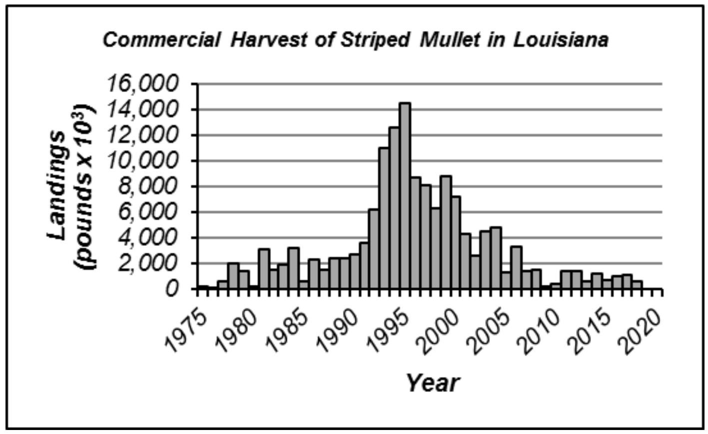
Update Assessment of Striped Mullet *Mugil cephalus* in Louisiana Waters
2020 Report

Executive Summary

Commercial landings of striped mullet *Mugil cephalus* in Louisiana have significantly decreased in the last 20 years, with the highest harvest observed in 1995. The passages of Hurricanes Katrina and Rita caused substantial reduction in the directed effort of the commercial fleet when compared to previous years. Since 2007, annual harvest has remained below two-million pounds, with extremely low landings in 2009 and 2010. Since 2010, landings have increased, but remain at historically low levels. The marked decline in commercial landings since 2000 can be attributed to impacts from several hurricanes, increases in operating costs, increases in foreign wild-caught and aquaculture mullet production, and decreases in the demand and price of mullet roe.



A statistical catch at age model is used in this assessment to describe the dynamics of the Louisiana striped mullet stock. This model uses a maximum likelihood fitting criterion to project population size from abundance estimates in the initial year and recruitment estimates in subsequent years. Fishing mortality is estimated as year and age-specific components. Landings are taken from the Louisiana Department of Wildlife and Fisheries (LDWF) Trip Ticket Program and National Marine Fisheries Service commercial statistical records. An abundance index is developed from the LDWF fishery-independent marine gillnet survey. Age composition of fishery and survey catches are estimated with age-length keys developed from samples directly from the fishery and a von Bertalanffy growth function.

The conservation threshold established by the Louisiana Legislature for striped mullet is a 30% spawning potential ratio. Based on results of this assessment, the Louisiana striped mullet stock is currently neither overfished or experiencing overfishing. The current spawning potential ratio estimate is 54%.

Summary of Changes from 2019 Assessment

Assessment model inputs have been updated through 2018. No changes have been made to the assessment model itself. A change was made in this assessment update to the abundance indices developed from the LDWF fishery-independent experimental marine gillnet survey that were used as data inputs of the assessment model. In the previous assessment, an "old" and "new' time-series of abundance indices were used as data inputs. The "old" time-series (1996-2012) was developed exclusively from the long-term stations of the survey before the survey was expanded in October 2010 with the establishment of additional sampling locations. The "new" time-series (2010-2017) was developed using data from all stations currently sampled. In this assessment update, information from the "old" and "new" sampling locations are combined and a single abundance index time-series is developed (1996-2018; details in *2. Data Sources*) as a data input of the assessment model.

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1. Introduction

A statistical catch-at-age model is used in this assessment to describe the dynamics of the Louisiana (LA) striped mullet *Mugil cephalus* (SM) stock. The assessment model forward projects annual abundance at age from estimates of abundance in the initial year of the time-series and recruitment estimates in subsequent years. The model is fit to the data with a maximum likelihood fitting criterion. Minimum data requirements are fishery catch-at-age and an index of abundance (IOA). Landings values are taken from the Louisiana Department of Wildlife and Fisheries (LDWF) Trip Ticket Program and the National Marine Fisheries Service (NMFS) commercial statistical records. An abundance index is developed from the LDWF experimental marine gillnet survey. Age composition of fishery and survey catches are estimated with age-length keys derived from samples directly of the fishery and a von Bertalanffy growth function.

1.1 Fishery Regulations

The LA SM fishery is governed by the Louisiana State Legislature, the Wildlife and Fisheries Commission and the LDWF. Louisiana commercial and recreational SM fishery regulations were reviewed in the 2014 assessment report (West *et al.* 2014); full descriptions of historical regulations can be found in Mapes *et al*. (1998) and GSMFC (1995).

1.2 Trends in Harvest

Time-series of commercial and recreational SM landings in the Gulf of Mexico are presented (Table 1, Figure 1). Trends in harvest were reviewed in the 2014 assessment report (West *et al.* 2014).

2. Data Sources

2.1 Fishery Independent

The LDWF conducts routine fishery-independent (FI) monitoring surveys across Louisiana's coastal zone primarily to measure relative abundance and size compositions of recreationally and commercially important marine species. For sampling purposes, coastal Louisiana is currently divided into five LDWF coastal study areas (CSAs). Current CSA definitions are as follows: CSA 1 – Mississippi State line to South Pass of the Mississippi River (Pontchartrain Basin); CSA 3 – South Pass of the Mississippi River to

Bayou Lafourche (Barataria Basin); CSA 5 – Bayou Lafourche to eastern shore of Atchafalaya Bay (Terrebonne Basin); CSA 6 – Eastern shore of Atchafalaya Bay to western shore of Freshwater Bayou Canal (Vermillion/Teche/Atchafalaya Basins); CSA 7 – western shore of Freshwater Bayou Canal to Texas State line (Mermentau/Calcasieu/Sabine Basins).

The LDWF fishery-independent experimental marine gillnet survey is used in this assessment to develop an index of abundance as a data input of the assessment model. Below is a brief description of this surveys methodology. Complete details can be found in LDWF (2018).

The experimental marine gillnet survey is conducted with a standardized design and is one of the primary gears used to sample inshore finfish. The survey is conducted year-round. Sampling gear is a 750-foot long gillnet made up of equal sized panels of 2.0, 2.5, 3.0, 3.5, and 4.0-inch stretch meshes.

Samples are taken by 'striking' the net. All captured SM are enumerated and a maximum of 30 randomly selected SM per mesh panel are collected for length measurements, gender determination, and maturity information. When more than 30 SM are captured per mesh panel, catch-at-size is derived as the product of total catch and proportional subsample-at-size.

This survey was conducted from 1986 to April 2013 at fixed sampling stations within each CSA. The 2.5 and 3.5-inch mesh sizes were not included in this survey until 1988. In October of 2010, additional fixed stations were added to the survey allowing more spatial coverage within each CSA (Figure 2). Beginning in April 2013, the survey design was modified where sampling locations are now selected randomly from the established stations within each CSA.

2.2 Fishery Dependent

Commercial

Commercial SM landings are taken from NMFS commercial statistical records (NMFS 2019) and the LDWF Trip Ticket Program (Figure 1). Annual size composition of commercial catches (Table 2) are derived from the Trip Interview Program (TIPS; 1996-2001), the Fishery Information Network (FIN; 2007-2018), and by combination of data collection programs (TIPS+FIN; 2002-2006). Ages of commercial SM landings are derived from otoliths collected from LDWF sampling effort (see *Catch at Age Estimation*).

Recreational

As in prior assessments, the effects of recreational harvest on the stock are not considered. Harvest data from the LDWF Recreational Creel Survey (LA Creel) indicates that LA recreational harvest is negligible relative to commercial harvest (Table 1). Furthermore, only limited recreational size composition information is available. The size information that is available indicates the recreational harvest is primarily taken at sizes (age-0) prior to entering the commercial fishery (age-1+).

3. Life History Information

3.1 Unit Stock Definition

Striped mullet are a catadromous schooling fish common in warm, temperate coastal waters throughout the world. They are ubiquitous in the Gulf of Mexico (GOM) and can be found along the full salinity gradient, from fresh to hyper-saline. Little or no genetic sub-structuring has been documented for GOM striped mullet. Thompson *et al.* (1991) found no differences in enzyme polymorphisms in striped mullet collected from various locations across Louisiana, or between those areas and mullet collected from the Pascagoula River (Mississippi), Mobile Bay (Alabama), and Charleston Bay (South Carolina). Campton and Mahmoudi (1991) also found little evidence for genetic sub-structuring of striped mullet populations between the Atlantic and GOM coasts of Florida. For the purpose of this assessment, the unit stock is defined as those female SM occurring in LA waters. This approach is consistent with the current statewide management strategy.

3.2 Morphometrics

Weight-length regressions for LA SM were developed by Thompson *et al.* (1991). Regression equation slopes comparing males and females were not significantly different. For the purpose of this assessment, the non-sex-specific formulation is used with weight calculated from size as:

$$W = 2.1 \times 10^{-5} (FL)^{2.93} \quad [1]$$

where W is total weight in grams and FL is fork length in mm. Fish with only TL measurements available are converted to FL (and conversely) using the relationship provided by Thompson *et al*. (1991) where:

$$FL = (TL + 3.40)/1.13 \quad [2]$$

3.3 Growth

Von Bertalanffy growth functions for female LA SM collected from fishery-independent data sources were developed by Thompson *et al.* (1991) with size-at-age calculated from:

$$FL_a = 471.70 \times (1 - e^{-0.28(a-0.03)}) \quad [3]$$

where FL_a is FL-at-age in mm and years.

3.4 Sex Ratio

The probability of being female at a specific size for landings and survey catches was estimated with a logistic function developed in an earlier assessment (West *et al.* 2014) as:

$$P_{fem,l} = \frac{1}{\left[1+e^{[-0.24(TL-10.04]}\right]} \quad [4]$$

where $P_{fem,l}$ is the estimated proportion of females in 1 inch TL intervals. The minimum sex ratio-at-size is assumed as 50:50.

3.5 Fecundity/Maturity

Per capita fecundity functions for LA SM were developed by Thompson *et al*. (1991) with fecundity-at-size computed as:

$$f_l = 5.6 \times 10^{-3}(FL)^{3.18} \quad [5]$$

Where f_l is the average fecundity of a size l female in FL. Fecundity-at-age f_a is then computed by substituting equation [5] into equation [3]. Female SM maturity is assumed knife-edged at age-2.

3.6 Natural Mortality

Striped mullet can live to at least ten years of age (Thompson *et al.* 1991). For purposes of this assessment, a constant value of M is assumed (0.3), but is allowed to vary with weight-at-age to calculate a declining natural mortality rate with age. This value of M is consistent with a stock where approximately 5% of the population remains alive to 10 years of age (Quinn and Deriso 1999). Following SEDAR 12 (SEDAR 2006b), the estimate is rescaled where the average mortality rate over ages vulnerable to the fishery is equivalent to the constant rate over ages as:

$$M_a = M \frac{nL(a)}{\sum_{a_c}^{a_{max}} L(a)} \quad [6]$$

where M is the constant mortality rate over exploitable ages a, a_{max} is the oldest age-class, a_c is the first fully-exploited age-class, n is the number of exploitable ages, and $L(a)$ is the Lorenzen curve as a function of age. The Lorenzen curve as a function of age is calculated from:

$$L(a) = W_a^{-0.288} \quad [7]$$

where -0.288 is the allometric exponent estimated for natural ecosystems (Lorenzen 1996) and W_a is weight-at-age.

3.7 Relative Productivity / Resilience

The key parameter in age-structured population dynamics models is the steepness parameter (h) of the stock-recruitment relationship. Steepness is defined as the ratio of recruitment levels when the spawning stock is reduced to 20% of its unexploited level relative to the unexploited level and determines the degree of compensation in the population (Mace and Doonan 1988). Populations with higher steepness values are more resilient to perturbation and if the spawning stock is reduced to levels where recruitment is impaired are more likely to recover sooner once overfishing has ended. Generally, this parameter is difficult to estimate due to a lack of contrast in spawning stock size (*i.e.*, data not available at both high and low levels of stock size) and is typically fixed or constrained during the model fitting process. Published estimates of steepness are not available for GOM striped mullet.

Productivity is a function of fecundity, growth rates, natural mortality, age of maturity, and longevity and can be a reasonable proxy for resilience. We characterize the relative productivity of LA SM based on life-history characteristics, following SEDAR 9, with a classification scheme developed at the FAO second technical consultation on the suitability of the CITES criteria for listing commercially-exploited aquatic species (FAO 2001; Table 3). Each life history characteristic (von Bertalanffy growth rate, age at maturity, longevity, and natural mortality rate) is assigned a rank (low=1, medium=2, and high=3) and then averaged to compute an overall productivity score. In this case, the overall productivity score is 2.5 for LA striped mullet indicating medium to high productivity and resilience.

4. Abundance Index Development

A striped mullet index of abundance (IOA) is developed from the LDWF experimental marine gillnet survey. Only the CSAs (1, 5, 6, and 7), months (November – February), and mesh panels (2.0, 2.5, 3.0, 3.5 inch) with ≥5% positive samples (*i.e*., non-zero catches) on average were included in IOA development. Samples collected during the months of January and February are grouped with the previous year's November and December samples. Catch per unit effort is defined as the number of female striped mullet caught per net sample. The number of female mullet caught per gillnet sample is calculated from each samples catch at size and equation [4]. To reduce unexplained variability in catch rates unrelated to changes in abundance, the IOA was standardized using methods described below.

A delta lognormal approach (Lo *et al.* 1992; Ingram *et al.* 2010) is used to standardize female SM catch-rates in each year as:

$$I_y = c_y p_y \quad [8]$$

where c_y are estimated annual mean CPUEs of non-zero catches modeled as lognormal distributions and p_y are estimated annual mean probabilities of capture modeled as binomial distributions. The lognormal model considers only the positive samples in which SM were captured; the binomial model considers all samples. The lognormal and binomial means and their standard errors were estimated with generalized linear mixed models as least square means and back transformed. Each IOA was then computed from equation [8] using the estimated least-squares means with variances calculated from:

$$V(I_y) \approx V(c_y)p_y^2 + c_y^2 V(p_y) + 2c_y p_y \mathrm{Cov}(c,p) \quad [9]$$

where Cov$(c,p)\approx \rho_{c,p}\left[SE(c_y)SE(p_y)\right]$ and $\rho_{c,p}$ represents the correlation of c and p among years.

