

An Aggregate Biomass Model: The Search for Tradeoffs

Robert J. Gamble^{1,2}, Hassan Moustahfid¹, Megan C. Tyrrell¹, Brian E. Smith¹, Jason S. Link¹

¹National Marine Fisheries Service, Northeast Fisheries Science Center, Woods Hole, MA. 02543

²Integrated Statistics Inc, Woods Hole, MA. 02543



ABSTRACT

Species interactions can have notable implications for fisheries management. If the effects of competition and predation are not considered, stock status and associated advice can be misrepresented and thus inconsistent with a precautionary approach. We present an aggregate biomass model based on modifications to the Schaefer production model, emphasizing a functional guild approach. Our model includes biotic and abiotic constraints to carrying capacity for both the entire system and individual guilds. The model explicitly accounts for harvest rates, predation, and competition among species and guilds. A spatial overlap parameter is included to modify these species interactions. We ran simulations based on a hypothetical food web, loosely analogous to the U.S. northwest Atlantic finfish community. Model results are not necessarily linear, involve copious indirect effects, and can result in further constraints to species and guild dynamics than is typically assumed. Several scenarios, specifically ones that excessively remove planktivores, are similar to those observed in the ecosystem, based on 45 years of observations. From a systemic perspective, these simulation results suggest that the potential for foregone yields is high, emphasizing the importance of explicitly including species interactions in ecosystem models.

MODEL

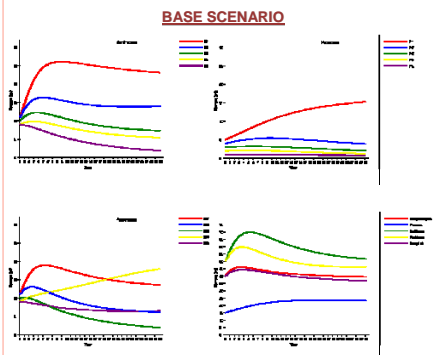
$$\frac{dN_i}{dt} = r_i N_i \left(1 - \frac{N_i}{K_G} - \frac{\sum_g \beta_{ig} N_g}{K_G} - \frac{\sum_G \beta_{iG} N_G}{(K_G - K_G)} - \sum_p \alpha_{ip} N_p \right) - H_i N_i$$

N = biomass
 r = growth rate
 H = harvest rate
 β = competition coefficient
 α = predation coefficient
 K = carrying capacity
 i = species
 p = predator (on species i)
 g = guild member
 G = guild
 σ = system

ECOLOGICAL SCENARIOS

- We examined a suite of ecological scenarios, some of which are described below.
- The ecological scenarios were created by modifying competition and predation parameters.
- The goal of these scenarios was to determine the effects of modifying the various terms in the model.

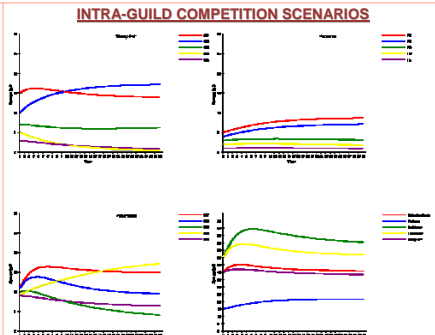
- Five guilds were chosen to represent an ecosystem comparable to the Northeast U.S. ecosystem. These five guilds were Benthivores (B), Planktivores (PL), Piscivores (PI), Shrimp-fish eaters (SF) and Shrimp-amphipod eaters (SA).
- A Base Scenario was constructed such that one species within each guild would achieve dominance over the others.
- In most guilds, species 1 (for instance, B1 in Benthivores, P1 in Piscivores) was set up to be the dominant species in terms of higher growth rates, lower competition and lower predation.
- The Planktivore guild was used to test the importance of initial biomass. PL4 was set to be less affected by predation than the other members of the guild. Even with an initial lower biomass than PL1 and PL2, by 30 years it achieved dominance within the guild, indicating that starting biomass is less important than the biotic effects on biomass.
- The other goal of the Base Scenario was to set up an equilibrium biomass level such that each guild's total biomass was near its carrying capacity.



