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# An Aggregate and MS Production Model: A Simulator Tool

GARM-III Biological Reference Point Meeting, System Capacity Analyses

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**Introduction:**

This Working paper addresses TOR 3 of section F: Ecosystem Approaches to Gulf of Maine/Georges Bank fisheries. It provides analyses to determine those factors which affect productivity of commercial stocks, and aggregate groups thereof, for the Northeast Shelf LME (Large Marine Ecosystem). The purpose of this working paper is to provide a parameterized model closely resembling the NE Shelf LME that tests the effects of carrying capacity constraints, turning fishing on or off, and turning species interactions on or off. It is NOT intended to be a fitting or tuning model; rather it is intended to provide a scoping of the issue within a reasonable set of fixed parameter space as a simulating tool.

The technical basis for simulating MS and aggregate dynamics for GARM, elasmobranch and pelagic stocks is founded on the following observations.

1. Fish stocks have a carrying capacity that is distinct from an aggregate and/or total system carrying capacity, but such a systemic carrying capacity also exists (e.g., Brown et al. 1976; May et al. 1979; Pauly and Christensen 1995; Pauly et al. 1998; Pauly et al. 2002).
2. Fishing rates below growth rates engender a stock reaching its carrying capacity; and vice versa (e.g., Graham 1943; Schaeffer 1954).
3. Species interactions, both competition and predation, may similarly influence a stock's ability to reach carrying capacity (e.g., May 1975; Pope 1975; Fukuda 1976; Brown et al. 1976; Pope 1979, Mueter and Megrey 2007).

Information summarized for other system capacity issues (Working Papers 3.1-3.3) are used to inform the parameterization of the present set of analyses. The aim of this work is to provide approximate bounds to fish stock production in the presence and absence of set carrying capacities (based off of $B_{MSY}$), fishing removals of biomass, and species interactions.

## Methods

*Model Structure*

The Aggregate Biomass model we present is derived from the Schaeffer production model (Schaeffer 1954):

$$\frac{dN}{dt} = rN(1 - \frac{N}{K}) - qEN \qquad \text{EQ. 1}$$

where $N$ is the biomass of the considered species, $r$ is the intrinsic growth rate, $k$ is the carrying capacity, and the product $q$ (catchability) $E$ (fishing effort) $N$ is the fishery harvest of the species. For simplicity of parameterization as described below, we combine $q$ and $E$ into $H$, for harvest rate. Our model incorporates a guild structure within which multiple species can be included. Each species $i$ belongs to a particular guild $g$, resulting in a series of Schaeffer equations for each species/stock.

Our first modification incorporated a variation of Volterra's (via Gause) two species competition model to account for any number of species (Volterra 1931):

$$\frac{dN_i}{dt} = r_i N_i (1 - \frac{N_i}{K_G} - \frac{\sum_1^g \beta_{ig} N_g}{K_G}) - H_i N_i \qquad \text{EQ. 2}$$

where $K_G$ is the carrying capacity of the functional guild $G$ that species $i$ is in. $N_g$ is the biomass of guild member $g$, and $\beta_{ig}$ is the competition coefficient between species $g$ and species $i$. Since this term only accounts for competition within a guild, we refer to it as intra-guild competition. We combine catchability ($q$) and fishing effort ($E$) together into a single harvest rate ($H_i$) on species $i$.

Next we incorporated a term to account for competition between guilds, which we refer to as inter-guild competition:

$$\frac{dN_i}{dt} = r_i N_i (1 - \frac{N_i}{K_G} - \frac{\sum_1^g \beta_{ig} N_g}{K_G} - \frac{\sum_1^G \beta_{iG} N_G}{(K_\sigma - K_G)}) - H_i N_i \qquad \text{EQ. 3}$$

where $K_\sigma$ is the system carrying capacity. $N_G$ is the total biomass of all species within guild $G$, and $\beta_{iG}$ is the competition coefficient between species $i$ and guild $G$.

Finally we incorporated a predation term derived from the Lotka-Volterra model of predation (Volterra 1926) as modified by Leslie and Gower (1960; a la Rosenzweig and MacArthur):

$$\frac{dN_i}{dt} = r_i N_i (1 - \frac{N_i}{K_G}) - N_i \sum_1^p \alpha_{ip} N_p \qquad \text{EQ. 4}$$

Which when integrated with prior competition and harvest terms results in the following final model structure:

$$\frac{dN_i}{dt} = r_i N_i (1 - \frac{N_i}{K_G} - \frac{\sum_1^g \beta_{ig} N_g}{K_G} - \frac{\sum_1^G \beta_{iG} N_G}{(K_\sigma - K_G)}) - N_i \sum_1^p \alpha_{ip} N_p - H_i N_i \qquad \text{EQ. 5}$$

where $\alpha_{ip}$ is the predation coefficient representing the effect of predation on species *i* by predator *p* and $N_p$ is the biomass of predator *p*. Inter-guild and intra-guild predation are both accounted for by this term, since the species of each guild are explicitly included. Further, to account for spatio-temporal variability, we weighted all α and β by a spatial overlap index (ranging from 0 to 1).

This resultant form is similar to other multispecies fisheries production models that have been constructed elsewhere (e.g. Mueter and Megrey 2007) and in this region (Spencer and Collie 1996, Collie and DeLong 1999). This approach, before some modifications to separate each term in the model structure, has also been presented previously (Link 2003).

*Model Parameterization and Simulations*

Data for the 19 GARM stocks, 3 pelagic stocks, and elasmobranchs (Spiny dogfish and 7 skate stocks) were assembled from available information (c.f. Working Papers 3.1 to 3.3) on initial biomass values for individual stocks. Estimates of $B_{MSY}$ were doubled and used for *k* and estimates of $F_{MSY}$ were doubled and used for *r* (Applegate et al. 1998; NEFSC 2002, 2007; other working papers for this TOR). Values for small pelagics and elasmobranch were approximated from the status of the stocks values and although equivalent to approach used for the GARM species just noted, were a little more

flexible in initial parameterization. Based upon WP 3.1, we set the system fish carrying capacity to 8 million MT, the GARM *K* to 2.8 million MT, the pelagics *K* to 2.6 million MT, and the elasmobranch *K* to 2.3 million MT (all two times the $B_{MSY}$ estimates from WP 3.1).

We assigned each stock to one of three guilds: GARM species, small pelagics, or elasmobranchs. We ran the model with both a multispecies and an aggregate approach for these guilds, with the former parameterized for each of the ~30 stocks and the latter parameterized for just the three aggregate groups (with intra-guild competition turned off).

In terms of species interactions, we set the inter-guild $\beta_{iG}$ to 0.2 between GARM stocks and elasmobranchs and to 0.02 between elasmobranchs and small pelagics. We parameterized the within guild $\beta_{ig}$ as an approximation from a diet overlap matrix (Table 1). We set the predation $\alpha_{ip}$ only on the small pelagics which was informed by stomach contents data (see Link and Almeida 2000). Finally, we set the inter-specific spatial overlaps based upon a spatial overlap matrix of survey data (Table 2).

