Greater Amberjack Yield-per-recruit and Spawning Potential Ratio Analysis for the Gulf of Mexico

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Introduction

A stock assessment of Gulf of Mexico greater amberjack determined the stock remained overfished and is undergoing overfishing (SEDAR 9 Update 2010). The Gulf of Mexico Fishery Management Council is considering management measures to reduce total allowable catch (TAC) of greater amberjack in order to rebuild the stock, including increasing the minimum size limit. The commercial minimum size limit is 36 inches fork length (FL) and has been in effect since implementation of Amendment 1 to the Reef Fish FMP in 1990. The current recreational minimum size limit of 30 inches FL was implemented in 2008 through Amendment 30A to the Reef Fish Fishery Management Plan. Greater amberjack begin maturing at 28 inches FL, reach 50% maturity at 34.7 inches FL, and reach full maturity at 40 inches FL (Murie and Parkyn 2008). Thus, the current recreational minimum size limit is below the size at 50% maturity. The following analyses evaluate the yield-per-recruit (YPR) and spawning potential ratios achieved at various recreational minimum size limits under a variety of fishing mortality rates. Two methods were considered: one that assumes knife-edge selectivity of greater amberjack at the minimum size limit, and another method that includes discard selectivity for sub-legal fish and harvest selectivity for legal-sized fish.

Method

YPR and SPR with knife-edge selectivity

Following Ault et al. (1998, 2008), a length-based computer algorithm (REEFS - Reef Ecosystem Exploited Fishery Simulator) that employed an age-independent continuous population model was used to determine population numbers and biomass at given lengths over time. The algorithm begins with determining the average number of fish at a given length ($\overline{N}(L)$):

$$\overline{N}(L) = \int_{L_r}^{L_\lambda} R(\tau - a)S(a)P(L|a)da. \qquad (1)$$

The equation is integrated from size at recruitment (L_r) to the largest size (L_λ). *R(τ-a)* is cohort recruitment lagged back to birth date, *S(a)* is survivorship to age *a*, and $P(L|a)$ is the conditional probability of being length *L* given the fish is age *a*.

Population biomass, $B(L|a,t)$, is the product of numbers-at-age, $N(L|a,t)$, times weight-at-age, $W(L|a,t)$, where $(L|a,t)$ represents the length (L) for a given age *a* at time *t*. Yield in weight (Y_w) was calculated as the fishing mortality rate multiplied by the exploited population biomass:

$$Y_W = F(t)\int_{L_c}^{L_\lambda} B(L|a,t)dL = F(t)\int_{L_c}^{L_\lambda} N(L|a,t)W(L|a,t)dL \qquad (2)$$

where *F(t)* is the fishing mortality rate applied to the exploited phase (L_c to L_λ) in year *t*. YPR was calculated by dividing the yield (Y_w) by the initial number of recruits. Spawning stock biomass (SSB), a measure of stock reproductive potential, was integrated between the minimum size of sexual maturity (L_m) and the maximum size (L_λ):

$$SSB(t) = \int_{L_m}^{L_\lambda} B(L|a,t)dL. \qquad (3)$$

SPR is a management benchmark that measures the stock's reproductive potential to produce optimum yields on a sustainable basis. SPR is calculated as

$$SPR = \frac{SSB_{exploited}}{SSB_{unexploited}} \qquad (4)$$

where $SSB_{exploited}$ is the spawning stock biomass associated with a fishing mortality rate and $SSB_{unexploited}$ is the spawning stock biomass with no fishing mortality.

REEFS model inputs came from the literature and are summarized in **Table 1**. Additional detail on the maturity of females by length is provided in **Figure 1** (Murie and Parkyn 2008).

Table 1- REEFS model input values for amberjack life history parameter estimates and the source of the information.

Parameter	Estimate	Unit	Definition	Source
t_0	-2.526	years	Age at zero length	Murie and Parkyn (2008)
K	0.144	per year	Brody growth coefficient	Murie and Parkyn (2008)
L_∞	1489	mm fl	Ultimate length	Murie and Parkyn (2008)
W_∞	39.73	kilograms	Ultimate weight	Murie and Parkyn (2008)
t_{max}	15	years	Maximum age	Murie and Parkyn (2008)
α	6.7E-08	dimensionless	Weight-length parameter	Murie and Parkyn (2008)
β	2.765	dimensionless	Weight-length parameter	Murie and Parkyn (2008)
L_m	34.7	inches	Length at 50% maturity	Murie and Parkyn (2008)
M	0.25	per year	Natural mortality rate	SEDAR 9 (2010)
$F_{current}$	0.609	per year	Current fishing mortality rate	SEDAR 9 (2010)
F_{msy}	0.333	per year	Fishing mortality rate maximizing sustainable yield	SEDAR 9 (2010)

