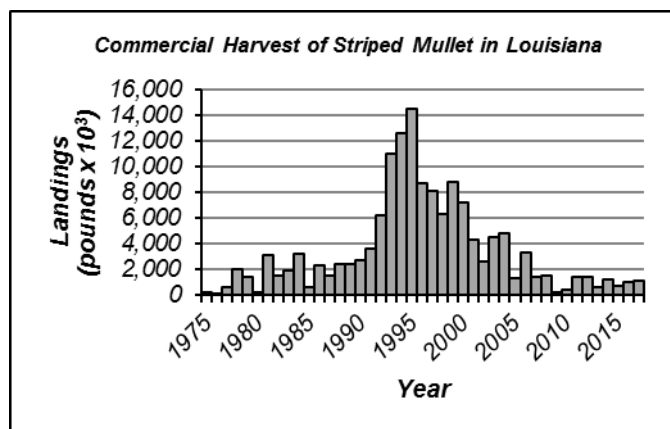


Update Assessment of Striped Mullet *Mugil cephalus* in Louisiana Waters 2019 Report

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 (1996-2017). 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. Indices of abundance are 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 66%.

Summary of Changes from 2018 Assessment

Assessment model inputs have been updated through 2017. A change was made in this assessment update to the assessment models recruitment variability parameter to improve model stability. The input

coefficient of variation that controls deviations between recruitment predicted from the stock recruitment relationship and the annual recruitment estimates was reduced from 0.5 to 0.3.

Update Assessment of Striped Mullet *Mugil cephalus* in Louisiana Waters 2019 Report

Joe West
Office of Fisheries
Louisiana Department of Wildlife and Fisheries

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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. Indices of abundance are 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.* (2001) 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 to primarily 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 – Atchafalaya Bay to western shore of Vermillion Bay (Vermillion/Teche/Atchafalaya Basins); CSA 7 – western shore of Vermillion Bay to Texas State line (Mermentau/Calcasieu/Sabine Basins).

The LDWF fishery-independent experimental marine gillnet survey is used in this assessment to develop indices of abundance for use in the statistical catch-at-age assessment model. This survey is conducted with 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; where the net is set either parallel to the shore (or reef) or set in a crescent-shape. The vessel is then maneuvered both inside and outside of the net in gradually tightening circles a minimum of three times to force fish into 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, however, 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 CSAs. Beginning in April 2013, the survey design was modified where sampling locations are now selected randomly within each CSA. To alleviate time-series biases associated with the addition of these new stations and the changes in survey methodology, two discrete time-series of catch-rates were developed. The first or the “old” time-series (1988-2012) was developed by retaining long-term stations only for analyses (Figure 2). The second or the “new” time-series (2010-present) was developed by retaining all current sampling stations for analyses (Figure 2).

2.2 Fishery Dependent

Commercial

Commercial SM landings were taken from NMFS commercial statistical records (NMFS 2014a) and the LDWF Trip Ticket Program (Figure 1). Annual size composition of commercial catches (Table 2) were derived from the Trip Interview Program (TIPS; 1996-2001), the Fishery Information Network (FIN; 2007-2017), and by combination of data collection programs (TIPS+FIN; 2002-2006). Ages of

commercial SM landings were 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 were not considered. The MRIP harvest data indicates that LA recreational harvest is negligible relative to commercial harvest (Table 1; NMFS 2018b). Furthermore, only limited recreational size composition information is available from MRIP. The available size information 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 extreme salinity gradients, 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, however, 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 was 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 were converted to FL 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 was estimated with a logistic function developed in an earlier assessment (West *et al.* 2014) as:

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

where $P_{fem,l}$ is the estimated proportion of females in 1 inch TL intervals. The minimum sex ratio-at-size was 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 was then computed by substituting equation [5] into equation [3]. Female SM maturity was 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, an average value of M was assumed (0.3), but was allowed to vary with weight-at-age to calculate a declining natural mortality rate with age. This average 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 2006), the estimate was rescaled where the mean mortality rate over ages vulnerable to the fishery is equivalent to the average rate as:

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

Where \bar{M} is the average 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 was 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. 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

Striped mullet IOAs of the “old” and “new” time-series were developed from the LDWF experimental marine gillnet survey. Only CSAs (1, 5, 6, and 7), months (November – February), and mesh panels (2.0, 2.5, 3.0, 3.5 inch) with $\geq 5\%$ positive samples (*i.e.*, non-zero catches) on average (using the “old” time-series) were included in IOA development. Samples collected during the months of January and February were 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 was calculated from each samples catch at size and equation [4].

To reduce unexplained variability in catch rates unrelated to changes in abundance, each IOA was standardized using methods described below. A delta lognormal approach (Lo *et al.* 1992; Ingram *et al.* 2010) was 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; 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:

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

where $\text{Cov}(c, p) \approx \rho_{c,p} [SE(c_y)SE(p_y)]$ 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 2009). 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).

Annual sample sizes, observed percent positive samples, nominal CPUEs, standardized IOAs, and corresponding coefficients of variation of the "old" and "new" time-series are presented (Table 4). Standardized IOAs and 95% confidence intervals of the "old" and "new" time-series are also presented graphically (Figure 3). Conditional residual plots of the lognormal sub-models indicate reasonable fits. Pearson's chi-square per degree of freedom statistics indicate no overdispersion in the binomial sub-models ("old" time-series=1.0; "new" time-series=0.9).

5. Catch at Age Estimation

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

5.1 Fishery

Only female SM otoliths collected from fishery-dependent sources were used in age assignments of fishery landings in this assessment. Ages were 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 were 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). Table 5 was used to calculate $P(a|l)_y$ for 1996-2002 landings, where limited annual sample sizes preclude use of annual ALKs. Annual fishery catch-at-age (females only) was then calculated as:

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

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 were computed as:

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

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

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

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 was estimated from Equation [3] and rearrangement of Equation [2]. The standard deviation in length-at-age was approximated from $\sigma_a = l_a CV_l$, where the coefficient of variation in length-at-age was assumed constant (in this case 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 was also calculated from equation [11] with annual survey catch-at-size substituted for fishery catch-at-size. Annual survey catch-at-size was derived using only those samples included in abundance index development. Annual survey catch-at-size and resulting annual survey age compositions (females only) for the “old” and “new” time-series are presented (Tables 10-12).

6. Assessment Model

In this assessment update, the Age-Structured Assessment Program (ASAP3 Version 3.0.12; NOAA Fisheries Toolbox <http://nft.nefsc.noaa.gov>) was 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 a tuning index. 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

The model was configured with annual time-steps (1996-2017) and a calendar year time frame. As in earlier assessments, only the years beginning in 1996 were 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 were 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:

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

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

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 $\sum_a \hat{C}_{ay} \bar{W}_{ay}$, where \bar{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 tuning indices modeled. Parameters are estimated in log-space and then back transformed. In this assessment, 63 parameters were estimated:

1. 10 selectivity parameters (2 for the fishery; 4 for each survey)
2. 22 apical fishing mortality rates (F_{mult} in the initial year and 20 deviations in subsequent years)
3. 22 recruitment deviations (1996-2017)
4. 6 initial population abundance deviations (age-2 through 7-plus)
5. 2 catchability coefficients (1 for each 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, $\ln L_i$ are log-likelihoods of lognormal estimations, λ_i are user-defined weights applied to lognormal estimations, and $\ln L_j$ 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:

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

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 for each time-series, 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 (2003-2016) 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 13.

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 of the "old" time-series match the data adequately with no strong pattern in residuals, but fail to fit the high catch rate observed in 2005 and are overestimated before 2000 (Figure 5). Predicted survey catch rates of the "new" time-series are generally underestimated in earlier years and overestimated in the

more recent years of the series (Figure 6). Predicted fishery and survey age compositions provide reasonable fits to the input age proportions (Figures 7-9). 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.

Selectivities

Estimated fishery and survey selectivities are presented in Figure 10. Fishery estimates indicate full-vulnerability to the commercial gill net fishery at age 5 with over 50% vulnerable at age 3. Survey estimates of the “old” and “new” time-series 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 14. Stock size has varied over the time-series. Stock size decreased from 29.4 million females in 1996 to a minimum of 9.5 million females in 2005. Since 2005, stock size has increased to a peak of 24.3 million females in 2016. The 2017 stock size estimate is 22.6 million females.

Recruitment estimates from the base model are presented in Figure 11. Recruitment has varied over the time-series. Age-1 recruit estimates decreased from 10.8 million fish in 1996 to 3.4 million age-1 fish in 2008. Since 2008, recruitment increased to a peak of 12.5 million age-1 fish estimated in 2015. The 2017 estimate of age-1 recruits is 6.6 million age-1 females.