We set the fisheries removals as a rate of removal for each year. We set these to 0.1 (i.e., ~10% of the biomass) for each year in the base scenarios. These were not set to mimic any particular fishing trajectory; rather to show the effects of fishing or not when this portion of the model was turned on. We ran the simulations for 30 years with an annual time step.

*Scenarios*

We did four scenarios for both an aggregate and multispecies (MS) parameterization. For either the aggregate or MS set up, we did a simulation with no fishing and no species interactions, fishing and no species interactions, no fishing and species interactions, and fishing and species interactions. Basic parameterizations for both the aggregate and MS versions are given in Tables 3 and 4, respectively.

We then fixed the species interactions as full-on for the MS version and then varied the levels of harvest from 0.01, 0.05, 0.1, 0.2, 0.3, and 0.5. This represented a sensitivity test of sorts regarding harvest rates.

Finally, we examined the outcome of differential harvest rates across the main guilds. Again, we fixed the species interactions as full-on in the MS version and then turned fishing on (at 0.1) or off for different species groups. Scenarios we evaluated were: fishing on groundfish only, elasmobranchs only, pelagics only, elasmobranchs and pelagics, and groundfish and elasmobranchs.

For all scenarios we present individual species biomass trajectories, guild biomass trajectories, total demersal biomass, total pelagic biomass, total biomass trajectories, and for selected species "losses" or biomass removals due to harvest, predation, within guild competition, and between guild competition.

## Results and Discussion

### *Scenarios*

The aggregate biomass simulations showed four main results (Figures 1-6; Table 5). First, all groups of species were at approximately equal levels with no fishing and no species interactions, with groundfish slightly more abundant. Second, harvesting impacts

the pelagics and elasmobranchs more than the groundfish (Figures 2a, 5, 6a, 6c). Third, species interactions impacted small pelagics the most (as would be expected due to predation; Figures 3a, 3b, 4c, 5, 6c). Finally, with no harvest or interactions, the system produced a total biomass close to system carrying capacity (Table 5; Figure 1b). As either interactions or harvest were turned on (Figures 2b, 3b; Table 5), the total biomass in the system was less. With both factors occurring, the total biomass was approximately half of the system carrying capacity (Table 5; Figure 5b).

The multispecies biomass simulations showed five main results (Fig. 7-18; Table 6). First, with no harvest or interactions, most species achieve their guild's carrying capacity (Figure 7). And because of this, with a higher number of species in the group groundfish tend to dominate the systemic biomass (Figures 7, 8b). Similarly, biomasses for the entire system tend to be quite high, with each species at their guild's carrying capacity. Second when species interactions are turned on, simulations suggest that not all species may reach their carrying capacities; or if they do it will take much, much longer to reach that biomass level (Figures 11, 15). Thus it appears that species interactions, particularly, competition, is a significant source of influence on many of these fish species (Figures 13, 14, 17, 18). Predation can also be an important factor for small pelagic fishes (Figures 14 c, d, 18 c, d). Third, when just harvest is accounted for with no species interactions, the simulations suggest that this source of removal is minimal compared to those which include interactions (c.f., Figures 10 and 16). Fourth, when both harvest and species interactions are acting, the simulations show that all species are at much lower values and the total biomass of the system is nearly an order of magnitude lower than if these are not included, particularly interactions (Table 6; Figures 15, 16).

This implies that within guild interactions and species-specific predation (Figures 17, 18) are a particularly notable factor to consider in the dynamics of these species and their associated ecosystem. Finally, comparing the aggregate versus MS versions showed that these results had a higher ending total biomass than the aggregate version (Table 3, 4). This suggests that the number of species being considered may inflate estimates of total biomass in the ecosystem (by assuming all can reach their carrying capacities), especially if species interactions are not accounted for.

For the MS set of simulations, one could parameterize the model with K set per species as opposed to sums thereof for each guild. Yet doing this or parameterizing with Ks per guild can both produce some unrealistic results. In the latter instance the biomasses can exceed system carrying capacity with limited removals (harvest, interactions). In the former instance when we set the Ks all to a species level (not shown here), there was no possibility for species to replace or compensate for biomass when another species was reduced in biomass, either within or between guilds. The lack of between guild compensation would also occur in the aggregate simulation scenarios. We chose the latter approach (K per guild) to allow for this systemic compensation but could certainly explore the former in future efforts. By choosing the Ks per species, we would pre-condition the results to never all be at or near K; by choosing the Ks per guild, and recognizing that harvesting and species interactions do occur at some level, we were able to explore potential tradeoffs among and within guilds more fully.

The differing levels of harvest simulations showed four main results (Fig. 19-42; Table 7). First, as would be expected, when harvest levels increased (particularly above the basal level (0.1)), elasmobranchs declined (Table 7; Figures 19a, 20a, 22b, 23a, 24a,

26b, 27a, 28a, 30b, 31a, 32a, 34b, 35a, 36a, 38b, 39a, 40a, 42b). Second, and a bit unexpectedly, small pelagics were largely unaffected by differing harvest rates, implying that as harvest increased on all groups, groundfish and elasmobranch predation on and competition with small pelagics was lessened (Table 7; Figures 19c, 20a, 22c,d, 23c, 24a, 26c,d, 27c, 28a, 30c,d, 31c, 32a, 34c,d, 35c, 36a, 38c,d, 39c, 40a, 42c,d). Third, groundfish tended to compensate (largely via competitive release) for declining elasmobranchs and actually increased with increased harvest rates, up to the highest rate we accounted for where they then start to decline (Table 7; Figures 19b, 20a, 21a-d, 22a, 23b, 24a, 25a-d, 26a, 27b, 28a, 29a-d, 30a, 31b, 32a, 33a-d, 34a, 35b, 36a, 37a-d, 38a, 39b, 40a, 41a-d, 42a). This may be explainable by the comparison of H (+ predation + competition) to r, particularly if r was high for some species (e.g. Pollock). Finally, total system biomass was relatively stable except at the highest harvest rate (0.5), with a decline at that point (Table 7; Figures 20b, 24b, 28b, 32b, 36b, 40b). This implies compensation among and across guilds.

The differential harvest rate simulations showed three main results (Fig. 43-66; Table 8). First, the total biomass of the system was mostly similar, at or above system carrying capacity (Table 8; Figures 44b, 48b, 52b, 56b, 60b, 64b). Second, fishing on elasmobranchs alone had the largest simulated response in these simulations (Table 8, Figures 55-58). Total system ending biomass exceeded systemic carrying capacity, and predatory release of small pelagics and competitive release of groundfish were observed. The latter is particularly observed if only groundfish are harvested, with elasmobranchs then dominating (Figures 47-50). Fishing solely on small pelagics has less of a systemic impact as they are not predators or strong competitors with groundfish or elasmobranchs

(and those two groups can eat other types of food not modeled; Figures 63-66). Third, fishing combinations of groups has the result that the non-harvested group improves (Table 8; Figures 51-54, 59-62) not only by lack of direct removals but also via indirect influences from changes in predatory or competitive interactions (Figures 53, 54, 61, 62).

