Incorporating bioenergetics into multi-species statistical catch-at-age models (MSM) : *an example from the Bering Sea*

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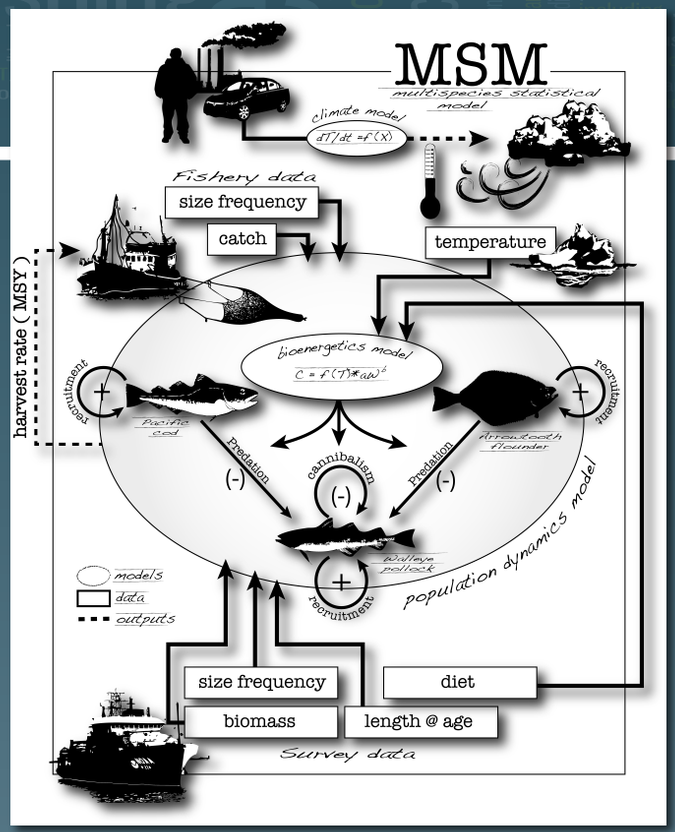

background

Consideration of trophodynamic interactions in both stock assessments and harvest policies might improve assessment accuracy and identify trade-offs that emerge between fisheries that target multiple species in a food web. A variety of tools have emerged to incorporate species interactions in stock assessment models including multi- species age- structured statistical models (MSM). MSM uses abundance and diet data to estimate fishing mortality, recruitment, stock size, and predation mortality. Here we modified an existing MSM for three species of fish from the Bering Sea (walleye pollock, Pacific cod, and arrowtooth flounder) to incorporate temperature dependent predator rations. Additionally, we also used projections of the model to derive biological reference points (BRPs) for various harvest control rules. Our approach thus provides a statistical framework to evaluate and manage both the direct and indirect effects of fisheries harvest on multiple species under various climate scenarios.

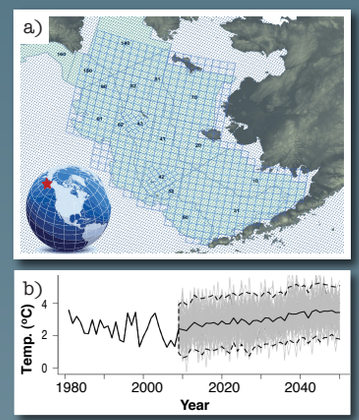

Figure 1. a) EBS survey locations and b) model input temperatures.

methods

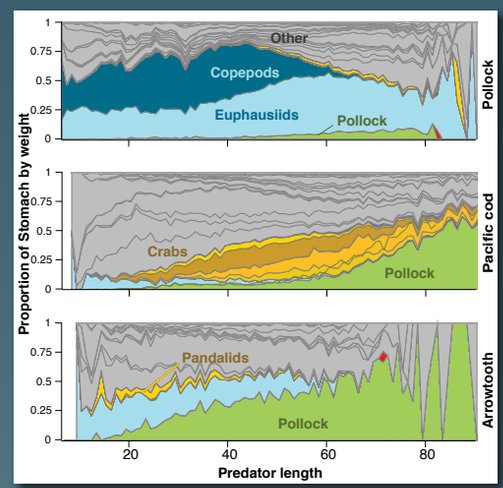

Figure 2. Predator stomach proportions by weight.

MSM is composed of an age- structured population dynamics model and a predation mortality sub-model. The model uses catch, biomass, and length at age data from the fishery and annual NOAA surveys to estimate abundance and fishing mortality (F_{rate}). The predation sub-model uses diet data for each predator to estimate the proportion of total prey mortality due to predation (Z = F + M1 + M2, where M1 and M2 are residual and predation mortalities, respectfully).

Our approach in this study was to:

1. Link stock-assessment models for three species with bioenergetic-based predation models.
2. Hindcast MSM to fit eastern Bering Sea catch and survey data from 1979 - 2011 to estimate spawning biomass, mortality, mean recruitment, and selectivity.
3. Use model estimates to project model forward 50 years to forecast biomass with and without fishing.
4. Approximate F_{35} and other biological reference points using forecast estimates of unfished spawning biomass (B_0).

Table 1. Likelihood objective functions.

