Appendix 7. SRA results

Stock Reduction Analysis (SRA) Model: A brief description and summary of results for Gulf of Mexico red snapper

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The description of the SRA model and summary of results is provided at the request of the red snapper SEDAR assessment group because it is one of the several models considered for the stock assessment.

The stock reduction analysis does the following.

1. The method starts the population at projected unfished conditions (based on data derived from historical documents dating back to 1872) and projects the population to the present time taking into account the fishery removals from the population.

2. The model uses a stock-recruit function that can incorporate density dependence in survival rates for the juvenile phases of the fish's life history. Density dependence can be specified to occur just before the shrimp trawl bycatch of age-0 fish, just after the first six months after emergence (called age-1), or just after the first 18 months following shrimp trawl bycatch of age 1 fish (called age-2).

3. The model requires life history parameter inputs such as mass at age, fecundity at age, steepness in the stock-recruit function and natural mortality rate at age which are provided by NMFS and agreed to by SEDAR participants

4. The model requires fishery inputs such as observed bycatch, landings for recreational and commercial fisheries, out of season discards for recreational and commercial fisheries, selectivity at age for each of the different fisheries modelled, including the selectivity of discarded fish, relative to the landed fish. Selectivity at age for shrimp trawl bycatch has been computed separately for the years before 1999 and then after 1999 to take into account the introduction of bycatch reduction devices late in 1998. These are provided by NMFS and agreed to by SEDAR participants.

5. The model can be fitted to relative abundance indices by estimating average unfished recruitment (R_0) and the constants of proportionality (i.e., factors that scale model predicted abundance to each abundance index) for each index of abundance. The model finds the best fit of the predicted abundance trends to the observed abundance trends. Catch-age estimates of stock-recruit deviates can also be included to account for variation in cohort strength. The model can also be constrained to fit recent estimates of fishing mortality rates obtained from other analyses (e.g., ASAP, CATCHEM).

6. Density-dependent survival rate implies that the average survival rate of individuals of a given age group in a population depends on the abundance of conspecifics of that age group; higher abundance will tend to lower the survival rate for example due to increased exposure to predation when the availability of hiding spots is limited. When density dependent survival rate is specified to occur at either age-one or two years the model calculates density independent survival of eggs to age-0 just at settlement and applies the density-independent rates of natural mortality for each age that have been previously specified in the data workshop. The model uses the initial slope of the stock recruit function under the age-0

density dependent scenario to obtain the number of age-0 fish in models with density dependence at either age-1 or 2 years. This permits the model to account for shrimp bycatch removals, directed fishery bycatch and natural mortality regardless of the age at which density dependence is assumed to occur.

7. Once a value for R_0 is obtained, the model can be projected from unfished conditions in 1872 to the present and then from the present into the future to evaluate the potential consequences of alternative fishery management options.

<u>The general advantages of the stock reduction analysis are as follows</u>:

1. The model runs very fast (a few seconds to do an estimation and projection) and permits a "gaming" approach in which a large variety of model assumptions and input settings can be efficiently evaluated. This is facilitated because the model has on-screen graphics to show the fit of the model to the abundance indices and the results of model projections. This permits quick learning about the sensitivity of assessment model results to different input assumptions.

2. The model permits an evaluation of the plausibility of stock-recruit parameter estimates obtained in catch-age analyses of the last few decades in over a century of exploitation of this fish stock. Specifically, the appropriateness of specific catch-age estimated R_0 and steepness values can be evaluated based on the criteria that subsequent model outputs should be consistent with the historical record. For example, if the modelled stock hardly depletes at all with these inputs, this model prediction is inconsistent with the high values of fishing mortality rate implied in the catch-age data and this provides reason to question the credibility of the catch-age stock-recruit parameter estimates and assumptions.

3. The model permits an evaluation of the credibility of alternative assumptions about where in the life history density dependence occurs. The model can be fitted to indices of abundance and catch-age fishing mortality rate estimates under the different assumptions about the ages of density dependence. The goodness of fits of the model to the data under the different assumptions about the age of density dependence can be assessed.