*Observations*

In an ideal world with no fishing and enough food, it still takes a long time for each fish species (or groups thereof) to reach carrying capacity (K), if at all. Generally speaking, with fishing turned on, there were lower simulated biomass estimates. With species interactions turned on, simulated biomass estimates were lower still. Also with species interactions turned on, there were generally less stable biomass trajectories and slower time to K, if at all.

In any of the scenarios, the aggregate group biomasses were more stable than individual species. Particularly in scenarios with species interactions turned on, this observation might imply that there is some within guild compensation to keep species from growing too fast simultaneously and conversely from the entire guild declining too rapidly.

Aggregate simulation results were slightly lower than the comparable MS simulation results. We originally expected the opposite (due to less effect of species interactions), but it is likely a function of the number of species growing towards K that when summed, is higher than when just three groups are modeled.

In both the different levels of and differential harvest scenarios, the observation was that species respond differently to harvest pressure. Inherent differences such as

growth rates or susceptibility to species interactions produced distinct results for species within the same guild even if experiencing the same level of fishing pressure. Clearly differential harvest impacted the different guilds uniquely, but also highlighted the resiliency and/or compensatory response from a systemic perspective.

*Conclusions*

The approach presented here is a useful simulation tool to provide hypothetical bounds across a range of possible scenarios. Although initialized and parameterized off of the Northeast U.S. fish community, we stress again that this model is neither a fitting tool nor a mechanism to calculate precise reference points. Perhaps we will develop the modeling approach to that end in the future, but that was not the intended scope of this present effort.

Even without fitting to time series data for biomass trends, the model could also be further explored with respect to the species interaction terms. The terms used in this exercise were based off of food habits data and were intended to provide a range of values across species. Yet more refined estimates of these α's and β's, particularly for competition (which emerged from the modeling exercise as an important factor to consider), will be helpful. Sensitivity analyses would also elucidate the behavior of these terms.

With respect to the main question at hand — can we have all species at $B_{MSY}$ simultaneously?— these results imply that we may not. Particularly as seen in the differential fishing scenario, it is possible to have all members of a group at or close to their K (and by extension $B_{MSY}$), but likely not all groups at that level (K or K/2)

simultaneously unless there some unreasonable assumptions made (e.g. there is extremely minimal harvest and absolutely no species interactions). Additionally, the aggregate scenarios produce more conservative results than the MS simulations, implying that there may be some systemic or model structural limitations in the aggregate that are more fully captured than when a more species-specific approach is employed.

The main point of this work is to emphasize the importance of including species interactions. Certainly the magnitudes of these parameters can be debated and refined (as noted above) but even if they are wrong, the differences between scenarios when they are on or off result in notable and non-trivial differences in the simulation outputs. This is seen especially in the MS simulations. If one assumes that generally these interaction terms are of comparable magnitude (even +/- three orders of magnitude) relative to r and H, their effects are quite pronounced. Often harvest was the lowest source of fish "loss" compared to species interactions. As such, this merits consideration in the broader context of the assessment of these stocks.

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Table 1. Diet Overlap Matrix.

| | Spiny Dogfish | Winter Skate | Little Skate | Thorny Skate | Atlantic Herring | Cod | Haddock | Pollock | White Hake | Halibut | American Plaice | Yellowtail Fl. | Winter Fl. | Witch Fl. | Windowpane Fl. | Atlantic Mackerel | Butterfish | Redfish | Ocean pout |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spiny Dogfish | 1 | 0.369 | 0.267 | 0.542 | 0.173 | 0.584 | 0.220 | 0.378 | 0.521 | 0.316 | 0.168 | 0.158 | 0.137 | 0.120 | 0.243 | 0.253 | 0.162 | 0.233 | 0.116 |
| Winter Skate | 0.369 | 1 | 0.566 | 0.486 | 0.230 | 0.485 | 0.382 | 0.459 | 0.273 | 0.290 | 0.181 | 0.334 | 0.294 | 0.221 | 0.455 | 0.272 | 0.166 | 0.258 | 0.317 |
| Little Skate | 0.267 | 0.566 | 1 | 0.405 | 0.373 | 0.422 | 0.472 | 0.286 | 0.182 | 0.254 | 0.199 | 0.495 | 0.352 | 0.280 | 0.493 | 0.301 | 0.220 | 0.224 | 0.344 |
| Thorny Skate | 0.542 | 0.486 | 0.405 | 1 | 0.205 | 0.597 | 0.316 | 0.506 | 0.557 | 0.421 | 0.154 | 0.387 | 0.342 | 0.348 | 0.346 | 0.241 | 0.187 | 0.386 | 0.198 |
| Atlantic Herring | 0.173 | 0.230 | 0.373 | 0.205 | 1 | 0.160 | 0.370 | 0.330 | 0.164 | 0.095 | 0.120 | 0.324 | 0.233 | 0.151 | 0.442 | 0.750 | 0.351 | 0.308 | 0.156 |
| Cod | 0.584 | 0.485 | 0.422 | 0.597 | 0.160 | 1 | 0.265 | 0.602 | 0.590 | 0.525 | 0.198 | 0.157 | 0.120 | 0.105 | 0.417 | 0.207 | 0.143 | 0.349 | 0.285 |
| Haddock | 0.220 | 0.382 | 0.472 | 0.316 | 0.370 | 0.265 | 1 | 0.203 | 0.164 | 0.116 | 0.476 | 0.452 | 0.360 | 0.292 | 0.299 | 0.315 | 0.239 | 0.150 | 0.283 |
| Pollock | 0.378 | 0.459 | 0.286 | 0.506 | 0.330 | 0.602 | 0.203 | 1 | 0.546 | 0.496 | 0.105 | 0.114 | 0.062 | 0.069 | 0.485 | 0.330 | 0.112 | 0.572 | 0.187 |
| White Hake | 0.521 | 0.273 | 0.182 | 0.557 | 0.164 | 0.590 | 0.164 | 0.546 | 1 | 0.477 | 0.098 | 0.082 | 0.042 | 0.056 | 0.260 | 0.203 | 0.096 | 0.328 | 0.086 |
| Halibut | 0.316 | 0.290 | 0.254 | 0.421 | 0.095 | 0.525 | 0.116 | 0.496 | 0.477 | 1 | 0.056 | 0.059 | 0.017 | 0.015 | 0.299 | 0.133 | 0.069 | 0.308 | 0.152 |
| American Plaice | 0.168 | 0.181 | 0.199 | 0.154 | 0.120 | 0.198 | 0.476 | 0.105 | 0.098 | 0.056 | 1 | 0.173 | 0.131 | 0.127 | 0.117 | 0.096 | 0.097 | 0.088 | 0.450 |
| Yellowtail Fl. | 0.158 | 0.334 | 0.495 | 0.387 | 0.324 | 0.157 | 0.452 | 0.114 | 0.082 | 0.059 | 0.173 | 1 | 0.731 | 0.659 | 0.284 | 0.238 | 0.201 | 0.087 | 0.203 |
| Winter Fl. | 0.137 | 0.294 | 0.352 | 0.342 | 0.233 | 0.120 | 0.360 | 0.062 | 0.042 | 0.017 | 0.131 | 0.731 | 1 | 0.669 | 0.146 | 0.224 | 0.251 | 0.049 | 0.177 |
| Witch Fl. | 0.120 | 0.221 | 0.280 | 0.348 | 0.151 | 0.105 | 0.292 | 0.069 | 0.056 | 0.015 | 0.127 | 0.659 | 0.669 | 1 | 0.087 | 0.148 | 0.216 | 0.056 | 0.098 |
| Windowpane Fl. | 0.243 | 0.455 | 0.493 | 0.346 | 0.442 | 0.417 | 0.299 | 0.485 | 0.260 | 0.299 | 0.117 | 0.284 | 0.146 | 0.087 | 1 | 0.382 | 0.120 | 0.324 | 0.247 |
| Atlantic Mackerel | 0.253 | 0.272 | 0.301 | 0.241 | 0.750 | 0.207 | 0.315 | 0.330 | 0.203 | 0.133 | 0.096 | 0.238 | 0.224 | 0.148 | 0.382 | 1 | 0.424 | 0.252 | 0.118 |
| Butterfish | 0.162 | 0.166 | 0.220 | 0.187 | 0.351 | 0.143 | 0.239 | 0.112 | 0.096 | 0.069 | 0.097 | 0.201 | 0.251 | 0.216 | 0.120 | 0.424 | 1 | 0.081 | 0.078 |
| Redfish | 0.233 | 0.258 | 0.224 | 0.386 | 0.308 | 0.349 | 0.150 | 0.572 | 0.328 | 0.308 | 0.088 | 0.087 | 0.049 | 0.056 | 0.324 | 0.252 | 0.081 | 1 | 0.146 |
| Ocean pout | 0.116 | 0.317 | 0.344 | 0.198 | 0.156 | 0.285 | 0.283 | 0.187 | 0.086 | 0.152 | 0.450 | 0.203 | 0.177 | 0.098 | 0.247 | 0.118 | 0.078 | 0.146 | 1 |