Spawning stock estimates (total egg production) are presented in Figure 12. 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 5.3 trillion eggs in 1996 to a minimum of 1.9 trillion eggs in 2007. Since 2007, the trend has generally been upward with an estimate of 6.6 trillion eggs in 2017.

Fishing Mortality

Estimated fishing mortality rates are presented in Table 15 (apical, average, and age-specific) and Figure 13 (average only). Average rates are weighted by population numbers at age estimates. 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 (0.29 and 0.31 yr^{-1}). Since 2004, average fishing mortality rates decreased to a minimum of 0.01 yr^{-1} in 2009 and has remained low. The 2017 estimate of average F is 0.03 yr^{-1} .

Stock-Recruitment

No discernable relationship is observed between spawning stock and subsequent age-1 recruitment (Figure 14). 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 8.5 trillion eggs and the corresponding unexploited recruitment was 6.3 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, 63 parameters were estimated. Asymptotic standard errors for the time-series of age-1 recruits are presented in Figure 11. Markov Chain Monte Carlo derived confidence intervals (95%) for average fishing mortality rates and the spawning stock time-series are presented in Figures 12 and 13.

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 (2015-2017).

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 $M_a + v_a F_{mult}$; vulnerability at age v_a is taken by rescaling the current F-at-age estimate (geometric mean 2015-2017) 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 $\sum_a C_a \bar{W}_a$ where \bar{W}_a are current mean fishery weights at age (arithmetic mean 2015-2017).

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 16). 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 22% and a maximum of 77% (Figure 15). The current estimate of equilibrium SPR is 66%.

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 ($F_{30\%}$, $SS_{30\%}$, $Y_{30\%}$, $F_{\text{current}}/F_{30\%}$, and $SS_{\text{current}}/SS_{30\%}$) 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 (2015-2017). 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 17. Reference point estimates from all sensitivity runs with the exception of the run with steepness fixed at 0.6 indicate the fishery is currently operating below $F_{30\%}$ and above SS_{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 (1.1-3.4 trillion eggs, and 1.2-3.9 million pounds, respectively).

Retrospective Analysis

A retrospective analysis was conducted by sequentially truncating the base model by a year (terminal years 2014-2017). Retrospective estimates of recruitment, $SS/SS_{30\%}$, and $F/F_{30\%}$ are presented in Figure 16, 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 negative bias, where estimates increase 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 17. 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.

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.

9. References

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10. Tables

Table 1: Annual Louisiana commercial and recreational striped mullet *Mugil cephalus* landings (pounds x 10³) derived from NMFS statistical records, LDWF trip ticket program, and MRIP. Recreational landings are A+B1 catches only. Note: Louisiana MRIP estimates presented below are CHTS estimates calibrated to the 2013 APAIS design change (ACAL) and are not available after 2013.

Year	Harvest		%_Recreational
	Commercial	Recreational	
1981	3,051	1	0.0%
1982	1,533	13	0.8%
1983	1,887	0	0.0%
1984	3,157	2	0.1%
1985	579	3	0.5%
1986	2,278	40	1.7%
1987	1,439	0	0.0%
1988	2,367	0	0.0%
1989	2,414	75	3.0%
1990	2,646	108	3.9%
1991	3,563	18	0.5%
1992	6,215	83	1.3%
1993	11,026	205	1.8%
1994	12,560	76	0.6%
1995	14,546	116	0.8%
1996	8,659	170	1.9%
1997	8,083	96	1.2%
1998	6,252	12	0.2%
1999	8,806	32	0.4%
2000	7,245	65	0.9%
2001	4,313	29	0.7%
2002	2,555	57	2.2%
2003	4,524	4	0.1%
2004	4,754	4	0.1%
2005	1,238	13	1.1%
2006	3,329	4	0.1%
2007	1,375	77	5.3%
2008	1,503	2	0.1%
2009	194	29	13.1%
2010	362	47	11.6%
2011	1,385	9	0.6%
2012	1,385	78	5.3%
2013	609	64	9.5%
2014	1,186	--	--
2015	692	--	--
2016	1,021	--	--
2017	1,093	--	--

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; 2007-2017), 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	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017		
6																								
7																								
8																								
9																								
10	3																	2						
11	8	2	1										1					1						
12	59	44	1	10				3	1		10	8	7		1	1	1	8				2		
13	271	183	5	20	1	3	11	30	22	11	25	25	35		26	22	19	38	11	12	5	2		
14	518	537	45	37	9	20	37	101	68	61	53	78	103	1	50	39	45	131	73	33	35	42		
15	401	595	73	114	40	41	49	142	122	151	107	194	150	10	23	40	112	255	139	99	70	104		
16	308	453	110	244	83	40	53	169	267	182	164	256	155	49	41	94	153	276	262	230	91	173		
17	202	230	126	248	87	75	31	151	342	154	135	187	160	165	33	254	260	181	115	271	97	140		
18	121	108	94	259	73	41	7	110	209	117	117	127	106	215	34	330	244	43	17	121	67	52		
19	61	36	36	148	43	18	4	36	58	19	47	74	37	134	6	118	63	5	1	19	37	11		
20	14	14	6	49	16	1		8	20		15	12	16	79	1	19	5		1	12	28			
21	6	3		13	2				2		1	2	1	20		3				4	16	1		
22	2			2	1							1		6			2					2		
23													1	1										
24	1																							
25																								
26																								
27	2																							
28																								
Totals	1977	2205	497	1144	355	239	192	750	1111	695	674	964	772	680	215	920	904	940	619	801	450	525		

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

Parameter	Productivity			Species	Score
	Low	Medium	High	Striped Mullet	
<i>M</i>	<0.2	0.2 - 0.5	>0.5	0.3	2
<i>K</i>	<0.15	0.15 - 0.33	>0.33	0.28	2
<i>t_{mat}</i>	>8	3.3 - 8	<3.3	2	3
<i>t_{max}</i>	>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, indices of abundance, and corresponding coefficients of variation of the “old” and “new” time-series derived from the LDWF fishery-independent marine gillnet survey.

Year	Old IOA					New IOA				
	<i>n</i>	%Pos	CPUE	IOA	CV	<i>n</i>	%Pos	CPUE	IOA	CV
1988	229	20%	1.79	0.15	0.29	--	--	--	--	--
1989	243	19%	2.09	0.16	0.29	--	--	--	--	--
1990	253	20%	2.49	0.19	0.29	--	--	--	--	--
1991	257	19%	3.02	0.19	0.29	--	--	--	--	--
1992	175	21%	2.65	0.21	0.29	--	--	--	--	--
1993	172	20%	2.5	0.19	0.3	--	--	--	--	--
1994	167	22%	4.91	0.22	0.29	--	--	--	--	--
1995	133	27%	5.21	0.31	0.28	--	--	--	--	--
1996	136	18%	1.59	0.12	0.32	--	--	--	--	--
1997	144	18%	8.93	0.27	0.31	--	--	--	--	--
1998	148	22%	3.22	0.23	0.29	--	--	--	--	--
1999	148	15%	3.86	0.12	0.33	--	--	--	--	--
2000	141	18%	4.26	0.23	0.31	--	--	--	--	--
2001	148	16%	5.37	0.14	0.32	--	--	--	--	--
2002	148	19%	3.08	0.16	0.31	--	--	--	--	--
2003	148	16%	3.98	0.15	0.32	--	--	--	--	--
2004	149	20%	2.91	0.19	0.3	--	--	--	--	--
2005	141	23%	3.68	0.3	0.29	--	--	--	--	--
2006	148	18%	4.47	0.19	0.31	--	--	--	--	--
2007	146	20%	3.55	0.22	0.3	--	--	--	--	--
2008	148	17%	3.09	0.17	0.32	--	--	--	--	--
2009	145	16%	2.7	0.11	0.33	--	--	--	--	--
2010	139	18%	6.18	0.23	0.32	307	15%	4.36	0.15	0.32
2011	140	19%	2.78	0.17	0.31	328	17%	2.66	0.17	0.31
2012	138	19%	2.18	0.15	0.31	315	16%	2.04	0.13	0.32
2013	--	--	--	--	--	150	16%	2.7	0.17	0.34
2014	--	--	--	--	--	150	13%	2.82	0.12	0.36
2015	--	--	--	--	--	152	12%	1.23	0.08	0.36
2016	--	--	--	--	--	151	14%	2.32	0.10	0.35
2017	--	--	--	--	--	150	13%	2.39	0.14	0.35

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

TL _{in}	1996-2002										Total
	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7	Age_8	Age_9	Age_10	
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 2003-2017 (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	8	6	3				31
20				2	1	2	1				6
21											
22											
23											
24											
25											
26											
Total	0	40	123	146	97	22	12	3	0	0	443

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											
Total	0	16	119	166	108	63	5	0	0	0	477

