Interim Catch Advice for the Gulf of Mexico Red Snapper Stock Derived from Estimates of Absolute Abundance Produced as Part of the Great Red Snapper Count

NMFS Southeast Fisheries Science Center
Sustainable Fisheries Division

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Summary

The Great Red Snapper Count (GRSC) estimate of absolute abundance for Gulf of Mexico Red Snapper has changed our understanding of the stock and necessitated the re-evaluation of current management advice. The Gulf-wide estimate of 110 million Red Snapper (age 2 and older) from the GRSC is about three times greater than the corresponding estimate from the latest stock assessment (SEDAR 52), which suggests the stock may be able to support more removals than previously thought. Importantly, the GRSC estimates of the number of red snapper on the high-relief natural and artificial reefs where the fishery primarily operates are very similar to the estimates from SEDAR 52. The higher total estimates from the GRSC are due to the finding that two-thirds of the red snapper population lives scattered across the vast plains of low relief bottom that characterize most of the Gulf of Mexico, where the fishery seldom operates. Catch advice would typically be updated in light of such new information via a full stock assessment; however, the urgent nature of this analysis made that impossible. Consequently, simplified spreadsheet projections were completed that use the GRSC estimate of abundance to scale projections that initially used abundance estimates from the last accepted Gulf Red Snapper stock assessment, SEDAR 52. Six projection scenarios were completed to provide a range of alternatives based on two F_{MSY} proxies ($F_{SPR26\%}$ and $F_{SPR40\%}$) and three subsets of the GRSC absolute abundance estimate. When projections were completed using all 110 million fish across all habitats in the Gulf, catch advice ranged from 45 – 55 million pounds depending on the F_{MSY} proxy. Using the GRSC estimates for fish over structure (artificial reef, natural reef, and pipeline) resulted in catch advice that ranged from 17 – 21 million pounds depending on the F_{MSY} proxy.

Introduction

The Great Red Snapper Count (Stunz et al. 2021) was an unprecedented study undertaken to improve the collective understanding of Red Snapper, one of the Gulf of Mexico's most important fish species. The GRSC provides numerous insights into the distribution, abundance, exploitation, and habitat utilization of Red Snapper. Yet, despite the scope and scale of the study, many additional questions remain. Foremost in the mind of managers and members of the fishing community is to what extent the estimated increase in abundance translates into increased yield. This critically important question would normally be addressed through the stock assessment process, as it will be in the upcoming research track assessment of Red Snapper, SEDAR 74. Unfortunately, the research track assessment is in the early stages, and the results will likely not be available until late 2022 or early 2023. Consequently, the Gulf of Mexico Fisheries Management Council ("Council") requested that the National Marine Fisheries Service Southeast Fisheries Science Center ("Center") conduct an interim assessment in order to provide catch advice that incorporates the results of the GRSC prior to the completion of SEDAR 74.

Based on the results of SEDAR 52 (SEDAR 2018), the most recent Gulf Red Snapper stock assessment, the acceptable biological catch ("ABC") for Gulf of Mexico Red Snapper was set at 15.1 million pounds whole weight. The ABC was derived from projections of $F_{REBUILD}$ (the fishing mortality rate that is projected to rebuild the stock to a 26% spawning potential ratio ("SPR") by 2032) on an estimated abundance of 41 million age 2+ fish. The overfishing limit ("OFL") for the stock was set at 15.5 million pounds and was derived from an equilibrium projection of $F_{SPR26\%}$ of the estimated abundance in SEDAR 52. The Red Snapper stock assessment is a two area model with an east and west sub-region separated by the Mississippi River outflow. The projections, and the fleet-specific fishing mortality rates estimated therein, are also region specific and therefore dependent on the estimated abundance in each region. One of the many intriguing results from the GRSC was the nearly even split of abundance in numbers of age 2+ fish by region (~53% east and ~47% west). This result differs from the SEDAR 52 estimates which place about 68% of the age 2+ abundance in the west and the remaining 32 % in the east. This discrepancy in regional abundance between SEDAR 52 and the GRSC, as well as the magnitude of the abundance estimate from the GRSC, meant that the fishing mortality rates estimated in SEDAR 52 could not be directly applied to the GRSC estimate of abundance to produce updated catch advice. Therefore, spreadsheet projections were undertaken in order to utilize the information in SEDAR 52 (relative fishing mortality rates, fleet selectivities, and compositions), but scale the catch advice using the abundance and distribution of fish estimated by the GRSC. In the absence of an updated assessment model that fully integrates the results of the GRSC, the scaled relative fishing mortality rates derived in this analysis are thought to provide the best approach possible for providing interim catch advice in a short timeline with GRSC data for the Gulf of Mexico Red Snapper stock.