Because of the designed nature of LDWF fishery-independent surveys, model development was rather straightforward. Variables considered in model inclusion were year, CSA, and sampling location. Because only seasonal samples were included in each IOA (i.e., November-February), time of year was not considered in model inclusion. To determine the most appropriate models, we began the model selection process with fully-reduced models that included only year as a fixed effect. More complex models were then developed including interactions and random effects and compared using Akaike information criterion (Akaike 1973) and log-likelihood values. All sub-models were estimated with the SAS generalized linear mixed modeling procedure (PROC GLIMMIX; SAS 2008). In the final sub-models, year was considered a fixed effect, CSA was considered a random block effect, and sampling locations within CSAs were considered random subsampling block effects. Fits of lognormal sub-models were evaluated with conditional residual plots. Binomial sub-models were evaluated for overdispersion via Pearson's chi-square per degree of freedom statistic (Stroup 2013).

Sample sizes, observed proportion positive samples, nominal CPUEs, standardized IOA, and corresponding coefficients of variation are presented (Table 4). The standardized IOA and nominal CPUEs, normalized to 1 for comparison, are also presented graphically (Figure 3).

5. Catch at Age Estimation

Age-length-keys (ALKs) are developed to estimate the annual age composition of fishery and survey catches as described below.

5.1 Fishery

Female SM otoliths collected from fishery-dependent sources are used in age assignments of fishery landings in this assessment. Ages are assigned by assuming a January 1st birthday, where SM spawned the previous year become age-1 on January 1st and remain age-1 until the beginning of the following year.

Probabilities of age given length for annual fishery landings are computed as:

$$P(a|l)_y = \frac{n_{lay}}{\sum_a n_{lay}} \quad [10]$$

where n_{lay} are annual female SM sample sizes occurring in each total length/age bin (Tables 5 and 6). When $\sum_a n_{lay} < 5$, the $P(a|l)$ for that 1 inch TL interval is estimated by pooling all samples in Table 6 from the corresponding size bin. Table 5 is used to calculate $P(a|l)_y$ for the 1996-2002 landings, where limited annual sample sizes preclude use of annual ALKs.

Annual fishery catch-at-age (females only) is then calculated as:

$$C_{ay} = \sum_l P_{fem,l} C_{ly} \, P(a|l)_y \qquad [11]$$

where $P_{fem,l}$ is taken from equation [4], C_{ly} is annual fishery catch-at-size, and $P(a|l)_y$ are taken from equation [10]. Resulting annual fishery catch-at-age and associated mean weights-at-age are presented (Tables 7 and 8).

5.2 Survey

Probabilities of age given length for female SM catches of the experimental marine gillnet survey are computed as:

$$P(a|l) = \frac{P(l|a)}{\sum_a P(l|a)} \qquad [12]$$

where the probability of length given age is estimated from a normal probability density as:

$$P(l|a) = \frac{1}{\sigma_a\sqrt{2\pi}} \int_{l-d}^{l+d} exp\left[-\frac{(l-l_a)^2}{2\sigma_a^2}\right] dl \qquad [13]$$

where length bins are 1 inch TL intervals with midpoint l, maximum $l + d$, and minimum $l - d$ lengths. Mean total length-at-age l_a is estimated from Equation [3] and Equation [2]. Variance in length-at-age is approximated from $\sigma_a = l_a CV_l$, where the coefficient of variation in length-at-age is assumed constant (in this case approximated as 0.05). To approximate changes in growth with the timing of the survey, mean l_a was calculated at the end of the calendar year (*i.e.*, age=$a + 1.0$). Resulting survey $P(a|l)$ is presented (Table 9). Annual survey female catch-at-age is also calculated from equation [11] with annual survey catch-at-size substituted for fishery catch-at-size. Annual survey catch-at-size is derived using only those samples included in abundance index development. Annual survey catch-at-size and resulting annual survey age composition (females only) are presented (Tables 10 and 11).

6. Assessment Model

In this assessment update, the Age-Structured Assessment Program (ASAP3 Version 3.0.12; NOAA Fisheries Toolbox) is used to model the dynamics of the female proportion of the LA SM stock. ASAP is a statistical catch-at-age model that allows internal estimation of a Beverton-Holt stock recruitment relationship and MSY-related reference points. Minimum data requirements are fishery catch-at-age, corresponding mean weights-at-age, and an index of abundance. ASAP projects abundance at age from estimates of abundance in the initial year of the time-series and recruitment estimates in subsequent years. The model is fit to the data with a maximum likelihood fitting criterion. An overview of the basic model configuration, equations, and their estimation, as applied in this assessment, are provided below. Specific details and full capabilities of ASAP can be found in the technical documentation (ASAP3; NOAA Fisheries Toolbox).

6.1 Model Configuration

For purposes of this assessment, the model is configured with annual time-steps and a calendar year time frame. As in earlier assessments, 1996 is the first year modeled due to the limited information available from earlier years of the fishery. Since the commercial SM strike net fishery season runs from the 3rd Monday in October through the 3rd Monday of the following January, SM harvested in January are grouped with the previous year's landings for modeling purposes.

Mortality

Fishing mortality is assumed separable by age a and year y as:

$$F_{ay} = v_a Fmult_y \quad [14]$$

where v_a are fishery selectivities and $Fmult_y$ are fully-selected fishing mortality rates. Apical fishing mortality is estimated in the initial year and as deviations from the initial estimate in subsequent years.

Age-specific fishery selectivities are modeled with a single logistic function as:

$$v_a = \frac{1}{1+e^{-(a-\alpha)/\beta}} \quad [15]$$

Total mortality for each age and year is estimated from the age-specific natural mortality rate M_a and estimated fishing mortalities as:

$$Z_{ay} = M_a + F_{ay} \quad [16]$$

For reporting purposes, annual fishing mortalities are averaged by weighting by estimated population abundance as:

$$F_y = \frac{\sum_a F_{ay} N_{ay}}{\sum_a N_{ay}} \quad [17]$$

Abundance

Abundance in the initial year of the time series and recruitment in subsequent years are estimated and used to forward calculate the remaining numbers at age from the age and year specific total mortality rates as:

$$N_{ay} = N_{a-1,y-1}e^{-Z_{a-1,y-1}} \quad [18]$$

Numbers in the plus group A are calculated from:

$$N_{Ay} = N_{A-1,y-1}e^{-Z_{A-1,y-1}} + N_{A,y-1}e^{-Z_{A,t-1}} \quad [19]$$

Stock Recruitment

Expected recruitment is calculated from the Beverton-Holt stock recruitment relationship, reparametrized by Mace and Doonan (1988), with annual lognormal deviations as:

$$\hat{R}_{y+1} = \frac{\alpha SS_y}{\beta + SS_y} + e^{\delta_{y+1}} \quad [20]$$

$$\alpha = \frac{4\tau(SS_0/SPR_0)}{5\tau - 1} \text{ and } \beta = \frac{SS_0(1-\tau)}{5\tau - 1}$$

where SS_0 is unexploited spawning stock, SPR_0 is unexploited spawning stock per recruit, τ is steepness, and $e^{\delta_{y+1}}$ are annual lognormal recruitment deviations..

Spawning Stock

Spawning stock in each year is calculated from:

$$SS_y = \sum_{i=1}^{A} N_{ay}\Phi_{ay}\, e^{-Z_{ay}(0.0)} \quad [21]$$

where Φ_{ay} is per capita fecundity at age, and $-Z_{ay}(0.0)$ is the proportion of total mortality occurring prior to spawning on January 1st .

Catch

Expected fishery catches are estimated from the Baranov catch equation as:

$$\hat{C}_{ay} = N_{ay}F_{ay}\frac{(1-e^{-Z_{ay}})}{Z_{ay}} \quad [22]$$

Expected age composition of fishery catches are then calculated from $\frac{\hat{C}_{ay}}{\sum_a \hat{C}_{ay}}$. Expected yields are then computed as $\sum_a \hat{C}_{ay}\overline{W}_{ay}$, where $\overline{W}_{ay}$ are observed mean catch weights.

Catch-rates

Expected survey catch-rates are computed from:

$$\hat{I}_{ay} = q\sum_a N_{ay}(1 - e^{-Z_{ay}(1.0)})v_a \quad [23]$$

where v_a are the age-specific survey selectivities, q is the estimated catchability coefficient, and $-Z_{ay}(1.0)$ is the proportion of the total mortality occurring prior to the time of the survey (December 31st midpoint). Age-specific survey selectivities are modeled with a double logistic function as:

$$v_a = \left(\frac{1}{1+e^{-(a-\alpha)/\beta}}\right)\left(1-\frac{1}{1+e^{-(a-\alpha 2)/\beta 2}}\right) \quad [24]$$

Expected survey age composition is then calculated as $\frac{\hat{I}_{ay}}{\sum_a \hat{I}_{ay}}$.

Parameter Estimation

The number of parameters estimated is dependent on the length of the time-series, number of fisheries and selectivity blocks modeled, and number of abundance indices modeled. Parameters are estimated in log-space and then back transformed. In this assessment, 60 parameters were estimated:

1. 6 selectivity parameters (2 for the fishery; 4 for the survey)
2. 23 apical fishing mortality rates (F_{mult} in the initial year and 22 deviations in subsequent years)
3. 23 recruitment deviations (1996-2018)
4. 6 initial population abundance deviations (age-2 through 7-plus)
5. 1 catchability coefficient (survey)
6. 1 stock-recruitment parameter (virgin stock size; the steepness parameter is fixed at 1.0 in the base run).

The model is fit to the data by minimizing the objective function:

$$-ln(L) = \sum_i \lambda_i(-ln\, L_i) + \sum_j(-ln\, L_j) \quad [25]$$

where $-ln(L)$ is the entire negative log-likelihood , lnL_i are log-likelihoods of lognormal estimations, λ_i are user-defined weights applied to lognormal estimations, and lnL_j are log-likelihoods of multinomial estimations.

Negative log-likelihoods with assumed lognormal error are derived (ignoring constants) as:

$$-ln(L_i) = ln(\sigma) + 0.5\sum_i \frac{[ln(obs_i)-ln(pred_i)]^2}{\sigma^2} \quad [26]$$

where obs_i and $pred_i$ are observed and predicted values; standard deviations σ are user-defined coefficients of variation (CV) as $\sqrt{ln(CV^2+1)}$.

Negative log-likelihoods with assumed multinomial error are derived (ignoring constants) as:

$$-ln\left(L_j\right) = -ESS\sum_{i=1}^{A} p_i\, ln(\hat{p}_i) \quad [27]$$

where p_i and $\hat{p}_i$ are observed and predicted age composition. Effective sample-sizes (ESS) are used to create the expected numbers $\hat{n}_a$ in each age bin and act as multinomial weighting factors.

6.2 Model Assumptions/Inputs

Model assumptions include: 1) the unit stock is adequately defined and closed to migration, 2) observations are unbiased, 3) errors are independent and their structures adequately specified, 4) fishery vulnerabilities are flat topped; survey vulnerabilities are dome-shaped, 5) abundance indices are proportional to absolute abundance, and 6) natural mortality, fecundity, growth and sex ratio at size/age do not vary significantly with time. Lognormal error distributions are assumed for catches, abundance indices, the stock-recruitment relationship, apical fishing mortality, selectivity parameters, initial abundance deviations, and catchability. Multinomial error distributions are assumed for fishery and survey age compositions.

The base model was defined with an age-7 plus group, steepness fixed at 1.0, one fishery selectivity block, one survey selectivity block, and input levels of error and weighting factors as described as follows. Input levels of error for fishery landings were specified with CV's of 0.05 for each year of the time-series; annual recruitment deviations were specified with CV's of 0.3. All lambdas for lognormal components included in the objective function were equally weighted (=1). Input effective sample sizes (ESS) for estimation of fishery age compositions were specified as ESS=50 for years where annual ALKs were available (2003-2018) and down weighted to ESS=25 for years where the pooled ALK was used (1996-2002). Input effective sample size for estimation of survey age compositions, where ages were assigned from a von Bertalanffy growth function, were specified as ESS=10 for all years.

6.3 Model Results

Objective function components, weighting factors, and likelihood values of the base model are summarized in Table 12.

Model Fit

The base model provides an overall reasonable fit to the data. Predicted catches match the observations well. A residual pattern is apparent, however, where catch observations are generally underestimated in earlier years and overestimated in more recent years of the time-series (Figure 4). Predicted survey catch-rates match the data adequately with no strong pattern in residuals, but fail to fit the high catch rate observed in 2005 and overestimates the most recent observations (Figure 5). Predicted fishery and survey age compositions provide reasonable fits to the input age proportions (Figures 6 and 7). However, the predicted fishery age compositions overestimate the age-7-plus group input proportions in the most recent years of the time-series beginning in 2013. The model adequately tracks the 2005 year-class into the plus-group in 2012, but fails to adequately track subsequent year-classes into the plus-group causing the overestimation.

Selectivities

Estimated fishery and survey selectivities are presented in Figure 8. Fishery estimates indicate full-vulnerability to the commercial gill net fishery at age 5 with over 75% vulnerable at age 3. Survey estimates indicate full vulnerability to the FI survey gear at age 2.

Abundance, Recruitment, and Spawning Stock

Total stock size and abundance at age estimates from the base model are presented in Table 13. Stock size has varied over the time-series. Stock size decreased from 27.1 million females in 1996 to a minimum of 6.8 million females estimated in 2009. Since 2009, stock size has increased to a peak of 15.7 million females in 2017. The 2018 stock size estimate is 14.4 million females.

