Findings of EwE South Atlantic Region Ecosystem Model Exploration of High Red Snapper Recruitment Impacts
Report to SSC
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Purpose

South Atlantic Fisheries Management Council (SAFMC) asked the Model Team (MT) to explore the impacts of recent high recruitment of red snapper *(Lutjanus campechanus*) on other species in the snapper-grouper complex.

Introduction

Workshop

On September 21st, 2021 – September 23rd, 2021, a virtual workshop was held with the Model Team (MT), SSC Model Workgroup (WG), and SAFMC staff. During this workshop, the MT presented the results of their preliminary explorations of high recent red snapper recruitment impacts on other species. This included background on the model, question-specific modifications, and the results of preliminary scenario testing. The WG discussed the results, requested changes and new scenarios, and reviewed the new scenario results. The WG and MT discussed the interpretation of these results, the implications to management, and future directions as outlined in this report.

EwE

Ecopath with Ecosim and Ecospace (EwE) is a marine ecosystem modeling software. It consists of three components: Ecopath, Ecosim, and Ecospace. The current South Atlantic Region (SAR) model includes Ecopath and Ecosim.

Ecopath creates a mass-balance model to represent a snapshot of the ecosystem's trophic structure during a moment in time. Inputs for each trophic group include biomass, diets, growth parameters, fishing fleets, landings, and discards. Trophic groups are linked via their diets. This portion of the model allows for exploration of key groups and ecosystem indicators that help describe the system.

Ecosim uses Ecopath as the initial starting point and simulates biomass dynamics over time for each trophic group using a system of differential equations. Ecosim forcing functions may include primary productivity, fishing mortality, fishing effort, and environmental variables. The model can be fitted to observed trends in abundance and catch (when catch is not forced directly). EwE models predation based on the foraging-arena theory, assuming that predator-prey interactions are not random. Prey may move from ‘vulnerable’ arenas (e.g., foraging in the open) to ‘invulnerable’ arenas (e.g., hiding). Each predator-prey pair in the model has a vulnerability parameter which is calibrated to ‘fit’ the Ecosim estimates to the observed data points in the time series. This may be done in both a systematic stepwise fitting routine and manually.

South Atlantic Region EwE Model

The South Atlantic Region (SAR) EwE Model was adapted and refined from South Atlantic Bight models first developed in 2001 (Okey and Pugliese 2001). It has since been through 20 years of improvements and updates, with the current iteration reviewed and endorsed by the SSC in 2020.

Model Specifics:

- Ecopath Model Year: 1995
- Model area: 532,855 km^2 extending from North Carolina to the Florida Keys and out to the 200-m isobath contour
- 140 Trophic Groups including 700+ species. Single-species groups are primarily SAFMC-managed species (See Appendices A&B)
- Diets obtained from published literature and stomach-content studies
    - 250+ diets used in creating EwE Diet Matrix, 100+ more checked for similarity
    - % wet weight or % volume was used for diet composition
    - Multiple diets for one trophic group are averaged, weighted by sample size
    - Diet studies published up to July 2021 are included
- Biomass estimates from SEDAR Stock Assessments or GIS-derived tools
- Growth parameters from Fishbase and published literature
- Landings from The Atlantic Coast Cooperative Statistics Program, Marine Recreational Information Program, and Southeast Region Headboat Survey
- Discard mortalities from SEDAR Stock Assessments and published literature
- Ecosim Model Years: 1995 – 2016 (observed data), 2017-2044 (projections)
- Primary productivity time series: satellite-derived Chlorophyll *a*
- 155 time series: 107 Catch, 34 Relative Biomass, 12 Absolute Biomass, 2 Fishing Mortality
- Ecosim estimates of biomass for key groups calibrated to observed data via vulnerability fitting

Methods

Red snapper-specific modifications – Ecopath

To prepare the Ecopath (snapshot) model for use in this project, the MT added age stanzas to the red snapper group in order to better capture changes in recruitment from one age class to the next. It was determined that stanzas of Age 0, Age 1-3, and Age 4+ best captured the ontogenetic shifts seen in diet, fishing mortality, fecundity, length, weight, and habitat, without adding too much more complexity to the model.
The sources for basic Ecopath inputs for each red snapper age stanza were:

- Biomass: SEDAR73
- Consumption Rate: Fishbase
- Total Mortality: MT estimated growth across monthly ages, applied Lorenzen estimator scaled to M_{target} = 0.13, and used mid-year M + F for Z
- Discard mortality rate: SEDAR73 reported dead discards, so a discard mortality of 1 was used.

Diets for each of these age stanzas were compiled from published literature and stomach-content analyses that reported the range of fish lengths or ages in their results. In order to capture the full breadth of the diet of a species considered to be a generalist predator, additional red snapper diet studies were checked to ensure that all prey groups were already represented in the model's diet matrix. The MT also confirmed that the general proportion of each prey was similar to the proportions in the studies used in calculating the model's diet matrix for red snapper.

Source	N (stomachs with food)	Location	Age Group
SEAMAP	219	SAR	Age 1-3, Age 4+
FWRI-FIM Gut Lab	244	SAR/GOM	Age 0
FWRI-FIM Gut Lab	171	SAR/GOM	Age 1-3, 4+
Szedlmayer and Lee 2004	789*	GOM	Age 0
Szedlmayer and Lee 2004	789*	GOM	Age 1-3
Tarnecki and Patterson 2015	343	GOM	Age 1-3, 4+

Table 1. Sources used to construct the diets for groups Red Snapper Age 0, Red Snapper Age 1-3, and Red Snapper Age 4+. N represents only stomachs that contained food items, if reported by the study. *Szedlmayer and Lee 2004 did not report size-specific sample size.

Abbreviated results from each of the studies used in calculating the age-specific diets, as well as the compiled diets used in the model are available in Appendix C.I & II.

Since studies using animals captured in both the South Atlantic Region (SAR) and Gulf of Mexico (GoM) were used, the relative importance of each of these locations was discussed during the workshop. The WG requested that the MT recalculate the diets, weighted 80:20 SAR to GoM. This recalculation included the weighting by sample size that was already being used. Percent changes and the weighted diets are shown in **Tables 2&3**. The weighting increased the percentage for some fish preys (other grunts, herrings, invertivores, etc.) and decreased the percentage of diet composed by invertebrate groups (squids, zooplankton, epifauna), though overall the changes were minor.

% Diet Change with SAR vs. GOM weighted (>1% Change)			
Red Snapper Age 1-3		Red Snapper Age 4+	
9%	Other grunts	5%	Other grunts
5%	Herrings	2%	Herrings
4%	Benthic oceanic invertivores	2%	Benthic oceanic invertivores
2%	Benthic oceanic piscivores	1%	Benthic oceanic piscivores
1%	Scads	1%	Scads
1%	Black seabass	-1%	Penaeid shrimps
1%	Octopods	-1%	Stomatopods
-1%	Anchovies	-1%	Mega-invertebrate predators
-1%	Rock/Bank seabass	-4%	Small mobile epifauna
-1%	Penaeid shrimps	-5%	Other zooplankton
-2%	Demersal coastal omnivores		
-2%	Other shallow snapper		
-3%	Small mobile epifauna		
-3%	Other zooplankton		
-4%	Benthic coastal invertivores		
-6%	Squids		

Table 2. Percent differences to the affected red snapper diets after weighting 80:20 SAR to GoM.

Age 0		Age 1-3		Age 4+	
Prey	%	Prey	%	Prey	%
Mega-invertebrate predators	29	Other grunts	16	Other grunts	20
Stomatopods	20	Mega-invertebrate predators	14	Mega-invertebrate predators	16
Squids	14	Squids	10	Herrings	10
Bivalves/oysters	8	Herrings	8	Other zooplankton	10
Small mobile epifauna	5	Benthic oceanic invertivores	7	Benthic oceanic invertivores	8
Offshore polychaetes	4	Benthic coastal invertivores	6	Small mobile epifauna	7
Benthic coastal invertivores	3	Other zooplankton	4	Benthic oceanic piscivores	5
Pelagic planktivores	2	Benthic oceanic piscivores	4	Stomatopods	3
Other zooplankton	2	Small mobile epifauna	3	Scads	3
Octopods	2	Benthic coastal piscivores	3	Benthic coastal piscivores	2
Benthic coastal piscivores	1	Rock/Bank seabass	2	Black seabass	2
Anchovies	1	Other shallow snapper	2	Rock shrimps	2
Carnivorous zooplankton	1	Rock shrimps	2	Octopods	2
Encrusting fauna	1	Stomatopods	2	Squids	2
Rock shrimps	1	Scads	2	Offshore infaunal crustaceans	1
Penaeid shrimps	1	Demersal coastal omnivores	2	Benthic coastal invertivores	1
Estuarine infaunal crustaceans	1	Octopods	2	Rock/Bank seabass	1
Estuarine polychaetes	1	Black seabass	2	Penaeid shrimps	1
Benthic oceanic piscivores	1	Penaeid shrimps	1	Other porgys	1
Demersal coastal piscivores	1	Offshore infaunal crustaceans	1	Echinoderms and gastropods	1
		Anchovies	1		
		Other porgys	1		

Table 3. Diets for Red Snapper Age Stanzas 0, 1-3, and 4+ after weighting diet studies 80:20 SAR to GoM. Only prey items comprising >1% of diet are shown here. Complete weighted diets are in Appendix CII.

Methods - Ecopath

To identify species that would likely be competitors with red snapper and sensitive to changes in red snapper biomass, the MT used multiple analytical tools available in EwE and compared the results across these tools for a more comprehensive view of the impacts. In Ecopath (ecosystem snapshot), these tools were 1) Niche Overlap and 2) Mixed Trophic Impacts.

-Niche Overlap

Trophic niches of functional groups can be measured by an index derived from the competition coefficients of the Lotka-Volterra equations (Pianka 1973). The index assumes values between zero and one - a value of zero suggests that the two species do not share resources, while a value of one indicates complete overlap. Indices of predator overlap and prey overlap are internally calculated within Ecopath for each pair of functional groups. Similar to Pianka (1973), an index of prey overlap ($O_{j,k}$) in Ecopath is estimated, for two functional groups (*j*) and (*k*), from

$$O_{j,k} = \frac{\sum_{i=1}^{n}(p_{ji}p_{ki})}{(\sum_{i=1}^{n} p_{ji}^2 + p_{ki}^2)/2}$$

wherein p_{ji} and p_{ki} are the fraction prey *i* contributes to the diets of functional group *j* and *k*, respectively. Groups that have a high prey overlap index would be expected to impact each other through competition.

Using an approach similar to that above, it is possible to quantify a 'predator overlap index' (P) between two functional groups *j* and *k*. A value of zero suggests that the two species do not share predators, while a value of one implies whether two groups tend to be preyed upon by the same predators.

First, the fraction of predation of functional group *l* to the total predation on functional group *j* is calculated as

$$X_{jl} = {Q_l p_{lj}} \Big/ {\sum_{l=1}^{n} Q_l * p_{lj}}$$

wherein Q_l is the total consumption for predator *l*. Then a 'predator overlap index' (P) between two functional groups *j* and *k* is derived by

$$P_{j,k} = {\sum_{l=1}^{n} X_{jl} * X_{kl}} \Big/ {(\sum_{l=1}^{n} X_{jl}^2 + X_{kl}^2)/2}$$

-Mixed Trophic Impact

Mixed Trophic Impact (MTI) is a tool which reports the direction and magnitude of the effects that an infinitesimal increase in the biomass of one group will have on the biomass of all other groups. This is calculated via both direct impacts (e.g., predation) and indirect impacts (e.g., competition) and is the product of all net impacts (Ulanowicz and Puccia 1990). The MTI is based on Ecopath and thus assumes that the overall trophic structure remains constant. Therefore, it is not used to make predictions of what will happen in the future if certain interaction terms are changed. Rather, MTI can be regarded as a tool for indicating possible trophic interactions of interest for further consideration.

In Ecopath, the MTI of functional group *i* on functional group *j* is calculated as

$$MTI_{i,j} = DC_{ij} - FC_{ji}$$

where DC_{ij} is the diet composition term expressing how much functional group *j* contributes to the diet of functional group *i*. FC_{ji} gives the proportion of the predation on functional group *j* that is due to predator *i*. The diagonal elements of the MTI matrix are then increased by 1 and the matrix is inversed using a standard matrix inversion routine (Christensen et al. 2008). Negative MTI values indicate prevalence of predator effects (top-down effects) while positive values indicate prevalence of prey effects (bottom-up effects). An increase on the biomass of a predator group would result in a negative impact on its prey groups, while positively impacting the prey of its preys through a reduction in predation pressure.

An example of mixed trophic impacts (MTI) is shown in **Figure 1** taken from Christensen et al. (2008). This figure illustrates the combined direct and indirect trophic impacts that an infinitesimal increase of any of the groups on the left is predicted to have on the groups in the columns. The bars should not be interpreted in an absolute sense: the impacts are relative, but comparable between groups. For example, Figure 1 shows the effect of Sharks on any other group to be negligible. This suggests that parameter estimates for this group are lower in priority compared to other groups. Also, groups typically have a negative impact on themselves, reflecting increased within-group competition for resources.

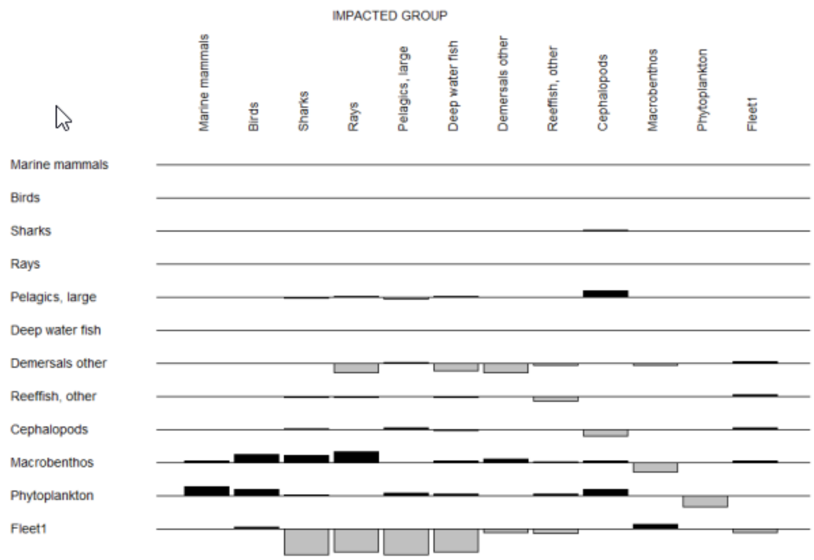


Figure 1. An example of mixed trophic impacts (MTI) from Christensen et al. (2008) showing the combined direct and indirect trophic impacts that an infinitesimal increase of any of the groups on the left is predicted to have on the groups in the columns.