Methods

Projections based on an updated stock assessment model that integrated the GRSC results could not be completed as part of this interim assessment process. Therefore, interim catch advice was produced using spreadsheet projections based on some of the results of SEDAR 52 and the GRSC estimate of total abundance. SEDAR 52 was used to define the life history relationships (e.g., natural mortality-at-age, fecundity and maturity-at-age, and mean weight-at-age),

age-compositions, and the fleet-specific selectivity and retention functions (**Table 1**). The fleet-specific equilibrium instantaneous Fs ("harvest rates") estimated from the SEDAR 52 projection of $F_{SPR26\%}$ were used to establish the relative harvest rates of the directed fleets (commercial handline and longline and recreational private/charter and headboat) and the absolute harvest rates of the discard and bycatch fleets (commercial and recreational closed season/no IFQ discards and shrimp bycatch; **Table 2**).

Three different subsets of the GRSC absolute abundance estimate were used to produce catch advice (Grand Total, All Structure, and All Structure +; **Table 3**). The Grand Total subset used all fish estimated in the GRSC report (109,927,229). The All Structure subset only used fish estimated over high-relief natural reefs, artificial reefs, and pipelines (41,990,061). The All Structure + subset used all fish in the All Structure subset plus 15% of the fish estimated over the uncharacterized bottom (52,180,636). The subsetting was done in an attempt to mimic the current distribution of the fisheries. Other All Structure+ subset values may be run as data are provided about the extent to which the uncharacterized bottom habitat can be used or accessed by the fleets. Projections were completed using the spatial structure of SEDAR 52 (2 areas, east and west Gulf divided at the Mississippi River outflow). Therefore, prior to projections all abundance estimate subsets were further divided into eastern (FL, AL, and MS) and western (TX and LA) components (**Table 3**). Since the GRSC did not provide direct estimates of age-composition, the area-specific estimates of age 2+ fish were tabulated into numbers-at-age using the age composition information from SEDAR 52. The SEDAR 52 age composition from 2016 (terminal data year of the assessment) was used to calculate area-specific age frequency distributions ("AFD") for age 2+ red snapper (**Table 4a**). Then for each projection scenario, numbers-at-age by area was calculated by multiplying the area-specific AFDs by the various subsets of GRSC estimated age 2+ fish (**Table 4b**).

Six different projection scenarios were run using combinations of the three subsets of abundance and two F_{MSY} proxies ($F_{SPR26\%}$ and $F_{SPR40\%}$). Fleet-specific harvest rates and selectivity/retention functions were used in all projections and derived from estimates produced in SEDAR 52. The relative harvest rates of the directed fishing fleets were used as the starting conditions in the projections and then adjusted to achieve a desired SPR target (26% or 40%) in equilibrium. The SEDAR 52 estimates of the absolute harvest rates for the discard and bycatch fleets were fixed throughout the projections. Recruitment was fixed and set equal to the number of age 2 fish estimated for each GRSC abundance subset scenario (**Table 4b**). In order for the projections to converge on an SPR target, an estimate of virgin spawning stock biomass ("SSB0") was required. SSB0 was estimated by dividing 2019 SSB (calculated from the 2019 GRSC numbers-at-age and the SEDAR 52 age-specific maturity and fecundity functions) by the estimated 2019 SPR from SEDAR 52 (0.207).

Results

Yield recommendations varied based on the subset of GRSC abundance used and reference point assumed ($F_{SPR26\%}$ or $F_{SPR40\%;}$ **Table 5**). The largest yield was obtained using all the GRSC fish (Grand Total) and projecting at $F_{SPR26\%}$ which produced a yield estimate of 54.79 million pounds whole weight in 2021. This represents a 263% increase over the current ABC of 15.1 million pounds and roughly 253% increase over the current OFL of 15.5 million pounds. Subsetting the GRSC abundance estimate to those fish occurring over structure and those occurring over structure plus 15% of the uncharacterized bottom reduced the resulting catch advice. When utilizing the estimate of the fish occurring over structure (All Structure) the catch advice for 2021 is 21.4 million pounds and 16.24 million pounds when projections were done using $F_{SPR26\%}$ and $F_{SPR40\%}$ respectively. Using the fish over structure and an additional 15% of the fish over uncharacterized bottom (All Structure +) resulted in catch advice for 2021 of 26.11 million pounds and 20.81 million pounds when projections were done using $F_{SPR26\%}$ and $F_{SPR40\%}$ respectively. Comparisons of the 5 year average ('21-'25) yield from the four All Structure and All Structure + scenarios to the current ABC showed that adoption of the GRSC adjusted yields would represent an increase of between 15% (All Structure, $F_{SPR40\%}$) and 73% (All Structure +, $F_{SPR26\%}$) over existing catch recommendations (**Table 5**).

