SEDAR 52 OVERFISHING LIMITS AND ACCEPTABLE BIOLOGICAL CATCHES FOR THE RED SNAPPER FISHERY IN THE U.S. GULF OF MEXICO

Southeast Fisheries Science Center
June 20, 2018

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1. Introduction

As part of the SEDAR 52 standard assessment for Gulf of Mexico red snapper (SEDAR 2018), the terms of reference (TOR) requested a series of equilibrium projections (i.e., $F_{SPR26\%}$, F_{OY}, and F = 0) along with near-term projections of overfishing limits (OFLs) and acceptable biological catches (ABCs) based on $F_{Rebuild}$ that included provisional landings for 2017. The final SEDAR 52 stock assessment report (SAR) provided equilibrium catch projections, but provisional landings were not yet available. During the May 2018 Gulf of Mexico Science and Statistical Committee (SSC) meeting, the SEDAR 52 assessment was approved as the best available science and deemed suitable as the basis of setting catch advice for Gulf of Mexico red snapper. During the SSC meeting, updated projections using 2017 provisional landings were presented to the SSC and utilized to recommend catch advice (OFLs and ABCs) for the years 2019 – 2021. This document summarizes stock status for Gulf of Mexico red snapper based on the results of the final accepted SEDAR 52 base model and associated equilibrium reference point projections (as provided in the final SEDAR 52 assessment report) and documents the short-term catch limit projections provided to and utilized by the Gulf SSC to recommend OFL and ABCs.

2. Methods

Deterministic projections were run using the final SEDAR 52 Stock Synthesis 3 (SS3) base model accepted by the Gulf of Mexico SSC. As outlined in the SEDAR 52 TORs and requested by the Gulf of Mexico SSC, a number of projection runs were carried out including:

A) Project F_{MSY} or proxy (i.e., $F_{SPR26\%}$) to determine reference points.
B) Project F_{OY} (i.e., 75% of $F_{SPR26\%}$).
C) Project F = 0.
D) Project the overfishing limit (OFL, based on equilibrium $F_{SPR26\%}$) utilizing 2017 provisional landings and 2018 annual catch limits (ACLs).
E) Project $F_{Rebuild}$ (i.e., to SPR 26% in 2032) utilizing 2017 provisional landings and 2018 annual catch limits (ACLs).
F) Provide acceptable biological catches (ABCs) based on $F_{Rebuild}$ and a P* = 0.4.

Requests A-C were provided in the SEDAR 52 stock assessment report and are summarized in the current document, while D-F were provided to the SSC at their May meeting and are documented for the first time here. General assumptions were maintained across all projection runs and runs varied only in the length of the projections (i.e., equilibrium or rebuilding by 2032) and assumptions regarding target fishing mortality. General methods are provided and run-specific alterations are then described for each scenario.

$F_{SPR26\%}$ was chosen as the proxy for F_{MSY} during the 2014 SEDAR 31 Update Assessment process and projections were undertaken using this value and assuming fixed levels of bycatch and discards (i.e., the MSY|fixed_discards method; Goethel et al. 2018) to define rebuilding targets (following the methods of the 2014 SEDAR 31 Update Assessment; SEDAR 2015). Therefore, the maximum fishing mortality threshold (MFMT) was assumed to be equal to the fishing mortality rate that produces a spawning potential ratio (SPR) of 26% in equilibrium. However, since the 2014 SEDAR 31 Update Assessment, there has been a change in the minimum stock size threshold (MSST) value based on Amendment 44 to the Gulf of Mexico Reef Fish Fishery Management Plan (SERO 2017). Previously MSST was calculated as (1-M) * $SSB_{FSPR26\%}$, where M = 0.09 (i.e., the average value of M from the Lorenzen M curve for fully selected ages). The new value for MSST is 0.5 * $SSB_{FSPR26\%}$. Therefore, stock status is provided based on both values of MSST to provide continuity from the previous assessment.

Projections began in 2017 using the same parameter values and population dynamics as the base model. Projections were either run to equilibrium, which was assumed to be obtained over the last 10 years of a 60 year projection (i.e., 2067-2076), or 2032 (in the case of rebuilding scenarios). A full description of the model settings can be found in **Table 1** with additional details provided in the SEDAR 52 stock assessment report (SEDAR 2018). Because the base model assumes a fixed steepness of essentially 1.0, the projections assumed that forecasted recruitment would continue at recent average levels (i.e., projected recruitment was near the 'virgin' recruitment level for the recent productivity regime, 1984 – 2016, of 163 million fish) and historical average recruitment apportionment levels were assumed (i.e., 34% to the east and 66% to the west). For all years of the projections it was assumed that recent fishery dynamics would continue indefinitely including maintaining a 51% to 49% allocation of commercial to recreational catch. The selectivity for each fleet was taken from the terminal timeblock and relative harvest rates for the directed fisheries were assumed to stay in proportion to the terminal three year average (2013 – 2016) values. Similarly, discarding and retention practices were assumed to continue as they had in the three most recent years (2013 - 2016). The projected fishing mortality levels for the six bycatch fleets (shrimp bycatch, recreational closed season, and commercial closed season/no-IFQ) were assumed to be the same as in 2016 (i.e., fixed at their associated 2016 values; see **Figure 1** for terminal year relative fishing mortality rates by fleet).

For SPR-based analyses, the harvest rate (total number killed / total abundance) that led to a SPR of 26% (i.e., $SPR = \frac{\frac{SSB}{R}}{\frac{SSB_0}{R_0}} = 0.26$, which is equivalent to $\frac{SSB}{SSB_0}$ when steepness = 1.0 and recruitment is constant) was obtained by iteratively adjusting yield streams. Basically, the fishing mortality rates exerted by the directed fleets were scaled up or down by the same proportional amount (with the fishing mortality rates exerted by the bycatch and discard fleets held constant at assessment terminal year values) until the fishing mortality that achieved a SPR of 26% in the desired timeframe (i.e., either equilibrium or 2032) was obtained.

As currently implemented in SS3, the projections do not utilize constant fleet-specific fishing mortalities (i.e., a constant set of fleet-specific $F_{SPR26\%}$ values are not implemented for the entire timeseries of the projections). Although SPR 26% is achieved in the desired timeframe, it is accomplished with time-varying fleet-specific fishing mortalities (instead of fixed values as is typically assumed for single fleet SPR projections). The main reason for this is that it is not necessarily possible to conform to each constraint of the projections (i.e., a constant sector allocation, maintenance of proportional fishing mortalities across directed fleets, and obtaining SPR 26% with constant fleet-specific fishing mortality rates). SS3 performs projections in multiple phases with different constraints being adhered to in each phase to create a final set of projections that best abide by all of the desired constraints. The final projections maintain the desired sector allocation and the input directed fleet relative effort. Despite being constrained to achieve essentially the same population trajectories as projections that maintain constant fleet-specific fishing mortalities in each year (as achieved in earlier projection phases), the fleet-specific fishing mortalities are not constant in the final projections (see Methot and Wetzel 2013 or Methot 2015 for further details).

Stock status for red snapper was determined based on comparison of the given year fishing mortality to the MFMT (i.e., $F_{SPR26\%}$) and the given year SSB compared to the MSST (i.e., 0.5 * $SSB_{SPR26\%}$). As mentioned, the approach for calculating MSST used in the 2014 SEDAR 31 Update Assessment MSST [i.e., (1-M) * $SSB_{FSPR26\%}$, where M = 0.09] was also provided as a bridge to the results of the previous assessment.

Per the terms of reference, additional projection runs included projecting optimal yield (i.e., F_{OY} = 75% * $F_{SPR26\%}$) and F = 0. For the optimal yield run, the directed fishing mortality was decreased to 75% of the directed fishing mortality at $F_{SPR26\%}$, while the bycatch and discard fleet fishing mortality rates were held constant as in the $F_{SPR26\%}$ runs (following the methods outlined in the 2014 SEDAR 31 Update Assessment projections; SEDAR 2015). For the F = 0 run all fishing mortality was eliminated including bycatch and discards and the population was projected until equilibrium.

Overfishing limits (OFLs) were calculated as the median (50^{th} percentile) of the probability density function (PDF) of retained yield (millions of pounds) using the projection of $F_{SPR26\%}$(i.e., the yields that achieved the SSB target in equilibrium). Uncertainty in derived quantities (including retained yield) was carried through the projections from the parameter estimation phase in the stock assessment model and represented the approximate variance from the inversion of the Hessian matrix. The probability density function (PDF) and 95% confidence intervals are calculated assuming a normal distribution of the derived quantity.