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											
Total	1	90	132	230	128	37	17	1	0	0	636

Table 6 (continued):

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	39	42	33	8	1				145
17		11	35	31	33	14	2	2			128
18		1	18	44	35	9	3				110
19				13	17	11	3	2			46
20					5	3	5				13
21								1			1
22											
23											
24											
25											
26											
Total	1	63	127	149	148	48	15	5	0	0	556

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	6	3		1	1					12
14	1	17	12	6	3	2					41
15	2	51	48	15	13	6					135
16		48	71	55	22	21	1			1	219
17		10	48	48	32	27	6				171
18	1	3	12	31	30	27	6	3			113
19	1	1	1	9	22	21	9				64
20				1	2	3	2	1	1		10
21		1	1								2
22						1					1
23											
24											
25											
26											
Total	6	139	197	167	125	109	24	4	1	1	773

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	93	19	6	2					129
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											
Total	1	27	371	178	48	30	6	3	0	0	664

Table 6 (continued):

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		1						2			3
23											
24											
25											
26											
Total	1	5	45	102	22	9	4	3	0	0	191

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											
Total	0	7	46	93	59	9	0	1	0	0	215

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											
Total	1	22	52	99	314	181	31	3	0	0	703

Table 6 (continued):

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	0	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			1								1
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	0	110	180	115	49	18	10	0	0	0	482

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	0	50	388	142	25	5	2	2	0	0	614

Table 6 (continued):

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	0	95	188	410	77	8	0	0	0	0	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	0	0	0	430

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	0	0	0	520

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

TL_in / Year	1996	1997	1998	1999	2000	2001	2001	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
5		1															
6													1				
7	2	2	6	8	2	63	16	20	3	5	8	8	19	7	9	24	6
8	25	32	43	94	26	124	87	83	32	52	119	99	63	30	103	87	50
9	16	23	43	47	27	37	37	47	23	38	47	57	23	21	75	24	23
10	24	91	88	42	97	111	46	96	65	106	103	83	58	66	206	35	40
11	16	179	44	38	58	87	23	66	43	63	84	50	37	57	91	25	42
12	21	298	56	56	64	60	26	26	58	94	49	53	62	35	97	36	43
13	23	156	57	30	54	17	35	23	36	62	31	30	31	14	28	29	13
14	13	75	37	15	45	10	36	14	25	41	25	20	13	11	10	14	4
15	9	37	14	6	37	9	22	8	18	20	15	15	4	2	8	9	3
16	5	30	19	4	23	3	8	2	24	3		4	1	1	3	7	1
17	1	20	19	1	3	1			13	2	1		1			2	
18	1	3	2		1		3		4	2	1	1		1			
19		1	1	1	1			1									
20	1			1													
21																	1
22																	
Totals	156	946	428	343	438	521	339	386	344	486	483	419	312	243	630	292	227

Table 11: Annual female striped mullet *Mugil cephalus* catch-at-size of the “new” time-series derived from the LDWF fishery-independent marine gillnet survey.

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

Table 12: Annual female striped mullet survey age composition and sample sizes of the “old” and “new” time-series derived from the LDWF fishery-independent marine gillnet survey.

Year	Old IOA								New IOA							
	n	Age_1	Age_2	Age_3	Age_4	Age_5	Age_6	Age_7+	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	630	0.30	0.60	0.08	0.02	0.00	0.00	0.00	811	0.33	0.57	0.08	0.02	0.01	0.00	0.00
2011	292	0.46	0.30	0.16	0.05	0.02	0.01	0.00	585	0.41	0.32	0.18	0.06	0.02	0.01	0.00
2012	227	0.35	0.51	0.11	0.02	0.00	0.00	0.00	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

Table 13: Summary of objective function components and negative log-likelihood values of the ASAP base model.

Objective function =1680			
Component	Lambda	ESS	Obj_fun
Catch_Fleet_Total	1		-65.3
Index_Fit_Total	2		-0.1
Catch_Age_Comps		875	1426.3
Index_Age_Comps		240	327.9
Recruit_devs	1		-8.0

Table 14: 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	10,752,000	8,622,530	5,954,920	2,700,010	890,966	333,479	148,433	29,402,338
1997	9,165,380	6,552,690	5,285,150	2,438,550	986,318	329,284	182,195	24,939,567
1998	7,772,450	5,585,660	4,015,490	2,161,390	889,306	363,903	193,136	20,981,335
1999	8,690,080	4,743,030	3,510,210	1,888,890	940,388	392,277	251,476	20,416,351
2000	7,801,680	5,290,060	2,845,020	1,274,650	592,984	298,134	208,932	18,311,460
2001	7,248,740	4,747,250	3,147,750	987,976	378,241	177,582	155,482	16,843,021
2002	6,557,030	4,421,330	2,956,230	1,407,520	403,238	156,393	141,108	16,042,849
2003	4,014,700	4,006,510	2,847,900	1,594,950	727,949	211,873	160,202	13,564,084
2004	3,899,490	2,448,370	2,487,740	1,253,090	637,886	294,866	154,372	11,175,814
2005	3,813,600	2,375,620	1,490,130	979,401	435,587	224,199	161,573	9,480,110
2006	6,766,900	2,332,360	1,557,350	886,511	572,972	259,272	235,216	12,610,581
2007	5,461,420	4,124,340	1,431,810	643,195	327,341	214,074	189,311	12,391,491
2008	3,377,510	3,338,810	2,683,080	816,270	356,594	184,528	233,046	10,989,838
2009	3,404,930	2,065,610	2,187,800	1,592,250	476,035	211,579	254,149	10,192,353
2010	3,745,390	2,085,690	1,395,280	1,537,210	1,148,950	350,372	351,625	10,614,517
2011	5,609,070	2,293,740	1,403,020	958,009	1,077,430	821,122	514,397	12,676,788
2012	9,965,280	3,432,060	1,517,210	877,284	596,759	683,369	867,439	17,939,401
2013	4,987,060	6,097,140	2,267,350	942,185	541,755	375,190	1,000,210	16,210,890
2014	6,698,540	3,053,720	4,090,050	1,532,860	647,612	379,603	990,346	17,392,731
2015	12,517,700	4,100,650	2,038,390	2,690,280	1,017,790	438,168	952,434	23,755,412
2016	8,960,650	7,665,160	2,752,350	1,382,480	1,856,640	716,073	1,004,970	24,338,323
2017	6,577,150	5,487,000	5,144,350	1,865,680	953,431	1,305,340	1,241,650	22,574,601

Table 15: 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	0.24
1997	0.01	0.10	0.55	0.70	0.71	0.71	0.71	0.71	0.26
1998	0.00	0.07	0.41	0.52	0.53	0.53	0.53	0.53	0.19
1999	0.01	0.12	0.67	0.85	0.86	0.86	0.86	0.86	0.29
2000	0.01	0.13	0.72	0.90	0.92	0.92	0.92	0.92	0.27
2001	0.00	0.08	0.46	0.59	0.59	0.59	0.59	0.59	0.17
2002	0.00	0.05	0.28	0.35	0.35	0.35	0.35	0.35	0.11
2003	0.00	0.09	0.48	0.61	0.61	0.61	0.61	0.61	0.25
2004	0.01	0.11	0.59	0.75	0.76	0.76	0.76	0.76	0.31
2005	0.00	0.03	0.18	0.23	0.23	0.23	0.23	0.23	0.08
2006	0.01	0.10	0.54	0.69	0.69	0.69	0.69	0.69	0.20
2007	0.00	0.04	0.22	0.28	0.28	0.28	0.28	0.28	0.07
2008	0.00	0.03	0.18	0.23	0.23	0.23	0.23	0.23	0.09
2009	0.00	0.00	0.01	0.02	0.02	0.02	0.02	0.02	0.01
2010	0.00	0.01	0.04	0.05	0.05	0.05	0.05	0.05	0.02
2011	0.00	0.02	0.13	0.16	0.17	0.17	0.17	0.17	0.06
2012	0.00	0.02	0.14	0.17	0.17	0.17	0.17	0.17	0.05
2013	0.00	0.01	0.05	0.06	0.07	0.07	0.07	0.07	0.02
2014	0.00	0.01	0.08	0.10	0.10	0.10	0.10	0.10	0.04
2015	0.00	0.01	0.05	0.06	0.06	0.06	0.06	0.06	0.02
2016	0.00	0.01	0.05	0.06	0.06	0.06	0.06	0.06	0.02
2017	0.00	0.01	0.05	0.06	0.06	0.06	0.06	0.06	0.03

Table 16: 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}	2.58

Table 17: Sensitivity analysis table. Current estimates are geometric means of 2015-2017 estimates. Yield units are pounds ($\times 10^3$), 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	1679.8	3,014	0.16	2.58	0.14	2.19
LA_SM-01	$h=.9$	1678.1	2,887	0.16	2.47	0.14	2.18
LA_SM-02	$h=.8$	1676.0	2,708	0.16	2.32	0.15	2.13
LA_SM-03	$h=.6$	1660.2	1,245	0.16	1.07	1.22	0.45
LA_SM-04	Yield lambda (x5)	1416.6	3,073	0.16	2.63	0.14	2.07
LA_SM-05	Survey lambda (x5)	1635.4	3,933	0.16	3.37	0.13	2.45

11. Figures

Figure 1: Reported commercial striped mullet *Mugil cephalus* landings (pounds x 10³) of the Gulf of Mexico derived from NMFS statistical records and the LDWF trip ticket program.