Discussion

The GRSC represents an unprecedented, collaborative effort to estimate the absolute abundance of Red Snapper age 2+ over their entire range in the Gulf of Mexico. The results of the GRSC have provided invaluable insight into the distribution, abundance, and habitat utilization of Red Snapper, but have also raised a number of critical questions for the interpretation of the science and the execution of management. A key topic in need of further study is our understanding of the connectivity and mixing of the age classes of the stock, particularly the recruits. Models of larval distribution and stock connectivity have been developed for the Gulf of Mexico Red Snapper stock (Karnauskas et al. 2017a and 2017b). Updated runs of these models produced for the Red Snapper research track confirm the previous result that many portions of the Red Snapper stock rely largely on self-recruitment to sustain local abundance (**Figure 1**). Going forward, connectivity models, similar to Karnauskas et al. can be refined to account for the distribution of biomass estimated by the GRSC across the various habitat types. Equally important is the need to better understand the immigration and emigration rates of adult biomass from the uncharacterized habitat to the structured habitats. A substantial body of work exists on the movement rates of Red Snapper over reefs (e.g., Diamond et. al. 2007, Patterson et al. 2001, Szedlmayer and Shipp 1994, Topping and Szedlmayer 2011); however, little information is yet known about the population living on the vast uncharacterized bottom likely due to the difficulty of conducting tagging study experiments over a widely distributed, low density population. Quantifying the rates at which the different components of the Red Snapper population mix through recruitment and immigration/emigration, are key to understanding how much additional fishing pressure can be sustained without negatively impacting the fisheries.

There is a limit to the sustainable harvest of Red Snapper in the Gulf of Mexico and all habitat cannot be accessed equally by all fleets. The history of the stock demonstrates that abundance, specifically abundance on the fishing grounds, can be depleted to the point that it negatively affects the recreational and commercial fishing sectors (**Figure 2**). Furthermore, a depleted Red Snapper stock can negatively affect non-directed fisheries (e.g., low abundance led to effort reductions in the Gulf shrimp fishery). While it may be theoretically possible to redistribute the fishery across the entire range of red snapper so as to remove the largest catch presented in this analysis, it is unlikely that such a strategy would be acceptable to anglers owing to the general low catch rates over low-relief bottom. More likely, the fishery will continue to operate as it has and extract most of the red snapper from extant fishing grounds, which may result in localized stock depletion. Significant amounts of additional research and assessment model development will be needed before an integrated assessment model can be developed that captures all of the complex information provided, including that from the GRSC. Therefore, it is critical that at this junction we balance the need for updated management advice for an important species with the uncertainty surrounding not only the estimates obtained from the GRSC but also the dynamics and resilience of the stock reflected in other time series for this species.

As part of this interim analysis, a number of sensitivity runs were conducted using combinations of F_{MSY} proxies and subsets of the overall GRSC abundance estimate to provide a range of management alternatives. Two different fishing mortality rate reference points ($F_{SPR26\%}$ and $F_{SPR40\%}$) were projected as a proxy for F_{MSY}. $F_{SPR26\%}$ was selected since it is the current F_{MSY} proxy codified in the Red Snapper fishery management plan. $F_{SPR40\%}$ was selected to represent an alternate management paradigm for Red Snapper and warranted exploration for a number of reasons. The GRSC estimates of overall abundance and distribution suggest that the previous lack of a strong stock recruit relationship was due to the substantial unknown reproductive capacity located off the fishing grounds. If true, the GRSC results would imply that the stock may, in fact, not be as productive on a per-capita basis as previously thought. The specific value of 40% was selected based on simulation research completed by Harford et al. (2019) which demonstrated for a variety of tropical demersal stocks that F_{MSY} proxies on the order of $F_{SPR40\%}$ to $F_{SPR50\%}$ had the highest probability of achieving long-term MSY. While the current FMP specifies $F_{SPR26\%}$ as the maximum fishing mortality threshold (MFMT) for generating the OFL, we suggest that $F_{SPR40\%}$ may be a more reasonable value upon which to base ABC advice.