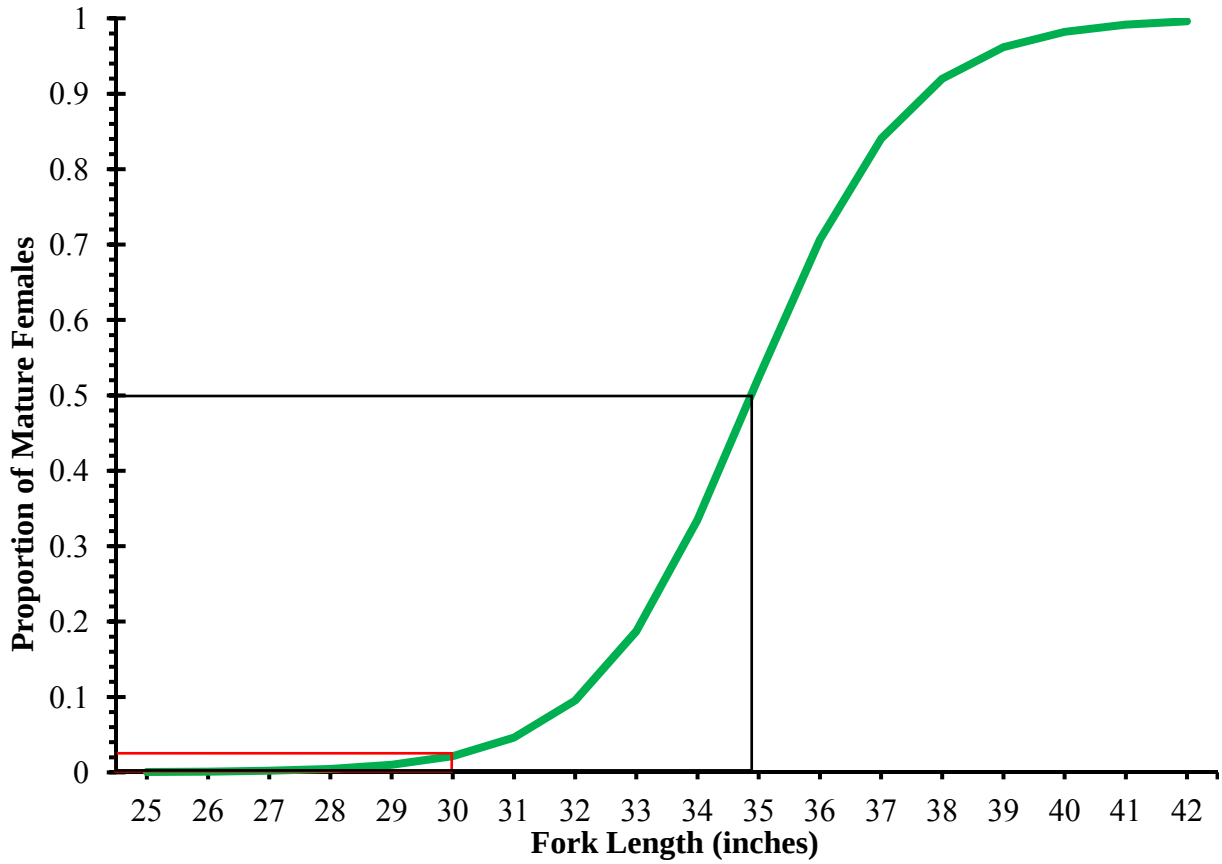

Figure 1.- Proportion of mature females by length for greater amberjack in the Gulf of Mexico. Data comes from Murie and Parkyn (2008). Black lines denote size at 50% maturity; red lines denote percent maturity at current recreational size limit.

YPR and SPR values were calculated using the current recreational minimum size limit (30 inches FL) with the current fishing mortality rate ($F_{current} = 0.609\ y^{-1}$) and the maximum sustainable yield fishing mortality rate ($F_{msy} = 0.333\ y^{-1}$) provided from the most recent stock assessment (SEDAR 9 2010). YPR and SPR were also computed across a range of reasonable combinations of fishing mortality rates and minimum sizes.

