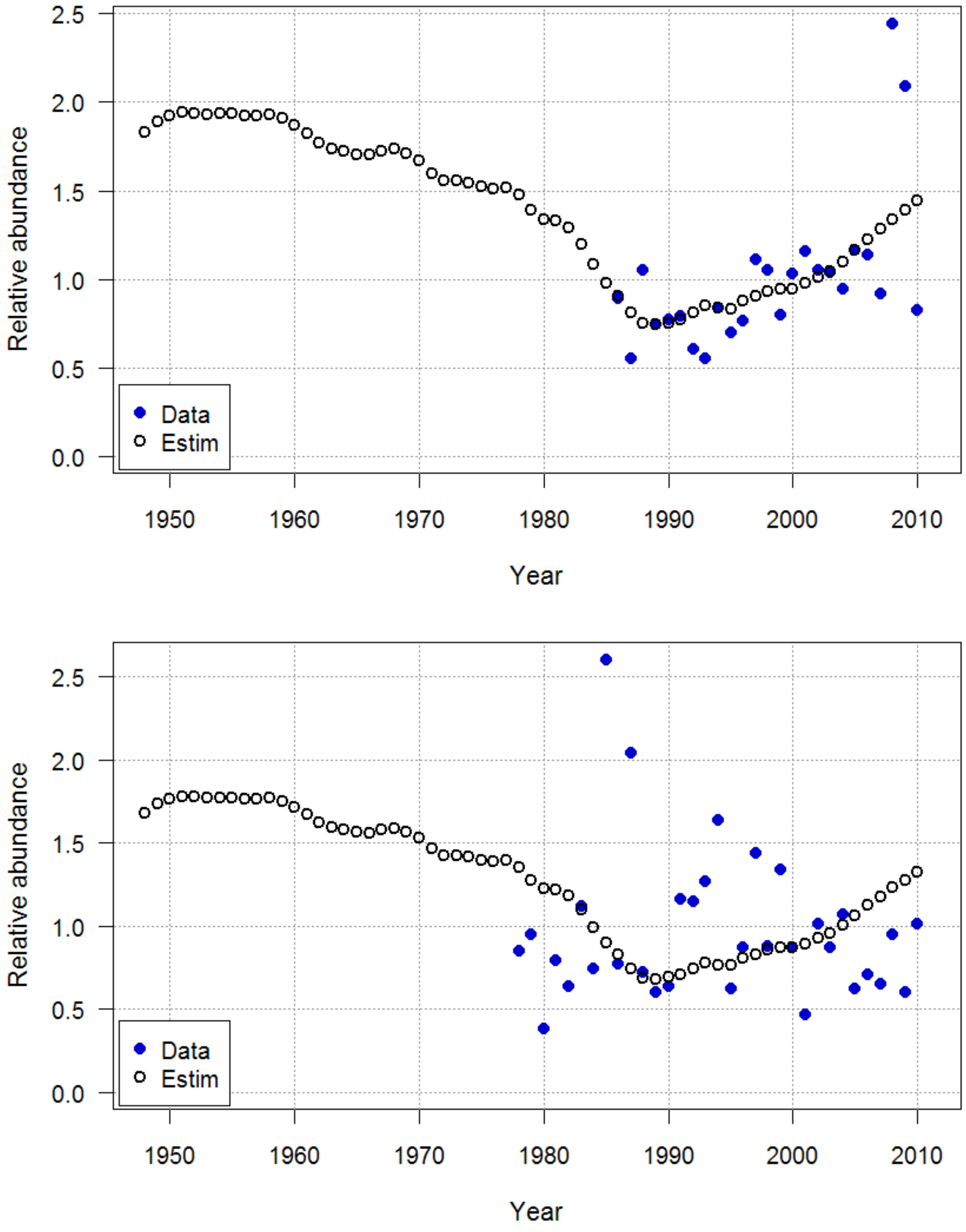


**Figure 8.39** Fit of production model sensitivity run with different juvenile index (run 109). Top, fit to gillnet index; bottom, to trawl index.

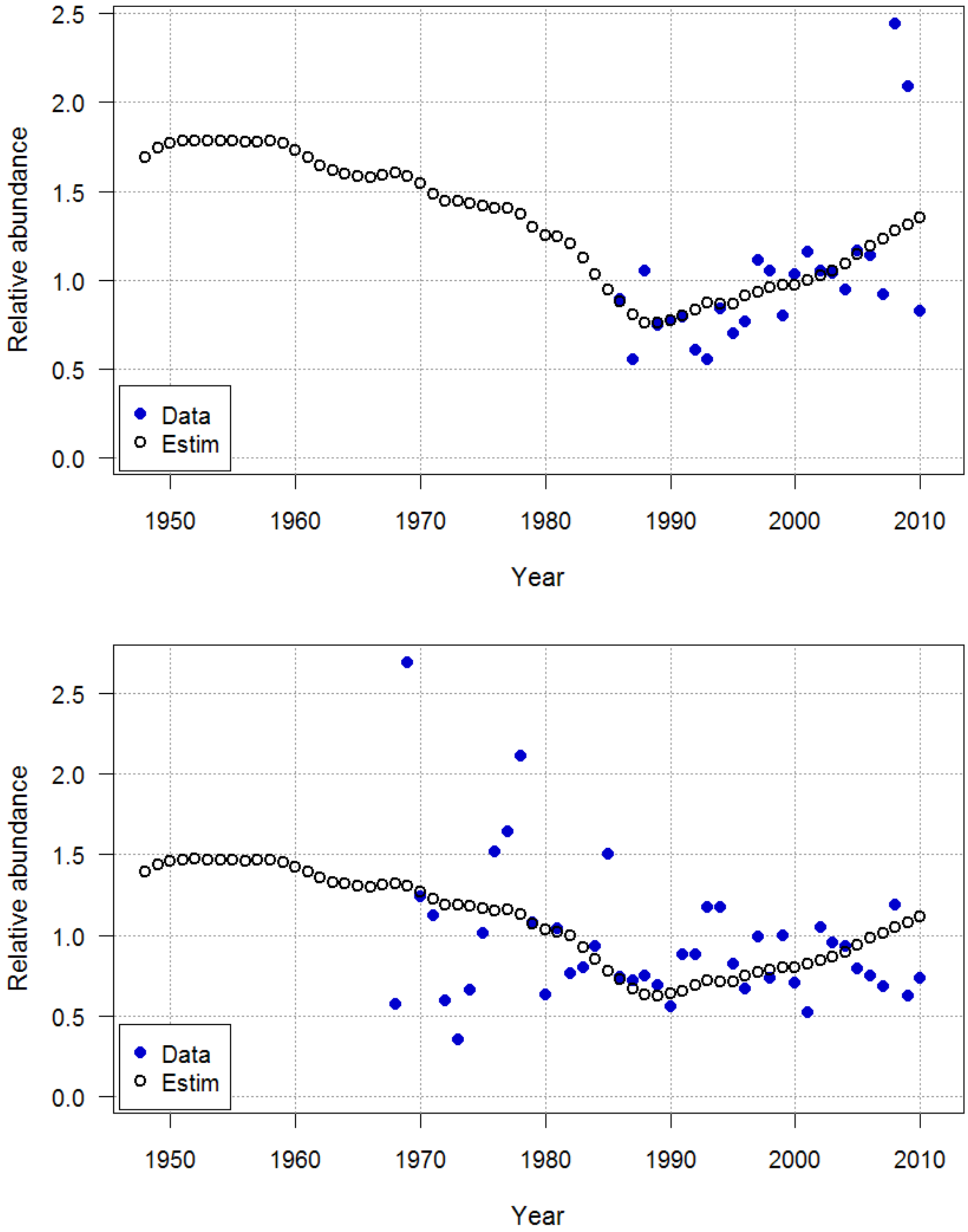


**Figure 8.40** Fit of production model sensitivity run with different adult index (run 110). Top, fit to reduction index; bottom, to seine index.

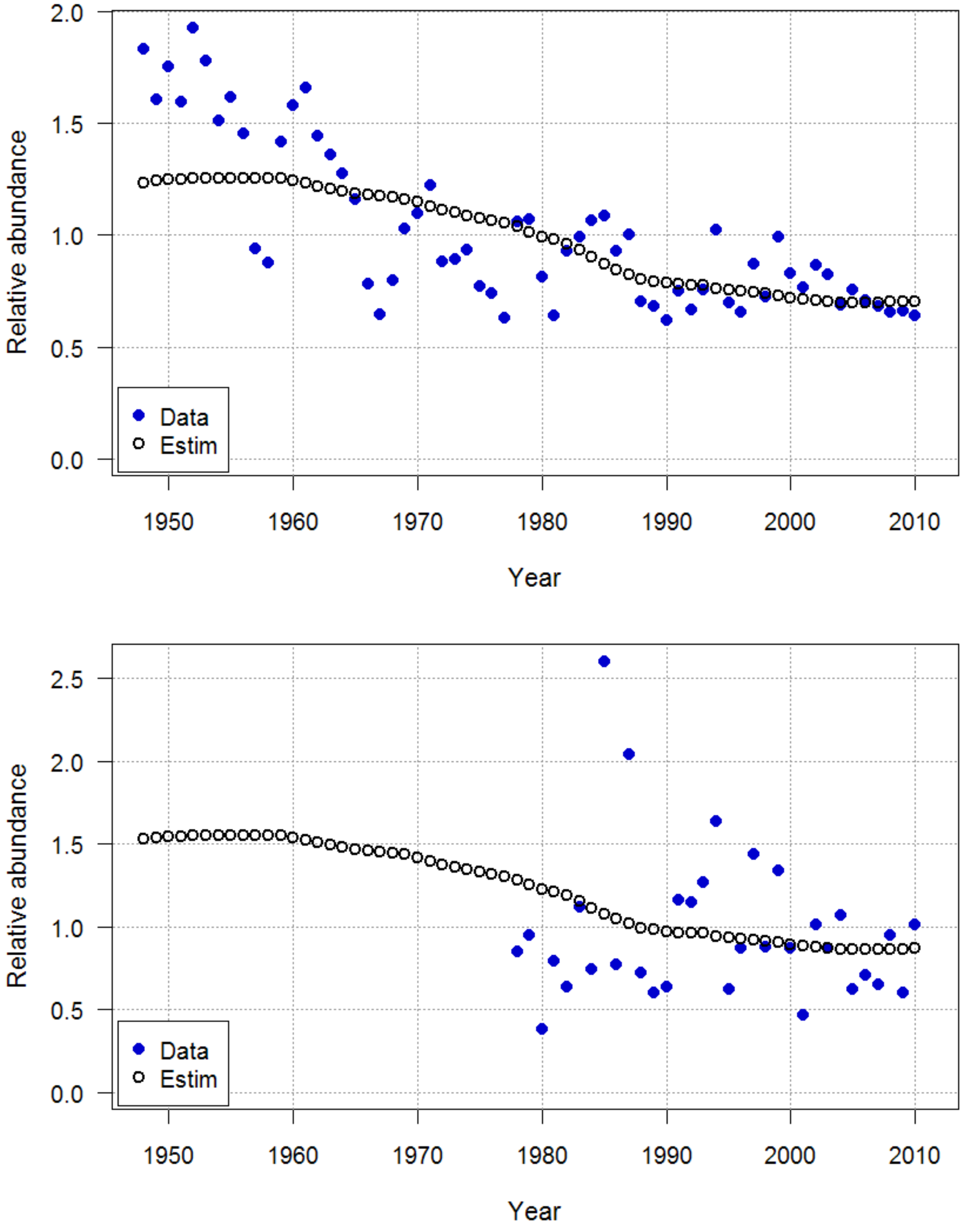


**Figure 8.41** Trajectories of relative biomass and fishing mortality estimated from base production model run.

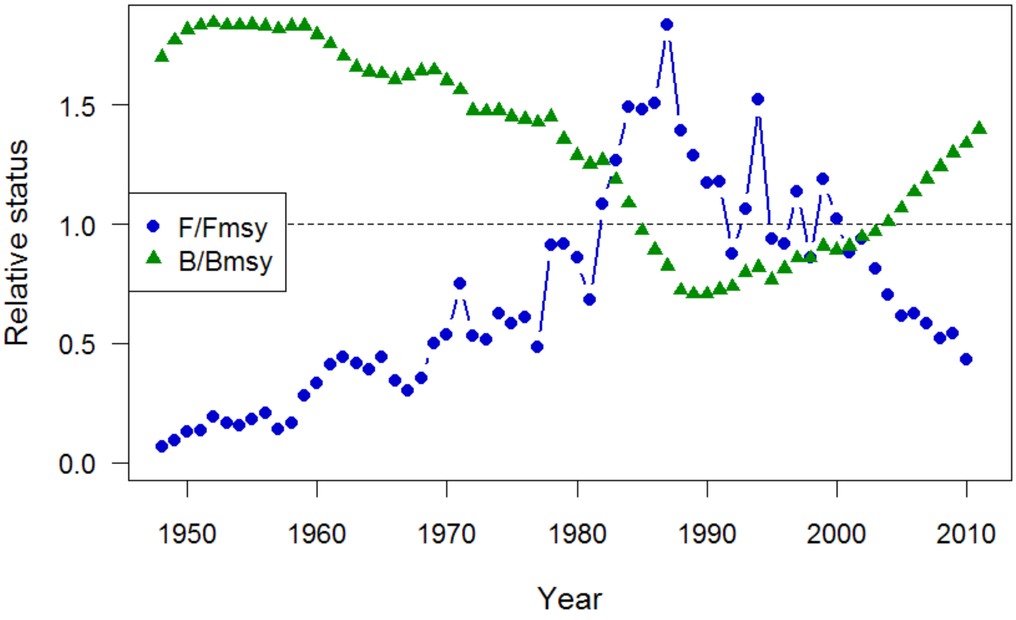


**Figure 8.42** Trajectories of relative biomass and fishing mortality estimated from production model sensitivity run (#110) in which fishery-dependent reduction CPUE index replaces fishery-independent gillnet abundance index.

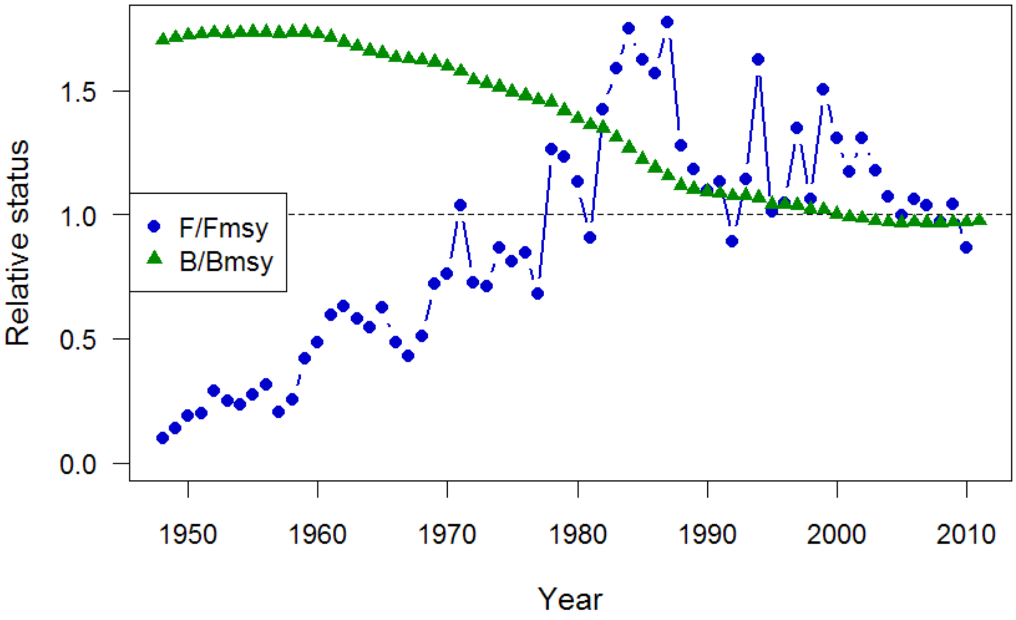


**Figure 8.43** Sensitivity of production model to assumed initial conditions. Run 107 is base run and assumes $B_1 = 0.85K$. Runs 119 and 120 are sensitivity runs and assume $B_1 = 0.85K$ and $B_1 = 0.85K$, respectively. Top panel: time trajectory of stock-status estimates. Bottom panel: of fishing-status estimates.

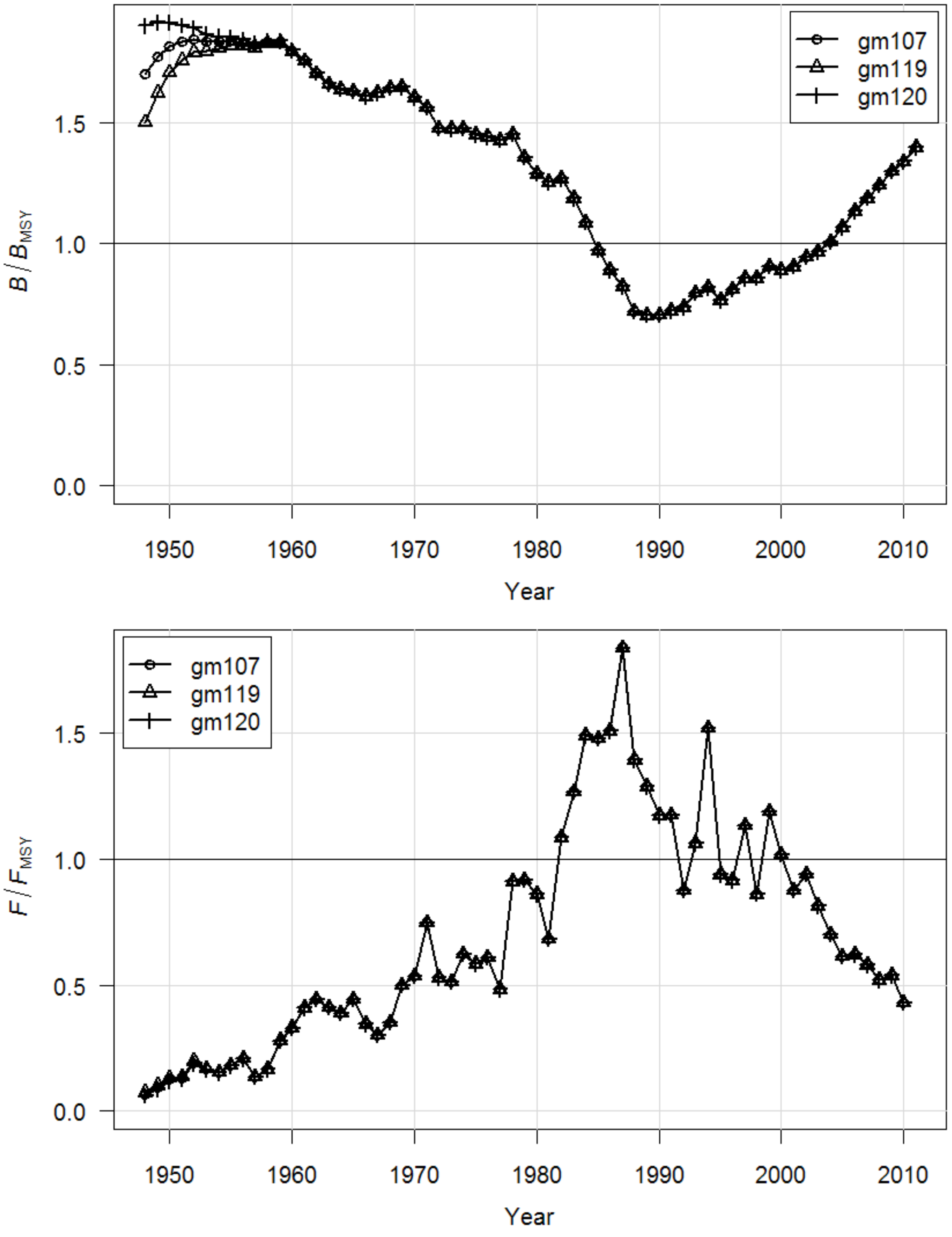
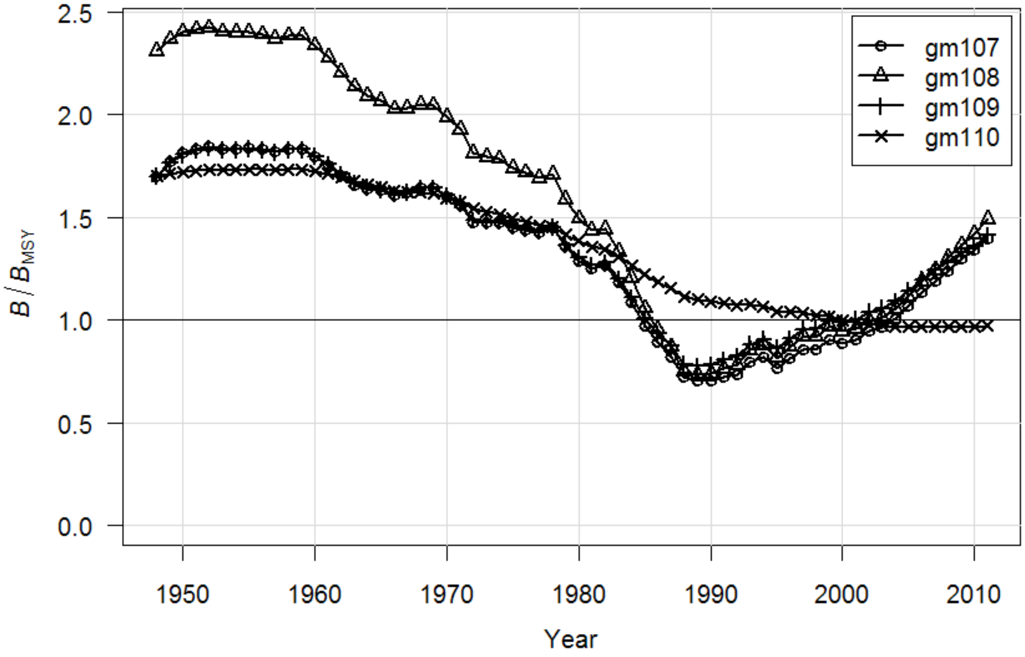


**Figure 8.44** Status trajectories from base production-model run and sensitivity runs 108–110. See Table 8.9 for run descriptions.



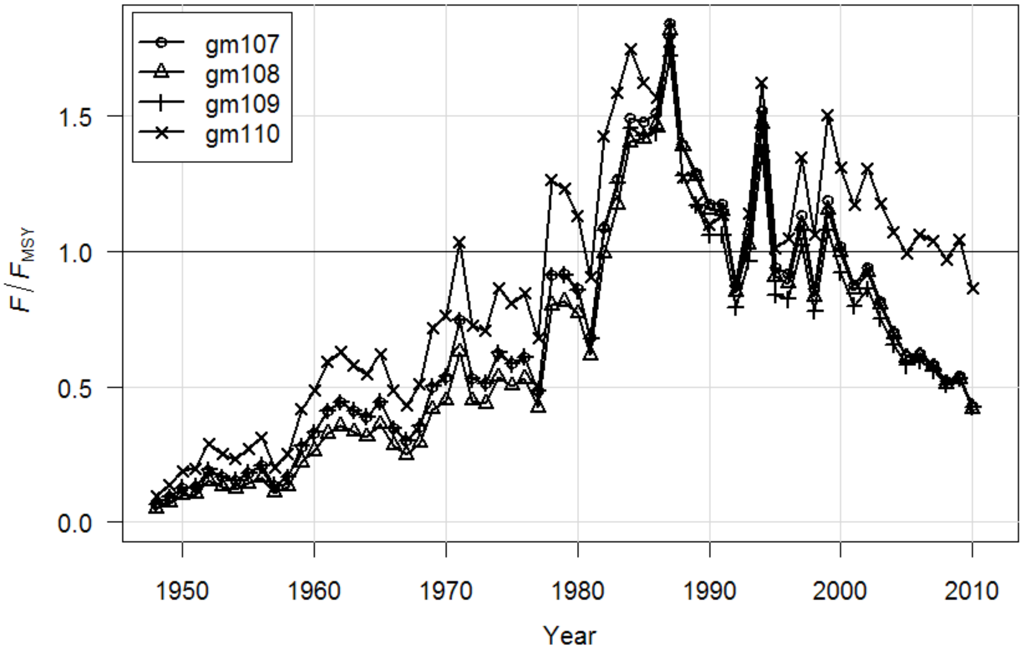


**Figure 8.45** Retrospective analysis of production model.

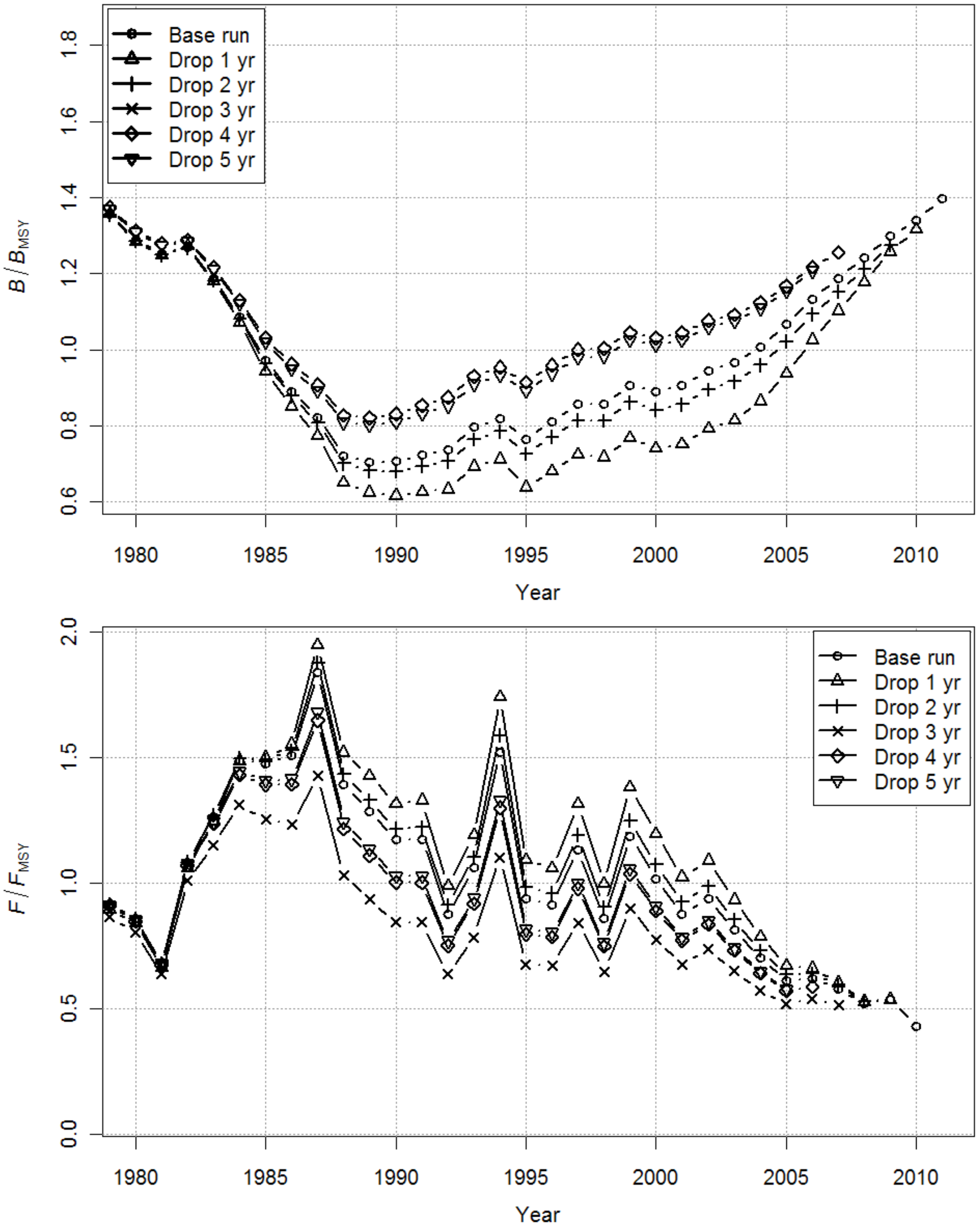


**Figure 8.46** The stochasticSRA model fits to the gill net index (alternate-1 model runs, left panel) and fits to the reduction fishery index (alternate-2 model runs, right panel) with the current exploitation rate parameter set at *U*=0.3, *U*=0.4, *U*=0.5, and *U*=0.6.

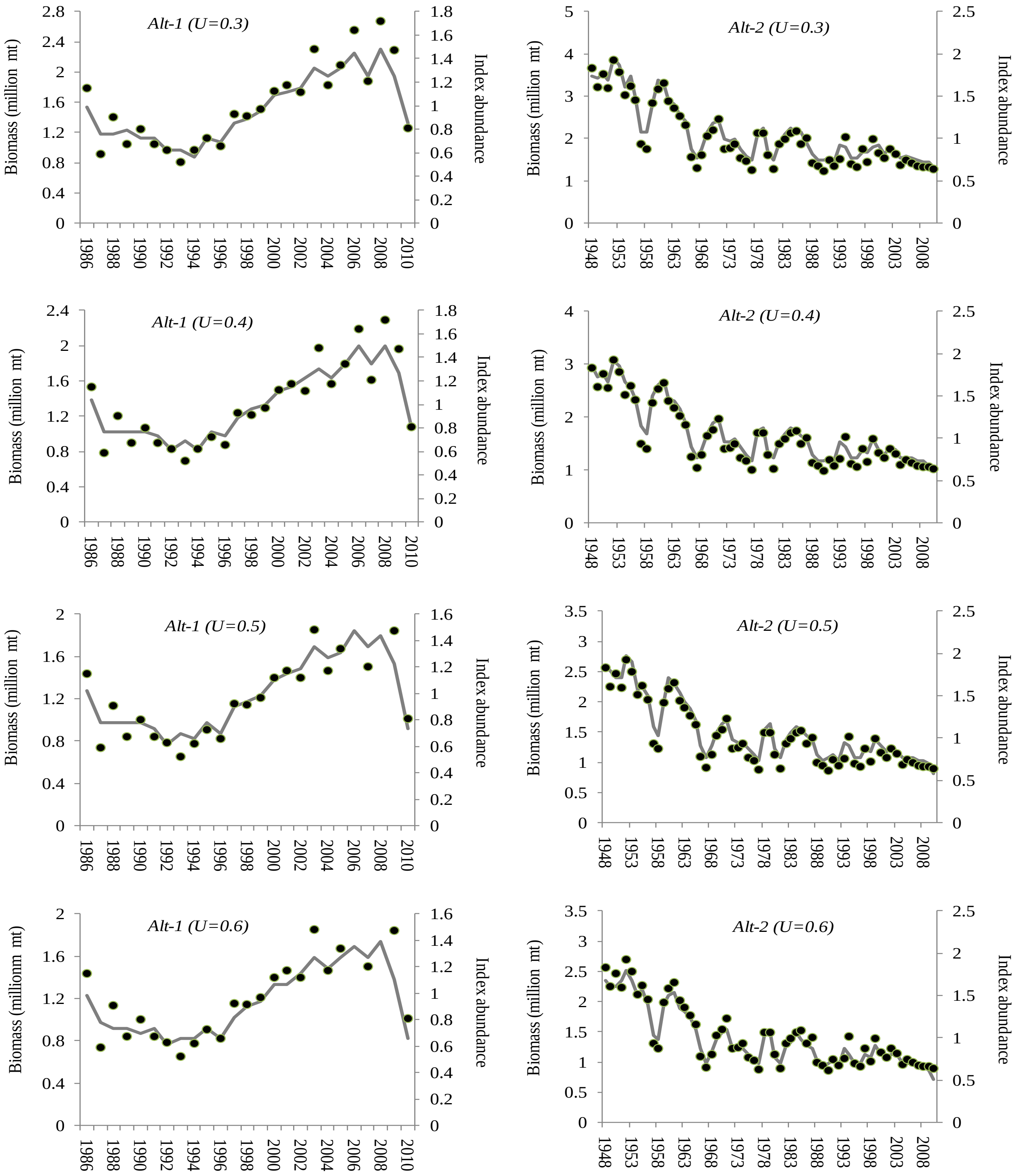


**Figure 8.47** Estimates of exploitable stock biomass and exploitation rate generated from the alternate-1 and alternate-2 models runs with the current exploitation rate parameter set at $U$=0.3, $U$=0.4, $U$=0.5, and $U$=0.6.

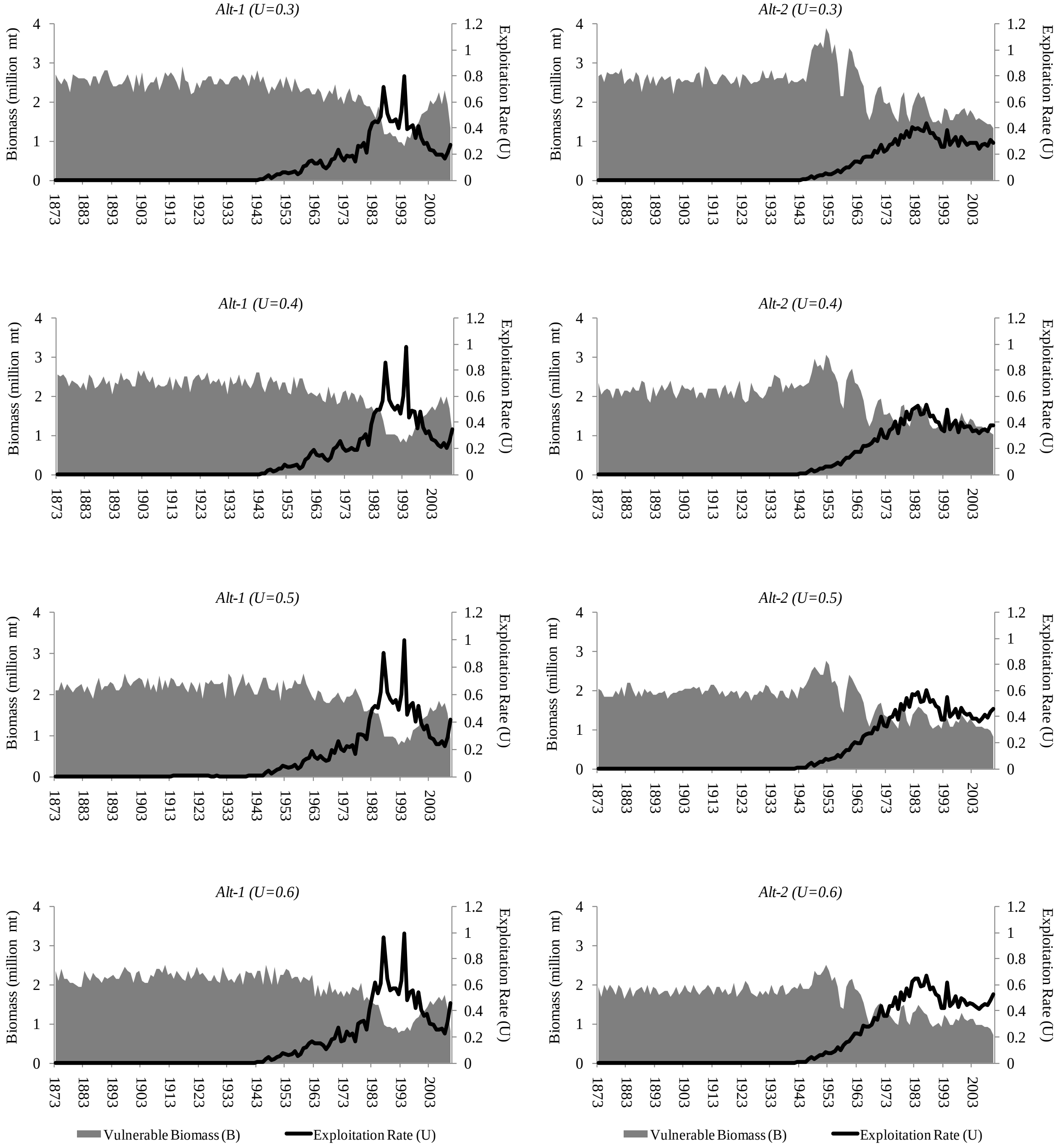


**Figure 8.48** Estimates of exploitable biomass and fishing mortality rate from the alternate-1 model run (SRA-Coast, using the coast wide gill net index) compared to estimates of exploitable biomass and fishing mortality rate from the BAM_base (using the Louisiana based gill net index), BAM-Coast (using coast wide gill net index), and $B/B_{MSY}$ and $F/F_{MSY}$ ratios from the ASPIC model (ASPIC_Coast, using the coast wide gill net index).

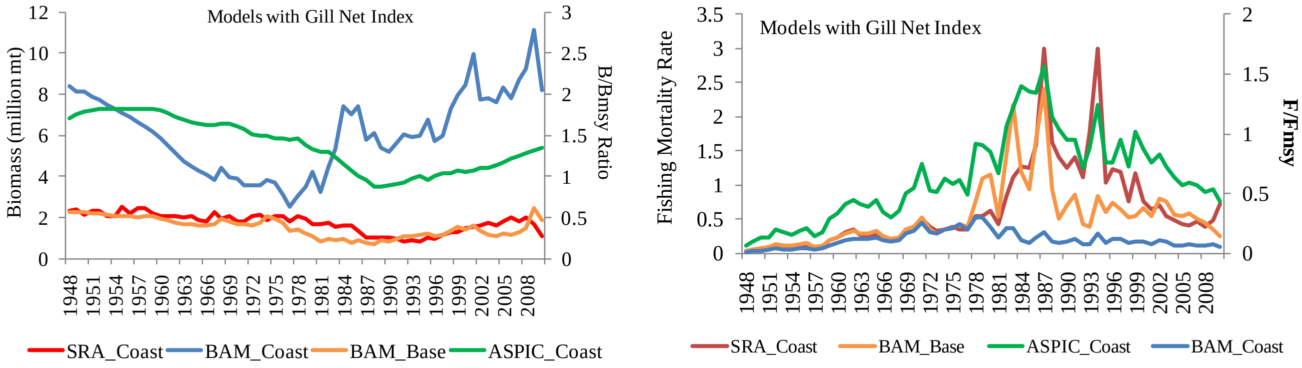


**Figure 8.49** Estimates of exploitable biomass and fishing mortality rate from the alternate-2 model run (SRA-Red, using the reduction fishery index) compared to estimates of exploitable biomass and fishing mortality rate from the BAM sensitivity run using the reduction fishery index (BAM_Red), and $B/B_{MSY}$ and $F/F_{MSY}$ ratios from the ASPIC model (ASPIC_Red, using the coast wide gill net index).

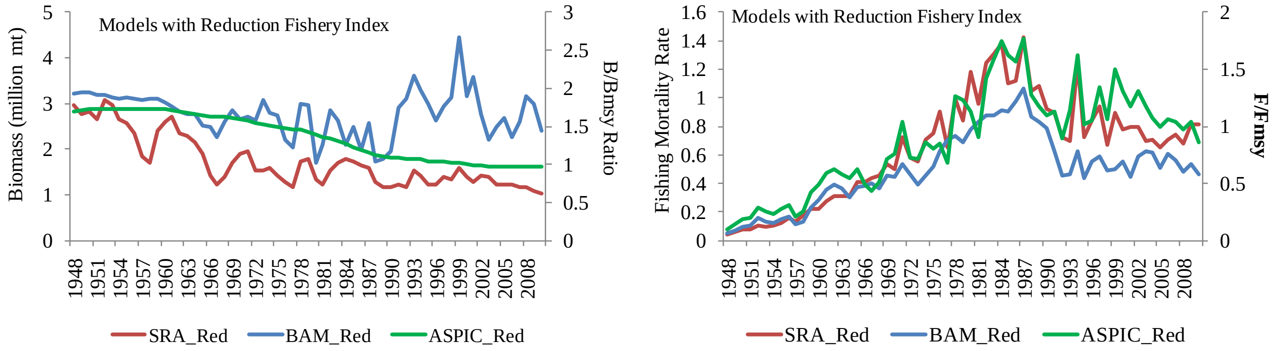


**Figure 8.50** The exploitable biomass estimates generated from one of the alternate-1 model runs (*U*=0.4) for three different values of standard deviation associated with the recruitment parameter.

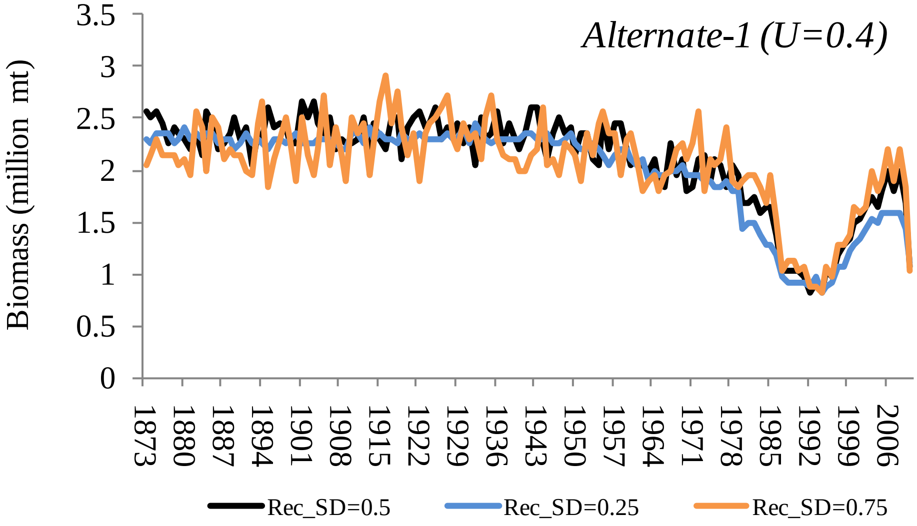


**Figure 8.51** The exploitable biomass estimates generated from one of the alternate-2 model runs (*U*=0.4) for three different values of standard deviation associated with the recruitment parameter.

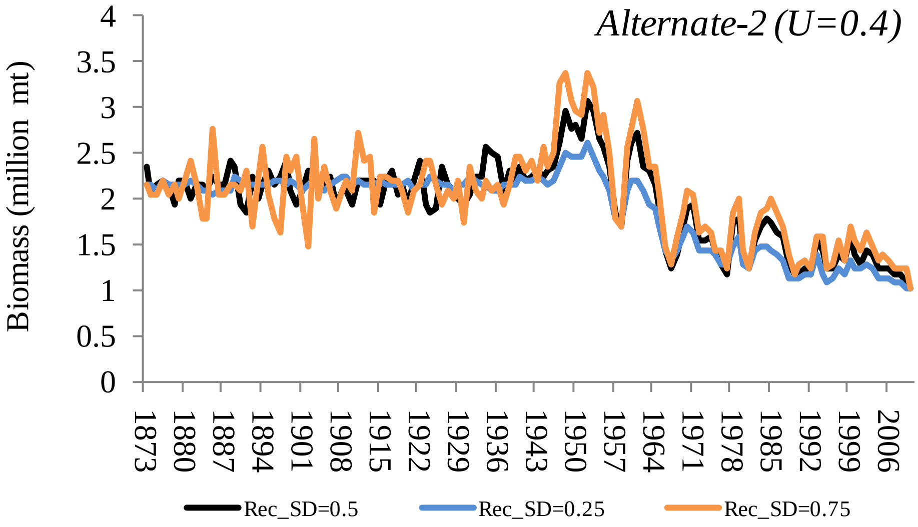


**Figure 8.52** The exploitable biomass estimates generated from one of the alternate-1 model runs (*U*=0.4) for two different CV values associated with the gill net survey tuning index.

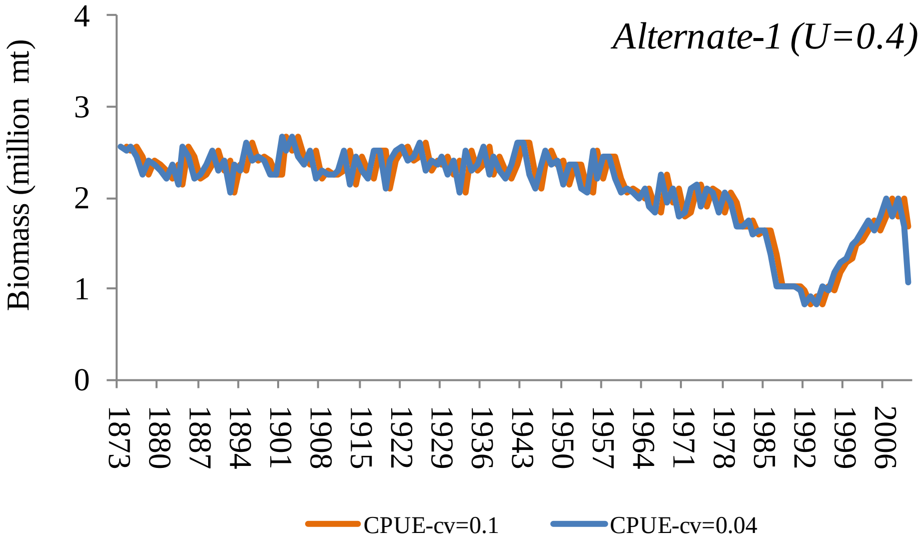


**Figure 8.53** The exploitable biomass estimates generated from one of the alternate-2 model runs (*U*=0.4) for two different CV values associated with the reduction fishery tuning index.