Two sets of OFL values are provided, which correspond to equilibrium projections of $F_{SPR26\%}$ with and without 2017 provisional landings (15.36 million pounds) and a fully utilized 2018 ACL (13.74 million pounds). The OFL calculated without provisional landings was used to define the biological reference points (e.g., $F_{SPR26\%}$) and determine stock status. The OFL calculated utilizing provisional landings is the SSC accepted OFL value that accounts for interim removals during the lag period between the assessment terminal year (2016) and the setting of catch advice (i.e., beginning in 2019) based on the SEDAR 52 assessment.

Because the Gulf of Mexico red snapper resource is in a rebuilding plan, a $F_{Rebuild}$ projection was undertaken to project catches that will lead to a gulfwide SPR proxy of 26% in 2032. ABCs were based on the rebuilding projections assuming a probability of overfishing (P*) of 0.40 (i.e., the 40^{th} percentile of the PDF of the landings in retained yield), which was lowered by the SSC from the SEDAR 31 value of 0.427 based on a reassessment of scientific uncertainty at the May 2018 SSC meeting. Rebuilding projections also incorporated 2017 provisional landings and assumed a fully utilized 2018 ACL.

Additionally, F_{MAX_Global} (i.e., the fishing mortality corresponding to the global maximum yield-per-recruit), which is identical to F_{MSY_Global} in this case (because steepness is fixed at 1.0 and no relationship is incorporated between spawners and recruits), was calculated using one 'optimal' fleet with near infinite fishing mortality and knife-edge selectivity at the age that produced the highest yield-per-recruit. The resulting maximum yield-per-recruit was the global maximum possible given the life history characteristics of red snapper, and balanced gains due to growth and recruitment versus losses due to natural mortality. The value of F_{MAX_Global} can be used as comparison for $F_{SPR26\%}$ to see if the latter falls in the vicinity of F_{MSY} as stipulated in the Magnuson-Stevens Reauthorization Act (MSRA 2007; Goethel et al. 2018).

3. Results

3.1 Reference Point Projections and Stock Status

The harvest rate that results in SPR 26% in equilibrium was around 0.0588, while the resulting SSB at SPR 26% was 1.23E+15 eggs with an MSST of 6.15E+14 eggs (see **Table 2** for the relevant MSRA management reference points and benchmarks). The continuity value for MSST was equal to 1.12E+15. All of the calculated MSRA benchmarks compare favorably with the 2014 SEDAR 31 Update Assessment values. Virgin recruitment was estimated to be slightly lower along with virgin SSB. The result has been a decrease in MSST benchmarks, but a slight increase in MFMT. The latter result is likely due to larger estimated recent recruitment events than in the 2014 SEDAR 31 Update Assessment and higher terminal year SSB along with a lower SSB_0, which decreases the level of rebuilding required to achieve $SSB_{SPR26\%}$ and allows the stock to rebuild faster even at higher harvest rates.

The SEDAR 52 Base assessment model indicates that the Gulf of Mexico red snapper stock is recovering and based on current definitions of MSST and MFMT the stock is not overfished and there is no overfishing occurring (SSB_{2016}/ $MSST_{NEW}$ = 1.41; $F_{CURRENT}$ / MFMT = 0.823; **Table 2**). An important caveat to this result is that under the previous definition of MSST the red snapper resource would still be considered overfished (SSB_{2016}/ $MSST_{OLD}$ = 0.77). If both MSST values were being presented during the 2014 SEDAR 31 Update Assessment, a similar situation would have occurred (i.e., based on the results of that model SSB_{2014}/ $MSST_{NEW}$ = 1.08 and SSB_{2014}/ $MSST_{OLD}$ = 0.59 with $F_{CURRENT}$ / MFMT = 0.994). However, the SEDAR 52 model estimates that the stock was actually in slightly better condition in 2014 than estimated by the previous assessment (i.e., a SPR of 15% instead of 14% and a slightly lower relative harvest rate; **See Figure 2**). Regardless of MSST definition, the resource has been steadily rebuilding since the 2014 SEDAR 31 Update Assessment was undertaken. The OFL associated with the reference points (i.e., not utilizing provisional landings) start at relatively high levels (20.7 million pounds) before leveling off to equilibrium values around 13.4 million pounds (**Figure 3**).

3.2 F_{OY} and F = 0

Results of the F_{OY} projections were not substantially different from the reference point projections. Initial catches were high and leveled off as the 2015 yearclass was fished out (**Figure 4**). It is important to reiterate that the forecasts of optimal yield assumed the fishing mortality by the directed fisheries would be reduced by 25% (i.e., $F_{OY, Directed} = 0.75 * F_{SPRtarget, Directed}$), but not that of the bycatch fleets (the latter's F values were input and held constant). The result was that the realized total harvest rate (i.e., total removals in numbers / total abundance) in the OY projections was around 96% of the F_{Proxy} instead of 75% (**Table 2**). The disparity between realized and intended harvest rate is due to the substantial contribution of the bycatch fleets to the total annual removals (as detailed in SEDAR 2015). Given the many approaches to calculating optimal yield when multiple directed and bycatch fleets exist (e.g., average directed F is 75% of the target F, average F across all directed and bycatch fleets is 75% of target F, or total harvest rate is 75% of that at the biomass target), consideration of a standard OY approach should be undertaken in the future to avoid further confusion.

In the absence of any fishery removals (including bycatch or discards) the Gulf of Mexico red snapper population would be expected to rebuild rapidly and achieve a SPR target of 26% in 2019 (**Figure 5**).

3.3 Overfishing Limit (OFL) and Acceptable Biological Catch (ABC)

As described, two versions of the OFL were calculated (the version without provisional landings was used to determine reference points and the version utilizing provisional landings was used as the final accepted OFL). Both versions were nearly identical from 2019 onwards (**Figure 3**), despite 2017 provisional landings and 2018 ACLs being much less than (by approximately 5 million pounds) the reference point projections of OFL.

The OFL for the three years of management advice (2019-2021) set by the SSC based on SEDAR 52 decrease from 16.6 million pounds in 2019 to 14.6 million pounds in 2021, while the ABC declines from 16 million pounds in 2019 to 14.3 million pounds in 2021 (**Table 4**). The near-term OFL is higher than predicted by the 2014 SEDAR 31 Update projections, while corresponding SPR values are also higher (**Figure 6**). Similar results hold for ABCs and corresponding levels of SPR at $F_{Rebuild}$ (**Figure 7; Table 3**).

There are 2 primary factors controlling these differences. The SEDAR 52 projections begin from a relatively better off position (i.e., larger stock size, partially due to lower removals than estimated and projected in the 2014 SEDAR 31 Update Assessment) and benefit from a large estimated 2015 yearclass that supports higher catches in the near-term (**Figure 8**). In the first few years of the SEDAR 52 projections the 2015 yearclass is just beginning to enter the various fisheries. The model can fish the yearclass down and allows initial catches to be high in the first few years of the projections. Once this recruitment event has been fished out and the projections begin to rely on constant average recruitment levels, associated OFLs and ABCs begin to decrease and level out (nearly overlapping with those from the 2014 SEDAR 31 Update Assessment; **Figures 6 - 7**). Additionally, for ABC comparisons it should be noted that the SSC decided to reduce P* for SEDAR 52 ABC calculations (due to a reassessment of scientific uncertainty), which is another reason for discrepancies in ABC values across assessments.

3.4 Global F_{MAX}

Projections of global F_{MAX} (i.e., global MSY with steepness = 1.0) indicate that maximum yield was obtained when knife-edge selectivity occurred at age 10 and resulted in a SPR of 24% (**Figure 9**). These results match what was estimated for the 2014 SEDAR 31 Update Assessment (SEDAR 2015) and subsequent analyses (Goethel et al. 2018). The SPR corresponding to the global F_{MAX} should be considered a lower limit for sustainable spawning stock biomass, because it represents the SPR that results when maximizing yield in the absence of any relationship between spawners and recruits. Accounting for the decline in recruitment as the number of spawners decreases (i.e., including a stock-recruit relationship) would generally result in a higher equilibrium SPR if global MSY could be calculated directly (Goethel et al. 2018).However, these results generally support the use of a SPR of 26% as chosen for red snapper during the 2014 SEDAR 31 Update Assessment process.

4. Discussion

There are a number of important caveats for these projections. First, these calculations do not account for the highly variable nature of recruitment events nor the fundamental relation between adult spawners and subsequent recruits. Projections are completely deterministic and based on the assumption that future recruitment will remain constant at recent averages (i.e., steepness is approximately 1.0). Despite uncertainty about the nature of the spawner recruit relationship for red snapper, it should not be presumed that one does not exist. The constant recruitment approach for projections is not necessarily ideal because it eliminates the dependency of recruitment on spawners, which implies that recruitment never falters even at extremely low stock sizes (i.e., recruitment overfishing is not possible). Clearly, some relationship must exist between mature fish and resulting recruits (i.e., there must be spawning fish to make progeny). The constant recruitment assumption is appropriate for short-term projections where SSB is not likely to decrease rapidly, but can lead to inappropriate long-term or equilibrium projections. Therefore, the current projections must be interpreted carefully due to the strong assumptions that were made, and should not be used for equilibrium calculations (i.e., catch limits should be updated regularly to account for changes in recruitment dynamics).