YPR and SPR with discard and harvest selectivity

YPR and SPR were calculated using a modified version of a model originally developed by the Florida Fish and Wildlife Institute (FWRI-YPR). The original model was age-based and was converted to a length-based model using the age-length relationship described by Murie and Parkyn (2008; see **Table 1**). The lengths considered corresponded to ages ranging from 0 to 15 years. Natural mortality was set equal to 0.25, consistent with the 2010 greater amberjack update assessment (SEDAR 9 2010). Selectivity was assumed to be flat-topped and was based on headboat and for-hire observer data obtained from the Gulf States Marine Fisheries Commission and Florida Fish and Wildlife Conservation Commission. The observer data indicated that the frequency of greater amberjack caught increased from 10 to 20 inches, then remained stable or declined thereafter (**Figures 2A, B**). Discard selectivity was assumed to increase from 0 to 1

between 10 and 20 inches FL, then reduced from 1 to 0 within two inches of the specified minimum size limit (**Figure 3**). Harvest selectivity increased from 0 to 1 within 2 inches of the minimum size limit (**Figure 3**). All fish were assumed to be fully selected once reaching the minimum size limit.

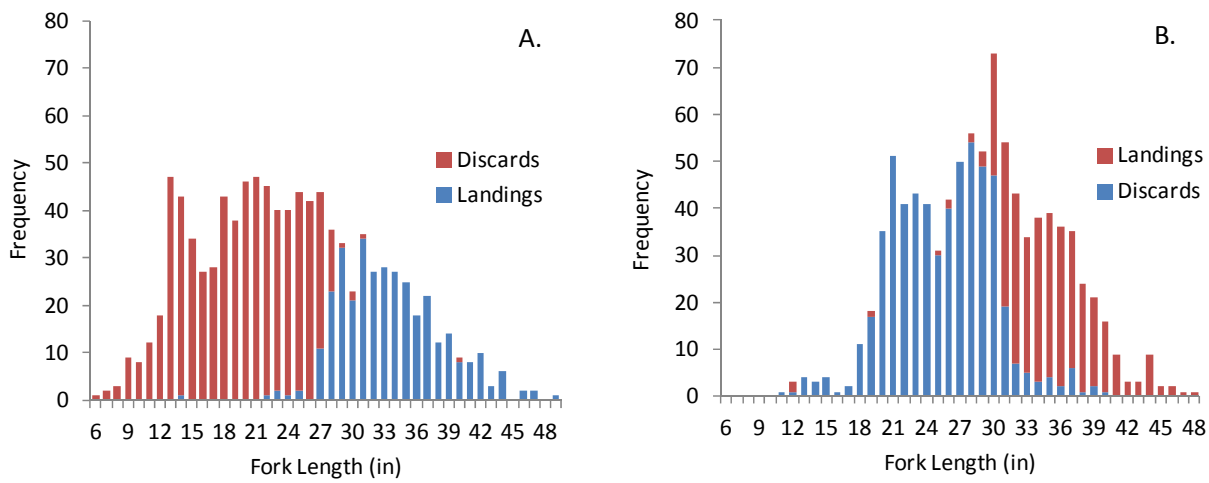

Figure 2.- Length frequency distribution for Gulf of Mexico greater amberjack landings and discards observed on **A)** headboats (2004-2007) and **B)** charter boats and headboats (2009-2011).

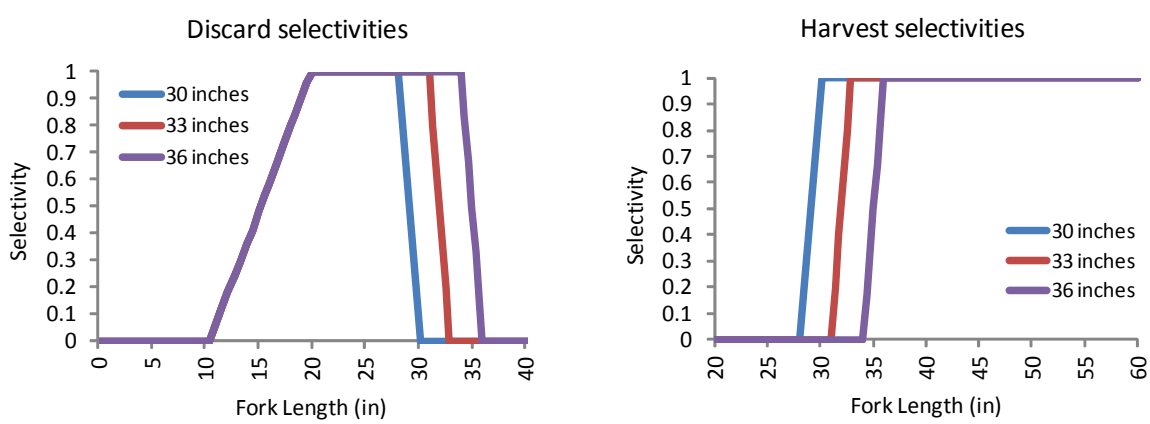

Figure 3.- Assumed harvest and discard selectivity used in the FWRI-YPR model to calculate YPR and SPR for various minimum recreational size limits.