<u>Methods – Ecosim</u>

Further exploration of the red snapper recruitment question was done via scenario testing in Ecosim (ecosystem through time). The approach was to modify three separate Ecosim scenarios which were all built upon the same Ecopath model. For each scenario only the red snapper time series were modified while all other groups were left unchanged. These scenarios were:

1) Longterm Mean Recruitment through 2044, which replicated the projected biomass of red snapper under longterm mean recruitment as estimated by Scenario 7 of the SEDAR73 Red Snapper Forecasts reviewed by the SSC in July 2021 (SEDAR 2021a).

SEDAR73 Scenario 7 was defined as:

Recruitment: Geometric mean recruitment over the full assessment period ("Longterm")
Fishing Mortality: $F_{REBUILD}$
Discard Mortality: Mixed (Block 3 benchmarks and Block 4 discard mortality)
Reallocation: No reallocation of F towards landings

2) High Recent Recruitment, which replicated the projected biomass of red snapper under high recent recruitment as estimated by Scenario 13 of the SEDAR73 Red Snapper Forecasts reviewed by the SSC in July 2021 (SEDAR 2021a).

SEDAR73 Scenario 13 was defined as:

Recruitment: Geometric mean recruitment over 2010-2019 ("Recent")
Fishing Mortality: $F_{REBUILD}$ (capped at F_{30})
Discard Mortality: Mixed (Block 3 benchmarks and Block 4 discard mortality
Reallocation: No reallocation of F towards landings

3) Status Quo Biomass, which capped the biomass of red snapper at approximately the same weight as 2016 (SEDAR 2021b). This was used to confirm that the effects were consistent and directional across three different biomass scenarios.

These three scenarios were run on the same Ecopath model, allowing the MT to examine the relative impacts of red snapper biomass changes on the other groups' biomass projections as estimated by EwE. The MT used the differences between the scenarios to construct a 'winners/losers' list to further explore the impacts that red snapper biomass had on these groups.

Red snapper-specific modifications – Ecosim

To create the three biomass scenarios (Longterm Mean Recruitment, High Recent Recruitment, and Status Quo), modifications were made only in Ecosim, while Ecopath was left unchanged. In all three scenarios catch time series values were extended from 2016 to 2044 for all groups for which catch was used to direct the Ecosim estimates. All other time series (absolute biomass and relative biomass) were used as reference/calibration only and thus were left blank after 2016.

The MT did not use red snapper catch forcing time series to drive fishing mortality in Ecosim, as this caused poor fits and unstable dynamics. Instead, a time series of Fishing Mortality (F) was calculated via F = Catch/Biomass for age stanzas 1-3 and 4+, using estimates of total removals and biomass at age from the SEDAR stock assessment. These F time series were used to "force" the fishing mortality term directly in Ecosim, and the model was recalibrated via a stepwise vulnerability fitting routine to fit the estimates to the SEDAR biomasses for each age stanza.

While possible to do so, it is generally inadvisable to force biomass in Ecosim because the forced group will no longer change dynamically under density-dependent processes, or with changes in predator and prey abundances. Therefore, the MT modified either fishing mortality and/or vulnerabilities to simulate the desired biomass trends in the future projections. These scenario modifications are explained below.

Scenario 1: Longterm Mean Recruitment

To simulate the biomass projections under longterm mean recruitment (Scenario 7, SEDAR 2021a), the F from 2017 to 2044 was set to 0.0188 for both Age 1-3 and Age 4+. This F allowed the red snapper age stanzas to increase at a rate and magnitude similar to that estimated by the SEDAR scenario. The estimated 2044 total red snapper biomass was nearly equal to the SEDAR-projected 2044 biomass (SEDAR = 0.0132 t/km^2, EwE = 0.0132 t/km^2)

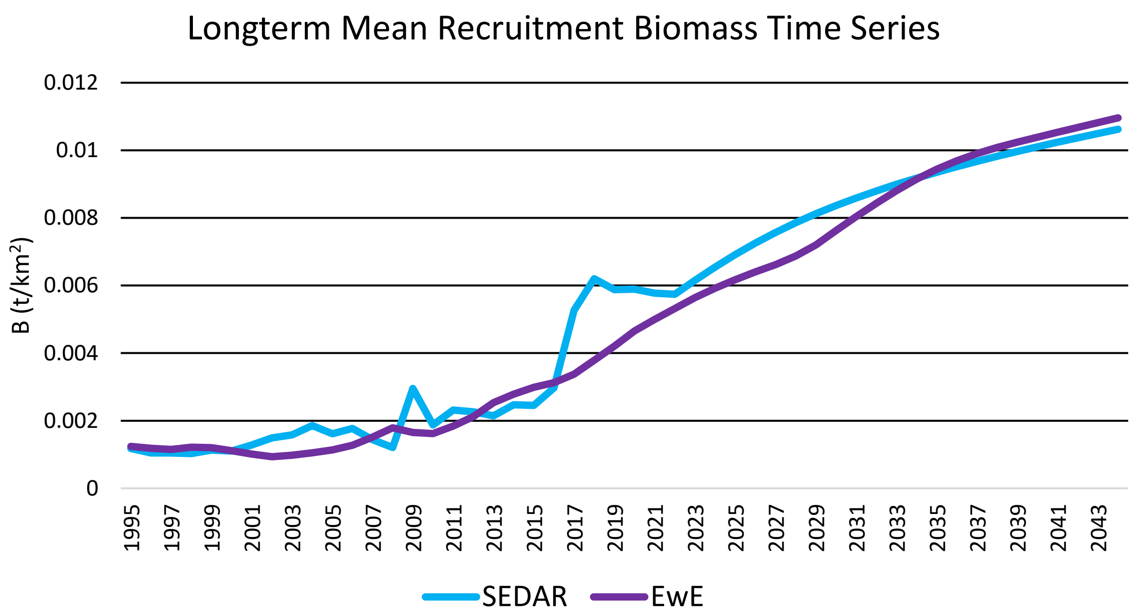


Figure 2. Longterm Mean Recruitment biomass (t/km^2) estimated by Ecosim and biomass projections from Scenario 7 of SEDAR 73: Additional Scenarios (SEDAR 2021a).

Scenario 2: High Recent Recruitment

To simulate the biomass projections under high recent recruitment (Scenario 13, SEDAR 2021a), the F from 2017 to 2044 was set to 0.0188 for both Age 1-3 and Age 4+ as it was in the Longterm Mean Recruitment scenario. In addition, a forcing function time series was added to increase the vulnerabilities of prey to Red Snapper Age 0. Higher vulnerability values increase the flux rate of prey biomass into the vulnerable pool and determines how high predation mortality can be at high predator densities. Since consumption drives the biomass estimates in Ecosim, increasing the vulnerability of RS Age 0's prey increases the consumption by RS Age 0, thus increasing the biomass of RS Age 0. This RS Age 0 biomass increase is then reflected in the older age stanzas as each juvenile stanza recruits to each older stanza.

In order to track these biomass increases to the SEDAR projections, the vulnerability forcing function time series was scaled directly from those projections. This allowed the total red snapper biomass estimates to follow approximately the same course. The estimated 2044 total red snapper biomass was nearly equal to the projected SEDAR 2044 biomass (SEDAR 73 = 0.02122 t/km^2, EwE = 0.02122 t/km^2).

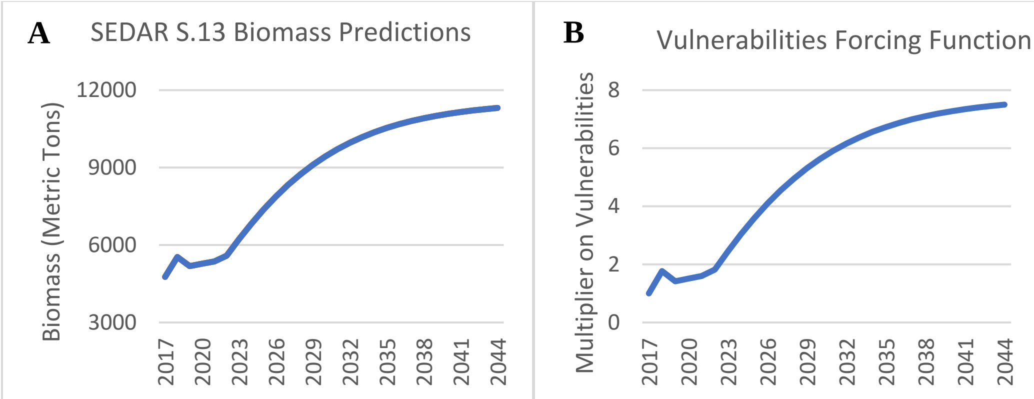


Figure 3. A) Biomass observations (2017-2020) and projections (2021-2044) of Scenario 13 of SEDAR 73: Additional Scenarios (SEDAR 2021a). B) Scale of forcing function used to increase the vulnerabilities of prey of Red Snapper Age 0 in the High Recent Recruitment scenario.

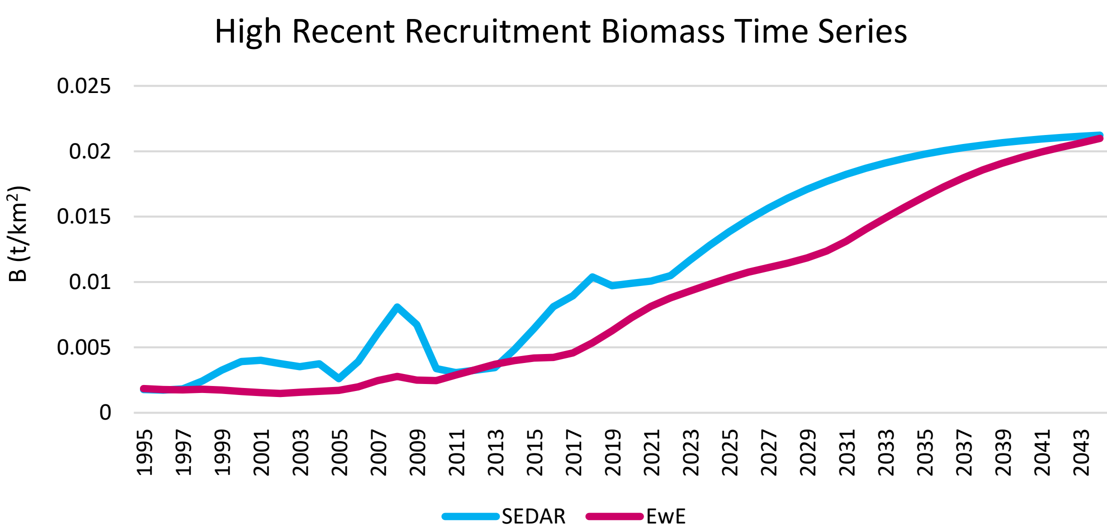


Figure 4. High Recent Recruitment biomass (t/km^2) estimated by Ecosim and biomass projections from Scenario 7 of SEDAR 73: Additional Scenarios (SEDAR 2021a).

Scenario 3: Status Quo

To simulate the total biomass of red snapper remaining capped around the 2016 biomass (SEDAR 73), the Red Snapper Age 4+ Fishing Mortality Time Series from 2017 to 2044 was set to 0.1. This arbitrary number was selected in order to constrain the total red snapper biomass below or at the weight reported for 2016. This scenario was not intended to represent any particular future situation but to create an artificially low biomass scenario.

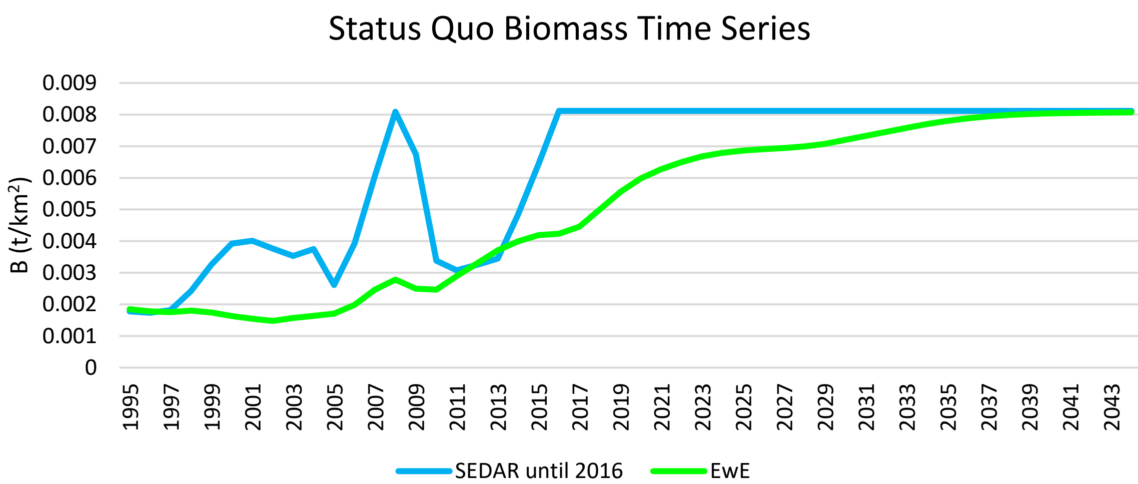


Figure 5. Status Quo scenario biomass (t/km^2) estimated by Ecosim and biomass observations from SEDAR73 for red snapper (1995-2016) (SEDAR 2021b).

These three scenarios gave the MT a range of red snapper biomasses with which the model could be tested.