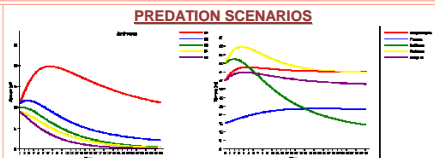
HARVEST SCENARIOS

- Harvest scenarios were created by modifying only the harvest rates in the Base Scenario
- The goal of these scenarios was to explore the impact of different levels of harvest on different groups, and to determine if similar patterns to a real world system could be observed.

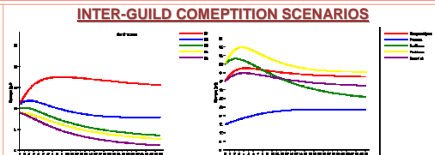
- Intra-Guild Competition was doubled on each dominant species (those that had the highest total biomass after 30 years in the Base Scenario) within each guild. SF1 and SF2 swapped biomass rankings in their guild, compared to the Base Scenario.
- The Planktivore guild didn't show a swap in the dominant member (PL4) with another species, but it did show a swap between PL2 and PL5. PL2 suffered more from predation by P11 than PL5. With P11's biomass lowered, PL2 suffered less loss of biomass than PL5.
- Compared to the Base Scenario, each guild (except Piscivores) increased in biomass, resulting in an higher system biomass. This occurred because the dominant predator's (P11) biomass dropped substantially compared to the Base Scenario. This suggests that predation is a more dominant biotic factor than Intra-Guild competition itself.



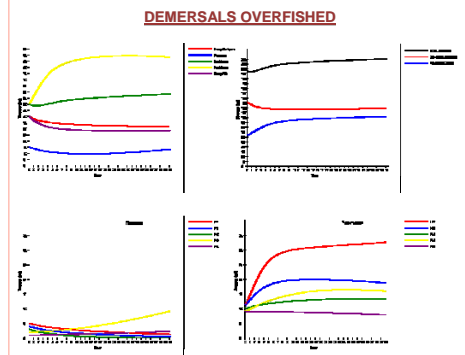
- Predation was doubled on Benthivores.
- While the overall ranking within the guild stayed relatively consistent, B3, B4 and B5 crashed.
- Due to the reduction in Benthivore biomass, Shrimp-Amphipods increased overall biomass since the two guilds interact through Inter-Guild Competition.
- Total Benthivore biomass dropped from first to last in guild ranking.



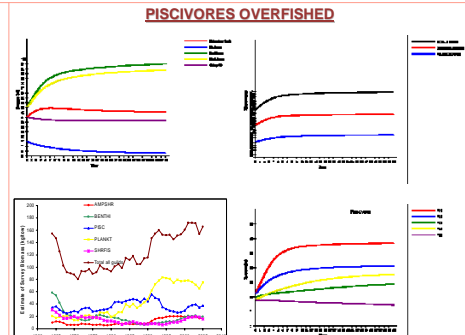
- Inter-Guild Competition was doubled on Benthivores.
- The overall effect was to lower each individual Benthivore's biomass, but to a lesser degree than the similar Predation Scenario.
- Total Benthivore biomass dropped to second last in guild ranking, but not to the same degree as in the similar Predation scenario.



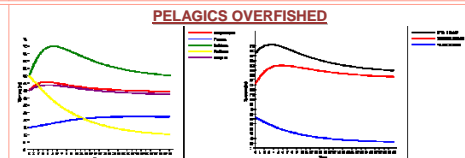
- When Demersals (P11, PL2, PL3, and all members of Benthivore, Shrimp-Fish and Shrimp-Amphipod guilds) were overfished, the total biomass of the system increased.
- The two guilds (Piscivores and Shrimp-Fish) which contained the predators, both experienced a reduction in biomass compared to the base scenario.
- Planktivores benefited the most in this scenario, exceeding their guild's carrying capacity (set at 50). This likely occurred due to the reduction of both their predators (Piscivores, Shrimp-Fish) and primary competitors (Shrimp-Fish). Even though total biomass increased, the previously dominant member (PL4) dropped in biomass to third in ranking.
- Benthivores increased in biomass in spite of overfishing due to a higher growth rate for some of its members than in other guilds, and a reduction in competition and predation as a result of other guilds losing biomass.
- The loss of predation appears to be the main reason why this scenario resulted in an increase in overall biomass.