Table 2. Spatial Overlap Matrix from NEFSC bottom trawl survey. We used silver hake as a proxy for some of the small pelagics.

| | Spiny Dogfish | Winter Skate | Little Skate | Thorny Skate | Silver Hake | Cod | Haddock | Pollock | White Hake | Halibut | American Plaice | Yellowtail Flounder | Winter Flounder | Witch Flounder | Windowpane Flounder | Redfish | Ocean Pout |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spiny Dogfish | 1 | 0.255 | 0.448 | 0.197 | 0.669 | 0.319 | 0.264 | 0.166 | 0.435 | 0.022 | 0.249 | 0.315 | 0.254 | 0.217 | 0.267 | 0.177 | 0.227 |
| Winter Skate | 0.499 | 1 | 0.784 | 0.121 | 0.449 | 0.462 | 0.311 | 0.116 | 0.272 | 0.028 | 0.181 | 0.547 | 0.525 | 0.070 | 0.547 | 0.029 | 0.349 |
| Little Skate | 0.504 | 0.449 | 1 | 0.085 | 0.546 | 0.306 | 0.213 | 0.083 | 0.355 | 0.021 | 0.122 | 0.482 | 0.451 | 0.091 | 0.526 | 0.021 | 0.324 |
| Thorny Skate | 0.425 | 0.133 | 0.164 | 1 | 0.698 | 0.638 | 0.557 | 0.365 | 0.498 | 0.070 | 0.695 | 0.216 | 0.192 | 0.477 | 0.040 | 0.499 | 0.206 |
| Silver Hake | 0.528 | 0.181 | 0.384 | 0.255 | 1 | 0.316 | 0.259 | 0.163 | 0.569 | 0.023 | 0.337 | 0.303 | 0.237 | 0.275 | 0.220 | 0.233 | 0.236 |
| Cod | 0.434 | 0.321 | 0.370 | 0.401 | 0.544 | 1 | 0.562 | 0.327 | 0.364 | 0.070 | 0.486 | 0.406 | 0.378 | 0.279 | 0.219 | 0.287 | 0.341 |
| Haddock | 0.443 | 0.266 | 0.318 | 0.433 | 0.550 | 0.693 | 1 | 0.345 | 0.351 | 0.086 | 0.498 | 0.354 | 0.247 | 0.271 | 0.122 | 0.305 | 0.241 |
| Pollock | 0.501 | 0.179 | 0.223 | 0.508 | 0.620 | 0.725 | 0.618 | 1 | 0.439 | 0.074 | 0.568 | 0.237 | 0.249 | 0.368 | 0.100 | 0.434 | 0.256 |
| White Hake | 0.542 | 0.173 | 0.394 | 0.287 | 0.899 | 0.334 | 0.261 | 0.182 | 1 | 0.020 | 0.401 | 0.325 | 0.244 | 0.339 | 0.205 | 0.247 | 0.284 |
| Halibut | 0.353 | 0.226 | 0.306 | 0.517 | 0.465 | 0.821 | 0.819 | 0.391 | 0.254 | 1 | 0.570 | 0.474 | 0.377 | 0.238 | 0.057 | 0.199 | 0.206 |
| American Plaice | 0.421 | 0.156 | 0.184 | 0.545 | 0.724 | 0.605 | 0.503 | 0.320 | 0.545 | 0.060 | 1 | 0.281 | 0.227 | 0.484 | 0.090 | 0.476 | 0.253 |
| Yellowtail Flounder | 0.504 | 0.446 | 0.685 | 0.160 | 0.614 | 0.477 | 0.337 | 0.126 | 0.417 | 0.047 | 0.265 | 1 | 0.508 | 0.126 | 0.423 | 0.048 | 0.459 |
| Winter Flounder | 0.419 | 0.441 | 0.661 | 0.146 | 0.495 | 0.458 | 0.243 | 0.136 | 0.322 | 0.039 | 0.221 | 0.524 | 1 | 0.096 | 0.524 | 0.067 | 0.387 |
| Witch Flounder | 0.513 | 0.085 | 0.191 | 0.521 | 0.824 | 0.484 | 0.381 | 0.289 | 0.642 | 0.035 | 0.674 | 0.186 | 0.137 | 1 | 0.080 | 0.510 | 0.228 |
| Windowpane Flounder | 0.438 | 0.457 | 0.766 | 0.030 | 0.457 | 0.264 | 0.119 | 0.055 | 0.269 | 0.006 | 0.087 | 0.433 | 0.521 | 0.056 | 1 | 0.010 | 0.315 |
| Redfish | 0.468 | 0.040 | 0.050 | 0.611 | 0.781 | 0.558 | 0.481 | 0.382 | 0.525 | 0.033 | 0.743 | 0.079 | 0.107 | 0.572 | 0.017 | 1 | 0.149 |
| Ocean Pout | 0.480 | 0.376 | 0.609 | 0.201 | 0.632 | 0.529 | 0.303 | 0.180 | 0.480 | 0.027 | 0.315 | 0.606 | 0.496 | 0.204 | 0.406 | 0.119 | 1 |