Similarly, the benchmarks and associated stock status are calculated for the entire gulfwide stock, which ignores the regional impact on the eastern or western component of the stock complex individually. When biomass trends are viewed regionally highly disparate outlooks are projected (**Figure 10**). These results support the projections undertaken for the 2014 SEDAR 31 Update Assessment (see Appendix 3, Figure 12 in SEDAR 2015), and suggest that the western region may be responsible for much of the future rebuilding whereas the eastern region may be more susceptible to future declines (**Figure 10**). Again long-term predictions should be interpreted cautiously, but the leveling off in SSB and biomass for the eastern region predicted by the 2014 SEDAR 31 Update Projections has been generally corroborated with the SEDAR 52 assessment estimates for 2014-2016 (**Figure 10**).

The reasons for the discrepancy in regional biomass trends are well documented in SEDAR (2015) and Goethel et al. (2018) and are largely caused by the discrepancy in recruitment and removals (fishing mortality) within the eastern stock. The eastern region only receives 34% of the total recruitment during the projection period, while the time-invariant recreational closed season fishing mortality in the eastern region assumed in the projections (based on the terminal year estimate) has increased from 0.34 in the 2014 SEDAR 31 Update projections to 0.42 for the SEDAR 52 projections (see **Figure 1**). Because the eastern region is assumed to receive fewer recruits and undergoes a higher rate of discard fishing mortality, it is not surprising that the projections forecast declines in eastern region biomass. However, recruitment and mortality are more balanced in the western region, which allows the biomass to consistently increase in that region. The outcome is a gulfwide trend that more closely reflects the western trend than that in the eastern region. Although the projection assumptions (i.e., constant recruitment, constant relative fishing mortality, and constant bycatch fishing mortality) are unlikely to remain stationary in the long-term, it may be reasonable to assume that they will remain at or near recent averages during the short-term forecasts (i.e., three years) used to develop management advice.

Due to an extension of the recreational fishing season in 2017, the estimated provisional landings for 2017 (15.36 million pounds) exceeded both the ABC (13.74 million pounds) and OFL (14.79 million pounds) for Gulf of Mexico red snapper as calculated based on the 2014 SEDAR 31 Update Assessment. However, based on the SEDAR 52 reference point projections, overfishing did not occur in 2017 ($F_{2017} / F_{MFMT} = 0.93$; $Yield_{2017} / OFL_{Ref\ Pts} = 0.74$). The reason for the discrepancy was again based on the large estimated 2015 yearclass and the difference between projected and realized removals in 2015 and 2016. In the interim years between the assessments (i.e., 2015-2016), the projected recruitment assumed in the 2014 SEDAR 31 Update projections was much lower than estimated in SEDAR 52 assessment, whereas the projected removals were much higher than realized (**Figure 8**). Therefore, in 2017 the gulfwide red snapper resource had rebuilt to a higher biomass and SPR than projected by the 2014 SEDAR 31 Update Assessment, which allowed it to undergo larger removals (i.e., a higher fishing pressure) without any major negative impacts to the rebuilding schedule. Although the result is beneficial for the future status of the red snapper resource, it cannot be expected that projections will always underestimate rebuilding success. It is possible that future recruitment may be below average, which, in combination with higher than predicted removals, would result in overestimation of rebuilding progress.

Overall, the SEDAR 52 model corroborated and agreed with many of the estimates and projections from the 2014 SEDAR 31 Update Assessment. The Gulf of Mexico red snapper resource continues to rebuild from severely overfished and depleted conditions during the 1980s and 1990s. Under current conditions, it is expected that the resource will continue to rebuild. However, projections demonstrate opposing trends in regional population sizes with the eastern region expected to stagnate, while the western region continues to rebuild. These outcomes may simply be the result of imperfect projection assumptions, but the eastern region may warrant careful monitoring over time.

5. Acknowledgements

The SEDAR 52 assessment would not have been possible without the efforts of the numerous SEFSC, SERO, and GMFMC staff along with the many academic and research partners involved throughout the Gulf of Mexico. In particular, those who helped compile the documents and input data sets including: Julie Neer (SEDAR Coordinator); Ryan Rindone (Management History); Refik Orhun and Beth Wrege (Commercial Catch); Vivian Matter and Kelly Fitzpatrick

(Recreational Catch and Discards); Kevin McCarthy (Commercial discards); Adyan Rios and Skyler Sagarese (Recreational CPUE); Robert Allman, Gary Fitzhugh, and Linda Lombardi-Carlson (Life History); Adam Pollack, Walter Ingram, Kevin Thompson, Matt Campbell, David Hanisko, Sean Powers, John Walter, and Mandy Karnauskas (Fishery Independent Indices); Rick Hart and Jeff Isely (Shrimp bycatch); Ching-Ping Chih (Size and Age composition); Matthew Campbell and Beverly Sauls (Discard mortality); Dominique Lazarre (Headboat Discard Length Frequency); and Elizabeth Scott-Denton (Shrimp Bycatch Length Frequency).

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7. Tables

Table 1. Summary of projection settings and equations. Citations to Tables and Figures refer to those in the SEDAR 52 stock assessment report (SEDAR 2018).

Derived quantity	Equation	Parameter values
Recruitment (R)	$R_{Reg,Year} = P_{Area}\dfrac{4hR_0SSB_{Year}}{SSB_0(1-h)+SSB_{Year}(5h-1)}$	P_{East} = 0.23, P_{West} = 0.77, h = 0.99, R_0 = 163 million fish
Growth Curve	$L(t) = L_\infty\left[1-e^{-k(t-t_0)}\right]$	L_∞ = 85.64cm, k = 0.19yr^{-1}, t_0 = -0.39, See **Figure 2.4**
Weight-Length Relationship	$Weight = aL^b$	a = 1.7E-5, b = 3, See **Figure 2.5**
Fecundity-at-Age (Fec)	Input	See **Table 2.3**
Selectivity (S)	Input	See **Figure 4.9**
Retention (Ret)	Input	See **Figure 4.13**
Discard Mortality (DM)	Input	See **Table 2.2**
Natural Mortality (M)	Input	See **Table 2.1**
Directed Fishing Mortality (F_{Dir}) by Fleet	$F^{Fleet}_{Dir,Reg,Age,Year} = S^{Fleet}_{Dir,Reg,Age}F^{Fleet}_{Dir\_Mult,Reg,year}Ret^{Fleet}_{Dir,Reg,Age}$	Directed Fleets are HL, LL, HBT, and MRIP
Directed Discard Fishing Mortality (F_{Disc}) by Fleet	$F^{Fleet}_{Disc,Reg,Age,Year} = F^{Fleet}_{Dir\_Mult,Reg,year}(1-Ret^{Fleet}_{Dir,Reg,Age})\ DM^{Fleet}_{Dir}$	Fishing mortality due to open season discards for a directed fleet
Total Directed Fishing Mortality (F_{Tot_Dir}) by Fleet	$F^{Fleet}_{Tot\_Dir,Reg,Age,Year} = F^{Fleet}_{Dir,Reg,Age,Year} + F^{Fleet}_{Disc,Reg,Age,Year}$	Total fishing mortality for a directed fleet
Bycatch/Closed Season Discard Fishing Mortality (F_{Byc}) by Fleet	$F^{Fleet}_{Byc,Reg,Age,Year} = S^{Fleet}_{Byc,Reg,Age}F^{Fleet}_{Byc\_Mult,Reg,year}$	Bycatch and Closed Season Discard Fleets are C_No_IFQ, R_Closed, and SHR
Total Fishing Mortality (F_{Tot})	$F_{Tot,Reg,Age,Year} = \sum_{Fleet} F^{Fleet}_{Tot\_Dir,Reg,Age,Year} + F^{Fleet}_{Byc,Reg,Age,Year}$	Total Fishing Mortality Summed Across All Fleets
Total Mortality (Z)	$Z_{Reg,Age,Year} = F_{Tot,Reg,Age,Year} + M_{Age}$	Total Mortality Summed Across All Fleets
Abundance-at-Age (N)	$N_{Reg,Age+1,Year+1} = N_{Reg,Age,Year}e^{-Z_{Reg,Age,Year}}$	Total Abundance by Region
Spawning Stock Biomass (SSB)	$SSB_{Year} = \sum_{Reg}\sum_{Age=0}^{20}(Fec_{Age}N_{Reg,Age,Year}e^{-0.5Z_{Reg,Age,Year}})$	Note that Mortality is Discounted for Midyear Spawning
Retained Catch-at-Age (C) by Fleet	$C^{Fleet}_{Dir,Reg,Age,Year} = N_{Reg,Age,Year}(1-e^{-Z_{Reg,Age,Year}})\dfrac{F^{Fleet}_{Dir,Reg,Age,Year}}{Z_{Reg,Age,Year}}$	Retained Catch for a Directed Fleet
Retained Yield (Y) by Fleet	$Y^{Fleet}_{Dir,Reg,Year} = \sum_{Age=0}^{20}\overline{W^{Fleet}_{Age}}C^{Fleet}_{Dir,Reg,Age,Year}$	See SS3 Manual (Methot 2015) for a Complete Description of the Length Integrated Fleet-Specific Weight-at-Age (W)
Spawning Potential Ratio (SPR)	$SPR = \dfrac{\frac{SSB}{R}}{\frac{SSB_0}{R_0}}$	SSB_0 = 4.72E+15 eggs