Catch advice was generated for two different subsets of the GRSC estimate to provide a range of options for the SSC and Council to consider when making management recommendations. The subsets were selected to represent different assumptions about the proportion of the Red Snapper population that is vulnerable to the fishery as the sectors are currently distributed. Preliminary work based on linking commercial vessel monitoring system (“VMS”) data to landings suggests that for the commercial fleet approximately 24% of Red Snapper are not exploited at all in a given year and a further 45% experience only light exploitation (**Figure 3,** Gardner et al. *In progress*). It would seem reasonable to assume that the recreational fleet would exploit a similar if not smaller proportion of the population, as they are even less likely than the commercial fleet to venture far away from shore (>40 nm). Based on these ongoing studies it seems likely that in any given year between 40-70% of the stock experiences little to no fishing pressure. Conversely, the results also suggest that between 30-60% of Red Snapper experience moderate to heavy fishing pressure. Presumably the fishing activity is most likely to be occurring over aggregating (for both fish and fishers) structures like artificial reefs or high relief natural reefs. The All Structure subset accounted for roughly 38% of the total numbers estimated by the GRSC. This represents a reasonable proxy for the lower end of the proportion of the population vulnerable to the fishery. The All Structure + subset accounted for about 47% of the numbers estimated by the GRSC and provides a reasonable proxy for average vulnerability (~ 50% of the population in any given year).

Any catch recommendations adopted from this analysis would require changes be made to both the OFL and ABC since none of the candidate ABC values presented fall below the current OFL of 15.5 million pounds. Since $F_{SPR26\%}$ is the current reference point for Gulf of Mexico Red Snapper and there is insufficient time to adjust the value before the onset of the 2021 fishing season, we assume the OFL will need to be based on projections of $F_{SPR26\%}$. Given that limitation, two possible choices emerge. Use the yield obtained from the Grand Total subset projected at $F_{SPR26\%}$ as the OFL for the entire stock or select the yield obtained using a subset of the GRSC numbers at $F_{SPR26\%}$ as an OFL for the exploited portion of the stock. Within the structure of this analysis the SSC can produce ABC advice by selecting a subset scenario, using an alternate reference point, like $F_{SPR40\%}$, applying the P* control rule, or any combination of the above. Alternate subset scenarios and reference point calculations can be completed at the request of the SSC, and it is likely the discussions during the review of the GRSC itself will prompt the SSC to request alternative subsets to what is provided here. Implementation of the P* approach requires a measure of uncertainty. This would be accomplished assuming that catch is roughly equal to exploitation rate * numbers * mean landed weight and that the exploitation rate and mean landed weight are known with negligible error. The error associated with the numbers would either be derived from the CVs estimated in the GRSC or set at a rate agreed upon by the SSC. From these assumptions and data, an estimate of error around the catch can be produced and used in the P* calculation.

The SSC will review the GRSC in the days immediately preceding their review of this document. The analyses provided here are contingent upon the results of the independent and SSC reviews of the GRSC. Any changes in abundance estimates will necessitate the revisions of this work.

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Tables.

Table 1. Life history, selectivity, and retention functions from SEDAR 52 that were used to parameterize the spreadsheet projections.