Table 3. Basic parameters for the aggregate simulation model.

| Parameter | Groundfish (GF) | Pelagics (PE) | Elasmobranchs (EL) |
|---|---|---|---|
| ***Guild Carrying Capacity*** | 2849576 | 2591956 | 2311462 |
| ***Growth Rate*** | 0.4 | 0.6 | 0.2 |
| ***Initial Biomass*** | 834002 | 756418 | 3377800 |
| ***Competition Coefficient*** | | | |
| between Guild & Guild GF | 0 | 0 | 0.2 |
| between Guild & Guild PE | 0 | 0 | 0.02 |
| between Guild & Guild EL | 0.2 | 0.02 | 0 |
| ***Predatory Loss Rates*** | | | |
| with Elasmobranchs | 0 | 0.0000001 | 0 |
| with Groundfish | 0 | 0.0000001 | 0 |
| ***Spatial Overlap*** | | | |
| between Guild & Guild GF | 1 | 1 | 1 |
| between Guild & Guild PE | 1 | 1 | 1 |
| between Guild & Guild EL | 1 | 1 | 1 |
| ***Harvest Loss Rate*** | 0.1 | 0.1 | 0.1 |
| ***Demersal*** | 1 | 0 | 1 |
| ***Pelagic*** | 0 | 1 | 0 |

**System Carrying Capacity (mt)** 8000000

Table 4. Basic parameterization for the MS simulation model. The system and guild parameters carrying capacities are the same as in Table 3.