4. Because this model runs very fast, it would permit simulation testing of the accuracy of the model or extension so that it could be applied in Bayesian probabilistic calculations to take into account parameter uncertainty. These extensions may be implemented at some later date to test the accuracy of the estimation and provide measures of the uncertainty in estimated quantities.

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5. The model computes an Akaike Information Criterion (AIC) to permit evaluations of the goodness of fit of the different model assumptions to the data and model selection, taking into account differences in the numbers of parameters estimated.

6. The model computes MSY reference points to permit evaluations of stock status and future states of the stock under different management methods with respect to MSY reference points.

7. The program is written in Visual Basic and can be easily learned and modified by those who know VB.

<u>Some of the limitations of SRA analysis are as follows</u>:

1. The model currently does not permit computation of probability intervals or confidence intervals of modelled quantities which should normally be done for any stock assessment method to allow inspection of the statistical uncertainty in parameter estimates. This

capability will be included in the near future. Providing confidence intervals will not change the point estimates much at all but will provide indications of the relative amount of uncertainty in them given the fit of the model to the available data.

2. The model depends upon outputs from catch-age analyses for selectivity functions and stock-recruit function deviates. This could increase potential biases in model outputs in some runs when settings (e.g., natural mortality rate at age and steepness) different from the catch-age analysis are applied. Such biases could be reduced by updating the SRA analysis to estimate stock-recruit deviates and fishery selectivity parameters and by fitting the SRA model to additional age-structured datasets.

3. The SRA models mortality as a discrete process in the year rather than as a continuous process and could introduce some biases. Although mortality rates occur as continuous processes over time, it is computationally more efficient to model them as discrete processes that occur at a specific point within each year. Previous modelling work, however, demonstrates that under most conditions, representing mortality rate as events at discrete points in time produces similar results as the full continuous case.

4. It is most likely that density dependence in survival rate occurs over a range of ages rather than at one single age. To increase computational efficiency and maintain a simple approach to keeping track of mortality rates from fishing, density independent natural mortality rates, fishing mortality rates and shrimp trawl bycatch, the density dependence in survival rate is modelled to occur at a single age, rather than as a continuous process and this could introduce bias in estimates of abundance and abundance trends. The direction and magnitude of the bias introduced by the simplifying assumption is not immediately obvious. However, the basic effects on the stock assessment of assuming different mean ages over which density dependence occurs can still be readily evaluated with the current model.

5. The SRA does not compute SPR reference points (due to lack of time to implement these).

6. The model assumes stationarity in most parameters over time. For example, it assumes that the fisheries' catchabilities, the carrying capacity and selectivity functions for the commercial and recreational fisheries have remained constant over time. However, the introduction of additional offshore oil and gas platforms could mean that the stock has become more resilient to exploitation if carrying capacity is increased– or it may mean that it is more susceptible because it aggregates snapper making them easy to find for even novice fishermen. The assumption of stationarity in the SRA model could thus lead to underestimates of the recent potentially higher values for carrying capacity and MSY (average unfished recruitment) or underestimates of potential recent increases in catchability. These assumptions could be modified however to evaluate the sensitivity of model results to such alternative hypotheses.

7. The SRA model assumes that the inputted catches are known without error, when in fact there may be pronounced observation error in some of the catch time series such as the bycatch time series and earlier parts of the commercial and recreational catch time series.

<u>Key results</u>

1. Under density dependence at age 0, and using the 1999 ASAP settings (most recent past stock assessment settings) for steepness (h), average unfished recruitment (R_0) natural mortality rates, and stock-recruit deviates, the SRA model was run from 1872 to the present. This was done to evaluate the plausibility of stock-recruit parameter estimates obtained in the 1999 stock assessment and others presented at SEDAR when the stock assessments fitted to shorter time series. According to the SRA model, it was not possible to obtain values for fishing mortality rates as high as those from current and past ASAP or