Variable	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
M	1	1.6	0.695	0.17	0.14	0.122	0.11	0.103	0.097	0.093	0.09	0.087	0.085	0.084	0.083	0.082	0.081	0.08	0.08	0.079	0.079
Fecundity*Mat (1000's of eggs)	0	0	350000	2.62E+06	9.07E+06	2.03E+07	3.47E+07	5.00E+07	6.43E+07	7.68E+07	8.72E+07	9.55E+07	1.02E+08	1.07E+08	1.11E+08	1.14E+08	1.17E+08	1.18E+08	1.20E+08	1.21E+08	1.23E+08
Commercial Retained Wt (kg)	0.028	0.395	0.695	1.124	1.756	2.491	3.244	3.969	4.640	5.242	5.773	6.233	6.626	6.958	7.238	7.470	7.663	7.821	7.951	8.057	8.255
Recreational Retained Wt. (kg)	0.028	0.477	1.028	1.378	1.896	2.555	3.272	3.981	4.645	5.244	5.774	6.233	6.626	6.958	7.238	7.470	7.663	7.821	7.951	8.057	8.255
Population Mean Weight (kg)	0.012	0.040	0.276	0.739	1.372	2.102	2.864	3.611	4.312	4.950	5.517	6.011	6.437	6.799	7.104	7.359	7.571	7.746	7.890	8.007	8.216
Selectivity by Fleet																					
HL_E	0.000	0.016	0.230	0.856	1.000	0.992	0.906	0.749	0.564	0.393	0.260	0.172	0.121	0.095	0.083	0.079	0.077	0.077	0.077	0.077	0.077
HL_W	0.000	0.001	0.077	0.670	0.999	0.995	0.855	0.602	0.355	0.188	0.103	0.070	0.060	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
LL_E	0.000	0.001	0.019	0.164	0.611	0.997	1.000	1.000	1.000	0.873	0.563	0.347	0.272	0.257	0.256	0.255	0.255	0.255	0.255	0.255	0.255
LL_W	0.000	0.002	0.010	0.035	0.097	0.222	0.423	0.675	0.899	0.999	1.000	1.000	1.000	1.000	1.000	0.983	0.926	0.833	0.709	0.562	0.400
MRIP_E	0.000	0.000	0.475	1.000	1.000	1.000	1.000	1.000	1.000	0.860	0.551	0.270	0.110	0.049	0.032	0.029	0.028	0.028	0.028	0.028	0.028
MRIP_W	0.000	0.072	0.318	0.745	1.000	1.000	0.965	0.839	0.656	0.466	0.305	0.191	0.121	0.084	0.066	0.059	0.057	0.056	0.056	0.056	0.056
HBT_E	0.000	0.005	0.113	0.675	0.999	0.999	0.941	0.804	0.626	0.447	0.297	0.189	0.120	0.082	0.063	0.055	0.052	0.051	0.050	0.050	0.050
HBT_W	0.000	0.000	0.010	0.173	0.784	1.000	0.982	0.711	0.349	0.127	0.048	0.031	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
C_Clsd_E	0.000	0.010	0.229	0.919	1.000	1.000	0.953	0.833	0.670	0.499	0.350	0.237	0.161	0.116	0.092	0.081	0.076	0.074	0.073	0.073	0.073
C_Clsd_W	0.000	0.002	0.106	0.765	1.000	0.984	0.786	0.498	0.278	0.168	0.130	0.121	0.120	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119
R_Clsd_E	0.000	0.000	0.475	1.000	1.000	1.000	1.000	1.000	1.000	0.860	0.551	0.270	0.110	0.049	0.032	0.029	0.028	0.028	0.028	0.028	0.028
R_Clsd_W	0.000	0.072	0.318	0.745	1.000	1.000	0.965	0.839	0.656	0.466	0.305	0.191	0.121	0.084	0.066	0.059	0.057	0.056	0.056	0.056	0.056
Shr_E	1.000	0.036	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Shr_W	1.000	0.062	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Retention by Fleet																					
HL_E	0.000	0.001	0.362	0.806	0.897	0.913	0.915	0.916	0.916	0.916	0.916	0.916	0.916	0.916	0.916	0.916	0.916	0.916	0.916	0.916	0.916
HL_W	0.000	0.001	0.382	0.851	0.947	0.963	0.966	0.966	0.967	0.967	0.967	0.967	0.967	0.967	0.967	0.967	0.967	0.967	0.967	0.967	0.967
LL_E	0.000	0.000	0.221	0.494	0.550	0.559	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561	0.561
LL_W	0.000	0.001	0.375	0.836	0.931	0.946	0.949	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950	0.950
MRIP_E	0.000	0.000	0.050	0.521	0.854	0.959	0.988	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
MRIP_W	0.000	0.000	0.050	0.521	0.854	0.959	0.988	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HBT_E	0.000	0.000	0.050	0.521	0.854	0.959	0.988	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
HBT_W	0.000	0.000	0.050	0.521	0.854	0.959	0.988	0.996	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
C_Clsd_E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C_Clsd_W	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R_Clsd_E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
R_Clsd_W	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Shr_E	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Shr_W	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 2. Fleet-specific apical instantaneous Fs (“harvest rates”) estimated from the SEDAR 52 projection of $F_{SPR26\%}$ were used to establish relative harvest rates of the directed fleets (commercial handline-HL, longline-LL, recreational private/charter-MRIP, and headboat-HBT) for the eastern and western Gulf of Mexico, for spreadsheet projections. Absolute harvest rates were used for the discard and bycatch fleets (commercial and recreational closed season/no IFQ discards-Clsd, and shrimp bycatch-Shr).