| **Parameter** | **Am plaice** | **CC-GOM Yt** | **GB Yt** | **GB Cod** | **GB Haddock** | **GB Wntr fldr** | **GOM-GB Wndwpne** | **GOM Cod** | **GOM Haddock** | **GOM Wntr fldr** | **Halibut** | **Ocean pout** | **Pollock** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Growth Rate*** | 0.38 | 0.8 | 0.66 | 0.64 | 0.52 | 0.74 | 0.6 | 0.46 | 0.52 | 0.74 | 0.212 | 0.12 | 1.3 |
| ***Initial Biomass*** | 14149 | 1100 | 8000 | 22563 | 400941 | 4301 | 7288 | 28904 | 21976 | 3436 | 288 | 10993 | 40937 |
| ***Competition Coefficient #1*** | | | | | | | | | | | | | |
| between Guild & Guild GF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| between Guild & Guild PE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| between Guild & Guild EL | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| ***Competition Coefficient #2*** | | | | | | | | | | | | | |
| with Am plaice | 0 | 0.597 | 0.597 | 0.678 | 1.928 | 0.525 | 0.427 | 0.678 | 1.928 | 0.525 | 0.218 | 1.766 | 0.358 |
| with CC-GOM Yt | 0.597 | 0 | 0 | 0.529 | 1.809 | 3.076 | 1.113 | 0.529 | 1.809 | 3.076 | 0.124 | 0.729 | 0.367 |
| with GB Yt | 0.597 | 0 | 0 | 0.529 | 1.809 | 3.076 | 1.113 | 0.529 | 1.809 | 3.076 | 0.124 | 0.729 | 0.367 |
| with GB Cod | 0.678 | 0.529 | 0.529 | 0 | 1.007 | 0.431 | 1.058 | 0 | 1.007 | 0.431 | 1.651 | 1.037 | 1.903 |
| with GB Haddock | 1.928 | 1.809 | 1.809 | 1.007 | 0 | 1.455 | 0.994 | 1.007 | 0 | 1.455 | 0.316 | 1.067 | 0.712 |
| with GB Wntr fldr | 0.525 | 3.076 | 3.076 | 0.431 | 1.455 | 0 | 0.563 | 0.431 | 1.455 | 0 | 0.064 | 0.636 | 0.183 |
| with GOM-GB Wndwpne | 0.427 | 1.113 | 1.113 | 1.058 | 0.994 | 0.563 | 0 | 1.058 | 0.994 | 0.563 | 0.7 | 0.38 | 1.493 |
| with GOM Cod | 0.678 | 0.529 | 0.529 | 0 | 1.007 | 0.431 | 1.058 | 0 | 1.007 | 0.431 | 1.651 | 1.037 | 1.903 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| with GOM Haddock | 1.928 | 1.809 | 1.809 | 1.007 | 0 | 1.455 | 0.994 | 1.007 | 0 | 1.455 | 0.316 | 1.067 | 0.712 |
| with GOM Wntr fldr | 0.525 | 3.076 | 3.076 | 0.431 | 1.455 | 0 | 0.563 | 0.431 | 1.455 | 0 | 0.064 | 0.636 | 0.183 |
| with Halibut | 0.218 | 0.124 | 0.124 | 1.651 | 0.316 | 0.064 | 0.7 | 1.651 | 0.316 | 0.064 | 0 | 0.23 | 1.237 |
| with Ocean pout | 1.766 | 0.729 | 0.729 | 1.037 | 1.067 | 0.636 | 0.38 | 1.037 | 1.067 | 0.636 | 0.23 | 0 | 0.154 |
| with Pollock | 0.358 | 0.367 | 0.367 | 1.903 | 0.712 | 0.183 | 1.493 | 1.903 | 0.712 | 0.183 | 1.237 | 0.154 | 0 |
| with Redfish | 0.307 | 0.324 | 0.324 | 1.177 | 0.533 | 0.175 | 0.934 | 1.177 | 0.533 | 0.175 | 0.943 | 0.171 | 2.38 |
| with SNE-MA Wndwpne | 0.427 | 1.113 | 1.113 | 1.058 | 0.994 | 0.563 | 0 | 1.058 | 0.994 | 0.563 | 0.7 | 0.38 | 1.493 |
| with SNE-MA Wntr fldr | 0.525 | 3.076 | 3.076 | 0.431 | 1.455 | 0 | 0.563 | 0.431 | 1.455 | 0 | 0.064 | 0.636 | 0.183 |
| with SNE-MA Yt | 0.597 | 0 | 0 | 0.529 | 1.809 | 3.076 | 1.113 | 0.529 | 1.809 | 3.076 | 0.124 | 0.729 | 0.367 |
| with White Hake | 0.708 | 0.904 | 0.904 | 2.295 | 1.271 | 0.695 | 1.621 | 2.295 | 1.271 | 0.695 | 1.711 | 0.789 | 2.368 |
| with Witch fldr | 0.708 | 2.752 | 2.752 | 0.35 | 1.194 | 2.79 | 0.363 | 0.35 | 1.194 | 2.79 | 0.051 | 0.397 | 0.239 |
| with Butterfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Herring | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Mackerel | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Skates | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Spiny dogfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ***Predatory Loss Rates*** | | | | | | | | | | | | | |
| with GB Cod | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| with GOM Cod | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Halibut | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Pollock | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Redfish | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Skates | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Spiny Dogfish | 0 | 0 | 0 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| ***Spatial Overlap*** | | | | | | | | | | | | | |
| with Am plaice | 1.000 | 0.281 | 0.281 | 0.605 | 0.503 | 0.227 | 0.090 | 0.605 | 0.503 | 0.227 | 0.060 | 0.253 | 0.320 |
| with CC-GOM Yt | 0.281 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.423 | 0.477 | 0.337 | 0.508 | 0.047 | 0.459 | 0.126 |
| with GB Yt | 0.281 | 0.000 | 1.000 | 0.477 | 0.337 | 0.508 | 0.423 | 0.000 | 0.000 | 0.000 | 0.047 | 0.459 | 0.126 |
| with GB Cod | 0.605 | 0.000 | 0.477 | 1.000 | 0.562 | 0.378 | 0.264 | 0.000 | 0.000 | 0.000 | 0.070 | 0.341 | 0.327 |
| with GB Haddock | 0.503 | 0.000 | 0.337 | 0.562 | 1.000 | 0.247 | 0.122 | 0.000 | 0.000 | 0.000 | 0.086 | 0.241 | 0.345 |
| with GB Wntr fldr | 0.227 | 0.000 | 0.508 | 0.378 | 0.247 | 1.000 | 0.524 | 0.000 | 0.000 | 0.000 | 0.039 | 0.387 | 0.136 |
| with GOM-GB Wndwpne | 0.090 | 0.423 | 0.423 | 0.264 | 0.122 | 0.524 | 1.000 | 0.264 | 0.122 | 0.524 | 0.006 | 0.315 | 0.055 |
| with GOM Cod | 0.605 | 0.477 | 0.000 | 0.000 | 0.000 | 0.000 | 0.264 | 1.000 | 0.562 | 0.378 | 0.070 | 0.341 | 0.327 |
| with GOM Haddock | 0.503 | 0.337 | 0.000 | 0.000 | 0.000 | 0.000 | 0.122 | 0.562 | 1.000 | 0.247 | 0.086 | 0.241 | 0.345 |
| with GOM Wntr fldr | 0.227 | 0.508 | 0.000 | 0.000 | 0.000 | 0.000 | 0.524 | 0.378 | 0.247 | 1.000 | 0.039 | 0.387 | 0.136 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| with Halibut | 0.060 | 0.047 | 0.047 | 0.070 | 0.086 | 0.039 | 0.006 | 0.070 | 0.086 | 0.039 | 1.000 | 0.206 | 0.391 |
| with Ocean pout | 0.253 | 0.459 | 0.459 | 0.341 | 0.241 | 0.387 | 0.315 | 0.341 | 0.241 | 0.387 | 0.206 | 1.000 | 0.180 |
| with Pollock | 0.320 | 0.126 | 0.126 | 0.327 | 0.345 | 0.136 | 0.055 | 0.327 | 0.345 | 0.136 | 0.391 | 0.180 | 1.000 |
| with Redfish | 0.476 | 0.048 | 0.048 | 0.287 | 0.305 | 0.067 | 0.010 | 0.287 | 0.305 | 0.067 | 0.199 | 0.119 | 0.382 |
| with SNE-MA Wndwpne | 0.090 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.006 | 0.315 | 0.055 |
| with SNE-MA Wntr fldr | 0.227 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.039 | 0.387 | 0.136 |
| with SNE-MA Yt | 0.281 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.047 | 0.459 | 0.126 |
| with White Hake | 0.545 | 0.417 | 0.417 | 0.364 | 0.351 | 0.322 | 0.269 | 0.364 | 0.351 | 0.322 | 0.254 | 0.480 | 0.439 |
| with Witch fldr | 0.484 | 0.126 | 0.126 | 0.279 | 0.271 | 0.096 | 0.056 | 0.279 | 0.271 | 0.096 | 0.238 | 0.204 | 0.368 |
| with Butterfish | 0.545 | 0.417 | 0.417 | 0.364 | 0.351 | 0.322 | 0.269 | 0.364 | 0.351 | 0.322 | 0.254 | 0.480 | 0.439 |
| with Herring | 0.545 | 0.417 | 0.417 | 0.364 | 0.351 | 0.322 | 0.269 | 0.364 | 0.351 | 0.322 | 0.254 | 0.480 | 0.439 |
| with Mackerel | 0.545 | 0.417 | 0.417 | 0.364 | 0.351 | 0.322 | 0.269 | 0.364 | 0.351 | 0.322 | 0.254 | 0.480 | 0.439 |