Fishing mortality rates ranging from 0.0 to 1.0 were modeled in increments of 0.05. The following equations were used to model the fishing mortality associated with harvest ($F_{harvest}$) and discards ($F_{discards}$):

$$F_{harvest} = hs*F \quad (5)$$

$$F_{discards} = ds*F*r \quad (6)$$

where, *hs* is the selectivity at length for harvested fish for a particular size limit, *ds* is the selectivity at length for discarded fish for a particular size limit, *F* is the fishing mortality rate, and *r* is the discard mortality rate. Following SEDAR 9 (2010) the discard mortality rate was 20%. To estimate total fishing mortality (F_{total}) and total mortality (Z) for each length the following equations were used:

$$F_{total} = F_{harvest} + F_{discards} \quad (7)$$

$$Z = F_{total} + M \quad (8)$$

The number of survivors for each length (N_L) was estimated using the following equations:

$$N_L = R*\exp(-Z) \quad (9)$$

$$N_bar = N_L*(1 - \exp(-Z))/Z \quad (10)$$

where, R is the proportion of initial recruitment to length *L*, N_L is the number of survivors for each length, and *N_bar* is the estimated number of survivors between length *L* and length *L + 1*.

Predicted weight (WW) was calculated with

$$WW = \alpha(Length)^{\beta}$$

where a and b are weight-length parameters given in **Table 1**.

YPR and SSB for each length were calculated using equations 11 and 12:

$$YPR = WW*F_{harvest}*N_bar \quad (11)$$

$$SSB = WW*N_bar*\%mature \quad (12)$$

Total YPR for each size limit across all lengths were calculated as the sum of YPR. Total SPR for each size limit across all lengths was calculated using equation 13:

$$SPR = SSB_{Fexploited}/SSB_{unexploited\ (F=0)} \quad (13)$$

Results

The REEFS model estimated YPR equal to 7.01 pounds whole weight for the 30 inch minimum size limit at $F_{current}$ (0.609 y^{-1}). YPR contours (**Figure 4**) revealed YPR at F_{msy} was maximized at 6.6 pounds. At F_{msy}, YPR decreased if the minimum size limit was greater than or less than 30 inches FL. YPR did increase for larger minimum size limits, but only when F was greater than $F_{msy,}$ which would result in overfishing. SPR at $F_{current}$ for the 30 inch FL minimum size limit was 10%, while SPR at F_{msy} for the 30 inch FL minimum size limit was 23% (**Figure 5**). Increasing the minimum size limit at F_{msy} would result in higher SPR.