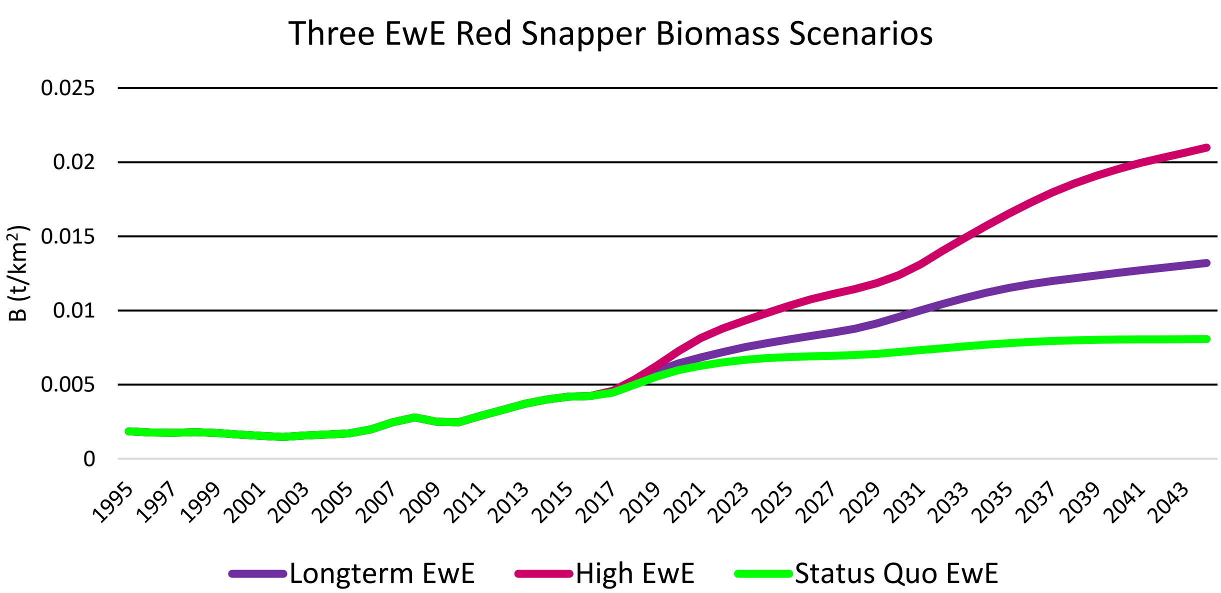
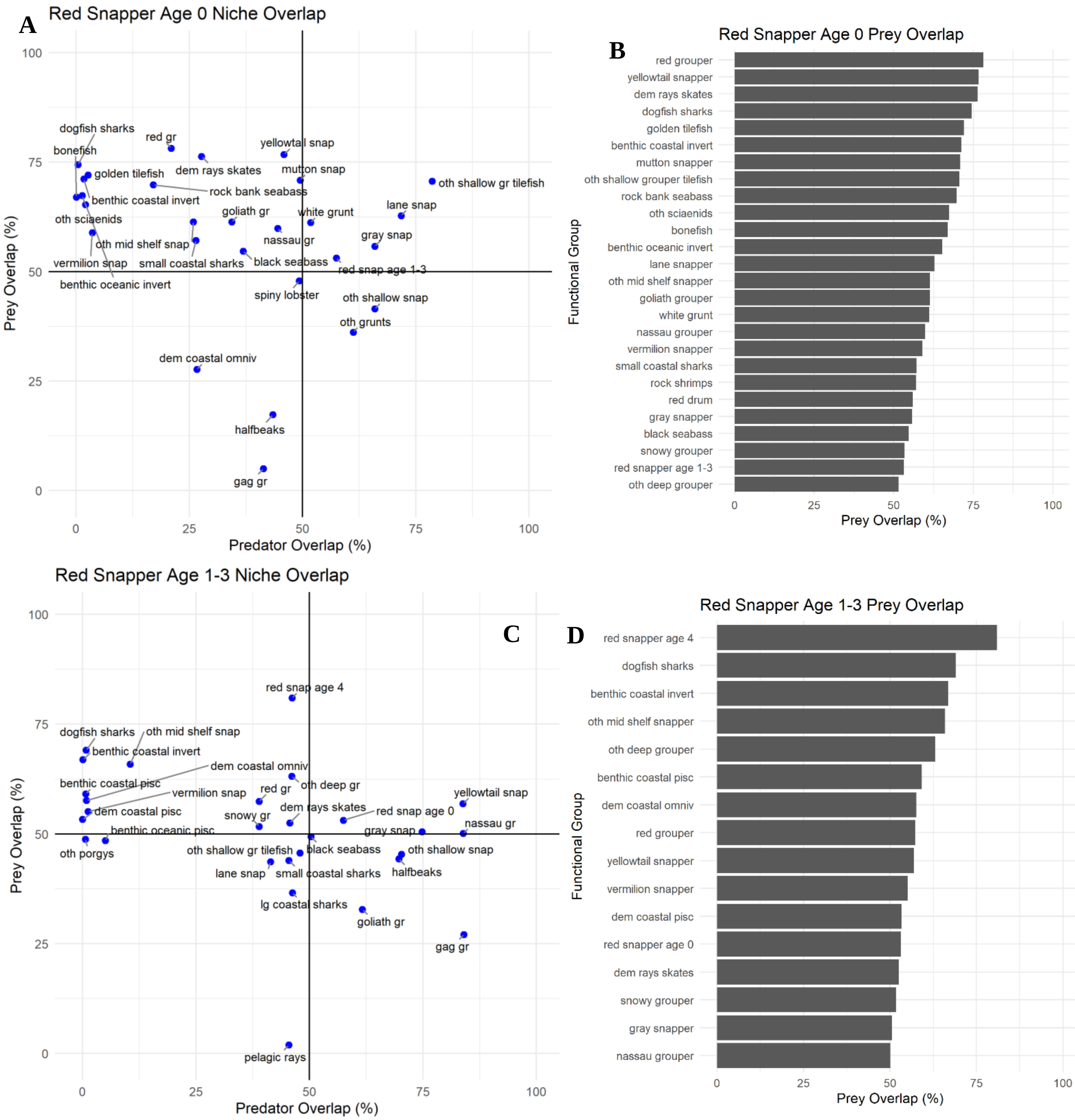


Figure 6. Red snapper biomass estimates from Ecosim for Longterm Mean Recruitment, High Recent Recruitment, and Status Quo scenarios.

Results

Niche Overlap (Ecopath)

Niche overlap, which is made up of 2 separate indices (prey overlap and predator overlap) was calculated for each of the red snapper age stanzas. All results of over 50% overlap are shown here, while some points under 50% for both indices have been removed for clarity. As red snappers are a top predator in this ecosystem, predator overlap was minimal. Prey overlap however yielded a large list of species with whom each red snapper age stanza may compete. The average prey overlap for all fish species was around 20%, and many ecological indices for niche/prey overlap consider values over 60% to be of importance for potential competition.



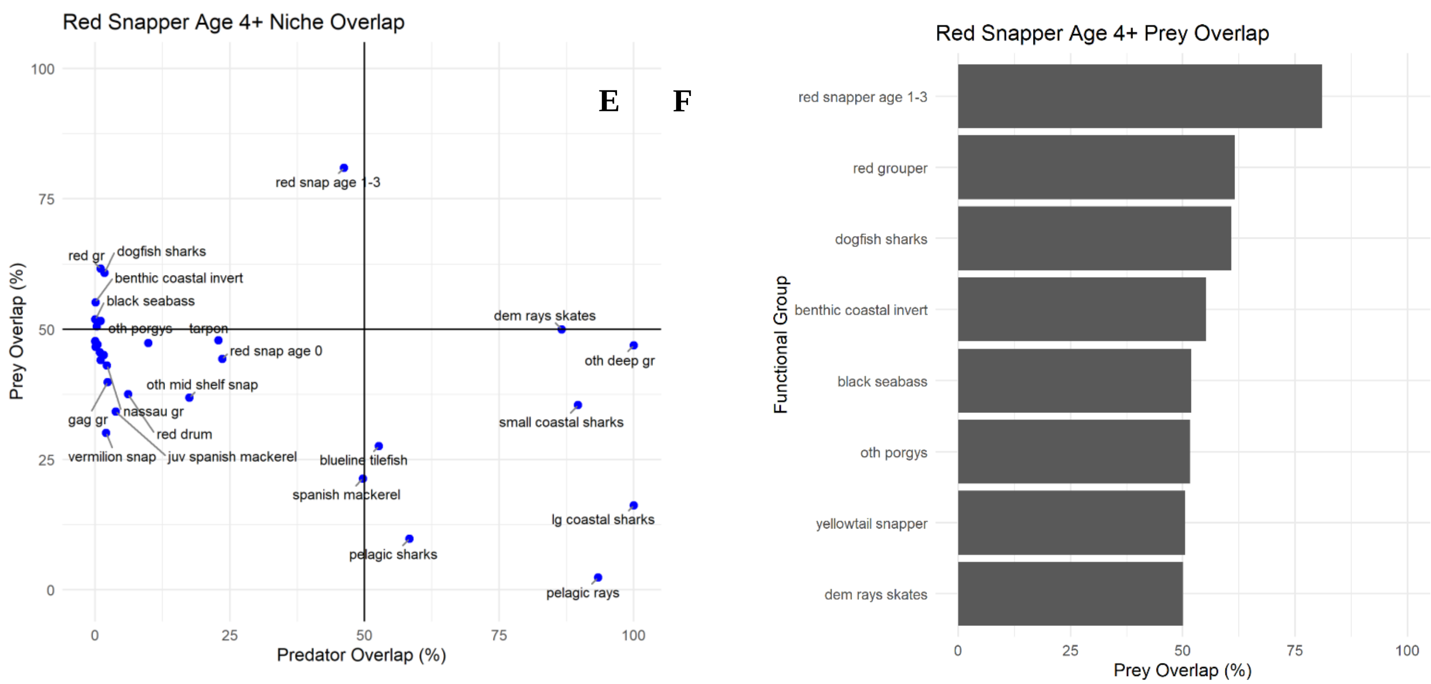


Figure 7. A, C, E: Niche Overlap plots for Red Snapper Age 0, Red Snapper Age 1-3, and Red Snapper Age 4+, respectively. Not shown: other groups of <50% prey overlap and <50% predator overlap. **B, D, F**: Ranked prey overlap indices >50% for Red Snapper Age 0, Red Snapper Age 1-3, and Red Snapper Age 4+, respectively. Prey overlap indices are also available in **Table 5.**

Mixed Trophic Impacts (Ecopath)

Mixed Trophic Impacts (MTI), which reports the direction and magnitude of the impact of one group's infinitesimal biomass increase on each other groups' biomasses were calculated for each of the red snapper age stanzas. These impacts include both direct effects (e.g., predation) and indirect effects (e.g., competition). These results are unitless and do not represent a concrete value. However, they are comparable in magnitude and direction across groups. For context, the MTI results for Herrings (a high-impact group in the model) are shown, though attention should be paid to the scale of each graph. During the workshop, the WG requested that each of the red snapper age stanzas be added to the graphs (shown in **Figure 8** at the top). Negative results for in-group impacts represent within-group competition (Christensen 2008).

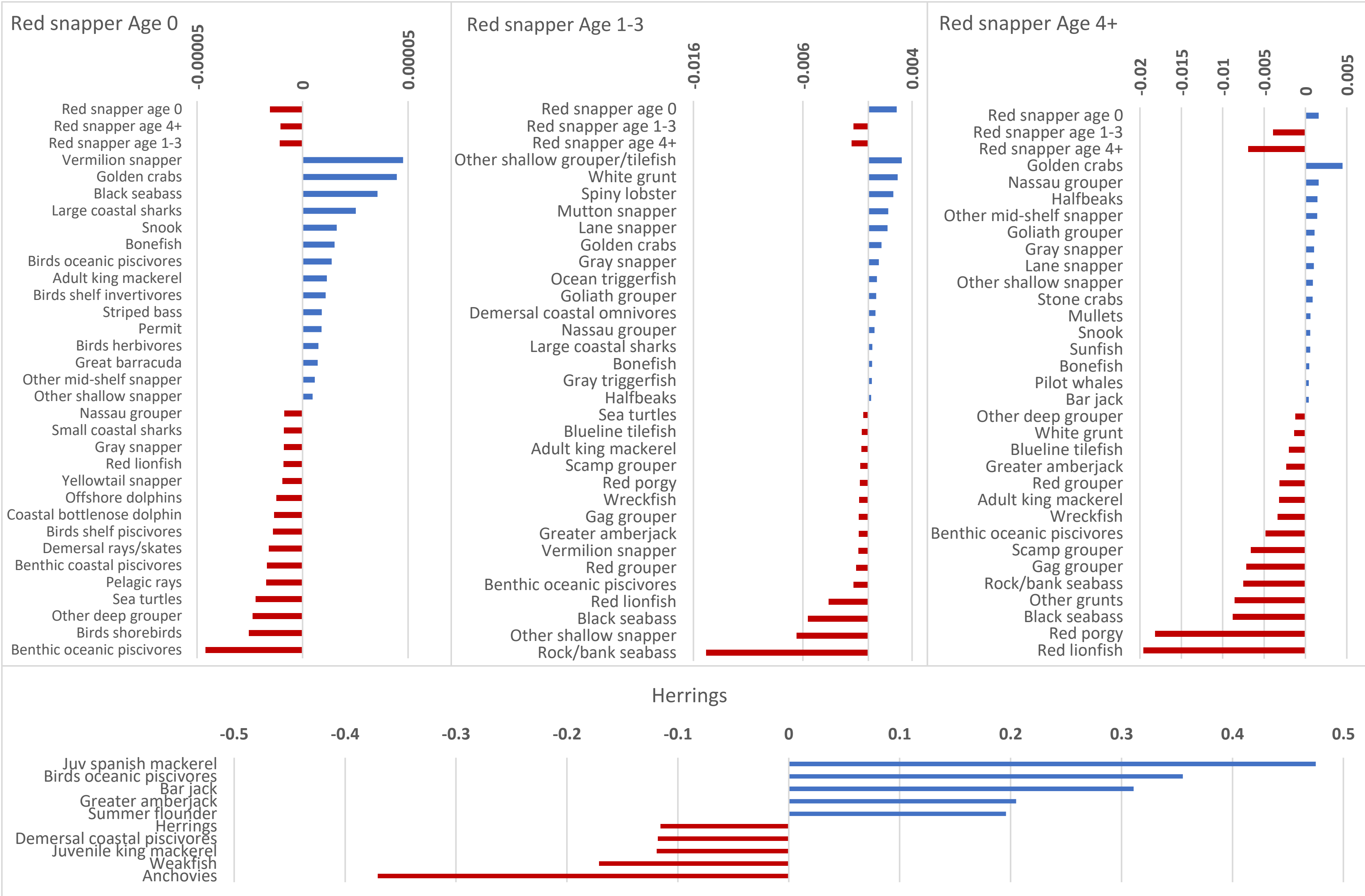


Figure 8. Mixed Trophic Impact results for A) Age 0 Red Snapper, B) Age 1-3 Red Snapper, C) Age 4+ Red Snapper, and D) Herrings. Ranked Mixed Trophic Impact results are also available in **Table 5.**

Scenario Testing (Ecosim)
All three scenarios (Longterm Mean, High Recent, and Status Quo) were run in Ecosim, and the 2044 biomasses of all other groups were compared across scenarios to look for sensitivity to the changes in red snapper biomass. Percent difference of each group's 2044 biomass under Longterm Mean Red Snapper Recruitment vs. High Recent Red Snapper Recruitment were calculated ((B2044High – B2044Longterm)/B2044Longterm), and a ranked winners/losers list was created. These top/bottom 10 functional groups represent the most sensitive to an increase in red snapper biomass.