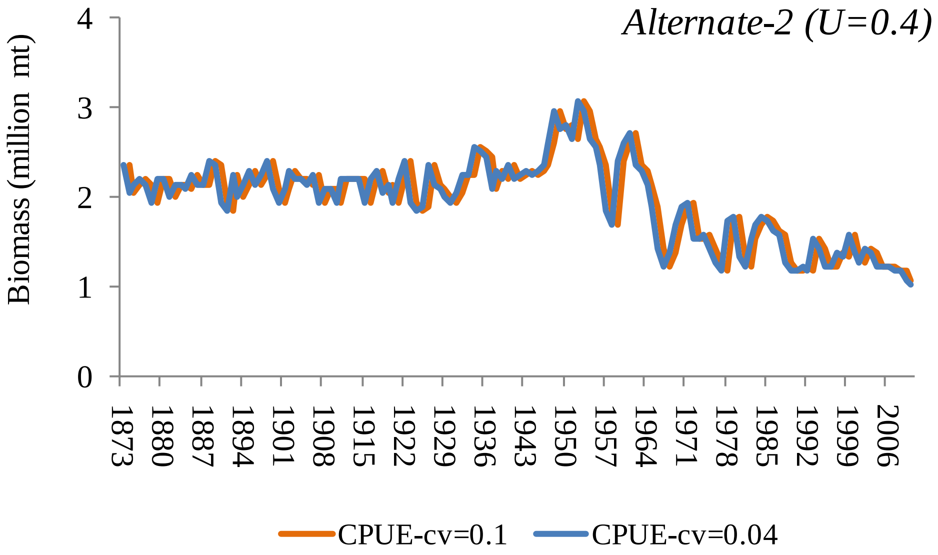


**Figure 8.54** The exploitable biomass trajectories from models runs tuned with the coast wide gill net index (alternate-1), reduction fishery catch per vessel-ton-weeks index (alternate-2), trawl survey index (lagged by one-year), and reduction fishery catch-per-set index.

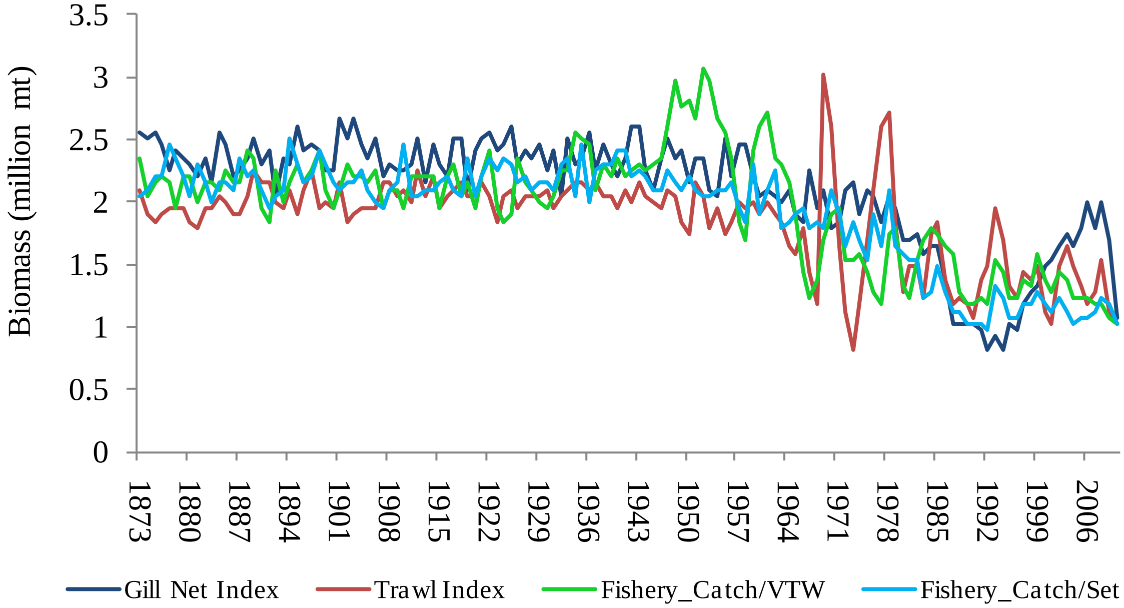


**Figure 8.55** MCMC posterior distributions of MSY and $U_{MSY}$ generated from the alternate-1 model runs with the current exploitation rate parameter set at *U*=0.3, *U*=0.4, *U*=0.5, and *U*=0.6.

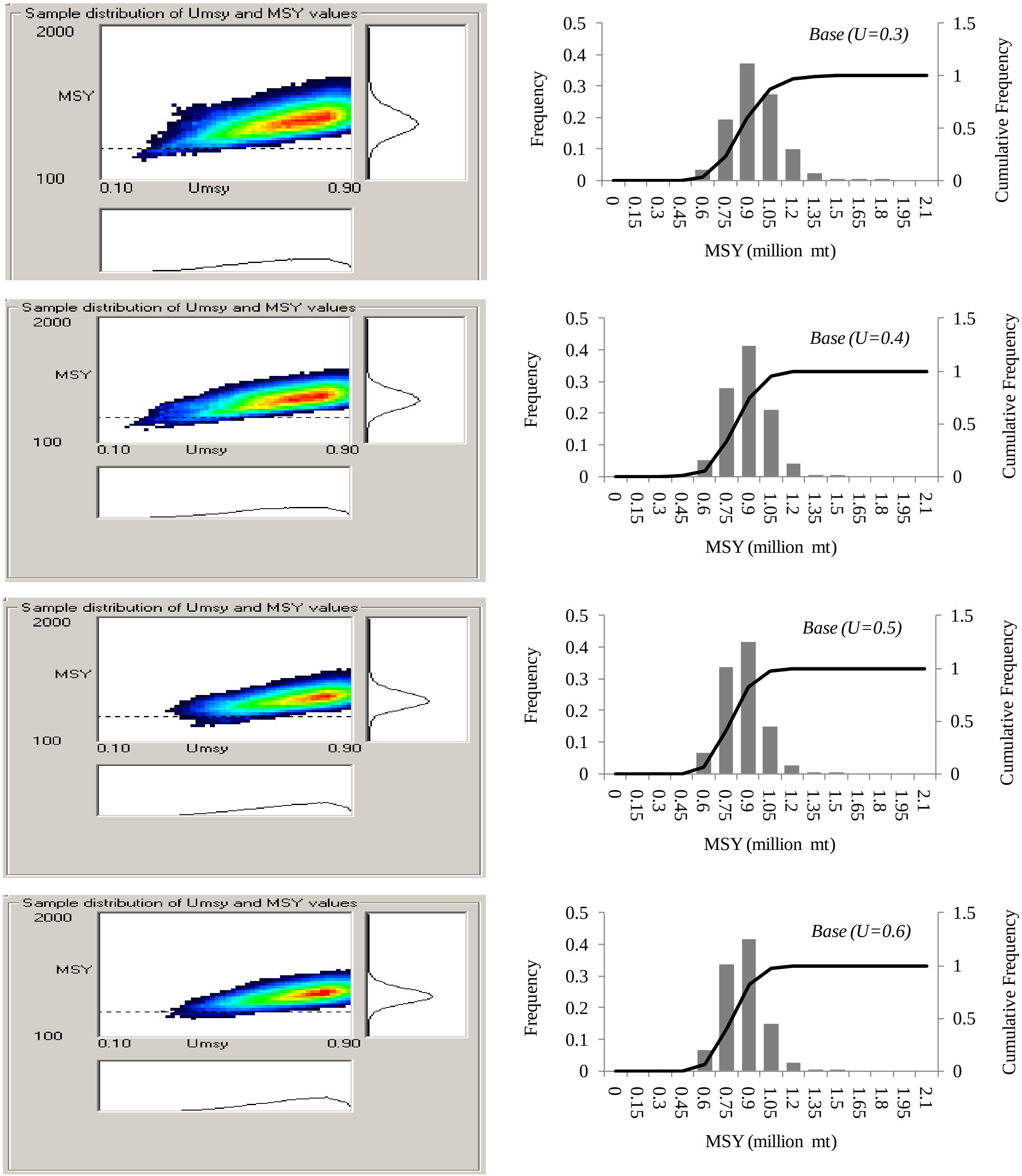


**Figure 8.56** MCMC posterior distributions of MSY and $U_{MSY}$ generated from the alternate-2 model runs with the current exploitation rate parameter set at $U$=0.3, $U$=0.4, $U$=0.5, and $U$=0.6.

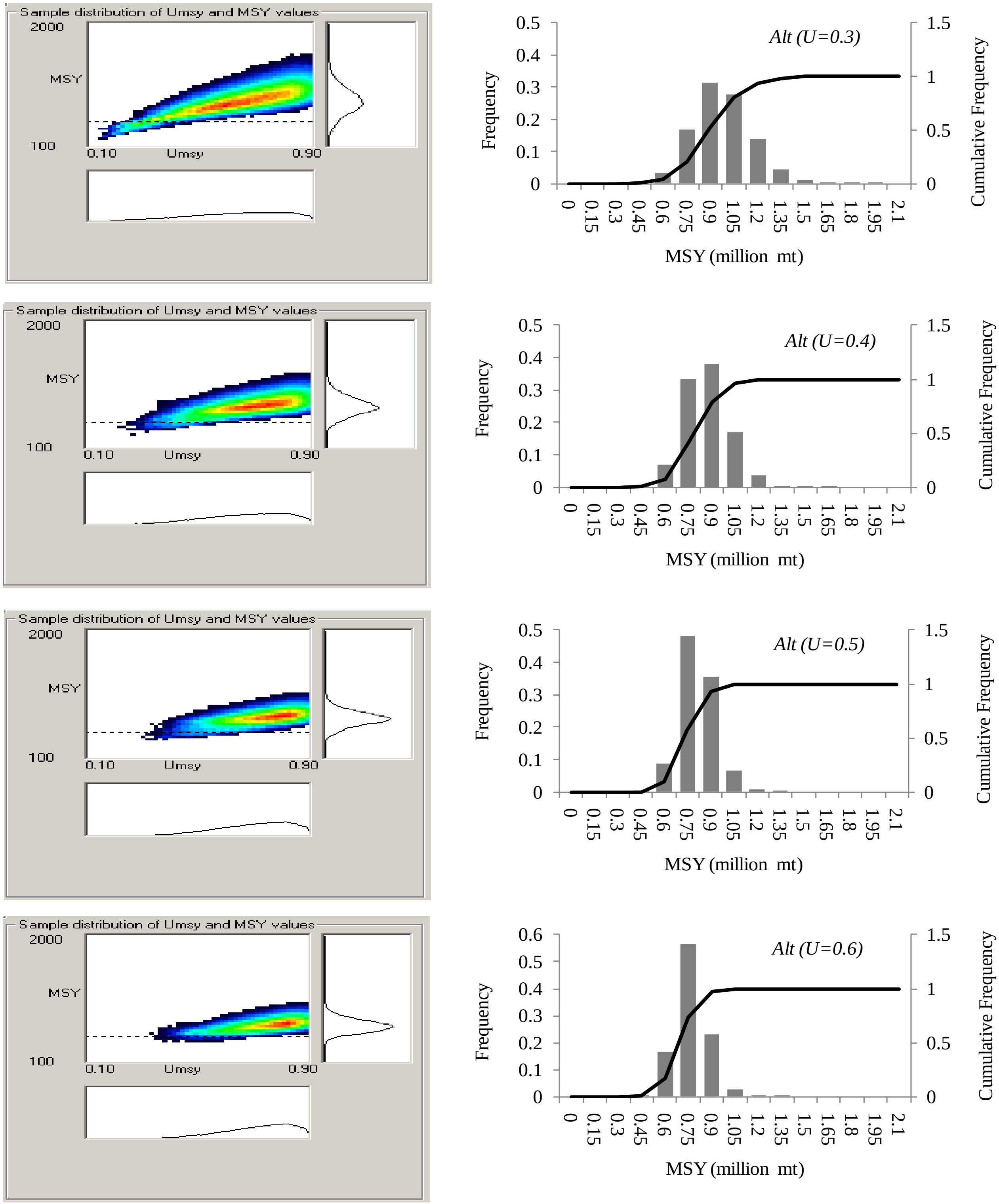


**Figure 8.57** MCMC posterior distributions of $U_{2010}/U_{MSY}$ generated from the alternate-1 (left panels) and alternate-2 (right panels) model runs with the current exploitation rate parameter set at *U*=0.3, *U*=0.4, *U*=0.5, *U*=0.6, and *U*=0.7.

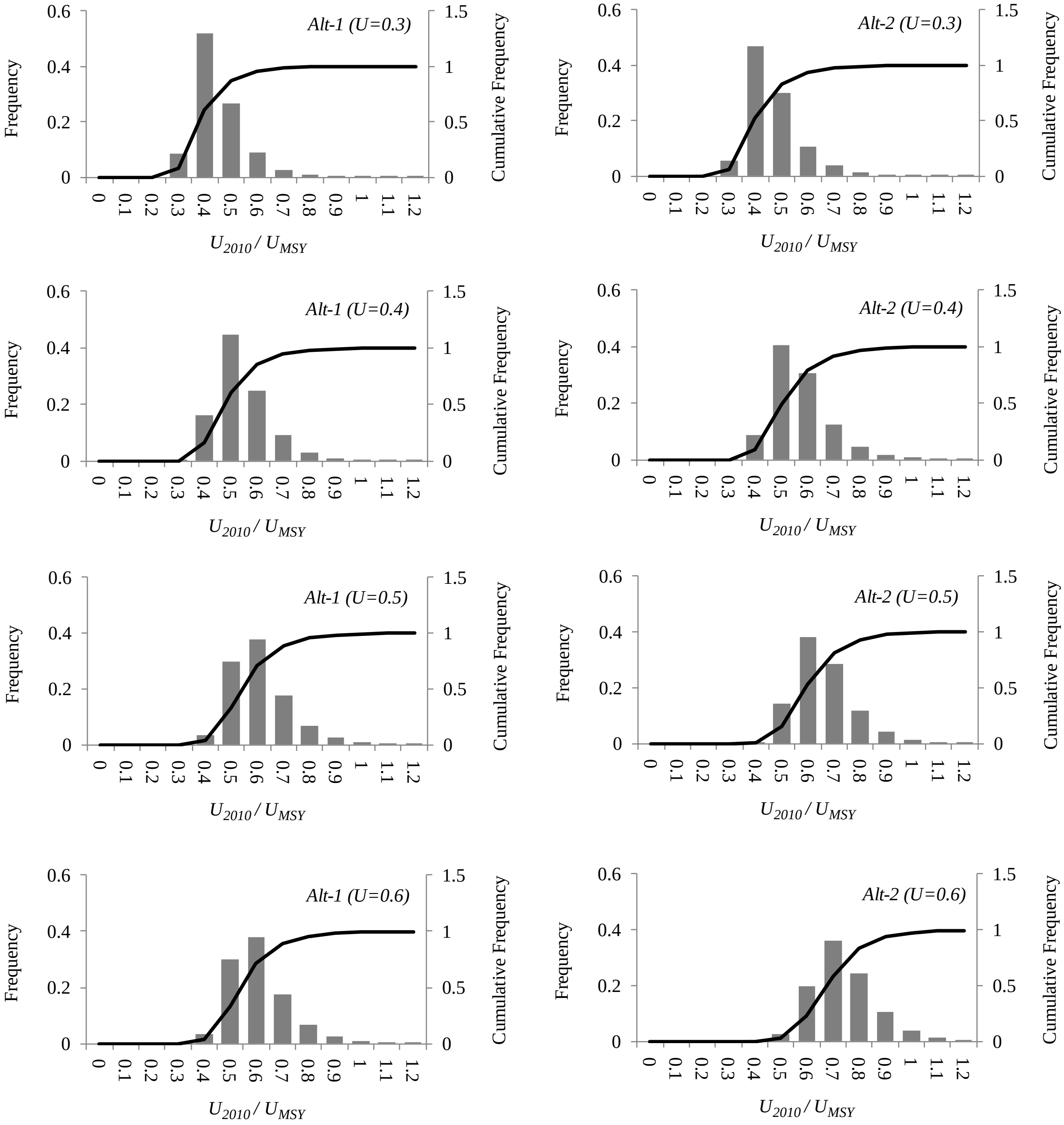


**Figure 8.58** MCMC posterior distributions of $E_{2010}/E_0$ generated from the alternate-1 (left panels) and alternate-2 (right panels) model runs with the current exploitation rate parameter set at $U$=0.3, $U$=0.4, $U$=0.5, $U$=0.6, and $U$=0.7.

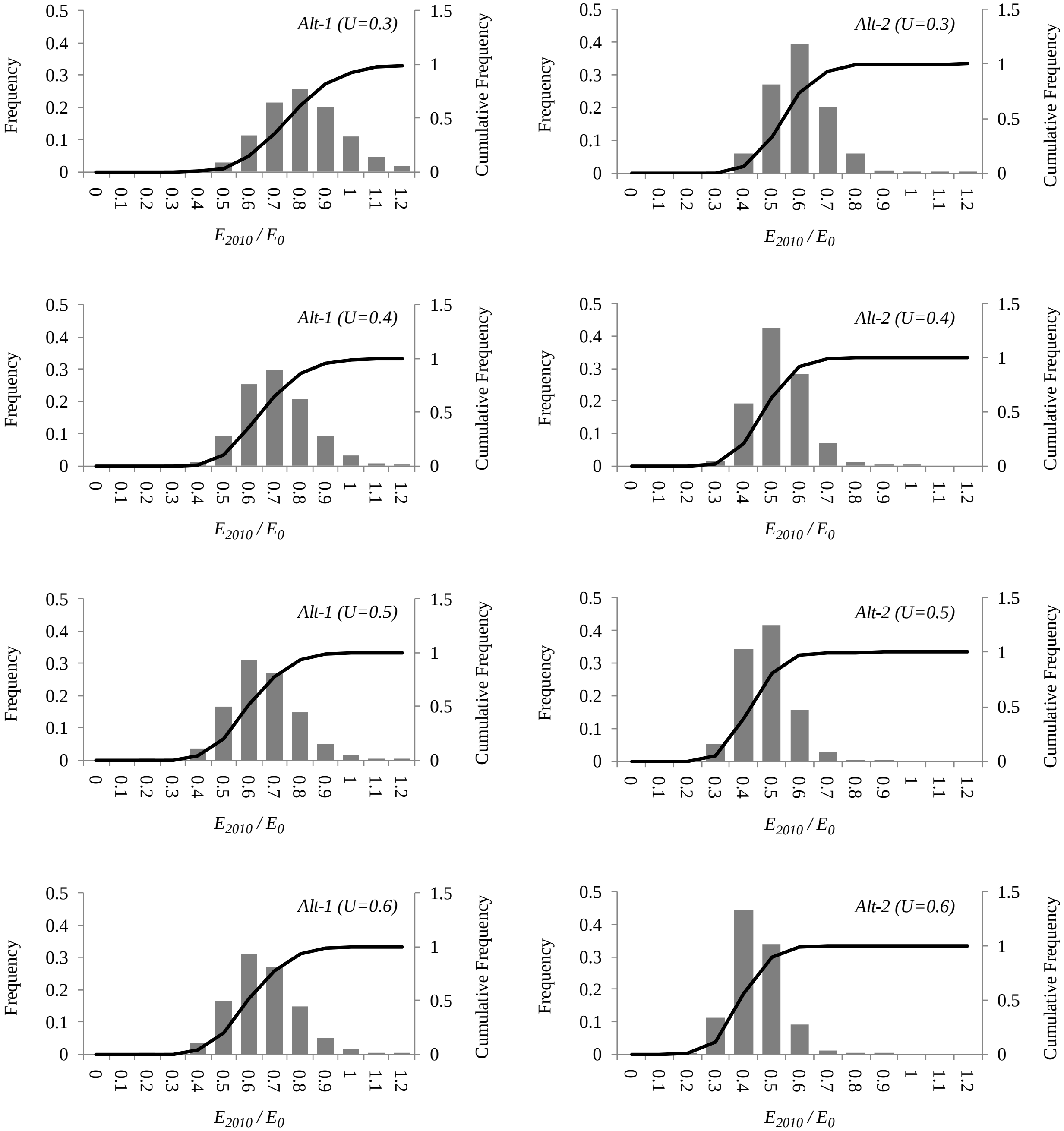


**Figure 8.59** Control plots based on MCMC posterior distributions of current stock ($E_{2010}/E_0$) and harvest rate ($U_{2010}/U_{MSY}$) generated from the alternate-1 (left panel) and alternate-2 (right panel) model runs with the current exploitation rate parameter set at $U$=0.3, $U$=0.4, $U$=0.5, and $U$=0.6.

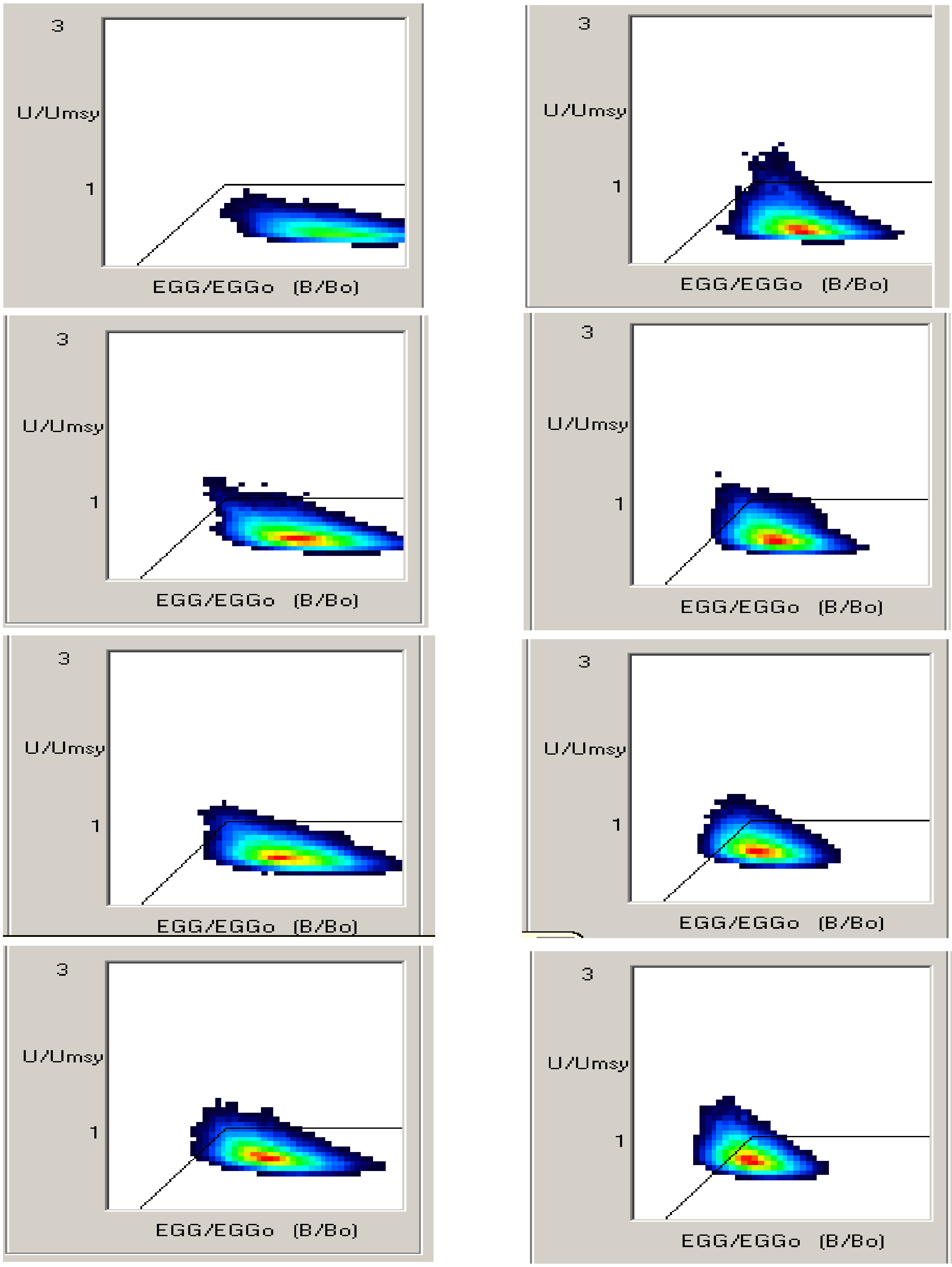
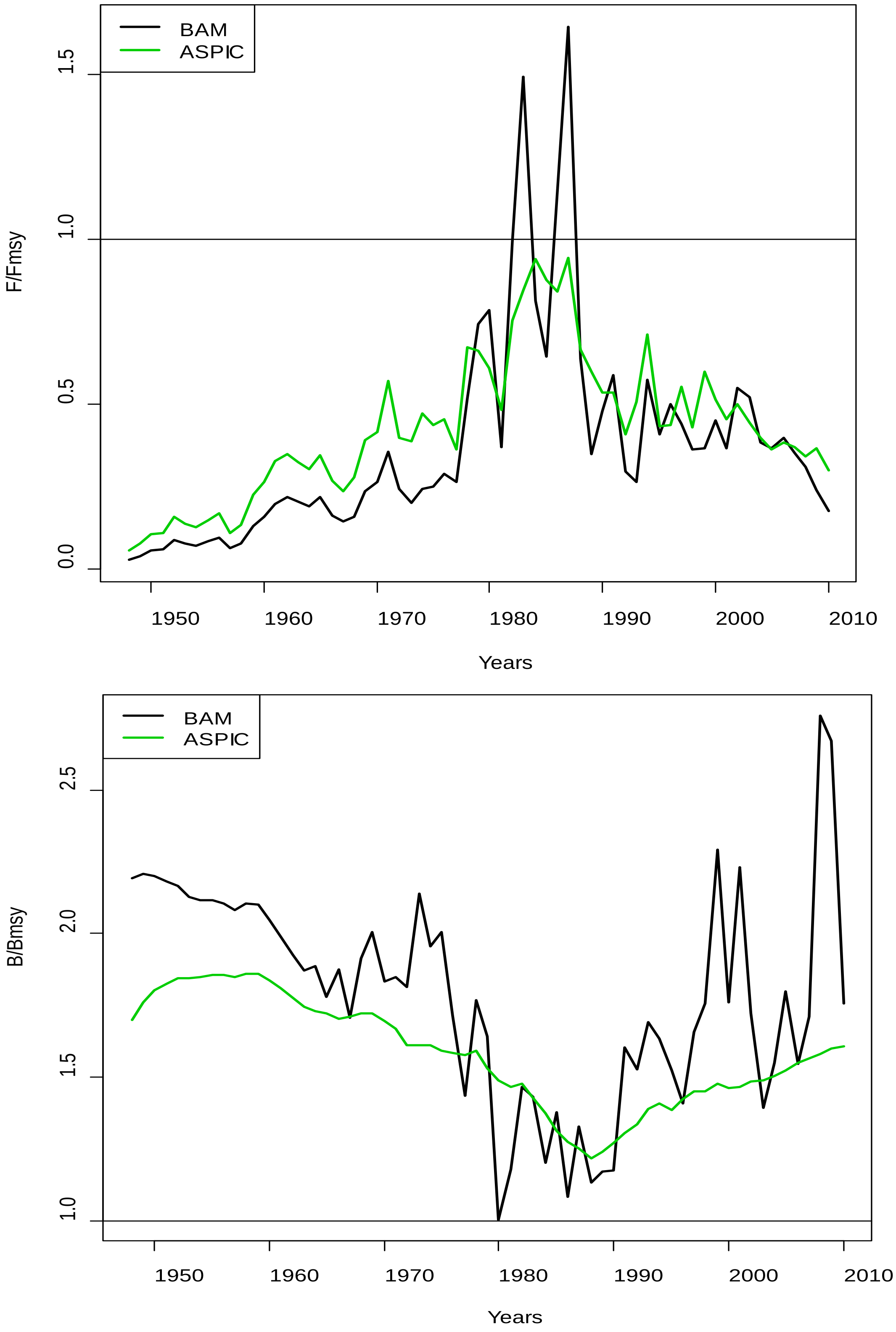