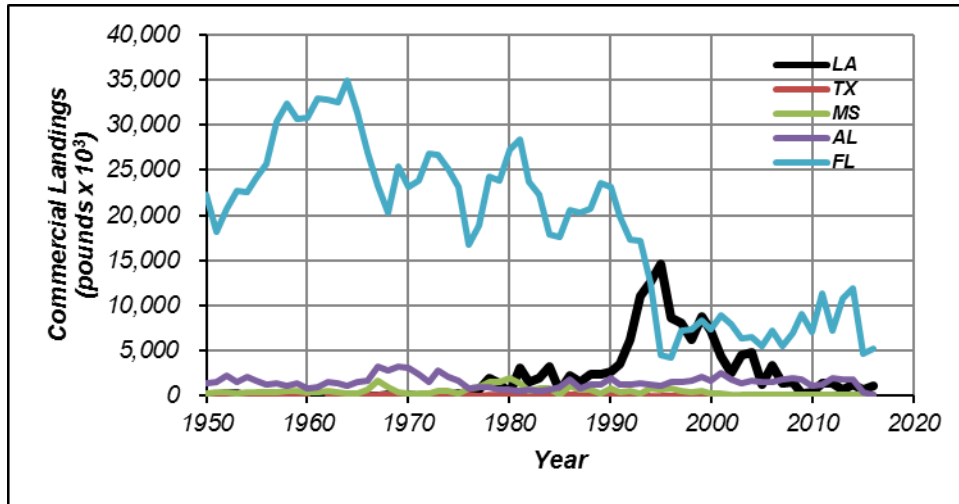


Figure 2: Station locations of the LDWF experimental marine gillnet survey. Yellow lines delineate LDWF Coastal Study Areas. Red circles represent long-term stations; green circles represent stations added in October 2010.

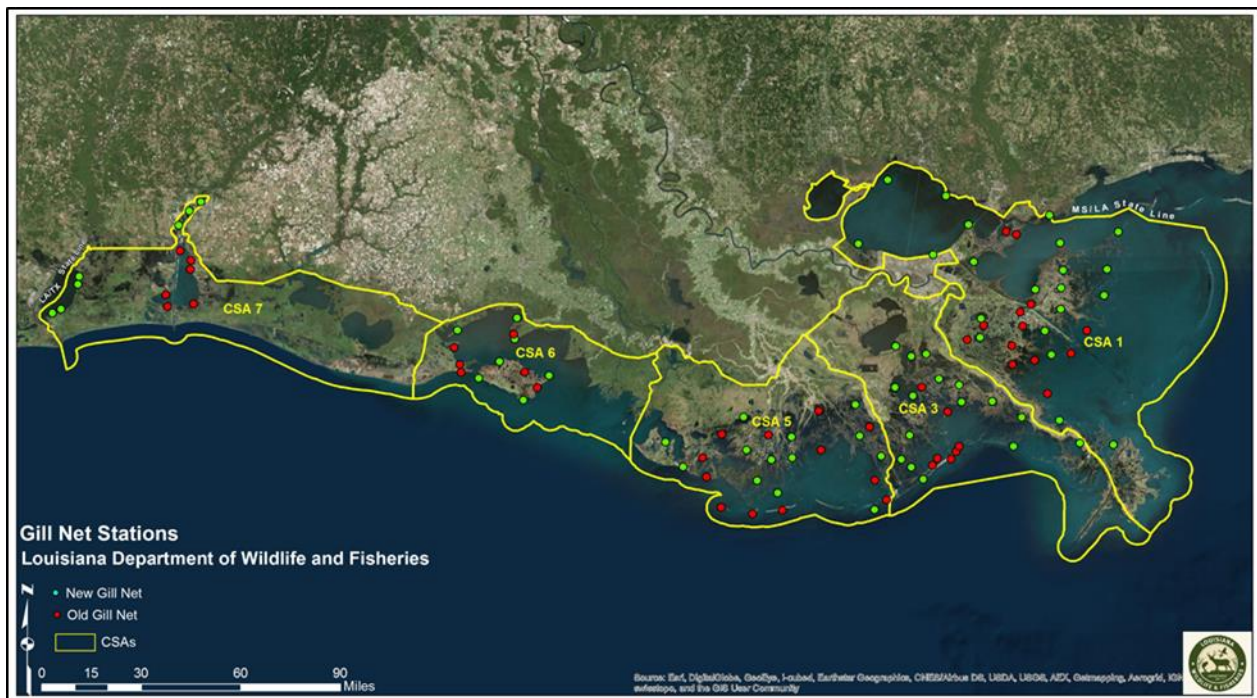


Figure 3: Standardized striped mullet indices of abundance, nominal catch-per-unit-effort, and 95% confidence intervals of the standardized indices derived from the LDWF marine gillnet survey. Each time-series has been normalized to its individual long-term mean for comparison. Top graphic depicts the “old” time-series. Bottom graphic depicts the “new” time-series.

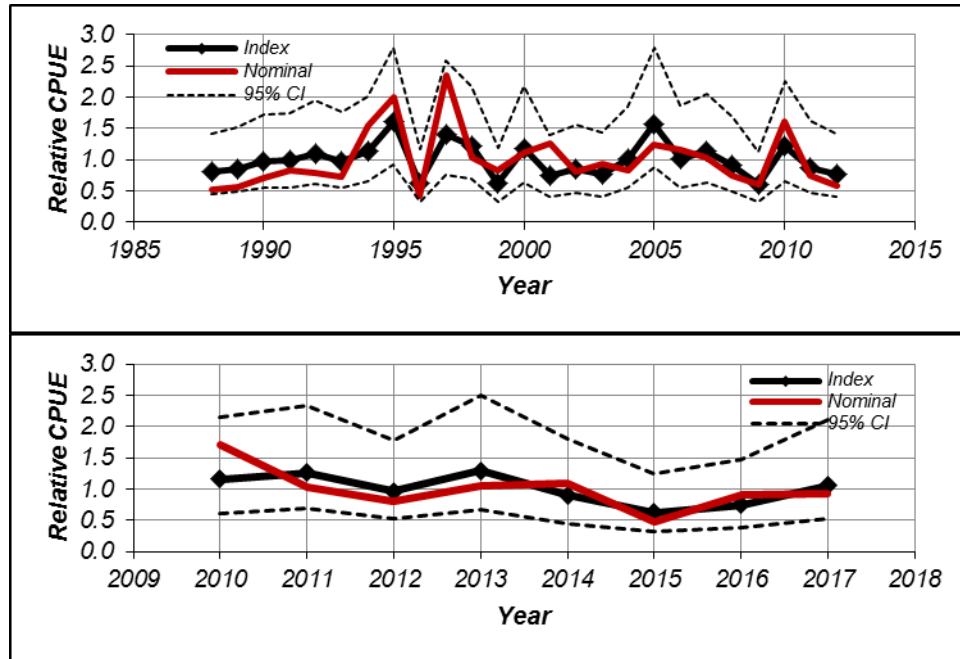


Figure 4: Observed and ASAP base model estimated commercial yield (females only; top) and standardized residuals (bottom).

