THEME 3: Methods and models for assessing small pelagic fish stocks/
Méthodes et modèles pour l'évaluation des stocks de petits poissons pélagiques

An aggregate biomass model: the search for tradeoffs

Un modèle global de biomasse: la recherche de compromis
(English only/En anglais seulement)

R.J. Gamble[1,2], H. Moustahfid[1*], M.C. Tyrrell[1], B.E. Smith[1] and J.S. Link[1]
[1]National Marine Fisheries Service
Robert.Gamble@noaa.gov
Northeast Fisheries Science Center
Woods Hole, MA. 02543, USA
*hassan.moustahfid@noaa.gov
[2]Integrated Statistics Inc, Woods Hole, MA. 02543

Gamble, R.J., Moustahfid, H., Tyrrell, M.C., Smith, B.E. and Link, J.S. 2012. An aggregate biomass model: the search for tradeoffs. *In/Dans* S. Garcia, M. Tandstad and A.M. Caramelo (eds.). Science and Management of Small Pelagics. Symposium on Science and the Challenge of Managing Small Pelagic Fisheries on Shared Stocks in Northwest Africa, 11–14 March 2008, Casablanca, Morocco/Science et aménagement des petits pélagiques. Symposium sur la science et le défi de l'aménagement des pêcheries de petits pélagiques sur les stocks partagés en Afrique nord-occidentale, 11-14 mars 2008, Casablanca, Maroc. *FAO Fisheries and Aquaculture Proceedings/FAO Comptes rendus des pêches et de l'aquaculture.* No. 18. Rome, FAO. pp. 489–492.

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 US 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.

RÉSUMÉ

Les interactions entre les espèces peuvent avoir des implications notables sur la gestion de la pêche. Si les effets de la compétition et de la prédation ne sont pas pris en considération, le statut courant des stocks et le conseil associé peuvent être mal représentés et ainsi contradictoires avec le principe de précaution. Nous présentons un modèle global de biomasse basé sur des modifications du modèle de production de Schaefer, soulignant une approche fonctionnelle de guilde. Notre modèle inclut des contraintes biotiques et abiotiques sur la capacité de charge pour le système entier et sur différentes guildes. Le modèle tient compte explicitement des taux d'exploitation, de la prédation et de la concurrence entre les espèces et les guildes. Un paramètre spatial de chevauchement est inclus pour modifier ces interactions d'espèces. Nous avons mené des simulations basées sur une chaîne trophique hypothétique, lâchement analogue à la communauté de poissons nord-ouest atlantique des États-Unis. Les résultats des modèles ne sont pas nécessairement linéaires, impliquent des effets indirects copieux, et ne peuvent pas avoir comme conséquence d'autres contraintes aux espèces et à la dynamique de guilde qui est normalement supposée. Plusieurs scénarios, en particulier ceux qui éliminent les

planktivores, sont semblables à ceux observés dans l'écosystème, basé sur 45 ans d'observations. D'un point de vue systémique, ces résultats de simulation suggèrent que le potentiel pour les rendements perdus soit élevé, soulignant l'importance d'inclure explicitement les interactions des espèces dans les modèles écosystémiques.

1. MODEL DESCRIPTION

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

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

2. SCENARIOS

2.1 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.

Base scenario

Five guilds were chosen to represent an ecosystem comparable to the Northeast US 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 where one species within each guild would achieve dominance over the others. In most guilds, species 1 (for instance, B1 in Benthivores, PI1 in Piscivores) was set 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 an equilibrium biomass level where each guild's total biomass was near its carrying capacity.

Intra-guild competition scenarios

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 did not 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 PI1 than PL5. With PI1'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 a higher system biomass. This occurred because the dominant predator's (PI1) biomass dropped substantially compared to the Base Scenario. This suggests that predation is a more dominant biotic factor than Intra-Guild competition itself.

Predation scenarios

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 scenarios

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 least in guild ranking, but not to the same degree as in the similar Predation scenario.

2.2 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.

Demersal fish overfished

When Demersals (PI1, PI2, PI3, 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 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 their predators (Piscivores, Shrimp-Fish) and primary competitors (Shrimp-Fish). Even though total biomass increased, the previously dominant member (PL4) dropped to third in biomass within the guild. Benthivores increased in biomass in spite of overfishing due to a higher growth rate for some of its members compared to 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.

Piscivores overfished

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 US Atlantic Ecosystem. Starting in the early 1990s, Piscivore biomass began to decline, resulting in an increase in Planktivore biomass. Additionally, increasing trends in Benthivore and Shrimp-amphipod biomasses occured 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.

Pelagics overfished

When Pelagics (PI4, PI5 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.

Dominant species overfished

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.

3. BIOLOGICAL REFERENCES POINTS

The harvest scenarios were evaluated to compare B' (final biomass) to BMSY. In the Base Scenario (BS), the harvest rate (H) for all species was set to 0.0. 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). BMSY was set as K/2 for each guild. The BMSY 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'/BMSY 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'/BMSY greater than 1.0. Our results show that when harvested, the guild or affected species typically exhibit a lower B'/BMSY. Further analysis show that indirect effects of harvesting other species cascade through the species interactions, changing the BRP proxy for non-harvested species. For example, when Benthivores are harvested, SA4's B'/BMSY becomes greater than 1.0 while SF3's B'/BMSY becomes less than 1.0 due to the levels of competition changing among these three guilds.

4. 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 percent increase in system biomass which was the largest increase in biomass of any scenario. Additionally, the predation scenarios generally showed a greater effect on system biomass than the competition scenarios. Even though changing biotic factors can greatly affect individual species biomasses within a guild, overall biomass of the 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 important in determining appropriate biomass tradeoffs in fishery management.