VPA. If h is set at 0.95 and R_0 is set at 245 million (obtained from the 1999 stock assessment), then the computed fishing mortality rates were very low (e.g., 0.002 yr^{-1} for the average F for age 3 for years 1987-1998 ($F_{3,\ 87\text{-}89}$)) compared to about 0.47 yr^{-1} in the 2005 ASAP assessment. In this case, the estimate of spawner potential in 2004 ($Eggs_{04}/Eggs_{unfished}$) turned out to be implausible, i.e., at 110% of unfished conditions. This value resulted because the ASAP stock-recruit residuals for the 1990s were strongly positive and the fishery removals were insufficient to appreciably reduce the stock at the R_0 of 245 million fish and steepness of 0.95. The main conclusion that can be drawn is that stock-recruit parameter estimates obtained by fitting a model to data obtained at the end of a time series of exploitation such as has been done in the 1999 and 2004 ASAP assessments, can produce stock-recruit parameter estimates that are inconsistent with the longer historical time series and possibly highly biased.

2. The sensitivity of stock assessment model output to differing assumptions about the age at which density dependent survival rate occurs was evaluated. With density dependence set at age 0 years, as in the 1999 and 2004 ASAP assessment, and when R_0 and constants of proportionality for abundance indices were estimated and the model was fitted to the relative abundance indices, it was not possible to find parameters values that achieved estimates of depletion and fishing mortality rates as high as the values found in the 1999 and 2004 ASAP and 2004 VPA assessments. For example, under a variety of conditions, and different sets of abundance indices used, the estimates of $Eggs_{04}/Eggs_{unfished}$ were between 33% and 89% and $F_{3,\ 87\text{-}89}$ were between 0.004 and 0.04 yr^{-1}. Thus, the SRA model results indicate that 1999 ASAP settings for density dependence at age 0 and average unfished recruitment (both the low and high values assumed) are inconsistent with the historical record of catch removals -- and that the 1999 ASAP results which are based on the assumptions that density dependence occurs at age 0 and that recruitment was either near to unfished conditions in 1971 or near to unfished conditions in the mid to late 1970s should not be applied to provide management advice.

3. With density dependence set at either age 1 or age 2 years (both are equally plausible given current knowledge) rather than age 0, it became possible to obtain estimates of current stock status similar to those obtained in the ASAP and VPA assessments of the recent catch-age data. This provides empirical support in favour of the hypothesis that density dependence occurs at age 1 or 2 years rather than at age 0. Estimates of $Eggs_{04}/Eggs_{unfished}$ ranged between 8% and 37% and $F_{3,87\text{-}89}$ ranged between 0.09 and 0.18 yr^{-1}. The MSY values estimated under these more plausible settings were far lower than those under density dependence at age 0, and indicate that the current TAC may be higher than the MSY.

4. Under projections with density dependence at age 1 or age 2 years, the projected recovery time was highly sensitive to the TAC but relatively insensitive to different future values for shrimp trawl bycatch (STBC) removals. For example, under the scenarios and constant TAC policies evaluated (ranging between 0 and 9 million pounds per year), future annual STBC from zero to 25 million age 0 to 2 year fish changed stock recovery rates relatively little.

5. The projections changed very little when minimum size limits were removed in the recreational and commercial fisheries. This was partly because the low capture induced mortality rates for fish released by the recreational sector permitted the majority of these fish to survive and contribute the annual catch at later ages and larger sizes. The average age of fish discarded in the recreational fishery was one year (as opposed to two years for the commercial fishery), and a far larger number of fish are discarded in the recreational

fishery. In contrast, if all of the discarded recreational fish are retained, then due to the small size of recreational discards, the number of fish killed before the TAC is met can be nearly as high or higher than when discarding is permitted. Thus, the high survival rate of fish discarded from the recreational fishery and the larger numbers of small fish required to make up the TAC reduced considerably the potential positive effects of eliminating the minimum size limits in both the commercial and recreational fisheries.

6. Under the scenarios (which) considered, stock recovery to B_{MSY} before 2032 could only be achieved only by reducing the TAC. TACs between about 2.0 and 4.5 mp permitted recovery to B_{msy} before 2032. Failure to reduce the TAC by about half resulted in projected stock collapse within the next 10 years.