| with Skates | 0.295 | 0.430 | 0.430 | 0.364 | 0.339 | 0.416 | 0.418 | 0.364 | 0.339 | 0.416 | 0.350 | 0.395 | 0.303 |
| with Spiny dogfish | 0.421 | 0.315 | 0.315 | 0.434 | 0.264 | 0.254 | 0.267 | 0.434 | 0.264 | 0.254 | 0.022 | 0.227 | 0.166 |
| ***Harvest Loss Rate*** | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| ***Demersal*** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | | 1 | 1 |
| ***Pelagic*** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| Parameter | Redfish | SNE-MA Wndwpne | SNE-MA Wntr fldr | SNE-MA Yt | White hake | Witch fldr | Butterfish | Herring | Mackerel | Skates | Spiny dogfish |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Growth Rate*** | 0.232 | 0.6 | 0.74 | 0.8 | 0.58 | 0.38 | 0.76 | 0.62 | 0.32 | 0.2 | 0.2 |
| ***Initial Biomass*** | 200244 | 2373 | 3938 | 690 | 43077 | 21175 | 7800 | 1047000 | 2323000 | 303418 | 453000 |
| ***Competition Coefficient #1*** | | | | | | | | | | | |
| between Guild & Guild GF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.5 | 0.5 |
| between Guild & Guild PE | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.1 | 0.1 |
| between Guild & Guild EL | 1 | 1 | 1 | 1 | 1 | 1 | 0.05 | 0.05 | 0.05 | 0 | 0 |
| ***Competition Coefficient #2*** | | | | | | | | | | | |
| with Am plaice | 0.307 | 0.427 | 0.525 | 0.597 | 0.708 | 0.495 | 0 | 0 | 0 | 0 | 0 |
| with CC-GOM Yt | 0.324 | 1.113 | 3.076 | 0 | 0.904 | 2.752 | 0 | 0 | 0 | 0 | 0 |
| with GB Yt | 0.324 | 1.113 | 3.076 | 0 | 0.904 | 2.752 | 0 | 0 | 0 | 0 | 0 |
| with GB Cod | 1.177 | 1.058 | 0.431 | 0.529 | 2.295 | 0.35 | 0 | 0 | 0 | 0 | 0 |
| with GB Haddock | 0.533 | 0.994 | 1.455 | 1.809 | 1.271 | 1.194 | 0 | 0 | 0 | 0 | 0 |
| with GB Wntr fldr | 0.175 | 0.563 | 0 | 3.076 | 0.695 | 2.79 | 0 | 0 | 0 | 0 | 0 |
| with GOM-GB Wndwpne | 0.934 | 0 | 0.563 | 1.113 | 1.621 | 0.363 | 0 | 0 | 0 | 0 | 0 |
| with GOM Cod | 1.177 | 1.058 | 0.431 | 0.529 | 2.295 | 0.35 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| with GOM Haddock | 0.533 | 0.994 | 1.455 | 1.809 | 1.271 | 1.194 | 0 | 0 | 0 | 0 | 0 |
| with GOM Wntr fldr | 0.175 | 0.563 | 0 | 3.076 | 0.695 | 2.79 | 0 | 0 | 0 | 0 | 0 |
| with Halibut | 0.943 | 0.7 | 0.064 | 0.124 | 1.711 | 0.051 | 0 | 0 | 0 | 0 | 0 |
| with Ocean pout | 0.171 | 0.38 | 0.636 | 0.729 | 0.789 | 0.397 | 0 | 0 | 0 | 0 | 0 |
| with Pollock | 2.38 | 1.493 | 0.183 | 0.367 | 2.368 | 0.239 | 0 | 0 | 0 | 0 | 0 |
| with Redfish | 0 | 0.934 | 0.175 | 0.324 | 2.099 | 0.218 | 0 | 0 | 0 | 0 | 0 |
| with SNE-MA Wndwpne | 0.934 | 0 | 0.563 | 1.113 | 1.621 | 0.363 | 0 | 0 | 0 | 0 | 0 |
| with SNE-MA Wntr fldr | 0.175 | 0.563 | 0 | 3.076 | 0.695 | 2.79 | 0 | 0 | 0 | 0 | 0 |
| with SNE-MA Yt | 0.324 | 1.113 | 3.076 | 0 | 0.904 | 2.752 | 0 | 0 | 0 | 0 | 0 |
| with White Hake | 2.099 | 1.621 | 0.695 | 0.904 | 0 | 0.576 | 0 | 0 | 0 | 0 | 0 |
| with Witch fldr | 0.218 | 0.363 | 2.79 | 2.752 | 0.576 | 0 | 0 | 0 | 0 | 0 | 0 |
| with Butterfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.4 | 0.4 | 0 | 0 |
| with Herring | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | 0 | 0.5 | 0 | 0 |
| with Mackerel | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | 0.5 | 0 | 0 | 0 |
| with Skates | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 |
| with Spiny dogfish | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.6 | 0 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Predatory Loss Rates*** | | | | | | | | | | | |
| with GB Cod | 0 | 0 | 0 | 0 | 0 | 0 | 2E-07 | 2E-07 | 2E-07 | 0 | 0 |
| with GOM Cod | 0 | 0 | 0 | 0 | 0 | 0 | 2E-07 | 2E-07 | 2E-07 | 0 | 0 |
| with Halibut | 0 | 0 | 0 | 0 | 0 | 0 | 2E-07 | 2E-07 | 2E-07 | 0 | 0 |
| with Pollock | 0 | 0 | 0 | 0 | 0 | 0 | 2E-07 | 2E-07 | 2E-07 | 0 | 0 |
| with Redfish | 0 | 0 | 0 | 0 | 0 | 0 | 2E-07 | 2E-07 | 2E-07 | 0 | 0 |
| with Skates | 0 | 0 | 0 | 0 | 0 | 0 | 2E-07 | 2E-07 | 2E-07 | 0 | 0 |
| with Spiny Dogfish | 0 | 0 | 0 | 0 | 0 | 0 | 2E-07 | 2E-07 | 2E-07 | 0 | 0 |
| ***Spatial Overlap*** | | | | | | | | | | | |
| with Am plaice | 0.476 | 0.090 | 0.227 | 0.281 | 0.545 | 0.484 | 0.545 | 0.545 | 0.545 | 0.295 | 0.421 |
| with CC-GOM Yt | 0.048 | 0.000 | 0.000 | 0.000 | 0.417 | 0.126 | 0.417 | 0.417 | 0.417 | 0.430 | 0.315 |
| with GB Yt | 0.048 | 0.000 | 0.000 | 0.000 | 0.417 | 0.126 | 0.417 | 0.417 | 0.417 | 0.430 | 0.315 |
| with GB Cod | 0.287 | 0.000 | 0.000 | 0.000 | 0.364 | 0.279 | 0.364 | 0.364 | 0.364 | 0.364 | 0.434 |
| with GB Haddock | 0.305 | 0.000 | 0.000 | 0.000 | 0.351 | 0.271 | 0.351 | 0.351 | 0.351 | 0.339 | 0.264 |
| with GB Wntr fldr | 0.067 | 0.000 | 0.000 | 0.000 | 0.322 | 0.096 | 0.322 | 0.322 | 0.322 | 0.416 | 0.254 |
| with GOM-GB Wndwpne | 0.010 | 0.000 | 0.000 | 0.000 | 0.269 | 0.056 | 0.269 | 0.269 | 0.269 | 0.418 | 0.267 |
| with GOM Cod | 0.287 | 0.000 | 0.000 | 0.000 | 0.364 | 0.279 | 0.364 | 0.364 | 0.364 | 0.364 | 0.434 |
| with GOM Haddock | 0.305 | 0.000 | 0.000 | 0.000 | 0.351 | 0.271 | 0.351 | 0.351 | 0.351 | 0.339 | 0.264 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| with GOM Wntr fldr | 0.067 | 0.000 | 0.000 | 0.000 | 0.322 | 0.096 | 0.322 | 0.322 | 0.322 | 0.416 | 0.254 |
| with Halibut | 0.199 | 0.006 | 0.039 | 0.047 | 0.254 | 0.238 | 0.254 | 0.254 | 0.254 | 0.350 | 0.022 |
| with Ocean pout | 0.119 | 0.315 | 0.387 | 0.459 | 0.480 | 0.204 | 0.480 | 0.480 | 0.480 | 0.395 | 0.227 |
| with Pollock | 0.382 | 0.055 | 0.136 | 0.126 | 0.439 | 0.368 | 0.439 | 0.439 | 0.439 | 0.303 | 0.166 |
| with Redfish | 1.000 | 0.010 | 0.067 | 0.048 | 0.525 | 0.572 | 0.525 | 0.525 | 0.525 | 0.234 | 0.267 |
| with SNE-MA Wndwpne | 0.010 | 1.000 | 0.524 | 0.423 | 0.269 | 0.056 | 0.269 | 0.269 | 0.269 | 0.418 | 0.267 |
| with SNE-MA Wntr fldr | 0.067 | 0.524 | 1.000 | 0.508 | 0.322 | 0.096 | 0.322 | 0.322 | 0.322 | 0.416 | 0.254 |
| with SNE-MA Yt | 0.048 | 0.423 | 0.508 | 1.000 | 0.417 | 0.126 | 0.417 | 0.417 | 0.417 | 0.430 | 0.315 |
| with White Hake | 0.525 | 0.269 | 0.322 | 0.417 | 1.000 | 0.642 | 0.550 | 0.550 | 0.550 | 0.285 | 0.435 |
| with Witch fldr | 0.572 | 0.056 | 0.096 | 0.126 | 0.642 | 1.000 | 0.642 | 0.642 | 0.642 | 0.266 | 0.217 |
| with Butterfish | 0.525 | 0.269 | 0.322 | 0.417 | 0.550 | 0.642 | 1.000 | 0.550 | 0.550 | 0.285 | 0.435 |
| with Herring | 0.525 | 0.269 | 0.322 | 0.417 | 0.550 | 0.642 | 0.550 | 1.000 | 0.550 | 0.285 | 0.435 |
| with Mackerel | 0.525 | 0.269 | 0.322 | 0.417 | 0.550 | 0.642 | 0.550 | 0.550 | 1.000 | 0.285 | 0.435 |
| with Skates | 0.234 | 0.418 | 0.416 | 0.430 | 0.285 | 0.266 | 0.285 | 0.285 | 0.285 | 1.000 | 0.300 |
| with Spiny dogfish | 0.267 | 0.267 | 0.254 | 0.315 | 0.435 | 0.217 | 0.435 | 0.435 | 0.435 | 0.300 | 1.000 |
| ***Harvest Loss Rate*** | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Demersal*** | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 |
| ***Pelagic*** | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 |