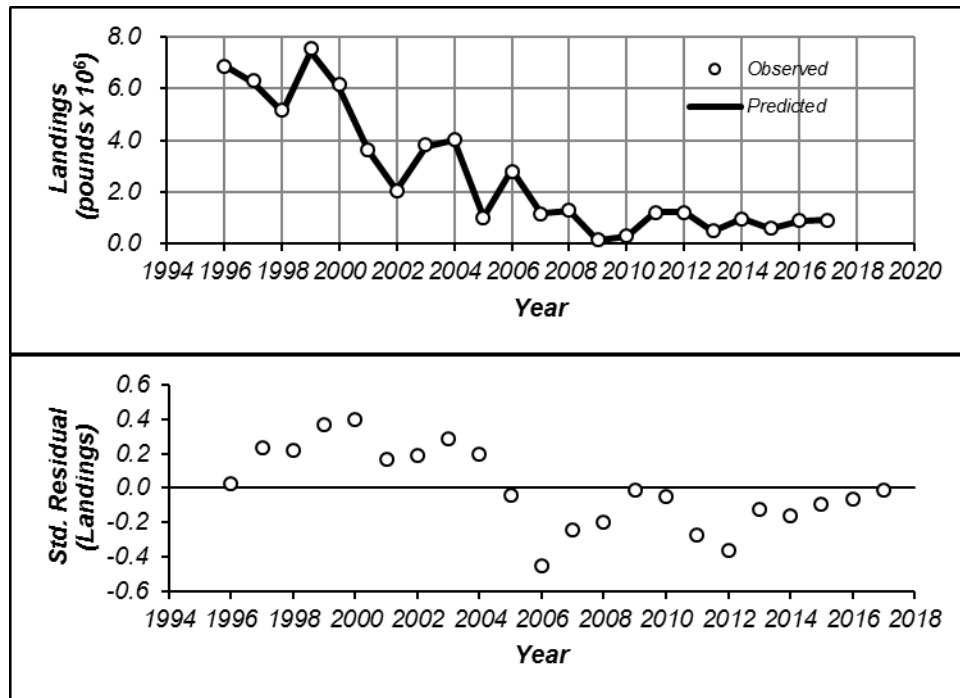


Figure 5: Observed and ASAP base model estimated fishery-independent CPUE (females only, top) and standardized residuals (bottom) of the “old” time-series.

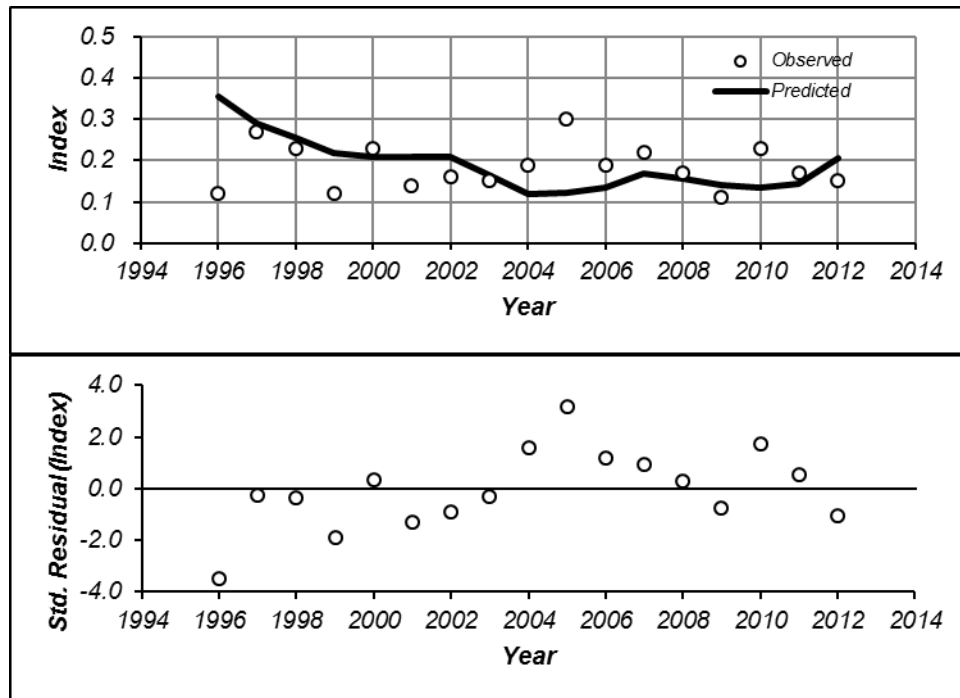


Figure 6: Observed and ASAP base model estimated fishery-independent CPUE (females only, top) and standardized residuals (bottom) of the “new” time-series.

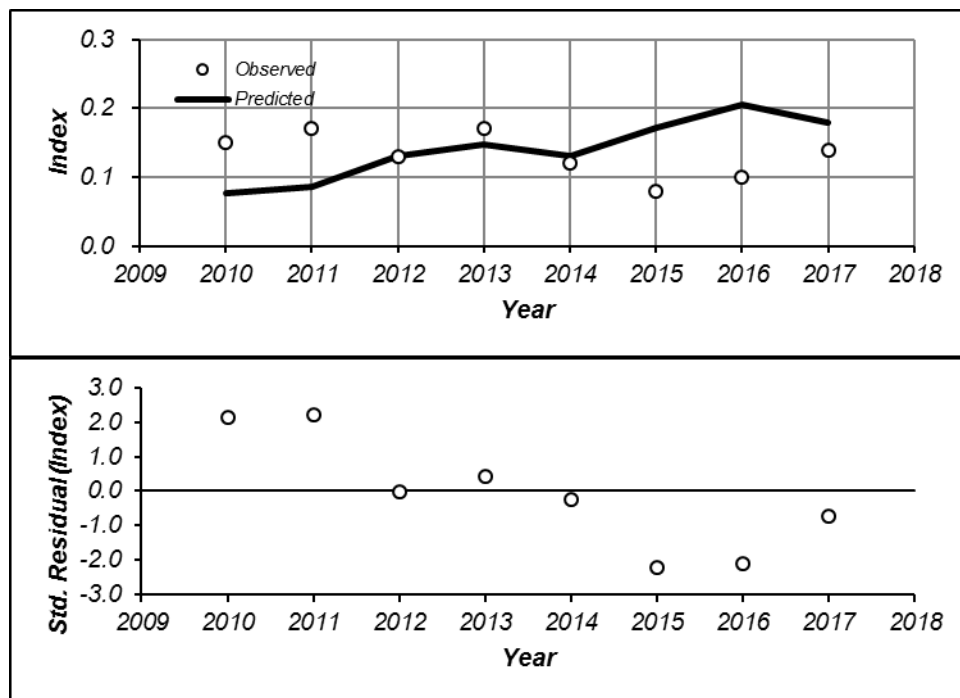


Figure 7: Annual input (open circles) and ASAP estimated (bold lines) commercial harvest age compositions.

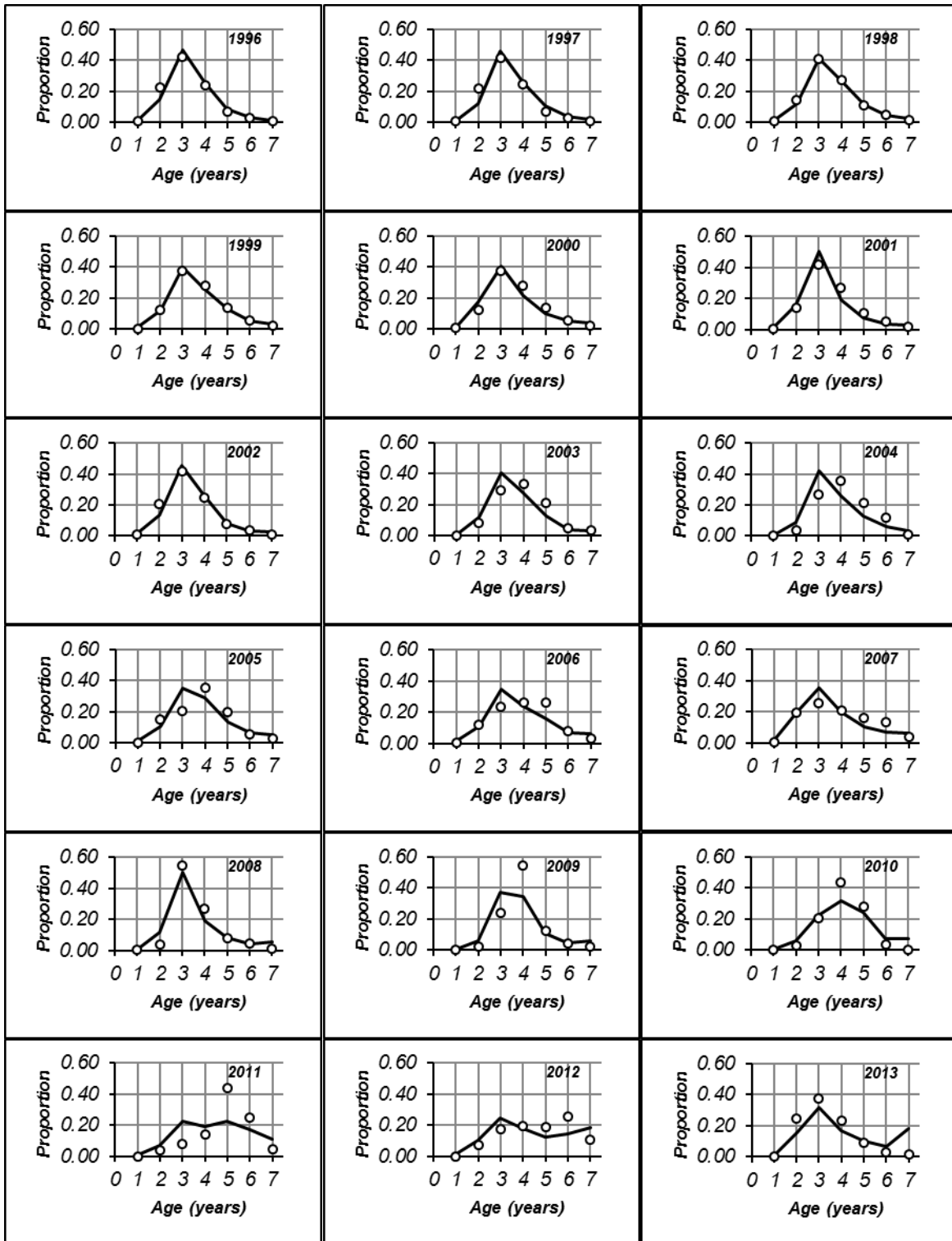


Figure 7 (continued):