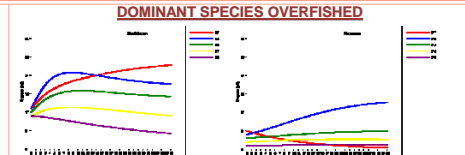
- When Piscivores were overfished, the total biomass of the system increased, indicating that predation has a strong effect on the base scenario we created.
- This scenario shows a strong similarity to the historical situation in the Northeast U.S. Atlantic Ecosystem in the bottom left of this panel. Starting in the early 1990's, Piscivore biomass began to decline, resulting in an increase in Planktivore biomass. Additionally, increasing trends in Benthivore and Shrimp-amphipod biomass occur in both the real world situation and this scenario.
- The overfishing of Piscivores also changed the rankings of species within the Planktivore guild. This was because more predation occurred on PL1 and PL2 than PL4. When predation effects were lowered, PL1 and PL2 were able to outcompete PL4.



- When Pelagics (P14, P15 and all Planktivores) were overfished, the total biomass of the system decreased.
- Most of this decrease can be attributed to the much lower biomass of Planktivores compared to the base scenario.



- When the Dominant Species of each guild was overfished, the overall biomass of the system increased due to the reduction of the most important predators in the system.
- While some guilds showed a new dominant species under this scenario, after 30 years, B1 again was the dominant species, due primarily to its only predator's (P1) loss of biomass.



BIOLOGICAL REFERENCE POINTS

The harvest scenarios were evaluated to compare B' (final biomass) to B_{MSY} . In the Base Scenario (BS), the harvest rate (H) for all species was set to 0. In all other scenarios, $H=0.2$ for the harvested species (B=Benthivores, PL=Planktivores, PI=Piscivores, SE=Shrimp eaters, Dom=Dominant species, Dem=Demersals, Pel=Pelagics).

B_{MSY} was set as $K/2$ for each guild. The B_{MSY} for each species was set to 1/5 that of the guild since there were five species in each guild. We used the metric B'/B_{MSY} as a BRP proxy.

The addition of ecological interaction terms creates a way to evaluate biotic effects combined with fishing pressure. For instance, when Piscivores are harvested, more of their prey species (e.g., Benthivores and Planktivores) show a B'/B_{MSY} greater than 1.0.

Our results show that when harvested, the guild or affected species typically exhibit a lower B'/B_{MSY} .

Our results show that indirect effects of harvesting other species cascade through the species interactions, changing the BRP proxy for non-harvested spp. For example, when Benthivores are harvested, SA4's B'/B_{MSY} becomes greater than 1.0 while SF2's B'/B_{MSY} becomes less than 1.0 due to the levels of competition changing among these three guilds.

Scenario	Harvested Species	B1	B2	B3	B4	B5	PL1	PL2	PL3	PL4	PL5	PI1	PI2	PI3	PI4	PI5	SF1	SF2	SA1	SA2	SA3	SA4
Base	None	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Intra-Guild	None	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Predation	B	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Inter-Guild	B	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Demersals	P11, PL2, PL3	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Piscivores	PI1	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
Pelagics	P14, P15	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Dominant	B1, PL4, PI1	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

CONCLUSIONS

- Predation appears to be the dominant biotic term within the model. This is emphasized in the Harvest Scenario where Piscivores are overfished. There was a 36% increase in system biomass which was the largest increase in biomass in any scenario. Additionally, the predation scenarios generally showed a greater effect on system biomass than the competition scenarios.
- Even though individual species biomasses within a guild can be greatly affected by changing biotic factors, overall biomass of a guild tends to be more stable.
- The model is sophisticated enough that a change in one biotic factor could have unexpected, but realistic, results due to the interactions between biomass, predation and competition terms.
- The BRP proxy we use demonstrates that indirect ecological interactions can be of importance in determining appropriate biomass tradeoffs in fishery management.
- A demonstration copy of a simulation software package that utilizes this model can be obtained by contacting Robert Gamble (Robert.Gamble@noaa.gov).