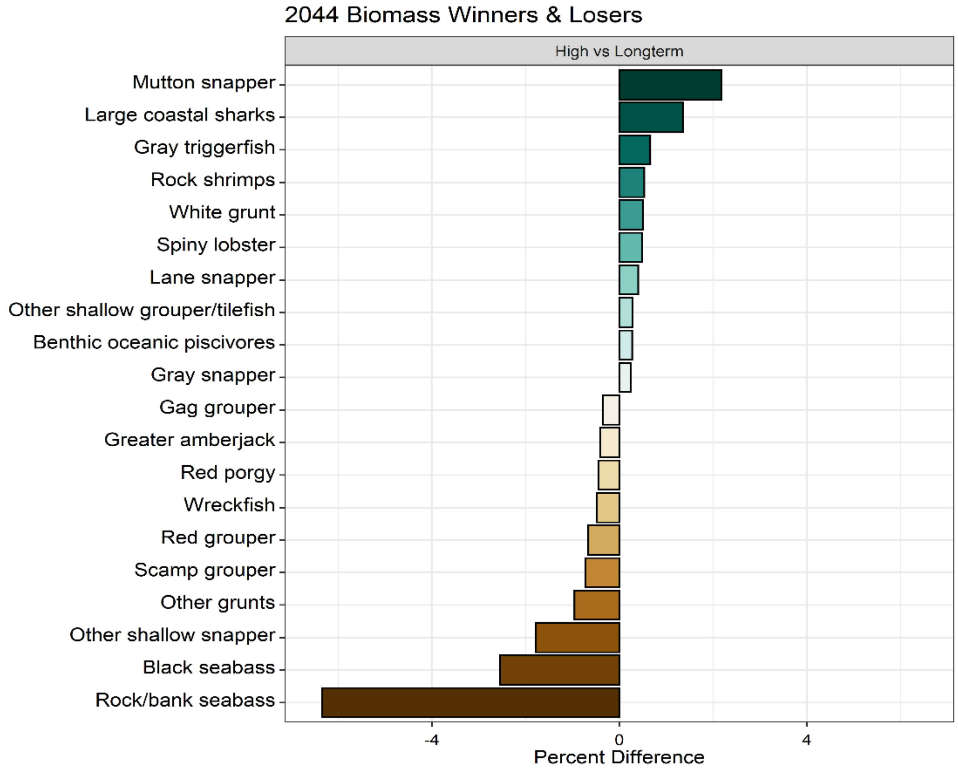


Figure 9. Top 10 winners and bottom 10 losers of High Recent vs. Longterm Mean scenario testing. Values represent the percent change of each group's 2044 biomass during high recent red snapper recruitment as compared to their 2044 biomass during longterm mean red snapper recruitment.

The size of impacts of Status Quo vs. Longterm were much smaller (**Figure 10).**

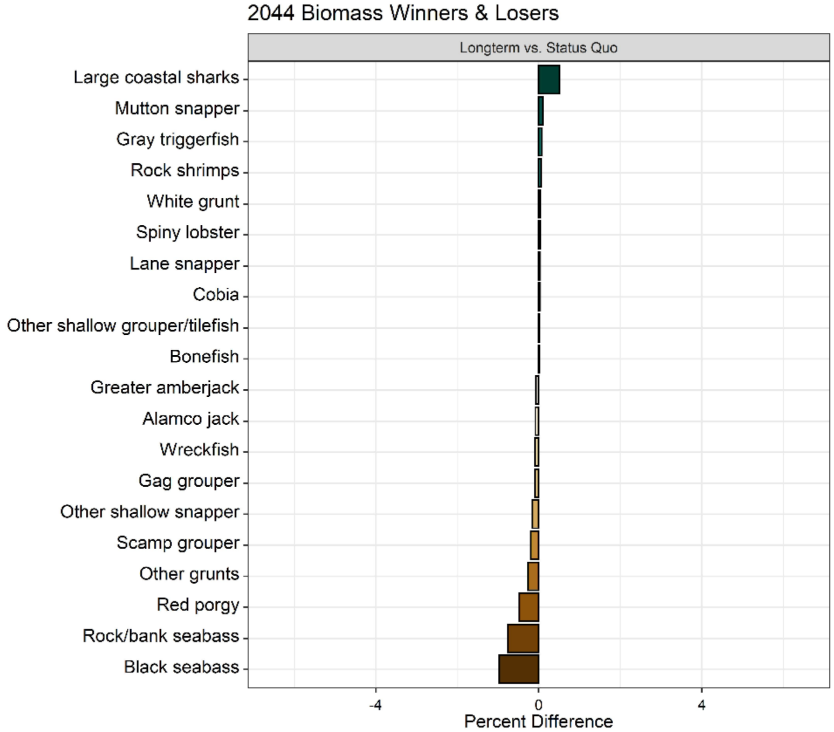


Figure 10. Top 10 winners and bottom 10 losers of Longterm Mean vs. Status Quo scenario testing. Values represent the percent change of each group's 2044 biomass during longterm mean red snapper recruitment as compared to their 2044 biomass during the 'status quo' artificially low red snapper biomass.

As mentioned above, the WG requested that the diets be reweighted 80:20 SAR to GoM studies. The winners/losers for High Recent Recruitment vs. Longterm Mean Recruitment showed little change in magnitude or species composition.

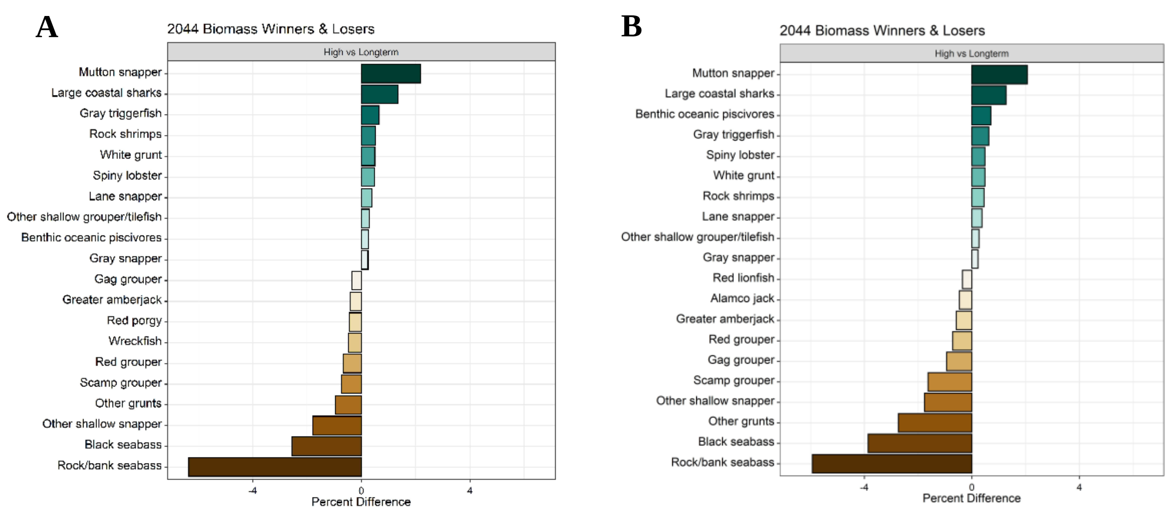


Figure 11. Top 10 winners and bottom 10 losers of High Recent vs. Longterm Mean scenario testing with the unweighted red snapper diets (**A**) and weighted red snapper diets (**B**).

Workshop-requested scenarios and results

Synergistic effects of catch and red snapper recruitment on Black Sea Bass

The WG members discussed that the negative impacts of red snapper on other species could be exacerbated by high fishing mortality on particular species of concern. The WG and MT discussed methods for exploring this question in EwE. The decision was made to compare the impacts of high recent red snapper recruitment vs. longterm mean red snapper recruitment across three different catch levels of black sea bass (BSB). The three BSB catch levels used for 2017-2044 were:

- 2016 catch (0.00115 t/km^2, 610 metric tons). This was baseline for previous scenarios.
- 2004 catch (0.00295 t/km^2, 1520 metric tons). This was chosen due to 2004 having the highest recorded catch from the time series.
- Unrealistically Large catch (0.008 t/km^2, 4300 tons). This was chosen as it drove the BSB biomass as near to zero as EwE would allow.

Results showed only minor changes to the impact of red snapper on BSB biomass under the three different BSB catch levels (-2.36%, -2.34%, and -2.13% respectively). It also had very minimal impacts on other winners/losers in the ecosystem (**Fig. 13**). The WG discussed that the impacts of red snapper on other species did not appear to be exacerbated by high catch on the other species.

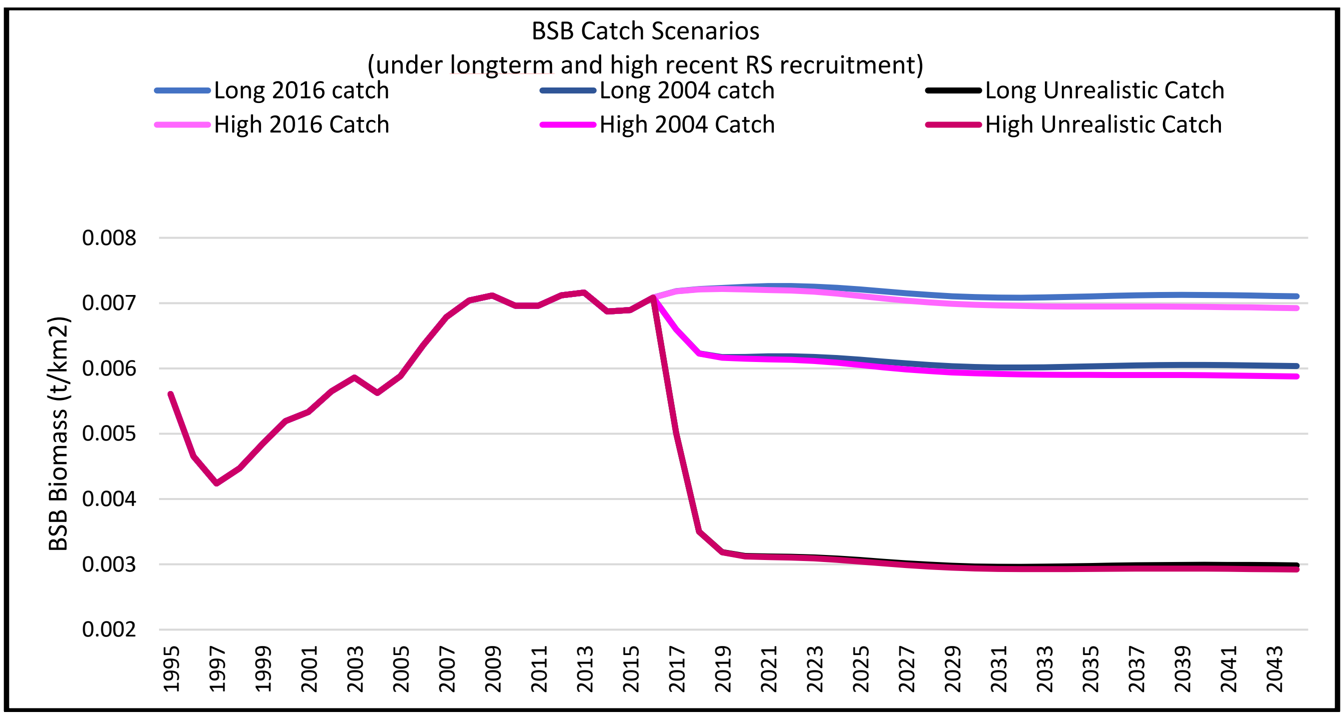


Figure 12. Black sea bass biomass estimates from EwE under three different catch levels (2016, 2004, and Unrealistically Large) and two different red snapper recruitment scenarios (Longterm Mean and High Recent).