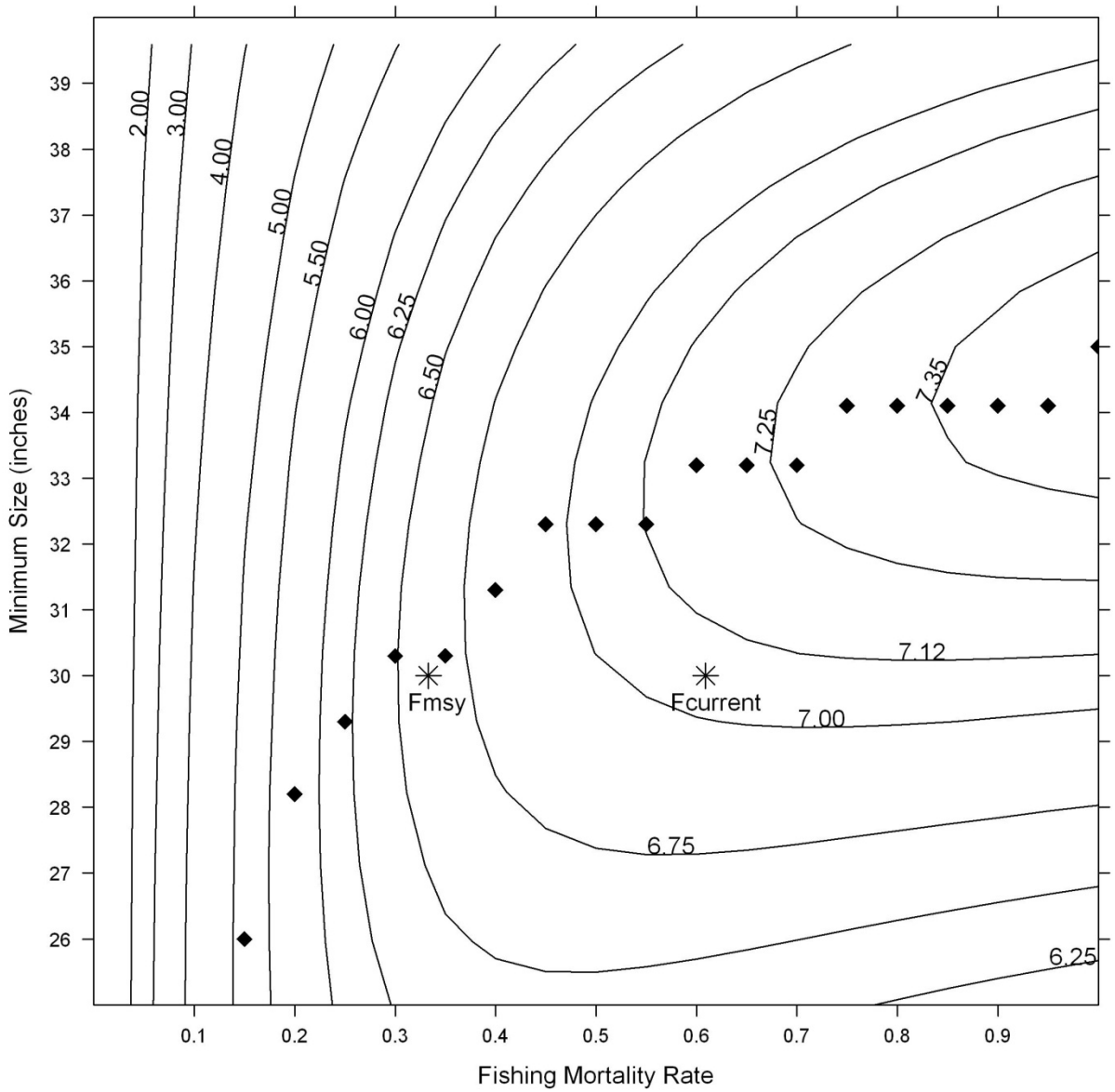

Figure 4.- REEFS model generated contours for yield-per-recruit in pounds for greater amberjack in the Gulf of Mexico obtained from combinations of fishing mortality rates and minimum sizes. The diamond points represent the maximum yield-per-recruit for each fishing mortality rate. The asterisks represent $F_{current}$ and F_{msy} (SEDAR 9 2010) for the current 30 inch FL minimum recreational size limit.