**Figure 9.1** $F/F_{MSY}$ and $B/B_{MSY}$ over time for the both the ASPIC and BAM base runs.



## Appendix A.1. ADMB base run tpl file

```
  //##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##
//##  GSMFC Assessment: Gulf Menhaden, July 2011
//##
//##  NMFS, Beaufort Lab, Sustainable Fisheries Branch
//##
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>

DATA_SECTION

!!cout << "Starting Gulf Menhaden Assessment Model" << endl;

// 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;
//!!cout << styr_rec_dev <<endl;
//possible 3 phases of constraints on recruitment deviations
init_int endyr_rec_phase1;
init_int endyr_rec_phase2;

//3 periods of size regs: styr-83 no restrictions, 1984-91 12-inch TL, 1992-08 20-in TL
init_int endyr_period1;
init_int endyr_period2;
init_int endyr_period3;

//end of first period of selectivity for gillnet survey and length comps
init_int endyr_period1_gill;

//starting and ending years to use for benchmark calculations
init_int styr_bench;
init_int endyr_bench;

//Total number of ages
init_int nages;

// Vector of ages for age bins
init_vector agebins(1,nages);

//Number of length bins and number in plus group
init_int nlen;
init_int nlenplus;
```

```
number nlenbins;
 LOCAL_CALCS
   nlenbins=nlen-nlenplus;
 END_CALCS

//Vectors of length bins and vector of plus group length bins
init_ivector lenbinstotal(1,nlen);
init_ivector lenplusbins(1,nlenplus);
init_ivector lenbins(1,nlenbins);

//number assessment years
number nyrs;
number nyrs_rec;
//this section MUST BE INDENTED!!!
 LOCAL_CALCS
   nyrs=endyr-styr+1.;
   nyrs_rec=endyr-styr_rec_dev+1.;
 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;
//Female maturity and proportion female at age
init_vector maturity_f_obs(1,nages);          //proportion females mature at age
init_vector maturity_m_obs(1,nages);          //proportion males mature at age
init_vector prop_f_obs(1,nages);              //proportion female at age
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 set_M_constant; //age-independent: used only for MSST
init_matrix set_M_mat(styr,endyr,1,nages); //age and year specific M
//Spawner-recruit parameters (Initial guesses or fixed values)
init_number set_SR_switch;  //switch for SR curve
init_number set_steep;      //recruitment steepness
init_number set_steep_se;   //SE or recruitment steepness
```

```
init_number set_log_R0;     //Recruitment R0
init_number set_R_autocorr; //Recruitment autocorrelation
init_number set_rec_sigma;  //recruitment standard deviation in log space
init_number set_rec_sigma_se;//SE of recruiment standard deviation in log space

//--><>--><>--><>-- Weight-at-age in the fishery (g) --><>--><>--><>--><>--><>--><>--><>--><>
init_matrix wgt_fish_g(styr,endyr,1,nages);

//--><>--><>--><>-- Weight-at-age for the spawning population - start of year (g) --><>--><>--><>--><>
init_matrix wgt_spawn_g(styr,endyr,1,nages);

//--><>--><>--><>-- Fecundity-at-age - not adjusted for maturity (trillions) --><>--><>--><>--><>
init_matrix fec_eggs(styr,endyr,1,nages);

//--><>--><>--><>-- Juvenile Abundance Index from seine surveys --><>--><>--><>--><>--><>
init_int JAI_cpue_switch;
//CPUE
init_int styr_JAIs_cpue;
init_int endyr_JAIs_cpue;
init_vector obs_JAIs_cpue(styr_JAIs_cpue,endyr_JAIs_cpue);   //Observed CPUE
init_vector JAIs_cpue_cv(styr_JAIs_cpue,endyr_JAIs_cpue);    //CV of cpue

//--><>--><>--><>-- Juvenile Abundance Indices from seine surveys --><>--><>--><>--><>--><>
//CPUE, must have zeros in place of missing values
init_vector obs_JAI1_cpue(styr_JAIs_cpue,endyr_JAIs_cpue);   //Observed CPUE 1
init_vector JAI1_cpue_cv(styr_JAIs_cpue,endyr_JAIs_cpue);    //CV of cpue 1
init_vector obs_JAI2_cpue(styr_JAIs_cpue,endyr_JAIs_cpue);   //Observed CPUE 2
init_vector JAI2_cpue_cv(styr_JAIs_cpue,endyr_JAIs_cpue);    //CV of cpue 2
init_vector obs_JAI3_cpue(styr_JAIs_cpue,endyr_JAIs_cpue);   //Observed CPUE 3
init_vector JAI3_cpue_cv(styr_JAIs_cpue,endyr_JAIs_cpue);    //CV of cpue 3
init_vector obs_JAI4_cpue(styr_JAIs_cpue,endyr_JAIs_cpue);   //Observed CPUE 4
init_vector JAI4_cpue_cv(styr_JAIs_cpue,endyr_JAIs_cpue);    //CV of cpue 4

//--><>--><>--><>-- Juvenile Abundance Index from trawl surveys --><>--><>--><>--><>--><>
//CPUE
init_int styr_JAIt_cpue;
init_int endyr_JAIt_cpue;
init_vector obs_JAIt_cpue(styr_JAIt_cpue,endyr_JAIt_cpue);   //Observed CPUE
init_vector JAIt_cpue_cv(styr_JAIt_cpue,endyr_JAIt_cpue);    //CV of cpue
```

```
//--><>--><>--><>-- Adult abundance index from gillnet surveys --><>--><>--><>--><>--
          ><>
//CPUE
init_int styr_gill_cpue;
init_int endyr_gill_cpue;
init_vector obs_gill_cpue(styr_gill_cpue,endyr_gill_cpue);   //Observed CPUE
init_vector gill_cpue_cv(styr_gill_cpue,endyr_gill_cpue);    //cv of cpue

// Length Compositions (10 mm bins)
init_int nyr_gill_lenc;
init_int styr_gill_lenc;
init_int endyr_gill_lenc;
init_ivector yrs_gill_lenc(1,nyr_gill_lenc);
init_vector nsamp_gill_lenc(styr_gill_lenc,endyr_gill_lenc);
init_vector neff_gill_lenc(styr_gill_lenc,endyr_gill_lenc);
init_matrix obs_gill_lenc(styr_gill_lenc,endyr_gill_lenc,1,nlenbins);

//--><>--><>--><>-- Commercial Reduction fishery (also includes bait and recreational) --
          ><>--><>--><>--><>--><>--><>--><>
// 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 styr_cR_agec;
init_int endyr_cR_agec;
init_int nyr_cR_agec;
!!cout << "number years agec" << nyr_cR_agec << endl;

init_ivector yrs_cR_agec(1,nyr_cR_agec);
init_vector nsamp_cR_agec(styr_cR_agec,endyr_cR_agec);
init_vector neff_cR_agec(styr_cR_agec,endyr_cR_agec);
init_matrix obs_cR_agec(styr_cR_agec,endyr_cR_agec,1,nages);

//##############################################################################
          #
//##################Parameter values and initial guesses
          ###################################
//Initial guesses of estimated selectivity parameters
init_number set_selpar_L50_cR;
init_number set_selpar_slope_cR;
init_number set_selpar_L502_cR;
init_number set_selpar_slope2_cR;
```

```
init_number set_selpar_L50_gill;
init_number set_selpar_slope_gill;
init_number set_selpar_L502_gill;
init_number set_selpar_slope2_gill;

init_number set_sel_age0_gill; //input in logit space
init_number set_sel_age1_gill;
init_number set_sel_age2_gill;
init_number set_sel_age3_gill;
init_number set_sel_age4_gill;

init_number set_sel_age0_cR1; //input in logit space
init_number set_sel_age1_cR1;
init_number set_sel_age2_cR1;
init_number set_sel_age3_cR1;
init_number set_sel_age4_cR1;

init_number set_sel_age0_cR3; //input in logit space
init_number set_sel_age1_cR3;
init_number set_sel_age2_cR3;
init_number set_sel_age3_cR3;
init_number set_sel_age4_cR3;

init_number set_sel_age0_cR4; //input in logit space
init_number set_sel_age1_cR4;
init_number set_sel_age2_cR4;
init_number set_sel_age3_cR4;
init_number set_sel_age4_cR4;

//--weights for likelihood components-------------------------------------------------------------------
        ----------
init_number set_w_L;
init_number set_w_ac;
init_number set_w_I_JAIs;      //JAI-seine
init_number set_w_I_JAIt;      //JAI-trawl
init_number set_w_I_gill;      //Adult index-gillnet
init_number set_w_gill_lenc;   //gillnet length comps
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_JAI_wgts;    //weight for penalty to keep JAI combination weights
        summing to 1.0
```

```
////--index catchability----------------------------------------------------------------------------------------------------------
init_number set_logq_JAIs;      //catchability coefficient (log) for seine JAI
init_number set_logq_JAIt;      //catchability coefficient (log) for trawl JAI
init_number set_logq_gill;      //catchability coefficient (log) for gillnet adult abundance

init_number set_JAI_exp;        //exponent for cpue index

//--JAI index combination weights------------------------------------------------------
init_number set_wgt_JAI1;
init_number set_wgt_JAI2;
init_number set_wgt_JAI3;
init_number set_wgt_JAI4;

//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_PN_var;     //assumed variance of RW q

////--F's--------------------------------
init_number set_log_avg_F_cR;
init_number set_F_init_ratio;  //defines initialization F as a ratio of that from first several yrs of assessment

//Tune Fapex (tuning removed in final year of optimization)
init_number set_Ftune;//not ok
init_int set_Ftune_yr;

//threshold sample sizes for length and age comps
init_number minSS_gill_lenc;
init_number minSS_cR_agec;

//switch to turn priors on off (-1 = off, 1 = on)
init_number switch_prior;
```

```
//ageing error matrix (columns are true ages, rows are ages as read for age comps)
init_matrix age_error(1,nages,1,nages);

//environmental factor (Mississippi River Flow)
init_vector env_fac(styr_cR_agec,endyr_cR_agec);

//switch to turn environmental factors  on/off in s-r function (1=on,2=off)
init_number switch_env_sr;
!!cout << switch_env_sr << endl;
//initial guess of s-r beta for environmental factors
init_number set_sr_beta_env;

//lengths at age and cv from reduction fishery to use for age-length conversions
init_vector set_length_age(1,nages);
init_vector set_len_cv(1,nages);
init_vector set_len_cv_se(1,nages);

//Von Bert parameters in TL mm
init_number set_Linf;
init_number set_K;
init_number set_t0;
init_number set_Linf_se;
init_number set_K_se;
init_number set_t0_se;


// #######Indexing integers for year(iyear), age(iage) ###############
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)
  {
   for(iyear=1; iyear<=1000; iyear++)
   {
    cout << "*** WARNING: Data File NOT READ CORRECTLY ****" << endl;
    cout << "" <<endl;
   }
  }
  else
  {
   cout << "Data File read correctly" << endl;
  }
 END_CALCS

//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>

PARAMETER_SECTION
//////--------------------------------------------------------------------------------------------

 matrix wgt_fish_kg(styr,endyr,1,nages);
 matrix wgt_fish_mt(styr,endyr,1,nages);
 matrix wgt_spawn_kg(styr,endyr,1,nages);
 matrix wgt_spawn_mt(styr,endyr,1,nages);

 matrix wgt_cR_mt(styr,endyr,1,nages);      //wgt of cR landings in 1000 mt

 matrix lenprob(1,nages,1,nlenbins);           //distn of size at age (age-length key, 10 mm bins) in population
 matrix lenprob_plus(1,nages,1,nlenplus); //used to compute mass in last length bin (a plus group)
 matrix pred_gill_lenc(styr_gill_lenc,endyr_gill_lenc,1,nlenbins);

 init_bounded_vector len_cv(1,nages,0,0.8,-4);
 init_bounded_number Linf(150,1000,-2);  //Linf from VonB curve
 init_bounded_number K(0.1,0.8,-2);     //K from VonB curve
 init_bounded_number t0(-3,1,-2);       //t0 from VonB curve
 vector length_age(1,nages);           //vector of length at age

 vector nsamp_gill_lenc_allyr(styr_gill_lenc,endyr_gill_lenc);
 vector neff_gill_lenc_allyr(styr_gill_lenc,endyr_gill_lenc);
 vector neff_gill_lenc_allyr_out(styr_gill_lenc,endyr_gill_lenc);

 matrix pred_cR_agec(styr_cR_agec,endyr_cR_agec,1,nages);
 matrix ErrorFree_cR_agec(styr_cR_agec,endyr_cR_agec,1,nages); //age comps prior to applying ageing error matrix
```

```
  //nsamp_X_allyr vectors used only for R output of comps with nonconsecutive yrs, given
          sample size cutoffs
  vector nsamp_cR_agec_allyr(styr_cR_agec,endyr_cR_agec);

//effective sample size applied in multinomial distributions
  vector neff_cR_agec_allyr(styr_cR_agec,endyr_cR_agec);

//Computed effective sample size for output (not used in fitting)
  vector neff_cR_agec_allyr_out(styr_cR_agec,endyr_cR_agec);

//-----Population-------------------------------------------------------------------------------
  matrix N(styr,endyr,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
  matrix N_pred_agec(styr_cR_agec,endyr_cR_agec,1,nages);
  init_bounded_vector log_Nage_dev(2,nages,-5,5,1); //log deviations on initial abundance at
          age
  //vector log_Nage_dev(2,nages);
  vector log_Nage_dev_output(1,nages);             //used in output. equals zero for first age
  matrix B(styr,endyr,1,nages);           //Population biomass by year and age at start of yr
  vector totB(styr,endyr);               //Total biomass by year
  vector totN(styr,endyr);               //Total abundance by year
  vector SSB(styr,endyr);                 ///Total spawning biomass by year
  vector rec(styr,endyr);                //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 maturity_m(1,nages);              //Proportion of male mature at age
  matrix reprod(styr,endyr,1,nages);
  vector wgted_reprod(1,nages);            //average reprod in last few years
//
////---Stock-Recruit Function (Beverton-Holt, steepness parameterization)----------
  init_bounded_number log_R0(1,20,1);      //log(virgin Recruitment)
  //number log_R0;
  number R0;                              //virgin recruitment
  init_bounded_number steep(0.21,0.99,3);   //steepness
  //number steep;  //uncomment to fix steepness, comment line directly above
  init_bounded_number rec_sigma(0.1,1.5,4);  //sd recruitment residuals
  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,-15,15,2); //log recruitment
        deviations
 //vector log_rec_dev(styr_rec_dev,endyr);
 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
                                 //Estimate from yrs with unconstrainted S-R(XXXX-XXXX)
 number sigma_rec_dev;                 //sample SD of log residuals (may not equal
        rec_sigma
 init_bounded_number sr_beta_env(-10,20,-4);  //beta for environmental factor on stock-
        recruit function

 number BiasCor;                       //Bias correction in equilibrium recruits
 init_bounded_number R_autocorr(-1.0,1.0,-4);  //autocorrelation in SR
 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);                //SSB / virgin SSB

////---Selectivity-------------------------------------------------------------------

//Commercial reduction----------------------------------------------
 matrix sel_cR(styr,endyr,1,nages);
 init_bounded_number selpar_slope_cR1(0.5,10.0,-1); //period 1
 init_bounded_number selpar_L50_cR1(0.5,4.0,-1);
 init_bounded_number selpar_slope2_cR1(0.0,10.0,-2); //period 1
 init_bounded_number selpar_L502_cR1(0.0,6.0,-2);

 //init_bounded_number selpar_slope_cR2(0.5,10.0,-2); //period 2
 //init_bounded_number selpar_L50_cR2(0.5,4.0,-2);
 //init_bounded_number selpar_slope2_cR2(0.0,10.0,-3); //period 2
 //init_bounded_number selpar_L502_cR2(0.0,6.0,-3);
 //vector sel_cR2_vec(1,nages);

 init_bounded_number selpar_slope_cR3(0.5,10.0,-2); //period 3
 init_bounded_number selpar_L50_cR3(0.5,4.0,-2);
 init_bounded_number selpar_slope2_cR3(0.0,10.0,-3); //period 3
 init_bounded_number selpar_L502_cR3(0.0,6.0,-3);

 init_bounded_number selpar_slope_cR4(0.5,10.0,-3); //period 4
 init_bounded_number selpar_L50_cR4(0.5,4.0,-3);
 init_bounded_number selpar_slope2_cR4(0.0,10.0,-3); //period 4
 init_bounded_number selpar_L502_cR4(0.0,6.0,-3);

 init_bounded_vector sel_age0_cR1_logit(styr,endyr_period2,-15,15,-2);  //in logit space
```

```
  init_bounded_vector sel_age1_cR1_logit(styr,endyr_period2,-5,15,2);
  init_bounded_vector sel_age2_cR1_logit(styr,endyr_period2,-15,15,-2);
  init_bounded_vector sel_age3_cR1_logit(styr,endyr_period2,-5,15,2);
  init_bounded_vector sel_age4_cR1_logit(styr,endyr_period2,-5,15,2);
  vector sel_age_cR1_vec(1,nages);
  vector selpar_age0_cR1(styr,endyr_period2);
  vector selpar_age1_cR1(styr,endyr_period2);
  vector selpar_age2_cR1(styr,endyr_period2);
  vector selpar_age3_cR1(styr,endyr_period2);
  vector selpar_age4_cR1(styr,endyr_period2);

  init_bounded_vector sel_age0_cR3_logit(endyr_period2+1,endyr_period3,-15,15,-3);  //in logit space
  init_bounded_vector sel_age1_cR3_logit(endyr_period2+1,endyr_period3,-15,15,3);
  init_bounded_vector sel_age2_cR3_logit(endyr_period2+1,endyr_period3,-15,15,-3);
  init_bounded_vector sel_age3_cR3_logit(endyr_period2+1,endyr_period3,-15,15,-3);
  init_bounded_vector sel_age4_cR3_logit(endyr_period2+1,endyr_period3,-15,15,-3);
  vector sel_age_cR3_vec(1,nages);
  vector selpar_age0_cR3(endyr_period2+1,endyr_period3);
  vector selpar_age1_cR3(endyr_period2+1,endyr_period3);
  vector selpar_age2_cR3(endyr_period2+1,endyr_period3);
  vector selpar_age3_cR3(endyr_period2+1,endyr_period3);
  vector selpar_age4_cR3(endyr_period2+1,endyr_period3);

  init_bounded_vector sel_age0_cR4_logit(endyr_period3+1,endyr,-15,15,-3);  //in logit space
  init_bounded_vector sel_age1_cR4_logit(endyr_period3+1,endyr,-15,15,3);
  init_bounded_vector sel_age2_cR4_logit(endyr_period3+1,endyr,-15,15,-3);
  init_bounded_vector sel_age3_cR4_logit(endyr_period3+1,endyr,-15,15,-3);
  init_bounded_vector sel_age4_cR4_logit(endyr_period3+1,endyr,-15,15,-3);
  vector sel_age_cR4_vec(1,nages);
  vector selpar_age0_cR4(endyr_period3+1,endyr);
  vector selpar_age1_cR4(endyr_period3+1,endyr);
  vector selpar_age2_cR4(endyr_period3+1,endyr);
  vector selpar_age3_cR4(endyr_period3+1,endyr);
  vector selpar_age4_cR4(endyr_period3+1,endyr);

//Adult index from gillnet surveys-----------------------------------------
  matrix sel_gill(styr_gill_cpue,endyr_gill_cpue,1,nages);
  init_bounded_number selpar_slope_gill(0.5,20.0,-2); //period 1
  init_bounded_number selpar_L50_gill(0.0,4.0,-2);
  init_bounded_number selpar_slope2_gill(0.0,20.0,-3); //period 1
  init_bounded_number selpar_L502_gill(0.0,6.0,-3);

  init_bounded_number selpar_slope_gill2(0.5,10.0,-3); //period 2
  init_bounded_number selpar_L50_gill2(0.5,4.0,-3);
```

```
 init_bounded_number selpar_slope2_gill2(0.0,10.0,-4); //period 2
 init_bounded_number selpar_L502_gill2(0.0,6.0,-4);

 init_bounded_number sel_age0_gill_logit(-15,15,-3);  //in logit space
 init_bounded_number sel_age1_gill_logit(-15,15,3);
 init_bounded_number sel_age2_gill_logit(-15,15,-3);
 init_bounded_number sel_age3_gill_logit(-15,15,3);
 init_bounded_number sel_age4_gill_logit(-15,15,3);
 vector sel_age_gill_vec(1,nages);
 number selpar_age0_gill;
 number selpar_age1_gill;
 number selpar_age2_gill;
 number selpar_age3_gill;
 number selpar_age4_gill;

 //effort-weighted, recent selectivities
 vector sel_wgted_L(1,nages);  //toward landings
 vector sel_wgted_tot(1,nages);//toward Z

//-------CPUE Predictions--------------------------------
 vector obs_JAIs_cpue_final(styr_JAIs_cpue,endyr_JAIs_cpue);     //used to store cpue
        used in likelihood fit
 vector JAIs_cpue_cv_final(styr_JAIs_cpue,endyr_JAIs_cpue);
 vector pred_JAIs_cpue(styr_JAIs_cpue,endyr_JAIs_cpue);         //predicted JAI U for
        seine survey
 vector N_JAIs(styr_JAIs_cpue,endyr_JAIs_cpue);         //used to compute JAI index

 vector obs_JAIt_cpue_final(styr_JAIt_cpue,endyr_JAIt_cpue);     //used to store cpue
        used in likelihood fit
 vector JAIt_cpue_cv_final(styr_JAIt_cpue,endyr_JAIt_cpue);
 vector pred_JAIt_cpue(styr_JAIt_cpue,endyr_JAIt_cpue);         //predicted JAI U for
        trawl survey
 vector N_JAIt(styr_JAIt_cpue,endyr_JAIt_cpue);         //used to compute JAI index

 vector pred_gill_cpue(styr_gill_cpue,endyr_gill_cpue);         //predicted gillnet U
 matrix N_gill(styr_gill_lenc,endyr_gill_lenc,1,nages);         //used to compute gillnet index

//------Index exponent--------------------------------
 init_bounded_number JAI_exp(0.01,1.0,-3);

//------Index combination weights--------------------------------
 init_bounded_number wgt_JAI1(0.001,1.0,-3);
 init_bounded_number wgt_JAI2(0.001,1.0,-3);
 init_bounded_number wgt_JAI3(0.001,1.0,-3);
 init_bounded_number wgt_JAI4(0.001,1.0,-3);
 number JAI_wgt_sum_constraint;
```

```
////---Catchability (CPUE q's)-------------------------------------------------------
  init_bounded_number log_q_JAIs(-20,10,1);    //seine
  init_bounded_number log_q_JAIt(-20,-5,-1);    //trawl
  init_bounded_number log_q_gill(-20,10,1);    //gillnet
  init_bounded_number q_rate(0.001,0.1,set_q_rate_phase);
  //number q_rate;
  //vector q_rate_fcn_PN(styr_PN_cpue,endyr_PN_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

  //init_bounded_vector q_RW_log_dev_gill(styr_gill_cpue,endyr_gill_cpue-1,-3.0,3.0,set_q_RW_phase);
  //vector q_gill(styr_gill_cpue,endyr_gill_cpue);

//---Landings in numbers (total or 1000 fish) and in wgt (klb)------------------------------------------------
  matrix L_cR_num(styr,endyr,1,nages);            //landings (numbers) at age
  matrix L_cR_mt(styr,endyr,1,nages);            //landings (1000 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 1000 mt summed over ages
  matrix L_cR_num_agec(styr_cR_agec,endyr_cR_agec,1,nages);

  matrix L_total_num(styr,endyr,1,nages);               //total landings in number at age
  matrix L_total_mt(styr,endyr,1,nages);               //landings in 1000 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 (1000 mt) by yr summed over ages

////---Fmed calcs--------------------------------------------------------------------------
  number quant_decimal;
  number quant_diff;
  number quant_result;

  number R_med;                             //median recruitment for chosen benchmark years
  vector R_temp(styr_bench,endyr_bench);
  vector R_sort(styr_bench,endyr_bench);
  number SPR_med;                            //median SSB/R (R = SSB year+1) for chosen SSB years
```

```
  number SPR_75th;
  vector SPR_temp(styr_bench,endyr_bench);
  vector SPR_sort(styr_bench,endyr_bench);
  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;

////---MSY calcs---------------------------------------------------------------------------
  number F_cR_prop;      //proportion of F_sum attributable to reduction, last
          X=selpar_n_yrs_wgted yrs, used for avg body weights
  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 mature biomass) at msy
  number F_msy_out;            //F at msy
  number msy_mt_out;           //max sustainable yield (1000 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(1000 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 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);
  number SdSSB_msy_end;
  number FdF_msy_end;
  number FdF_msy_end_mean;        //geometric mean of last 3 years

  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)

////--------Mortality------------------------------------------------------------------
  vector M(1,nages);                     //age-dependent natural mortality
  number M_constant;                     //age-indpendent: used only for MSST
  matrix M_mat(styr,endyr,1,nages);
  vector wgted_M(1,nages);               //weighted M vector for last few years

  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
  matrix Z(styr,endyr,1,nages);

  vector E(styr,endyr);                  //Exploitation rate
  vector F_age2plus(styr,endyr);         //population weighted age 2+ F
  vector F_cR_age2plus(styr,endyr);      //population weighted age 2+ F

  init_bounded_number log_avg_F_cR(-10,5.0,1);
  init_bounded_dev_vector log_F_dev_cR(styr_cR_L,endyr_cR_L,-10.0,10.0,2);
  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;

  init_bounded_number F_init_ratio(0.05,1.5,-3);

//---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 F_spr_age2plus(1,n_iter_spr);  //values of F age2+ 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
  vector spr_F0(styr,endyr);         //Spawning biomass per recruit at F=0
  vector bpr_F0(styr,endyr);         //Biomass per recruit at F=0
  number wgted_spr_F0;

  number iter_inc_spr;               //increments used to compute msy, equals
        max_F_spr_msy/(n_iter_spr-1)


////-------Objective function components-----------------------------------------------------------------
        -----------
  number w_L;
  number w_ac;
  number w_I_JAIs;
  number w_I_JAIt;
  number w_I_gill;
  number w_I_gill_lc;
  number w_rec;
  number w_rec_early;
  number w_rec_end;
  number w_fullF;
  number w_Ftune;
  number w_JAI_wgts;

  number f_JAIs_cpue;
  number f_JAIt_cpue;
  number f_gill_cpue;

  number f_cR_L;
```

```
  number f_cR_agec;

  number f_gill_lenc;

  //number f_PN_RW_cpue; //random walk component of indices

  //Penalties and constraints. Not all are used.
  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_Ftune;                //penalty for tuning F in Ftune yr.  Not applied in final
         optimization phase.
  number f_fullF_constraint;     //penalty for Fapex>X
  number f_JAI_wgts;

  number f_priors;               //prior information on parameters

  objective_function_value fval;
  number fval_unwgt;

//--Dummy variables ----
  number denom;                  //denominator used in some calculations
  number numer;                  //numerator used in some calculations
  number numer1;
  number denom1;
  vector temp_agevec(1,nages);
  number dum1;

//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
INITIALIZATION_SECTION


//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
GLOBALS_SECTION
  #include "admodel.h"         // Include AD class definitions
  #include "admb2r.cpp"    // Include S-compatible output functions (needs preceding)

//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
RUNTIME_SECTION
 maximum_function_evaluations 1000, 4000,8000, 10000;
 convergence_criteria 1e-2, 1e-5,1e-6, 1e-7;

//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
```

```
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
PRELIMINARY_CALCS_SECTION

// Set values of fixed parameters or set initial guess of estimated parameters
  M=set_M;
  M_constant=set_M_constant;
  M_mat=set_M_mat;

  steep=set_steep;
  R_autocorr=set_R_autocorr;
  sr_beta_env=set_sr_beta_env;
  rec_sigma=set_rec_sigma;

  log_q_JAIs=set_logq_JAIs;
  log_q_JAIt=set_logq_JAIt;
  log_q_gill=set_logq_gill;

  JAI_exp=set_JAI_exp;

  wgt_JAI1=set_wgt_JAI1;
  wgt_JAI2=set_wgt_JAI2;
  wgt_JAI3=set_wgt_JAI3;
  wgt_JAI4=set_wgt_JAI4;

  q_rate=set_q_rate;
  //q_rate_fcn_PN=1.0;
  q_DD_beta=set_q_DD_beta;
  q_DD_fcn=1.0;
  //q_RW_log_dev_gill.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_cL(iyear)=(1.0+q_rate)*q_rate_fcn_cL(iyear-1); //compound
  //            q_rate_fcn_PN(iyear)=(1.0+(iyear-
            styr_PN_cpue)*q_rate)*q_rate_fcn_PN(styr_PN_cpue);  //linear
  //        }
  //        if (iyear>2003) {q_rate_fcn_PN(iyear)=q_rate_fcn_PN(iyear-1);}
  //    }
  //} //end q_rate conditional

  w_L=set_w_L;
  w_ac=set_w_ac;
  w_I_JAIs=set_w_I_JAIs;
  w_I_JAIt=set_w_I_JAIt;
```

```
w_I_gill=set_w_I_gill;
w_I_gill_lc=set_w_gill_lenc;
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_JAI_wgts=set_w_JAI_wgts;

log_avg_F_cR=set_log_avg_F_cR;
F_init_ratio=set_F_init_ratio;

log_R0=set_log_R0;

length_age=set_length_age;
len_cv=set_len_cv;
Linf=set_Linf;
K=set_K;
t0=set_t0;

selpar_L50_cR1=set_selpar_L50_cR;
selpar_slope_cR1=set_selpar_slope_cR;
selpar_L502_cR1=set_selpar_L502_cR;
selpar_slope2_cR1=set_selpar_slope2_cR;

//selpar_L50_cR2=set_selpar_L50_cR;
//selpar_slope_cR2=set_selpar_slope_cR;
//selpar_L502_cR2=set_selpar_L502_cR;
//selpar_slope2_cR2=set_selpar_slope2_cR;

selpar_L50_cR3=set_selpar_L50_cR;
selpar_slope_cR3=set_selpar_slope_cR;
selpar_L502_cR3=set_selpar_L502_cR;
selpar_slope2_cR3=set_selpar_slope2_cR;

selpar_L50_cR4=set_selpar_L50_cR;
selpar_slope_cR4=set_selpar_slope_cR;
selpar_L502_cR4=set_selpar_L502_cR;
selpar_slope2_cR4=set_selpar_slope2_cR;

selpar_L50_gill=set_selpar_L50_gill;
selpar_slope_gill=set_selpar_slope_gill;
selpar_L502_gill=set_selpar_L502_gill;
selpar_slope2_gill=set_selpar_slope2_gill;

selpar_L50_gill2=set_selpar_L50_gill;
```

```
 selpar_slope_gill2=set_selpar_slope_gill;
 selpar_L502_gill2=set_selpar_L502_gill;
 selpar_slope2_gill2=set_selpar_slope2_gill;

 sel_age0_gill_logit=set_sel_age0_gill;
 sel_age1_gill_logit=set_sel_age1_gill;
 sel_age2_gill_logit=set_sel_age2_gill;
 sel_age3_gill_logit=set_sel_age3_gill;
 sel_age4_gill_logit=set_sel_age4_gill;

 for (iyear=styr; iyear<=endyr_period2; iyear++)
   {
    sel_age0_cR1_logit(iyear)=set_sel_age0_cR1;
    sel_age1_cR1_logit(iyear)=set_sel_age1_cR1;
    sel_age2_cR1_logit(iyear)=set_sel_age2_cR1;
    sel_age3_cR1_logit(iyear)=set_sel_age3_cR1;
    sel_age4_cR1_logit(iyear)=set_sel_age4_cR1;
   }
 for (iyear=endyr_period2+1; iyear<=endyr_period3; iyear++)
   {
    sel_age0_cR3_logit(iyear)=set_sel_age0_cR3;
    sel_age1_cR3_logit(iyear)=set_sel_age1_cR3;
    sel_age2_cR3_logit(iyear)=set_sel_age2_cR3;
    sel_age3_cR3_logit(iyear)=set_sel_age3_cR3;
    sel_age4_cR3_logit(iyear)=set_sel_age4_cR3;
   }
 for (iyear=endyr_period3+1; iyear<=endyr; iyear++)
   {
    sel_age0_cR4_logit(iyear)=set_sel_age0_cR4;
    sel_age1_cR4_logit(iyear)=set_sel_age1_cR4;
    sel_age2_cR4_logit(iyear)=set_sel_age2_cR4;
    sel_age3_cR4_logit(iyear)=set_sel_age3_cR4;
    sel_age4_cR4_logit(iyear)=set_sel_age4_cR4;
   }

sqrt2pi=sqrt(2.*3.14159265);
//g2mt=0.000001;        //conversion of grams to metric tons
g2mt=1.0;
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;        //additive constant to prevent division by zero
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;
 maturity_m=maturity_m_obs;
 prop_f=prop_f_obs;

//Fill in sample sizes of comps sampled in nonconsec yrs.
//Used primarily for output in R object

      nsamp_cR_agec_allyr=missing;

      neff_cR_agec_allyr=missing;

      for (iyear=styr_cR_agec; iyear<=endyr_cR_agec; iyear++)
        {
         if (nsamp_cR_agec(iyear)>=minSS_cR_agec)
         {
           nsamp_cR_agec_allyr(iyear)=nsamp_cR_agec(iyear);
           neff_cR_agec_allyr(iyear)=neff_cR_agec(iyear);
         }
        }

      //cout << "nsamp_cR_agec" << nsamp_cR_agec_allyr << endl;

      nsamp_gill_lenc_allyr=missing;

      neff_gill_lenc_allyr=missing;

      for (iyear=styr_gill_lenc; iyear<=endyr_gill_lenc; iyear++)
        {
         if (nsamp_gill_lenc(iyear)>=minSS_gill_lenc)
         {
           nsamp_gill_lenc_allyr(iyear)=nsamp_gill_lenc(iyear);
           neff_gill_lenc_allyr(iyear)=neff_gill_lenc(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();

  L_total_knum_yr.initialize();
  L_total_mt_yr.initialize();

  log_rec_dev_output.initialize();
  log_Nage_dev_output.initialize();
  log_rec_dev.initialize();
  log_Nage_dev.initialize();


//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
TOP_OF_MAIN_SECTION
  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(500);


//>--><>--><>--><>--><>
//##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
PROCEDURE_SECTION

 R0=mfexp(log_R0);

 //cout<<"start"<<endl;
 get_weight_at_age();
 //cout << "got weight at age" << endl;
 get_reprod();
 //cout << "got reprod" << endl;
 get_length_at_age_dist();
 //cout << "got 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;
 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_weight_at_age
  //compute mean length (mm) and weight (whole) at age
    length_age=Linf*(1.0-mfexp(-K*(agebins-t0+0.5)));
    wgt_fish_kg=g2kg*wgt_fish_g;     //wgt in kilograms
    wgt_fish_mt=g2mt*wgt_fish_g;     //mt of whole wgt: g2mt converts g to mt
    wgt_spawn_kg=g2kg*wgt_spawn_g;   //wgt in kilograms
    wgt_spawn_mt=g2mt*wgt_spawn_g;   //mt of whole wgt: g2mt converts g to mt

FUNCTION get_reprod

  //product of stuff going into reproductive capacity calcs
  for (iyear=styr; iyear<=endyr; iyear++)
  {
    //reprod(iyear)=elem_prod((elem_prod(prop_f,maturity_f)+elem_prod((1.0-
          prop_f),maturity_m)),wgt_spawn_mt(iyear));
    //reprod(iyear)=elem_prod((elem_prod(prop_f,maturity_f)+elem_prod((1.0-
          prop_f),maturity_m)),fec_eggs(iyear));
    reprod(iyear)=elem_prod(elem_prod(prop_f,maturity_f),fec_eggs(iyear));
  }

  //compute average natural mortality
  wgted_M=M_mat(endyr)*0.0;
```

```
 for(iyear=(endyr-selpar_n_yrs_wgted+1); iyear<=endyr; iyear++)
 {
  wgted_M+=M_mat(iyear);
 }
 wgted_M=wgted_M/selpar_n_yrs_wgted;

 //average reprod for last few years for eq calculations
 wgted_reprod=reprod(endyr)*0.0;
 for(iyear=(endyr-selpar_n_yrs_wgted+1); iyear<=endyr; iyear++)
 {
  wgted_reprod+=reprod(iyear);
 }
 wgted_reprod=wgted_reprod/selpar_n_yrs_wgted;


FUNCTION get_length_at_age_dist
 //compute matrix of length at age, based on the normal distribution
 for (iage=1;iage<=nages;iage++)
 {
  for (ilen=1;ilen<=nlenbins;ilen++)
  {
   lenprob(iage,ilen)=(mfexp(-(square(lenbins(ilen)-length_age(iage))/
   (2.*square(len_cv(iage)*length_age(iage)))))/(sqrt2pi*len_cv(iage)*length_age(iage)));
  }
  for (ilen=1;ilen<=nlenplus;ilen++)
  {
   lenprob_plus(iage,ilen)=(mfexp(-(square(lenplusbins(ilen)-length_age(iage))/
   (2.*square(len_cv(iage)*length_age(iage)))))/(sqrt2pi*len_cv(iage)*length_age(iage)));
  }

  lenprob(iage)(nlenbins)=lenprob(iage)(nlenbins)+sum(lenprob_plus(iage)); //add mass to plus group
  lenprob(iage)/=sum(lenprob(iage)); //standardize to approximate integration and to account for truncated normal (i.e., no sizes<smallest)
 }

 //cout << "lenprob" << lenprob << endl;


FUNCTION get_weight_at_age_landings

 wgt_cR_mt=wgt_fish_mt;

FUNCTION get_spr_F0

 for (iyear=styr; iyear<=endyr; iyear++)
```

```
 {
  //at mdyr, apply half this yr's mortality, half next yr's
  N_spr_F0(1)=1.0*mfexp(-1.0*M_mat(iyear,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)));
   dum1=M_mat(iyear,iage-1)*(1.0-spawn_time_frac) +
      M_mat(iyear,iage)*spawn_time_frac;
   N_spr_F0(iage)=N_spr_F0(iage-1)*mfexp(-1.0*(dum1));
   N_bpr_F0(iage)=N_bpr_F0(iage-1)*mfexp(-1.0*(M_mat(iyear,iage-1)));
  }
  N_spr_F0(nages)=N_spr_F0(nages)/(1.0-mfexp(-1.0*M_mat(iyear,nages))); //plus group
      (sum of geometric series)
  N_bpr_F0(nages)=N_bpr_F0(nages)/(1.0-mfexp(-1.0*M_mat(iyear,nages)));

  spr_F0(iyear)=sum(elem_prod(N_spr_F0,reprod(iyear)));
  bpr_F0(iyear)=sum(elem_prod(N_bpr_F0,wgt_spawn_mt(iyear)));
 }

 N_spr_F0(1)=1.0*mfexp(-1.0*wgted_M(1)*spawn_time_frac); //at peak spawning time
 for (iage=2; iage<=nages; iage++)
 {
  dum1=wgted_M(iage-1)*(1.0-spawn_time_frac) + wgted_M(iage)*spawn_time_frac;
  N_spr_F0(iage)=N_spr_F0(iage-1)*mfexp(-1.0*(dum1));
 }
 N_spr_F0(nages)=N_spr_F0(nages)/(1.0-mfexp(-1.0*wgted_M(nages))); //plus group (sum
      of geometric series
 wgted_spr_F0=sum(elem_prod(N_spr_F0,wgted_reprod));

FUNCTION get_selectivity

//// ------- compute landings selectivities by period

 //gillnet survey selectivity
 selpar_age0_gill=1.0/(1.0+mfexp(-sel_age0_gill_logit));
 selpar_age1_gill=1.0/(1.0+mfexp(-sel_age1_gill_logit));
 selpar_age2_gill=1.0/(1.0+mfexp(-sel_age2_gill_logit));
 selpar_age3_gill=1.0/(1.0+mfexp(-sel_age3_gill_logit));
 selpar_age4_gill=1.0/(1.0+mfexp(-sel_age4_gill_logit));
 sel_age_gill_vec(1)=selpar_age0_gill;
 sel_age_gill_vec(2)=selpar_age1_gill;
 sel_age_gill_vec(3)=selpar_age2_gill;
 sel_age_gill_vec(4)=selpar_age3_gill;
 sel_age_gill_vec(5)=selpar_age4_gill;
```

```
//sel_age_gill_vec=sel_age_gill_vec/max(sel_age_gill_vec); //to scale to one
for (iyear=styr_gill_cpue; iyear<=endyr_period1_gill; iyear++)
//for (iyear=styr_gill_cpue; iyear<=endyr_gill_cpue; iyear++)
{  //time-invariant selectivities
  //sel_gill(iyear)=logistic(agebins, selpar_L50_gill, selpar_slope_gill);

       //sel_gill(iyear)=logistic_double(agebins,selpar_L50_gill,selpar_slope_gill,selpar_L5
       02_gill,selpar_slope2_gill);
  sel_gill(iyear)=sel_age_gill_vec;
}

//cout << "end_yrp1" << endyr_period1 << endl;

for (iyear=endyr_period1_gill+1; iyear<=endyr_gill_cpue; iyear++)
{  //time-invariant selectivities
  sel_gill(iyear)=sel_gill(styr_gill_cpue);
  //sel_gill(iyear)=logistic(agebins, selpar_L50_gill2, selpar_slope_gill2);

       //sel_gill(iyear)=logistic_double(agebins,selpar_L50_gill2,selpar_slope_gill2,selpar_
       L502_gill2,selpar_slope2_gill2);
}


//commercial reduction selectivity
//Period 1:
for (iyear=styr; iyear<=endyr_period2; iyear++)
 {
  if (iyear>endyr_period1) {selpar_age0_cR1(iyear)=1.0/(1.0+mfexp(-
       sel_age0_cR1_logit(iyear)));
   selpar_age1_cR1(iyear)=1.0/(1.0+mfexp(-sel_age1_cR1_logit(iyear)));
   selpar_age2_cR1(iyear)=1.0/(1.0+mfexp(-sel_age2_cR1_logit(iyear)));
   selpar_age3_cR1(iyear)=1.0/(1.0+mfexp(-sel_age3_cR1_logit(iyear)));
   selpar_age4_cR1(iyear)=1.0/(1.0+mfexp(-sel_age4_cR1_logit(iyear)));
   sel_age_cR1_vec(1)=selpar_age0_cR1(iyear);
   sel_age_cR1_vec(2)=selpar_age1_cR1(iyear);
   sel_age_cR1_vec(3)=selpar_age2_cR1(iyear);
   sel_age_cR1_vec(4)=selpar_age3_cR1(iyear);
   sel_age_cR1_vec(5)=selpar_age4_cR1(iyear);}
  else {selpar_age0_cR1(iyear)=1.0/(1.0+
      (mfexp(-sel_age0_cR1_logit(endyr_period1+1))+
       mfexp(-sel_age0_cR1_logit(endyr_period1+2))+
       mfexp(-sel_age0_cR1_logit(endyr_period1+3)))/3);
   selpar_age1_cR1(iyear)=1.0/(1.0+
      (mfexp(-sel_age1_cR1_logit(endyr_period1+1))+
       mfexp(-sel_age1_cR1_logit(endyr_period1+2))+
       mfexp(-sel_age1_cR1_logit(endyr_period1+3)))/3);
```

```
   selpar_age2_cR1(iyear)=1.0/(1.0+
      (mfexp(-sel_age2_cR1_logit(endyr_period1+1))+
       mfexp(-sel_age2_cR1_logit(endyr_period1+2))+
       mfexp(-sel_age2_cR1_logit(endyr_period1+3)))/3);
   selpar_age3_cR1(iyear)=1.0/(1.0+
      (mfexp(-sel_age3_cR1_logit(endyr_period1+1))+
       mfexp(-sel_age3_cR1_logit(endyr_period1+2))+
       mfexp(-sel_age3_cR1_logit(endyr_period1+3)))/3);
   selpar_age4_cR1(iyear)=1.0/(1.0+
      (mfexp(-sel_age4_cR1_logit(endyr_period1+1))+
       mfexp(-sel_age4_cR1_logit(endyr_period1+2))+
       mfexp(-sel_age4_cR1_logit(endyr_period1+3)))/3);
   sel_age_cR1_vec(1)=selpar_age0_cR1(iyear);
   sel_age_cR1_vec(2)=selpar_age1_cR1(iyear);
   sel_age_cR1_vec(3)=selpar_age2_cR1(iyear);
   sel_age_cR1_vec(4)=selpar_age3_cR1(iyear);
   sel_age_cR1_vec(5)=selpar_age4_cR1(iyear);}
  //sel_age_cR1_vec=sel_age_cR1_vec/max(sel_age_cR1_vec);
  //sel_age_cR1_vec=sel_age_cR1_vec/max(sel_age_cR1_vec); //to scale to one
  //sel_cR(iyear)=logistic(agebins,selpar_L50_cR1,selpar_slope_cR1);

        //sel_cR(iyear)=logistic_double(agebins,selpar_L50_cR1,selpar_slope_cR1,selpar_L
        502_cR1,selpar_slope2_cR1);
  sel_cR(iyear)=sel_age_cR1_vec;
}

//Period 2:
//for (iyear=endyr_period1+1; iyear<=endyr_period2; iyear++)
//{
//   sel_cR(iyear)=sel_cR(styr);
//}

//Period 3
for (iyear=endyr_period2+1; iyear<=endyr_period3; iyear++)
 {
  selpar_age0_cR3(iyear)=1.0/(1.0+mfexp(-sel_age0_cR3_logit(iyear)));
  selpar_age1_cR3(iyear)=1.0/(1.0+mfexp(-sel_age1_cR3_logit(iyear)));
  selpar_age2_cR3(iyear)=1.0/(1.0+mfexp(-sel_age2_cR3_logit(iyear)));
  selpar_age3_cR3(iyear)=1.0/(1.0+mfexp(-sel_age3_cR3_logit(iyear)));
  selpar_age4_cR3(iyear)=1.0/(1.0+mfexp(-sel_age4_cR3_logit(iyear)));
  sel_age_cR3_vec(1)=selpar_age0_cR3(iyear);
  sel_age_cR3_vec(2)=selpar_age1_cR3(iyear);
  sel_age_cR3_vec(3)=selpar_age2_cR3(iyear);
  sel_age_cR3_vec(4)=selpar_age3_cR3(iyear);
  sel_age_cR3_vec(5)=selpar_age4_cR3(iyear);
  //sel_age_cR3_vec=sel_age_cR3_vec/max(sel_age_cR3_vec); //to scale to one
```

```
   //sel_cR(iyear)=sel_cR(styr);
   //sel_cR(iyear)=logistic(agebins,selpar_L50_cR3,selpar_slope_cR3);

        //sel_cR(iyear)=logistic_double(agebins,selpar_L50_cR3,selpar_slope_cR3,selpar_L
        502_cR3,selpar_slope2_cR3);
   sel_cR(iyear)=sel_age_cR3_vec;
 }

 //Period 4
 for (iyear=endyr_period3+1; iyear<=endyr; iyear++)
  {
   selpar_age0_cR4(iyear)=1.0/(1.0+mfexp(-sel_age0_cR4_logit(iyear)));
   selpar_age1_cR4(iyear)=1.0/(1.0+mfexp(-sel_age1_cR4_logit(iyear)));
   selpar_age2_cR4(iyear)=1.0/(1.0+mfexp(-sel_age2_cR4_logit(iyear)));
   selpar_age3_cR4(iyear)=1.0/(1.0+mfexp(-sel_age3_cR4_logit(iyear)));
   selpar_age4_cR4(iyear)=1.0/(1.0+mfexp(-sel_age4_cR4_logit(iyear)));
   sel_age_cR4_vec(1)=selpar_age0_cR4(iyear);
   sel_age_cR4_vec(2)=selpar_age1_cR4(iyear);
   sel_age_cR4_vec(3)=selpar_age2_cR4(iyear);
   sel_age_cR4_vec(4)=selpar_age3_cR4(iyear);
   sel_age_cR4_vec(5)=selpar_age4_cR4(iyear);
   //sel_age_cR4_vec=sel_age_cR4_vec/max(sel_age_cR4_vec); //to scale to one
    //sel_cR(iyear)=logistic(agebins, selpar_L50_cR4,selpar_slope_cR4);

        //sel_cR(iyear)=logistic_double(agebins,selpar_L50_cR4,selpar_slope_cR4,selpar_L
        502_cR4,selpar_slope2_cR4);
   //sel_cR(iyear)=sel_cR(styr);
   sel_cR(iyear)=sel_age_cR4_vec;
 }

FUNCTION get_mortality
 Fsum.initialize();
 Fapex.initialize();
 F.initialize();
 ////initialization F is avg of 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));}
   if (iyear<styr_cR_L)
     {F_cR_out(iyear)=mfexp(log_avg_F_cR+log_F_dev_init_cR);}
   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_mat(iyear)+F(iyear);
  }  //end iyear

FUNCTION get_bias_corr
  //may exclude last BiasCor_exclude_yrs yrs bc constrained or lack info to estimate
  //var_rec_dev=norm2(log_rec_dev(styr_rec_dev,(endyr-BiasCor_exclude_yrs))-
  //          sum(log_rec_dev(styr_rec_dev,(endyr-BiasCor_exclude_yrs)))
  //          /(nyrs_rec-BiasCor_exclude_yrs))/(nyrs_rec-BiasCor_exclude_yrs-1.0);
  var_rec_dev=norm2(log_rec_dev(styr_rec_dev,endyr_rec_phase2)-
            sum(log_rec_dev(styr_rec_dev,endyr_rec_phase2))
            /(nyrs_rec-(endyr_rec_phase2-styr_rec_dev)))/(nyrs_rec-(endyr_rec_phase2-
          styr_rec_dev)-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(styr)*R0;

  if(set_SR_switch>1) //Beverton-Holt
  {
   R_virgin=(R0/((5.0*steep-1.0)*spr_F0(styr)))*
             (BiasCor*4.0*steep*spr_F0(styr)-spr_F0(styr)*(1.0-steep));
  }
  if(set_SR_switch<2) //Ricker
  {
   R_virgin=R0/spr_F0(styr)*(1+log(BiasCor*spr_F0(styr))/steep);
  }

  B0=bpr_F0(styr)*R_virgin;
  //temp_agevec=wgt_fish_mt(styr);

          //B0_q_DD=R_virgin*sum(elem_prod(N_bpr_F0(set_q_DD_stage,nages),temp_agev
          ec(set_q_DD_stage,nages)));

  F_initial=sel_cR(styr)*mfexp(log_avg_F_cR+log_F_dev_init_cR);
  Z_initial=M+F_init_ratio*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(styr)));

//with environmental factor
  if(switch_env_sr=1)
  {
  if(set_SR_switch>1) //Beverton-Holt
  {
    if (styr=styr_rec_dev) {R1=((R0/((5.0*steep-1.0)*spr_initial))*
              (4.0*steep*spr_initial-spr_F0(styr)*(1.0-steep)))
              *mfexp(sr_beta_env*env_fac(styr));} //without bias correction (deviation added
          later)
    else {R1=((R0/((5.0*steep-1.0)*spr_initial))*
              (BiasCor*4.0*steep*spr_initial-spr_F0(styr)*(1.0-steep)))
              *mfexp(sr_beta_env*env_fac(styr));} //with bias correction
  }
  if(set_SR_switch<2) //Ricker
  {
    if (styr=styr_rec_dev) {R1=(R0/spr_initial*(1+log(spr_initial/steep)))
                         *mfexp(sr_beta_env*env_fac(styr));} //without bias correction (deviation
          added later)
    else {R1=(R0/spr_initial*(1+log(BiasCor*spr_initial)/steep))
             *mfexp(sr_beta_env*env_fac(styr));} //with bias correction
  }
  }

//without environmental factor
 if(switch_env_sr=2)
 {
 if(set_SR_switch>1) //Beverton-Holt
  {
    if (styr=styr_rec_dev) {R1=(R0/((5.0*steep-1.0)*spr_initial))*
              (4.0*steep*spr_initial-spr_F0(styr)*(1.0-steep));} //without bias correction
          (deviation added later)
    else {R1=(R0/((5.0*steep-1.0)*spr_initial))*
              (BiasCor*4.0*steep*spr_initial-spr_F0(styr)*(1.0-steep));} //with bias correction
```

```
 }
 if(set_SR_switch<2) //Ricker
 {
  if (styr=styr_rec_dev) {R1=R0/spr_initial*(1+log(spr_initial/steep));} //without bias
        correction (deviation added later)
  else {R1=R0/spr_initial*(1+log(BiasCor*spr_initial)/steep);} //with bias correction
 }
}

 if(R1<0.0) {R1=10.0;} //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)*(1.0-spawn_time_frac) +
        Z_initial(iage)*spawn_time_frac));
 }
 //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_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(styr)));
 temp_agevec=wgt_fish_mt(styr);

        B_q_DD(styr)=sum(elem_prod(N(styr)(set_q_DD_stage,nages),temp_agevec(set_q_
        DD_stage,nages)));

//Rest of years
 for (iyear=styr; iyear<endyr; iyear++)
 {
  if(iyear<(styr_rec_dev-1)) //recruitment follows S-R curve exactly
  {
    N(iyear+1,1)=0.0;
```

```
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))); //mid year
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(iyear+1)));
temp_agevec=wgt_fish_mt(iyear+1);

   B_q_DD(iyear+1)=sum(elem_prod(N(iyear+1)(set_q_DD_stage,nages),temp_agevec(
   set_q_DD_stage,nages)));
//add dzero to avoid log(zero)
//with environmental factor
if(switch_env_sr=1)
{
if(set_SR_switch>1) //Beverton-Holt
{

   N(iyear+1,1)=(BiasCor*mfexp(log(((0.8*R0*steep*SSB(iyear+1))/(0.2*R0*spr_F0(iy
   ear+1)*
   (1.0-steep)+(steep-0.2)*SSB(iyear+1)))+dzero)))
   *mfexp(sr_beta_env*env_fac(iyear+1)); //Vaughan et al 2011
}
if(set_SR_switch<2) //Ricker
{
  N(iyear+1,1)=(mfexp(log(BiasCor*SSB(iyear+1)/spr_F0(iyear)*mfexp(steep*(1-
   SSB(iyear+1)/(R0*spr_F0(iyear+1)))))+dzero)))
            *mfexp(sr_beta_env*env_fac(iyear+1));
}
}
//without environmenal factor
if(switch_env_sr=2)
{
if(set_SR_switch>1) //Beverton-Holt
{

   N(iyear+1,1)=BiasCor*mfexp(log(((0.8*R0*steep*SSB(iyear+1))/(0.2*R0*spr_F0(iy
   ear+1)*
   (1.0-steep)+(steep-0.2)*SSB(iyear+1)))+dzero));
}
if(set_SR_switch<2) //Ricker
{
  N(iyear+1,1)=mfexp(log(BiasCor*SSB(iyear+1)/spr_F0(iyear+1)*mfexp(steep*(1-
   SSB(iyear+1)/(R0*spr_F0(iyear+1))))+dzero));
}
```

```
   }
}
else   //recruitment follows S-R curve with lognormal deviation
{
   N(iyear+1,1)=0.0;
   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))); //mid year
   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(iyear+1)));
   temp_agevec=wgt_fish_mt(iyear+1);

      B_q_DD(iyear+1)=sum(elem_prod(N(iyear+1)(set_q_DD_stage,nages),temp_agevec(
      set_q_DD_stage,nages)));
   //add dzero to avoid log(zero)
   //with environmental factor
   if(switch_env_sr=1)
   {
   if(set_SR_switch>1) //Beverton-Holt
   {
    N(iyear+1,1)=(mfexp(log(((0.8*R0*steep*SSB(iyear+1))/(0.2*R0*spr_F0(iyear+1)*
      (1.0-steep)+(steep-
      0.2)*SSB(iyear+1)))+dzero)+log_rec_dev(iyear+1)))*mfexp(sr_beta_env*env_fac(iye
      ar+1));
   }
   if(set_SR_switch<2) //Ricker
   {
    N(iyear+1,1)=(mfexp(log(SSB(iyear+1)/spr_F0(iyear+1)*mfexp(steep*(1-
      SSB(iyear+1)/(R0*spr_F0(iyear+1))))+dzero)+log_rec_dev(iyear+1)))
                *mfexp(sr_beta_env*env_fac(iyear+1));
   }
   }
   //without environmental factor
   if(switch_env_sr=2)
   {
   if(set_SR_switch>1) //Beverton-Holt
   {
    N(iyear+1,1)=mfexp(log(((0.8*R0*steep*SSB(iyear+1))/(0.2*R0*spr_F0(iyear+1)*
      (1.0-steep)+(steep-0.2)*SSB(iyear+1)))+dzero)+log_rec_dev(iyear+1));
   }
   if(set_SR_switch<2) //Ricker
   {
```

```
     N(iyear+1,1)=mfexp(log(SSB(iyear+1)/spr_F0(iyear+1)*mfexp(steep*(1-
      SSB(iyear+1)/(R0*spr_F0(iyear+1))))+dzero)+log_rec_dev(iyear+1));
    }
    }
    }
 }
 //cout << "N" << N << endl;
 //cout << "R0" << R0 << endl;

  //last year (projection) has no recruitment variability
  //N(endyr+1,1)=0.0;
  //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
  //if(set_SR_switch>1) //Beverton-Holt
 // {
  //  N(endyr+1,1)=mfexp(log(((0.8*R0*steep*SSB(endyr))/(0.2*R0*spr_F0(endyr)*
  //          (1.0-steep)+(steep-0.2)*SSB(endyr)))+dzero));
  //}
  ///if(set_SR_switch<2) //Ricker
  //{
  //  N(endyr+1,1)=mfexp(log(SSB(endyr+1)/spr_F0(endyr)*mfexp(steep*(1-
      SSB(endyr+1)/(R0*spr_F0(endyr))))+dzero));
  //}

//Time series of interest
 rec=column(N,1);

 SdS0=SSB/S0; //trillions of eggs/eggs
  //cout << "SDS0" << SdS0 << endl;
 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));
```

```
  }


FUNCTION get_landings_wgt

////---Predicted landings------------------------
  for (iyear=styr; iyear<=endyr; iyear++)
  {
    L_cR_mt(iyear)=elem_prod(L_cR_num(iyear),wgt_cR_mt(iyear)); //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_PN_cpue; iyear<=endyr_PN_cpue; iyear++)
 //     {   if (iyear>styr_PN_cpue & iyear <=2003)
 //         {//q_rate_fcn_cL(iyear)=(1.0+q_rate)*q_rate_fcn_cL(iyear-1); //compound
 //            q_rate_fcn_PN(iyear)=(1.0+(iyear-
           styr_PN_cpue)*q_rate)*q_rate_fcn_PN(styr_PN_cpue);  //linear
 //         }
 //         if (iyear>2003) {q_rate_fcn_PN(iyear)=q_rate_fcn_PN(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------------------------
 //combined JAI index
  if(JAI_cpue_switch==1)
  {
    obs_JAIs_cpue_final=pow(obs_JAIs_cpue,JAI_exp);
    JAIs_cpue_cv_final=JAIs_cpue_cv;
    obs_JAIt_cpue_final=pow(obs_JAIt_cpue,JAI_exp);
    JAIt_cpue_cv_final=JAIt_cpue_cv;
  }
```

```
 else
 {

        obs_JAIs_cpue_final=(obs_JAI1_cpue*wgt_JAI1+obs_JAI2_cpue*wgt_JAI2+obs_J
        AI3_cpue*wgt_JAI3+obs_JAI4_cpue*wgt_JAI4)
               /(wgt_JAI1+wgt_JAI2+wgt_JAI3+wgt_JAI4);
   obs_JAIs_cpue_final=pow(obs_JAIs_cpue_final,JAI_exp);

        JAIs_cpue_cv_final=(JAI1_cpue_cv*wgt_JAI1+JAI2_cpue_cv*wgt_JAI2+JAI3_cp
        ue_cv*wgt_JAI3+JAI4_cpue_cv*wgt_JAI4)
               /(wgt_JAI1+wgt_JAI2+wgt_JAI3+wgt_JAI4);
 }

//JAI seine  survey
 for (iyear=styr_JAIs_cpue; iyear<=endyr_JAIs_cpue; iyear++)
 {   //index in number units
    N_JAIs(iyear)=N(iyear,1);
    pred_JAIs_cpue(iyear)=mfexp(log_q_JAIs)*N_JAIs(iyear);
 }

//JAI trawl  survey
 for (iyear=styr_JAIt_cpue; iyear<=endyr_JAIt_cpue; iyear++)
 {   //index in number units
    N_JAIt(iyear)=N(iyear,1);
    pred_JAIt_cpue(iyear)=mfexp(log_q_JAIt)*N_JAIt(iyear);
 }

//Gillnet adult index
 for (iyear=styr_gill_cpue; iyear<=endyr_gill_cpue; iyear++)
 {   //index in number units
    N_gill(iyear)=elem_prod(N_mdyr(iyear),sel_gill(iyear));
    pred_gill_cpue(iyear)=mfexp(log_q_gill)*sum(N_gill(iyear));
 }

FUNCTION get_length_comps
//Fishery independent

 //cout << "N_gill" << N_gill << endl;
 //cout << "lenprob" << lenprob << endl;
 //cout << "pred_gill_lenc" << pred_gill_lenc << endl;

 for (iyear=styr_gill_lenc;iyear<=endyr_gill_lenc;iyear++)
 {
   pred_gill_lenc(iyear)=(N_gill(iyear)*lenprob)/sum(N_gill(iyear));
 }
// cout << "pred_gill_lenc" << pred_gill_lenc << endl;
```

```
FUNCTION get_age_comps

  //cout << "L_cR_num" << L_cR_num << endl;
  //cout << "yrs" << yrs_cR_agec << endl;

  for (iyear=styr_cR_agec;iyear<=endyr_cR_agec;iyear++)
  {
    L_cR_num_agec(iyear)=L_cR_num(iyear);
  }
  //cout << "L_cR_AGEC" << L_cR_num_agec << endl;

  //Commercial reduction
  for (iyear=styr_cR_agec;iyear<=endyr_cR_agec;iyear++)
  {
    ErrorFree_cR_agec(iyear)=L_cR_num_agec(iyear)/
                      sum(L_cR_num_agec(iyear));
    pred_cR_agec(iyear)=age_error*ErrorFree_cR_agec(iyear);
  }
  //cout << "FINISHED" << endl;

////----------------------------------------------------------------------------------------------------------------
           -----------------------------------------------------------------------------
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*wgt_cR_mt(endyr);
```

```
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=wgted_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,wgted_reprod));


    //Compute equilibrium values of R (including bias correction), SSB and Yield at each F
    if(set_SR_switch>1) //Beverton-Holt
    {
      R_eq(ff)=(R0/((5.0*steep-1.0)*spr_msy(ff)))*
             (BiasCor*4.0*steep*spr_msy(ff)-wgted_spr_F0*(1.0-steep));
    }
    if(set_SR_switch<2) //Ricker
    {
      R_eq(ff)=R0/spr_msy(ff)*(1+log(BiasCor*spr_msy(ff))/steep);
    }
    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,wgted_reprod));
    B_eq(ff)=sum(elem_prod(N_age_msy,wgt_spawn_mt(endyr)));
    L_eq_mt(ff)=sum(elem_prod(L_age_msy,wgt_wgted_L_mt));
    L_eq_knum(ff)=sum(L_age_msy);
  }

  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

  sigma_rec_dev=sqrt(var_rec_dev+dzero); //pow(var_rec_dev,0.5);  //sample SD of
            predicted residuals (may not equal rec_sigma)

  //compute total landings- and discards-at-age in 1000 fish and klb
  L_total_num.initialize();
  L_total_mt.initialize();

  L_total_num=L_cR_num; //catch in number fish
  L_total_mt=L_cR_mt;   //landings in klb whole weight

  for(iyear=styr; iyear<=endyr; iyear++)
  {
        L_total_mt_yr(iyear)=sum(L_total_mt(iyear));
        L_total_knum_yr(iyear)=sum(L_total_num(iyear));

        B(iyear)=elem_prod(N(iyear),wgt_spawn_mt(iyear));
        totN(iyear)=sum(N(iyear));
        totB(iyear)=sum(B(iyear));
```

```
 }
 //B(endyr+1)=elem_prod(N(endyr+1),wgt_spawn_mt(endyr));
 //totN(endyr+1)=sum(N(endyr+1));
 //totB(endyr+1)=sum(B(endyr+1));

//  steep_sd=steep;
//  fullF_sd=Fsum;

 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; 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);
 }

 //Compute the exploitation rate for ages 1+ and pop wgtd F for ages 2+
  for(iyear=styr; iyear<=endyr; iyear++)
  {
   E(iyear)=sum(L_cR_num(iyear)(2,nages))/sum(N(iyear)(2,nages));
   F_age2plus(iyear)=((F_cR(iyear)(3,nages))*N(iyear)(3,nages))/sum(N(iyear)(3,nages));

   F_cR_age2plus(iyear)=(F_cR(iyear)(3,nages)*N(iyear)(3,nages))/sum(N(iyear)(3,nages));
  }


//--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------
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(iyear)))/spr_F0(iyear);
}


cout << "sel_wgted_L = " << sel_wgted_L  << endl;
cout << "wgted_M     = " << wgted_M  << endl;
cout << "wgted_reprod = "  << wgted_reprod << endl;
cout << "wgt_wgted_L_mt = " << wgt_wgted_L_mt << endl;

//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=wgted_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)));

      F_spr_age2plus(ff)=F_L_age_spr(3,nages)*N_age_spr(3,nages)/sum(N_age_spr(3,na
      ges));
  spr_spr(ff)=sum(elem_prod(N_age_spr,wgted_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); //in mt
  }
 }

FUNCTION get_effective_sample_sizes

   neff_cR_agec_allyr_out=missing;
   neff_gill_lenc_allyr_out=missing;

   for (iyear=styr_cR_agec; iyear<=endyr_cR_agec; iyear++)
     {if (nsamp_cR_agec(iyear)>=minSS_cR_agec)
      { numer=sum( elem_prod(pred_cR_agec(iyear),(1.0-pred_cR_agec(iyear))) );
        denom=sum( square(obs_cR_agec(iyear)-pred_cR_agec(iyear)) );
         if (denom>0.0) {neff_cR_agec_allyr_out(iyear)=numer/denom;}
         else {neff_cR_agec_allyr_out(iyear)=-missing;}
      } else {neff_cR_agec_allyr_out(iyear)=-99;}
     }

   for (iyear=styr_gill_lenc; iyear<=endyr_gill_lenc; iyear++)
     {if (nsamp_gill_lenc(iyear)>=minSS_gill_lenc)
      { numer1=sum( elem_prod(pred_gill_lenc(iyear),(1.0-pred_gill_lenc(iyear))) );
        denom1=sum( square(obs_gill_lenc(iyear)-pred_gill_lenc(iyear)) );
         if (denom1>0.0) {neff_gill_lenc_allyr_out(iyear)=numer1/denom1;}
         else {neff_gill_lenc_allyr_out(iyear)=-missing;}
      } else {neff_gill_lenc_allyr_out(iyear)=-99;}
     }

//------------------------------------------------------------------------------------------------------------
      ---------------------------------------------------------------------

FUNCTION get_Fmed_benchmarks

 //sorting function for recruitment and SPR values (slow algorithm, but works)
 R_temp=rec(styr_bench,endyr_bench);
```

```
SPR_temp=pred_SPR(styr_bench,endyr_bench);
for(int jyear=endyr_bench; jyear>=styr_bench; jyear--)
{
  R_sort(jyear)=max(R_temp);
  SPR_sort(jyear)=max(SPR_temp);
  for(iyear=styr_bench; iyear<=endyr_bench; 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_bench-styr_bench)*0.5;
quant_whole=(endyr_bench-styr_bench)*0.5;
quant_diff=quant_decimal-quant_whole;
R_med=R_sort(styr_bench+quant_whole)*(1-
        quant_diff)+R_sort(styr_bench+quant_whole+1)*(quant_diff);
SPR_med=SPR_sort(styr_bench+quant_whole)*(1-
        quant_diff)+SPR_sort(styr_bench+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_bench-styr_bench)*0.75;
quant_whole=(endyr_bench-styr_bench)*0.75;
quant_diff=quant_decimal-quant_whole;
SPR_75th=SPR_sort(styr_bench+quant_whole)*(1-
        quant_diff)+SPR_sort(styr_bench+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);
   }
  }

FUNCTION evaluate_objective_function
  fval=0.0;
  fval_unwgt=0.0;

////---likelihoods--------------------------

////---Indices------------------------------
  f_JAIs_cpue=0.0;

        f_JAIs_cpue=lk_lognormal(pred_JAIs_cpue,obs_JAIs_cpue_final,JAIs_cpue_cv_fin
        al,w_I_JAIs);
  fval+=f_JAIs_cpue;
  fval_unwgt+=f_JAIs_cpue;

  //f_JAIt_cpue=0.0;
```

```
          //f_JAIt_cpue=lk_lognormal(pred_JAIt_cpue,obs_JAIt_cpue_final,JAIt_cpue_cv_fi
          nal,w_I_JAIt);
  //fval+=f_JAIt_cpue;
  //fval_unwgt+=f_JAIt_cpue;

  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_unwgt+=f_gill_cpue;

////---Landings-------------------------------

  f_cR_L=0.0; //in 1000 mt
  f_cR_L=lk_lognormal(pred_cR_L_mt(styr,endyr),obs_cR_L(styr,endyr),
                    cR_L_cv(styr,endyr),w_L);
  fval+=f_cR_L;
  fval_unwgt+=f_cR_L;



//////---Age comps-------------------------------
  //f_cR_agec=100.0;
  //f_cR_agec=lk_multinomial(nsamp_cR_agec,pred_cR_agec,obs_cR_agec,nyr_cR_agec,
          minSS_cR_agec, w_ac);
  //fval+=f_cR_agec;
  //fval_unwgt+=f_cR_agec;

  f_cR_agec=0.0;
  for (iyear=styr_cR_agec; iyear<=endyr_cR_agec; iyear++)
  {
    if (nsamp_cR_agec(iyear)>=minSS_cR_agec)
    {
    f_cR_agec-=neff_cR_agec(iyear)*
          sum(elem_prod((obs_cR_agec(iyear)+dzero),
            log(elem_div((pred_cR_agec(iyear)+dzero),
              (obs_cR_agec(iyear)+dzero)))));
    }
  }

  fval+=w_ac*f_cR_agec;
  fval_unwgt+=f_cR_agec;



////---Length comps-------------------------------
```

```
  f_gill_lenc=0.0;

  //cout << "nsamp_gill_lenc" << nsamp_gill_lenc << endl;
  //cout << "pred_gill_lenc" << pred_gill_lenc << endl;
  //cout << "obs_gill_lenc" << obs_gill_lenc << endl;
  //cout << "nyr_gill_lenc" << nyr_gill_lenc << endl;
  //cout << "minSS_gill_lenc" << minSS_gill_lenc << endl;
  //cout << "weight" << w_I_gill_lc << endl;


        //f_gill_lenc=lk_multinomial(nsamp_gill_lenc,pred_gill_lenc,obs_gill_lenc,nyr_gill_l
        enc,minSS_gill_lenc,w_I_gill_lc);
  //cout << "gill_lenc_like" << f_gill_lenc << endl;

  //fval+=f_gill_lenc;
 // fval_unwgt+=f_gill_lenc;

  for (iyear=styr_gill_lenc; iyear<=endyr_gill_lenc; iyear++)
  {
   if (nsamp_gill_lenc(iyear)>=minSS_gill_lenc)
   {
   f_gill_lenc-=neff_gill_lenc(iyear)*
      sum(elem_prod((obs_gill_lenc(iyear)+dzero),
        log(elem_div((pred_gill_lenc(iyear)+dzero),
          (obs_gill_lenc(iyear)+dzero)))));
   }
  }

  fval+=w_I_gill_lc*f_gill_lenc;
  fval_unwgt+=f_gill_lenc;


////-----------Constraints and penalties--------------------------------
  //f_rec_dev=0.0;
  ///f_rec_dev=norm2(log_rec_dev);
  ///f_rec_dev=pow(log_rec_dev(styr_rec_dev),2);
  //for(iyear=(styr_rec_dev+1); iyear<=endyr; iyear++)
  //{f_rec_dev+=pow(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1),2);}
  //fval+=w_rec*f_rec_dev;

  f_rec_dev=0.0;
  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; 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 (styr_rec_dev<endyr_rec_phase1)
 //  {
 //    f_rec_dev_early=pow(log_rec_dev(styr_rec_dev),2);
 //    for(iyear=(styr_rec_dev+1); iyear<=endyr_rec_phase1; iyear++)
 //    {f_rec_dev_early+=pow(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1),2);}
 //  }
 //fval+=w_rec_early*f_rec_dev_early;

 //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 (endyr_rec_phase2<endyr)
 // {
 //    for(iyear=(endyr_rec_phase2+1); iyear<=endyr; iyear++)
 //    {f_rec_dev_end+=pow(log_rec_dev(iyear)-R_autocorr*log_rec_dev(iyear-1),2);}
 //  }
 //fval+=w_rec_end*f_rec_dev_end;

 //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;
  //}
```

```
 //f_Ftune=0.0;
 //if (!last_phase()) {f_Ftune=square(Fapex(set_Ftune_yr)-set_Ftune);}
 //fval+=w_Ftune*f_Ftune;

 //code below contingent on four phases
 //f_fullF_constraint=0.0;
 //if (!last_phase())
 //{for (iyear=styr; iyear<=endyr; iyear++)
 //     {if (Fapex(iyear)>3.0){f_fullF_constraint+=mfexp(Fapex(iyear)-3.0);}}
 // if (current_phase()==1) {w_fullF=set_w_fullF;}
 // if (current_phase()==2) {w_fullF=set_w_fullF/10.0;}
 // if (current_phase()==3) {w_fullF=set_w_fullF/100.0;}
 // }

 // fval+=w_fullF*f_fullF_constraint;

 //Random walk components of fishery dependent indices
// f_PN_RW_cpue=0.0;
// for (iyear=styr_PN_cpue; iyear<endyr_PN_cpue; iyear++)
//     {f_PN_RW_cpue+=square(q_RW_log_dev_PN(iyear))/(2.0*set_q_RW_PN_var);}
// fval+=f_PN_RW_cpue;

 //JAI combination weights penalty to sum to 1.0
 //f_JAI_wgts=0.0;
 //f_JAI_wgts=square(1.0-(wgt_JAI1+wgt_JAI2+wgt_JAI3+wgt_JAI4));
 //fval+=w_JAI_wgts*f_JAI_wgts;

 f_priors=0.0;
 f_priors=norm2(log_Nage_dev);
 //f_priors+=neg_log_prior(steep,set_steep,square(set_steep_se),4);
 //f_priors+=square(R_autocorr-set_R_autocorr);
 //f_priors+=square(q_DD_beta-set_q_DD_beta)/square(set_q_DD_beta_se);
 //f_priors+=neg_log_prior(Linf,set_Linf,square(set_Linf_se),3);
 //f_priors+=neg_log_prior(K,set_K,square(set_K_se),3);
 //f_priors+=neg_log_prior(t0,set_t0,square(set_t0_se),3);
 //f_priors+=neg_log_prior(rec_sigma,set_rec_sigma,square(set_rec_sigma_se),3);


 //f_priors+=sum(square(len_cv-set_len_cv));
 //f_priors+=neg_log_prior(len_cv(1),set_len_cv(1),square(set_len_cv_se(1)),3);
 //f_priors+=neg_log_prior(len_cv(2),set_len_cv(2),square(set_len_cv_se(2)),3);
 //f_priors+=neg_log_prior(len_cv(3),set_len_cv(3),square(set_len_cv_se(3)),3);
 //f_priors+=neg_log_prior(len_cv(4),set_len_cv(4),square(set_len_cv_se(4)),3);
 //f_priors+=neg_log_prior(len_cv(5),set_len_cv(5),square(set_len_cv_se(5)),3);
```

```
//f_priors+=neg_log_prior(selpar_L50_gill, set_selpar_L50_gill, -1.0, 3);
//f_priors+=neg_log_prior(selpar_slope_gill, set_selpar_slope_gill, -1.0, 3);
//f_priors+=neg_log_prior(selpar_L502_gill, set_selpar_L502_gill, -1.0, 3);
//f_priors+=neg_log_prior(selpar_slope2_gill, set_selpar_slope2_gill, -1.0, 3);

//f_priors+=neg_log_prior(sel_age0_gill_logit, set_sel_age0_gill, -1.0, 3);
f_priors+=neg_log_prior(sel_age1_gill_logit, set_sel_age1_gill, -1.0, 3);
//f_priors+=neg_log_prior(sel_age2_gill_logit, set_sel_age2_gill, -1.0, 3);
f_priors+=neg_log_prior(sel_age3_gill_logit, set_sel_age3_gill, -1.0, 3);
f_priors+=neg_log_prior(sel_age4_gill_logit, set_sel_age4_gill, -1.0, 3);

//f_priors+=neg_log_prior(selpar_L50_cR1, set_selpar_L50_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_slope_cR1, set_selpar_slope_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_L50_cR3, set_selpar_L50_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_slope_cR3, set_selpar_slope_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_L50_cR4, set_selpar_L50_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_slope_cR4, set_selpar_slope_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_L502_cR1, set_selpar_L502_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_slope2_cR1, set_selpar_slope2_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_L502_cR4, set_selpar_L502_cR, -1.0, 3);
//f_priors+=neg_log_prior(selpar_slope2_cR4, set_selpar_slope2_cR, -1.0, 3);

//f_priors+=neg_log_prior(sel_age0_cR1_logit, set_sel_age0_cR1, -1.0, 3);
for (iyear=styr;iyear<=endyr_period2;iyear++)
  {
   f_priors+=neg_log_prior(sel_age1_cR1_logit(iyear), set_sel_age1_cR1, -1.0, 3);
   //f_priors+=neg_log_prior(sel_age2_cR1_logit, set_sel_age2_cR1, -1.0, 3);
   f_priors+=neg_log_prior(sel_age3_cR1_logit(iyear), set_sel_age3_cR1, -1.0, 3);
   f_priors+=neg_log_prior(sel_age4_cR1_logit(iyear), set_sel_age4_cR1, -1.0, 3);
  }

//f_priors+=neg_log_prior(sel_age0_cR3_logit, set_sel_age0_cR3, -1.0, 3);
//f_priors+=neg_log_prior(sel_age1_cR3_logit, set_sel_age1_cR3, -1.0, 3);
//f_priors+=neg_log_prior(sel_age2_cR3_logit, set_sel_age2_cR3, -1.0, 3);
//f_priors+=neg_log_prior(sel_age3_cR3_logit, set_sel_age3_cR3, -1.0, 3);
//f_priors+=neg_log_prior(sel_age4_cR3_logit, set_sel_age4_cR3, -1.0, 3);

//f_priors+=neg_log_prior(sel_age0_cR4_logit, set_sel_age0_cR4, -1.0, 3);
//f_priors+=neg_log_prior(sel_age1_cR4_logit, set_sel_age1_cR4, -1.0, 3);
//f_priors+=neg_log_prior(sel_age2_cR4_logit, set_sel_age2_cR4, -1.0, 3);
//f_priors+=neg_log_prior(sel_age3_cR4_logit, set_sel_age3_cR4, -1.0, 3);
//f_priors+=neg_log_prior(sel_age4_cR4_logit, set_sel_age4_cR4, -1.0, 3);


if(switch_prior==1)
{
```

```
    fval+=f_priors;
  }
//  cout << "fval = " << fval << "  fval_unwgt = " << fval_unwgt << 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;

//--------------------------------------------------------------------------------
//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
  //dzero is small value to avoid log(0) during search
  RETURN_ARRAYS_INCREMENT();
  dvariable LkvalTmp;
  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+dzero),(obs+dzero)))),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;
  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)+dzero),
        log(elem_div((pred_comp(ii)+dzero), (obs_comp(ii)+dzero)))));
  }
 }
 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;
  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=huge_number;
     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=huge_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;

//----------------------------------------------------------------------------
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();
 cout << "got effective sample sizes" << endl;
 get_Fmed_benchmarks();
 cout << "got Fmed benchmarks" << endl;

 //><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>-
      -><>--><>--><>--><>
 report << "Likelihood " << "Value " << "Weight" << endl;
 report << "JAI_seine_index " << f_JAIs_cpue << " " << w_I_JAIs << endl;
 //report << "JAI_trawl_index " << f_JAIt_cpue << " " << w_I_JAIt << endl;
 report << "Gillnet_index " << f_gill_cpue << " " << w_I_gill << endl;
 report << "Gillnet_lenc " << f_gill_lenc << " " << w_I_gill_lc << endl;
 report << "reduction_agec " << f_cR_agec << " " << w_ac << endl;
 report << "L_reduction " << f_cR_L << " " << w_L << endl;
 report << "R_dev " << f_rec_dev << " " << w_rec << endl;
 //report << "R_dev_early " << f_rec_dev_early << " " << w_rec_early << endl;
 //report << "R_dev_end " << f_rec_dev_end << " " << w_rec_end << endl;
 //report << "F_tune " << f_Ftune << " " << w_Ftune << endl;
 //report << "fullF_constraint " << f_fullF_constraint << " " << w_fullF << endl;
 report << "priors " << f_priors << " " << switch_prior << endl;

 report << "TotalLikelihood " << fval << endl;
 report << "UnwgtLikelihood " << fval_unwgt << endl;

 report << "Error levels in model" << endl;
 report << "JAI_seine_cv " << JAIs_cpue_cv << endl;
 report << "JAI_trawl_cv " << JAIt_cpue_cv << endl;
```

```
  report << "Gillnet_cv " << gill_cpue_cv << endl;
  report << "L_reduction_cv " << cR_L_cv << endl;

  report << "NaturalMortality Vector" << endl;
  report << "Age " << agebins << endl;
  report << "M_vector " << M << endl;
  report << "NaturalMortality Matrix " << endl;
  report << "Year " << agebins << endl;
  for(iyear=styr; iyear<=endyr; iyear++)
  {
   report << iyear << " " << M_mat(iyear) << endl;
  }

  report << "Steepness " << steep << endl;
  report << "R0 " << R0 << endl;

  report << "Recruits" << endl;
  report << "Year";
  for(iyear=styr; iyear<=endyr; iyear++)
  {
   report << " " << iyear;
  }
  report << endl;
  report << "Age-0_recruits " << column(N,1) << endl;
  report << "Age-1_recruits " << column(N,2) << endl;
  report << "SSB" << endl;
  report << "Year";
  for(iyear=styr; iyear<=endyr; iyear++)
  {
   report << " " << iyear;
  }
  report << endl;
  report << "FEC " << SSB << endl;
  //report << "SSB " << FEC << endl;
  report << "Lagged_R " << column(N,1)(styr+1,endyr) << endl;
  report << "wgt_wgted_L_mt" << wgt_wgted_L_mt << endl;

  report << "nsamp_cR_agec_allyr" << nsamp_cR_agec_allyr << endl;

//   cout<< mfexp(log_len_cv)<<endl;
// report << "TotalLikelihood " << fval << endl;
  #include "gmenhad_make_Robject003.cxx"   // write the S-compatible report
  }
```