Table 5. Aggregate Production Simulations Summary Results

| Harvest | Interactions | Ending ~ Total Biomass |
|---|---|---|
| Y | Y | 3.9 M mt |
| Y | N | 5.4 M mt |
| N | Y | 5.4 M mt |
| N | N | 7.5 M mt |

Table 6. Multispecies Production Simulation Summary Results

| Harvest | Interactions | Ending ~ Total Biomass |
|---|---|---|
| Y | Y | 7.7 mt |
| Y | N | 48 M mt |
| N | Y | 8.1 M mt |
| N | N | 63 M mt |

Table 7. Summary of Harvest Level Results.

| | GF | EL | PEL | Total |
|---|---|---|---|---|
| 0.01 | 3400000 | 2000000 | 2500000 | 7900000 |
| 0.05 | 4000000 | 1300000 | 2700000 | 8000000 |
| 0.1 | 4400000 | 600000 | 2400000 | 7400000 |
| 0.2 | 5400000 | 100000 | 2000000 | 7500000 |
| 0.3 | 5400000 | ~0 | 1200000 | 7600000 |
| 0.5 | 2800000 | ~0 | 2000000 | 4800000 |

Table 8. Summary of Differential Harvest Results.

| | GF | EL | PEL | Total |
|---|---|---|---|---|
| All | 4400000 | 600000 | 2400000 | 7400000 |
| GF Only | 1850000 | 2850000 | 2500000 | 7200000 |
| EL & PEL | 5600000 | 400000 | 2500000 | 8500000 |
| EL | 5600000 | 350000 | 3450000 | 9400000 |
| GF & EL | 4600000 | 595000 | 3400000 | 8595000 |
| PEL | 3200000 | 2500000 | 1800000 | 7500000 |

Figure Legends

*Aggregate Biomass Figures*

Figure 1. A. No harvest, no interactions, aggregate biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 2. A. . Harvest on, no interactions, aggregate biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 3. A. . No harvest, interactions on, aggregate biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 4. A. No harvest, interactions on, aggregate biomass scenarios, losses of elasmobranchs. B. Same, but for groundfish. C. Same, but for pelagics.

Figure 5. A. Harvest and interactions on, aggregate biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 6. A. Harvest and interactions on, aggregate biomass scenarios, losses of elasmobranchs. B. Same, but for groundfish. C. Same, but for pelagics.

*MS Biomass Figures*

Figure 7. A. No harvest, no interactions, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 8. A. No harvest, no interactions, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 9. A. Harvest on, no interactions, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 10. A. Harvest on, no interactions, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 11. A. No harvest, interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 12. A. No harvest, interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 13. A. No harvest, interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 14. A. No harvest, interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 15. A. Harvest and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 16. A. Harvest and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 17. A. Harvest and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 18. A. Harvest and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

*Harvest Level Figures*

Figure 19. A. Harvest at 0.1 and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 20. A. Harvest at 0.1 and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 21. A. Harvest at 0.1 and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 22. A. Harvest at 0.1 and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 23. A. Harvest at 0.01 and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 24. A. Harvest at 0.01 and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 25. A. Harvest at 0.01 and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 26. A. Harvest at 0.01 and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 27. A. Harvest at 0.05 and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 28. A. Harvest at 0.05 and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 29. A. Harvest at 0.05 and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 30. A. Harvest at 0.05 and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 31. A. Harvest at 0.2 and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 32. A. Harvest at 0.2 and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 33. A. Harvest at 0.2 and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 34. A. Harvest at 0.2 and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 35. A. Harvest at 0.3 and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 36. A. Harvest at 0.3 and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 37. A. Harvest at 0.3 and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 38. A. Harvest at 0.3 and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 39. A. Harvest at 0.5 and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 40. A. Harvest at 0.5 and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 41. A. Harvest at 0.5 and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 42. A. Harvest at 0.5 and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

*Differential Harvest Figures*

Figure 43. A. Harvest of all groups (at 0.1) and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 44. A. Harvest of all groups (at 0.1) and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 45. A. Harvest of all groups (at 0.1) and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 46. A. Harvest of all groups (at 0.1) and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 47. A. Harvest of groundfish only and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 48. A. Harvest of groundfish only and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 49. A. Harvest of groundfish only and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 50. A. Harvest of elasmobranchs and pelagics and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 51. A. Harvest of elasmobranchs and pelagics and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 52. A. Harvest of elasmobranchs and pelagics and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 53. A. Harvest of elasmobranchs and pelagics and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 54. A. Harvest of elasmobranchs and pelagics and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 55. A. Harvest of elasmobranchs only and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 56. A. Harvest of elasmobranchs only and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 57. A. Harvest of elasmobranchs only and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 58. A. Harvest of elasmobranchs only and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 59. A. Harvest of elasmobranchs and groundfish and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 60. A. Harvest of elasmobranchs and groundfish and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 61. A. Harvest of elasmobranchs and groundfish and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 62. A. Harvest of elasmobranchs and groundfish and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.

Figure 63. A. Harvest of pelagics only and interactions on, elasmobranch species biomasses. B. Same but for groundfish biomasses. C. Same but for pelagic biomasses.

Figure 64. A. Harvest of pelagics only and interactions on, MS biomass scenarios, guild biomasses. B. Same, but for demersals, pelagics and total biomasses.

Figure 65. A. Harvest of pelagics only and interactions on, losses of GB cod. B. Same but for GB haddock. C. Same but for GB yellowtail flounder. D. Same but for pollock.

Figure 66. A. Harvest of pelagics only and interactions on, losses of white hake. B. Same but for spiny dogfish. C. Same but for herring. D. Same but for mackerel.