	HL_E	HL_W	LL_E	LL_W	MRIP_E	MRIP_W	HBT_E	HBT_W	C_Clsd_E	C_Clsd_W	R_Clsd_E	R_Clsd_W	Shr_E	Shr_W
Apical F	0.1559	0.1144	0.0146	0.0014	0.3864	0.0480	0.0306	0.0209	0.0029	0.0008	0.4277	0.0322	0.0069	0.1537
Relative F	0.2019	0.1481	0.0189	0.0018	0.5003	0.0621	0.0396	0.0271	N/A	N/A	N/A	N/A	N/A	N/A
Initial Projection F	0.2019	0.1481	0.0189	0.0018	0.5003	0.0621	0.0396	0.0271	0.0029	0.0008	0.4277	0.0322	0.0069	0.1537

Table 3. Numbers of fish (age 2+) by area (East and West Gulf of Mexico) and scenario. The SEDAR 52 values were taken from 2017, the first year of projections for that assessment. GRSC scenarios are All Structure (fish estimated over natural reef, artificial reef, and pipeline habitat), All Structure + (all fish in All Structure plus 15% of fish over uncharacterized bottom), and Grand Total (fish on all habitats estimated from GRSC). Percent east and percent west show the percentage of numbers in each area by scenario. Percent change shows the percent difference between the total numbers for each of the GRSC scenarios and the SEDAR 52 scenario.

	All Structure	**All Structure +**	**Grand Total**	**SEDAR 52**
East	22,992,851	28,287,244	58,288,803	12,941,804
West	18,997,210	23,893,392	51,638,426	28,084,409
Total	41,990,061	52,180,636	109,927,229	41,026,213
% East	0.55	0.54	0.53	0.32
% West	0.45	0.46	0.47	0.68
% Change	2.3	27.2	167.9	–

Table 4a. Area-specific age frequency distributions for age 2+ Red Snapper derived from the SEDAR 52 assessment model estimates of area-specific numbers-at-age. Compositional data from 2016 were used as it was the terminal data year in the SEDAR 52 stock assessment.

SEDAR 52 AFD	Area	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Age 2+ 2016	East	0.486	0.151	0.095	0.061	0.041	0.036	0.026	0.030	0.026	0.016	0.011	0.007	0.005	0.003	0.002	0.001	0.000	0.000	0.002
Age 2+ 2016	West	0.272	0.125	0.171	0.103	0.071	0.070	0.026	0.034	0.038	0.029	0.020	0.009	0.005	0.003	0.003	0.003	0.002	0.002	0.014

Table 4b. Area-specific numbers-at-age derived by multiplying the area-specific age frequency distributions by the estimated number of age 2+ Red Snapper calculated for each subset of the GRSC total abundance estimate. The number of age 2 Red Snapper by area and subset was used as an estimate of recruitment and fixed during projections.

GRSC Subset	Area	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
All Structure	East	11,171,774	3,483,078	2,179,733	1,399,531	941,584	824,966	602,687	686,904	604,048	379,083	260,759	161,152	112,849	59,983	47,116	23,903	7,253	10,381	36,068
All Structure	West	5,176,209	2,372,249	3,243,826	1,957,019	1,350,291	1,332,646	497,546	645,255	714,984	553,356	380,956	176,939	92,367	54,099	59,474	54,029	29,412	33,013	273,539
All Structure +	East	13,744,215	4,285,101	2,681,644	1,721,791	1,158,395	1,014,925	741,464	845,072	743,138	466,372	320,801	198,260	138,834	73,794	57,965	29,406	8,923	12,772	44,373
All Structure +	West	6,510,282	2,983,653	4,079,862	2,461,405	1,698,304	1,676,111	625,780	811,557	899,258	695,974	479,140	222,542	116,172	68,042	74,802	67,954	36,992	41,521	344,039
Grand Total	East	28,321,383	8,829,895	5,525,806	3,547,929	2,386,993	2,091,358	1,527,863	1,741,359	1,531,313	961,007	661,045	408,534	286,081	152,061	119,443	60,595	18,386	26,318	91,435
Grand Total	West	14,070,029	6,448,275	8,817,403	5,319,590	3,670,376	3,622,414	1,352,436	1,753,938	1,943,476	1,504,140	1,035,519	480,959	251,072	147,053	161,663	146,863	79,948	89,736	743,537

Table 5. Catch advice derived from projections of three subsets of the GRSC estimate of abundance and two overfishing levels ($F_{SPR26\%}$ and $F_{SPR40\%}$). Annual catch levels are presented for years 2021-2025 as are three (2021-2023) and five (2021 - 2025) year averages. % increase of 5 yr. avg. shows the percent increase in the 5 year average estimate over the current ABC level of 15.1 mp.