## Appendix A.2.  ADMB base run data input file.

```
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>
##  Data Input File
##  GSMFC Assessment: Gulf Menhaden
##
##--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>--><>

#starting and ending year of model
1948
2010
#Starting year to estimate recruitment deviation from S-R curve
1948
#3 phases of constraints on recruitment deviations: allows possible heavier constraint in early and late period, with lighter constraint in the middle
#ending years of recruitment constraint phases
1967
2008
#4 periods of changing selectivity for reduction fishery: yr1-1970, 1971-1979, 1980-1993, 1994-2010---right now only using 2 periods yr1-1993 and 1994-2010
#ending years of regulation period
1963
1979
1993

#2 periods of changing selectivity for gillnet survey:  yr1-1993, 1994-2010
#ending year of early period
1993

#starting and ending years to use for benchmark calculations
1948
2010

#Number of ages (last age is plus group)
5
##vector of agebins, last is a plus group
0 1 2 3 4

#number length bins used to match length comps and number used to compute plus group
#26
#5
51
10

#Vector of length bins (mm)(midpoint of bin) used to match length comps and bins used to compute plus group
```

```
#10   30    50    70    90    110   130   150   170   190   210   230   250
      270   290   310   330   350   370   390   410
#430  450   470   490   510
#10   30    50    70    90    110   130   150   170   190   210   230   250
      270   290   310   330   350   370   390   410   430   450   470   490
      510
5     15    25    35    45    55    65    75    85    95    105   115   125
      135   145   155   165   175   185   195   205   215   225   235   245
      255   265   275   285   295   305   315   325   335   345   355   365
      375   385   395   405  415    425   435   445   455   465   475   485
      495   505
415   425   435   445   455   465   475   485   495   505
5     15    25    35    45    55    65    75    85    95    105   115   125
      135   145   155   165   175   185   195   205   215   225   235   245
      255   265   275   285   295   305   315   325   335   345   355   365
      375   385   395   405

#max value of F used in spr and msy calculations
10.0
#number of iterations in spr calculations
30001
#number of iterations in msy calculations
30001
#Number years at end of time series over which to average sector Fs, for weighted
selectivities
47
#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

##time-invariant vector of % maturity-at-age for females (ages 0-6+)
0.0     0.0     1      1 1
#0.0     0.2    1      1      1        #for a sensitivity run
##time-invariant vector of % maturity-at-age for males (ages 0-6+)
0.0     0.0     1       1       1
#0.0     0.2    1      1      1            #for a sensitivity run
#time-invariant vector of proportion female (ages 0-6+)
0.5 0.5 0.5 0.5 0.5
#time of year (as fraction) for spawning: Jan 1=0d/365d
0.0
#age-dependent natural mortality at age
1.67    1.31    1.1     1.0     0.94     #scaled to tagging data
#1.38   1.09    0.91    0.82    0.78    0.75    0.73  #scaled to lower tagging for sensitivity run
```

```
#1.93   1.52    1.27    1.15    1.09    1.05    1.02  #scaled to upper tagging for sensitivity run
#1.07   0.84    0.7     0.64    0.6     0.58    0.57  #scaled to Hoenig estimate
#age-independent natural mortality (used only to compute MSST=(1-M)SSBmsy)
1.1
#age and year specific natural mortality
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
```

```
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94
1.67    1.31    1.10    1.00    0.94


##Spawner-recruit parameters
#switch for S-R function to use Ricker (1) or Beverton-Holt (2)
2
#steepness (fixed or initial guess)
0.9
#standard error of steepness (from meta-analysis)
0.2
#log_R0 - log virgin recruitment
2.7
# R autocorrelation
0.0
# SD of recruitment in log space
0.5
# SE of SD recruitment
0.25


##--><>--><>--><>-- Weight-at-age in the fishery (g) --><>--><>--><>--><>--><>--><>--
><>--><>
32.8    67.8    125.9   189.9   254.8
32.8    67.8    125.9   189.9   254.8
```

| | | | | |
|---|---|---|---|---|
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 32.8 | 67.8 | 125.9 | 189.9 | 254.8 |
| 33.3 | 71.4 | 126.9 | 176.1 | 214.6 |
| 30.6 | 62.4 | 124.1 | 205.8 | 303.9 |
| 34.6 | 69.6 | 126.8 | 187.8 | 245.9 |
| 26.0 | 65.8 | 122.8 | 169.5 | 202.9 |
| 29.8 | 69.3 | 135.9 | 205.6 | 269.5 |
| 38.4 | 68.9 | 123.2 | 190.8 | 268.7 |
| 28.5 | 72.0 | 133.0 | 181.5 | 215.0 |
| 30.6 | 73.1 | 135.2 | 188.4 | 228.0 |
| 30.5 | 79.6 | 139.7 | 179.9 | 203.2 |
| 42.7 | 83.4 | 154.1 | 236.5 | 323.3 |
| 26.3 | 86.9 | 157.7 | 199.2 | 220.0 |
| 40.0 | 76.6 | 146.7 | 240.4 | 355.5 |
| 31.8 | 69.3 | 134.7 | 208.8 | 283.8 |
| 27.6 | 57.3 | 112.1 | 179.8 | 255.4 |
| 39.7 | 69.9 | 123.7 | 190.6 | 267.8 |
| 37.1 | 73.1 | 124.9 | 171.5 | 209.1 |
| 12.6 | 56.0 | 130.2 | 191.4 | 232.2 |
| 23.8 | 59.5 | 114.6 | 164.6 | 203.9 |
| 37.2 | 67.5 | 116.9 | 170.9 | 224.7 |
| 26.7 | 68.0 | 128.2 | 178.3 | 214.1 |
| 20.2 | 62.0 | 125.5 | 178.0 | 214.5 |
| 21.5 | 60.6 | 118.2 | 165.0 | 197.7 |
| 16.3 | 52.4 | 112.2 | 166.3 | 207.6 |
| 30.3 | 58.7 | 103.7 | 150.0 | 192.9 |
| 20.0 | 57.9 | 112.9 | 156.8 | 186.7 |
| 29.4 | 62.3 | 113.5 | 163.5 | 206.8 |
| 26.9 | 66.9 | 125.6 | 175.6 | 212.5 |
| 42.1 | 79.4 | 132.1 | 179.6 | 218.0 |
| 40.0 | 78.5 | 129.5 | 171.7 | 203.1 |
| 43.6 | 80.5 | 132.7 | 180.1 | 219.0 |
| 32.3 | 71.1 | 125.3 | 171.1 | 205.2 |
| 39.6 | 79.3 | 135.4 | 184.6 | 223.1 |

```
31.7    68.1    123.2   174.4   216.3
27.4    69.6    126.7   170.1   198.7
35.4    73.1    123.7   165.1   195.3
49.5    84.5    132.5   175.5   210.9
35.3    68.8    112.0   146.3   171.0
65.3    97.7    140.7   179.6   212.6
34.8    74.2    125.4   165.0   192.1
27.8    61.3    110.3   153.7   187.7
30.9    64.5    111.2   150.9   180.7
46.6    73.4    110.7   146.3   177.8
29.8    65.5    109.9   142.0   162.7
33.4    69.5    116.8   154.0   180.0
36.5    78.7    127.9   160.8   180.3
57.8    83.8    119.1   152.6   182.5
26.3    69.2    120.8   154.3   173.3


##--><>--><>--><>-- Weight-at-age - start of year (g) --><>--><>--><>--><>
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    43.3    95.7    157.6   222.4
0.00    45.0    99.3    152.7   196.7
0.00    39.8    90.5    162.7   253.1
0.00    45.2    97.2    157.3   217.5
0.00    38.1    94.9    147.8   187.8
0.00    41.4    101.4   171.0   238.6
0.00    47.6    94.2    155.5   228.7
0.00    41.8    103.4   159.2   200.0
0.00    43.6    104.6   163.4   209.9
0.00    46.0    111.8   162.3   193.3
0.00    54.9    116.8   194.3   279.7
0.00    45.1    125.9   181.8   211.5
0.00    50.7    108.6   190.7   295.4
```

```
0.00    42.9    100.3   171.2   246.6
0.00    36.3    82.7    144.6   216.9
0.00    48.8    95.0    155.7   228.1
0.00    48.4    99.2    149.2   191.5
0.00    24.2    93.3    163.3   214.2
0.00    34.4    87.0    140.8   185.7
0.00    46.5    91.2    143.6   198.1
0.00    39.2    98.7    155.0   197.9
0.00    32.4    94.2    153.7   198.1
0.00    33.1    90.0    143.4   183.0
0.00    26.6    82.0    140.7   188.7
0.00    39.0    80.6    127.0   172.0
0.00    31.3    86.1    136.7   173.4
0.00    39.4    87.5    139.1   186.2
0.00    39.0    96.6    152.1   195.6
0.00    53.9    106.0   156.9   200.0
0.00    52.3    104.7   152.0   188.7
0.00    55.3    106.8   157.3   200.6
0.00    44.4    98.8    149.6   189.6
0.00    52.0    107.7   161.3   205.2
0.00    42.9    95.5    149.7   196.6
0.00    40.5    99.3    150.4   186.1
0.00    47.4    99.2    145.8   181.6
0.00    60.7    108.8   154.9   194.2
0.00    46.1    91.2    130.4   159.8
0.00    75.9    119.5   160.8   196.9
0.00    47.3    100.9   146.8   179.9
0.00    38.1    86.0    133.0   171.9
0.00    41.4    88.3    132.2   167.0
0.00    55.3    92.1    128.9   162.6
0.00    41.3    89.0    127.6   153.6
0.00    44.9    94.1    136.9   168.3
0.00    50.3    105.2   146.4   171.9
0.00    66.3    101.5   136.2   168.0
0.00    39.9    97.1    139.8   165.3


##--><>--><>--><>-- Fecundity-at-age - not adjusted for maturity (number of maturing
ova per individual) --><>--><>--><>--><>
0.0     8493    21641   38974   58568
0.0     8493    21641   38974   58568
0.0     8493    21641   38974   58568
0.0     8493    21641   38974   58568
0.0     8493    21641   38974   58568
0.0     8493    21641   38974   58568
0.0     8493    21641   38974   58568
```

| | | | | |
|---|---|---|---|---|
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 8493 | 21641 | 38974 | 58568 |
| 0.0 | 9310 | 23161 | 38020 | 50894 |
| 0.0 | 7720 | 20105 | 39791 | 66601 |
| 0.0 | 8448 | 21657 | 39110 | 58210 |
| 0.0 | 7075 | 22273 | 38862 | 52492 |
| 0.0 | 7855 | 23500 | 44562 | 66991 |
| 0.0 | 9294 | 21812 | 40772 | 65957 |
| 0.0 | 8074 | 24020 | 40373 | 53114 |
| 0.0 | 8615 | 24348 | 41351 | 55631 |
| 0.0 | 9188 | 27162 | 42783 | 52917 |
| 0.0 | 10122 | 25417 | 47259 | 73668 |
| 0.0 | 8302 | 31388 | 50499 | 61438 |
| 0.0 | 10185 | 26047 | 52154 | 89510 |
| 0.0 | 8135 | 24503 | 49053 | 78743 |
| 0.0 | 7080 | 19862 | 39982 | 66398 |
| 0.0 | 9954 | 22119 | 39955 | 63125 |
| 0.0 | 10391 | 24331 | 39507 | 53133 |
| 0.0 | 4816 | 22174 | 41800 | 56802 |
| 0.0 | 6401 | 19909 | 35899 | 50373 |
| 0.0 | 9570 | 20845 | 35182 | 50972 |
| 0.0 | 7692 | 22931 | 39107 | 52201 |
| 0.0 | 5874 | 21289 | 38409 | 52161 |
| 0.0 | 6243 | 21518 | 38301 | 51818 |
| 0.0 | 4489 | 17635 | 33953 | 48483 |
| 0.0 | 7392 | 17956 | 31283 | 45328 |
| 0.0 | 5324 | 18838 | 33512 | 45084 |
| 0.0 | 7230 | 18982 | 33275 | 47351 |
| 0.0 | 6904 | 20835 | 36215 | 49185 |
| 0.0 | 10585 | 23594 | 37548 | 50055 |
| 0.0 | 9136 | 22873 | 37426 | 49828 |
| 0.0 | 10052 | 22850 | 37031 | 50148 |
| 0.0 | 8296 | 23083 | 39286 | 53176 |
| 0.0 | 10001 | 23829 | 38581 | 51452 |
| 0.0 | 8830 | 22398 | 37748 | 51799 |
| 0.0 | 7601 | 22869 | 38026 | 49370 |
| 0.0 | 8730 | 22434 | 36724 | 48589 |
| 0.0 | 12299 | 25058 | 38570 | 50845 |
| 0.0 | 8846 | 22503 | 36686 | 48445 |

```
0.0     15164  27114  39653  51381
0.0     9419   24290  38868  50145
0.0     7201   20208  35159  48665
0.0     7877   19700  32115  42592
0.0     10773  20634  31671  42563
0.0     7744   20214  31712  39984
0.0     8597   21106  33281  42765
0.0     10110  24183  35707  43176
0.0     14042  24338  35553  46606
0.0     7259   22489  35755  44264

##--><>--><>--><>-- Juvenile Abundance Index from seine surveys --><>--><>--><>--><>-
-><>
##Switch to use single index (=1) or let model combine indices (not equal to 1)
1
##Starting and ending years of time series, respectively
1977
2010
##Observed CPUE (numbers) and CV vectors, respectively
0.8532117    0.9539007    0.3765042    0.7936619    0.6447944    1.1169395
        0.7439912    2.6041844    0.766218     2.0378689    0.7151532    0.5974039
        0.6396402    1.1625989    1.1488432    1.2745629    1.6400419    0.6244874
        0.8701708    1.4388904    0.8811541    1.3375117    0.871577     0.4719151
        1.012841     0.8708502    1.0712156    0.6170468    0.7083236    0.6457001
        0.9499249    0.5974745    1.0092283    1.9521695
0.48118822   0.389104138  0.342169217  0.32661541   0.237447979  0.200948356
        0.186093321  0.159674922  0.196481516  0.140792789  0.149082264  0.15762195
        0.144771109  0.119772413  0.120532936  0.116682878  0.114211781  0.1250578
        0.116892518  0.112876121  0.109112583  0.107422125  0.117222422  0.125026892
        0.109825483  0.107561704  0.107970075  0.109646646  0.107792881  0.11475117
        0.102703325  0.106362308  0.106086634  0.108682567

##--><>--><>--><>-- Juvenile Abundance Indices (4 groups) from seine surveys --><>--
><>--><>--><>--><>
##Series 1 Observed CPUE (numbers) and CV vectors, respectively
##must have zeros in place of missing values and all series must be the same length as
single index above
0.8532117    0.9539007    0.3765042    0.7936619    0.6447944    1.1169395
        0.7439912    2.6041844    0.766218     2.0378689    0.7151532    0.5974039
        0.6396402    1.1625989    1.1488432    1.2745629    1.6400419    0.6244874
        0.8701708    1.4388904    0.8811541    1.3375117    0.871577     0.4719151
        1.012841     0.8708502    1.0712156    0.6170468    0.7083236    0.6457001
        0.9499249    0.5974745    1.0092283    1.9521695
0.48118822   0.389104138  0.342169217  0.32661541   0.237447979  0.200948356
        0.186093321  0.159674922  0.196481516  0.140792789  0.149082264  0.15762195
        0.144771109  0.119772413  0.120532936  0.116682878  0.114211781  0.1250578
```

```
        0.116892518  0.112876121  0.109112583  0.107422125  0.117222422  0.125026892
        0.109825483  0.107561704  0.107970075  0.109646646  0.107792881  0.11475117
        0.102703325  0.106362308  0.106086634  0.108682567
##Series 2 Observed CPUE (numbers) and CV vectors, respectively
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       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
##Series 3 Observed CPUE (numbers) and CV vectors, respectively
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       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
##Series 4 Observed CPUE (numbers) and CV vectors, respectively
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       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

##--><>--><>--><>-- Juvenile Abundance Index from trawl surveys --><>--><>--><>--><>-
-><>
##Starting and ending years of time series, respectively
1967
2010
##Observed CPUE (numbers) and CV vectors, respectively
0.5726388       2.6901819       1.2409177       1.117585        0.5862024       0.3520756
        0.6618439       1.0078254       1.5242414       1.6389502       2.1070125       1.0843953
        0.632725        1.0377783       0.7644635       0.7962733       0.9315196       1.4954697
        0.7443739       0.7183562       0.749796        0.6869988       0.5638866       0.8771056
        0.8758685       1.1675068       1.1723505       0.8211532       0.6677382       0.9882219
        0.732906        1.0012529       0.6989131       0.5152103       1.053807        0.9527749
        0.9331622       0.7879501       0.7512019       0.6815322       1.1871579       0.6214085
        0.7289429       3.0783241
0.16    0.16    0.21    0.15    0.18    0.16    0.13    0.09    0.16    0.20    0.14    0.12    0.13
        0.17    0.11    0.07    0.08    0.08    0.07    0.08    0.07    0.07    0.08    0.08    0.07
        0.06    0.07    0.08    0.07    0.07    0.06    0.07    0.08    0.07    0.07    0.06    0.06
        0.06    0.07    0.07    0.07    0.07    0.07    0.08

##--><>--><>--><>-- Adult Abundance Index from gillnet surveys --><>--><>--><>--><>--
><>
```

```
##Starting and ending years of time series, respectively
1986
2010
##Observed CPUE (numbers) and CV vectors, respectively
0.8876313   0.5516841   1.0535439   0.7457594   0.7682163   0.7921094
      0.6020293   0.5489181   0.8391153   0.6947594   0.7646888   1.1077033
      1.0512145   0.8004876   1.0328651   1.1544858   1.0518452   1.0397885
      0.9415808   1.1624293   1.1342473   0.9203316   2.4410209   2.0918482
      0.8216967
0.08336033  0.09139956  0.07209881  0.07521872  0.07851684  0.08009715
      0.08651338  0.08949987  0.0851033   0.0906863   0.08141417  0.07904502
      0.07571395  0.07672932  0.07134729  0.07843334  0.07403435  0.06792069
      0.0751475   0.07092119  0.06705314  0.06876212  0.06675556  0.0606661
      0.07674898

#Number of years, start year, end year,  and vector of years of length compositions for
gillnet survey
25
1986
2010
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
#sample size of gillnet survey length comp data by year (first row observed N, second row
effective N: effective may be set to observed)
#351  235   35    4     4     5     82    196   194   213   262   280   366
      325   410   353   383   387   348   374   460   375   439   461   287
#351  235   35    4     4     5     82    196   194   213   262   280   366
      325   410   353   383   387   348   374   460   375   439   461   287
200   200   35    4    4    5    82    196   194   200   200   200   200   200   200
200   200   200   200   200   200   200   200   200   200
200   200   35    4    4    5    82    196   194   200   200   200   200   200   200
200   200   200   200   200   200   200   200   200   200

#length composition samples (year,lengthbin 10 mm)
#unweighted length comps
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.02  0.03  0.10
      0.23  0.24  0.12  0.10  0.05  0.02  0.02  0.02  0.02  0.01  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.02  0.01  0.02  0.07
      0.22  0.28  0.11  0.06  0.03  0.03  0.03  0.05  0.03  0.02  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.00  0.03
      0.06  0.16  0.10  0.12  0.24  0.12  0.06  0.07  0.01  0.00  0.00  0.00
```

```
      0.00  0.01  0.00  0.01  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.20  0.20  0.00  0.00  0.20  0.20  0.00  0.00  0.00
      0.00  0.00  0.00  0.00  0.20  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.08  0.15  0.00  0.08  0.08  0.00  0.15  0.00  0.15  0.00  0.15  0.08
      0.00  0.08  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.11  0.22  0.22  0.33  0.11  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.03  0.03
      0.06  0.07  0.08  0.16  0.19  0.12  0.08  0.07  0.06  0.02  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.01  0.03
      0.10  0.13  0.08  0.14  0.18  0.10  0.06  0.06  0.05  0.03  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.05
      0.14  0.16  0.08  0.09  0.12  0.09  0.08  0.07  0.06  0.03  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.06
      0.16  0.14  0.09  0.10  0.13  0.09  0.06  0.05  0.04  0.03  0.02  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.01  0.02  0.06
      0.15  0.16  0.09  0.11  0.11  0.08  0.05  0.05  0.04  0.02  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.00  0.01  0.05
      0.12  0.14  0.11  0.11  0.14  0.10  0.07  0.06  0.03  0.02  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.03  0.07
      0.17  0.17  0.11  0.10  0.12  0.08  0.04  0.04  0.02  0.02  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.03  0.08
      0.16  0.14  0.09  0.10  0.12  0.09  0.07  0.06  0.03  0.02  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
```

```
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.02  0.07
      0.14  0.11  0.07  0.07  0.12  0.12  0.09  0.08  0.06  0.03  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.01  0.05
      0.11  0.10  0.08  0.11  0.13  0.10  0.08  0.08  0.06  0.03  0.02  0.01
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.02  0.03  0.06
      0.13  0.14  0.09  0.09  0.10  0.08  0.06  0.07  0.05  0.04  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.03  0.09
      0.18  0.18  0.10  0.10  0.13  0.08  0.03  0.03  0.03  0.01  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.02  0.04  0.11
      0.17  0.17  0.10  0.10  0.09  0.07  0.04  0.04  0.02  0.01  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.03  0.07
      0.15  0.17  0.11  0.11  0.13  0.09  0.04  0.04  0.02  0.01  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.01  0.02  0.09
      0.16  0.15  0.14  0.10  0.11  0.08  0.05  0.03  0.02  0.01  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.01  0.02  0.05
      0.14  0.17  0.14  0.14  0.13  0.07  0.04  0.03  0.02  0.01  0.00  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.02  0.04
      0.13  0.15  0.09  0.11  0.15  0.11  0.07  0.06  0.03  0.01  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.02  0.04
      0.09  0.13  0.10  0.11  0.12  0.12  0.08  0.08  0.05  0.02  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.01  0.01  0.02  0.07
      0.14  0.12  0.08  0.10  0.11  0.10  0.07  0.06  0.05  0.02  0.01  0.00
      0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00  0.00
      0.00  0.00  0.00  0.00
```

```
##--><>--><>--><>-- Commercial Reduction fishery --><>--><>--><>--><>--><>--><>--
><>
#Starting and ending years of landings time series, respectively
1948
2010
##Observed landings (1000 mt) and assumed CVs
#total landings including reduction, bait, and recretional
74.8187801	107.6187801	147.4101074	155.0130558	227.3137815	195.9112867
	181.4112414	213.5209029	244.2244863	159.513464	196.4501597	326.1193153
	377.0154598	456.1215379	479.2190432	437.7302923	408.0482092	461.6060142
	358.0642555	316.3678044	372.3173086	521.8473646	546.3899289	729.0759754
	502.4022666	487.0559892	587.9286657	543.0215724	561.7376468	447.6076643
	820.6137239	779.8369297	702.5088237	553.7127019	855.5306431	925.26319
	985.1222814	884.5466744	830.8792809	911.6692996	640.2078039	583.5437816
	539.5201795	552.9801032	432.8065373	551.552376	774.9238254	472.0244485
	491.7517232	623.1465888	487.1615644	685.3769203	580.294677	522.0985091
	575.0798298	517.7067425	469.1853195	434.1293029	464.6286697	454.0805233
	425.567131	457.6892615	379.9389777
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	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 reduction, bait, and recreational
fishery combined
1964
2010
47
1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
	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
##sample sizes of age comps by year  (first row observed N, second row effective N:
effective may be set to observed)
#number of fish sampled first row, number of net sets 2 and 3 rows
#12260		15185	12429	14065	15273	14764	10402	7654	9886	8953	10086	9527
	13389	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
#625	790	640	721	795	759	527	393	998	896	1009	953	1355
	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
```

```
#625    790    640    721    795    759    527    393    998    896    1009   953    1355
        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
#200     200    200    200    200    200    200    200    200    200    200    200    200
200    200    200    200    200    200    200    200    200    200    200    200    200    200
200    200    200    200    200    200    200    200    200    200    200    200    200    200
200    200    200    200    200
#200     200    200    200    200    200    200    200    200    200    200    200    200
200    200    200    200    200    200    200    200    200    200    200    200    200    200
200    200    200    200    200    200    200    200    200    200    200    200    200    200
200    200    200    200    200
10      10     10     10     10     10     10     10     10     10     10     10     10
        200    200    200    200    200    200    200    200    200    200    200    200
        200    200    200    200    200    200    200    200    200    200    200    200
        200    200    200    200    200    200    200    200    200    200
10      10     10     10     10     10     10     10     10     10     10     10     10
        200    200    200    200    200    200    200    200    200    200    200    200
        200    200    200    200    200    200    200    200    200    200    200    200
        200    200    200    200    200    200    200    200    200    200

#age composition samples (year,age)
0.001   0.673   0.302   0.024   0.001
0.007   0.807   0.173   0.013   0.000
0.007   0.781   0.204   0.008   0.000
0.005   0.920   0.073   0.003   0.000
0.014   0.759   0.219   0.008   0.000
0.003   0.819   0.174   0.004   0.000
0.009   0.581   0.404   0.006   0.000
0.003   0.727   0.247   0.023   0.001
0.004   0.623   0.354   0.018   0.001
0.012   0.707   0.258   0.023   0.000
0.000   0.715   0.274   0.011   0.000
0.024   0.541   0.332   0.102   0.000
0.000   0.744   0.223   0.033   0.000
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
0.000   0.667   0.293   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   0.543   0.386   0.067   0.003
0.000   0.362   0.564   0.062   0.012
0.000   0.250   0.672   0.073   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

##################Parameter values and initial
guesses#######################################################################
#######
###Selectivity parameters.
###Initial guess must be within boundaries.
# Initial guesses initialized near solutions from preliminary model runs
# zero in slope2 provides logistic selectivity

1.21 #selpar_L50_cR   ---commercial reduction fishery
3.56 #selpar_slope_cR
6.0 #selpar_L502_cR
0.0  #selpar_slope2_cR

1.2 #selpar_L50_gill  ---adult abundance index based on gillnet surveys
7.5 #selpar_slope_gill
3.2 #selpar_L502_gill
0.0 #selpar_slope2_gill

#vector of initial guesses for gillnet selectivity with a parameter estimated for each age
#-10.0  -10.0  10.0  10.0  10.0   #logit space
-10.0   0.915  9.918 10.0  10.0   #logit space
```