Recruitment estimates from the base model are presented in Figure 9. Recruitment has varied over the time-series. Age-1 recruit estimates decreased from 9.5 million fish in 1996 to 2.1 million age-1 fish in 2009. Since 2009, recruitment increased to a peak of 8.0 million age-1 fish estimated in 2015. The 2018 estimate of age-1 recruits is 4.1 million age-1 females.

Spawning stock estimates (total egg production) are presented in Figure 10. Spawning stock has varied over the time series with a decreasing trend in early years to an increasing trend in later years. Spawning stock decreased from 5.2 trillion eggs in 1996 to a minimum of 1.4 trillion eggs estimated in 2007. Since 2007, the trend has generally been upward with an estimate of 4.2 trillion eggs in 2018.

Fishing Mortality

Estimated fishing mortality rates are presented in Table 14 (apical, average, and age-specific) and Figure 11 (average only). Average rates are weighted by estimated population numbers at age. Average fishing mortality has varied over the time-series with an overall decreasing trend. The highest estimates of average F were in earlier years of the time series with peaks observed in 1999 and 2004 (0.31 and 0.36 yr^{-1}). Since 2004, average fishing mortality rates decreased to a minimum of 0.01 yr^{-1} in 2009 and has remained low. The 2018 estimate of average F is 0.02 yr^{-1}.

Stock-Recruitment

No discernable relationship is observed between spawning stock and subsequent age-1 recruitment (Figure 12). The ASAP base models stock-recruitment relationship was run with steepness fixed at 1.0 and scaled to unexploited spawning stock. The unexploited spawning stock estimate was 6.7 trillion eggs and the corresponding unexploited recruitment was 4.7 million age-1 females. Alternate model runs with steepness values fixed at 0.9, 0.8, and 0.6 are discussed in the *Model Diagnostics* Section below.

Parameter Uncertainty

In the ASAP base model, 60 parameters were estimated. Asymptotic standard errors for the time-series of age-1 recruits are presented in Figure 9. Markov Chain Monte Carlo derived confidence intervals (95%) for average fishing mortality rates and the spawning stock time-series are presented in Figures 10 and 11.

6.4 Management Benchmarks

The conservation standard established by the LA Legislature for striped mullet (RS 56:333) is a 30% spawning potential ratio (SPR; Goodyear 1993). Methodology used in this assessment to estimate equilibrium yield, spawning stock (total egg production), and average fishing mortality rates that lead to 30% SPR are described below. Current conditions are taken by averaging estimates from the final three years of the modeled time-series (2016-2018).

When the stock is in equilibrium, equation [21] can be solved, excluding the year index, for any given exploitation rate as:

$$\frac{SS}{R}(F) = \sum_{i=1}^{A} N_a \Phi_a \, e^{-Z_a(0.0)} \quad [28]$$

where total mortality at age Z_a is computed as $M_a + v_a \times Fmult$; vulnerability at age v_a is taken by rescaling the current F-at-age estimate (geometric mean 2016-2018) to the maximum. Per recruit abundance-at-age is estimated as $N_a = S_a$, where survivorship at age is calculated recursively from $S_a = S_{a-1}e^{-Z_a}$, $S_1 = 1$. Per recruit catch-at-age is then calculated with the Baranov catch equation [22], excluding the year index. Yield per recruit (Y/R) is then taken as $\sum_a C_a \overline{W}_a$ where $\overline{W}_a$ are current mean fishery weights at age (arithmetic mean 2016-2018).

Equilibrium spawning stock SS_{eq} is calculated by substituting SS/R estimated from equation [28] into the Beverton-Holt stock recruitment relationship as $\alpha \times SS/R - \beta$. Equilibrium recruitment R_{eq} and yield Y_{eq} are then taken as $SS_{eq} \div SS/R$ and $Y/R \times R_{eq}$. Fishing mortality is averaged as $\sum_a F_a N_a / \sum_a N_a$. Equilibrium SPR is then computed as the ratio of SS/R when F>0 to SS/R when F=0.

As reference points to guide management, we estimate the average fishing mortality rate and spawning stock size that lead to a 30% SPR ($F_{30\%}$ and $SS_{30\%}$; Table 15). Also presented are a plot of the stock recruitment data, equilibrium recruitment, and diagonals from the origin intersecting R_{eq} at the minimum and maximum spawning stock estimates of the time-series, corresponding with a minimum equilibrium SPR of 21% and a maximum of 77% (Figure 13). The current estimate of equilibrium SPR is 54%.

6.5 Model Diagnostics

Sensitivity Analysis

A series of sensitivity runs are used to explore uncertainty in the base model's configuration. The ASAP base model was run with steepness fixed at 1.0. Alternate runs were conducted examining reference point estimates ($F_{30\%}$, $SS_{30\%}$, $Y_{30\%}$, $F_{current}/F_{30\%,}$ and $SS_{current}/SS_{30\%}$) with steepness fixed at 0.9, 0.8 and 0.6. Current conditions are taken by averaging estimates from the final three years of the modeled time-series (2016-2018). Additional sensitivity runs were conducted by separately increasing the lognormal weighting factors of the catch and IOA components of the base models objective function (*i.e.*, lambdas increased from 1 to 5).

Results of the sensitivity analysis are presented in Table 16. Reference point estimates from all sensitivity runs with the exception of the runs with steepness fixed at 0.8 and 0.6 indicate the stock is currently above $SS_{30.}$ All sensitivity runs indicate the fishery is currently operating below $F_{30\%}$. Estimates of $F_{30\%}$ for each sensitivity run were similar in magnitude (0.16 yr^{-1}). Estimates of $SS_{30\%}$, and $Y_{30\%}$ for each sensitivity run varied in magnitude (1.3-3.0 trillion eggs, and 1.5-3.5 million pounds, respectively).

Retrospective Analysis

A retrospective analysis was conducted by sequentially truncating the base model by a year (terminal years 2015-2018). Retrospective estimates of recruitment, $SS/SS_{30\%}$, and $F/F_{30\%}$ are presented in Figure 14, where $SS_{30\%}$ and $F_{30\%}$ are computed from the base model run. Estimated terminal year $SS/SS_{30\%}$, $F/F_{30\%}$, and recruitment differed from the full base run. Terminal year $SS/SS_{30\%}$ estimates indicate positive bias, where $SS/SS_{30\%}$ estimates decrease as more years are added to the model. Terminal year $F/F_{30\%}$ estimates indicate a smaller negative bias, where estimates increase marginally as more years are added to the model. Terminal year recruitment estimates indicate both positive and negative bias, but estimates generally decrease as more years are added to the model.

7. Stock Status

The history of the LA striped mullet stock relative to $F/F_{30\%}$ and $SS/SS_{30\%}$ is presented in Figure 15. Given the established conservation standard of 30% SPR, fishing mortality rates exceeding $F_{30\%}$ ($F/F_{30\%}$>1.0) are defined as overfishing; spawning stock sizes below $SS_{30\%}$ ($SS/SS_{30\,\%}$< 1.0) are defined as the overfished condition.

Overfishing Status

Using results of the ASAP model presented in this assessment, the current estimate of $F/F_{30\%}$ is <1.0, suggesting the stock is currently not undergoing overfishing. However, the assessment model indicates that the stock did experience overfishing in earlier years of the time-series.

Overfished Status

The current estimate of $SS/SS_{30\%}$ is >1.0, suggesting the stock is currently not in an overfished state. However, the assessment model indicates that the stock was in an overfished state in earlier years of the time-series.

Control Rules

As specified in RS 56:333 (http://www.legis.la.gov/Legis/Law.aspx?d=105230), if the annual LDWF striped mullet stock assessment indicates that the current spawning potential ratio is <30%, the department shall close the season within two weeks for a period of at least one year.

8. Research and Data Needs

As with any analysis, the accuracy of this assessment is dependent on the accuracy of the information of which it is based. Mapes et al. (1998) identify several areas for research to address. Below we list additional recommendations to improve future LA stock assessments of striped mullet.

Only limited age data are available from the LDWF marine gillnet survey. Ages of survey catches in this assessment were assigned from a von Bertalanffy growth function. Age samples collected directly from the survey in question would allow a more accurate representation of survey age composition in future assessments.

An additional fishery-independent survey that effectively samples younger life-stages would allow for an index of abundance in future assessments that better characterizes year-class strength. Future efforts should re-examine existing LDWF fishery-independent surveys for adequacy in characterizing the relative abundance of younger striped mullet.

Methods to characterize fishery catch at size (age) for years prior to 1996 need to be examined. Inclusion of years prior to the 1995 peak in commercial striped mullet landings in the assessment model should provide better contrast in spawning stock size and allow more certainty in reference point estimation.

Factors that influence year-class strength of striped mullet are poorly understood. Investigation of these factors, including inter-annual variation in seasonal factors and the influence of environmental perturbations such as the Deepwater Horizon oil spill, could elucidate causes of inter-annual variation in abundance, as well as the species stock-recruitment relationship.

Fishery-dependent data alone is not a reliable source of information to assess status of a fish stock. Consistent fishery-dependent and fishery-independent data sources, in a comprehensive monitoring plan, are essential to understanding the status of fishery. A new LDWF fishery-independent survey methodology was implemented in 2013. This methodology should be assessed for adequacy with respect to its ability to evaluate stock status, and modified if deemed necessary.

With the recent trend toward ecosystem-based assessment models, more data is needed linking striped mullet population dynamics to environmental conditions. The addition of meteorological and physical oceanographic data coupled with food web data may lead to a better understanding of the striped mullet stock and its habitat.

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<u>*10. Tables*</u>

Table 1: Annual Louisiana commercial and recreational striped mullet *Mugil cephalus* landings (numbers x 10^3) derived from NMFS statistical records, and the LDWF Trip Ticket, LA Creel, and Biological Sampling Programs. Recreational landings represent harvest only. Note: recreational estimates from the LA Creel Program are not available for striped mullet prior to 2014.

	Harvest		
Year	*Commercial*	*Recreational*	*%_Recreational*
1996	*6,111*	--	--
1997	*5,508*	--	--
1998	*3,406*	--	--
1999	*4,471*	--	--
2000	*3,646*	--	--
2001	*2,390*	--	--
2002	*1,704*	--	--
2003	*2,731*	--	--
2004	*2,608*	--	--
2005	*714*	--	--
2006	*1,895*	--	--
2007	*792*	--	--
2008	*911*	--	--
2009	*71*	--	--
2010	*233*	--	--
2011	*687*	--	--
2012	*748*	--	--
2013	*392*	--	--
2014	*767*	*7*	*0.9%*
2015	*388*	*14*	*3.6%*
2016	*533*	*2*	*0.3%*
2017	*653*	*21*	*3.1%*
2018	*356*	*13*	*3.4%*

Table 2: Annual size frequency samples of Louisiana commercial striped mullet *Mugil cephalus* landings derived from the Trip Interview Program (TIPS; 1996-2001), the Fishery Information Network (FIN; 2007-2018), and by combination of data collection programs (TIPS+FIN; 2002-2006).

TL_in	*1996*	*1997*	*1998*	*1999*	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*
6												
7												
8												
9												
10	*3*											
11	*8*	*2*	*1*									
12	*59*	*44*	*1*	*10*				*3*	*1*		*10*	*8*
13	*271*	*183*	*5*	*20*	*1*	*3*	*11*	*30*	*22*	*11*	*25*	*25*
14	*518*	*537*	*45*	*37*	*9*	*20*	*37*	*101*	*68*	*61*	*53*	*78*
15	*401*	*595*	*73*	*114*	*40*	*41*	*49*	*142*	*122*	*151*	*107*	*194*
16	*308*	*453*	*110*	*244*	*83*	*40*	*53*	*169*	*267*	*182*	*164*	*256*
17	*202*	*230*	*126*	*248*	*87*	*75*	*31*	*151*	*342*	*154*	*135*	*187*
18	*121*	*108*	*94*	*259*	*73*	*41*	*7*	*110*	*209*	*117*	*117*	*127*
19	*61*	*36*	*36*	*148*	*43*	*18*	*4*	*36*	*58*	*19*	*47*	*74*
20	*14*	*14*	*6*	*49*	*16*	*1*		*8*	*20*		*15*	*12*
21	*6*	*3*		*13*	*2*				*2*		*1*	*2*
22	*2*			*2*	*1*							*1*
23												
24	*1*											
25												
26												
27	*2*											
28												
Totals	*1977*	*2205*	*497*	*1144*	*355*	*239*	*192*	*750*	*1111*	*695*	*674*	*964*

Table 2 (continued):

TL_in	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
6											
7											
8											
9											
10						2					
11	1					1					
12	7		1	1	1	8			2		1
13	35		26	22	19	38	11	12	5	2	2
14	103	1	50	39	45	131	73	33	35	42	6
15	150	10	23	40	112	255	139	99	70	104	16
16	155	49	41	94	153	276	262	230	91	173	19
17	160	165	33	254	260	181	115	271	97	140	40
18	106	215	34	330	244	43	17	121	67	52	19
19	37	134	6	118	63	5	1	19	37	11	5
20	16	79	1	19	5		1	12	28		1
21	1	20		3				4	16	1	
22		6			2				2		
23	1	1									
24											
25											
26											
27											
28											
Totals	772	680	215	920	904	940	619	801	450	525	109

Table 3: FAO proposed guidelines for indices of productivity for exploited fish species.

Parameter	**Productivity**			**Species**	
	Low	**Medium**	**High**	Striped Mullet	**Score**
M	<0.2	0.2 - 0.5	>0.5	**0.3**	2
K	<0.15	0.15 - 0.33	>0.33	**0.28**	2
tmat	>8	3.3 - 8	<3.3	**2**	3
tmax	>25	14 - 25	<14	**10**	3
Examples	orange roughy, many sharks	cod, hake	sardine, anchovy	**Striped Mullet Productivity Score = 2.5 (med/high)**	

Table 4: Annual sample sizes, proportion positive samples, nominal CPUEs, index of abundance, and corresponding coefficients of variation derived from the LDWF fishery-independent marine gillnet survey.