Catch @ age	$-\sum_k n_k \sum_y \sum_a \left(\frac{C_{k,a,y}}{\hat{C}_{k,y}}+v\right)\cdot ln\left(\frac{\hat{C}_{k,a,y}}{\hat{C}_{k,y}}+v\right)$
Survey catch @ age	$-\sum_k n_k \sum_y \sum_a \left(\frac{O_{k,a,y}}{\hat{O}_{k,y}}+v\right)\cdot ln\left(\frac{\hat{O}_{k,a,y}}{\hat{O}_{k,y}}+v\right)$
EIT survey catch @ age	$-n\cdot \sum_y \sum_a \left(\frac{E_{a,y}}{\hat{E}_y}+v\right)\cdot ln\left(\frac{\hat{E}_{a,y}}{\hat{E}_y}+v\right)$
Total catch	$\sum_k \sum_y \frac{\left[ln\left(\sum_a C_{k,a,y}\right)-ln\left(\sum_a \hat{C}_{k,a,y}\right)\right]^2}{2\cdot\sigma_C^2}, \quad \sigma_C = 0.05$
Survey biomass	$\sum_k \sum_y \frac{\left[ln\left(B_{k,y}^{bt}\right)-ln\left(\hat{B}_{k,y}^{bt}\right)\right]^2}{2\cdot\sigma_{bt}^2}$
EIT survey biomass	$\sum_y \frac{\left[ln\left(B_y^{eit}\right)-ln\left(\hat{B}_y^{eit}\right)\right]^2}{2\cdot\sigma_{eit}^2}, \quad \sigma_{eit} = 0.2$
Fisheries selectivity	$\sum_k \sum_{a=1}^{A-1} \begin{cases} \eta_a^F > \eta_{a+1}^F & \frac{\left[ln(\eta_a^F)-ln(\eta_{a+1}^F)\right]^2}{2\cdot\sigma_{\eta 1}^2}, \quad \sigma_{\eta 1} = 0.16 \\ \eta_a^F \le \eta_{a+1}^F & \frac{\left[ln(\eta_a^F)-ln(\eta_{a+1}^F)\right]^2}{2\cdot\sigma_{\eta 2}^2}, \quad \sigma_{\eta 2} = 0.2 \end{cases}$
Survey selectivity	$\sum_k \sum_{a=1}^{A-1} \frac{\left[ln\left(\eta_a^{bt}\right)-ln\left(\eta_{a+1}^{bt}\right)\right]^2}{2\cdot\sigma_\eta^2}, \quad \sigma_\eta = 0.2$
Diet preference	$\sum_{pred}\sum_j\sum_{prey}\sum_a\sum_y \frac{\left[ln\left(U_{prey_a,pred_j,y}\right)-ln\left(\hat{U}_{prey_a,pred_j,y}\right)\right]^2}{2\cdot\sigma_{ij}^2}$

$v = 0.0001$

results

Patterns in annual pollock recruitment estimated from MSM are similar, although lower than recruitment estimated from the 2010 pollock single species stock-assessment (Fig. 3.a.).

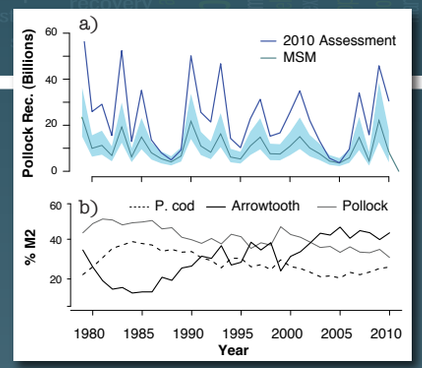

Figure 3. a) Model estimates of pollock recruitment (+/- 95% CI) from MSM and the 2010 stock assessment and b) proportion of pollock predation (M2) by each predator.

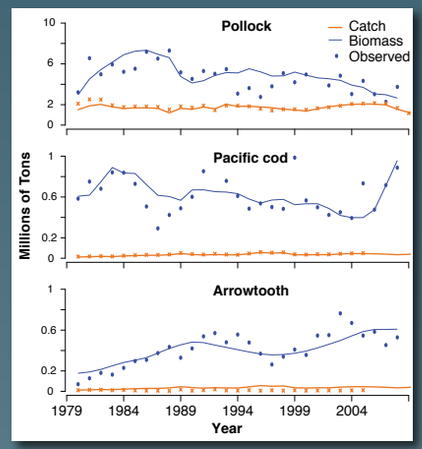

Figure 4. Predicted (line) and observed (points) catch and biomass.

Overall, MSM was able to fit biomass and catch data relatively well (Fig. 4) and estimates of predation revealed that cannibalism in pollock is an important source of natural mortality (in addition to predation by Pacific cod and arrowtooth flounder; Fig. 3.b.).

Constraining future spawning biomass of each species to 35% B_0 resulted in target harvest rates (F_{35}) similar to but slightly lower than estimates from single species models (F_{35} = 0.12 - 0.18).

Predation mortality was highest for pollock under no-fishing scenarios, thus unfished total and spawning biomass was more sensitive to future climate conditions than pollock biomass under a 0.2 fishing rate (Fig. 5).

conclusion

Projecting MSM forward under mean conditions provides a practical method for obtaining multispecies biological reference points for fisheries management (e.g., B_0 or F_{35}) that can account for climate induced changes in predation mortality.

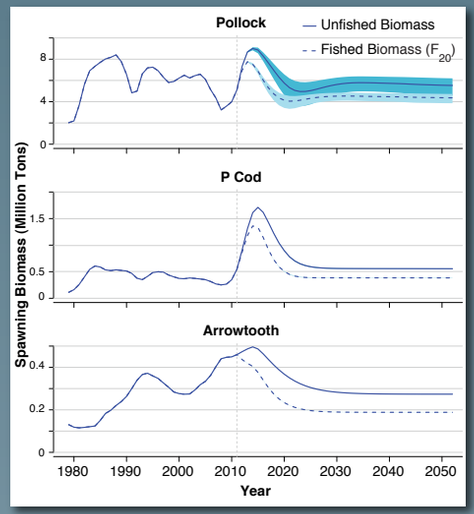

Figure 5. Hindcast and projected spawning biomass with (F = 0.2) and without fishing (B_0). Light-blue error distributions represent variability due to upper and lower temperature bounds.

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