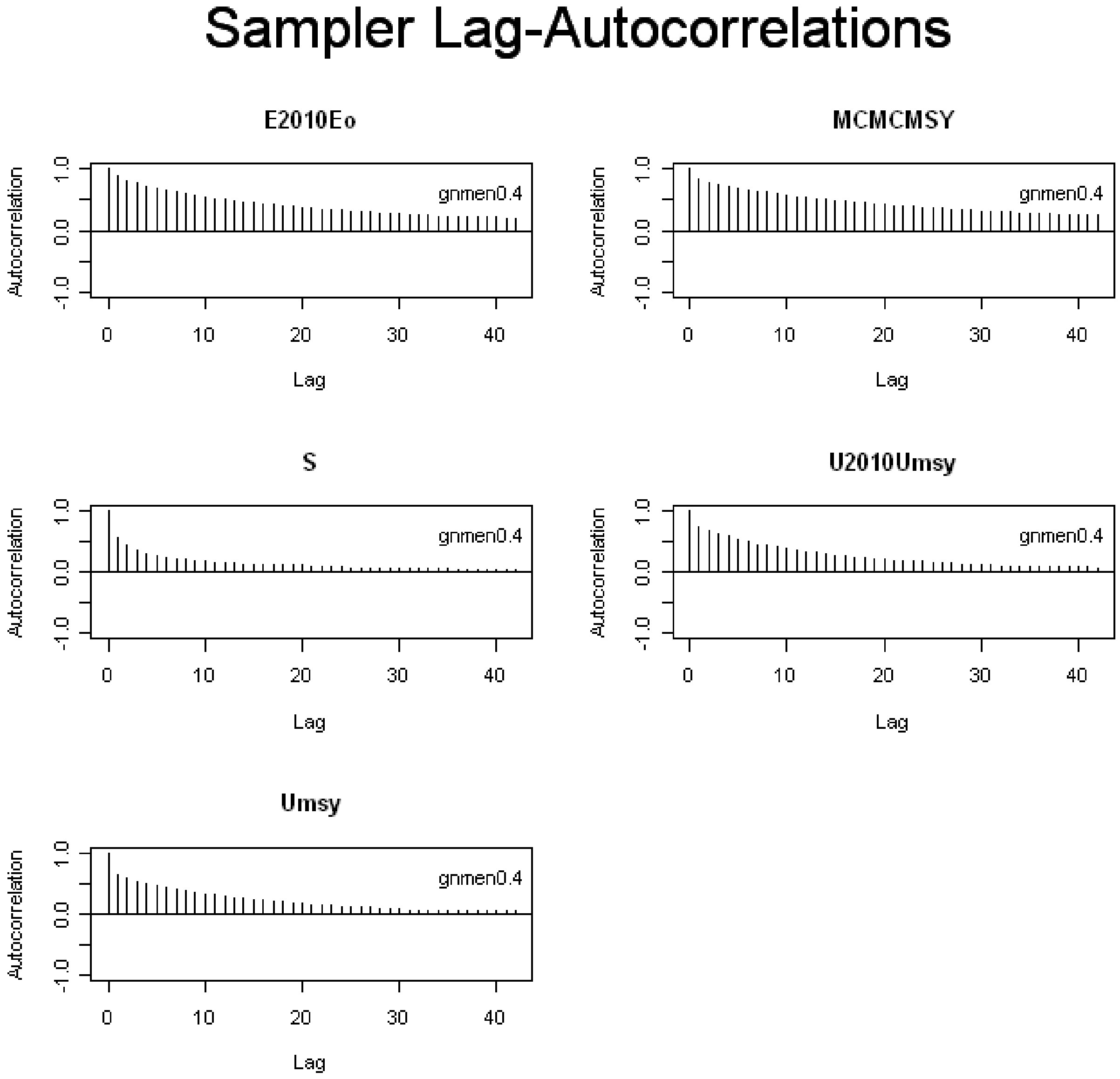
```
#vector of initial guesses for commercial reduction selectivity with a parameter estimated
for each age
-10.0   0.0   10.0   0.0   0.0  #period 1
-10.0   0.0   10.0   10.0   10.0  #period 3
-10.0   0.0   10.0   10.0  10.0  #period 4


##################Likelihood Component
Weighting#####################################################################
############
##Weights in objective fcn
1.0       #landings
0.25#0.742#1.0     #age comps
1.0#0.389#1.0 #JAI-seine index
0.0     #JAI-trawl index
1.0#2.0#0.300#1.0     #adult gillnet index
0.5#0.160#1.0     #length comps for gillnet index
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)
0.0       #weight on tuning F (penalty not applied in final phase of optimization)
0.0     #weight for penalty to keep JAI combination weights summing to 1.0

##############################################################################
####################################
##log catchabilities (initial guesses)
-13     #JAI seine survey
-13     #JAI trawl survey
6     #gillnet survey

#exponent for JAI cpue index
1.0

#JAI combination weights
0.25
0.25
0.25
0.25

#rate increase switch: Integer value (choose estimation phase, negative value turns it off)
-1
##annual positive rate of increase on all fishery dependent q 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

##log mean F (initial guesses) for commercial reduction, bait, and recreational combined
-0.2

#Initialization F as a proportion of  first few assessment years (set to 1.0 without evidence
otherwise)
1.0

#Tuning F (not applied in last phase of optimization)
1.5

#Year for tuning F
2006

#threshold sample sizes (greater than or equal to) for gillnet length comps and reduction
age comps
100.0
1.0

#switch to turn priors on/off (-1 = off, 1 = on)
1

##############################################################################
###################################
#Ageing error matrix (columns are true age 0-6, rows are ages as read for age comps)
#1      0       0       0       0
#0      1       0       0       0
#0      0       1       0       0
#0      0       0       1       0
#0      0       0       0       1

#scale to otolith comparison
1.00    0.00    0.00    0.00    0.00
```

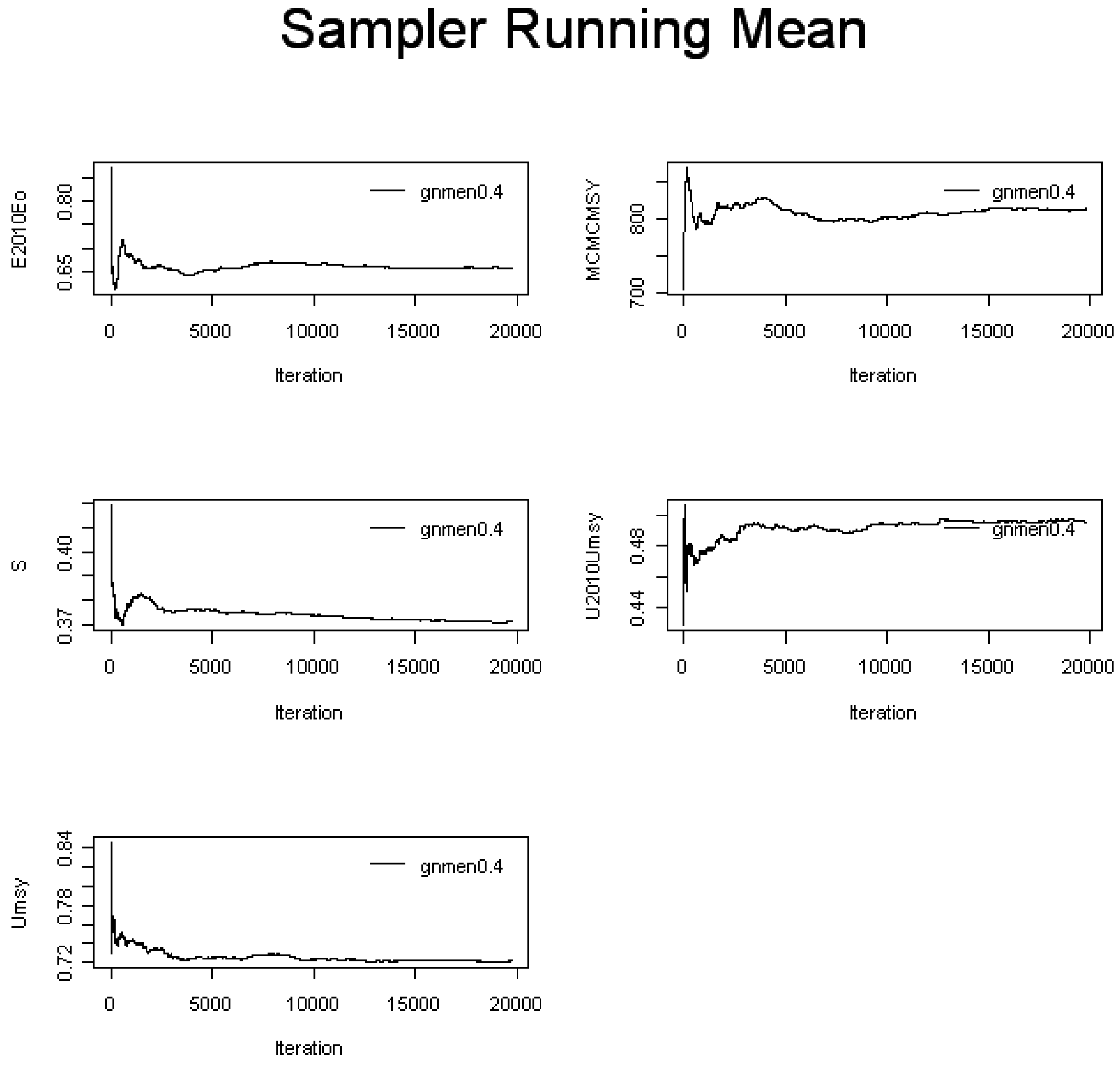
```
0.00    1.00    0.11    0.00    0.00
0.00    0.00    0.78    0.16    0.00
0.00    0.00    0.11    0.68    0.17
0.00    0.00    0.00    0.16    0.83

##############################################################################
####################################
#Environmental factors
###########Total River flow###################
10983.0
18437.0
16349.2
13215.0
21193.0
22515.0
17535.6
22496.0
20899.0
35071.2
35775.6
28075.8
21406.4
12878.6
22944.0
27794.4
21521.8
10943.6
21331.8
31445.0
25676.6
31048.6
27107.4
28229.2
24416.4
26665.2
24476.4
31715.2
24407.8
29912.8
30620.6
21659.4
18156.6
34671.2
25102.0
26949.2
11735.4
```

```
21751.0
23679.6
22235.8
23895.0
33908.4
14050.4
23438.2
22618.6
19011.8
33699.4

#switch for incorporation of environmental factor or not (1=on and 2=off)
2
#parameter for the environmental factor
0.005  #initial guess

############################################################################################
##########################################
#Length at age used for gillnet survey length comps but based on reduction fishery lengths
#observed lengths at midyear
110.34 148.92 178.2   199.38 208.95

#estimated variation in growth across ages, assumed constant across time
0.126077397   0.098063335   0.063808731   0.051807243   0.049427251
#se of the length at age
0.5       0.027525088   0.026459695   0.072955378   0.264434554

#Von B intial guesses for parameters
237.8
0.444
-0.808

#Standard errors of vonBert param (Linf, K, t0), applied if params are estimated
70.42
0.1618
0.6215

############################################################################################
##########################################
999 #end of data file flag
```

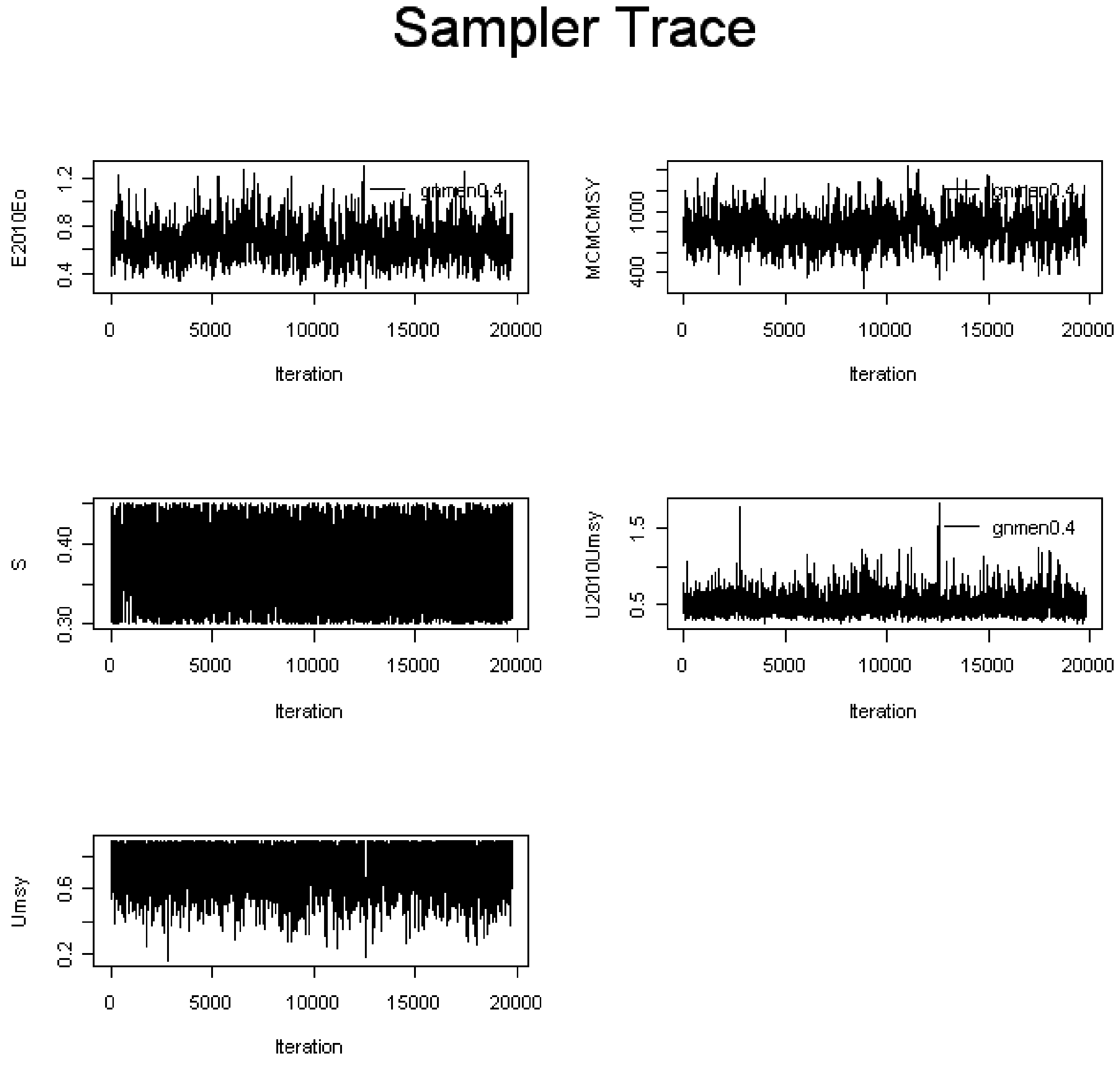
**Appendix B.1.**
MCMC convergence diagnostic for one of the alternate-1 model runs (U=0.4) - autocorrelations for five selected parameters (MSY, S, $U_{MSY}$, $E_{2010}/E_0$, and $U_{2010}/U_{MSY}$), indicating a declining pattern in autocorrelation with an increasing number of lags in the chain for five selected parameters.



**Appendix B.1.** (Cont.)
MCMC convergence diagnostic for one of the alternate-1 model runs (U=0.4) - running mean for five selected parameters MSY, S, $U_{MSY}$, $E_{2010}/E_0$, and $U_{2010}/U_{MSY}$, used to inspect plots of iterations against the mean of the draws up to each iteration.

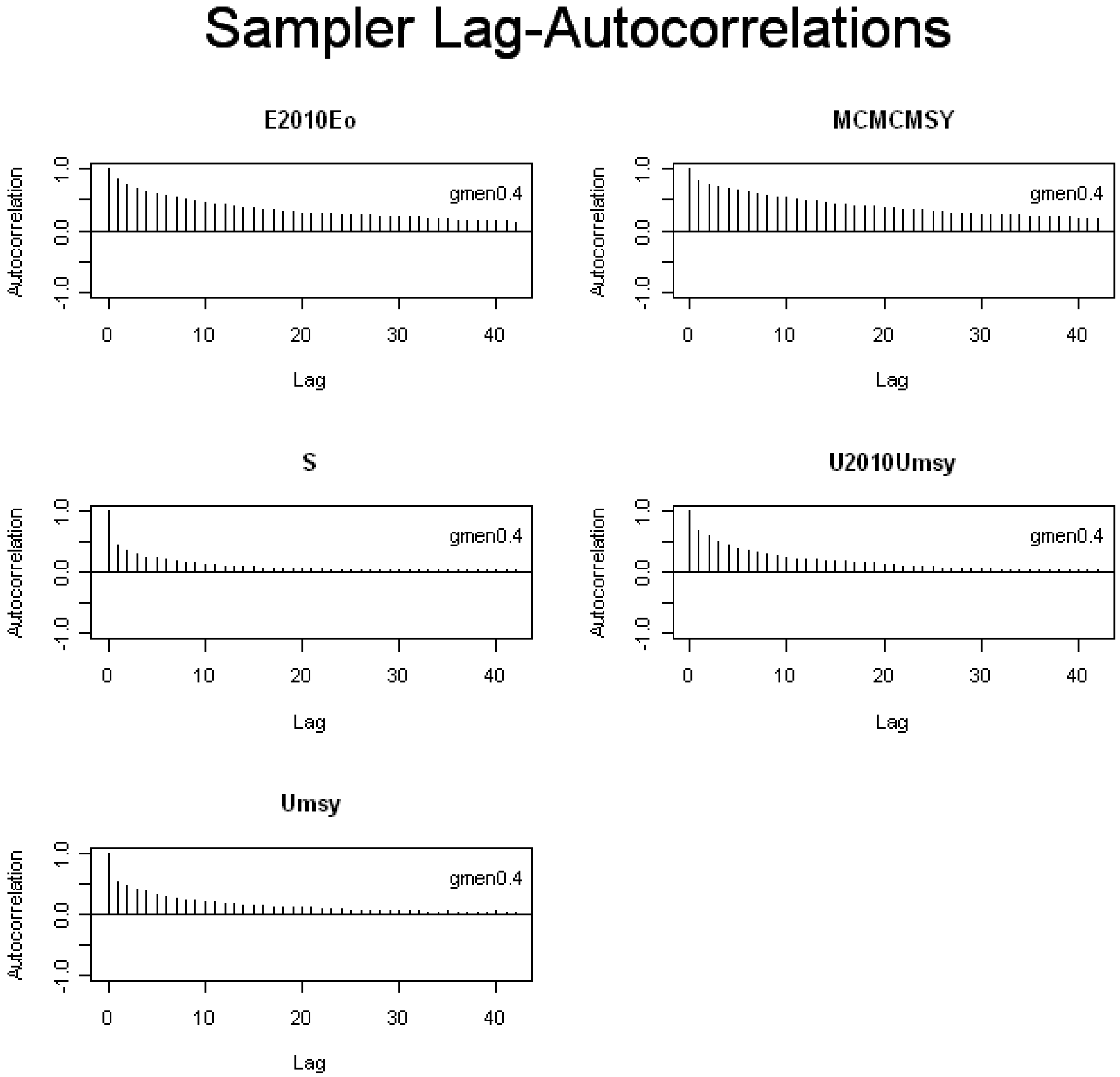


**Appendix B.1.** (Cont.)
MCMC convergence diagnostic for one of the alternate-1 model runs (U=0.4) - trace plots (parameter value at time against the iteration number) for five selected parameters (MSY, S, $U_{MSY}$, $E_{2010}/E_0$, and $U_{2010}/U_{MSY}$), indicating a fairly stable trend around the mode of the distribution for the selected parameters.



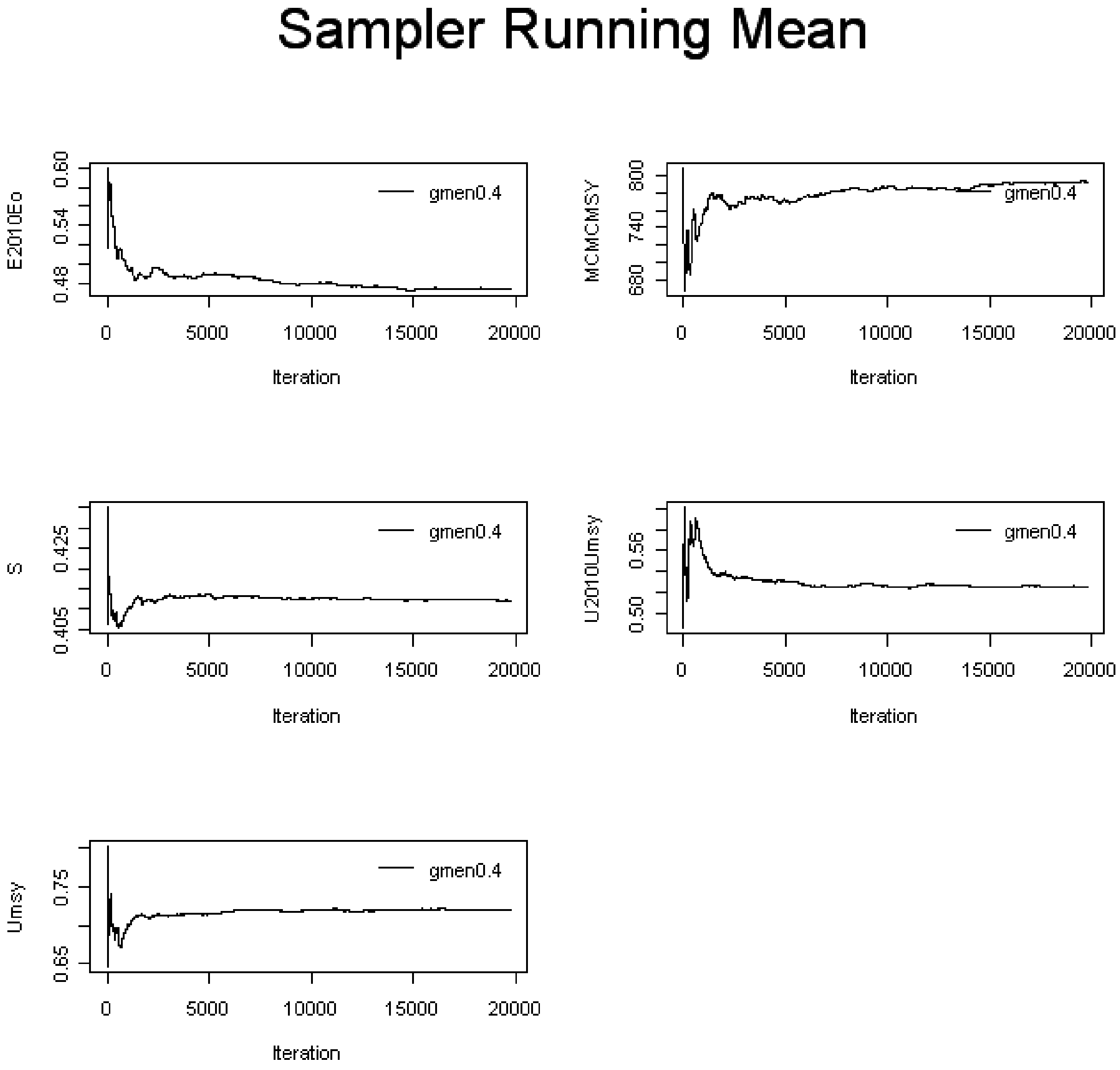
**Appendix B.2.**

MCMC convergence diagnostic for one of the alternate-2 model runs (U=0.4) - autocorrelations for five selected parameters (MSY, S, $U_{MSY}$, $E_{2010}/E_0$, and $U_{2010}/U_{MSY}$) , indicating a declining pattern in autocorrelation with an increasing number of lags in the chain for five selected parameters.



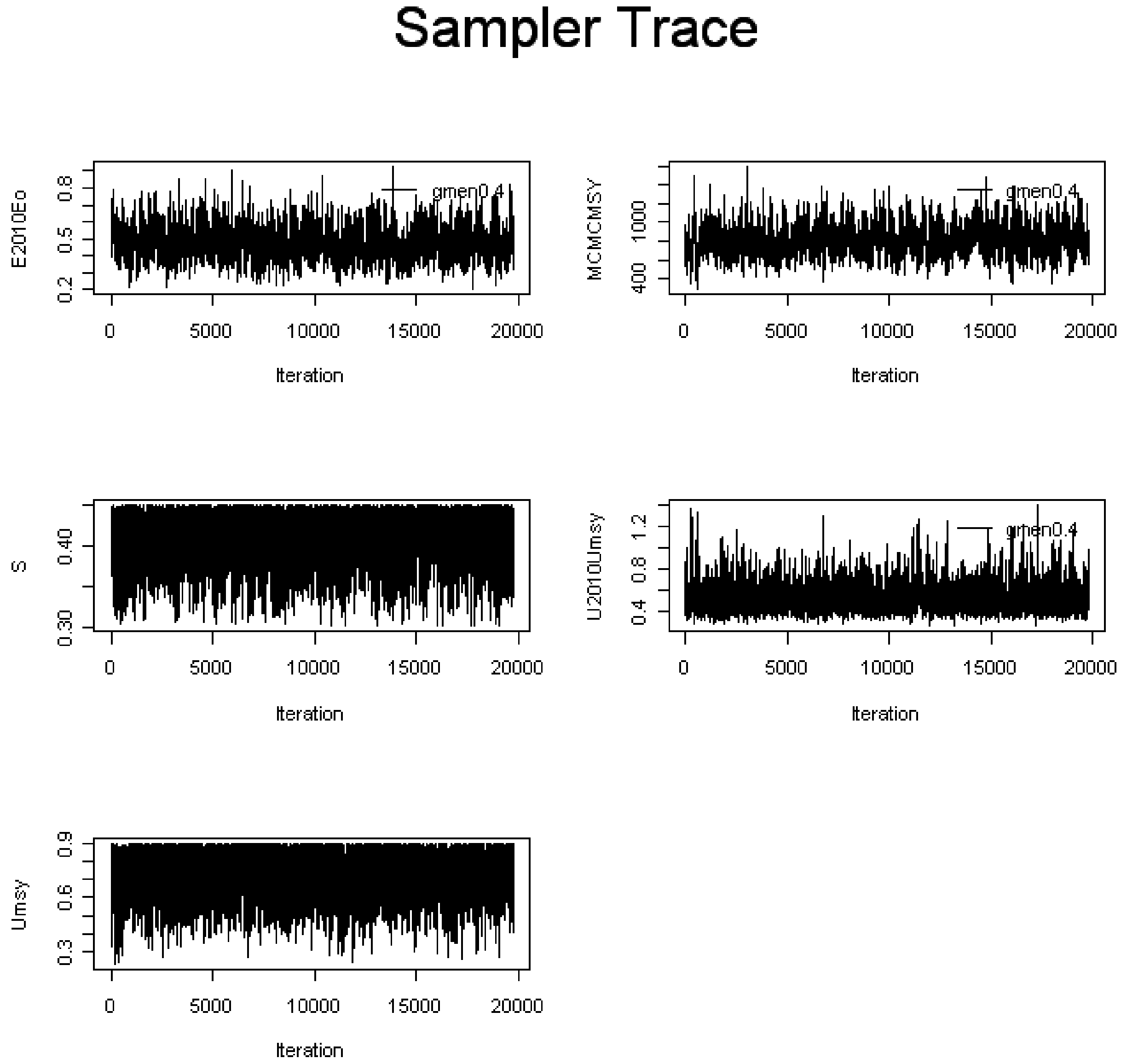
**Appendix B.2.** (Cont.)

MCMC convergence diagnostic for one of the alternate-2 model runs (U=0.4) - running mean for five selected parameters MSY, S, $U_{MSY}$, $E_{2010}/E_0$, and $U_{2010}/U_{MSY}$, used to inspect plots of iterations against the mean of the draws up to each iteration.



**Appendix B.2.** (Cont.)

MCMC convergence diagnostic for one of the alternate-2 model runs (U=0.4) - trace plots (parameter value at time against the iteration number) for five selected parameters (MSY, S, $U_{MSY}$, $E_{2010}/E_0$, and $U_{2010}/U_{MSY}$), indicating a fairly stable trend around the mode of the distribution for the selected parameters.



# SEDAR

## Southeast Data, Assessment, and Review

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# SEDAR 27

# Gulf of Mexico Menhaden

## SECTION V: Review Workshop Report

**December 2011**

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

## Table of Contents

## 1. INTRODUCTION

### *1.1 WORKSHOP TIME AND PLACE*

The SEDAR 27 Review Workshop was held November 1-4, 2011 in Saint Petersburg, Florida.

### *1.2 TERMS OF REFERENCE*

1. Evaluate precision and accuracy of fishery-dependent and fishery-independent data used in the assessment:
    a. Discuss data strengths and weaknesses (e.g. temporal and spatial scale, gear selectivities, aging accuracy, sampling intensity).
    b. Report metrics of precision for data inputs and use them to inform the model as appropriate.
    c. Describe and justify index standardization methods.
    d. Justify weighting or elimination of available data sources.
2. Evaluate models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points.
    a. Did the model have difficulty finding a stable solution?
    b. Were sensitivity analyses for starting parameter values, priors, etc. and other model diagnostics performed?
    c. Have the model strengths and limitations been clearly and thoroughly explained?
    d. Have the models been used in other peer reviewed assessments? If not, has new model code been verified with simulated data?
    e. Compare and discuss differences among alternative models.
3. State and evaluate assumptions made for all models and explain the likely effects of assumption violations on model outputs, including:
    a. Calculation of M.
    b. Choice of selectivity patterns.
    c. Error in the catch-at-age matrix.
    d. Choice of a plus group for age-structured species.
    e. Constant or variable ecosystem (e.g., abiotic) conditions.
    f. Choice of stock-recruitment function.

    g. Choice of reference points (e.g. equilibrium assumptions).
4. Evaluate uncertainty of model estimates and biological or empirical reference points.
    a. Choice of weighting likelihood components.
5. Review the findings from the retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., F, SSB), reference points, and/or management measures.
6. Recommend stock status as related to reference points.
7. Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

### *1.3 LIST OF PARTICIPANTS*

***Workshop Panel***

| | |
|---|---|
| Luiz Barbieri, Chair | FWRI |
| John Wheeler | CIE Reviewer |
| Patrick Cordue | CIE Reviewer |
| Sven Kupschus | CIE Reviewer |
| Will Patterson | GSMFC-appointed Reviewer |

***Analytic Representation***

| | |
|---|---|
| Amy Schueller | NMFS SEFSC Beaufort |
| Bezhad Mahmoudi | FWRI |
| Mike Prager | Prager Consulting |

***Rapporteur***

| | |
|---|---|
| Wade Cooper | FWRI |

***Observers***

| | |
|---|---|
| Doug Vaughan | GSMFC observer |
| Ron Lukens | Omega Protein |
| Lew Coggins | NMFS SEFSC Beaufort |

***Staff***

| | |
|---|---|
| Julie Neer | SEDAR |
| Rachael Silvas | SEDAR |
| Steve VanderKooy | GSMFC |

## 2. REVIEW PANEL REPORT

## 1. SEDAR 27 Review Panel Summary Report

The stock assessment presented by the SEDAR 27 Assessment Workshop provided the Review Panel with thorough descriptions of the data available for assessing Gulf menhaden, information about the life history of this species, as well as outputs and results from three assessment models. The primary (i.e., base) model was the Beaufort Assessment Model (BAM), a forward-projecting age-structured model. Additionally, Stock Production Model Incorporating Covariates (ASPIC), a non-equilibrium surplus production model, as well as a fully-Bayesian implementation of Stochastic Stock Reduction Analysis (SRA) were used as supporting models. The Panel identified serious areas of concern with both data and model components and felt that, as presented, none of the assessment models provided realistic representations of Gulf menhaden stock dynamics and productivity. Therefore, in the absence of an acceptable quantitative stock assessment the Panel could not recommend stock status in relation to reference points. However, on a qualitative basis, the Panel believes that information from the landings history, the reduction fishery catch-at-age data, and the “worst case” ASPIC model runs suggest that most likely the Gulf menhaden stock could be classified as “not overfished” and “not undergoing overfishing.” Although results were unsatisfactory for this stock assessment, they did serve to clarify additional research necessary for future assessment efforts. Prioritized lists of short- and long-term research recommendations are presented and briefly discussed.

## 2. Terms of Reference

1) **Evaluate precision and accuracy of fishery-dependent and fishery-independent data used in the assessment:**
    a. **Discuss data strengths and weaknesses (e.g. temporal and spatial scale, gear selectivities, aging accuracy, sampling intensity).**
    b. **Report metrics of precision for data inputs and use them to inform the model as appropriate.**
    c. **Describe and justify index standardization methods.**
    d. **Justify weighting or elimination of available data sources.**

There were several data inputs used in the different modeling frameworks to estimate stock dynamics and productivity in the Gulf menhaden fishery. These include estimated menhaden landings and fishing effort, size and age composition of the landings, and catch per unit of effort (CPUE) indices of abundance. The strengths and weaknesses of each of the specific data sources are evaluated below along with the metrics of precision for each data input. The methods for standardizing CPUE indices also are described and evaluated. The elimination or weighting of various data sources was specific to each modeling framework and is discussed for each of those separately below.

### Landings Data

Data workshop participants identified four fisheries in the northern Gulf of Mexico that historically have targeted Gulf menhaden or caught them as bycatch. The predominant source of menhaden landings has been the commercial reduction fishery, which is estimated to account for >99% of landings (Assessment Report Table 4.2). Other sources of landings include a bait fishery centered in Louisiana, for which landings have dropped from a peak of 2.5% of total landings in the mid 1990s to less than 0.1% in recent years, and a recreational castnet fishery that has accounted for approximately 0.01% of total landings over the past decade. Bycatch mortality likely results from the Gulf shrimp trawl fishery, but the magnitude of bycatch was poorly estimated and was not incorporated by the assessment panel in base model configurations.

There is evidence of minor Gulf menhaden landings dating back to the 1870s, but the commercial reduction fishery began in earnest following World War II (WWII). A near census of commercial reduction landings is available dating back to 1964 when the reduction plants began reporting daily offload data. Furthermore, reduction plant records made available to NMFS in the 1960s enabled the estimation of daily landings back to 1948. The landings data since 1964 represent one of the more comprehensive landings data sets among all US fisheries. No substantive errors were discussed with respect to landings data between 1948 and 1964, but it is important to note that landings size and age composition data are not available for that time period. The main concern panelists expressed with respect to landings estimates was the fact the industry self reports landings in 1,000s of standard fish instead of directly weighing the catch. This metric dates to the early days of the fishery 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 would hold 1,000 standard fish. Therefore, landings are not directly weighed (except at one plant following Hurricane Katrina), and panelists expressed some concern about the consistency of hopper dimensions, and therefore landings estimates, across time series.

Landings data input into both the BAM and ASPIC models included the time series from 1948-2010. However, the landings time series for the SSRA model was extended back to 1873. A linear interpolation based on the development of the Atlantic menhaden fishery was employed to estimate landings back to 1918, as landings data were not available for the fishery for all years between 1918 and 1948. Limited US menhaden landings data also exist back to 1873, and the mean percentage (2.46%) of Gulf menhaden landings among total (Gulf and Atlantic) menhaden landings from the time period 1918-1940 was applied to landings estimates from 1873 to 1917 to reconstruct Gulf menhaden landings back to the origin of the Gulf fishery. While there is high degree of uncertainty with respect to these early landings estimates, the consensus of the panel was that landings prior to the 1940s were so minor as to be inconsequential relative to the modern (post WWII) fishery.

### Size and Age Composition of Reduction Landings

Size and age composition estimates of commercial reduction fishery landings have been available since 1964 when NMFS scientists began two-stage cluster sampling of commercial landings. Originally, port agents randomly selected fishing vessels to sample then took a sample of fish from the top of the hold prior to offloading the catch. Samples are assumed to represent the last set of the day. Fish to be aged then were randomly selected from that sample, with a target sample of 20 fish in the early years and 10 fish since the early 1970s. Budget constraints meant a shift in sampling protocols after 1994 when temporary federal employee port samplers were replaced by dockside personnel. These samplers are trained by NMFS Beaufort scientists and paid a nominal fee per sample collected.

Scales are removed from sampled fish to estimate the age composition of the landings. Prior to 1992 six scales were sampled from each fish, but 10 scales have been sampled per fish since then. Scales were read by two independent readers prior to the early 1970s; a single reader has read all scale samples since the early 1970s. Smith and Levi (1990) reported 71% agreement between age estimates from otolith thin sections (n = 228) and those from scales, while Smith and Hall (2009) reported 82% agreement between a single reader's age estimates derived from scales (n = 3,405) on two occasions separated by several months. The assessment panel attempted to account for these sources of ageing error by developing an ageing error matrix with the method of Punt et al. (2008).

The data set that has resulted from NMFS sampling and ageing menhaden landings is among the more comprehensive for US Fisheries, especially considering that age composition data are available back to 1964. However, concerns were raised about the fact that only a single reader has aged fish since the early 1970s, and between and within reader variability is not routinely estimated. The ageing error matrix developed for this assessment was intended to address and control for ageing error, but comparisons between otolith- and scale-based ages could only be used for creating such a matrix if otolith ages are known to be error free. Furthermore, agreement between otolith- and scale-derived age estimates appears to be low (71%) given the perception that menhaden ageing is straightforward and not difficult. The fact that within reader ageing agreement was only 82% also caused concern among some panelists. There was concern expressed about the potential for ageing drift over the time series (e.g., a shift exists from predominantly age-1 to predominantly age-2 fish in the estimated age composition of landings from the 1960s to the present, as well as an increase in the number of age-3 and age-4 fish, without a concurrent shift in estimated size composition of landings). Verification of such an effect, or its absence, is possible given that archived scale samples exist and should be considered.

### Effort Data and Reduction Fishery CPUE

Logbooks were first placed on fishing vessels operating in the commercial reduction fishery in the 1960s but compliance was poor and the original program was abandoned. However, a logbook program was revived in the 1970s in the form of captains' daily fishing records (CDFRs). Subsequent full participation in the program resulted in more comprehensive effort data (e.g., duration of trip, number of sets, fishing location, etc.) being available since the early 1980s. For this more recent time period, nominal catch per set or trip can be computed. However, earlier effort data are only available at coarser resolution. The standard adopted by NMFS scientists has been to estimate CPUE as catch per vessel ton week (VTW = one vessel, fishing at least one day of a week, times its net tonnage), reflecting the level of resolution in the effort data prior to the 1980s. Trends in standardized CPUE computed as catch per VTW (1948-2010), trip (1964-2010, or set (1982-2010) were similar for time periods of overlap (Assessment Report Figure 4.6), with the exception being from 1964 to 1982 when VTW was increasing but the number of trips was high and without trend (Assessment Report Figure 4.5).

Nominal CPUE (C/VTW) from 1948 to 2010 was a data input into both ASPIC and SSRA, and examined as a sensitivity run in the BAM model. Concerns raised by review panelists included the likelihood of hyper-stability in CPUE for a schooling fish targeted with spotter aircraft, as well as uncertainty in the magnitude of change in fishing power of the fleet, hence catchability (q), over time. However, another view expressed was that an index of adult abundance was required and that perhaps the reduction fishery CPUE was more suitable than the only other candidate, the gillnet index (see below). In the end, panelists had considerable reservations with respect to using the reduction index in its current form (not standardized) or the gillnet index on the more fundamental grounds that it does not overlap with the fishery.

Fishery-independent CPUE Indices of Abundance

Three fishery-independent indices of abundance were computed as inputs for stock assessment models. These include seine and trawl indices that are thought to represent abundance trends in age-0 fish, and a gillnet index that was assumed to index adult abundance. The data used to compute each of these fishery-independent indices were collected during monitoring surveys within states' waters. However, methods and gear dimensions differed among states, and no surveys were conducted within any Gulf state that were specific to menhaden.