Year	n	%Pos	CPUE	IOA	CV
1996	136	0.18	1.59	0.10	0.30
1997	144	0.18	8.93	0.23	0.29
1998	148	0.22	3.22	0.20	0.27
1999	148	0.15	3.86	0.10	0.31
2000	141	0.18	4.26	0.20	0.29
2001	148	0.16	5.37	0.12	0.30
2002	148	0.19	3.08	0.14	0.29
2003	148	0.16	3.98	0.13	0.30
2004	149	0.20	2.91	0.17	0.28
2005	141	0.23	3.68	0.26	0.27
2006	148	0.18	4.47	0.17	0.29
2007	146	0.20	3.55	0.19	0.28
2008	148	0.17	3.09	0.15	0.30
2009	145	0.16	2.70	0.10	0.30
2010	307	0.15	4.36	0.15	0.27
2011	328	0.17	2.66	0.16	0.26
2012	315	0.16	2.04	0.13	0.26
2013	150	0.16	2.70	0.16	0.29
2014	150	0.13	2.82	0.11	0.31
2015	152	0.12	1.23	0.07	0.31
2016	151	0.14	2.32	0.09	0.30
2017	152	0.13	2.39	0.12	0.31
2018	152	0.12	2.62	0.10	0.31

Table 5: Length-at-age samples used for age assignments of commercial striped mullet *Mugil cephalus* landings 1996-2002 (females only).

1996-2002											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		4	2	1							7
13		21	27	6	1						55
14		28	65	35	4	1		1			134
15	2	28	43	28	6	4	1				112
16	1	18	29	20	8	2					78
17		7	34	15	6	5	2				69
18		3	23	21	9	2					58
19		1	8	11	7	3	1				31
20				2	4	2		1			9
21			1	1	1		1	1			5
22											
23											
24											
25											
26											
Total	3	110	232	140	46	19	5	3	0	0	558

Table 6: Annual length-at-age samples for age assignments of commercial striped mullet *Mugil cephalus* landings 2003-2018 (females only).

2003											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		1	1	1							3
13		13	3	4	3						23
14		9	18	17	6						50
15		6	34	18	4	1					63
16		3	37	38	20	3					101
17		4	17	40	29	6		1			97
18		1	8	20	26	4	8	2			69
19		3	5	6	9	6	3				32
20				2	1	2	1				6
21											
22											
23											
24											
25											
26											
Totals		40	123	146	98	22	12	3			444

2004											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13		1	4								5
14		2	10	4	3	2					21
15		6	28	12	5	3					54
16		5	24	33	13	8					83
17		2	37	58	32	9					138
18			14	47	34	27	1				123
19			2	10	15	9	3				39
20				2	6	4	1				13
21						1					1
22											
23											
24											
25											
26											
Totals		16	119	166	108	63	5				477

Table 6 (continued):

2005											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13	1	1	1								3
14		18	4	7	4						33
15		53	34	41	12						140
16		14	50	69	30	11	2				176
17		4	35	62	36	8	6				151
18			8	49	37	16	5	1			116
19				2	9	2	4				17
20											
21											
22											
23											
24											
25											
26											
Totals	1	90	132	230	128	37	17	1			636

2006											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13		5	3	2	1						11
14	1	2	5	4	4						16
15		22	27	13	20	3	1				86
16		22	40	44	34	8	1				149
17		11	36	31	33	14	2	2			129
18		1	19	45	36	9	3				113
19				13	17	11	3	2			46
20					6	3	5				14
21								1			1
22											
23											
24											
25											
26											
Totals	1	63	130	152	151	48	15	5			565

2007											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		2	1	2							5
13	1	7	3		1	1					13
14	1	17	12	6	3	2					41
15	2	51	48	15	13	6					135
16		48	72	56	22	21	1			1	221
17		11	48	49	32	27	6				173
18	1	3	13	31	31	27	6	3			115
19		1	1	9	22	21	9				63
20				1	2	3	2	1	1		10
21		1	1								2
22						1					1
23											
24											
25											
26											
Totals	5	141	199	169	126	109	24	4	1	1	779

Table 6 (continued):

2008											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		1	2	1							4
13		4	17	6	1						28
14		4	55	26	2						87
15		9	94	19	6	2					130
16	1	8	84	36	4	4	1				138
17		1	73	43	16	6	2				141
18			33	37	7	10	2	1			90
19			9	7	10	5					31
20			3	3	2	3	1	2			14
21			1								1
22											
23			1								1
24											
25											
26											
Totals	1	27	372	178	48	30	6	3			665

2009											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13											
14											
15		1									1
16			3	4							7
17	1	2	25	17	4	1					50
18		1	15	45	4	1	1				67
19			2	25	5	3	1				36
20				9	8	1					18
21				2	1	3	2	1			9
22								2			2
23											
24											
25											
26											
Totals	1	4	45	102	22	9	4	3			190

2010											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12					1						1
13		1	9	11	4	1					26
14		4	18	15	12	1					50
15			3	15	5						23
16		2	11	22	4	2					41
17			5	18	9	1					33
18				12	18	3		1			34
19					6						6
20						1					1
21											
22											
23											
24											
25											
26											
Totals		7	46	93	59	9		1			215

Table 6 (continued):

2011											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13	1	8	3								12
14		9	8	3	1						21
15		2	5	7	5		1				20
16		1	16	15	30	4	1	1			68
17		1	18	48	103	22	3	1			196
18		1		21	140	91	15	1			269
19			2	4	29	54	9				98
20					6	9	2				17
21				1		1					2
22											
23											
24											
25											
26											
Totals	1	22	52	99	314	181	31	3			703

2012											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13		3	1		1	1					6
14	1	15	16	5	1		1				39
15		29	47	14	9	5	2				106
16		7	55	37	21	12	6				138
17		3	24	69	60	49	10				215
18			4	23	39	96	31	1	1		195
19				1	6	17	18	2			44
20						1	2				3
21											
22			1								1
23											
24											
25											
26											
Totals	1	57	148	149	137	181	70	3	1		747

2013											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12			1								1
13		6	1	3							10
14		31	17	1	2						51
15		53	61	21	6	1					142
16		15	67	34	11	5	2				134
17		5	28	40	18	5	4				100
18			4	16	10	5	3				38
19					2	2	1				5
20											
21											
22											
23											
24											
25											
26											
Totals		110	179	115	49	18	10				481

Table 6 (continued):

2014											
TL_in	*Age_1*	*Age_2*	*Age_3*	*Age_4*	*Age_5*	*Age_6*	*Age_7*	*Age_8*	*Age_9*	*Age_10*	*Total*
8											
9											
10											
11											
12											
13		5	6								11
14		17	47	7	1						72
15		18	96	23	1						138
16		7	177	66	10						260
17		3	55	40	10	3	2	1			114
18			6	5	3	2		1			17
19				1							1
20			1								1
21											
22											
23											
24											
25											
26											
Totals		50	388	142	25	5	2	2			614

2015											
TL_in	*Age_1*	*Age_2*	*Age_3*	*Age_4*	*Age_5*	*Age_6*	*Age_7*	*Age_8*	*Age_9*	*Age_10*	*Total*
8											
9											
10											
11											
12											
13		3	1	3	2						9
14		8	4	11	5	1					29
15		32	21	37	4						94
16		41	64	108	12	2					227
17		8	71	153	33	1					266
18		2	20	78	16	2					118
19		1	3	11	2	2					19
20			3	8	1						12
21			1	1	2						4
22											
23											
24											
25											
26											
Totals		95	188	410	77	8					778

2016											
TL_in	*Age_1*	*Age_2*	*Age_3*	*Age_4*	*Age_5*	*Age_6*	*Age_7*	*Age_8*	*Age_9*	*Age_10*	*Total*
8											
9											
10											
11											
12		1	1								2
13		1	1	1	1	1					5
14	1	14	8	1	2	1	1				28
15	1	34	18	8	1						62
16		47	23	4	12	2					88
17		22	45	14	12	3					96
18		12	24	18	12	1					67
19		4	11	9	13						37
20			10	8	9	1					28
21			4	5	7						16
22			1								1
23											
24											
25											
26											
Totals	2	135	146	68	69	9	1				430

Table 6 (continued):

2017											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12											
13		1	1								2
14	1	12	21	7							41
15		19	61	19	4	1					104
16		34	112	18	6	3					173
17		15	96	19	6	2					138
18		5	32	10	1	1	1				50
19			4	6	1						11
20											
21			1								1
22											
23											
24											
25											
26											
Totals	1	86	328	79	18	7	1				520

2018											
TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	Total
8											
9											
10											
11											
12		1									1
13		1	1								2
14		1	2	2	1						6
15		9	3	3	1						16
16		9	5	5							19
17		1	18	17	4						40
18			4	14		1					19
19				5							5
20				1							1
21											
22											
23											
24											
25											
26											
Totals		22	33	47	6	1					109

Table 7: Commercial striped mullet *Mugil cephalus* catch-at-age and yield (females only).

	Commercial Catch-at-age (Females only)							
Year	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+	Yield (lbs)
1996	27,596	1,059,061	2,014,009	1,150,059	337,810	139,953	50,207	6,877,195
1997	32,981	949,646	1,822,990	1,072,076	309,034	132,590	41,343	6,304,535
1998	15,061	418,799	1,158,810	778,530	313,266	135,508	38,239	5,183,043
1999	16,408	475,931	1,426,793	1,069,842	522,937	215,276	83,930	7,562,303
2000	14,841	386,358	1,173,353	868,556	424,025	181,451	63,282	6,148,075
2001	10,031	286,125	834,342	539,097	209,687	98,324	29,004	3,630,090
2002	11,128	280,941	575,874	340,062	103,301	46,247	12,795	2,065,852
2003		184,922	661,082	745,900	483,259	102,774	72,003	3,812,451
2004		85,615	595,309	775,280	468,406	256,925	16,877	4,040,779
2005	143	90,657	120,827	210,744	118,959	33,832	16,838	1,010,220
2006	6,959	190,312	372,411	418,870	414,043	124,898	50,497	2,814,151
2007	4,941	126,366	168,258	138,303	104,945	89,412	25,419	1,150,464
2008	1,097	30,513	411,454	202,586	56,921	36,070	10,967	1,277,838
2009	299	1,129	15,136	34,134	7,832	2,871	1,549	146,197
2010		6,043	38,891	81,845	52,594	7,386	1,093	297,373
2011	957	22,070	47,983	85,101	260,992	147,052	28,351	1,210,446
2012	713	44,310	113,085	123,944	119,745	164,056	68,206	1,196,454
2013		77,770	119,109	73,915	29,735	10,246	5,654	484,356
2014		48,525	392,915	146,501	26,983	5,958	4,599	974,181
2015		38,938	78,493	172,673	32,292	3,653	197	588,293
2016	2,164	140,044	152,318	72,193	73,020	9,652	2,011	879,764
2017	984	87,802	341,574	83,363	19,365	7,591	1,274	913,827
2018	82	55,200	90,889	131,314	17,660	3,620	395	542,116

Table 8: Mean weight-at-age (pounds) of commercial striped mullet *Mugil cephalus* landings (females only).

	Commercial Mean Weight-at-age (Females only)						
Year	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+
1996	1.43	1.23	1.39	1.52	1.83	1.84	2.05
1997	1.43	1.30	1.41	1.49	1.73	1.74	1.86
1998	1.47	1.56	1.77	1.87	2.05	2.02	2.06
1999	1.50	1.62	1.89	2.04	2.27	2.25	2.63
2000	1.49	1.67	1.89	2.02	2.24	2.23	2.49
2001	1.45	1.58	1.78	1.86	2.02	1.97	1.98
2002	1.45	1.40	1.49	1.54	1.69	1.71	1.70
2003		1.34	1.53	1.69	1.88	2.13	2.31
2004		1.43	1.62	1.87	2.00	2.04	2.63
2005	0.89	1.31	1.61	1.75	1.89	1.99	2.15
2006	1.10	1.42	1.62	1.83	1.89	2.11	2.40
2007	1.33	1.40	1.59	1.80	1.98	2.04	2.39
2008	1.60	1.29	1.60	1.77	2.02	2.19	2.38
2009	1.89	1.86	2.03	2.33	2.63	2.79	3.09
2010		1.21	1.30	1.56	1.82	1.79	2.32
2011	0.89	1.15	1.58	1.87	2.08	2.32	2.26
2012	1.10	1.28	1.55	1.83	1.96	2.12	2.25
2013		1.27	1.50	1.67	1.77	1.88	1.94
2014		1.29	1.53	1.65	1.80	2.10	2.03
2015		1.50	1.79	1.86	1.88	2.09	3.45
2016	1.21	1.60	1.97	2.22	2.31	1.91	2.38
2017	1.09	1.57	1.69	1.74	1.77	1.78	2.35
2018	0.89	1.45	1.78	1.98	1.73	2.32	3.01

Table 9: Probabilities of age given length for age assignments of female striped mullet *Mugil cephalus* catches from the LDWF fishery-independent marine gillnet survey.

TL_in	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+
6	1.00	0.00	0.00	0.00	0.00	0.00	0.00
7	1.00	0.00	0.00	0.00	0.00	0.00	0.00
8	1.00	0.00	0.00	0.00	0.00	0.00	0.00
9	1.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	1.00	0.00	0.00	0.00	0.00	0.00
11	0.00	1.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.81	0.19	0.00	0.00	0.00	0.00
13	0.00	0.01	0.96	0.03	0.00	0.00	0.00
14	0.00	0.00	0.69	0.30	0.01	0.00	0.00
15	0.00	0.00	0.07	0.74	0.17	0.02	0.00
16	0.00	0.00	0.00	0.31	0.48	0.16	0.05
17	0.00	0.00	0.00	0.02	0.31	0.35	0.32
18	0.00	0.00	0.00	0.00	0.05	0.22	0.73
19	0.00	0.00	0.00	0.00	0.00	0.06	0.94
20	0.00	0.00	0.00	0.00	0.00	0.01	0.99
21	0.00	0.00	0.00	0.00	0.00	0.00	1.00
22	0.00	0.00	0.00	0.00	0.00	0.00	1.00

Table 10: Annual female striped mullet *Mugil cephalus* catch-at-size derived from the LDWF fishery-independent marine gillnet survey.