Table 2. Summary of MSRA benchmarks and reference points for the SEDAR 52 Gulf of Mexico red snapper assessment. Stock status is provided relative to both the current and old definitions of MSST. SSB is in number of eggs, whereas F is a harvest rate (total numbers killed / total numbers)

Criteria	Definition	2014 SEDAR 31 Update	SEDAR 52
Base M	Average M for Fully Selected Ages	0.09	0.09
Steepness	SR Parameter (h)	0.99	0.99
Virgin Recruitment	SR Parameter (R_0)	1.70E+08	1.63E+08
SSB Unfished (Eggs)		4.91E+15	4.72E+15
Generation Time	Fecundity-Weighted Mean Age	15	15
SPR target		0.26	0.26
	Mortality Rate Criteria		
F_{MSY} or Proxy	$F_{SPR26\%}$	0.0494	0.0588
MFMT	$F_{SPR26\%}$	0.0494	0.0588
F_{OY}	0.75 * Directed F at $F_{SPR26\%}$	0.0472	0.0564
$F_{Current}$	Average F Over Terminal 3 Years of Assessment	0.0491	0.0484
$F_{Current}$/MFMT		0.994	0.823
	Biomass Criteria		
SSB_{MSY} or Proxy	$SSB_{SPR26\%}$	1.28E+15	1.23E+15
$MSST_{OLD}$	(1-M) * $SSB_{SPR26\%}$	1.16E+15	1.12E+15
$MSST_{NEW}$	0.5 * $SSB_{SPR26\%}$	6.40E+14	6.15E+14
SSB_0	Virgin SSB	4.91E+15	4.72E+15
$SSB_{Current}$	Terminal Year SSB	6.90E+14	8.67E+14
$SSB_{Current}/SSB_{FSPR26\%}$		0.54	0.70
$SSB_{Current}/MSST_{OLD}$		0.59	0.77
$SSB_{Current}/MSST_{NEW}$		1.08	1.41
$SSB_{Current}/SSB_0$		0.14	0.18

Table 3. Results of projections at $F_{Rebuild}$ assuming 2017 provisional landings and 2018 ACLs. Recruitment is in numbers of age-0 fish, SSB is in number of eggs, F is the harvest rate (total numbers killed / total number), and yield and ABC are in millions of pounds. The ABC was calculated assuming a probability of overfishing (P*) of 0.40 (i.e., the 40^{th} percentile of the PDF of the yield in retained catch at $F_{Rebuild}$). Reference points are provided in **Table 2**. Due to uncertainty in forecasted recruitment, results are only shown for the rebuilding period (i.e., until 2032).

Year	Recruitment	F	F/MFMT	SSB	$SSB/SSB_{SPR26\%}$	$SSB/MSST_{OLD}$	$SSB/MSST_{NEW}$	SSB/SSB_0	Yield	ABC
2017	1.62E+08	0.055	0.93	9.32E+14	0.76	0.83	1.52	0.20	15.4	--
2018	1.62E+08	0.053	0.89	9.86E+14	0.80	0.88	1.60	0.21	13.7	--
2019	1.62E+08	0.054	0.91	1.05E+15	0.85	0.94	1.70	0.22	16.2	16.0
2020	1.62E+08	0.053	0.90	1.08E+15	0.88	0.97	1.76	0.23	15.2	15.0
2021	1.62E+08	0.053	0.89	1.11E+15	0.90	0.99	1.81	0.24	14.4	14.3
2022	1.62E+08	0.052	0.89	1.14E+15	0.92	1.01	1.85	0.24	13.9	13.8
2023	1.62E+08	0.052	0.89	1.15E+15	0.94	1.03	1.88	0.24	13.6	13.4
2024	1.62E+08	0.052	0.89	1.17E+15	0.95	1.04	1.90	0.25	13.4	13.2
2025	1.62E+08	0.052	0.89	1.18E+15	0.96	1.06	1.92	0.25	13.3	13.1
2026	1.62E+08	0.052	0.89	1.19E+15	0.97	1.06	1.94	0.25	13.2	13.0
2027	1.62E+08	0.052	0.89	1.20E+15	0.97	1.07	1.95	0.25	13.2	13.0
2028	1.62E+08	0.052	0.89	1.20E+15	0.98	1.08	1.96	0.26	13.2	13.0
2029	1.62E+08	0.052	0.89	1.21E+15	0.98	1.08	1.97	0.26	13.2	13.0
2030	1.62E+08	0.052	0.89	1.21E+15	0.99	1.08	1.97	0.26	13.2	13.0
2031	1.62E+08	0.052	0.89	1.22E+15	0.99	1.09	1.98	0.26	13.2	13.0
2032	1.62E+08	0.052	0.89	1.22E+15	1.00	1.09	1.98	0.26	13.2	13.0

Table 4. OFL and ABC (in million pounds whole weight) as recommended by the Gulf of Mexico SSC and calculated assuming 2017 provisional landings of 15.36 million pounds and a fully utilized 2018 ACL of 13.74 million pounds.

Year	OFL	ABC
2019	16.6	16.0
2020	15.4	15.0
2021	14.6	14.3

8. Figures

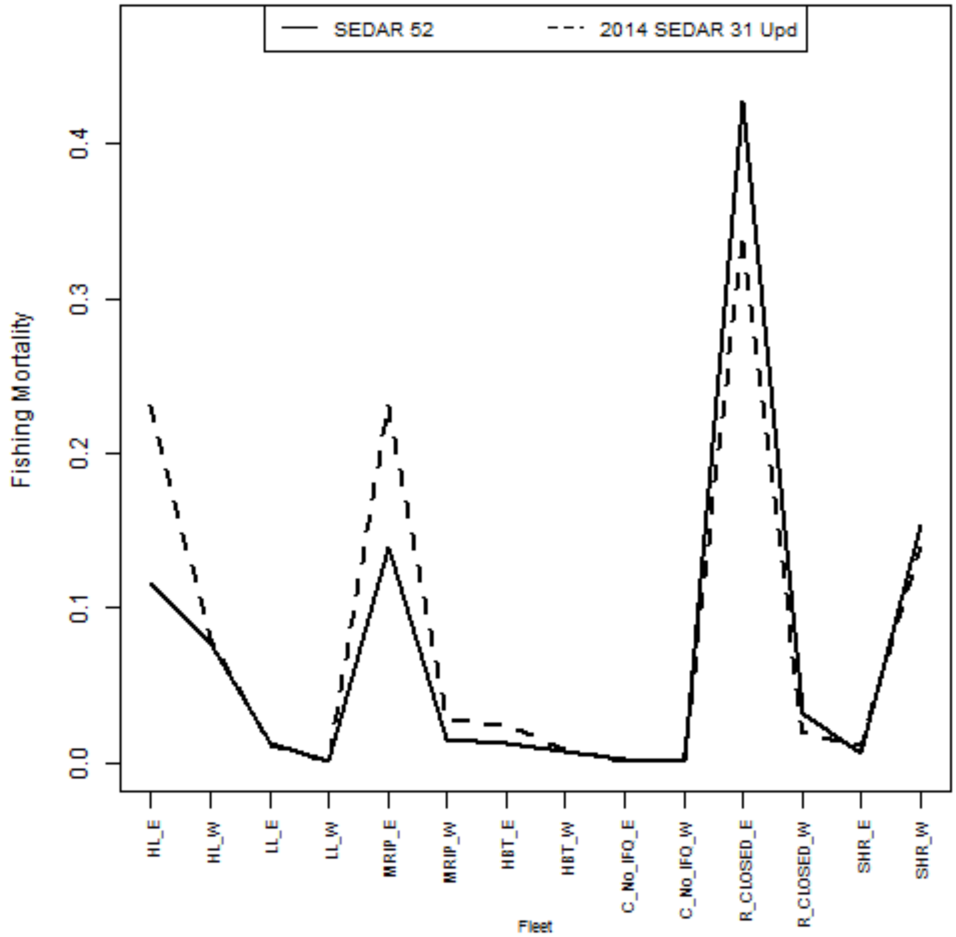

Figure 1. The terminal year fishing mortalities used in the projections for the SEDAR 52 Base Model (solid line) and the 2014 SEDAR 31 Update Assessment (dashed line). The directed fleet fishing mortalities represent three year averages from the terminal three years of the associated assessment model. The projections assume the directed fleet fishing mortalities are held in a constant proportion based on these values, whereas the bycatch and discard fleet fishing mortalties are fixed at the levels shown here for every year of the projection.