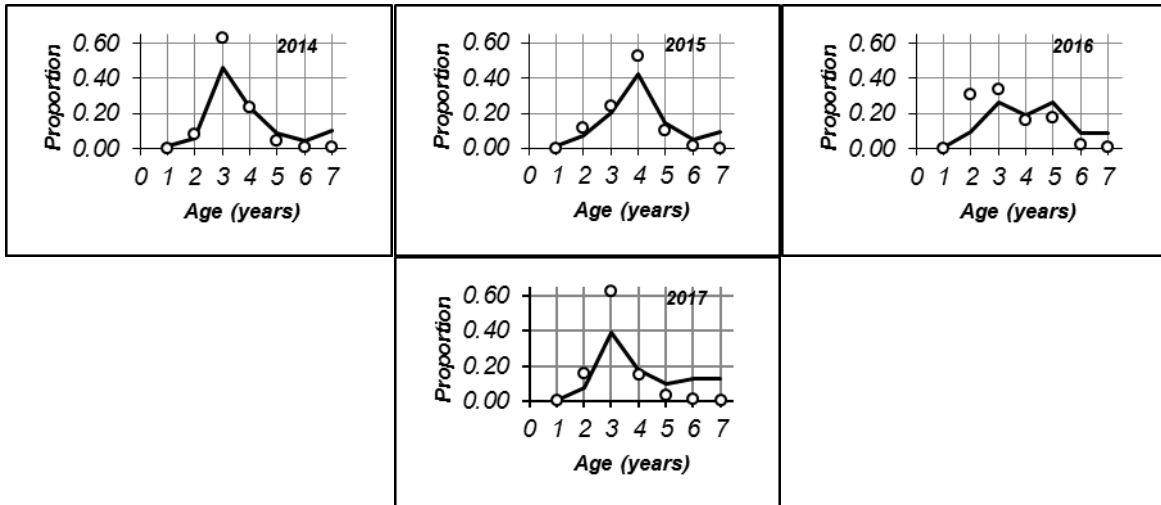


Figure 8: Annual input (open circles) and ASAP estimated (bold lines) survey age compositions of the “old” time-series.

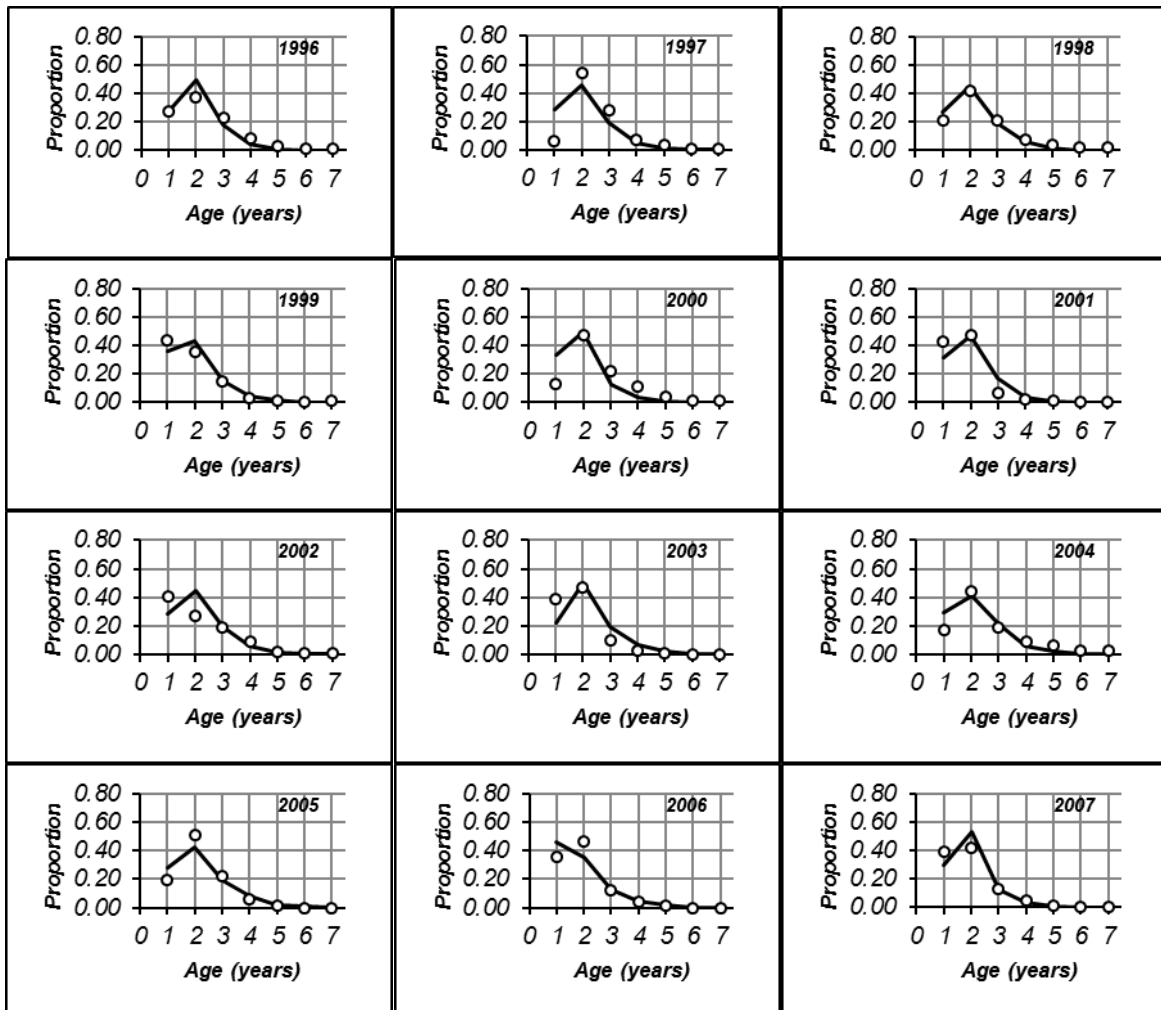


Figure 8 (continued):

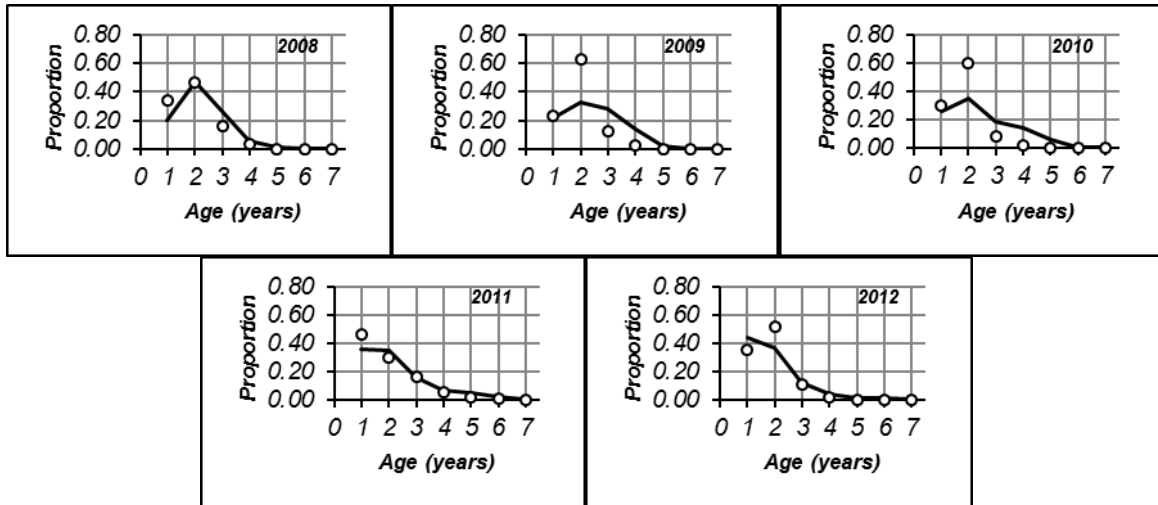


Figure 9: Annual input (open circles) and ASAP estimated (bold lines) survey age compositions of the “new” time-series.