Monitoring surveys differed among Gulf states with respect to seine dimensions, method of deployment, and years sampled. Seine catches of menhaden [< 100 mm total length (TL)] from 1977 to 2010 were ratioed to estimated area swept as the measure of sampling effort. Catch per unit effort was then modeled with the delta-lognormal generalized linear model (GLM) approach, with presence/absence and CPUE as the response variables and year, state, month, temperature, and salinity as explanatory variables. Separate Bernoulli and positive CPUE sub-models were computed, with explanatory variables selected with a stepwise AIC backwards selection algorithm for each sub-model. Standardized CPUE was then computed based on fits and retained explanatory variables of sub-models.

Monitoring surveys also differed among Gulf states with respect to trawl dimensions, survey design, sampling effort, and years sampled. Trawl catches of menhaden [< 100 mm total length (TL)] from 1967 to 2010 were ratioed to minutes towed as the measure of sampling effort. Catch per unit effort was then modeled with the delta-generalized linear model (GLM) approach described above, with CPUE as the response variable and year, state, month, temperature, salinity, and depth as explanatory variables.

The panelists concluded that the delta-lognormal approach to standardizing seine and CPUE indices was appropriate. However, there was some uncertainty as to how accurately either indexed abundance of age-0 menhaden, especially given different methodologies and sampling effort among states, as well as uncertainty as to the correspondence between seine sampling sites and juvenile habitat distribution. The fact that standardized seine and trawl CPUE were significantly correlated did provide some indication that both indexed similar age classes, which most likely were juveniles (Assessment Report Fig. 5.9).

The final fishery-independent index of abundance was the gillnet index, which was proposed as an index of adult abundance. Similar issues existed as indicated above for seine and trawl surveys with respect to differences in sampling effort and the time series of sampling among states, but gillnet dimensions, construction, and methods of deployment were more different among states than for those other two gears. A delta-GLM approach was taken to standardize gillnet CPUE, with year, state, month, temperature, salinity, mesh size, and day/night as explanatory variables, but concerns remained with how to standardize effort given that most states fish survey gillnets passively while the nets are fished as strike nets in Louisiana. Therefore, a second gillnet index was computed by removing the state effect and only modeling survey data from Louisiana.

There was quite a bit of discussion among panelists as to the utility and appropriateness of standardized gillnet CPUE to index adult menhaden biomass, with most discussion focused on the Louisiana-only index. Clearly, reduction fishery effort, which is targeted at adult menhaden, occurs offshore while gillnet stations are inshore. Fishery regulations that prohibit inshore purse seining for menhaden are part of the reason for this difference, as well as water depth limitations on commercial fishing vessels. However, no data were presented in the assessment report to indicate that the distribution of inshore gillnet sampling sites overlap significantly with the distribution of adults, or what the temporal variability in any such overlap is. More detailed information attained at the review workshop indicated that the overlap of the index with that of the fishery is very marginal at best, suggesting that the use of the index may introduce significant bias in the assessment irrespective of the way it is estimated. In addition the method of deploying survey gillnets in Louisiana also was of concern given that menhaden are schooling fish and schools might be targeted or avoided easily when setting strike gillnets. In the end, the only clear consensus among panelists was that neither the commercial reduction CPUE in its current form nor the standardized Louisiana gillnet CPUE were well-suited as indices of adult menhaden biomass.

2) **Evaluate models used to estimate population parameters (e.g., F, biomass, abundance) and biological reference points.**
    a. **Did the model have difficulty finding a stable solution?**
    b. **Were sensitivity analyses for starting parameter values, priors, etc. and other model diagnostics performed?**
    c. **Have the model strengths and limitations been clearly and thoroughly explained?**
    d. **Have the models been used in other peer reviewed assessments? If not, has new model code been verified with simulated data?**
    e. **Compare and discuss differences among alternative models.**

3) **State and evaluate assumptions made for all models and explain the likely effects of assumption violations on model outputs, including:**
    a. **Calculation of M.**
    b. **Choice of selectivity patterns.**
    c. **Error in the catch-at-age matrix.**
    d. **Choice of a plus group for age-structured species.**
    e. **Constant or variable ecosystem (e.g., abiotic) conditions.**
    f. **Choice of stock-recruitment function.**
    g. **Choice of reference points (e.g. equilibrium assumptions).**

Three models were presented: (1) Beaufort Assessment Model (BAM), (2) Surplus Production Model (ASPIC), and (3) Stochastic Stock Reduction Analysis (SRA). Based upon the conclusions from the Assessment Workshop, the BAM was presented as the base (preferred) model.

(1) Beaufort Assessment Model (BAM)

General Description:

The BAM, a forward-projecting age-structured model, was used in this assessment as it provides multiple options for benchmark computation and model diagnostics, and can account for uncertainty through sensitivity runs and Monte Carlo bootstrapping. It was also used in the previous gulf menhaden assessment (Vaughan et al. 2007).

Model Configuration:

Two abundance indices (discussed in the Data section of this report) were input into BAM: 1) a Louisiana gillnet index for adult fish (ages 1+), from 1977 to 2010, and 2) a multi-State seine index of recruitment for juvenile fish (age 0), from 1986 to 2010.

Parameters of the model (1948 – 2010) included:

1. an assumed constant age-specific natural mortality rate, scaled such that the age-2 mortality was 1.10, the mean from an Ahrenholz (1981) tagging study,
2. dome-shaped selectivity for the commercial reduction fishery from 1948 to1979, and flat-topped selectivity from 1980 to 2010,
3. dome-shaped selectivity for the gillnet index,
4. an ageing error matrix based on a comparison between scales and otoliths,
5. fish age 4 and older considered as a plus group,
6. an estimate of annual recruitment at age-0 with deviation parameters, conditioned about a Beverton-Holt stock recruitment curve,
7. maximum sustainable yield (*MSY*) benchmarks, where overfishing was defined as $F/F_{MSY}$ greater than one, and overfished defined as $SSB_{2010}/(0.5*SSB_{MSY})$ less than one,
8. weighting of data components, including indices, gillnet length composition, and commercial reduction fishery age composition.
9. estimation of steepness

Panel Concerns:

The Panel had many criticisms regarding the parameterization of the model and concerns regarding the results of the base BAM run. Criticisms regarding model parameterization included: the exclusion of the juvenile trawl index, the exclusion of a run including the adult reduction fishery index, and most importantly, the imposition of a penalty on the initial age structure. The Panel indicated that $B_0$ should approximate virgin biomass; otherwise, the model should only be run over years for which data are available. With regard to the base model output, the Panel expressed serious concerns regarding the residual pattern in ages, including the over-estimation of age 3 fish and underestimation of age 2 fish.

To address its concerns regarding this residual pattern, the Panel requested the assessment analyst to conduct a series of alternative model runs (see assessment addendum). A run with dome-shaped selectivity for the entire time period did not result in a change in the residual pattern. This increased the Panel's concerns regarding model structure. Further runs were requested, most of which were exploratory in nature, to examine model structure. Runs with varying levels of M (0.5 and 1.5) and selectivities fixed at ages 2 or 3 all hit bounds and provided little information. Similarly, runs with two selectivity blocks (pre and post 1992) also hit bounds. Initialization problems were evident in all runs. A run including the addition of the juvenile seine index eliminated the residual pattern for ages 2 and 3 but provided unrealistic estimates of initial biomass. Finally, a run in which the estimation of initial age structure was 'turned off' resulted in a dramatic change in the perception of stock status from the base model.

Conclusions:

The Panel concluded that there may be future potential for use of the BAM or other age-structured models to estimate stock dynamics and productivity for Gulf menhaden. However, there were too many unresolved questions regarding the current parameterization of the base BAM to use it to provide quantitative advice on current stock status.

(2) Surplus Production Model (ASPIC)

General Description:

ASPIC is a forward-projecting population model, and provides annual estimates of biomass, fishing mortality rate, etc. These are provided relative to their corresponding benchmarks, a procedure that reduces variance by removing the uncertainty in catchability (Prager 1994). The model describes the dynamics of exploited fish populations without requiring data on recruitment, growth, and mortality. It requires a time series of total landings from the population and one or more standardized indices of population abundance. It was presented as an alternative to the base model, as it includes different model assumptions, and can explore possible ranges in stock status relative to benchmarks.

Model Configuration:

As in the base BAM configuration, the juvenile seine index was used in the base production-model configuration. It was advanced one year for better correspondence with data on removals and with adult abundance indices. Tabulated *CV*s were doubled to address for the adjustment in time. The adult abundance index derived from fishery-independent gillnet sampling off Louisiana was used, as in BAM. Sensitivity runs were done using the reduction fishery index with a 1% correction for changes in the fishery.

Parameters of the model included:

1. $K$ (the carrying capacity),
2. $B_1/K$ (starting biomass relative to $K$),
3. $r$ (intrinsic rate of population increase)
4. a series of catchability coefficients $q_i$, $i = 1 \ldots m$, where $m$ is the number of abundance indices used.

Panel Concerns:

The biomass production model is a much simpler modeling framework than the age structured BAM model, but as a consequence it is more susceptible to assumptions made about stock productivity and the abundance indices used. The fact that the model indicated two very different stock trajectories on the basis of gillnet vs. stock reduction indices exemplifies this sensitivity. The panel felt the abundance signal provided by the Louisiana gillnet index was questionable. Although it did show that it was tracking density in the area, the area was not representative of the stock as a whole as it overlapped spatially only very marginally with the fishery. Regarding the potential use of the reduction index the Panel's concerns were twofold: (1) the gross vessel tonnage week is unlikely to compensate for increased efficiency of the fleet, and (2) the purse seine gear is known to be hyper-stable with respect to CPUE especially when as is the case here it is used in conjunction with spotter planes.

There is then no defensible adult index on theoretical grounds and the juvenile indices, although independently corroborated, are representative of recruitment only if they are lagged by a year. In other words, the models are likely to be biased, a problem that is confounded by the oversimplification of the biological processes (process error) involved in stock dynamics due to the need to maintain model parsimony with very little information. This does not mean that ASPIC cannot provide useful information on stock dynamics, but it does suggest that the interpretation of results is less than straightforward. For example, the estimate of $F_{MSY}$ is unrealistically low (~0.07) and suggests that in this case, as documented for other stocks, ASPIC is having difficulty with scaling the problem in absolute terms. This makes it insufficient for calculating benchmarks properly when based on proxies. It also suggests that the rates estimated in the model are overly sensitive, although this sensitivity is unlikely to have a major impact on the exploitation ratios $F/F_{MSY}$ and $B/B_{MSY}$.

Given the concerns over the adult index information the Panel felt unable to use ASPIC for quantitative advice. We focused instead on development of a worst case scenario to at least provide some qualitative information on the lower tails of the distribution of stock status. Four potential worst case scenarios were developed. Common among them was adjusting the reduction index for a 2% increase in efficiency compounded annually, which is equivalent to a 3.4 fold increase in efficiency over the time period of the index. Either a Shaefer or Fox production functions was assumed for model scenarios that only included the adjusted reduction index, as well as for models that included the adjusted reduction index and the juvenile indices.

All models indicated that F had declined recently and in three out of the four cases it was now below $F_{MSY}$ and close to the level estimated in the most pessimistic case, which turned out to be the Schaefer model with only the reduction index included. This model also the lowest value for $SSB/SSB_{MSY}$, with SSB at roughly 75% of $B_{MSY}$. However, even here the SSB appeared to be stable at near equilibrium conditions given the trajectory of recent F values. The other permutations suggested that the stock had been increasing recently, at least in part guided by the juvenile index, and that SSB was much closer to or above $B_{MSY}$.

Conclusions:

The Panel concluded from these worst case scenarios that there was little chance that overfishing was occurring in recent years. Given the pessimistic approach used, ASPIC results also suggested it was unlikely that the stock was in an overfished state (despite the fact that the majority of the models suggested that $SSB < B_{MSY}$).

### (3) Stock Reduction Analysis (SRA)

General Description:

Stock reduction analysis (SRA), put simply, attempts to recreate historic patterns in catch while maintaining a viable population structure given assumed MSY, MSY exploitation rate ($U_{MSY}$), and natural mortality. Internal to the model, these input parameters are converted to corresponding estimates of spawning biomass or equivalent given fixed estimates of growth and maturity. Index information is converted in parallel from susceptible biomass to total biomass by use of appropriately defined selectivity information informs the model on an appropriate set of Beverton-Holt stock-recruitment parameters, which then in conjunction with an estimate of current exploitation rate (U) provides information on the cohort and exploitation trajectories through the history of the fishery. The model is deterministic in the sense that there is a single set of Beverton-Holt parameters and is conditioned on the assumed current exploitation rate. In this way the model is akin to a tuned VPA model, though age implicit, in that the information on recruitment is provided by the stock-recruitment relationship rather than the age information from catches.

SRA, as used by the assessment panel, is a fully Bayesian implementation of the model coded in VISUAL BASIC and using prior distributions for MSY, $U_{MSY}$, and M to ascertain posterior distributions on management parameters such as $F_{MSY}$ and $B_{MSY}$, and stock status determinants.

Model Configuration:

The model was configured with the following data, parameters and prior distributions.

1. Historical annual landings: (*metric tons, 1873-2010)*
2. Selectivity at age: obtained from *BAM for three periods (*1873-1979, 1980-1993 and 1994-2010)
3. SD Recruitment=0.5 (log normal anomalies $e^w$) (Sd=0.25 and Sd=0.75)
4. Index variance (lognormal obs. error, defaulted to 0.04, SD=0.2)
5. Current estimate of exploitation rate *(U): Given uncertainty, four scenarios with U=0.3-0.6 for each alternate model (range from historical tagging and assessment)*
6. Life history parameters: *growth parameters (K=0.44, Linf=23.7cm,* $t_0$*=-0.808), maximum weight (0.27kg), length maturity (18.3cm)*
7. Leading parameters priors: MSY (100,000 - 2,000,000 mt); $U_{MSY}$ *(0.1 -0.9); natural mortality rate (M=0.8-1.1,* $S = e^{-M} = 0.3\text{-}0.45$*)—assumed uniform probability distribution for MSY ,* $U_{MSY}$ *, and S*
8. One hundred thousand combinations of the input parameters were run, and those that were able to maintain viable populations were checked for convergence.
9. Two indices were used to inform the model on the likely S-R parameters. Alternate 1 used the all-states gillnet index, while alternate 2 used the reduction fishery index based on effort in vessel tonnage days.

Panel Concerns:

The posterior distributions indicated that both MSY and $U_{MSY}$ were relatively stable with respect to their independent estimates, suggesting MSY is near 800 Kt with $U_{MSY}$ is around 0.75. However, the conditional probability density of $U_{MSY}$ varied with the chosen estimate of the current exploitation rate due to the choice of priors. Exploitable biomass trajectories differed dramatically between the two alternates, with recent stock levels declining from an initial high value to currently low values and when using the reduction index, while the gillnet index suggested an increase since 1996 before declining slightly more recently. Clearly the model was able to accommodate both ‘views’ of reality, but provided little or no information as to which alternate may be considered more realistic., Therefore, it is difficult to draw any conclusions with respect to the trajectory of this stockgiven the Panel’s concerns expressed with respect to either of the indices.

The Panel was concerned that SRA-derived estimates were strongly dependent on the selectivities chosen in the calculation of the exploitable biomass. The selectivities used were taken from the proposed BAM model which was deemed to be unrepresentative of likely stock dynamics based largely on the severe residual patterns in the catch at age matrix. In other words, precisely the information needed by the SRA to provide reliable output.

The results of alternative 2 using higher exploitation rates suggested current stock status may be approaching management reference points with respect to both overfishing and stock depletion, yet the index did not correct for either technological creep or index hyper-stability. Therefore, this view may be more optimistic than reality.

Lastly, the posterior distributions are dependent on the priors and only a limited number were examined. While natural mortality choices may be consistent with the current knowledge of the species, it is unclear whether values of $U_{MSY}$ and MSY have been explored sufficiently. In addition the sensitivity over a number of U values was highly informative in terms of management measures, but it is unclear whether higher values of current U would not have altered the conclusions significantly. However, no reruns were conducted given the Panel's concerns with respect to the previous two paragraphs..

Conclusions:

The panel considered this modeling approach useful with respect to the evaluation of stock status relative to management quantities, but felt that given the problematic selectivity input and questionable index information it is not possible to draw conclusions from this analysis. However, with respect to absolute levels of MSY the estimates are thought to be more realistic than from the other modeling approaches.

### 4) Evaluate uncertainty of model estimates and biological or empirical reference points.

#### a. Choice of weighting likelihood components.

The manual weighting of the likelihood components in the BAM model appeared, at least in part, to be questionable *a priori* choices. However, a full analysis of the uncertainty component was not conducted as the model failed to produce realistic dynamics. This suggests that the bias, which cannot be estimated, rather than the variance likely was the main contributor to model uncertainty.

The ASPIC model does not formally deal with weighting of likelihood components much beyond inclusion or exclusion of certain indices. The Panel felt the inclusion of either adult index was likely to bias estimates of management quantities to the point where the mean estimates were likely to be further from the current condition than the breadth of the uncertainty estimate. Therefore, a worst case scenario was tested, which provides no quantitative estimate of the uncertainty.

The SRA model is a fully Bayesian implementation and as such does not deal in likelihood components. Instead, uncertainty is modeled by way of prior distributions which can be considered as weights in the likelihood sense. However, the panel felt that a number of choices in the model set up, especially the use of a selectivity vector from the flawed BAM model, rendered any conclusion from SRA regarding the uncertainty in management parameters unreliable.

### 5) Review the findings from the retrospective analyses, assess magnitude and direction of retrospective patterns detected, and discuss implications of any observed retrospective pattern for uncertainty in population parameters (e.g., F, SSB), reference points, and/or management measures.

Retrospective analyses were not formally evaluated since the Review Panel concluded that none of the model runs presented produced realistic representations of Gulf menhaden stock dynamics and productivity.

### 6) Recommend stock status as related to reference points.

The Panel cannot recommend stock status in relation to reference points in the absence of an acceptable quantitative stock assessment. However, on the basis of the landings history, the reduction fishery catch-at-age data, and the "worst case" ASPIC model runs, the Panel can offer some qualitative advice on stock status.

Landings peaked in 1984 with a catch of almost 1,000,000 t, and in the 1980s there were six consecutive years with landings of over 800,000 t. If these removals had been associated with high fishing mortality they would have caused a contraction in the age structure of the landings during the period of high catches and in subsequent years. There is no strong evidence of this in the catch-at-age data. For example, the proportion of fish 3 years and older in the landings shows little trend from 1980 through to 2010.

Mean annual landings from 2000 to 2010 was approximately 480,000 t. This is a nearly 50% reduction in landings from the peak period and suggests current stock status is probably "not overfished" and "not overfishing."

The "worst case" ASPIC runs (using an annual 2% increase in efficiency since 1948 for the reduction CPUE indices) suggest that overfishing is not currently occurring (3 out of the 4 runs estimated $F_{2010}$ to be less than $F_{MSY}$). The runs do allow the possibility that the stock may be overfished, but 3 out of the 4 runs have $B_{2010}$ approximately equal to $B_{MSY}$. Given that these are "worst case" scenarios, the runs suggest that the most likely stock status is "not overfished" and "not overfishing".

### 7) Develop detailed short and long-term prioritized lists of recommendations for future research, data collection, and assessment methodology. Highlight improvements to be made by next benchmark review.

Although results were unsatisfactory for this stock assessment, they did serve to clarify additional research necessary for future assessment efforts. Prioritized lists of short- and long-term research recommendations are presented below.

Prioritized list of short-term research recommendations:

*Adult abundance index*: Review methods that could be used to provide a reliable fishery-independent adult abundance time series. A pilot survey should be implemented as soon as possible. Development of a long-term time series is needed to increase the certainty of menhaden stock assessments.

*Analysis of CDFR data*: These data may contain an abundance signal on a weekly and/or an annual basis. In the long-term, the data should be fully analyzed in this regard. In the short-term, a standardized CPUE time series should be developed from the data for use in stock assessment.

*Further analysis of fishery-independent state indices*: These data need to be fully analyzed with regard to determining the best methods to use the data to provide potential juvenile and adult abundance indices.

*Ageing:* The consistency of the age readings throughout the whole time series should be checked. The current reader has read scales since 1969 and there may be some drift in her readings. Also, other readers participated up to the early 1970s and there is evidence of relative bias in the readings up to 1970 which should be investigated.

*Further development of the SRA*: The incorporation of catch-at-age data into the SRA approach is encouraged as this would allow the method to provide a stand-alone stock assessment for menhaden.

Prioritized list of long-term research recommendations:

*Adult abundance survey*: The existing state sampling of coastal waters is not adequate for providing a defensible adult abundance index. In the absence of such an index, stock assessment of menhaden will continue to be problematic. The development of a fishery-independent adult-abundance index should be given a very high priority. A review of possible methods is the first step (see short-term research recommendations above). Aerial surveying using visual estimation and/or LIDAR should be considered among the options.

*Biological data*: All biological parameters pertinent to the stock assessment should be updated. Subsequently, they should be monitored every few years.

*Catch sampling*: The potential bias associated with sampling only the last catch of the day should be investigated. It is important to know if there could be a bias and whether it is towards larger/older fish or smaller/younger fish.

# SEDAR

Southeast Data, Assessment, and Review

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## SEDAR 27

# Gulf of Mexico Menhaden

## Addenda and Post-Review Updates

November 2011

SEDAR
4055 Faber Place Drive, Suite 201
North Charleston, SC 29405

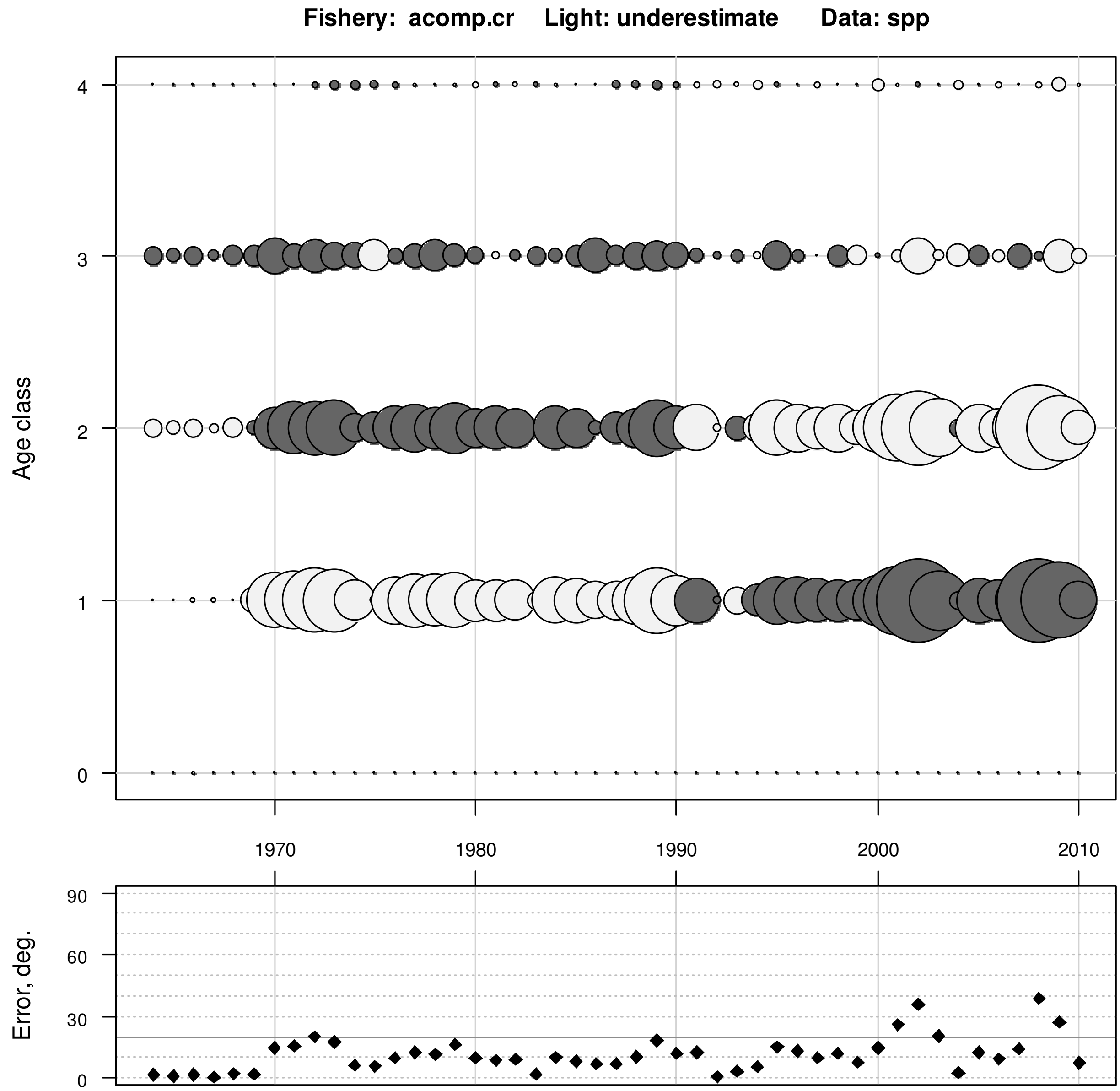
Addendum of runs completed at the review workshop November 1-4, 2010 in St. Petersburg, Florida.

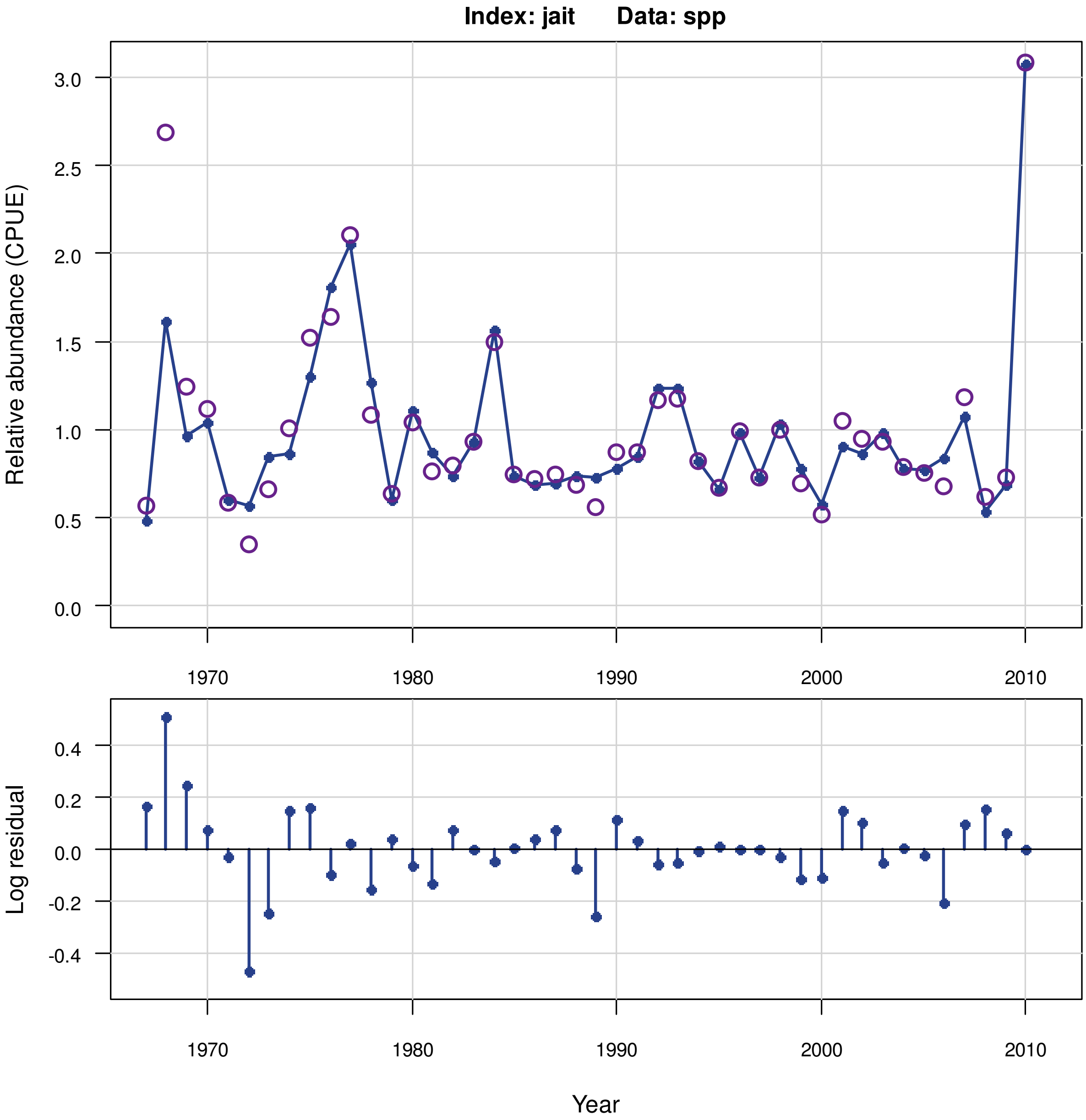
Modifications to base run in document:

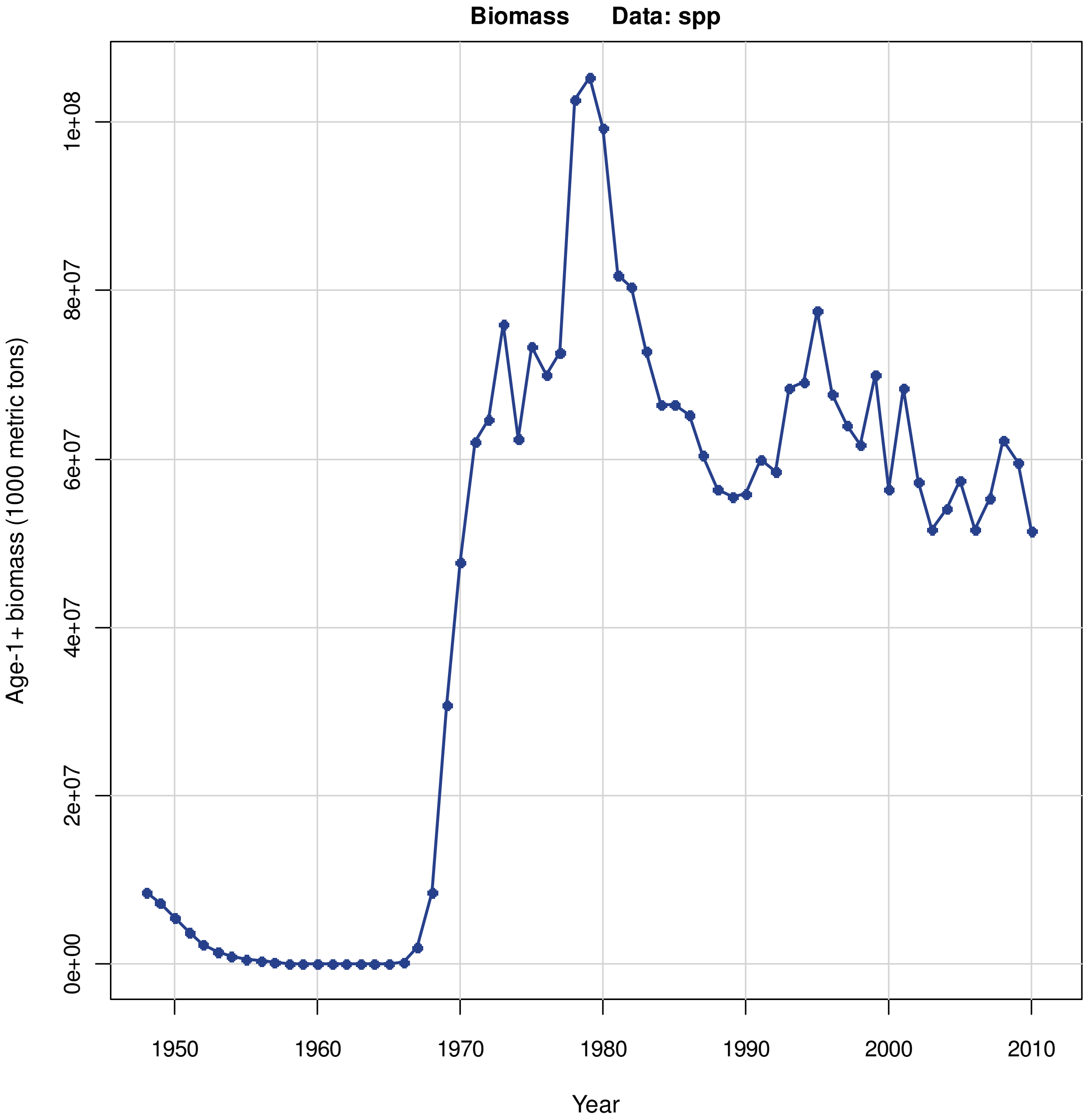
- Delete 2010 gillnet index data point from base run of assessment
    - See file SumW-OGill2010 in the homework/day 1 directory.
- Run base run without the gillnet index
    - Some parameters hit bounds, convergence wasn't reached; therefore, no plots were presented here.

Exploratory runs:

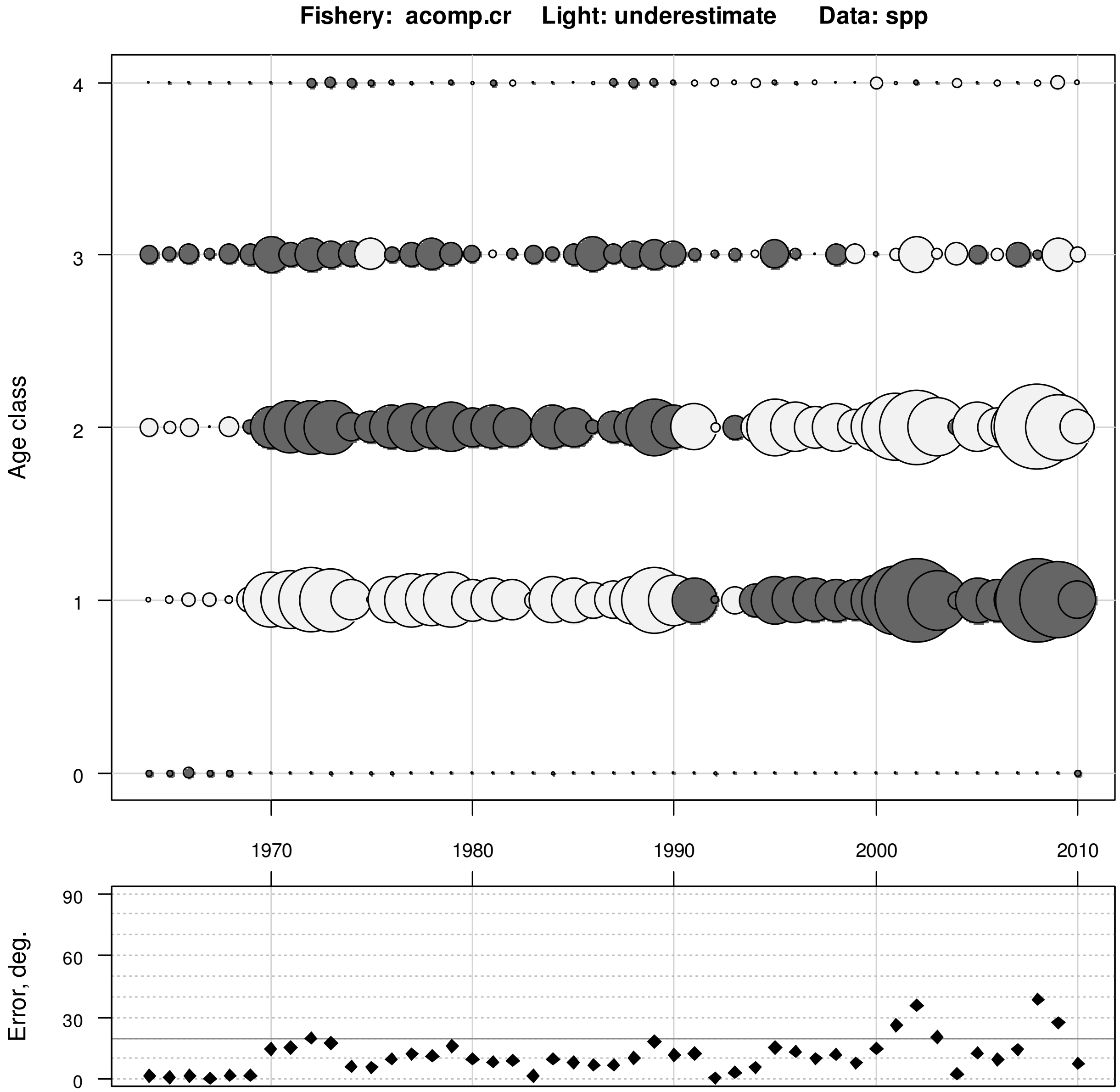
- gmenhad-064-RW1: First configuration contains the following
    - Trawl index for juvenile abundance index (no seine index)
    - Cap catch at age sample size at 200 (all sample sizes were larger than 200)
    - One selectivity over the entire time period 1948-2010 with age-0 fixed at 0.0 and age-2 fixed at 1.0 and ages 1, 3, and 4 estimated
    - Set age-0 catch to zero and then renormalized so age composition summed to one
    - Weights set to 1.0
    - No adult index, which also includes no length comps
    - M=0.5 constant across age and time
    - Fixed steepness at 0.75
    - Set recruitment penalty to zero
    - Recruitment variability (sigma_r) set to 1.0
    - Priors associated with selectivity were removed
        - Landings fit well, but unrealistic trends in F, B, and R.
        - Reduction fishery age composition residuals contained strong patterns (banding).
        - One of the problems with the exploratory runs done at the review workshop was that the initial biomass was estimated as a small fraction of unfished biomass. Thus, the trajectory of biomass was unrealistic. The fishery started near the start of the assessment (1948), so we would expect biomass to be high in the early years (see plot below of biomass).

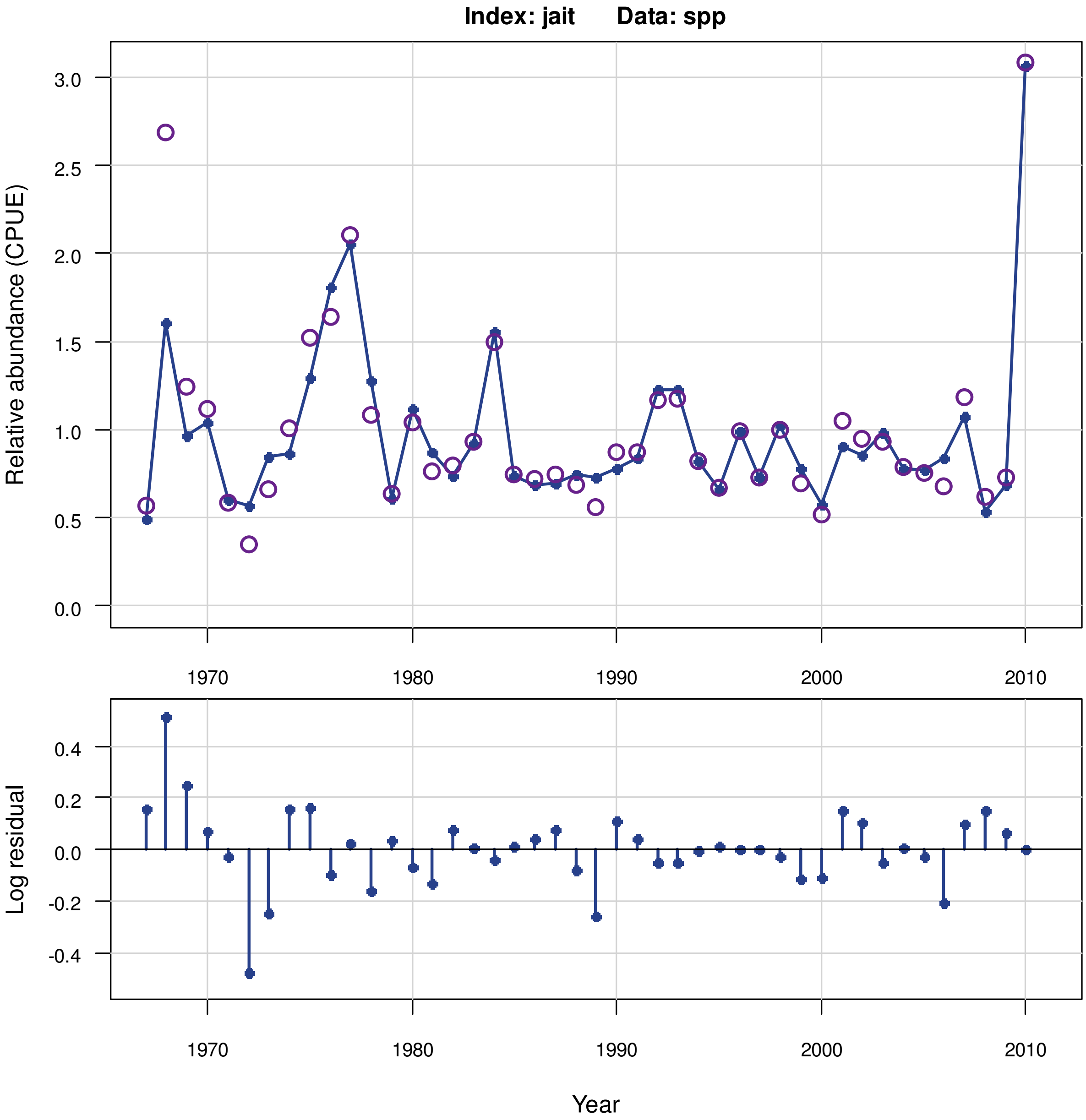

Fishery: acomp.cr Light: underestimate Data: spp
Age class
0
1
2
3
4
1970
1980
1990
2000
2010
Error, deg.
0
30
60
90


Index: jait      Data: spp
Relative abundance (CPUE)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1970
1980
1990
2000
2010
Log residual
-0.4
-0.2
0.0
0.2
0.4
1970
1980
1990
2000
2010
Year

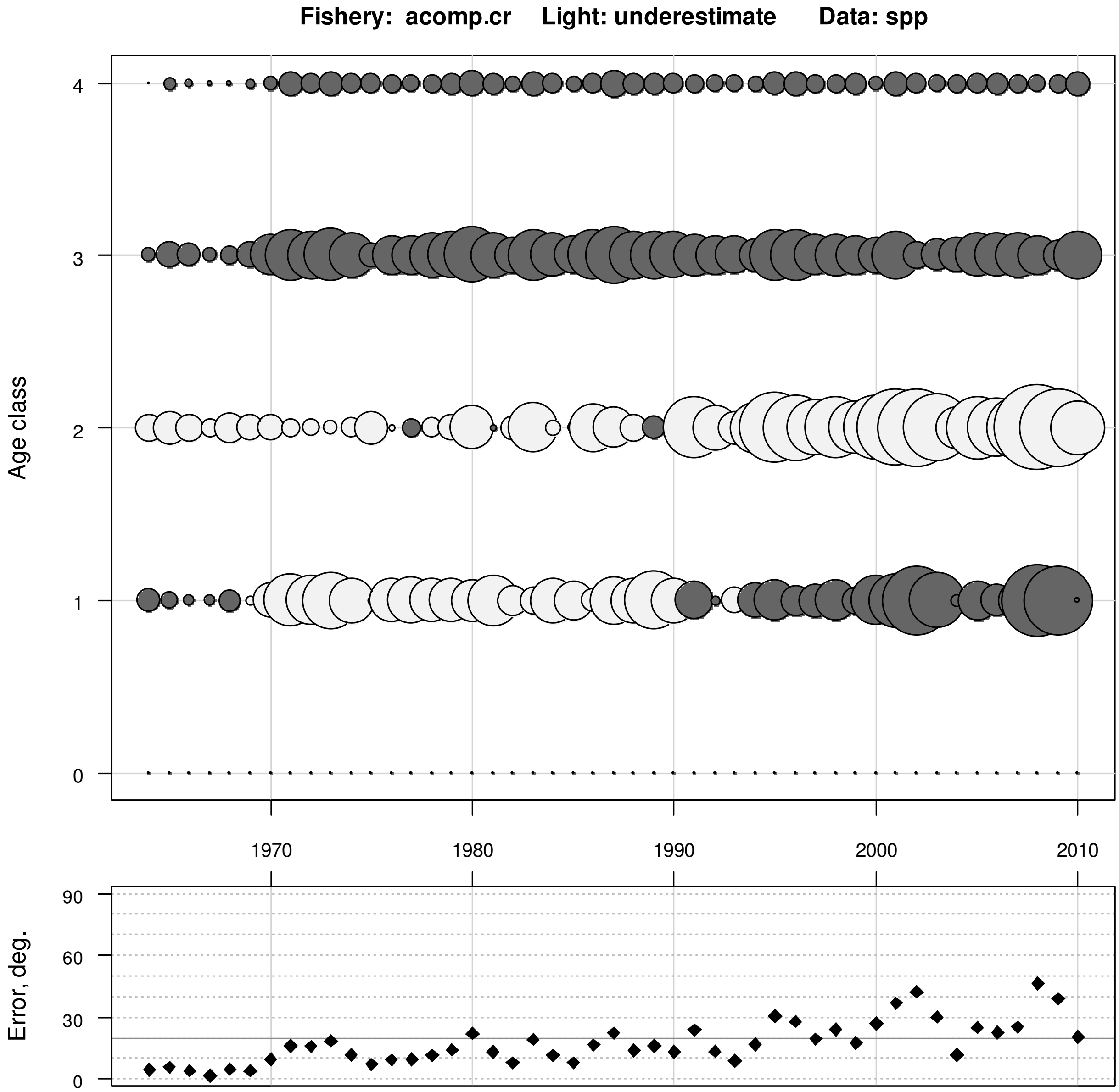

Biomass Data: spp
Age-1+ biomass (1000 metric tons)
0e+00
2e+07
4e+07
6e+07
8e+07
1e+08
1950
1960
1970
1980
1990
2000
2010
Year

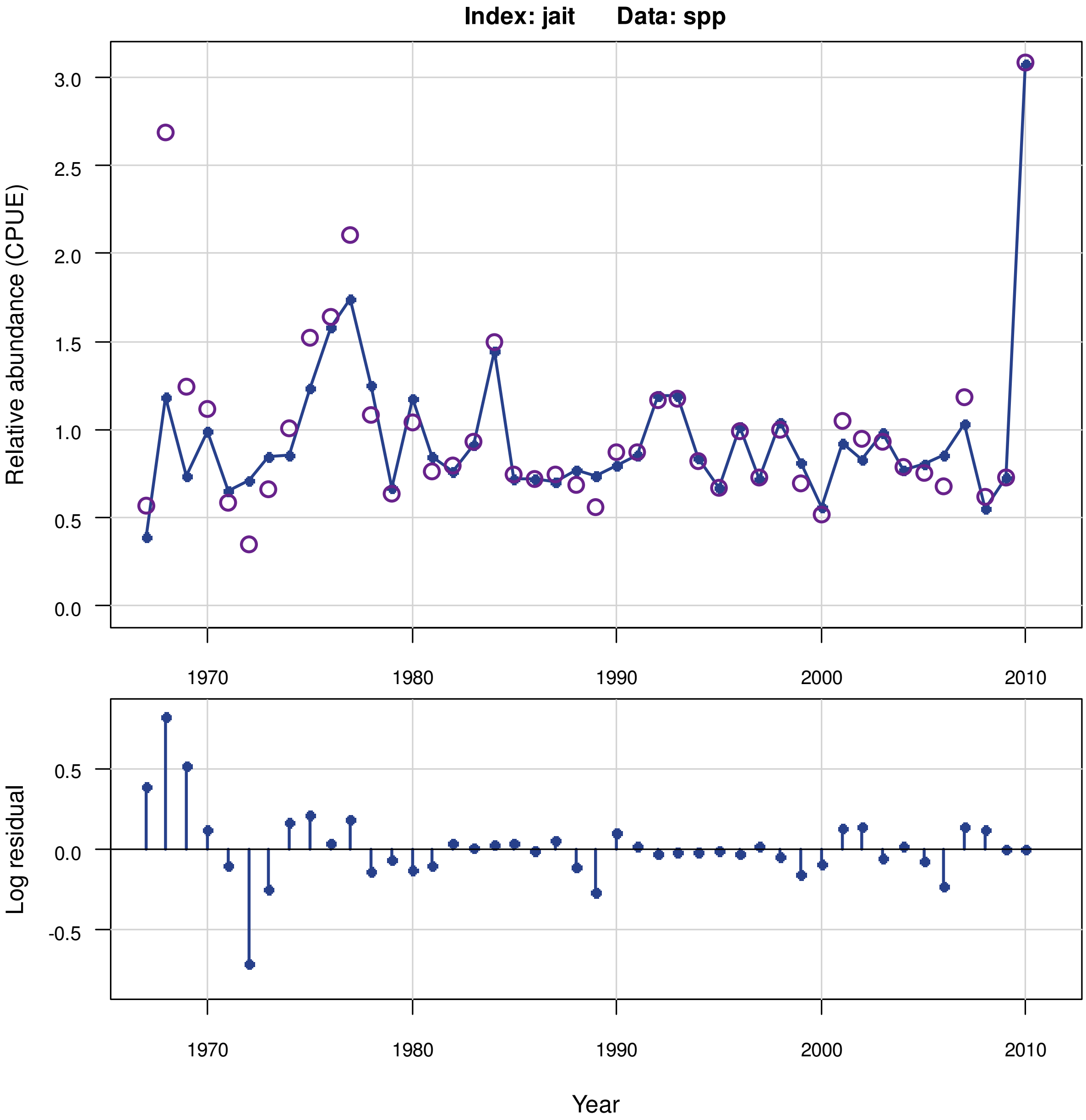
- gmenhad-064-RW2:
  - Same as gmenhad-064-RW1 except M=1.5
    - Landings fit well, but unrealistic trends in F, B, and R.
    - Reduction fishery age composition residuals contained strong patterns (banding).