	All Structure		All Structure +		Grand Total	
Year	$F_{SPR26\%}$	$F_{SPR40\%}$	$F_{SPR26\%}$	$F_{SPR40\%}$	$F_{SPR26\%}$	$F_{SPR40\%}$
2021	21.40	16.24	26.11	20.81	54.79	43.60
2022	21.05	16.79	26.05	21.51	54.58	45.01
2023	21.01	17.37	26.14	22.14	54.72	46.29
2024	21.09	17.88	26.27	22.66	54.97	47.33
2025	21.21	18.30	26.37	23.01	55.17	48.06
3 yr. avg. ('21-'23)	21.15	16.80	26.10	21.49	54.69	44.96
5 yr. avg. ('21-'25)	21.15	17.32	26.19	22.03	54.85	46.06
Current ABC	15.1	15.1	15.1	15.1	15.1	15.1
% increase of 5 yr. avg.	40	15	73	46	263	205

Figures

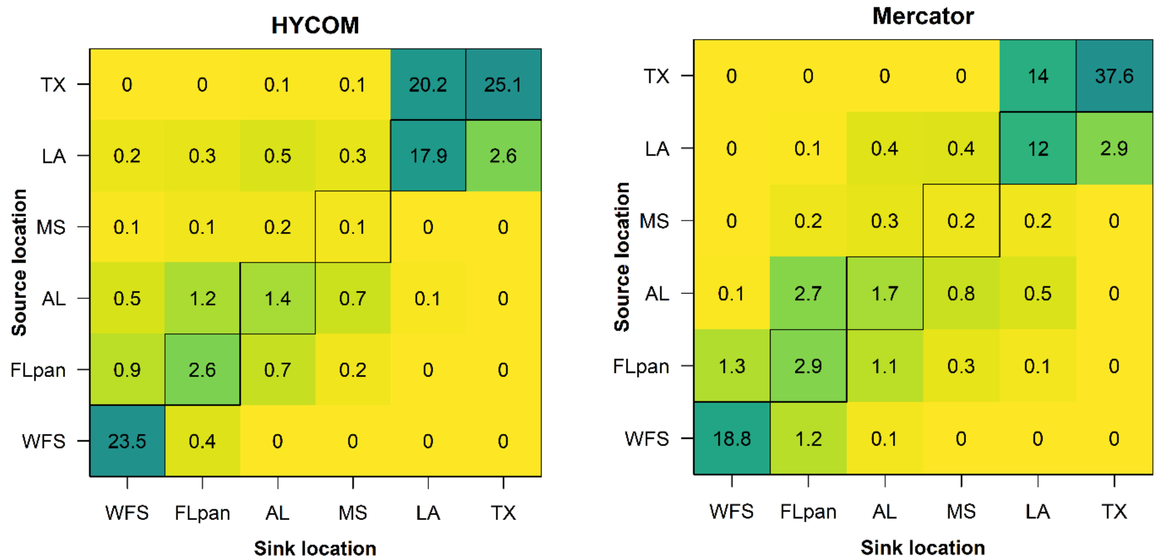

Figure 1. Connectivity matrices, summarized at the state boundary scale, for two different oceanographic models (HYCOM left; Mercator right). Source locations for each respective state appear as rows and settlement locations for each state appear as columns; the diagonal boxes outlined in black denote self-recruitment. For example, both models show that larval supply from TX to LA is much greater than supply from LA to TX. Greener shades indicate higher levels of relative recruitment; numbers in boxes are the percentage of successful recruits in each box out of the total number of successful recruits (i.e., the sum of all numbers in each respective subplot is 100%).