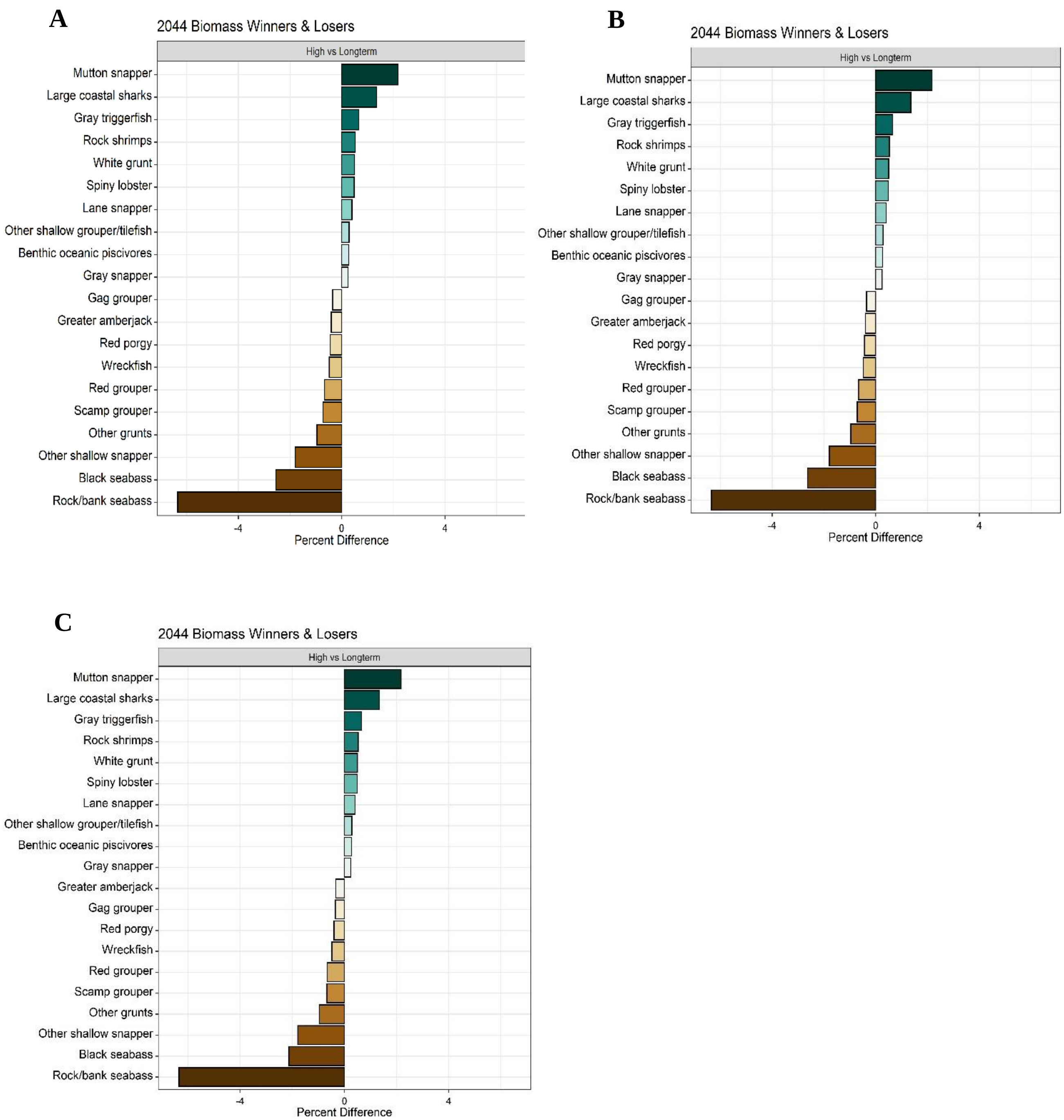


Figure 9. Top 10 winners and bottom 10 losers of High Recent Red Snapper Recruitment vs. Longterm Mean Red Snapper Recruitment scenario testing under three different black sea bass catch levels from 2017-2044. **A**) 2016 catch level (baseline). **B**) 2004 catch level (higher). **C**) Unrealistically Large catch (highest).

<u>What would it take to get to 10% loss of BSB? Additionally, how sensitive are the winner/loser results to changes in Vulnerability parameters?</u>

The WG discussed the relatively minor scale of impacts to all groups in the model, and the question was posed, “What would it take to get to a 10% loss of black sea bass biomass?” The MT discussed increasing the biomass of RS directly until this threshold was reached. Upon further discussion, the WG expressed interest in seeing how sensitive the model was to changes in vulnerability parameters. Raising the vulnerability of red snapper’s prey to predation increases the biomass of red snapper, so it was decided that the MT would increase the vulnerabilities of the prey of all red snapper age stanzas to see what the relative impacts were on winners/losers.

The MT chose 4 vulnerability multipliers: 1, 1.5, 2, and 10. **Table 4** shows the vulnerabilities used for all prey items of each red snapper age stanza under these 4 multipliers.

	Normal (1x)	**1.5x**	**2x**	**10x**
Age 0	5	7.5	10	50
Age 1-3	10	15	20	100
Age 4+	3.5	5.25	7	350

Table 4. Vulnerabilities applied to all of the prey items in each of the red snapper age stanza diets to test the impacts on higher vulnerabilities on model results.

As expected, the increased prey vulnerabilities increased the biomass of each red snapper stanza proportionally. Due to the extremely high biomass estimates under the 10x vulnerability multiplier, it is not included in the three graphs below (**Figures 14, 15, and 16**).

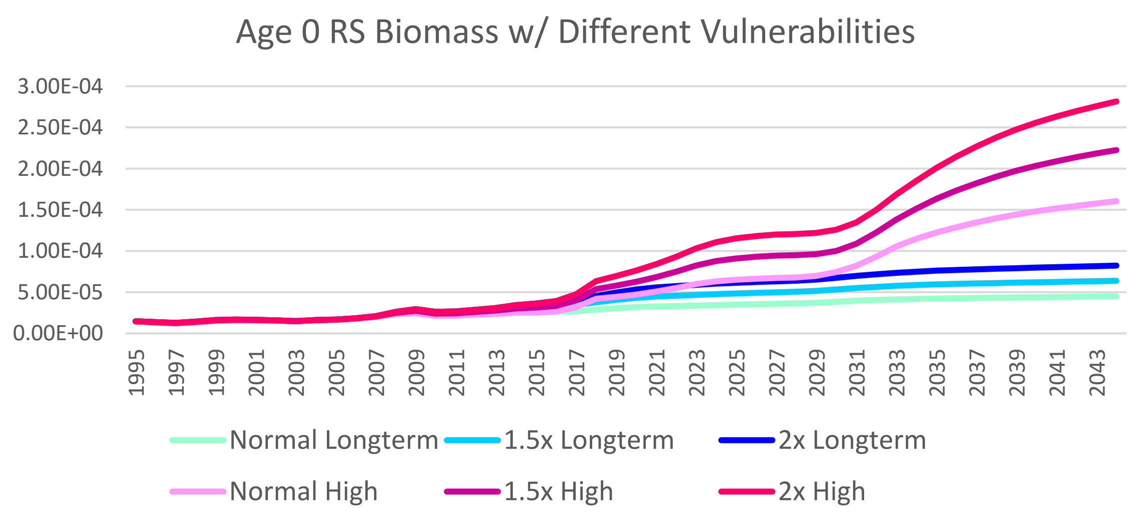


Figure 14. Red snapper Age 0 biomass estimates from Ecosim under Longterm Mean Recruitment and High Recent Recruitment with three different prey vulnerabilities (Normal 1x, 1.5x, and 2x).

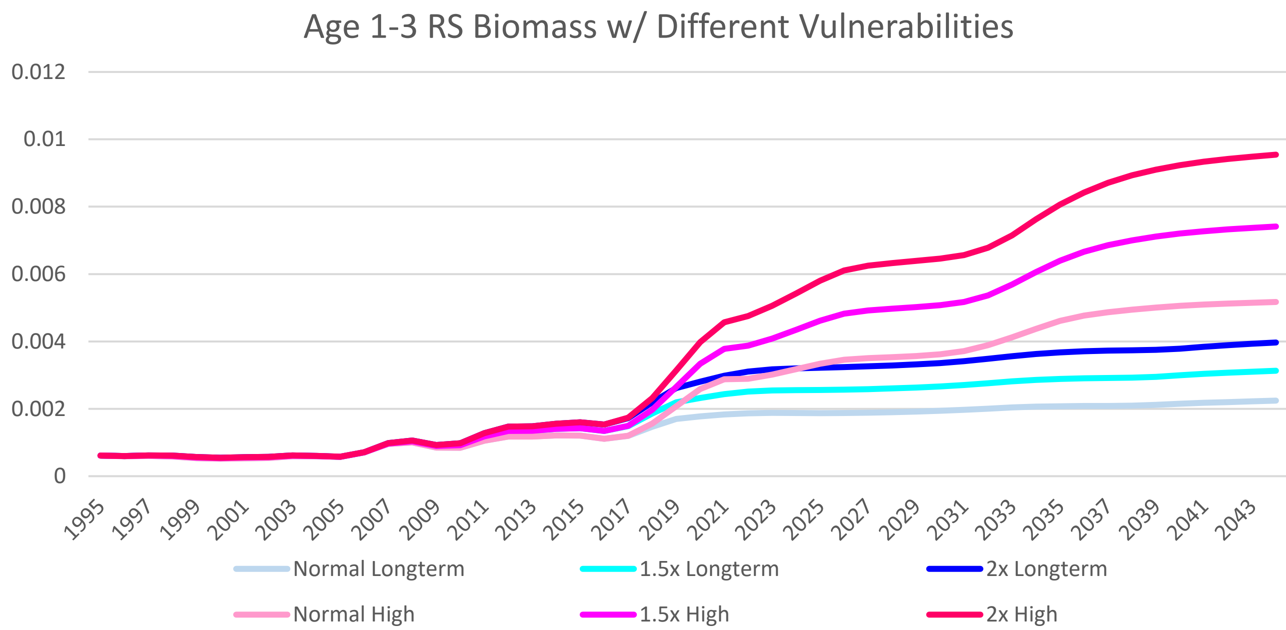


Figure 15. Red snapper Age 1-3 biomass estimates from Ecosim under Longterm Mean Recruitment and High Recent Recruitment with three different prey vulnerabilities (Normal 1x, 1.5x, and 2x).

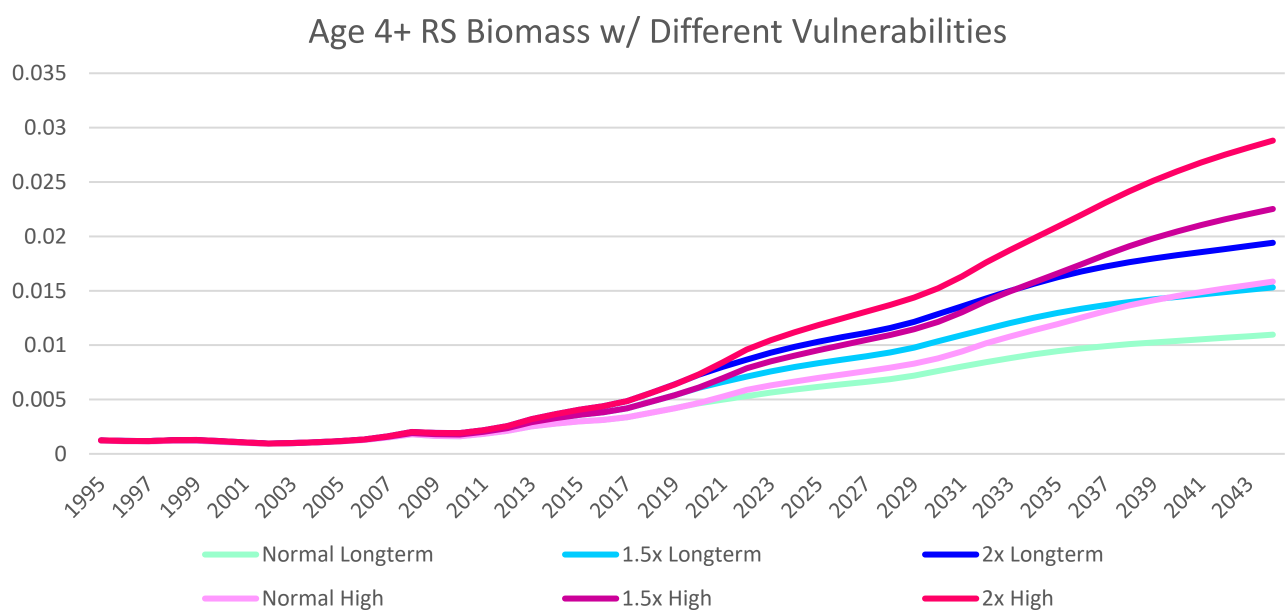


Figure 16. Red snapper Age 4+ biomass estimates from Ecosim under Longterm Mean Recruitment and High Recent Recruitment with three different prey vulnerabilities (Normal 1x, 1.5x, and 2x).

The change in impacts of red snapper High Recent vs. Longterm Mean recruitment on other groups was minimal for the 1.5x multiplier and was still minor for 2x vulnerabilities for most groups. It was discussed that the model is not overly sensitive to changes in vulnerability parameters, and the negative threshold of 10% BSB loss was reached between the 2x and 10x vulnerability multiplier. The WG discussed that this indicates that if an increase of red snapper biomass can have an impact of 4 to 5-fold beyond projections, there could be significant impacts to black sea bass and red porgy. The MT mentioned that the 10x run was highly chaotic, as such a large change 'unfits' the model estimates from the observed biomass data. The WG further stated that this process demonstrated the model's potential to answer these types of "how much impact to reach a threshold" questions, which could be useful for future management.