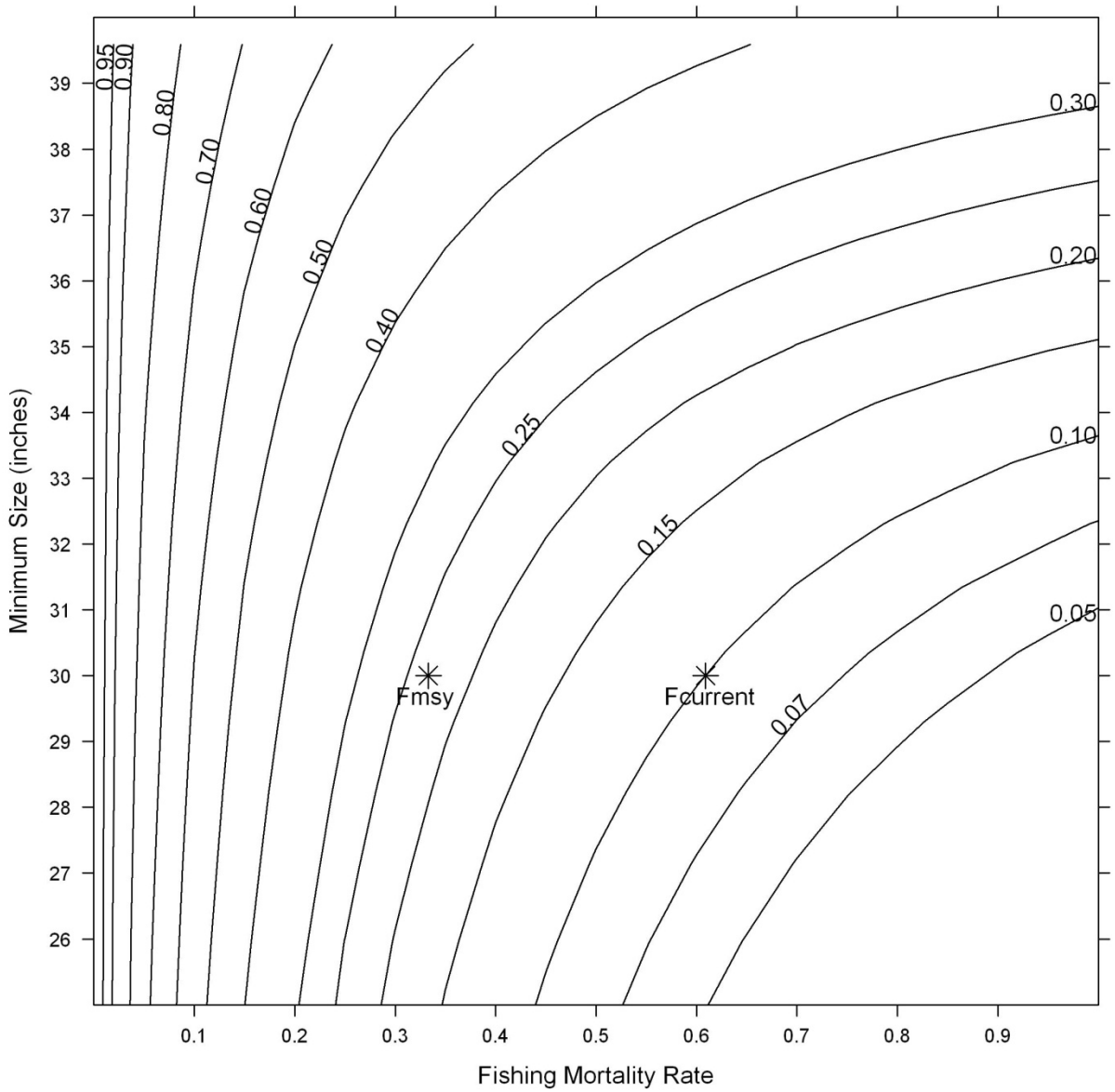

Figure 5- Spawning stock biomass ratio contours as functions of fishing mortality rate and minimum size. The asterisks represent $F_{current}$ and F_{msy} (SEDAR 9 2010) for the current 30 inch FL minimum recreational size limit.

The FWRI-YPR model generated similar results to the REEFS model. A size limit of 30 inches FL generated the highest YPR (6.1 pounds whole weight) (**Figure 6**). Conversely, the highest SPR was generated with a size limit of 36 inches FL (**Figure 7**). Unlike the REEFS model, YPR was projected to decline at fishing mortality rates above F_{msy}.

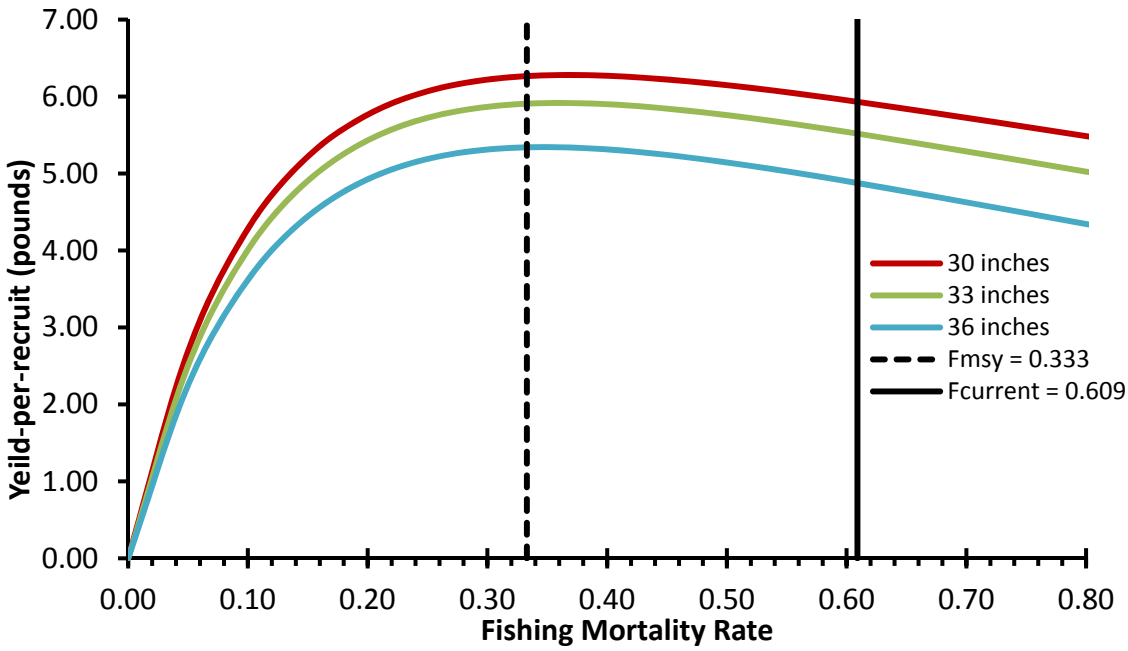

Figure 6.- FWRI-YPR model generated yield-per-recruit plotted against fishing mortality rates for three different minimum size limits. The black bar represents $F_{current}$ (0.609 y^{-1}) and the dashed line bar represents F_{msy} (0.333 y^{-1}) as estimated in SEDAR 9 (2010).