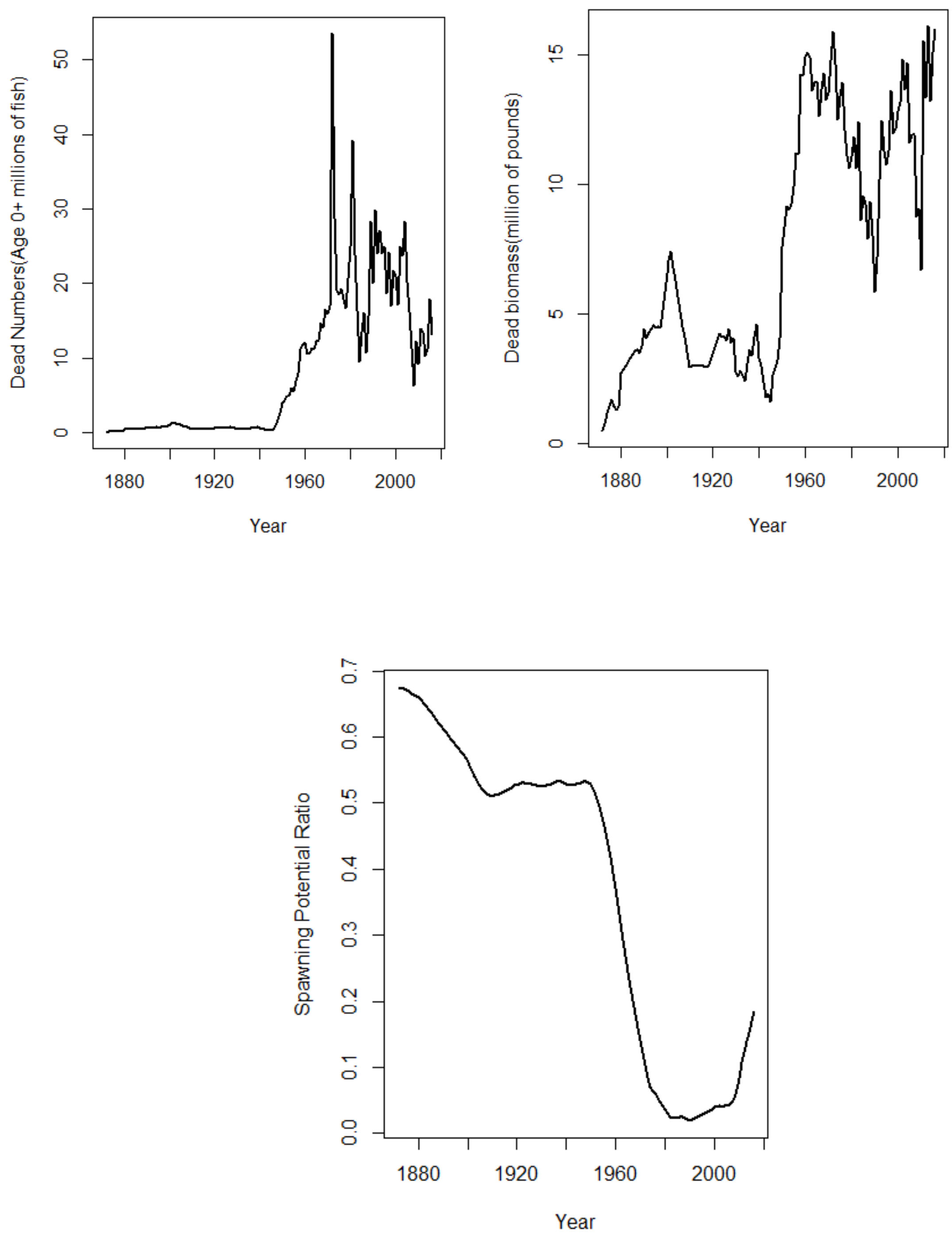

Figure 2. Plots of SEDAR 52 model estimates of historic total removals (all landings, discards, and bycatch removals) in dead numbers of age 0+ (top left), dead biomass of age 0+ (top right), and the resulting spawning potential ratio (bottom) of the stock.

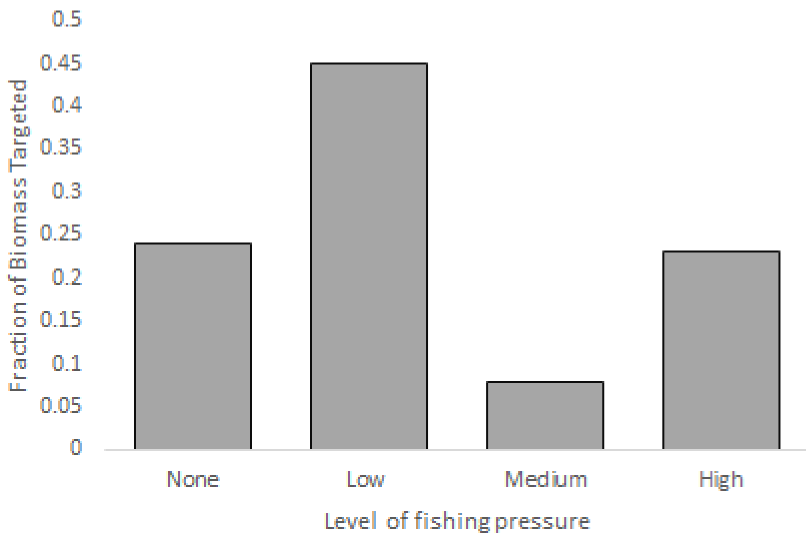

Figure 3. Preliminary analysis from the Gardner et al. manuscript showing the proportion of the stock susceptible to varying degrees of commercial fishing pressure by year. Results were obtained by assigning commercial landings to a 10km by 10km Gulf-wide Red Snapper biomass distribution map produced in Karnauskas et al. 2017b. Each grid cell was assigned a raw CPUE using VMS-TIP and grid cells with no VMS-TIP data were assigned the average value of all neighbouring cells. Lastly, CPUE estimates were standardized by the landings for each state.