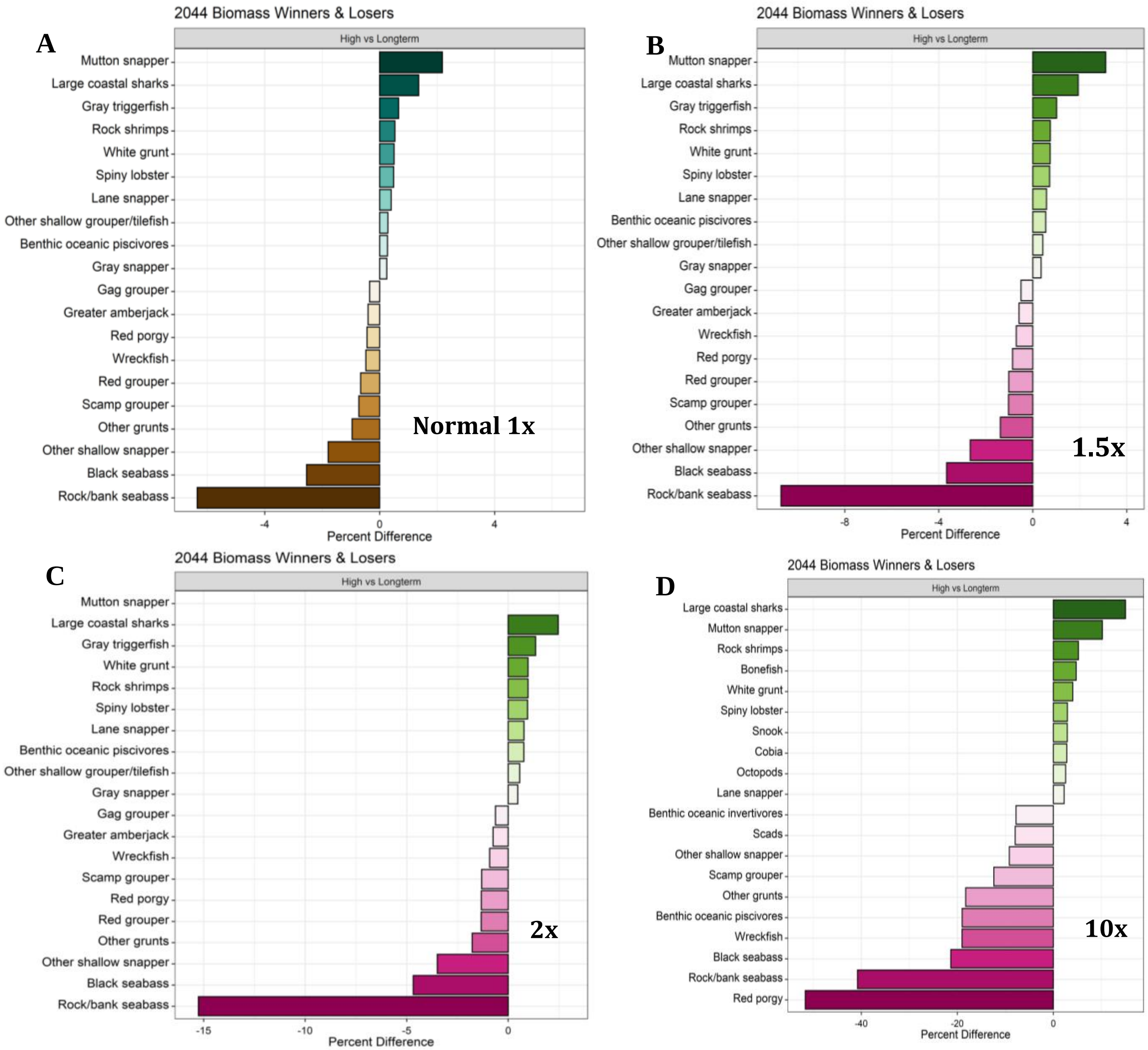


Figure 17. Top 10 winners and bottom 10 losers of High Recent Red Snapper Recruitment vs. Longterm Mean Red Snapper Recruitment scenario testing under four different vulnerability multipliers for all prey of red snapper age stanzas. **A**) Normal 1x **B**) 1.5x **C**) 2x **D**) 10x

<u>In which Black Sea Bass were made 25% of Red Snapper Age 4+ Diet. Additionally, how sensitive are the winner/loser results to changes in the diet?</u>

SAFMC staff indicated that a helpful frame of reference for discussing red snapper impacts could be “one out of every three fish eaten.” The MT was asked to see what would happen if black sea bass were made 1/3rd of the red snapper diets. The MT found that this “broke” the model (unbalanced the mass-balance in Ecopath), but it was possible to increase Black Sea Bass from 1.5% to 25% of the red snapper Age 4+ diet. This resulted in an increase in BSB biomass loss of ~2.5% to ~4.0% between the High Recruitment and Longterm Mean Recruitment scenarios. The WG discussed that these changes were not substantial, and the lack of impact on other winners/losers indicates that indirect impacts are not substantial either.

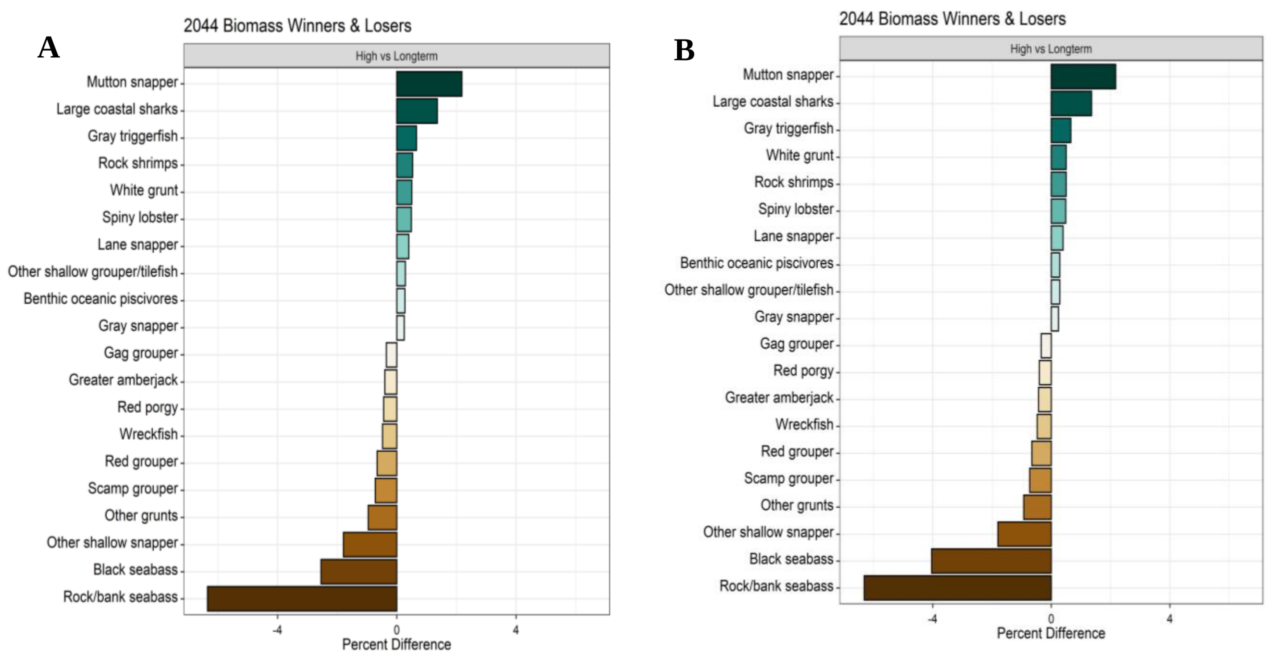


Figure 18. Top 10 winners and bottom 10 losers of High Recent Red Snapper Recruitment vs. Longterm Mean Red Snapper Recruitment scenario testing with (**A**) black sea bass as 1.5% of the Red Snapper Age 4+ diet, and (**B**) with black sea bass as 25% of the Red Snapper Age 4+ diet.

<u>Can we view all these results together?</u>

The WG and MT discussed that each section and tool (Diet Matrix, Niche Overlap, Mixed Trophic Impacts, and Scenario Testing) gave insight into different levels of red snapper effects, both by levels of impact (direct vs. indirect) and levels of EwE (Ecopath vs. Ecosim). The MT attempted to visualize the commonly impacted species in table form. The WG discussed that this format could be useful for tracking particular species of concern from tool to tool (**Table 5)**.

Diets (% wet weight)						Prey Overlap (%)						Mixed Trophic Impacts				Scenario Testing (%Δ B)	
Age 0		Age 1-3		Age 4+		Age 0		Age 1-3		Age 4+		Age 1-3		Age 4+		High vs Longterm	
29	Mega-invertebrate	16	Other grunts	20	Other grunts	78	Red grouper	81	Red snapper age 4+	81	Red snapper age 1-3	0.003	Other shallow grouper/tilefish	0.004	Golden crabs	2.06	Mutton snapper
20	Stomatopods	14	Mega-invertebrate	16	Mega-invertebrate	77	Yellowtail snapper	69	Dogfish sharks	62	Red grouper	0.003	White grunt	0.002	Nassau grouper	1.27	Large coastal sharks
14	Squids	10	Squids	10	Herrings	76	Demersal rays/skates	67	Benthic coastal invertivores	61	Dogfish sharks	0.002	Spiny lobster	0.001	Halfbeaks	0.71	Benthic oceanic
8	Bivalves/oysters	8	Herrings	10	Other zooplankton	74	Dogfish sharks	66	Other mid-shelf snapper	55	Benthic coastal invertivores	0.002	Mutton snapper	0.001	Other mid-shelf	0.63	Gray triggerfish
5	Small mobile epifauna	7	Benthic oceanic	8	Benthic oceanic invertivores	72	Golden tilefish	66	Greater amberjack	52	Black seabass	0.002	Lane snapper	0.001	Goliath grouper	0.49	Spiny lobster
4	Offshore polychaetes	6	Benthic coastal invertivores	7	Small mobile epifauna	72	Red porgy	63	Other deep grouper	52	Other porgys	0.001	Golden crabs	0.001	Gray snapper	0.49	White grunt
3	Benthic coastal invertivores	4	Other zooplankton	5	Benthic oceanic piscivores	71	Benthic coastal invertivores	59	Benthic coastal piscivores	51	Yellowtail snapper	0.001	Gray snapper	0.001	Lane snapper	0.45	Rock shrimps
2	Pelagic planktivores	4	Benthic oceanic	3	Stomatopods	71	Mutton snapper	58	Summer flounder	50	Demersal rays/skates	0.001	Ocean triggerfish	0.001	Other shallow	0.38	Lane snapper
2	Other zooplankton	3	Small mobile epifauna	3	Scads	71	Other shallow grouper/tilefish	58	Demersal coastal	50	Red lionfish	0.001	Goliath grouper	0.001	Stone crabs	0.27	Other shallow grouper/tilefish
2	Octopods	3	Benthic coastal piscivores	2	Benthic coastal piscivores	70	Rock/bank seabass	57	Red grouper	49	Halfbeaks	0.001	Demersal coastal omnivores	0.001	Mullets	0.23	Gray snapper
1	Benthic coastal piscivores	2	Rock/Bank seabass	2	Black seabass	67	Other sciaenids	57	Yellowtail snapper	48	Tarpon	0.001	Nassau grouper	0.001	Snook	-0.40	Red lionfish
1	Anchovies	2	Other shallow snapper	2	Rock shrimps	67	Bonefish	55	Vermilion snapper	48	Greater amberjack	0.0004	Large coastal sharks	0.001	Sunfish	-0.47	Alamco jack
1	Carnivorous zooplankton	2	Rock shrimps	2	Octopods	66	Cobia	54	Almaco jack	48	Almaco jack	0.0003	Bonefish	0.0005	Bonefish	-0.58	Greater amberjack
1	Encrusting fauna	2	Stomatopods	2	Squids	65	Benthic oceanic	53	Demersal coastal	47	Golden tilefish	0.0003	Gray triggerfish	0.0004	Pilot whales	-0.72	Red grouper
1	Rock shrimps	2	Scads	1	Offshore infaunal	63	Lane snapper	53	Red snapper age 0	47	Other grunts	0.0003	Halfbeaks	0.0004	Bar jack	-0.94	Gag grouper
1	Penaeid shrimps	2	Demersal coastal	1	Benthic coastal invertivores	61	Other mid-shelf snapper	53	Demersal rays/skates	47	Other deep grouper	-0.0005	Sea turtles	-0.001	Other deep grouper	-1.63	Scamp grouper
1	Estuarine infaunal	2	Octopods	1	Rock/Bank seabass	61	Goliath grouper	52	Snowy grouper	47	Red porgy	-0.001	Blueline tilefish	-0.001	White grunt	-1.76	Other shallow snapper
1	Estuarine polychaetes	2	Black seabass	1	Penaeid shrimps	61	White grunt	51	White grunt	46	Rock/bank seabass	-0.001	Adult king mackerel	-0.002	Blueline tilefish	-2.74	Other grunts
<1%	Benthic oceanic piscivores	1	Penaeid shrimps	1	Other porgys	60	Nassau grouper	50	Gray snapper	46	Other shallow snapper	-0.001	Scamp grouper	-0.002	Greater amberjack	-3.86	Black seabass
<1%	Demersal coastal piscivores	1	Offshore infaunal	1	Echinoderms and gastropods	59	Queen triggerfish	50	Nassau grouper	45	Goliath grouper	-0.001	Red porgy	-0.003	Red grouper	-5.94	Rock/bank seabass
<1%	Demersal coastal omnivores	1	Anchovies	<1%	Pelagic planktivores	59	Vermilion snapper	49	Black seabass	44	Red snapper age 0	-0.001	Wreckfish	-0.003	Adult king mackerel		
<1%	Ichthyoplankton	1	Other porgys	<1%	Encrusting fauna	57	Small coastal sharks	49	Other porgys	44	Scamp grouper	-0.001	Gag grouper	-0.003	Wreckfish		
<1%	Demersal coastal invertivores	<1%	Encrusting fauna	<1%	Other jacks	57	Rock shrimps	48	Benthic oceanic	43	Nassau grouper	-0.001	Greater amberjack	-0.005	Benthic oceanic		
<1%	Estuarine benthic detritus	<1%	Carnivorous zooplankton	<1%	Offshore benthic detritus	56	Red drum	48	Pelagic oceanic piscivores	43	Other shallow grouper/tilefish	-0.001	Vermilion snapper	-0.007	Scamp grouper		
<1%	Seagrasses	<1%	Estuarine infaunal	<1%	Red porgy	56	Gray snapper	48	Offshore dolphins	43	Cobia	-0.001	Red grouper	-0.007	Gag grouper		
<1%	Echinoderms and gastropods	<1%	Echinoderms and	<1%	Estuarine infaunal	55	Black seabass	47	Wreckfish	42	Bonefish	-0.001	Benthic oceanic piscivores	-0.007	Rock/bank seabass		
<1%	Benthic meiofauna	<1%	Other jacks	<1%	Syngnathids	53	Snowy grouper	46	Other shallow grouper/tilefish	42	Gray snapper	-0.004	Red lionfish	-0.009	Other grunts		
		<1%	Estuarine polychaetes	<1%	Demersal coastal piscivores	53	Red snapper age 1-3	45	Other shallow snapper	41	Mutton snapper	-0.006	Black seabass	-0.009	Black seabass		
		<1%	Pelagic planktivores	<1%	Other sciaenids	52	Other deep grouper	45	Beaked whales	40	Snowy grouper	-0.007	Other shallow snapper	-0.018	Red porgy		
		<1%	Offshore benthic	<1%	Ichthyoplankton	49	Octopods	44	Halfbeaks	40	Gag grouper	-0.015	Rock/bank seabass	-0.020	Red lionfish		

Table 5. Table of Diet items >1%, top Prey Overlap results, Top 15 and Bottom 15 Mixed Trophic Index Results, and the Top Winner and Bottom Losers of High Recent Recruitment vs. Longterm Average Recruitment scenario testing in Ecosim. Purple fill indicates species in common across Age 1-3 columns. Purple text indicates species in common across Age 4+ columns. Mixed Trophic Impacts for Age 0 were omitted due to the relatively small impact of those results.