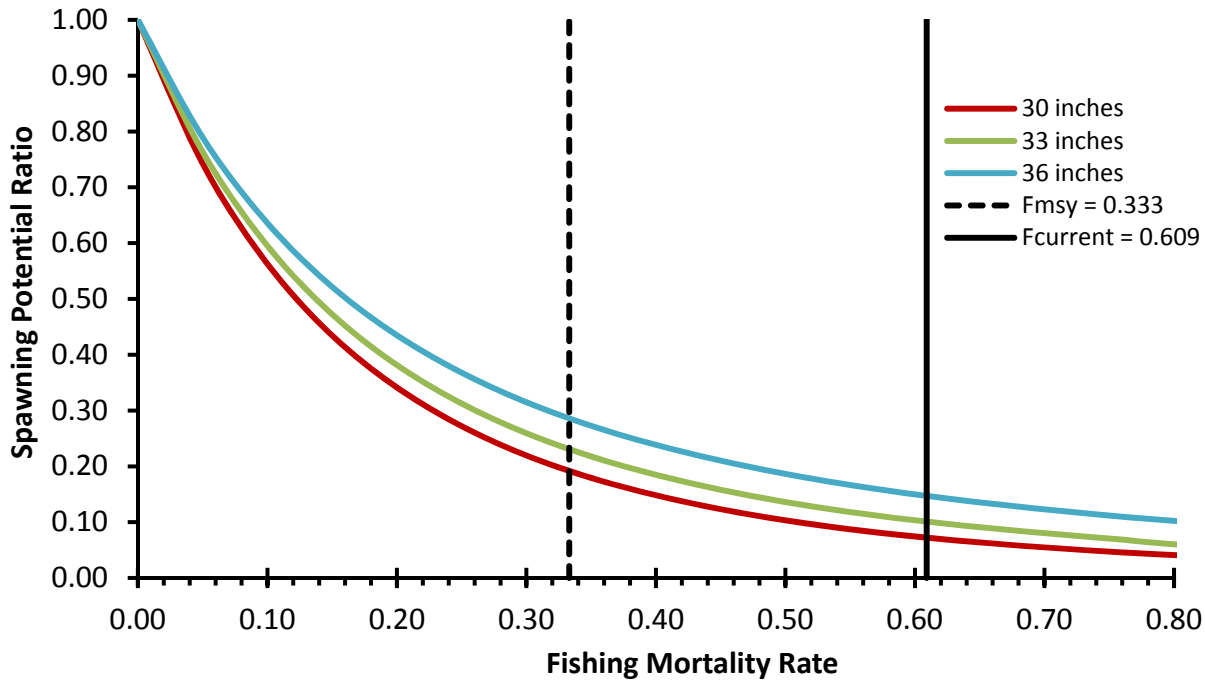

Figure 7.- FWRI-YPR model generated spawning potential ratios plotted against fishing mortality rates for three different minimum size limits. The black bar represents $F_{current}$ (0.609 y^{-1}) and the dashed line bar represents F_{msy} (0.333 y^{-1}) as stated in SEDAR 9 (2010).

A comparison of the YPR analysis results for the two different models is shown in **Figure 8** for a 30 inch FL minimum size limit. YPR generated by both models was comparable for fishing mortality rates less than 0.2 y^{-1}. At fishing mortality rates greater than 0.2 y^{-1}, YPR continued to increase under the REEFS model, but declined for the FWRI-YPR model. This difference was due to inclusion of discard selectivity in the FWRI-YPR model, which resulted in losses in potential yield and spawning biomass due to discarding of undersized fish.