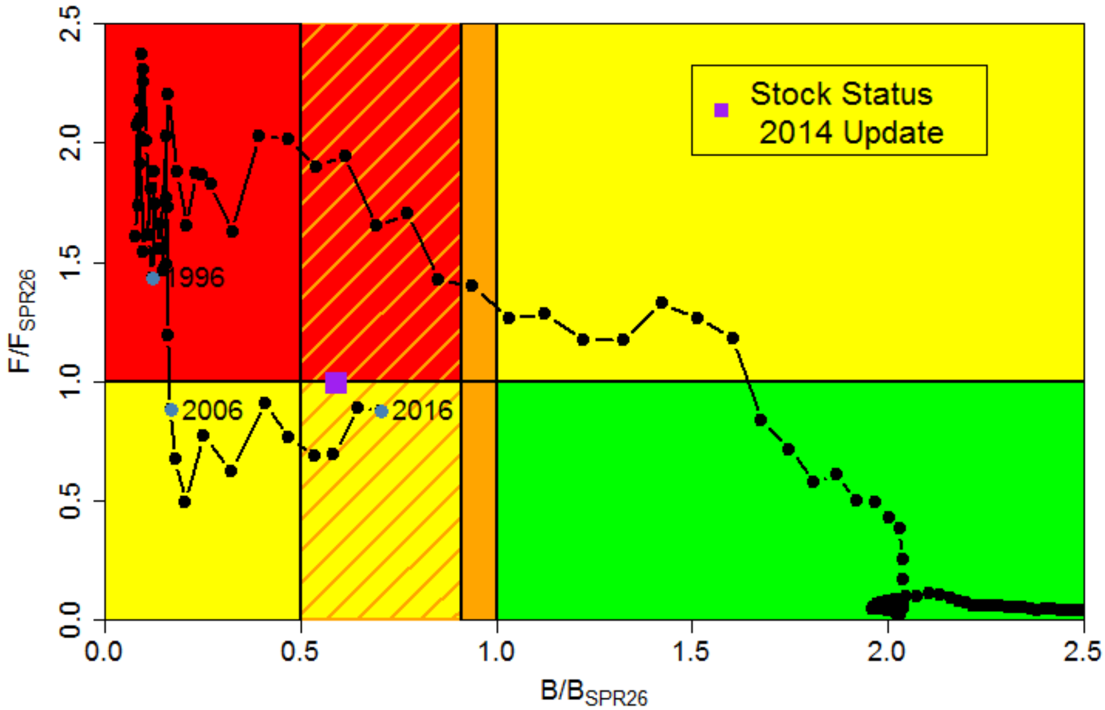

Figure 2. Kobe plot illustrating the timeseries of stock status for the the SEDAR 52 Base Model. The orange coloring indicates the region where the stock is below the biomass target ($SSB_{SPR26\%}$), but above the old biomass threshold ($MSST_{OLD}$). The orange striped region represents the region where the stock is below the biomass target ($SSB_{SPR26\%}$), but above the current biomass threshold ($MSST_{NEW}$). The purple square represents the terminal year stock status estimated by the 2014 SEDAR 31 Update Assessment.

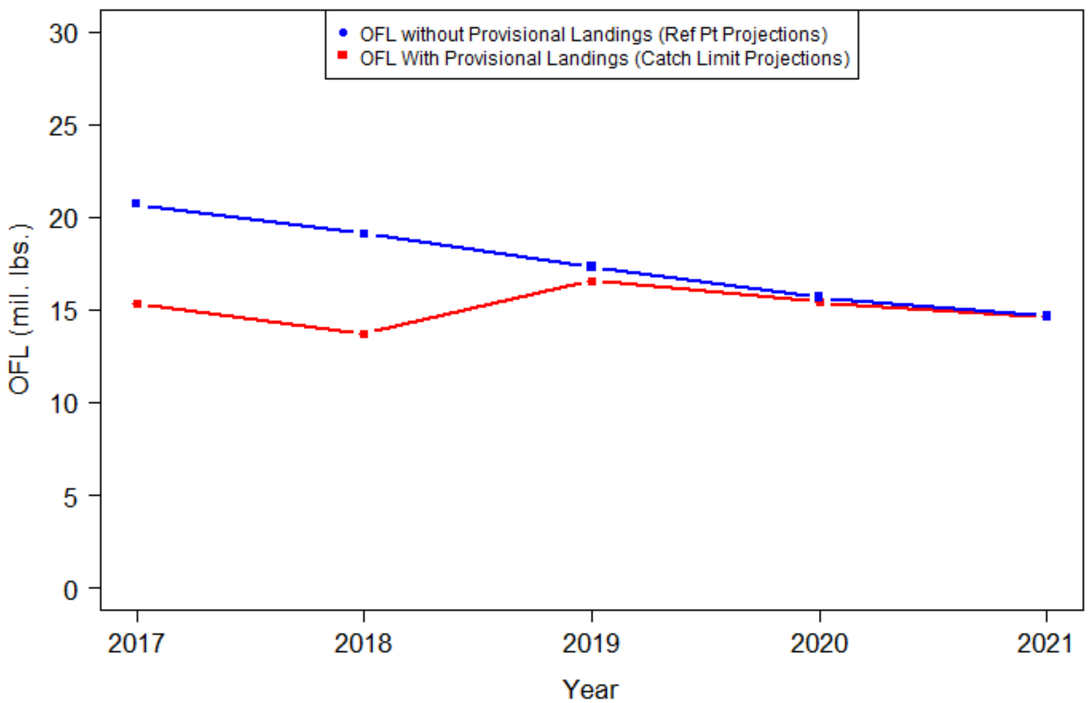

Figure 3. Overfishing limit (retained yield in millions of pounds) for reference point projections that do not account for 2017 provisional landings and 2018 ACLs (blue line) and for the final OFL values as recommended by the SSC which include 2017 provisional landings and 2018 ACLs (red line).