TL_in / Year	1996	1997	1998	1999	2000	2001	2001	2003	2004	2005	2006	2007
5	.	1	.	.	.	.	.	.	.	.	.	.
6	.	.	.	.	.	.	.	.	.	.	.	.
7	2	2	6	8	2	63	16	20	3	5	8	8
8	25	32	43	94	26	124	87	83	32	52	119	99
9	16	23	43	47	27	37	37	47	23	38	47	57
10	24	91	88	42	97	111	46	96	65	106	103	83
11	16	179	44	38	58	87	23	66	43	63	84	50
12	21	298	56	56	64	60	26	26	58	94	49	53
13	23	156	57	30	54	17	35	23	36	62	31	30
14	13	75	37	15	45	10	36	14	25	41	25	20
15	9	37	14	6	37	9	22	8	18	20	15	15
16	5	30	19	4	23	3	8	2	24	3	.	4
17	1	20	19	1	3	1	.	.	13	2	1	.
18	1	3	2	.	1	.	3	.	4	2	1	1
19	.	1	1	1	1	.	.	.	1	.	.	.
20	1	.	.	1	.	.	.	.	.	.	.	.
21	.	.	.	.	.	.	.	.	.	.	.	.
22	.	.	.	.	.	.	.	.	.	.	.	.
Totals	156	946	428	343	438	521	339	386	344	486	483	419

Table 10 (continued):

TL_in / Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
5	.	.	.	.	.	.	.	.	.	.	.
6	1	.	.	.	.	.	.	.	1	.	.
7	19	7	19	45	17	2	8	2	14	13	3
8	63	30	153	146	83	14	43	14	73	40	17
9	23	21	97	46	47	16	17	10	20	15	20
10	58	66	254	72	82	46	32	15	31	33	49
11	37	57	111	55	62	64	25	14	24	26	26
12	62	35	116	76	63	53	37	16	12	34	26
13	31	14	32	67	29	31	26	10	6	17	17
14	13	11	13	39	13	16	18	4	6	4	12
15	4	2	9	25	3	10	9	6	7	7	12
16	1	1	5	10	2	5	2	2	2	.	7
17	1	.	.	3	1	.	.	.	1	.	4
18	.	1	.	1	.	.	.	.	.	.	3
19	.	.	1	.	.	.	.	.	.	.	1
20	.	.	.	.	.	.	.	.	.	.	.
21	.	.	.	.	1	.	.	.	.	.	.
22	.	.	.	.	.	.	.	.	.	.	.
Totals	312	243	811	585	402	257	217	92	197	189	197

Table 11: Annual female striped mullet survey age composition and sample sizes derived from the LDWF fishery-independent marine gillnet survey.

Year	n	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+
1996	156	0.27	0.37	0.23	0.08	0.03	0.01	0.01
1997	946	0.06	0.54	0.28	0.07	0.03	0.01	0.01
1998	428	0.21	0.41	0.21	0.07	0.04	0.02	0.02
1999	343	0.44	0.36	0.15	0.03	0.01	0.00	0.01
2000	438	0.13	0.47	0.22	0.11	0.04	0.01	0.01
2001	521	0.43	0.47	0.07	0.02	0.01	0.00	0.00
2002	339	0.41	0.27	0.19	0.09	0.02	0.01	0.01
2003	386	0.39	0.47	0.10	0.03	0.01	0.00	0.00
2004	344	0.17	0.45	0.19	0.09	0.06	0.03	0.03
2005	486	0.19	0.50	0.22	0.06	0.01	0.00	0.00
2006	483	0.36	0.47	0.12	0.04	0.01	0.00	0.00
2007	419	0.39	0.42	0.13	0.05	0.01	0.00	0.00
2008	312	0.34	0.46	0.16	0.03	0.00	0.00	0.00
2009	243	0.23	0.62	0.12	0.02	0.00	0.00	0.00
2010	811	0.33	0.57	0.08	0.02	0.01	0.00	0.00
2011	585	0.41	0.32	0.18	0.06	0.02	0.01	0.00
2012	402	0.36	0.48	0.12	0.02	0.01	0.00	0.00
2013	257	0.12	0.59	0.20	0.06	0.02	0.00	0.00
2014	217	0.31	0.40	0.21	0.06	0.01	0.00	0.00
2015	92	0.28	0.45	0.17	0.07	0.02	0.01	0.00
2016	197	0.55	0.33	0.07	0.04	0.01	0.00	0.00
2017	189	0.36	0.46	0.14	0.04	0.01	0.00	0.00
2018	197	0.20	0.49	0.16	0.08	0.03	0.02	0.02

Table 12: Summary of objective function components and negative log-likelihood values of the ASAP base model.

Objective function =1753			
Component	***Lambda***	***ESS***	***Obj_fun***
Catch_Fleet_Total	*1*		*-67.3*
Index_Fit_Total	*1*		*17.8*
Catch_Age_Comps		*975*	*1493.2*
Index_Age_Comps		*230*	*309.9*
Recruit_devs	*1*		*-0.6*

Table 13: Annual female striped mullet abundance-at-age and stock size estimates from the ASAP base model.

Year	*Age_1*	*Age_2*	*Age_3*	*Age_4*	*Age_5*	*Age_6*	*Age_7+*	*Totals*
1996	*9,513,600*	*7,587,440*	*5,798,170*	*2,747,200*	*933,006*	*348,799*	*177,973*	*27,106,188*
1997	*8,928,300*	*5,853,560*	*4,686,010*	*2,424,650*	*1,020,320*	*346,806*	*200,348*	*23,459,994*
1998	*7,390,330*	*5,492,030*	*3,598,650*	*1,911,600*	*872,635*	*367,364*	*201,624*	*19,834,233*
1999	*8,185,150*	*4,552,190*	*3,460,150*	*1,676,340*	*814,192*	*372,647*	*248,679*	*19,309,348*
2000	*7,269,600*	*5,027,940*	*2,729,920*	*1,233,850*	*508,610*	*246,578*	*192,628*	*17,209,126*
2001	*6,694,280*	*4,463,370*	*2,988,870*	*928,268*	*352,438*	*144,899*	*128,136*	*15,700,261*
2002	*5,942,530*	*4,121,370*	*2,786,720*	*1,325,700*	*371,524*	*141,311*	*112,167*	*14,801,322*
2003	*3,496,830*	*3,666,060*	*2,669,710*	*1,508,750*	*683,382*	*192,499*	*134,551*	*12,351,782*
2004	*3,317,170*	*2,152,410*	*2,280,530*	*1,160,820*	*588,807*	*267,088*	*130,888*	*9,897,713*
2005	*3,016,840*	*2,038,860*	*1,304,450*	*860,918*	*378,631*	*191,884*	*132,680*	*7,924,263*
2006	*5,001,130*	*1,862,820*	*1,342,220*	*770,789*	*495,900*	*219,534*	*192,743*	*9,885,136*
2007	*3,829,470*	*3,073,410*	*1,125,860*	*499,239*	*246,723*	*158,554*	*135,037*	*9,068,293*
2008	*2,315,780*	*2,362,370*	*1,989,330*	*607,005*	*255,990*	*127,150*	*155,035*	*7,812,660*
2009	*2,101,460*	*1,429,190*	*1,540,690*	*1,117,320*	*327,833*	*139,050*	*157,205*	*6,812,748*
2010	*2,334,350*	*1,300,100*	*974,011*	*1,098,140*	*816,534*	*241,912*	*224,212*	*6,989,259*
2011	*3,242,490*	*1,443,690*	*880,658*	*671,706*	*769,606*	*577,502*	*337,942*	*7,923,594*
2012	*5,707,250*	*2,002,340*	*952,020*	*525,161*	*391,434*	*451,509*	*549,862*	*10,579,576*
2013	*2,830,110*	*3,523,270*	*1,312,780*	*550,167*	*294,078*	*220,557*	*578,697*	*9,309,659*
2014	*3,783,280*	*1,749,610*	*2,369,810*	*871,420*	*367,334*	*198,026*	*553,029*	*9,892,509*
2015	*7,993,030*	*2,337,610*	*1,165,500*	*1,492,910*	*544,451*	*231,264*	*485,909*	*14,250,674*
2016	*5,774,250*	*4,942,470*	*1,578,490*	*790,249*	*1,023,980*	*376,762*	*509,730*	*14,995,931*
2017	*5,904,230*	*3,569,830*	*3,326,350*	*1,051,160*	*529,778*	*692,374*	*615,005*	*15,688,727*
2018	*4,124,460*	*3,650,410*	*2,405,120*	*2,227,990*	*709,898*	*360,895*	*912,838*	*14,391,611*

Table 14: Annual female striped mullet age-specific, apical, and average fishing mortality rates estimated from the ASAP base model.

Year	*Age_1*	*Age_2*	*Age_3*	*Age_4*	*Age_5*	*Age_6*	*Age_7+*	*Fmult*	*Avg. F*
1996	*0.01*	*0.10*	*0.55*	*0.70*	*0.71*	*0.71*	*0.71*	*0.71*	*0.26*
1997	*0.01*	*0.11*	*0.58*	*0.73*	*0.74*	*0.74*	*0.74*	*0.74*	*0.27*
1998	*0.00*	*0.08*	*0.44*	*0.56*	*0.57*	*0.57*	*0.57*	*0.57*	*0.20*
1999	*0.01*	*0.13*	*0.71*	*0.90*	*0.91*	*0.92*	*0.92*	*0.92*	*0.31*
2000	*0.01*	*0.14*	*0.76*	*0.96*	*0.98*	*0.98*	*0.98*	*0.98*	*0.29*
2001	*0.01*	*0.09*	*0.49*	*0.63*	*0.63*	*0.63*	*0.63*	*0.63*	*0.18*
2002	*0.00*	*0.05*	*0.29*	*0.37*	*0.38*	*0.38*	*0.38*	*0.38*	*0.12*
2003	*0.01*	*0.09*	*0.51*	*0.65*	*0.66*	*0.66*	*0.66*	*0.66*	*0.27*
2004	*0.01*	*0.12*	*0.65*	*0.83*	*0.84*	*0.84*	*0.84*	*0.84*	*0.36*
2005	*0.00*	*0.04*	*0.21*	*0.26*	*0.27*	*0.27*	*0.27*	*0.27*	*0.10*
2006	*0.01*	*0.12*	*0.67*	*0.85*	*0.86*	*0.86*	*0.86*	*0.86*	*0.26*
2007	*0.00*	*0.05*	*0.30*	*0.38*	*0.38*	*0.38*	*0.38*	*0.38*	*0.10*
2008	*0.00*	*0.05*	*0.26*	*0.33*	*0.33*	*0.33*	*0.33*	*0.33*	*0.13*
2009	*0.00*	*0.00*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.02*	*0.01*
2010	*0.00*	*0.01*	*0.05*	*0.07*	*0.07*	*0.07*	*0.07*	*0.07*	*0.03*
2011	*0.00*	*0.04*	*0.20*	*0.25*	*0.25*	*0.25*	*0.25*	*0.25*	*0.10*
2012	*0.00*	*0.04*	*0.23*	*0.29*	*0.29*	*0.29*	*0.29*	*0.29*	*0.08*
2013	*0.00*	*0.02*	*0.09*	*0.11*	*0.12*	*0.12*	*0.12*	*0.12*	*0.04*
2014	*0.00*	*0.03*	*0.14*	*0.18*	*0.18*	*0.18*	*0.18*	*0.18*	*0.08*
2015	*0.00*	*0.01*	*0.07*	*0.09*	*0.09*	*0.09*	*0.09*	*0.09*	*0.03*
2016	*0.00*	*0.02*	*0.09*	*0.11*	*0.11*	*0.11*	*0.11*	*0.11*	*0.03*
2017	*0.00*	*0.01*	*0.08*	*0.10*	*0.10*	*0.10*	*0.10*	*0.10*	*0.04*
2018	*0.00*	*0.01*	*0.04*	*0.05*	*0.05*	*0.05*	*0.05*	*0.05*	*0.02*

Table 15: Limit reference point estimates for the Louisiana striped mullet stock. Spawning stock units are eggs x 10^{12}. Fishing mortality units are yr^{-1}.

Reference Points		
Parameter	*Derivation*	*Value*
SPR_{limit}	*RS 56:333*	*30%*
$F_{30\%SPR}$	*Equation 28 and SPR_{limit}*	*0.16*
$SS_{30\%SPR}$	*Equation 28 and SPR_{limit}*	*2.03*

Table 16: Sensitivity analysis table. Current estimates are geometric means of 2016-2018 estimates. Yield units are pounds (x10^3), fishing mortality units are yr^{-1}, and spawning stock units are eggs x 10^{12}.