Workshop Discussion

Additional topics discussed during the workshop are outlined below. Full notes are available in **Appendix D**.

Overall model conclusions

1. Model properly addressed the question and demonstrated which species have positive and negative changes in biomass due to Red Snapper recruitment. Higher red snapper biomass led to minor declines (<10%) in biomass to Bank Sea Bass, Black Sea Bass, and other grunts (Tomtate). Small negative changes (<1%) in biomass were observed for Red Grouper, Gag Grouper, and Scamp, while positive effects were observed for Mutton Snapper and large coastal sharks.
2. The model provided insights on the trophic impacts of Red Snapper on other species (EBFM).
3. Increasing Red Snapper recruitment could increase abundance of some species and lead to decreases for others. Higher Red Snapper recruitment could reduce biomass of black sea bass, but the scale of the impacts is minor (less than 5%).
4. These findings can be used to direct data collection needs such as Red Lionfish, which has minimal biomass in the model and shows negative impacts. These results could also inform better monitoring of species with high management interest and negative impacts when Red Snapper is increasing, such as black sea bass.
5. Exploration in the model of direct vs indirect impacts can help figure out what might be the driving factor for impacts (e.g., competition vs. predation) or even ways to improve populations (e.g., habitat restoration).
6. These results are on a similar scale to modeling efforts on reef fish from West Florida Shelf. This is likely due to the generalist nature of the species in question.
7. Operationalizing the model could be based on regular data updates which will require re-fitting (1-2 months for very large changes).
8. Development of EwE models is an iterative process and more the model is explored the better it will become

Assumptions of spatial structure in Ecosim estimates

The MT and WG discussed that Ecopath and Ecosim both assume entirely overlapping habitats for all groups. They looked at maps of red snapper and black sea bass centers of abundance and discussed that Ecospace would be beneficial for exploring how habitat overlap modifies the biomass impacts. The MT pointed out that, due to computing limitations of such a large model, the highest possible resolution in Ecospace is 15km^2, which may not be informative. The WG discussed that a simplified version of this model may be beneficial and that Ecospace would allow for further exploration of localized impacts.

Next step model improvements

The MT and WG discussed that the model cannot pick up random spikes in recruitment. This was proposed as a reason for why the model's estimates didn't fit to the observed black sea bass or red grouper data over particular stretches of years. The MT confirmed that one of the next steps is to add Fishing Mortality time series for more species of interest and use these data, rather than catch, to drive the Ecosim estimates. Additional methods will be explored for improving the fits of other important species if needed. The MT also confirmed that results of the recent Greater Amberjack SEDAR process will be added to the model soon.

Other options for simulating recruitment events

- Try to include environmental drivers that change recruitment as another forcing function.
- Take recruitment deviations and use those as multipliers to youngest age stanza.
- Simulate possible (hypothesis building) trends in abundance based on recent data (projections).
- Recruitment variability for some stocks is likely to occur - try to add into the model.

Longterm model improvements

- Explore ways to address or test uncertainties of model assumptions in a hypothesis-driven fashion.
- Add lionfish invasion if data is available.

MICE modeling techniques

The MT and WG discussed that this model is exceptionally large and is therefore limited by computing power and time for some iterative processes, tools, and sensitivity/uncertainty simulations. The MT introduced the idea of the MICE (Model of Intermediate Complexity for Ecosystem Assessment) modeling technique, in which a smaller version of any large model is created for a particular purpose or question. The large parent model's data and functional groups are usually combined to create a small model with most of the ecosystem in a handful of functional groups, but with all the groups central to a question being entirely articulated with age stanzas. These smaller models benefit from better fitting, faster simulation runs, easier interpretation, less trophic linkages, and higher spatial resolution in Ecospace. These smaller models can be used to do quick analyses that help inform decisions in the larger model, as well as explore particular interactions that are difficult to trace in the parent model. This technique was proposed as a method which may be employed in future modeling efforts.

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Appendix A: 140 Functional Groups of the SAR EwE Model

1	Coastal bottlenose dolphin	29	Pelagic oceanic piscivores	57	Benthic coastal invertivores	85	Bar jack	113	Golden crabs
2	Offshore dolphins	30	Snook	58	Hogfish	86	Blue runner	114	Stone crabs
3	Pilot whales	31	Tarpon	59	Benthic coastal planktivores	87	Other jacks	115	Spiny lobster
4	Beaked whales	32	Pelagic coastal piscivores	60	Ocean triggerfish	88	Red porgy	116	Rock shrimps
5	Sperm whales	33	Cobia	61	Gray triggerfish	89	Other porgys	117	Penaeid shrimps
6	Baleen whales	34	Bonefish	62	Queen triggerfish	90	White grunt	118	Mega-invertebrate predators
7	Manatees	35	Demersal coastal piscivores	63	Gag grouper	91	Other grunts	119	Echinoderms and gastropods
8	Planktivorous sharks	36	Pelagic planktivores	64	Red grouper	92	Black seabass	120	Estuarine infaunal crustaceans
9	Large coastal sharks	37	Herrings	65	Scamp grouper	93	Rock/Bank seabass	121	Estuarine polychaetes
10	Small coastal sharks	38	Sardines	66	Goliath grouper	94	Wreckfish	122	Bivalves/Oysters
11	Dogfish sharks	39	Anchovies	67	Nassau grouper	95	Great barracuda	123	Offshore infaunal crustaceans
12	Pelagic sharks	40	Silversides	68	Other shallow grouper/tilefish	96	Atlantic mackerel	124	Offshore polychaetes
13	Pelagic rays	41	Halfbeaks	69	Snowy grouper	97	Auxis mackerels	125	Small mobile epifauna
14	Demersal rays/skates	42	Scads	70	Other deep grouper	98	Sea turtles	126	Benthic meiofauna
15	Adult king mackerel	43	Shad	71	Blueline tilefish	99	Carnivorous jellies	127	Deep-burrowing infauna
16	Juvenile king mackerel	44	Syngnathids	72	Golden tilefish	100	Birds - oceanic piscivores	128	Carnivorous zooplankton
17	Spanish mackerel	45	Sunfish	73	Yellowtail snapper	101	Birds - shorebirds	129	Other zooplankton
18	Juvenile Spanish mackerel	46	Permit	74	Mutton snapper	102	Birds - shelf piscivores	130	Ichthyoplankton
19	Bluefish	47	Demersal coastal invertivores	75	Gray snapper	103	Birds - herbivores	131	Microbial heterotrophs
20	Weakfish	48	Demersal coastal omnivores	76	Lane snapper	104	Birds - wading piscivores	132	Phytoplankton
21	Red drum	49	Atlantic spadefish	77	Other shallow snapper	105	Birds - shelf invertivores	133	Microphytobenthos
22	Atlantic menhaden	50	Benthic oceanic piscivores	78	Vermilion snapper	106	Birds - raptors	134	Benthic macroalgae
23	Spotted seatrout	51	Benthic oceanic invertivores	79	Red snapper age 0	107	Encrusting fauna	135	Pelagic macroalgae
24	Mullets	52	Red Lionfish	80	Red snapper age 1-3	108	Squids	136	Seagrasses
25	Other sciaenids	53	Summer flounder	81	Red snapper age 3+	109	Stomatopods	137	Marsh vegetation
26	Striped Bass	54	Southern flounder	82	Other mid-shelf snapper	110	Octopods	138	Estuarine benthic detritus
27	Highly Migratory Pelagics	55	Gulf flounder	83	Greater amberjack	111	Blue crabs	139	Offshore benthic detritus
28	Dolphinfish	56	Benthic coastal piscivores	84	Almaco jack	112	Horseshoe crabs	140	Water-column detritus

Appendix B. Select Representatives of Aggregated Species Group

Benthic coastal invertivores: Gobies, dusky flounder, leopard sea robin

Benthic coastal piscivores: Inshore lizardfish, snake eels

Benthic coastal planktivores: Cardinalfish, reeffish, chromis

Benthic oceanic invertivores: Bighead sea robin, goldface tilefish, batfish

Benthic oceanic piscivores: Offshore lizardfish, pike-conger, goosefish

Demersal coastal invertivores: Catfish, pompano, mojarra, sturgeon

Demersal coastal omnivores: Puffers, filefish, damselfish, angelfish

Demersal coastal piscivores: Morays, conger eel, Atlantic cod, pollock

Highly migratory pelagics: Swordfish, sailfish, marlin, bluefin tuna

Large coastal sharks: Bull, dusky, blacktip, tiger, sandbar

Other deep grouper: Yellowedge, Warsaw, speckled hind

Other grunts: Tomtate, sailor's choice, margate

Other jacks: Banded rudderfish, lesser amberjack, crevalle

Other mid-shelf snapper: Silk, blackfin, queen

Other porgys: Scup, grass, jolthead, sheepshead

Other sciaenids: Spot, Atlantic croaker, kingfish

Other shallow grouper/tilefish: Rock hind, graysby, yellowmouth, yellowfin

Other shallow snapper: Dog, mahogany, schoolmaster, cubera

Pelagic coastal piscivores: Ladyfish, little tunny, bonito, cutlassfish

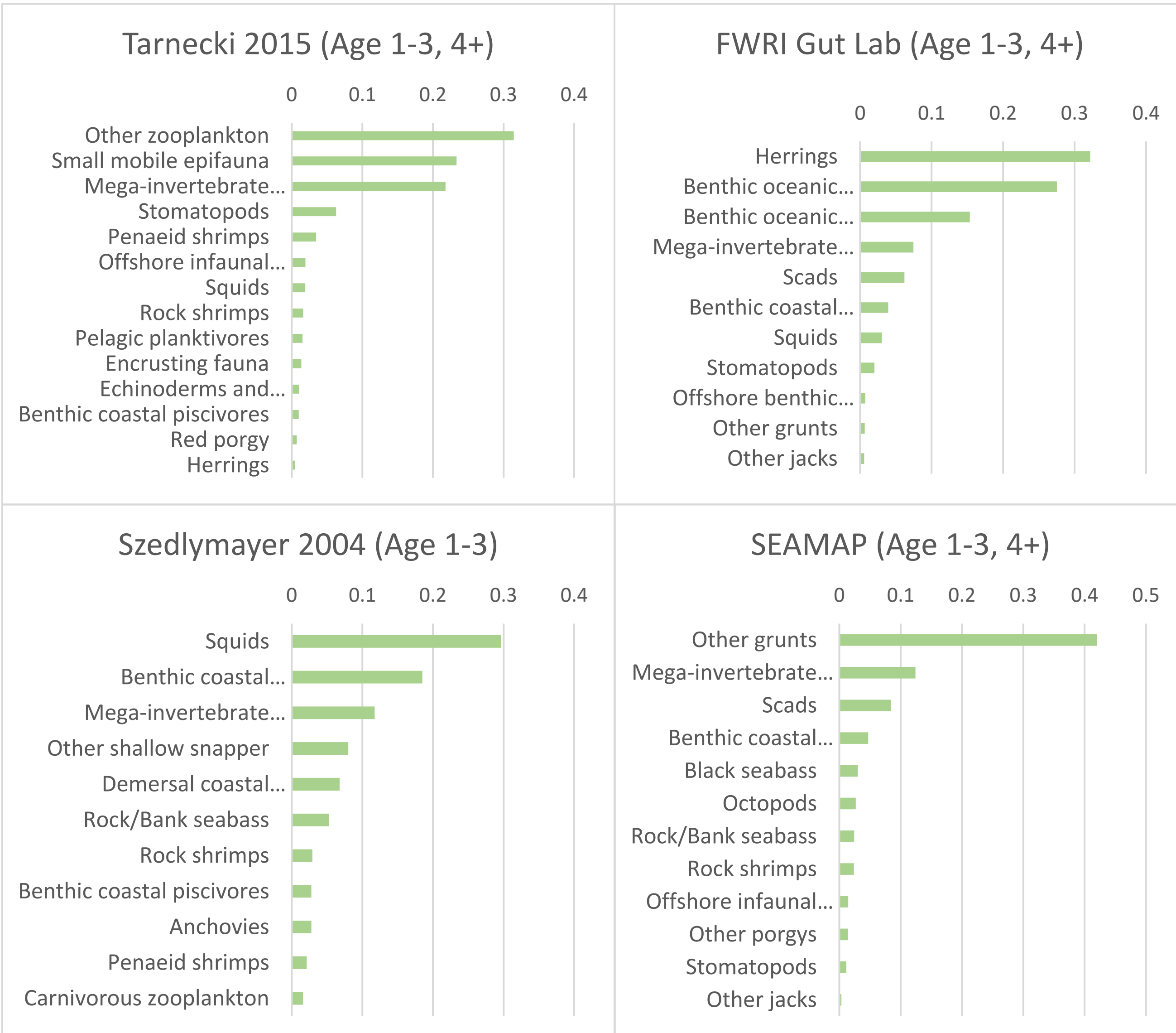
Pelagic oceanic piscivores: Offshore hake, flyingfish, needlefish, wahoo

Pelagic planktivores: Hatchetfish, lanternfish, gulf butterfish

Pelagic sharks: Thresher, white shark, mako, hammerhead

Appendix C.