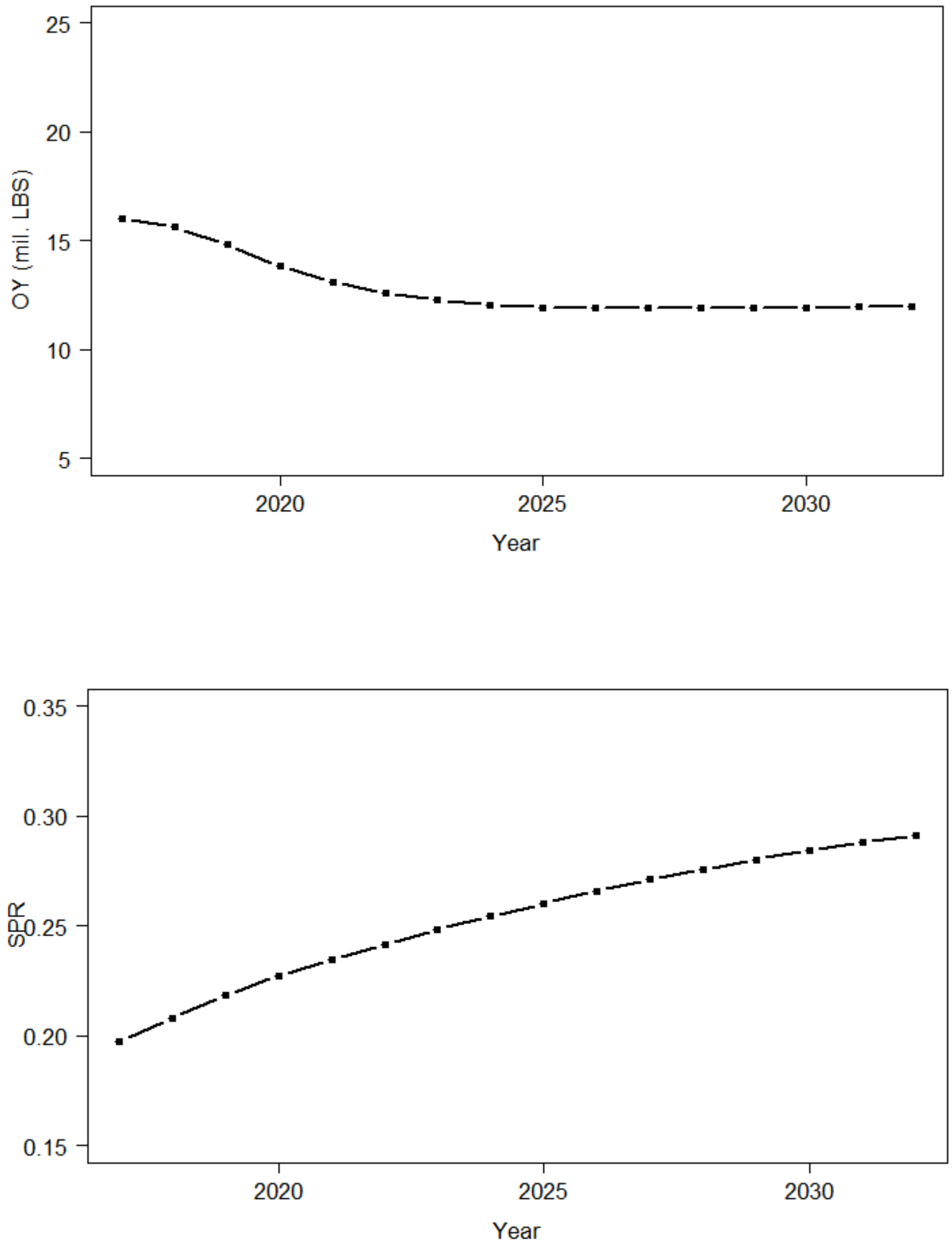

Figure 4. Yield (million pounds; Top Panel) and SPR (Bottom Panel) based on OY projections (i.e., directed fishing mortality = 0.75 * directed fishing mortality associated with $F_{SPR26\%}$) assuming recent average recruitment.

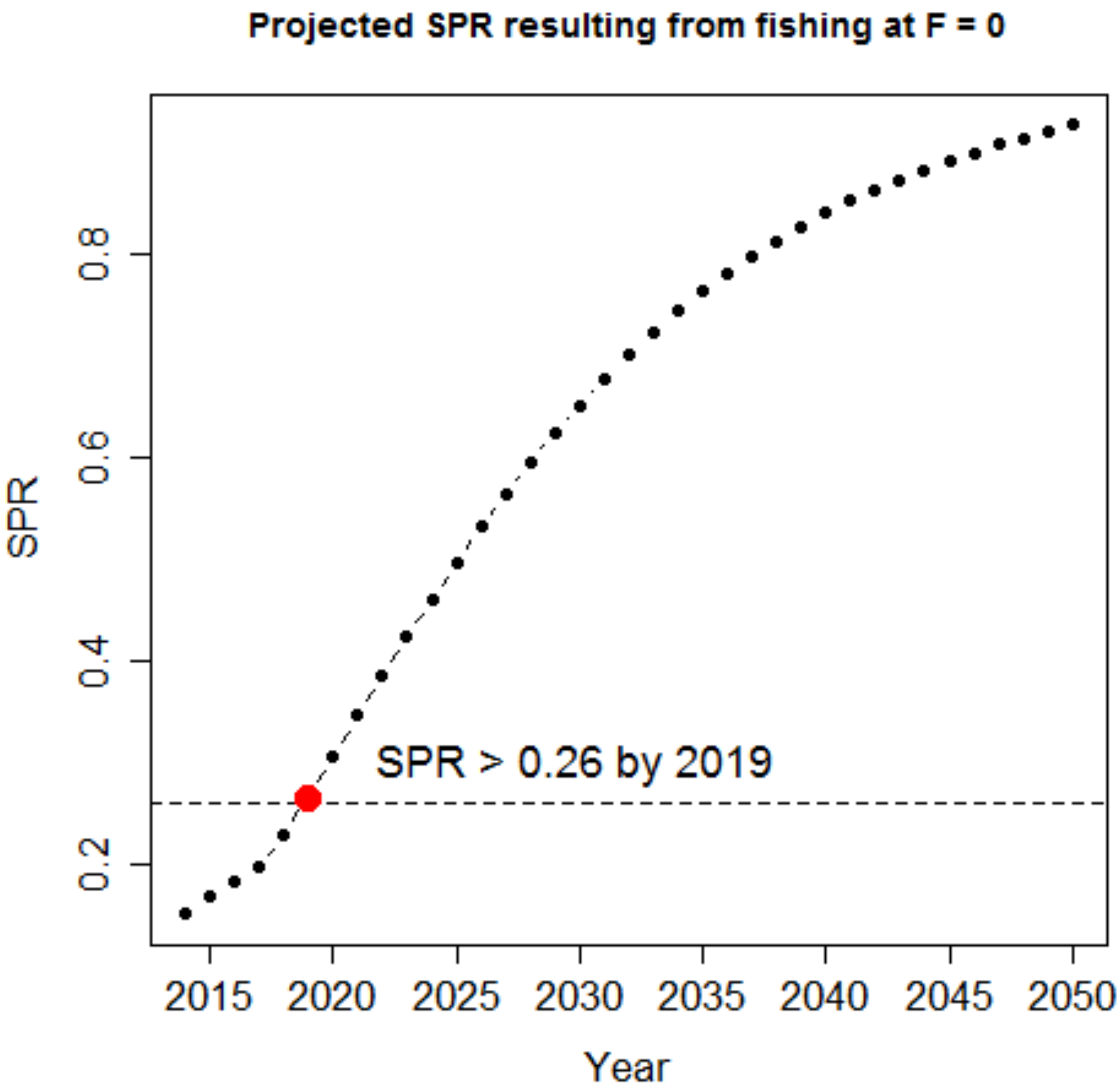

Figure 5. Timeseries of projected SPR in the absence of fishing mortality. The Gulf of Mexico red snapper resource is projected to be at the target SPR of 26% by 2019 if no fishing were to occur.