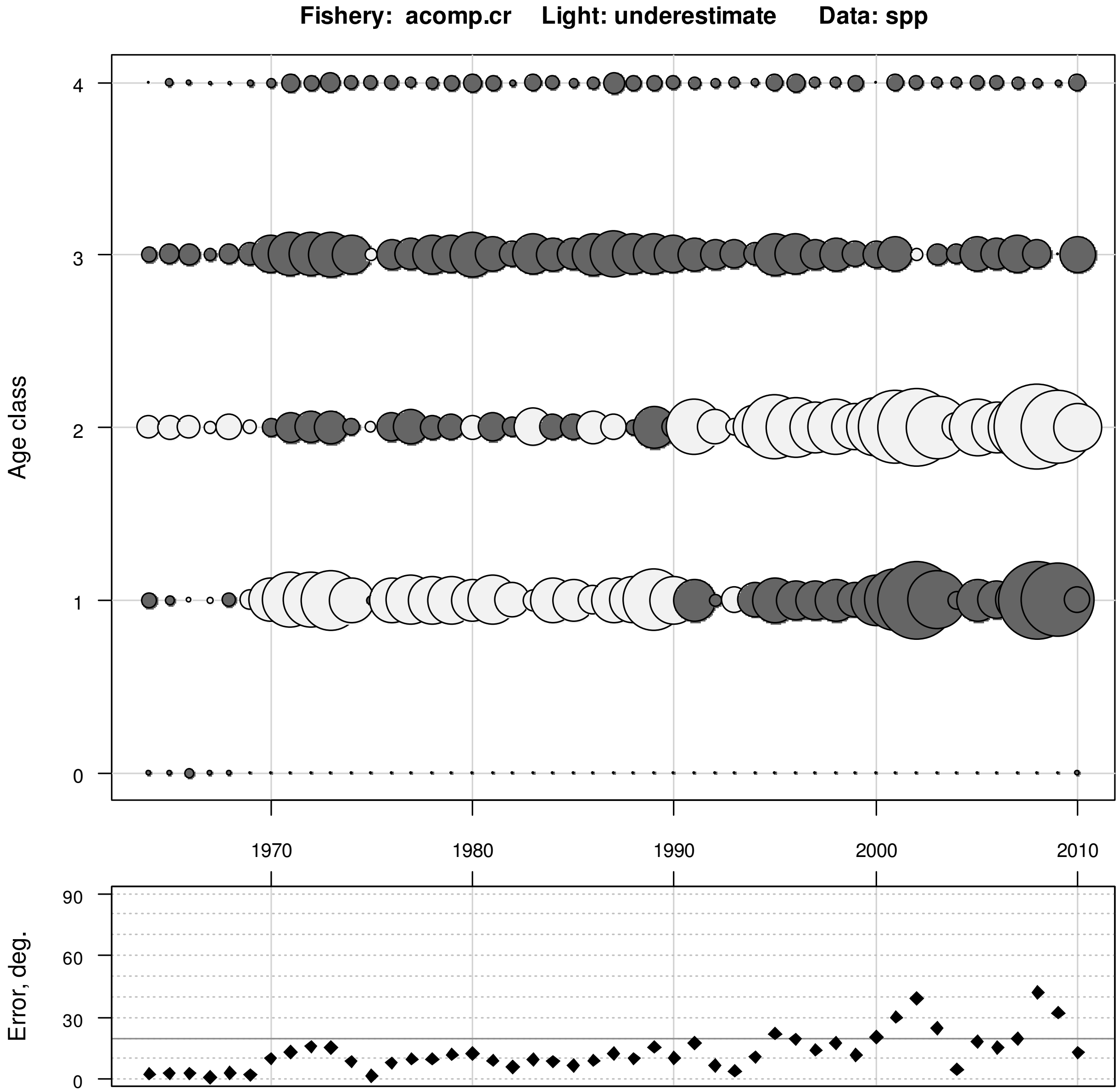

Index: jait Data: spp
Relative abundance (CPUE)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1970
1980
1990
2000
2010
Log residual
-0.4
-0.2
0.0
0.2
0.4
1970
1980
1990
2000
2010
Year

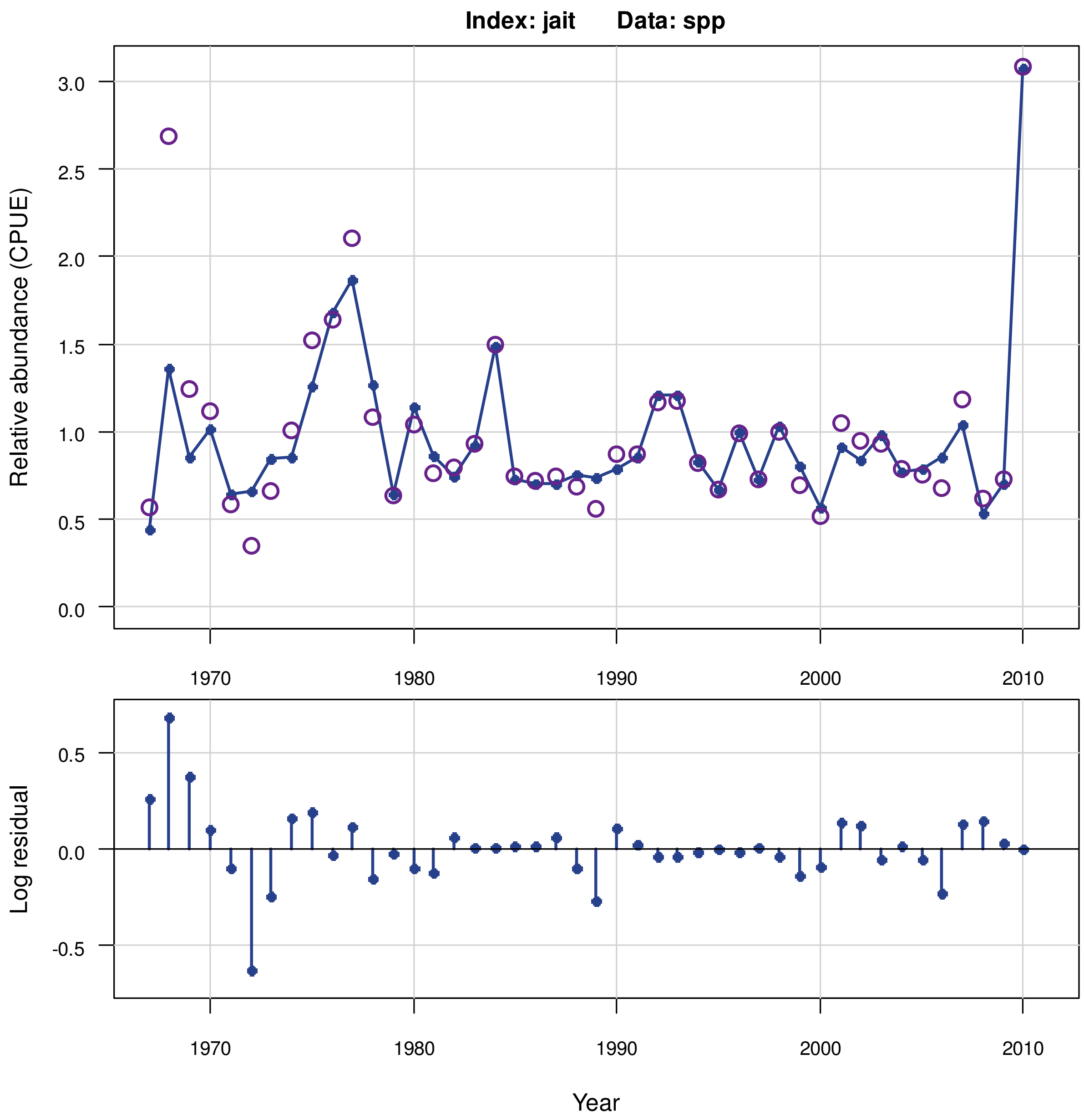
- gmenhad-064-RW3:
    - Same as gmenhad-064-RW1 except selectivity at age-3 fixed at 1.0 with age-2 being estimated
        - Landings fit well, but unrealistic trends in F, B, and R.
        - Reduction fishery age composition residuals contained strong patterns (banding).



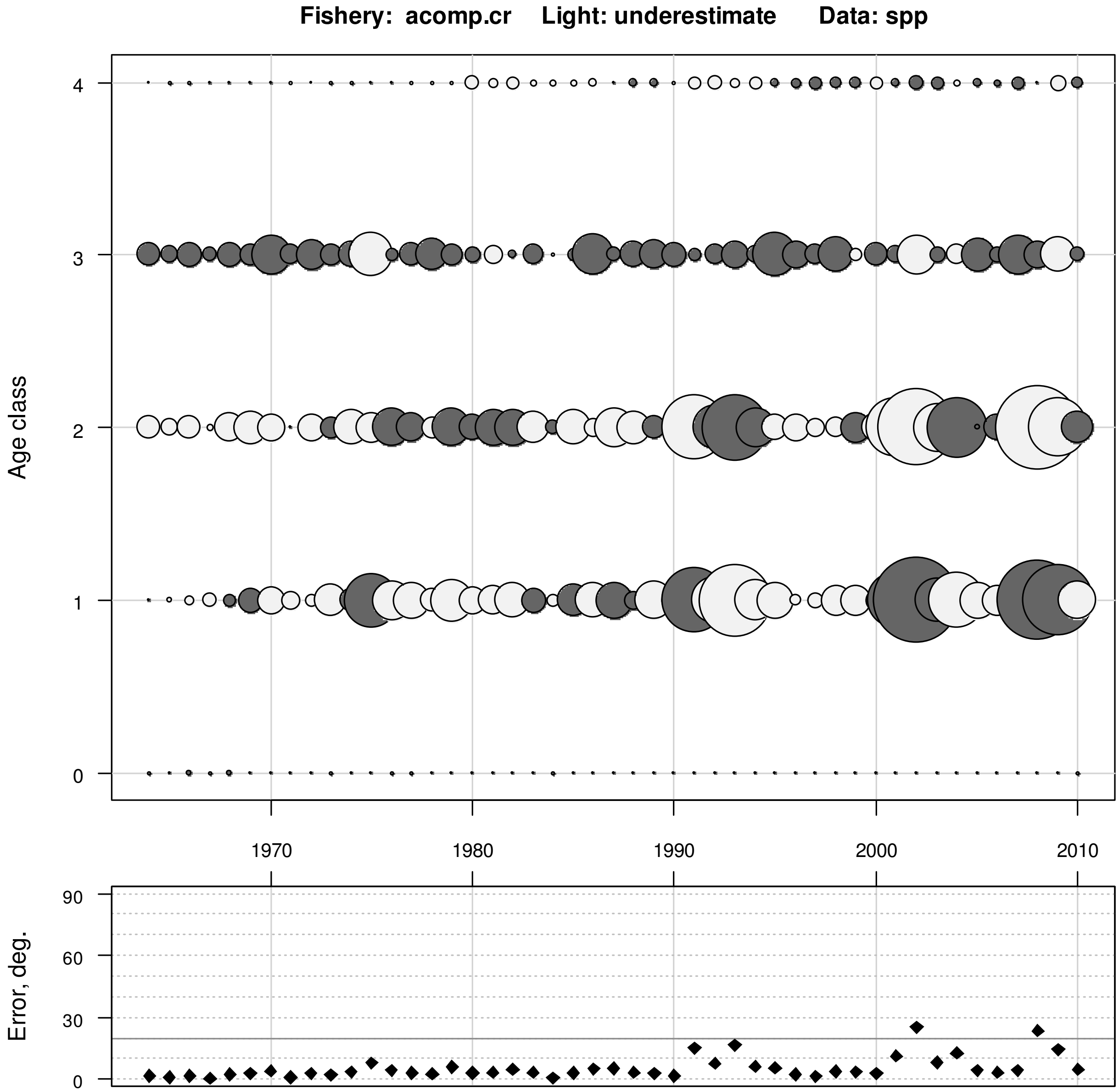

Index: jait Data: spp
Relative abundance (CPUE)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
1970
1980
1990
2000
2010
Log residual
-0.5
0.0
0.5
1970
1980
1990
2000
2010
Year

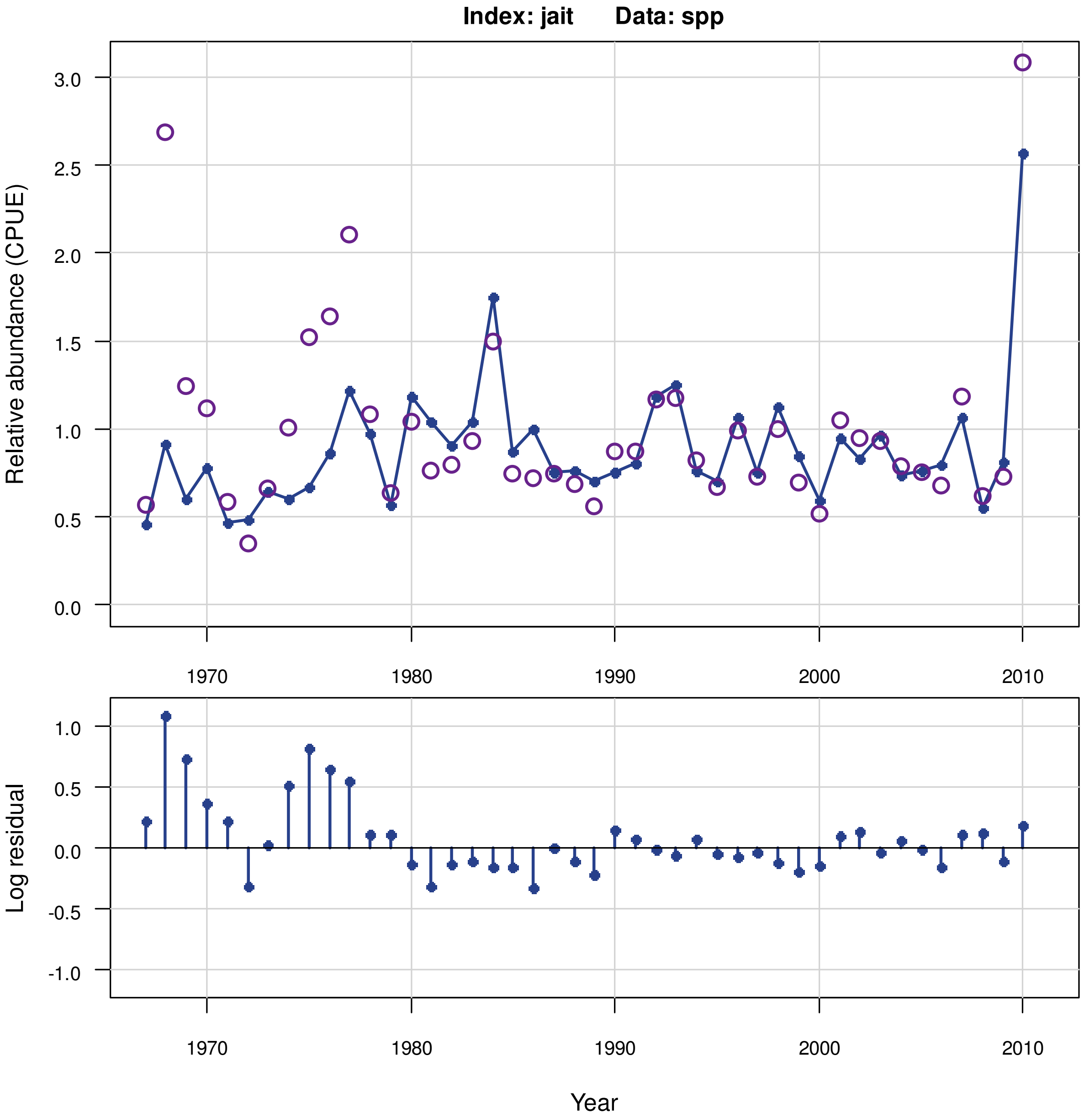
- gmenhad-064-RW4:
  - Same as gmenhad-064-RW3 except M=1.5
    - Landings fit well, but unrealistic trends in F, B, and R.
    - Reduction fishery age composition residuals still contained strong patterns (banding).

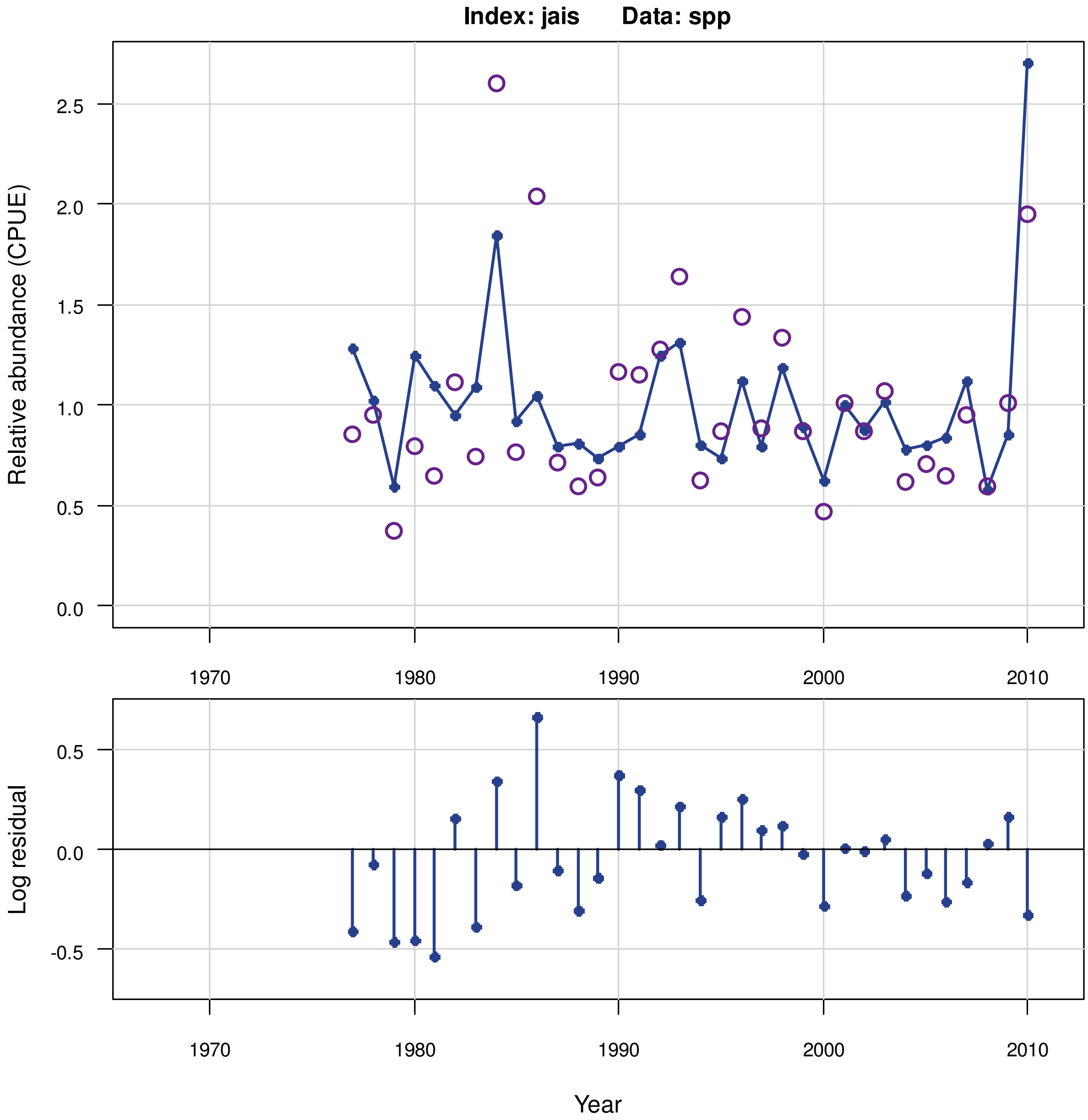



Index: jait      Data: spp
Relative abundance (CPUE)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1970
1980
1990
2000
2010
Log residual
0.5
0.0
-0.5
1970
1980
1990
2000
2010
Year

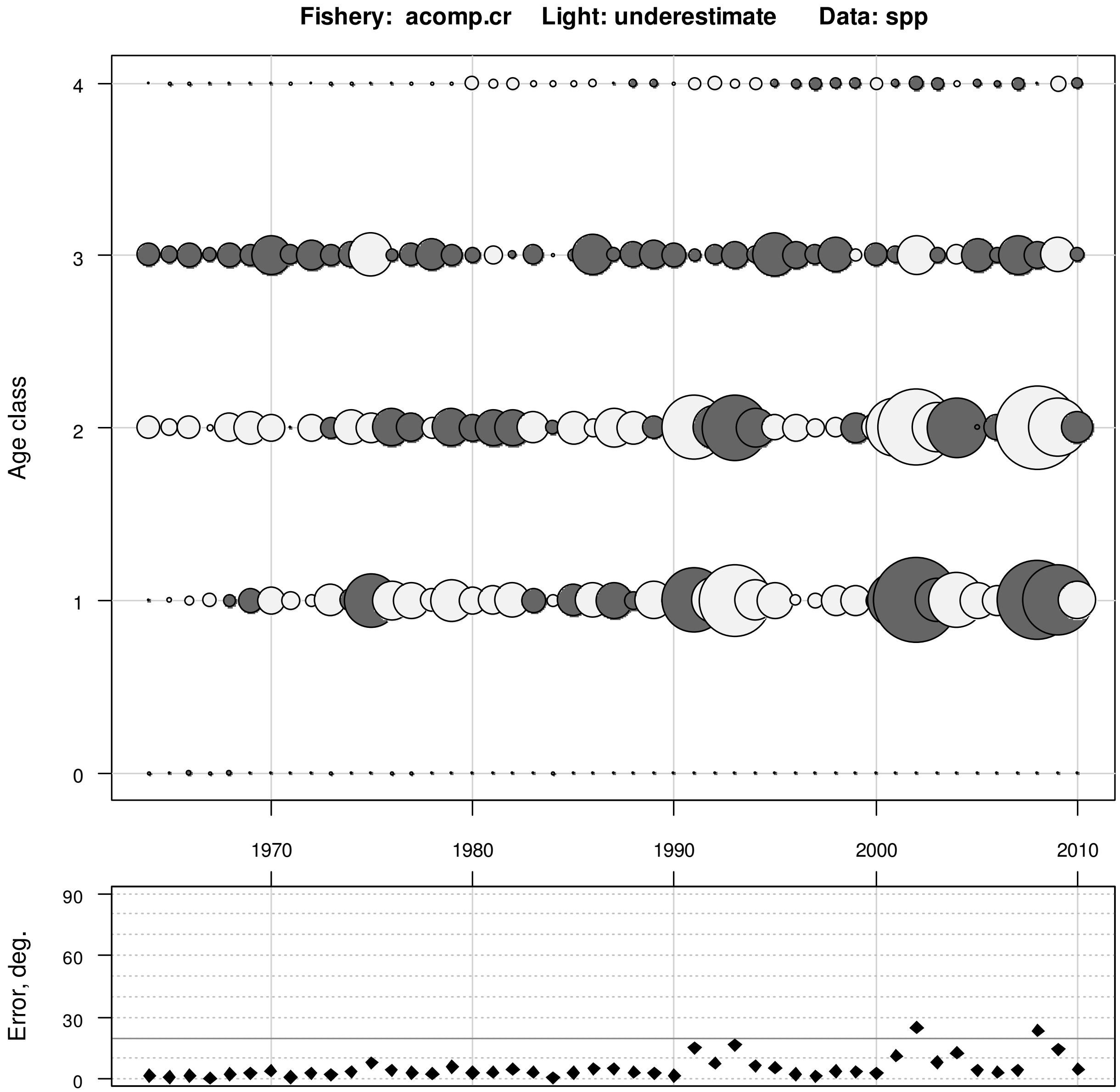
- gmenhad-064-RW5:
  - Same as gmenhad-064 expect included a recruitment penalty for deviation from S-R curve and included the seine juvenile abundance index
    - Landings fit well except in 1980s, and unrealistic trends in F, B, and R.
    - Reduction fishery age composition residuals contained fewer patterns.

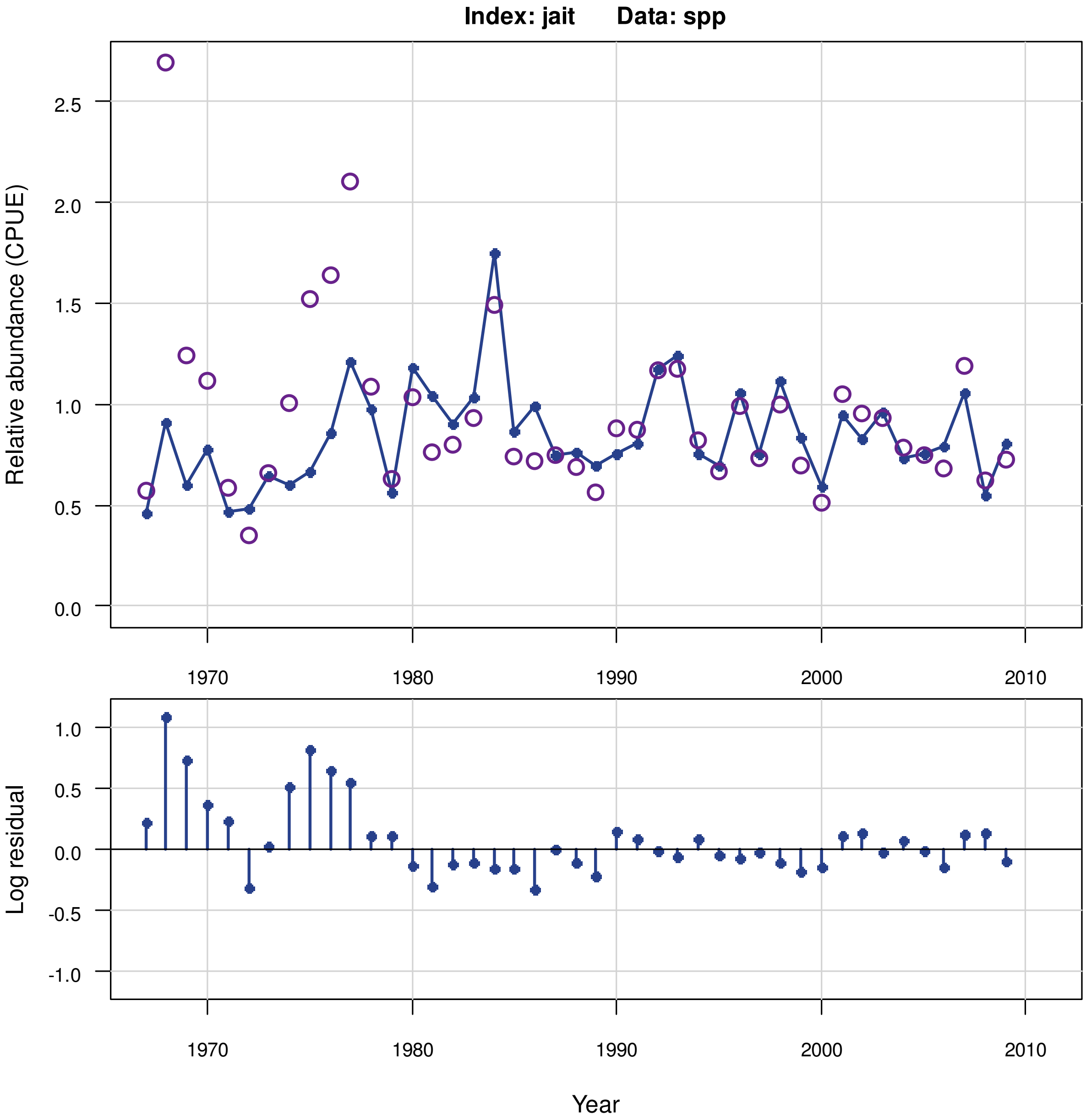


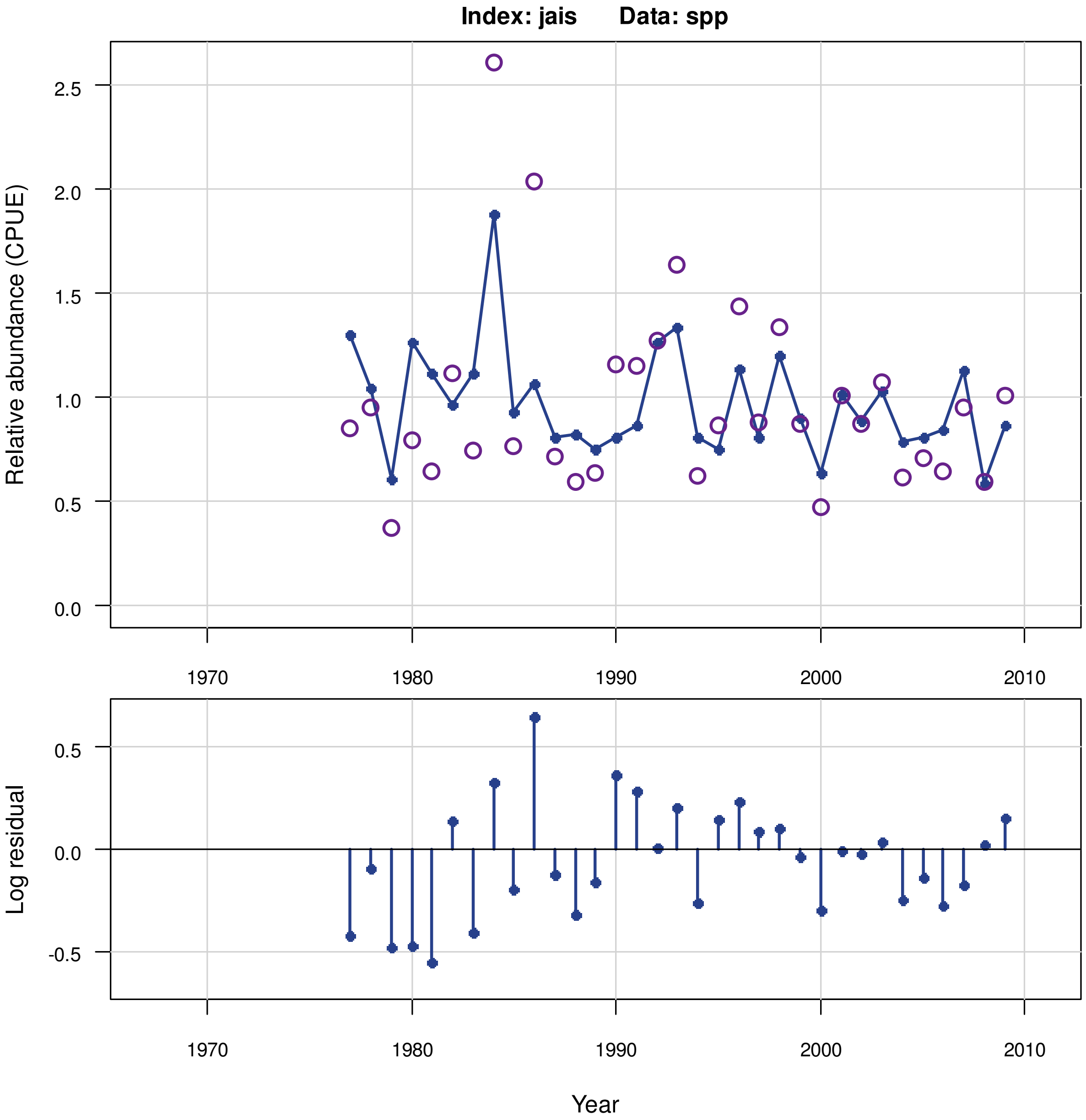

Index: jait Data: spp
Relative abundance (CPUE)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1970
1980
1990
2000
2010
Log residual
1.0
0.5
0.0
-0.5
-1.0
1970
1980
1990
2000
2010
Year


Index: jais Data: spp
Relative abundance (CPUE)
0.0
0.5
1.0
1.5
2.0
2.5
1970
1980
1990
2000
2010
Log residual
-0.5
0.0
0.5
1970
1980
1990
2000
2010
Year

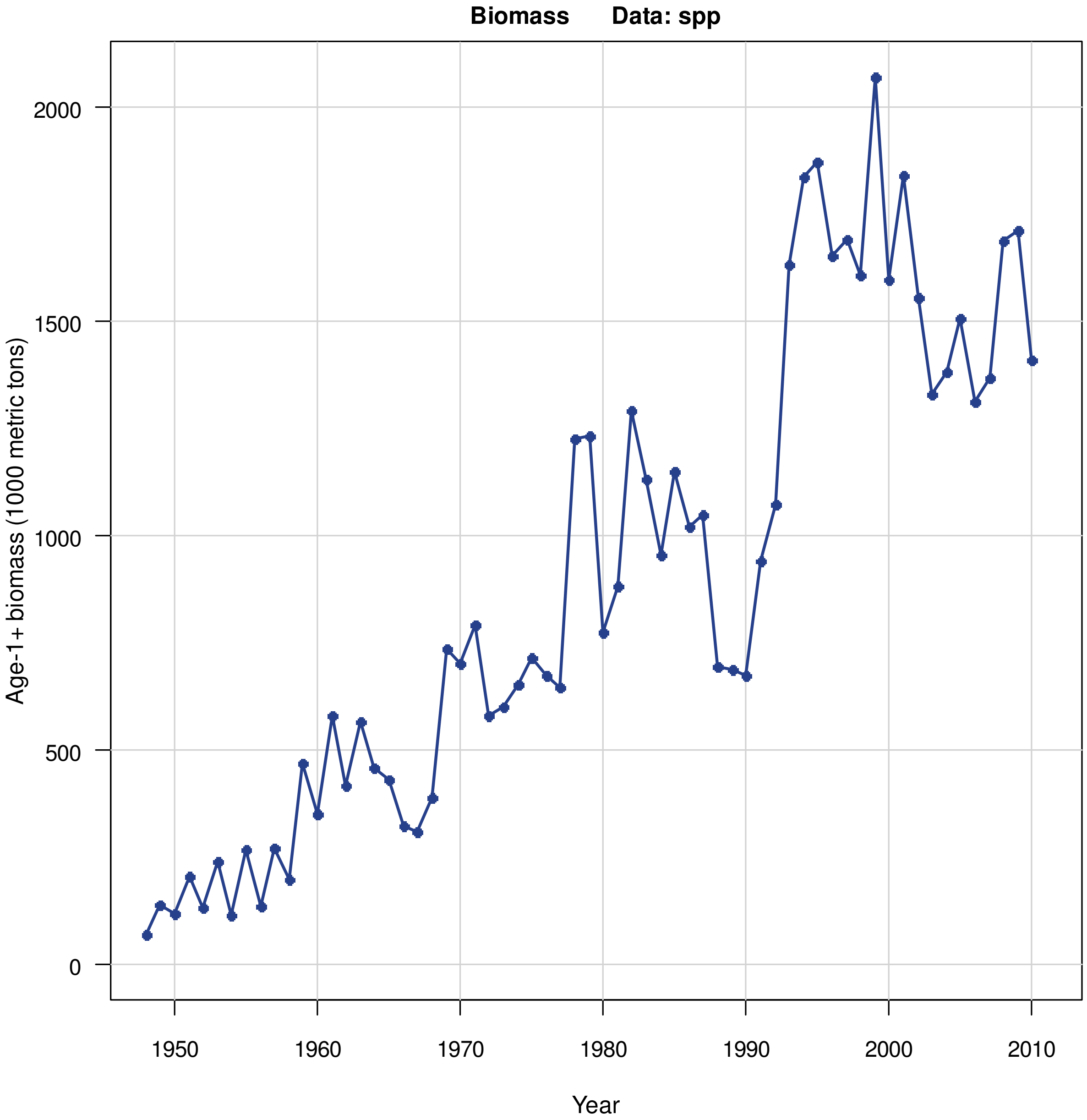
- gmenhad-064-RW6:
    - Same as gmenhad-064-RW5 except that the 2010 points from the trawl and seine juvenile abundance indices have been deleted
        - Landings fit fairly well except in the 1970s and 1980s, but unrealistic trends in F, B, and R.
        - Reduction fishery age composition residuals contained fewer patterns.