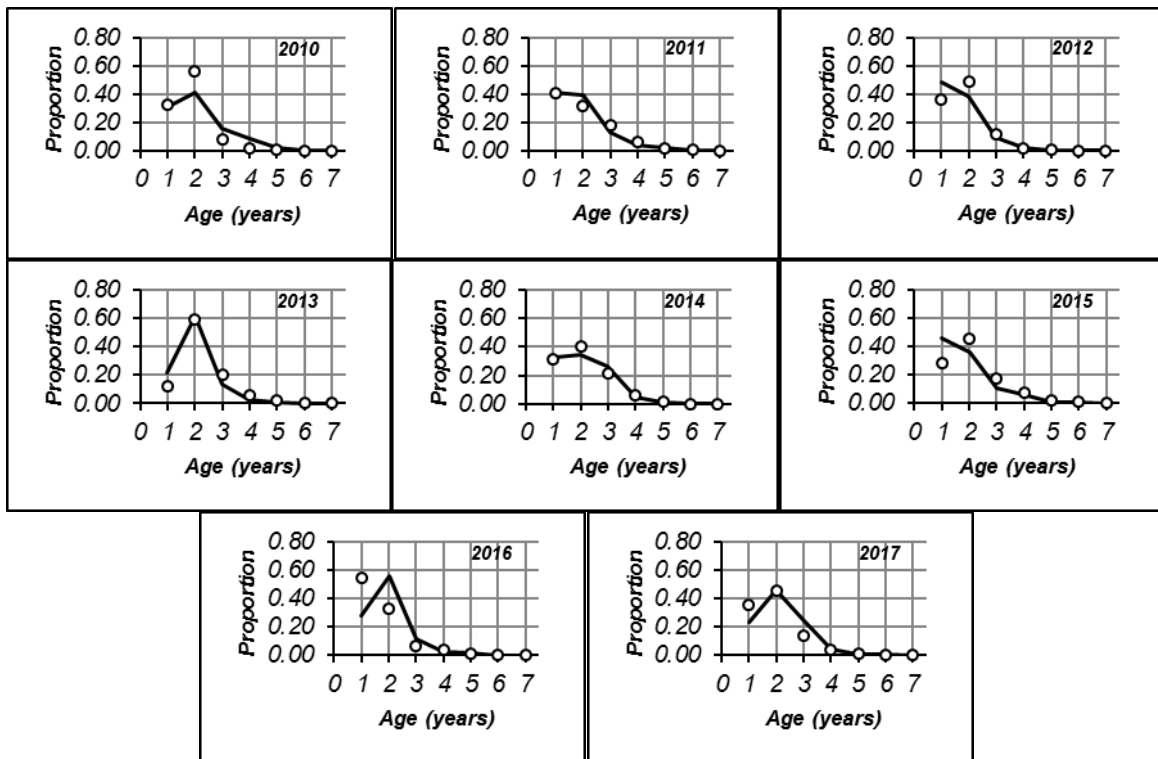


Figure 10: ASAP base model estimated fleet and survey selectivities (females only; ages 1-7+).

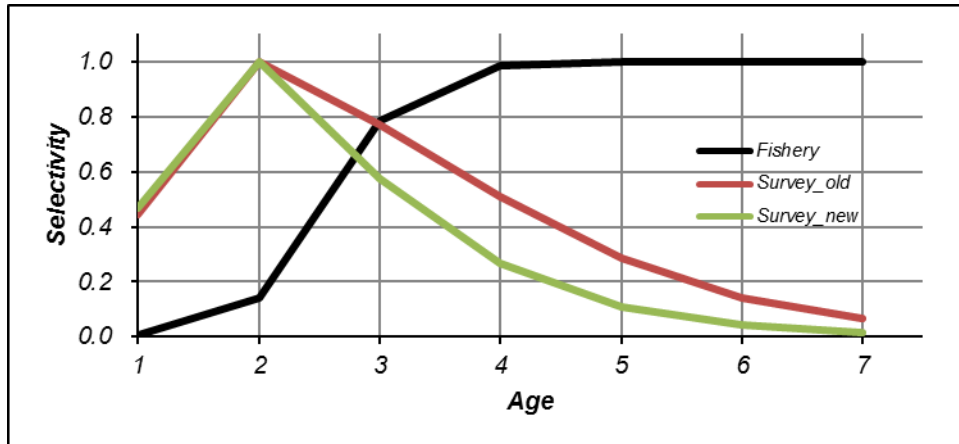


Figure 11: ASAP base model estimated recruitment (age-1 females). Dashed lines represent ± 1 asymptotic standard errors.

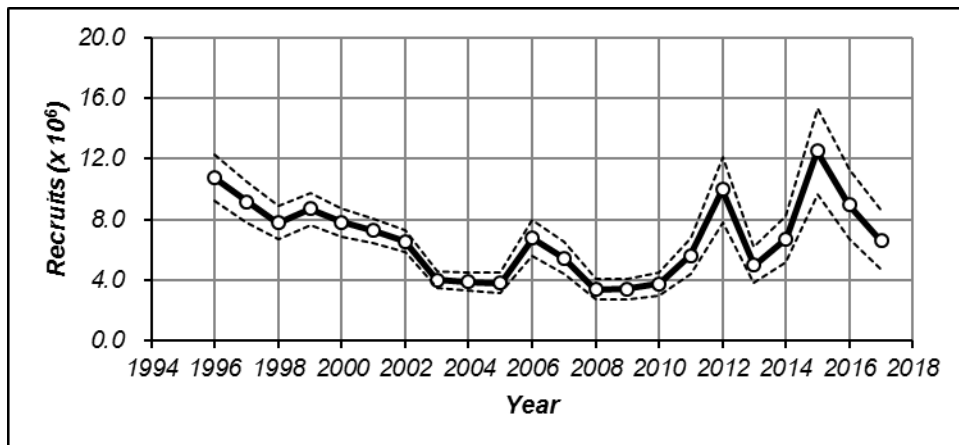


Figure 12: ASAP base model estimated egg production (MCMC median). Dashed lines represent 95% MCMC derived confidence intervals.

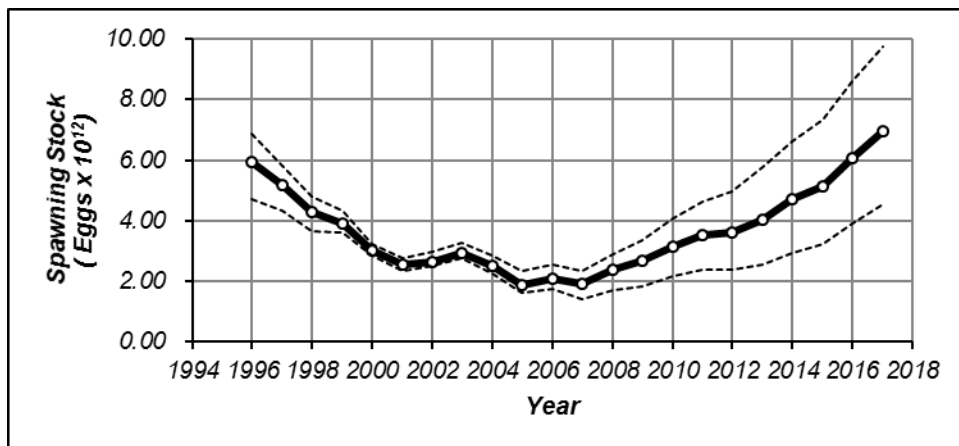


Figure 13: ASAP base model estimated average fishing mortality (MCMC median). Dashed lines represent 95% MCMC derived confidence intervals.

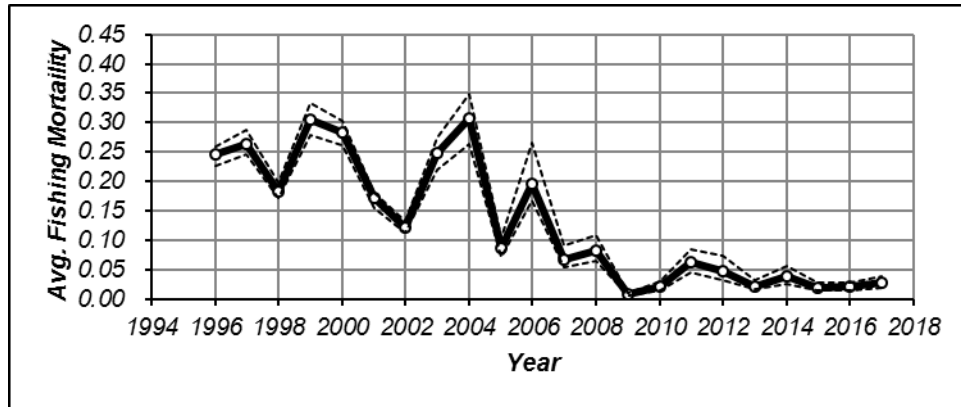


Figure 14: ASAP base model estimated age-1 recruits and spawning stock (total egg production). Arrow represents direction of the time-series. The yellow circle represents the most current data pair.