Run #	*Model run*	*negLL*	*$Yield_{30\%SPR}$*	*$F_{30\%SPR}$*	*$SS_{30\%SPR}$*	*$F_{current}/F_{30\%SPR}$*	*$SS_{current}/SS_{30\%SPR}$*
LA_SM-00	*Base Model*	*1753.0*	*2,369*	*0.16*	*2.03*	*0.20*	*1.81*
LA_SM-01	*h=.9*	*1750.3*	*2,006*	*0.16*	*1.72*	*0.26*	*1.44*
LA_SM-02	*h=.8*	*1744.7*	*1,688*	*0.16*	*1.44*	*0.41*	*0.93*
LA_SM-03	*h=.6*	*1728.7*	*1,475*	*0.16*	*1.26*	*0.59*	*0.72*
LA_SM-04	*Yield lambda (x5)*	*1478.6*	*2,504*	*0.16*	*2.14*	*0.18*	*1.94*
LA_SM-05	*Survey lambda (x5)*	*1728.2*	*3,521*	*0.16*	*3.01*	*0.14*	*2.30*

11. Figures

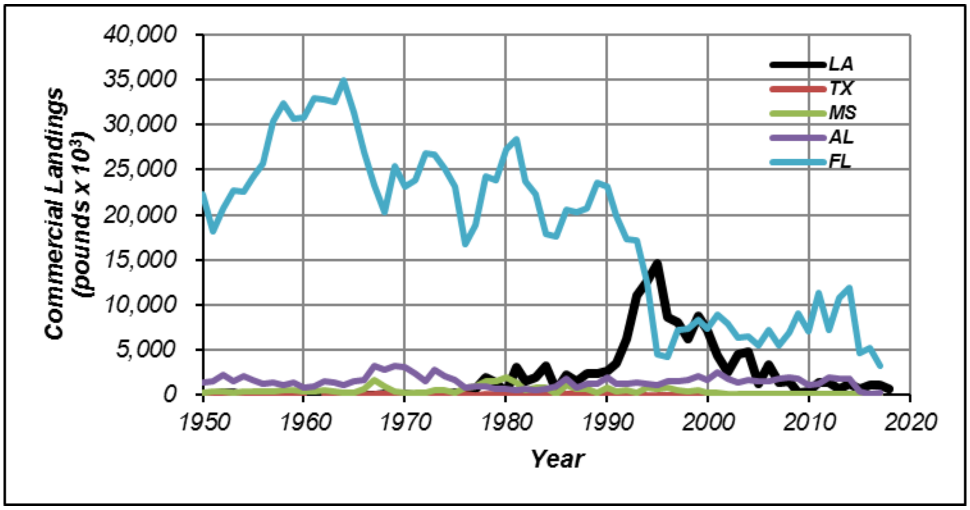

Figure 1: Reported commercial striped mullet *Mugil cephalus* landings (pounds x 10^3) of the Gulf of Mexico derived from NMFS statistical records and the LDWF trip ticket program.

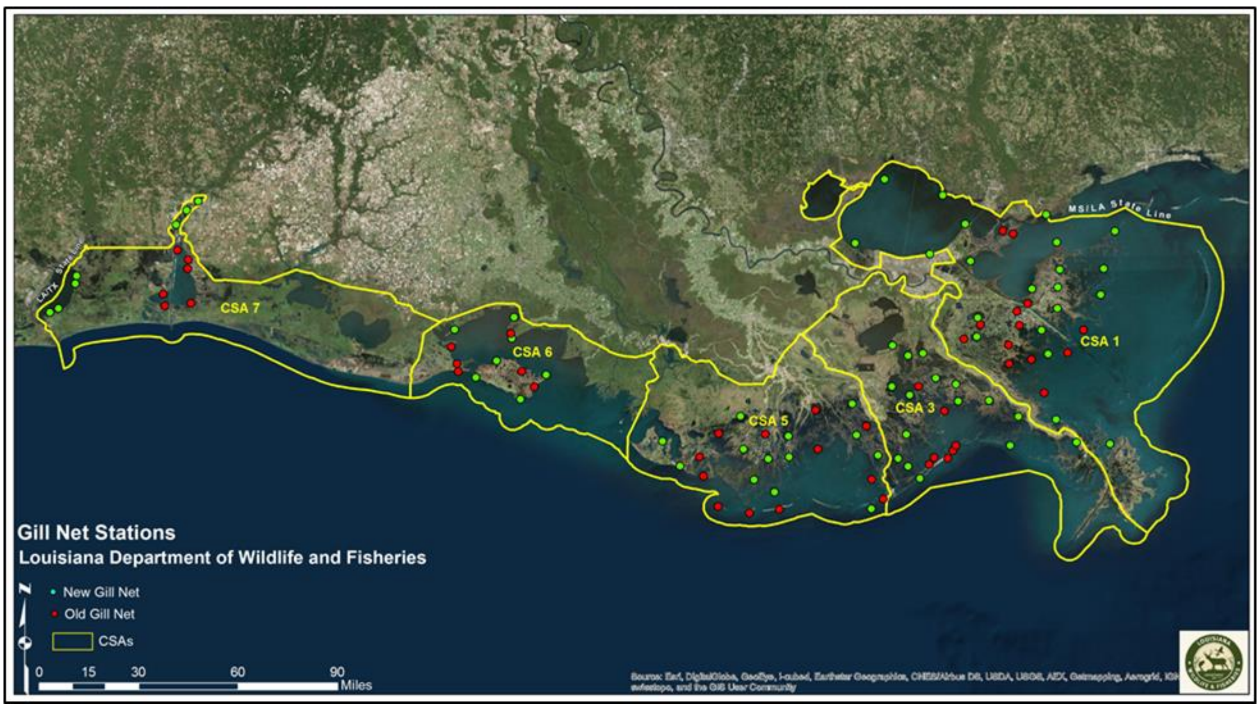

Figure 2: Station locations of the LDWF experimental marine gillnet survey. Yellow lines delineate LDWF Coastal Study Areas. Red circles represent long-term stations; green circles represent stations added in October 2010.

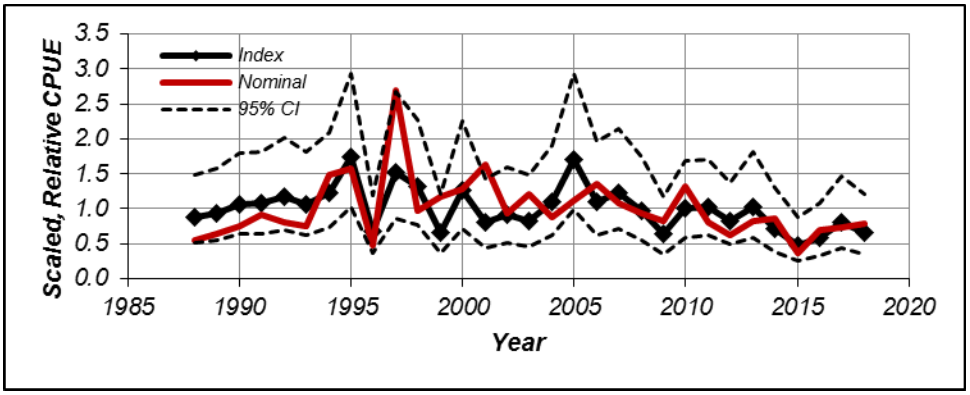

Figure 3: Standardized striped mullet index of abundance, nominal catch-per-unit-effort, and 95% confidence intervals of the standardized index derived from the LDWF marine gillnet survey. Each time-series has been normalized to its individual long-term mean.

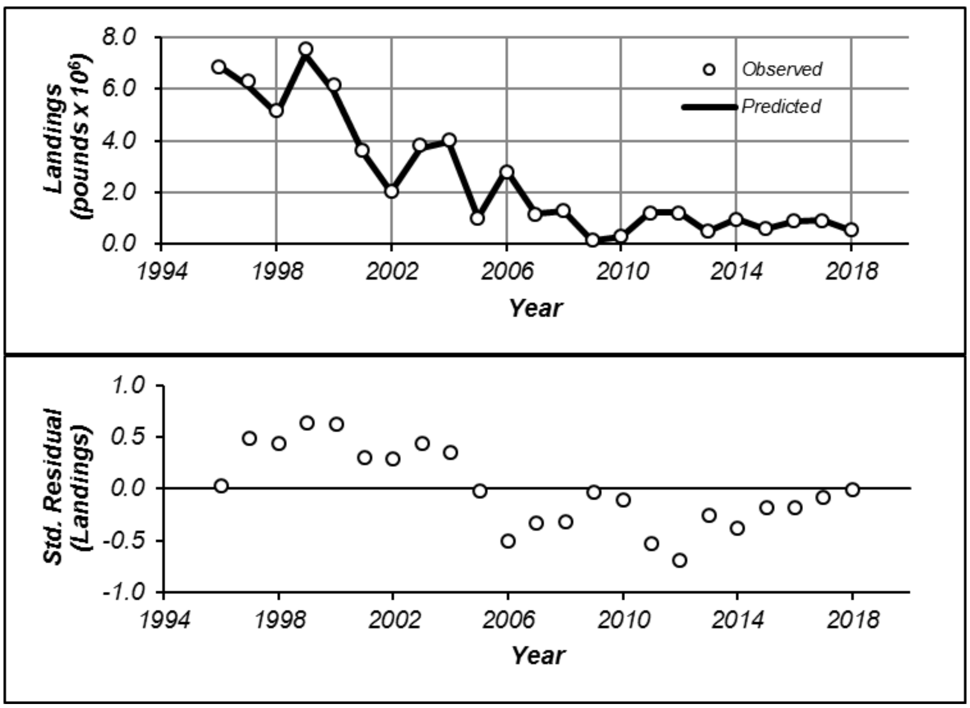

Figure 4: Observed and ASAP base model estimated commercial yield (females only; top) and standardized residuals (bottom).

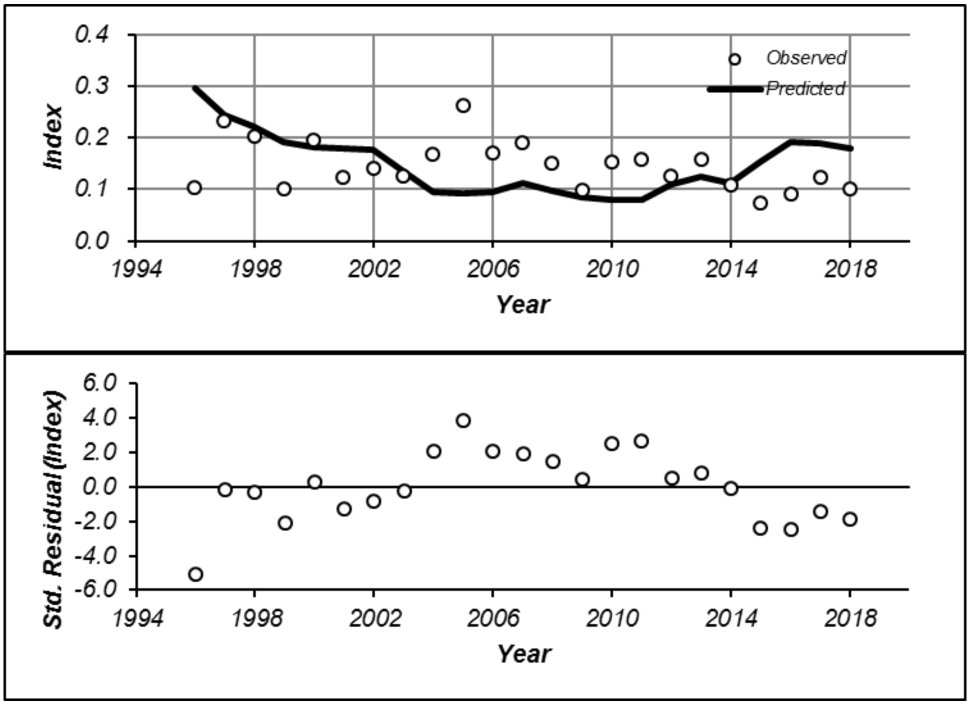

Figure 5: Observed and ASAP base model estimated fishery-independent CPUE (females only, top) and standardized residuals (bottom).

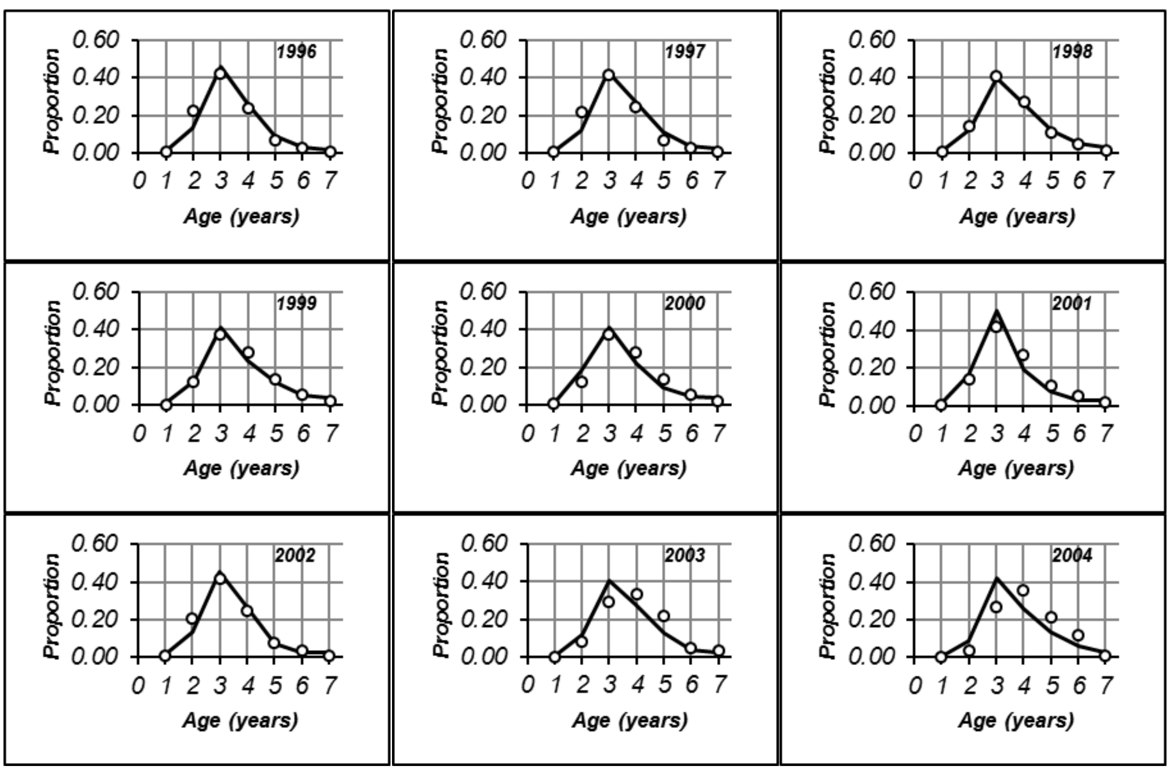

Figure 6: Annual input (open circles) and ASAP estimated (bold lines) commercial harvest age compositions.