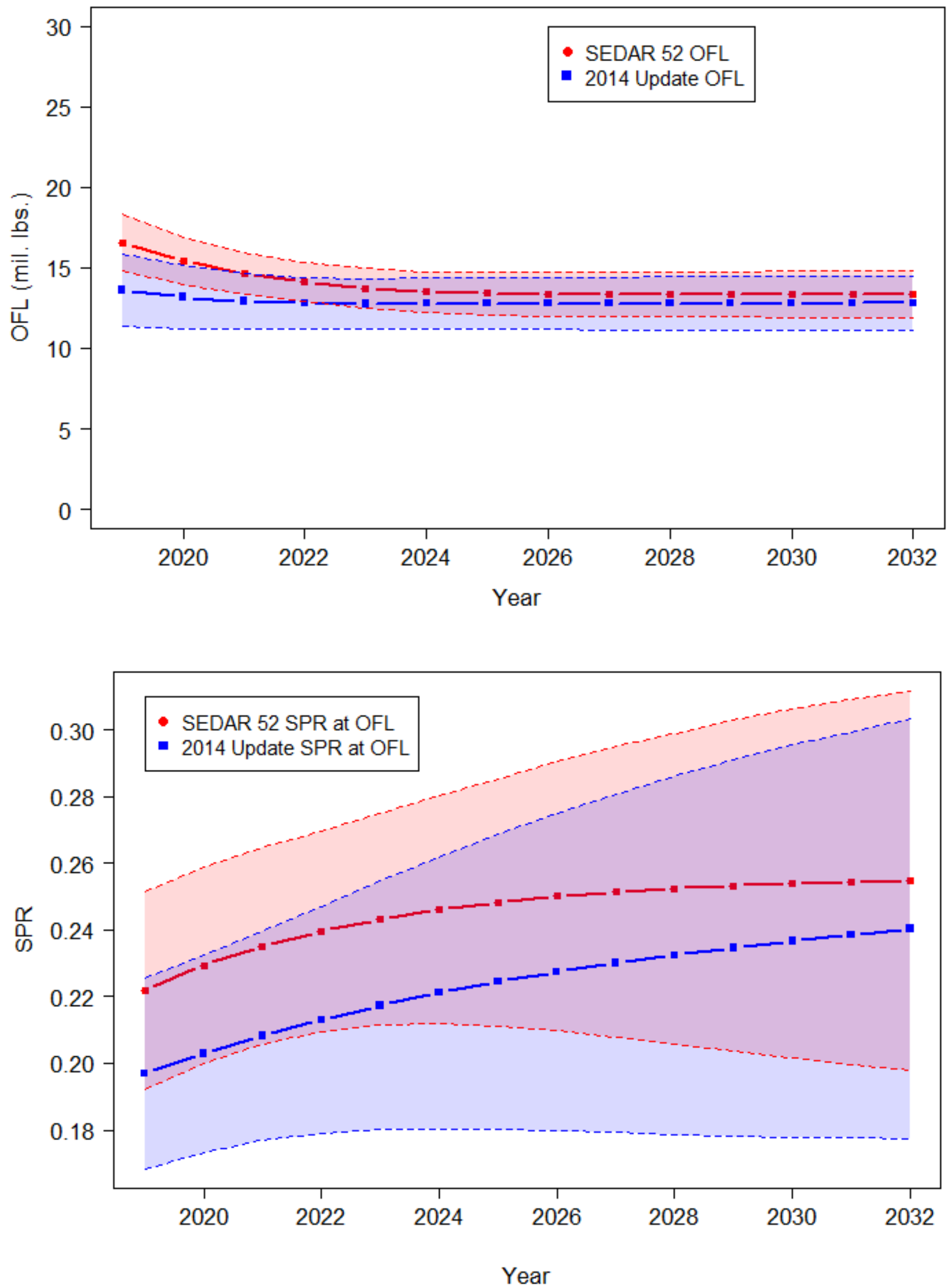

Figure 6. Overfishing limit (retained yield in millions of pounds; Top Panel) as recommended by the SSC (based on projections including 2017 provisional landings and 2018 ACLs) and resulting SPR (Bottom Panel) for projections that achieve SPR 26% in equilibrium assuming recent average recruitment. The results from the 2014 SEDAR 31 Update Assessment (blue lines) are compared with those from SEDAR 52 (red lines) with associated 95% confidence intervals (shaded regions).

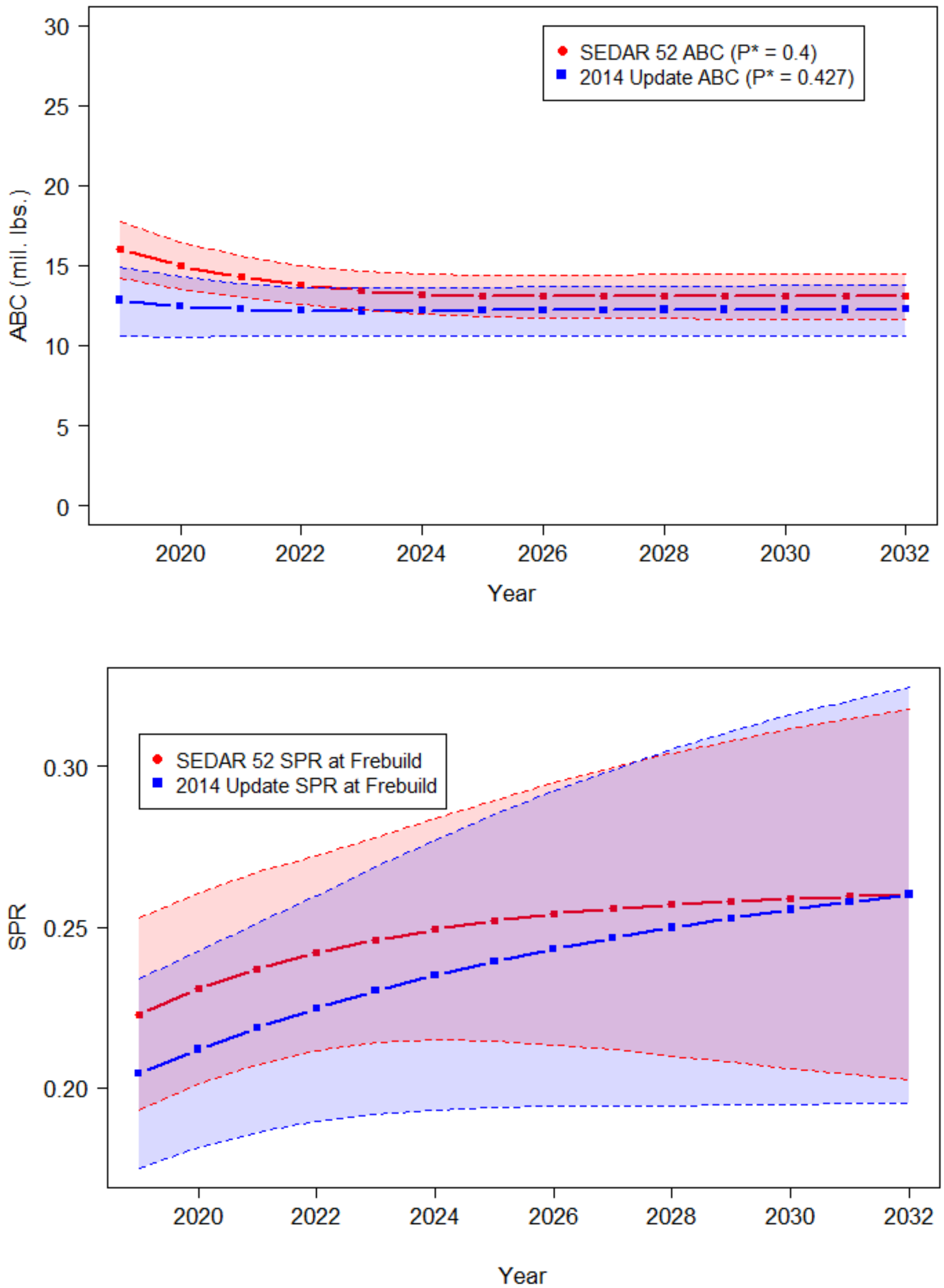

Figure 7. Acceptable biological catch (retained yield in millions of pounds; Top Panel) as recommended by the SSC (based on projections including 2017 provisional landings and 2018 ACLs and assuming a P* = 0.4) and SPR resulting from $F_{Rebuild}$ (Bottom Panel) for projections that achieve SPR 26% in 2032 assuming recent average recruitment. The results from the 2014 SEDAR 31 Update Assessment (P* = 0.427; blue lines) are compared with those from SEDAR 52 (red lines) with associated 95% confidence intervals (shaded regions).