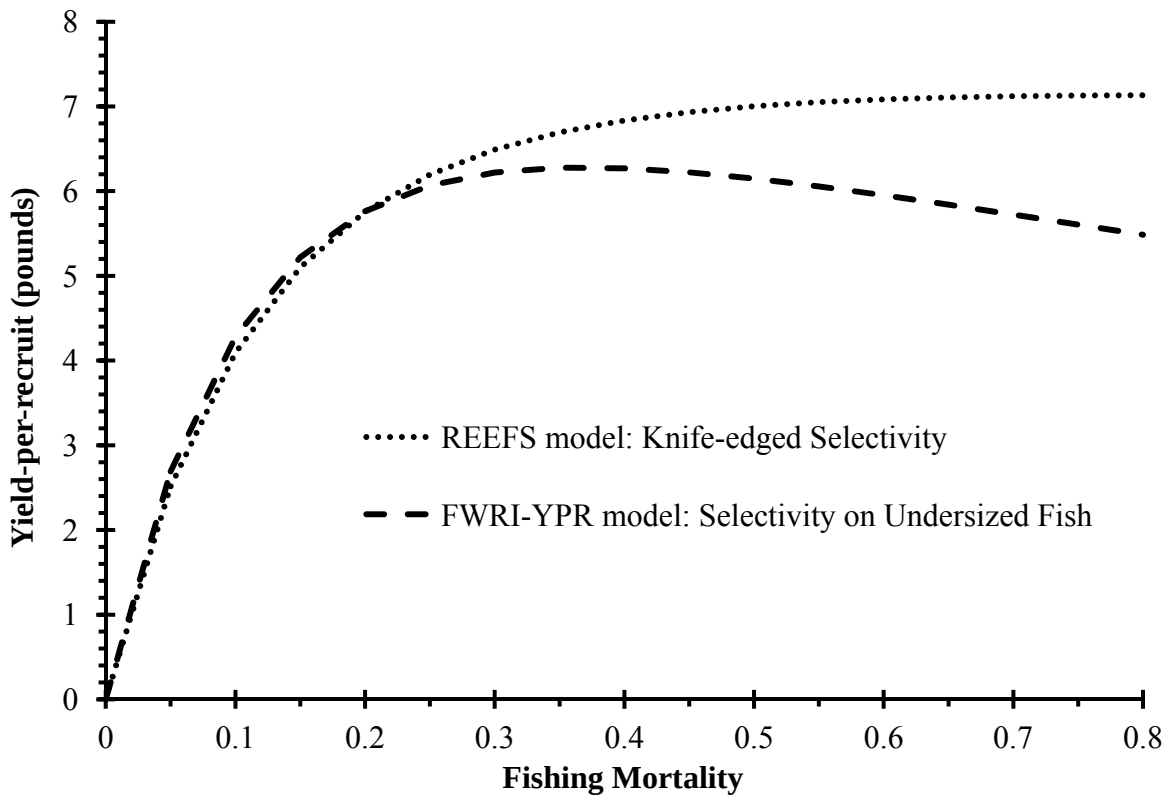

Figure 8.- Yield-per-recruit plotted against fishing mortality rates for a minimum size of 30 inches FL using the REEFS and FWRI-YPR models. The FWRI-YPR model applied selectivity to both discarded and harvested greater amberjack while the REEFS model applied knife-edged selectivity only to fish at or above the minimum size limit.

Discussion

Overall, both models used in this report yielded similar results despite different assumptions about selectivity. Both models indicated that there was a trade-off between YPR and SPR. If the management goal is to achieve a higher SPR, then increasing the minimum size limit would be beneficial; however, this would result in less YPR. If the management goal is to maximize YPR, then the current minimum size limit appears appropriate.

Applying selectivity and discard mortality to undersized fish (FWRI-YPR model) lowered the YPR achieved at fishing mortality rates exceeding 0.2 y^{-1} (**Figure 6**). The mortality of undersized fish due to release mortality reduced the potential harvest and yield from the fishery. Given the length frequency distributions of greater amberjack discards and landings

(**Figure 2**), application of selectivity and discard mortality to undersized fish is considered a more realistic assumption than knife-edged selection.

As with any analysis, results are limited by data inputs and assumptions. Both models assumed constant natural mortality across lengths. Natural mortality is likely highest at the smallest, youngest ages and declines with age and size. The analysis also assumed the population reached equilibrium with respect to fishing mortality; therefore, recruitment is constant. Lastly, for the FWRI-YPR model, it was assumed that selectivity followed a logistic relationship. This assumption is consistent with SEDAR 15 (2008), which assumed logistic selectivity for recreationally caught greater amberjack in the South Atlantic. Different assumptions about greater amberjack susceptibility to harvest and discard selectivity would affect YPR and SPR results. Additional sensitivity runs not presented herein were performed to evaluate what would happen to YPR and SPR if full discard selectivity was delayed from 20 to 28 inches FL. These sensitivity runs yielded similar results to the results presented herein; i.e., YPR was highest at 30 inches FL and increasing the minimum size limit resulted in higher SPR.

References

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