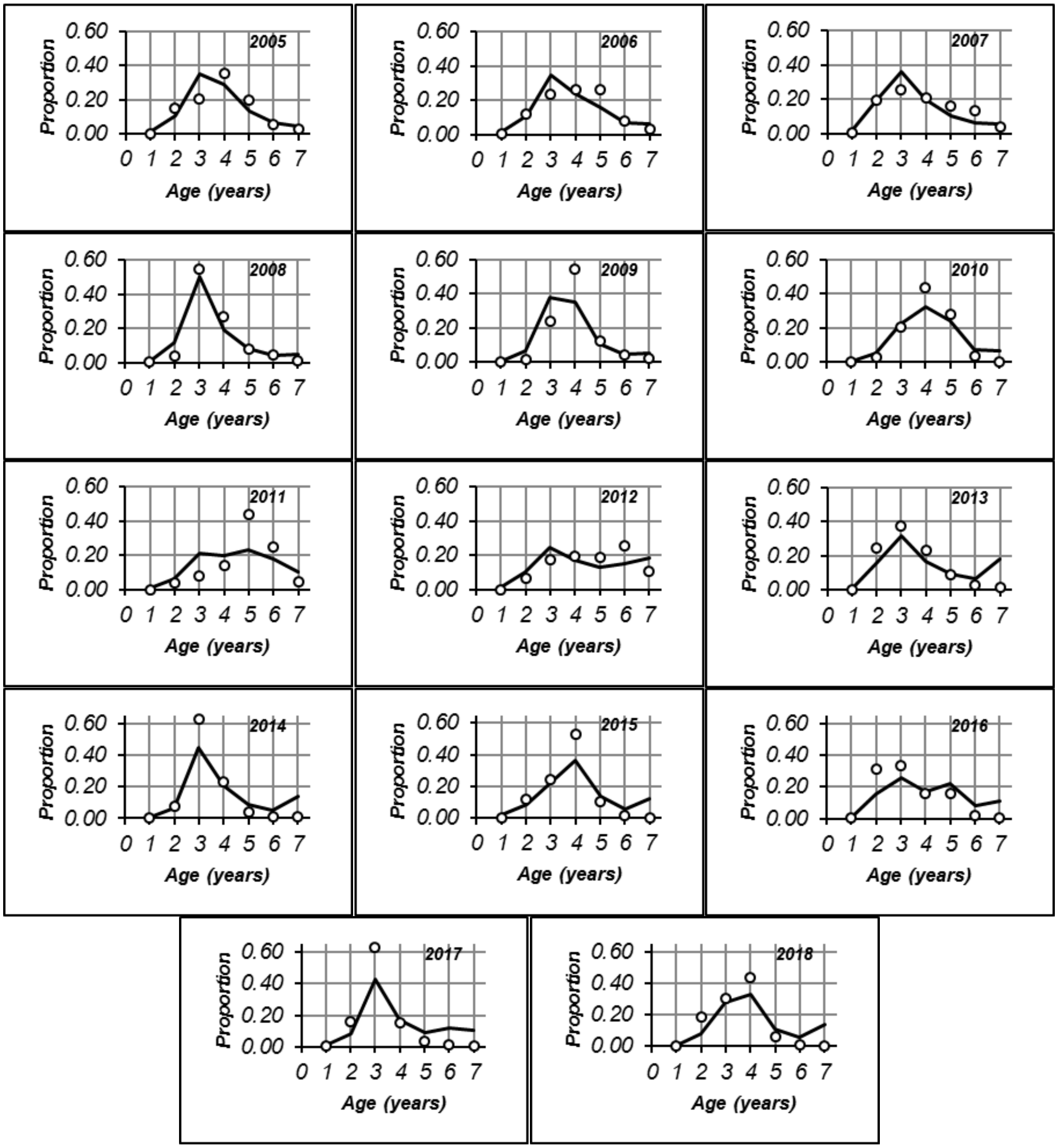

Figure 6 (continued):

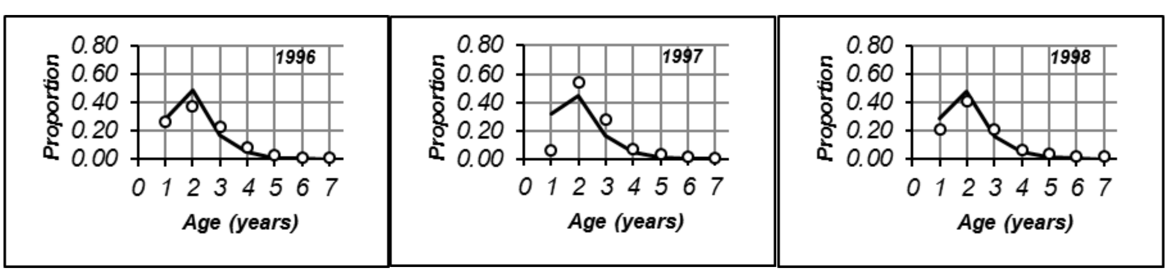

Figure 7: Annual input (open circles) and ASAP estimated (bold lines) survey age compositions.

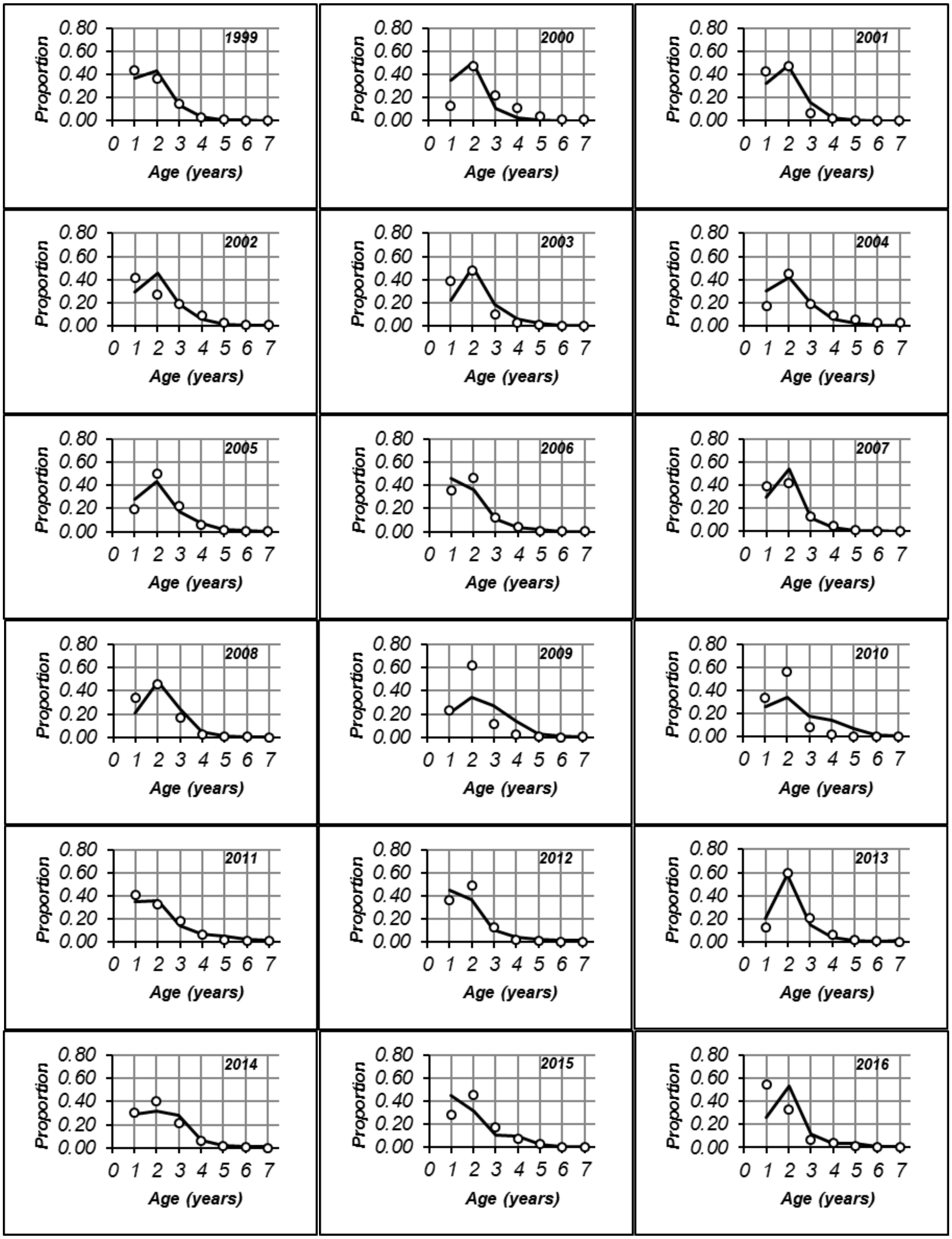

Figure 7 (continued):

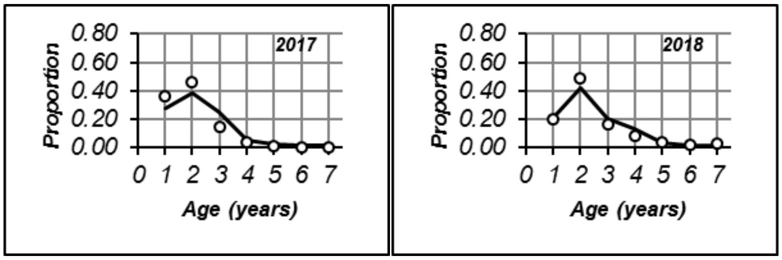

Figure 7 (continued):

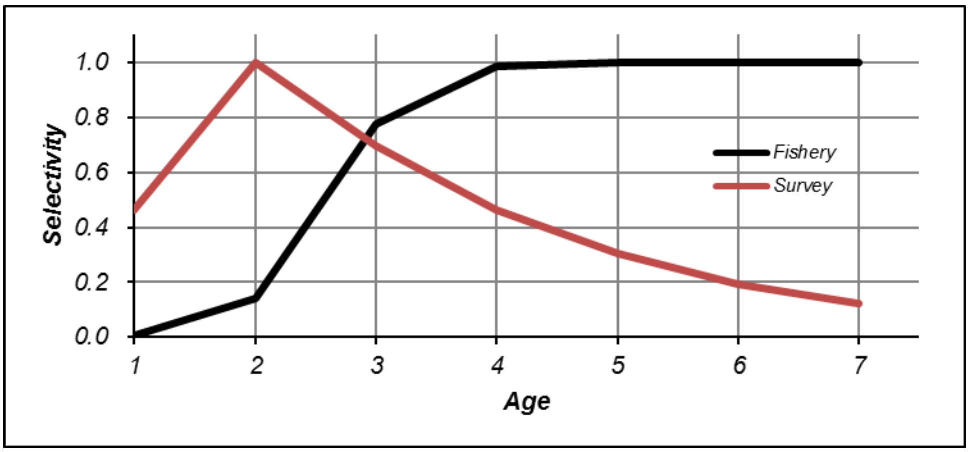

Figure 8: ASAP base model estimated fleet and survey selectivities (females only; ages 1-7+).

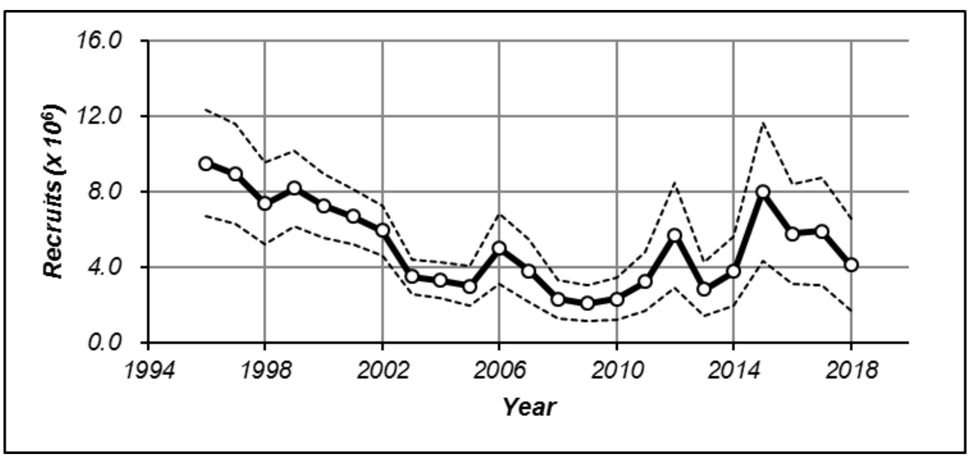

Figure 9: ASAP base model estimated recruitment (age-1 females). Dashed lines represent ± 2 asymptotic standard errors.

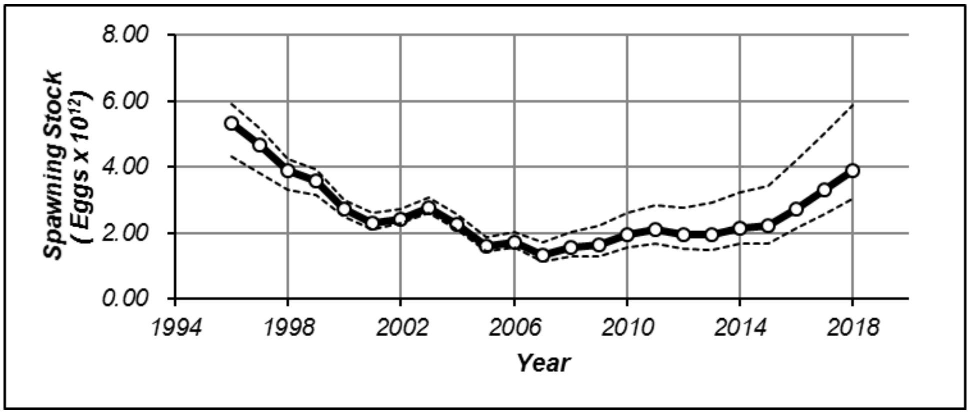

Figure 10: ASAP base model estimated egg production (MCMC median). Dashed lines represent 95% MCMC derived confidence intervals.