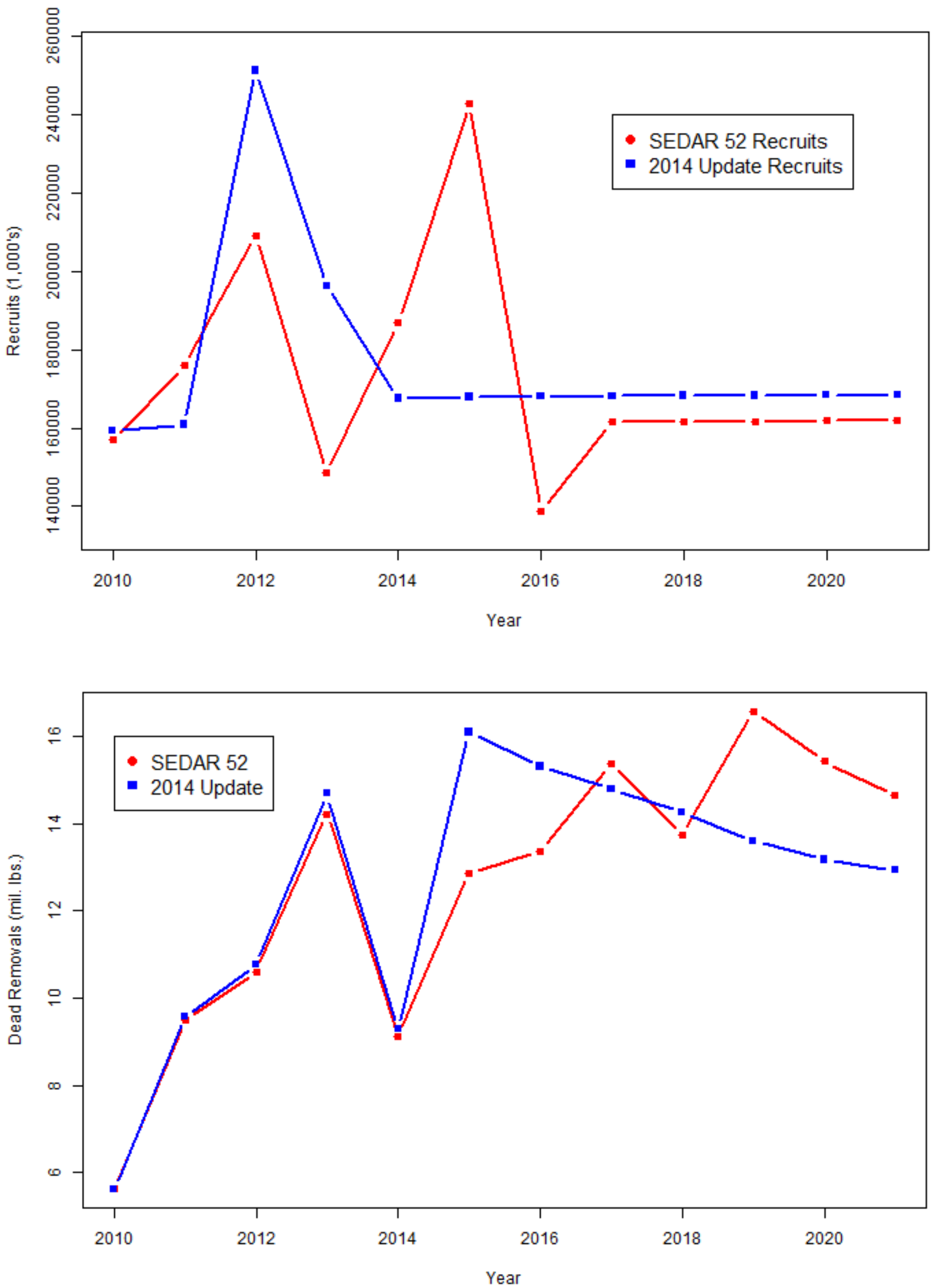

Figure 8. Recruitment (1000s of fish; Top Panel) and dead removals (millions of pounds; Bottom Panel) estimated by the assessment model then projected for OFL forecasts (assuming 2017 provisional landings and 2018 ACLs for SEDAR 52 projections). The results from the 2014 SEDAR 31 Update Assessment (assessment terminal year 2014; blue lines) are compared with those from SEDAR 52 (assessment terminal year 2016; red lines).

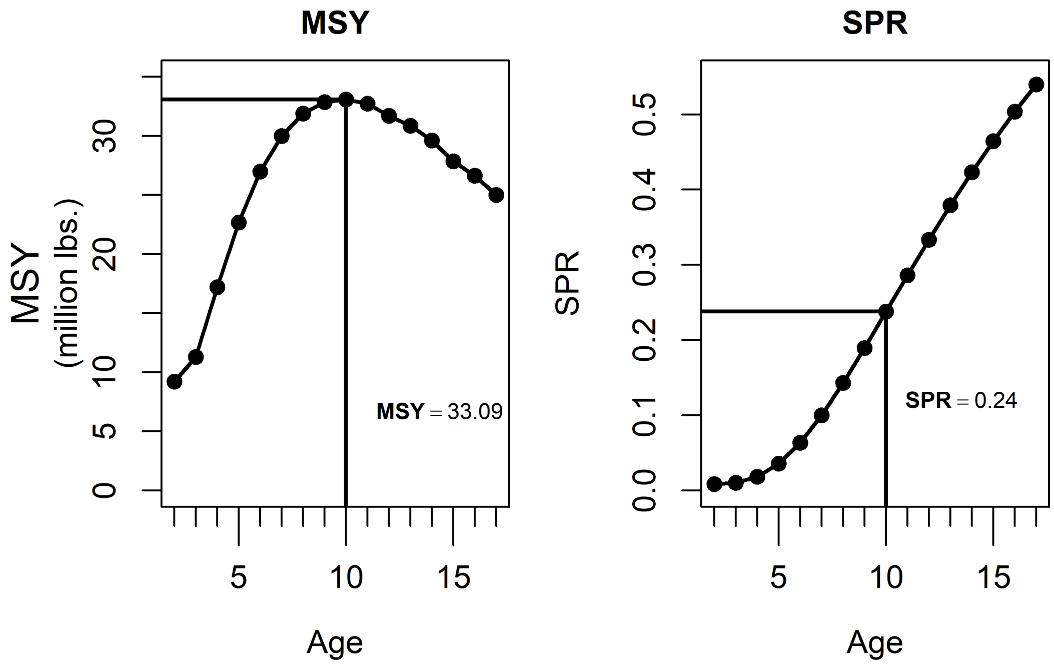

Figure 9. Results of the global YPR (i.e., global MSY with steepness = 1.0) projections assuming a single fleet with optimal knife-edge selectivity at a given age, no bycatch or discards, and near infinite fishing mortality. Projections were based on the assumption that average recent recruitment would continue in the future (i.e., steepness = 1.0). The left panel shows the yield curve, while the right panel shows the resulting SPR. The maximum yield occurs with selection by the fishery at age 10 and results in a SPR of 24%.

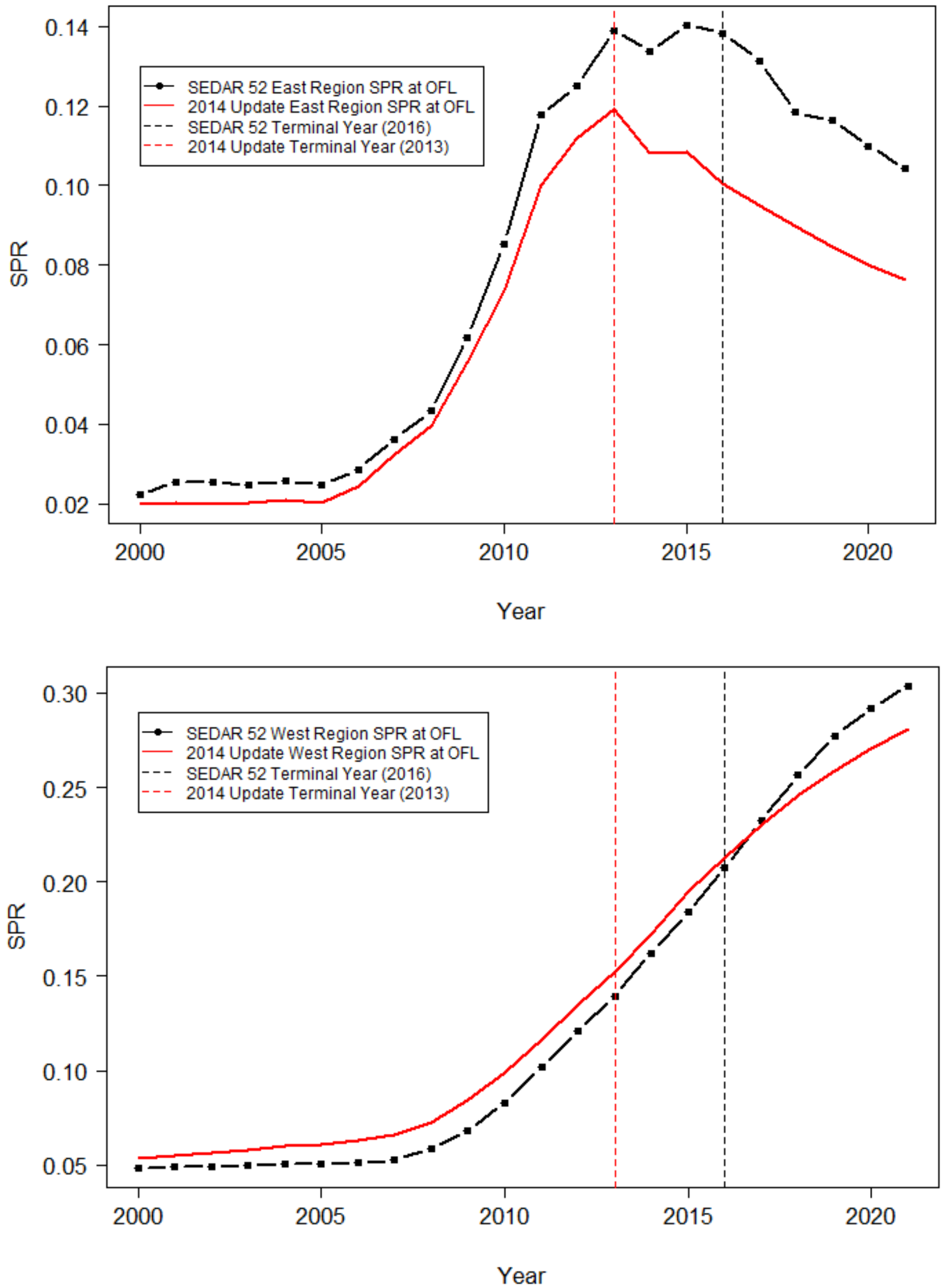

Figure 10. Estimated and projected regional SPR for the eastern (Top Panel) and western (Bottom Panel) Gulf of Mexico. Results and corresponding terminal assessment year for the 2014 SEDAR 31 Update Assessment (red lines) and SEDAR 52 Base Model (black lines) are illustrated. Results are provided for OFL projections (i.e., rebuilding to a SPR of 26% in equilibrium) where SEDAR 52 results incorporate 2017 provisional landings and 2018 ACLs.