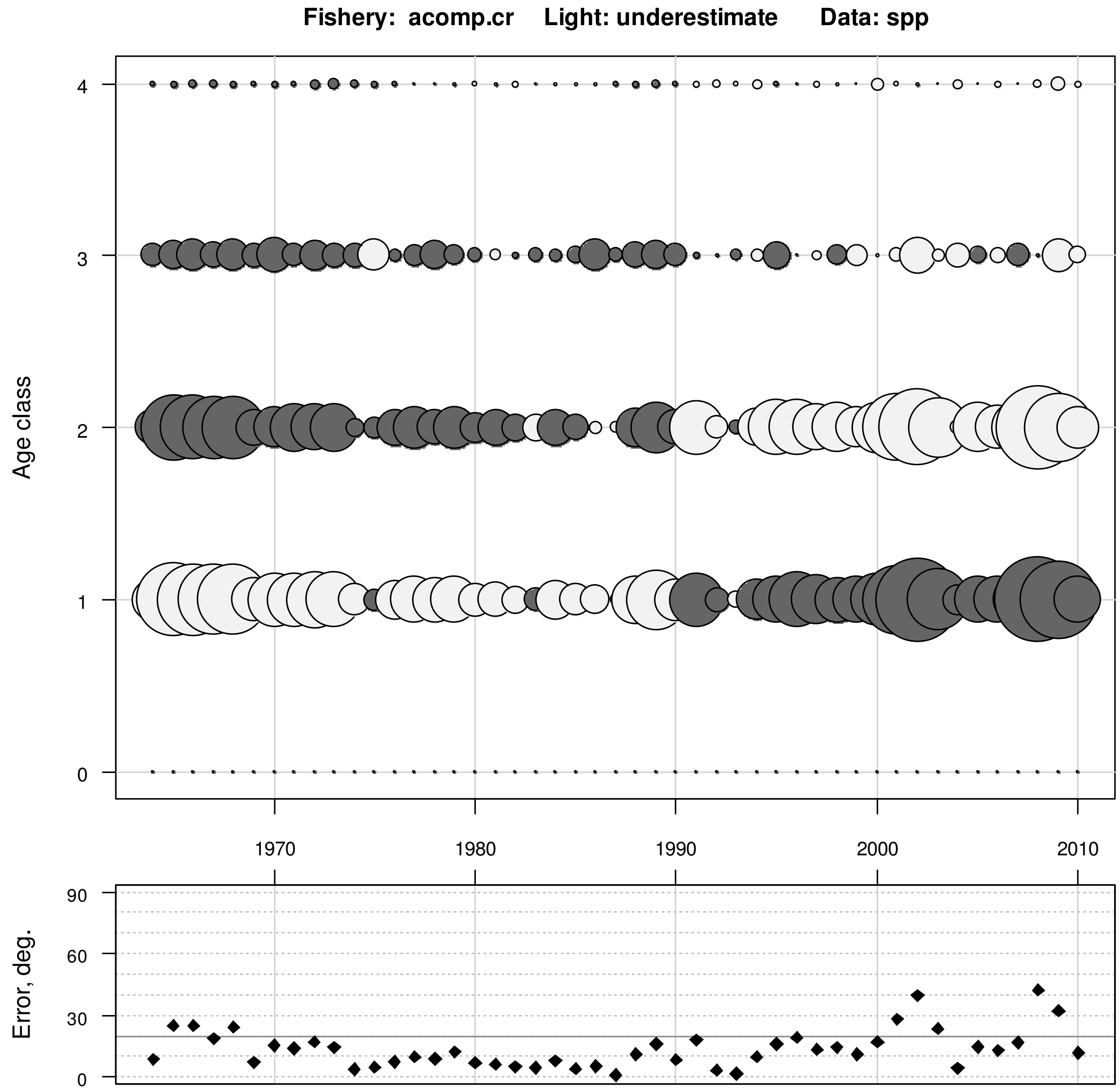

Index: jait Data: spp
Relative abundance (CPUE)
0.0
0.5
1.0
1.5
2.0
2.5
1970
1980
1990
2000
2010
Log residual
-1.0
-0.5
0.0
0.5
1.0
1970
1980
1990
2000
2010
Year

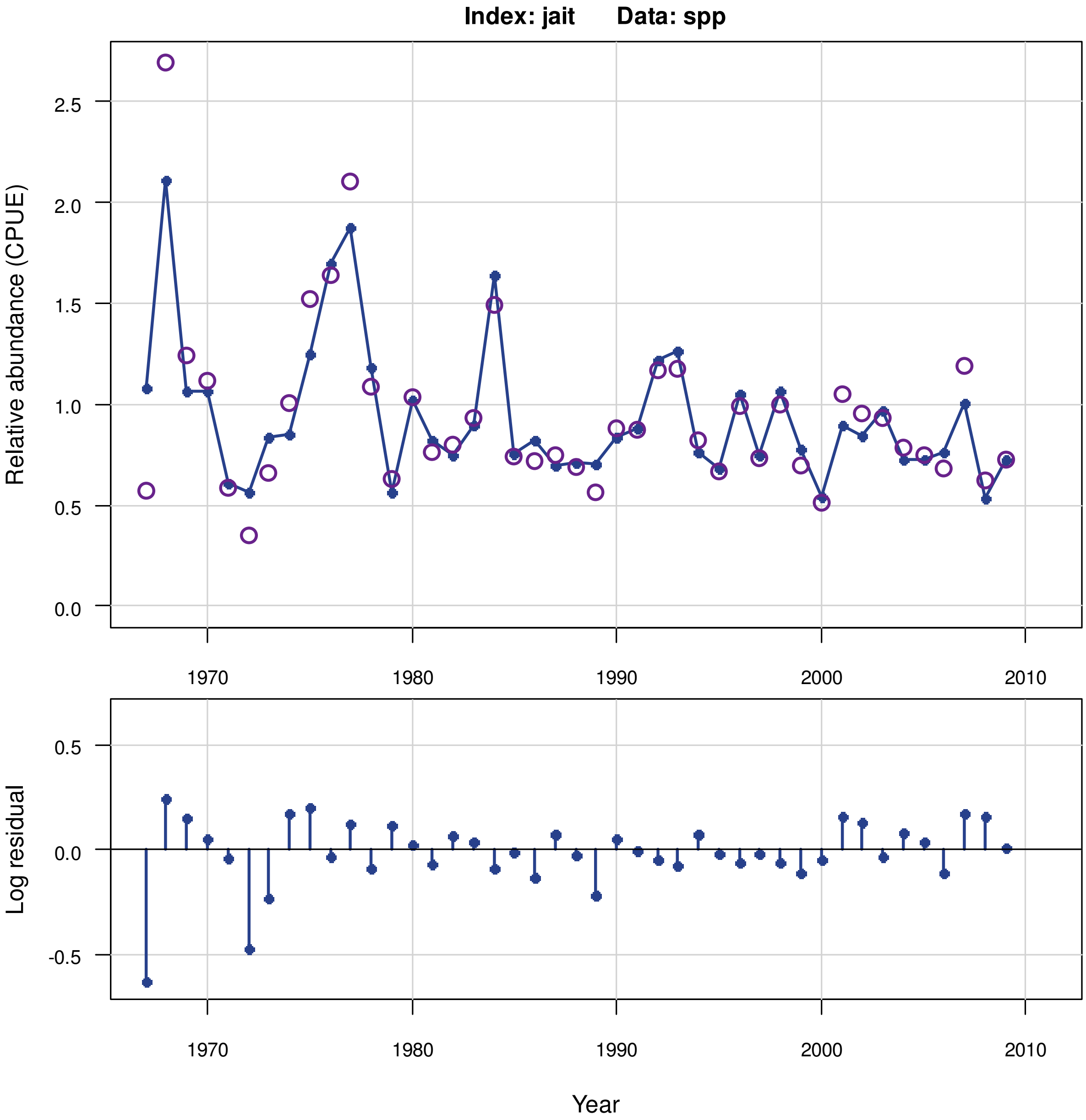

Index: jais Data: spp
Relative abundance (CPUE)
2.5
2.0
1.5
1.0
0.5
0.0
1970
1980
1990
2000
2010
Log residual
0.5
0.0
-0.5
1970
1980
1990
2000
2010
Year

- gmenhad-064-RW7:
    - same as gmenhad-064-RW6 except rec devs estimated starting in 1964
        - Landings fit fairly well except in the 1980s, but unrealistic trends in F, B, and R.
        - Plots of the trawl and seine fits and the reduction fishery age composition residuals all look very similar to gmenhad-064-RW6.
        - Initial biomass was estimated as a small fraction of unfished biomass. Thus, the trajectory of biomass was unrealistic. The fishery started near the start of the assessment (1948), so we would expect biomass to be high in the early years (see plot below).

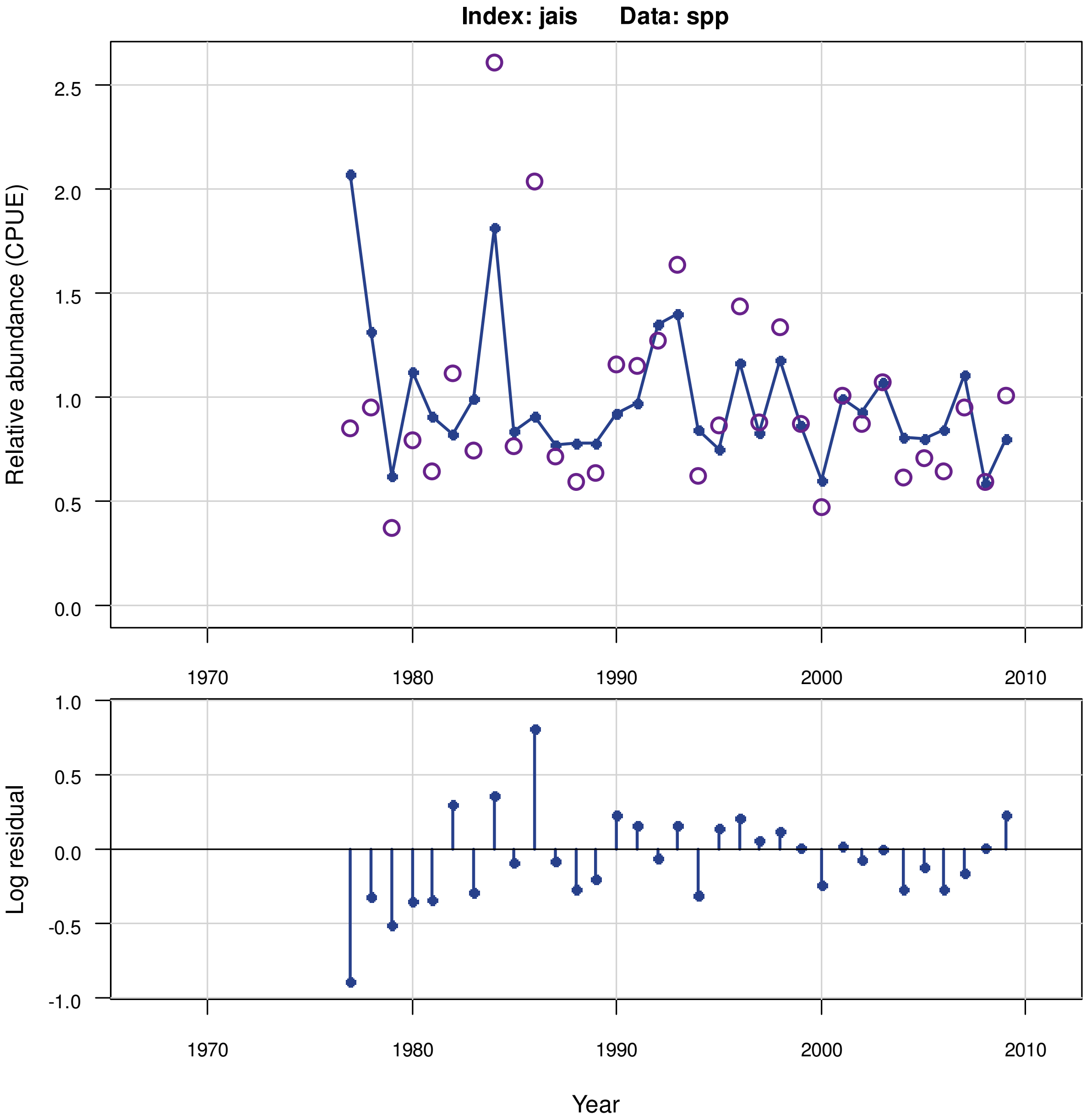


- gmenhad-064-RW8:
    - same as gmenhad-064-RW7 except that M=1.0
        - Landings fit well, B and R patterns realistic.
        - Reduction fishery age composition residuals contained strong patterns.

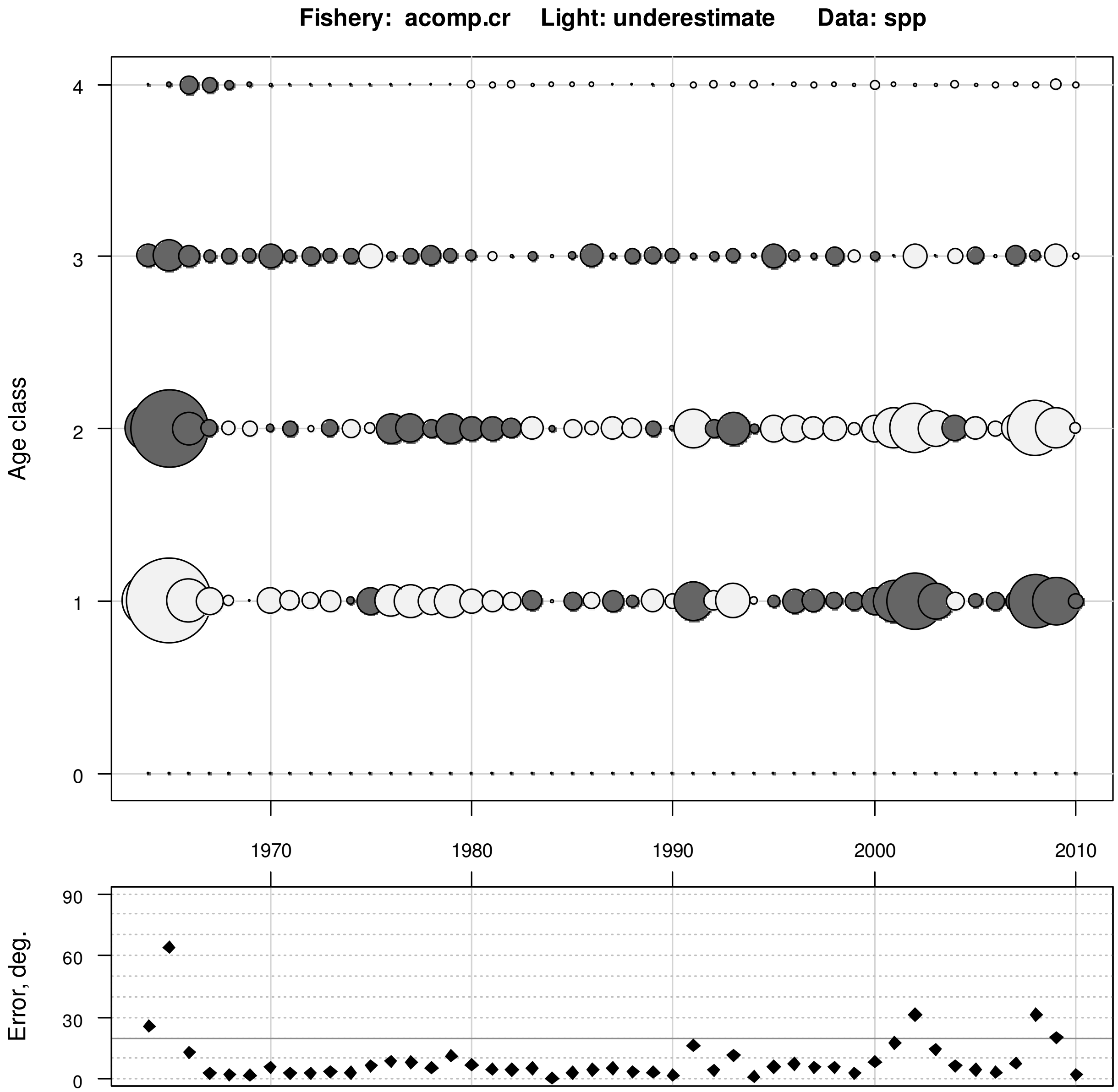


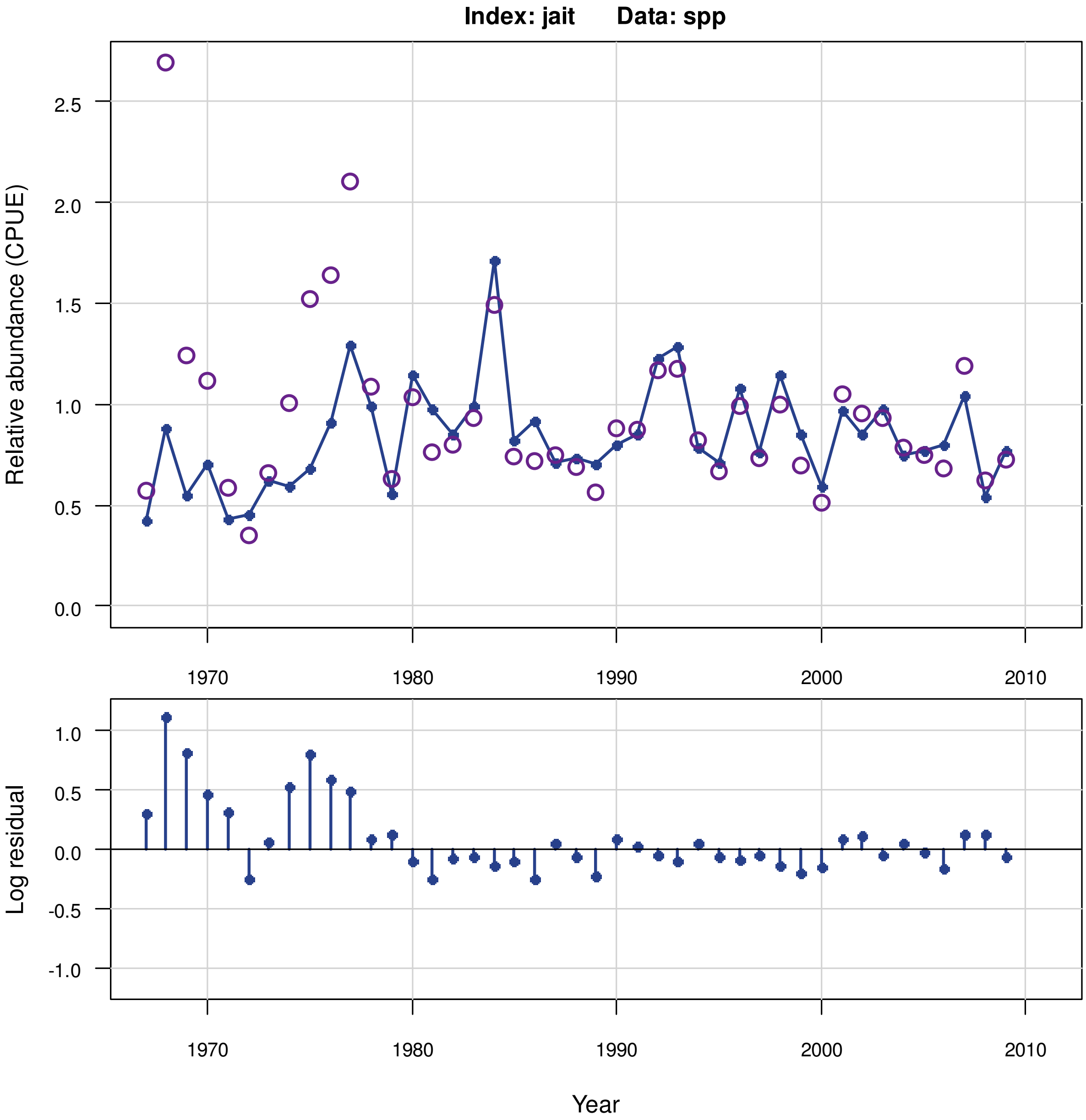


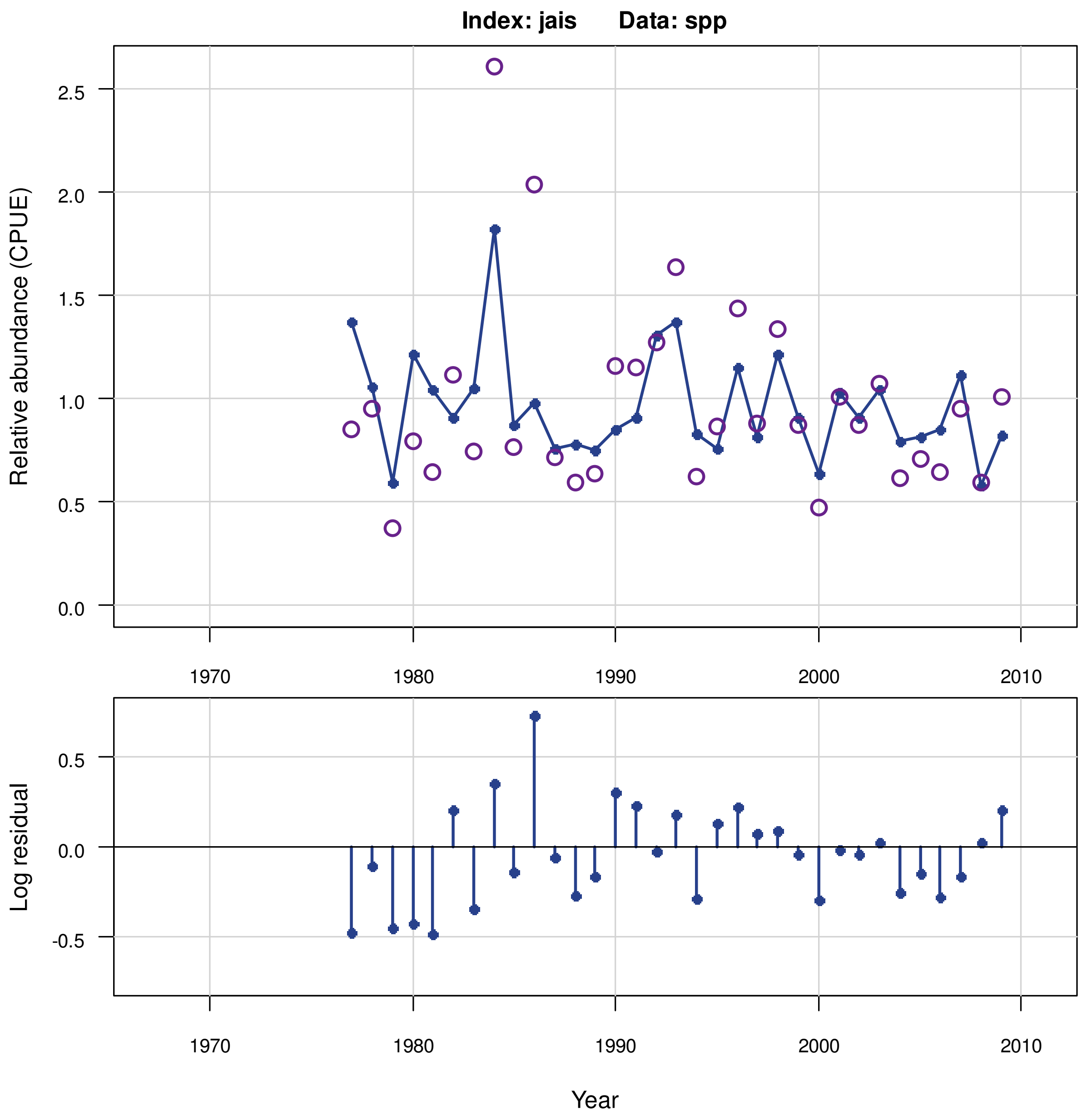
Index: jait Data: spp
Relative abundance (CPUE)
0.0
0.5
1.0
1.5
2.0
2.5
1970
1980
1990
2000
2010
Log residual
-0.5
0.0
0.5
1970
1980
1990
2000
2010
Year

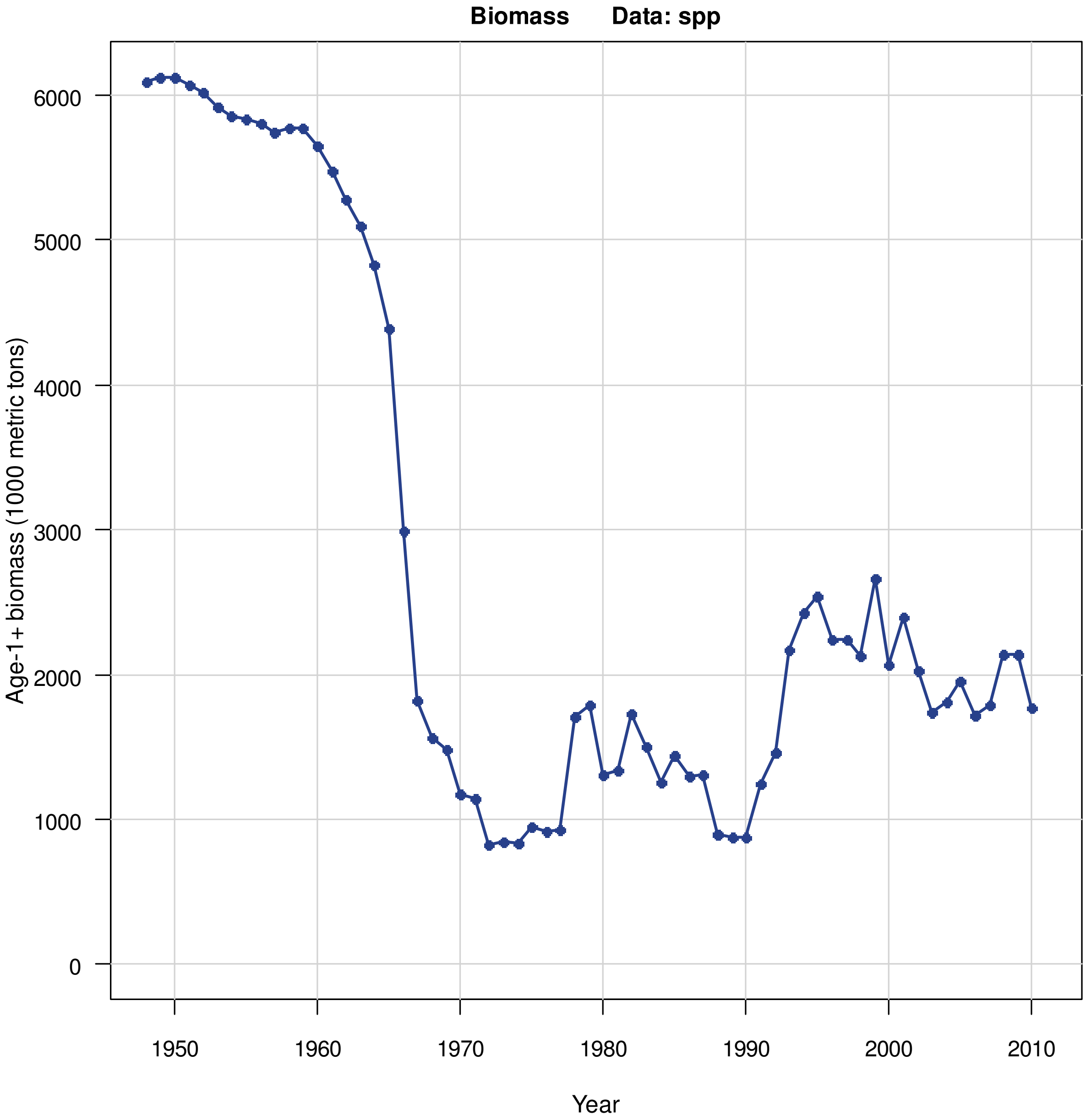

Index: jais Data: spp
Relative abundance (CPUE)
0.0
0.5
1.0
1.5
2.0
2.5
1970
1980
1990
2000
2010
Log residual
-1.0
-0.5
0.0
0.5
1.0
1970
1980
1990
2000
2010
Year

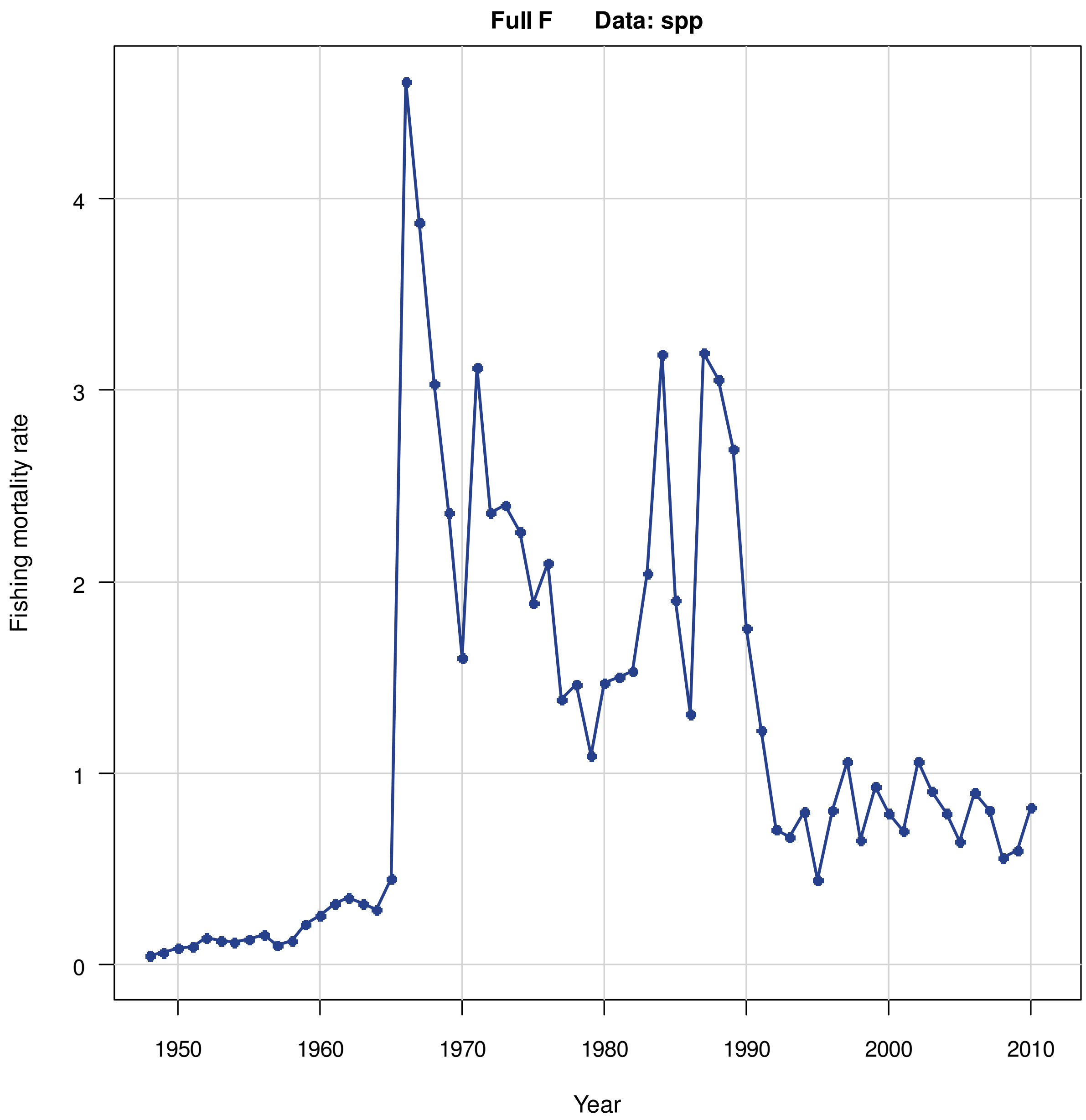
- gmenhad-064-RW9:
    - same as gmenhad-064-RW8 except that selectivity has two blocks as follows: 1948-1992 age-3 fixed at 1.0, age-0 fixed at 0.0, and ages 1, 2, and 4 estimated and 1993-2010 age-2 fixed at 1.0, age-0 fixed at 0.0, and ages 1, 3, and 4 estimated
    - Did not converge, thus didn't present results here.
- gmenhad-064-RW10:
    - same as gmenhad-064-RW8 except that selectivity has two blocks as follows: 1948-1992 age-2 fixed at 1.0, age-0 fixed at 0.0, and ages 1, 3, and 4 estimated and 1993-2010 age-3 fixed at 1.0, age-0 fixed at 0.0, and ages 1, 2, and 4 estimated
    - Did not converge, thus didn't present results here.
- gmenhad-064-RW11:
    - same as gmenhad-064-RW10 except with the addition of the gillnet index based on data from LA only and associated length compositions
    - Did not converge, thus didn't present results here.
- gmenhad-064-RW12:
    - same as gmenhad-064-RW11 except with the deletion of the 2010 data point from the gillnet index and associated length compositions
    - Did not converge, thus didn't present results here.
- gmenhad-064-RW13:
    - same as gmenhad-064-RW10 except with the addition of the commercial reduction CPUE as an index. The index was added in for the whole time period (1948-2010) with a 1% increase in catchability.
    - Did not converge, thus didn't present results here.
- gmenhad-064-RW14:
    - same as gmenhad-064-RW13 except that the commercial reduction CPUE was broken into two time periods of 1976-1990 and 2000-2010 with a catchability estimated for each time period.
    - Did not converge, thus didn't present results here.
- Gmenhad-064-RW17:
    - Same as RW7 except that the prior on the abundance initialization was removed and estimation of initial numbers at age was turned off.
        - Reduction fishery age composition residuals contained fewer patterns.
        - Landings fit fairly well except in the 1980s. Realistic trends in B and R. However, the problem with F peaking in the 1960s is still present. During the assessment workshop, the assessment panelists did not feel that this was an accurate picture of F in the 1960s.


Fishery: acomp.cr Light: underestimate Data: spp
Age class
0
1
2
3
4
1970
1980
1990
2000
2010
Error, deg.
0
30
60
90


Index: jait Data: spp
Relative abundance (CPUE)
0.0
0.5
1.0
1.5
2.0
2.5
1970
1980
1990
2000
2010
Log residual
-1.0
-0.5
0.0
0.5
1.0
1970
1980
1990
2000
2010
Year


Index: jais Data: spp
Relative abundance (CPUE)
2.5
2.0
1.5
1.0
0.5
0.0
1970
1980
1990
2000
2010
Log residual
0.5
0.0
-0.5
1970
1980
1990
2000
2010
Year


Biomass Data: spp
Age-1+ biomass (1000 metric tons)
0
1000
2000
3000
4000
5000
6000
1950
1960
1970
1980
1990
2000
2010
Year


Full F Data: spp
Fishing mortality rate
0
1
2
3
4
Year
1950
1960
1970
1980
1990
2000
2010

# Exploratory production model runs of gulf menhaden

Michael H. Prager

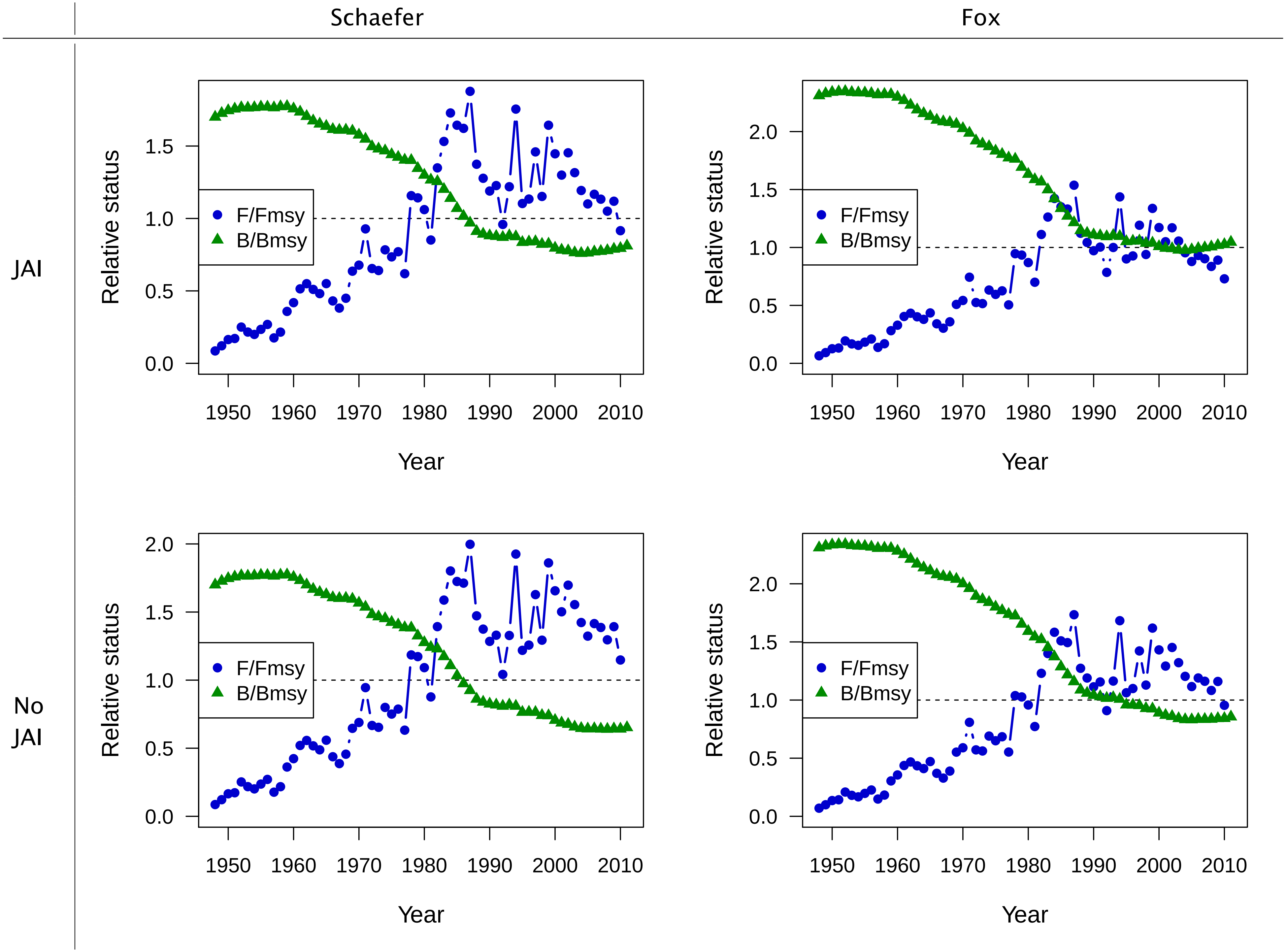
November 2, 2011

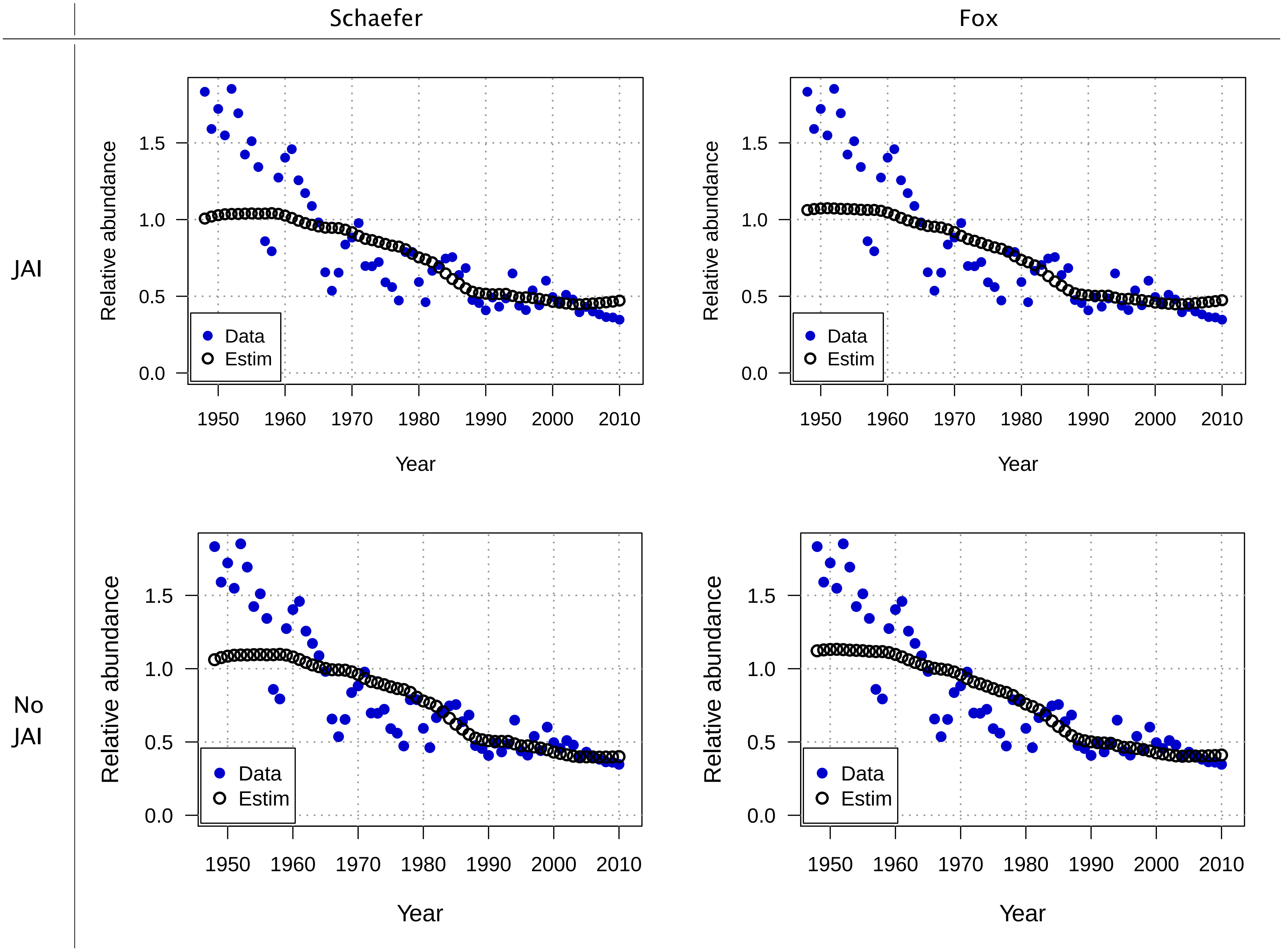
## Introduction

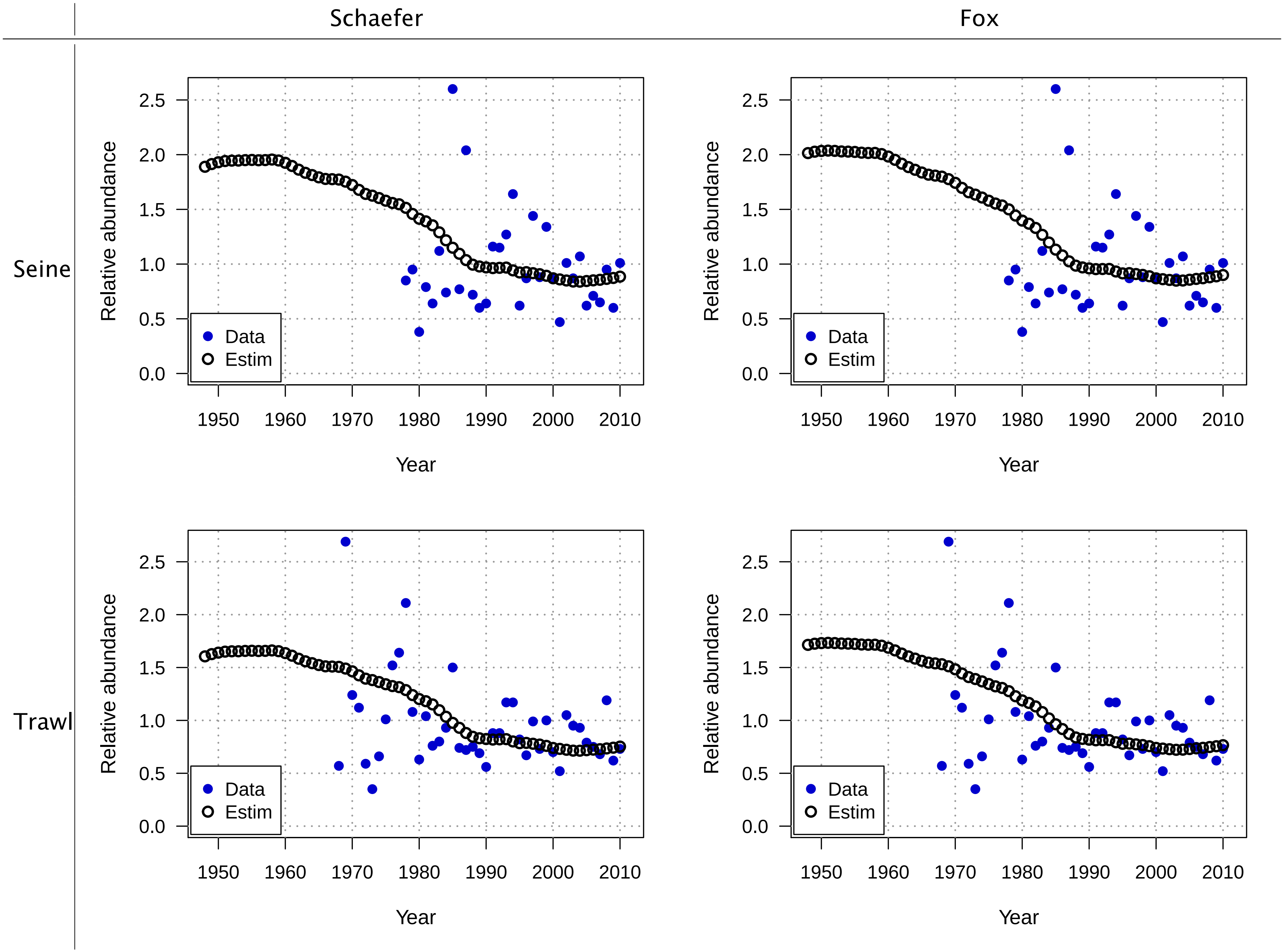
The following figures illustrate production model fits performed for the SEDAR 27 Review Workshop. These are intended to explore worst-case scenarios.

The data used were as follows:

- Total landings, as used in other modeling in this assessment.
- An adult abundance index based on CPUE in the reduction fishery. The measure of effort is vessel-ton-weeks, and an adjustment of 2% per year, compounded annually, is used to account for other increases in catchability, and perhaps to account for the hyperstability that is often characteristic of indices based on fishery-dependent data.
- The trawl and seine juvenile abundance indices are used in two of the four runs.
- The Schaefer model is used in two of the four model runs, the Fox model in the others.


Schaefer
Fox
JAI
No JAI
Relative status
0.0
0.5
1.0
1.5
2.0
F/Fmsy
B/Bmsy
1950
1960
1970
1980
1990
2000
2010
Year


Schaefer
Fox
JAI
No JAI
Relative abundance
0.0
0.5
1.0
1.5
Year
1950
1960
1970
1980
1990
2000
2010
Data
Estim


Schaefer
Fox
Seine
Trawl
Relative abundance
Year
0.0
0.5
1.0
1.5
2.0
2.5
1950
1960
1970
1980
1990
2000
2010
● Data
○ Estim