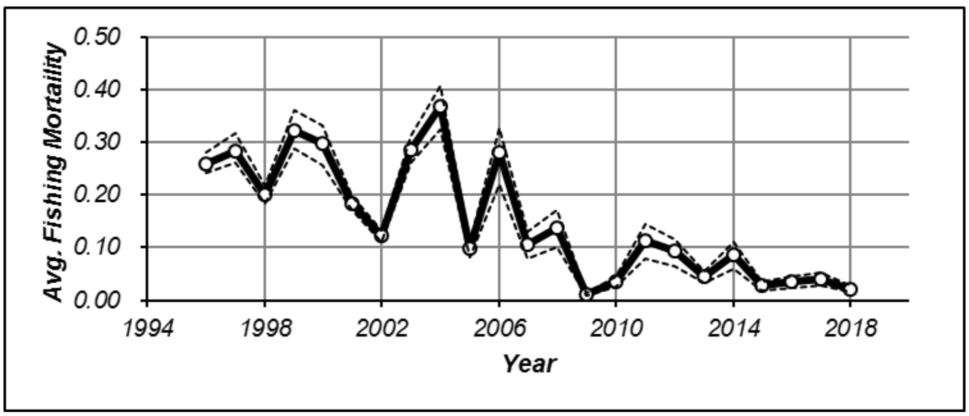

Figure 11: ASAP base model estimated average fishing mortality (MCMC median). Dashed lines represent 95% MCMC derived confidence intervals.

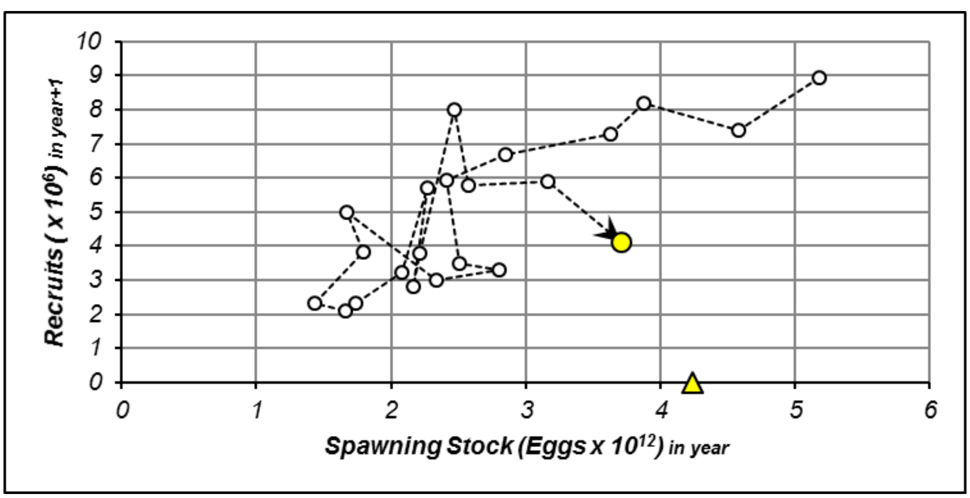

Figure 12: ASAP base model estimated age-1 recruits and spawning stock (total egg production). Arrow represents direction of the time-series. The yellow circle represents the most current data pair (2018 age-1 recruits / 2017 egg production). The yellow triangle represents the 2018 egg production estimate.

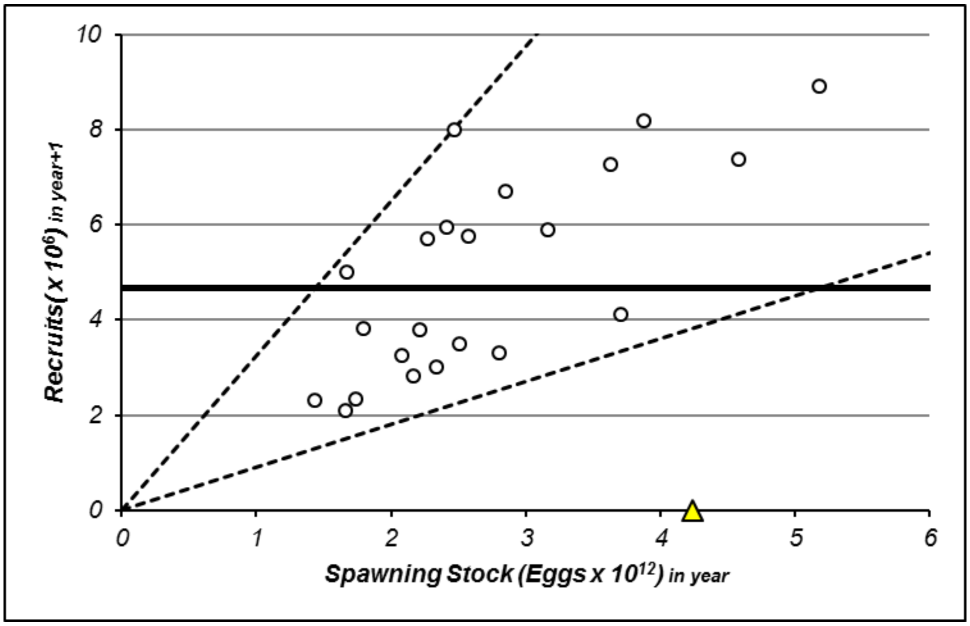

Figure 13: ASAP base model estimated age-1 recruits and spawning stock (open circles). Equilibrium recruitment is represented by the bold horizontal. The 2018 egg production estimate is represented by the yellow triangle. Equilibrium recruitment per spawning stock corresponding with the minimum and maximum spawning stock estimates are represented by the slopes of the dashed diagonals (min. spawning stock=21%SPR; max. spawning stock=77%SPR).

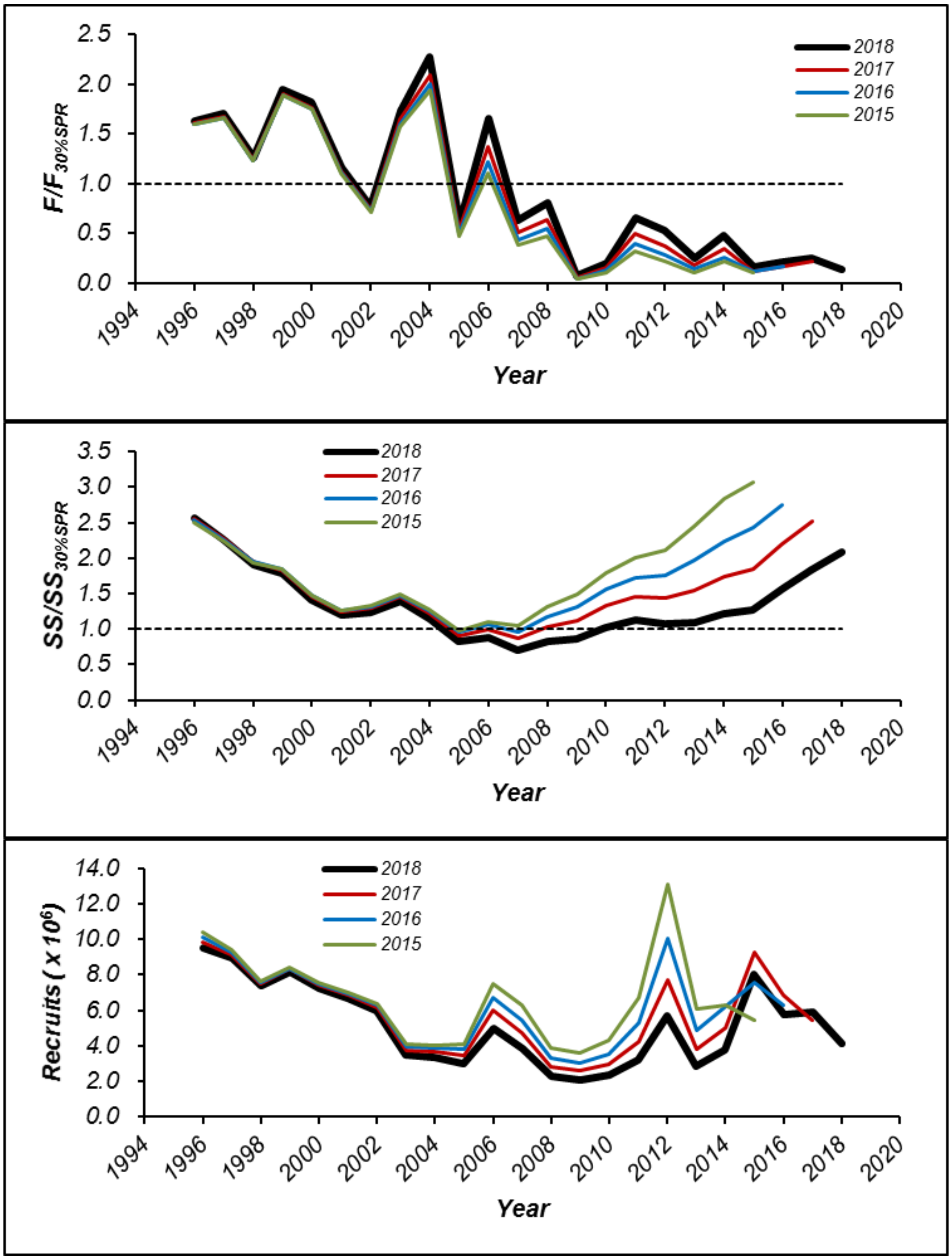

Figure 14: Retrospective analysis of ASAP base model. Top graphics depict estimated ratios of annual average fishing mortality to $F_{30\%}$ and spawning stock (egg production) to $SS_{30\%}$. Bottom graphic depicts estimated age-1 recruits.

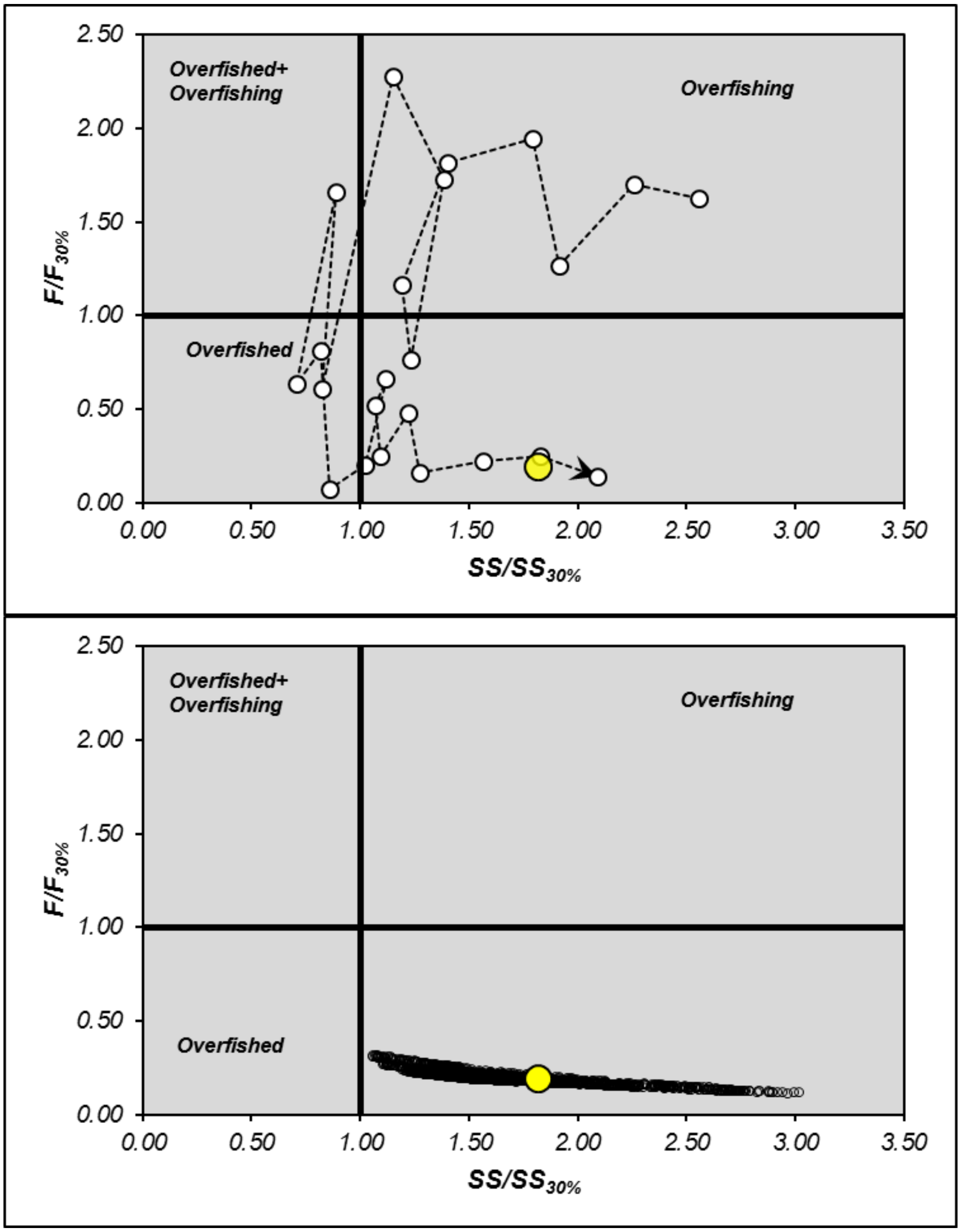

Figure 15: ASAP base model estimated ratios of annual average fishing mortality rates to $F_{30\%}$ and spawning stock size to $SS_{30\%}$. Arrow and dashed line represent direction of time-series (top graphic). The yellow circle represents current status (geometric mean 2016-2018 average F and SS). Bottom graphic depicts results of 2000 MCMC runs relative to limit reference points and current stock status.