I. Abbreviated Diets of Studies used for red snapper EwE diets (Age 1-3, Age 4+)



II. Final Weighted Red Snapper Diets

Age 0		Age 1-3		Age 4+	
Prey	Proportion	Prey	Proportion	Prey	Proportion
Mega-invertebrate predators	0.287634	Other grunts	0.164862	Other grunts	0.197600
Stomatopods	0.203153	Mega-invertebrate predators	0.142215	Mega-invertebrate predators	0.162447
Squids	0.135579	Squids	0.098629	Herrings	0.099471
Bivalves/oysters	0.076163	Herrings	0.082398	Other zooplankton	0.096017
Small mobile epifauna	0.050249	Benthic oceanic invertivores	0.072061	Benthic oceanic invertivores	0.084614
Offshore polychaetes	0.036488	Benthic coastal invertivores	0.064527	Small mobile epifauna	0.071448
Benthic coastal invertivores	0.033410	Other zooplankton	0.043295	Benthic oceanic piscivores	0.048142
Pelagic planktivores	0.022630	Benthic oceanic piscivores	0.039583	Stomatopods	0.031973
Other zooplankton	0.022124	Small mobile epifauna	0.032812	Scads	0.025550
Octopods	0.016636	Benthic coastal piscivores	0.027671	Benthic coastal piscivores	0.024915
Benthic coastal piscivores	0.014936	Rock/Bank seabass	0.024775	Black seabass	0.019185
Anchovies	0.013653	Other shallow snapper	0.023478	Rock shrimps	0.018869
Carnivorous zooplankton	0.010861	Rock shrimps	0.022223	Octopods	0.018036
Encrusting fauna	0.010316	Stomatopods	0.021622	Squids	0.017079
Rock shrimps	0.010299	Scads	0.021317	Offshore infaunal crustaceans	0.014412
Penaeid shrimps	0.010299	Demersal coastal omnivores	0.019866	Benthic coastal invertivores	0.012810
Estuarine infaunal	0.010299	Octopods	0.017051	Rock/Bank seabass	0.011295
Estuarine polychaetes	0.010299	Black seabass	0.016007	Penaeid shrimps	0.010825
Benthic oceanic piscivores	0.009957	Penaeid shrimps	0.010810	Other porgys	0.006707
Demersal coastal piscivores	0.008147	Offshore infaunal crustaceans	0.009569	Echinoderms and gastropods	0.005104
Demersal coastal omnivores	0.004731	Anchovies	0.008127	Pelagic planktivores	0.004613
Ichthyoplankton	0.000928	Other porgys	0.005596	Encrusting fauna	0.004186
Demersal coastal invertivores	0.000905	Encrusting fauna	0.004722	Other jacks	0.003287
Estuarine benthic detritus	0.000250	Carnivorous zooplankton	0.004708	Offshore benthic detritus	0.002243
Seagrasses	0.000025	Estuarine infaunal	0.004618	Red porgy	0.002139
Echinoderms and gastropods	0.000013	Echinoderms and gastropods	0.002990	Estuarine infaunal	0.001599
Benthic meiofauna	0.000012	Other jacks	0.002743	Syngnathids	0.000986
		Estuarine polychaetes	0.002688	Demersal coastal piscivores	0.000859
		Pelagic planktivores	0.001924	Other sciaenids	0.000816
		Offshore benthic detritus	0.001871	Ichthyoplankton	0.000544
		Offshore polychaetes	0.001103	Carnivorous jellies	0.000492
		Red porgy	0.000922	Offshore polychaetes	0.000431
		Syngnathids	0.000823	Estuarine polychaetes	0.000400
		Demersal coastal piscivores	0.000716	Bivalves/Oysters	0.000229
		Ichthyoplankton	0.000454	Benthic macroalgae	0.000208
		Other sciaenids	0.000340	Vermilion snapper	0.000137
		Carnivorous jellies	0.000245	Ocean triggerfish	0.000091
		Bivalves/Oysters	0.000191	Gray triggerfish	0.000091
		Benthic macroalgae	0.000174	Queen triggerfish	0.000091
		Vermilion snapper	0.000114	Blue crabs	0.000030
		Ocean triggerfish	0.000038	Other mid-shelf snapper	0.000023
		Gray triggerfish	0.000038	Pelagic macroalgae	0.000003
		Queen triggerfish	0.000038	Benthic meiofauna	0.000002
		Blue crabs	0.000025		
		Other mid-shelf snapper	0.000019		
		Pelagic macroalgae	0.000002		
		Benthic meiofauna	0.000001		

Appendix D. Full Workshop Notes

Day 1

Potential Items: preference highlighted, Day 2 notes

1. Focus on South Atlantic Region (SAR) studies and reduce Gulf of Mexico (GM) diet studies to adjust weights – new diet could change all fits. Vulnerability parameters will change and should be recalibrated (post workshop). Check to see if population trends are similar among regions.
    a. Remove GM diet studies – 100% SAR studies
    b. 80 SAR/20 GM and weighted by sample size
        i. Largest changes
            1. Positives – other grunts, herring, invertivores,
            2. Negatives – squids, other zooplankton
        ii. Red lionfish were added into bottom 10. Not a big change
        iii. Essentially an identical result
    c. Equally weight all studies – not based on sample size
    d. Status Quo - based on sample size
    e. Add in other studies
2. What would it take to get negative impact to 10% for Black Sea Bass?
    a. Increase the biomass of Red Snapper until this impact is reached
    b. Increase vulnerability of prey to Red Snapper potentially 50% (consider reduction in vulnerability as a future check)
        i. 3 levels were tested. 1.5 x, 2x, and 10 x
        ii. 10 x caused huge increase in Red Snapper biomass
        iii. Biomass of all ages goes up
        iv. Negative impact of 10% to Black Sea Bass was between 2 x and 10 x vulnerability. Other species were more impacted.
        v. If increase of Red Snapper biomass can impact 4 to 5 fold beyond projected level, there can be a significant impact to Black Sea Bass and Red Porgy
        vi. The fits to the time series got worse as vulnerability was increased. The 10x run was highly chaotic.
        vii. Vulnerability parameter is shared amongst all prey items by predator but differs among age groups for Red Snapper.
        viii. Model shows the potential to answer such questions and useful for management
3. Simulate biomass trends to see how it impacts outcomes
    a. Increasing catch of Black Sea Bass 2016 to 2044 and increase abundance of Red Snapper
    b. Increased constant catch of Black Sea Bass and increase abundance of Red Snapper
        i. Resulted in minor changes of Black Sea Bass population when catch of Black Sea Bass is held constant at higher levels and recruitment of Red Snapper varies.
    c. Scale to highest historic catch at 2044
4. ~~Lower vulnerability of Red Snapper to predators (instead of increasing Red Snapper prey vulnerability).~~ *Cannot be done for age 0 because the vulnerability is already set at 1*
5. Lauren will send out mixed trophic impacts paper

6. Luke and Dave will check on what scales represent for the impacts and if they can be compared across functional groups
7. Include impacts to other age groups of Red Snapper
8. Contact Kevin Spanik on his 2018/2019 data (later)
9. Possible reasons why model is not fitting well for Black Sea Bass and Red Grouper. The EwE model cannot pick up on random spikes in recruitment. It may be possible to improve fits for Black Sea Bass (post workshop)
10. Put winners and losers in a spreadsheet to note changes over the model.
11. Direct vs Impacts and look at reasons for bottom four/five species.
12. Invasive species are difficult to model and red lionfish have high prey overlap with Red Snapper. Dave has two papers on this. Future iterations of model might look into this
13. Potentially look at low recruitment for species like Red Porgy. Future iterations of model might look into this. Use a MICE model.

Day 2

1. Mixed trophic impacts (snapshot of time)
    a. Age 0 increase for red snapper will lead to decrease within group.
    b. Older age groups will benefit age 0.
    c. Impacts are not as strong as species on bottom. Within group impacts indicate results are reasonable
    d. Likely an indirect impact. Typically negative for in-species comparison with stanzas.
2. Niche Overlap (diet), Mixed Trophic (snapshot), Scenario Testing (ecosim)
    a. 20% is common overlap among all species in the database
    b. 40% or 50% indicates considerable overlap
    c. Black Sea Bass are one of the most sensitive to changes in Red Snapper biomass.
3. Drivers between mixed trophic impacts (can range from -1 to 1)
    a. Drivers are diet, competition, and predation
    b. Direct and indirect impacts of trophic cascade
    c. Where diets differ is sufficient to cause differences between age groups of Red Snapper
    d. Overlapping mixed trophic impacts are pretty small ranging from (-0.027 to .0004)
4. Black Sea Bass to 1/3 of diet of adult groups
    a. Breaks model
    b. 10 to 25% breaks
    c. 25% of 4+ and 1% of younger – the difference between the high recruitment and average recruitment does not have substantial impacts. Additionally other species do not change much indicating the indirect impacts are not substantial.
5. The original question has been addressed very well.
6. Given that diet composition and vulnerability appear to be the primary drivers, is there an efficient way to examine sensitivity to variation in these components?
    a. Monte Carlo simulations can investigate the sensitivity to diet composition but not vulnerability
    b. Uncertainty simulation would need to constrain vulnerability to an error estimate which is not an output of the model.

    c. The size of the model limits what can be done to understand the uncertainty.
7. Direct vs indirect impacts comparison could be based on predation mortality rate
8. Operationalizing the model could be updated based on new diet data. If changing forcing data, probably do not need to change the vulnerabilities.
    a. Refitting would likely take less than 4 months (1 or 2 months).
    b. Model takes 12 hours on normal computer or 6 hours on server.
9. Group homework:
    a. What implications do these results have for management?
    b. What improvements to the model?

Sensitivity analyses should best be hypothesis driven, right?

Yes. What is the output of interest? What is the practical application?

Day 3

1. Group homework:
    a. What improvements to the model would be helpful for understanding increased recruitment of Red Snapper? (some for future explorations and some for report to ssc)
        i. Explore ways to address or test uncertainties of model assumptions (way down the line)
        ii. Spanik et al. 2021 paper was already included
        iii. Explored reason lack of fit
            1. Black Sea Bass (seemed to be higher than average recruitment based on SEDAR 56).
            2. Red Grouper
            3. Snowy Grouper
        iv. The latest SEDAR results for Greater Amberjack will be included
        v. How does F from the EwE modelling compare to single species assessment F?
        vi. Techniques to force other populations?
            1. Used current level catch with estimates of catch
            2. What are possible trends in biomass given the history of fishery and stock dynamics?
            3. Planning team is trying to use F from stock assessments instead of catch
        vii. How can strong recruitment events be incorporated into the model?
            1. Try to include environmental drivers that change recruitment as another forcing function
            2. Take recruitment deviations and make those as multipliers to youngest age stanza.
            3. Simulate possible (hypothesis building) trends in abundance based on recent data (projections)
            4. Recruitment variability for some stocks is likely to occur and try to add into the model (projections)
            5. What is the goal? Random noise vs projection signals
                a. Look at winners and losers for those with stock assessments

b. Include stock status by stable trend in landings, increased from overfished condition, decrease from B >>Bmsy

viii. What is the influence of start year 1995?
1. Not much of impact on the model
2. Impact would be if the quality of the data was worse or bias when model was initialized

ix. Spatial preferences for species in the model. Red Snapper and Black Sea Bass center of abundance are not overlapping. Currently the model does not have spatial effect. Ecospace will require pretty specific questions. Highest resolution is 15 km and may not be able to be captured. Simplifying this model may be beneficial to running Ecospace

x. Discards by stanzas based on outputs of SEDAR 73

xi. Lionfish are included in the model (ecopath) but only a very small amount of biomass has been incorporated (no time series in ecosim). It is important but might not have sufficient data. Potentially use information from Gulf of Mexico or other trends. Look at data for SA maybe from USGS

xii. MICE model (model of intermediate complexity for ecosystem assessment) technique might be appropriate to address a focused group of species
1. Allows for better fitting
2. More simulations
3. Easier to interpret
4. Current model is difficult to track down causal factors
5. Consider species, stanzas, and how to force before starting to model
6. Easier to build a spatial model

b. What implications do these results have for management?

i. Model properly addressed the question and demonstrated which species have positive and negative changes in biomass due to Red Snapper recruitment

ii. The model provided insights on the impacts of Red Snapper management/recruitment on other species (EBFM). Scenario of increased recruitment based on 80% SAR diet and weighted by sample size
1. Led to negative changes in biomass to Bank Sea Bass, Black Sea Bass, and other grunts (Tomtate).
2. Minor negative changes in biomass were observed for Red Grouper, Gag Grouper, and Scamp
3. Positive effects were observed for Mutton Snapper and large coastal sharks

iii. Increasing Red Snapper recruitment could increase abundance of some species and decrease others. Higher Red Snapper recruitment could reduce biomass of Black Sea Bass but the scale of the impacts is minor (less than 5%).

iv. If the Red Snapper population is increased using the 2x vulnerability parameter (uncertain model and biomass was higher than historic levels), there can be a significant impact on some populations (15% reduction for Bank Sea Bass).

Model was not particularly sensitive to changes in the vulnerability parameter for Red Snapper.

v. The finding can be used to direct data collection needs such as Red Lionfish, which has minimal biomass in the model and shows negative impacts. Also could direct better monitoring of species with high management interest and negative impacts when Red Snapper is increasing such as Black Sea Bass.
vi. Direct vs Indirect Impacts – Can figure out what might be driving factor for impacts such as competition or predation, or even ways to improve populations such as habitat improvements.
vii. Localized impacts – could have larger impacts for localized areas where species overlap but currently unknown because the model does not have a spatial component.
viii. Reef fish tend to be generalists. Results from West Florida Shelf (some up to 10%) are on a similar scale to those observed in this model.
ix. Some species specialize during parts of their life history and research will need to be conducted to potentially incorporate into future versions of EwE.
x. Development of EwE models is an iterative process and the more the model is explored the better it will become