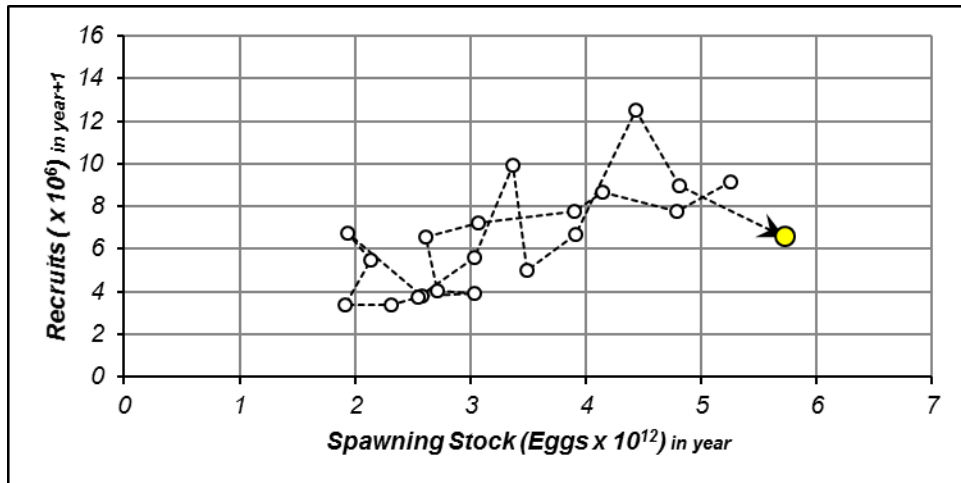


Figure 15: ASAP base model estimated age-1 recruits and spawning stock (open circles). Equilibrium recruitment is represented by the bold horizontal. The 2017 egg production estimate is represented by the yellow triangle. Equilibrium recruitment per spawning stock corresponding with the minimum and maximum spawning stock estimates are represented by the slopes of the dashed diagonals (min. spawning stock=22% SPR; max. spawning stock=77% SPR).

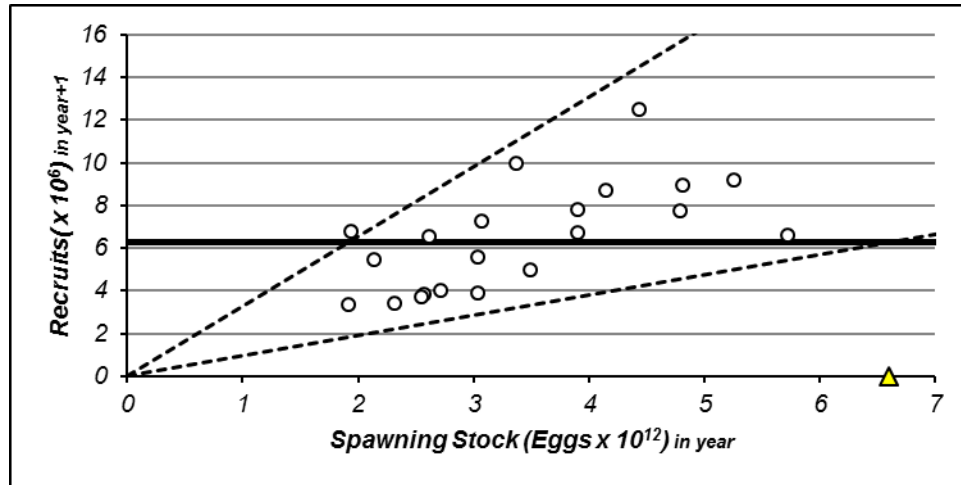


Figure 16: Retrospective analysis of ASAP base model. Top graphics depict estimated ratios of annual average fishing mortality to $F_{30\%}$ and spawning stock (egg production) to $SS_{30\%}$. Bottom graphic depicts estimated age-1 recruits.

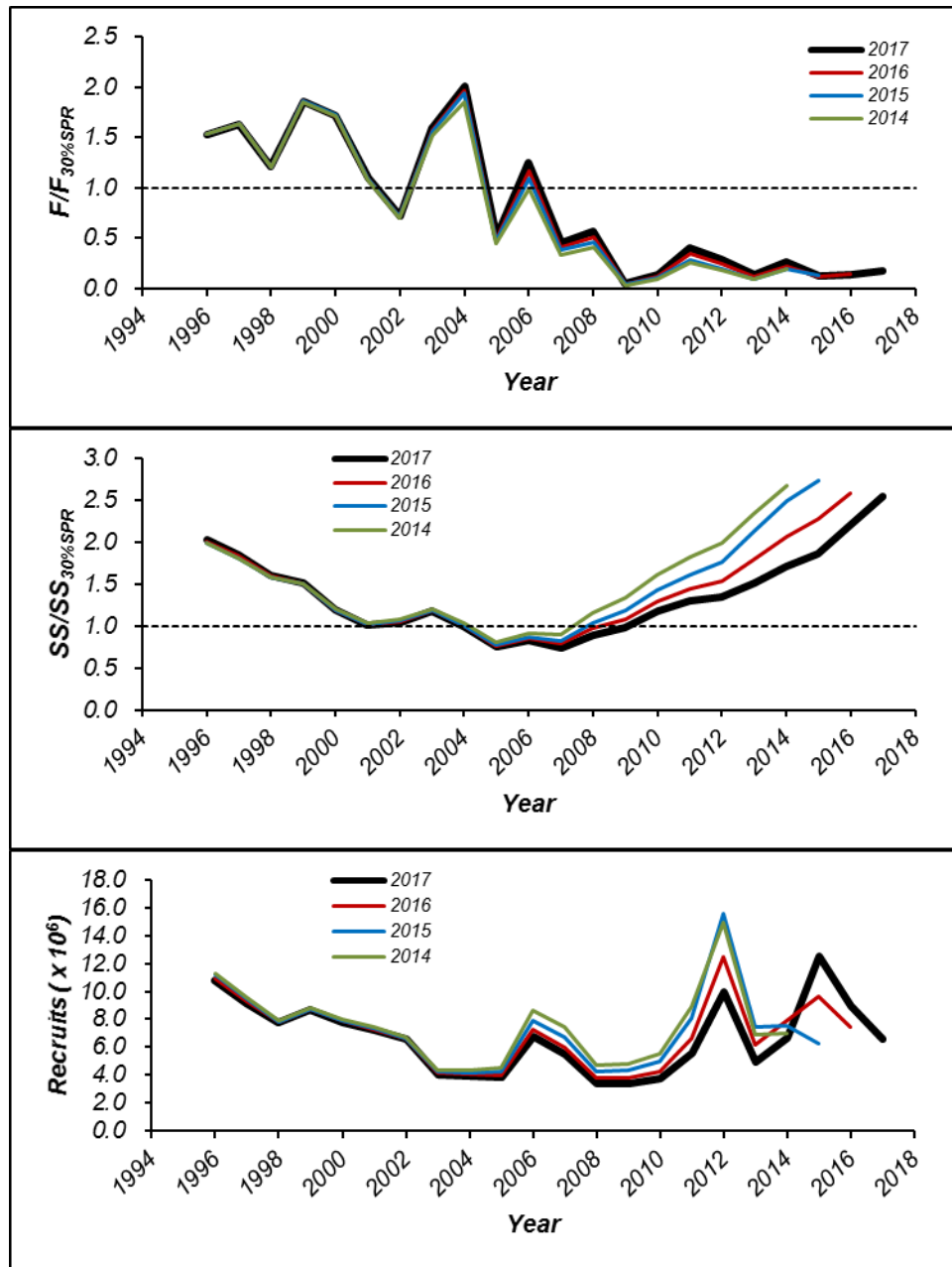


Figure 17: ASAP base model estimated ratios of annual average fishing mortality rates to $F_{30\%}$ and spawning stock size to $SS_{30\%}$. Arrows and dashed line represent direction of time-series (top graphic). The yellow circle represents current status (geometric mean 2015-2017 average F and SS). Bottom graphic depicts results of 2000 MCMC runs relative to limit reference points and current stock status.

