Exploring the dynamics of Scotian Shelf cod with a statistical framework for size-structured predator-prey models

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Introduction

- What has prevented the recovery of cod following the collapse of the fishery in the early 1990s?
- Evidence of ensuing trophic cascade[1].

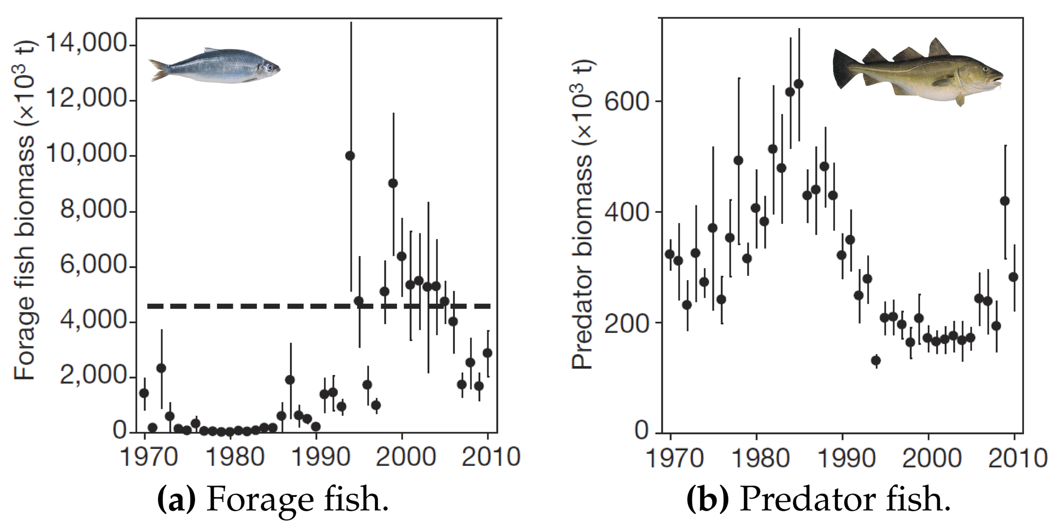

Figure 1: Trophic cascade on Scotian Shelf resulting from collapse of cod stocks.

- Hypothesized mechanisms for slow recovery (or alternative stable state) include:
  - Cultivation-depensation – now abundant forage fish compete with, and prey on, juvenile cod[2].
  - Overcompensation – increased competition within forage fish populations leads to a lack of suitably sized prey for larger cod[2].
  - Increased predation from growing seal population
  - Environmental changes

Data

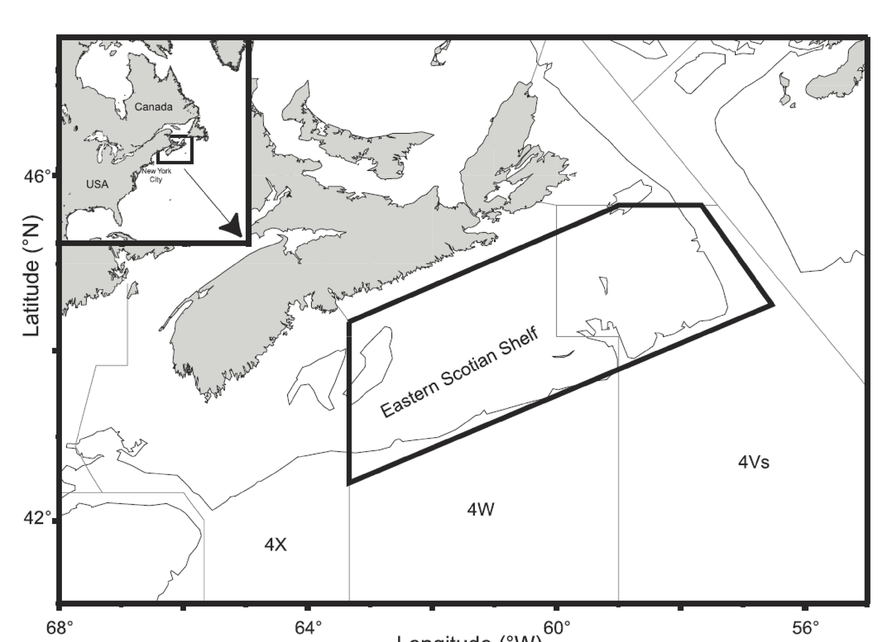

Figure 2: Scotian Shelf large marine ecosystem.

- 33 years of abundance-at-length estimates for 13 species from DFO, Canada.

Mechanistic model

We model the density of fish of species i and size m as:

$$\frac{\partial N_i(m)}{\partial t} = -\frac{\partial}{\partial m}(g_i(m)N_i(m)) - \mu_i(m)N(m)$$

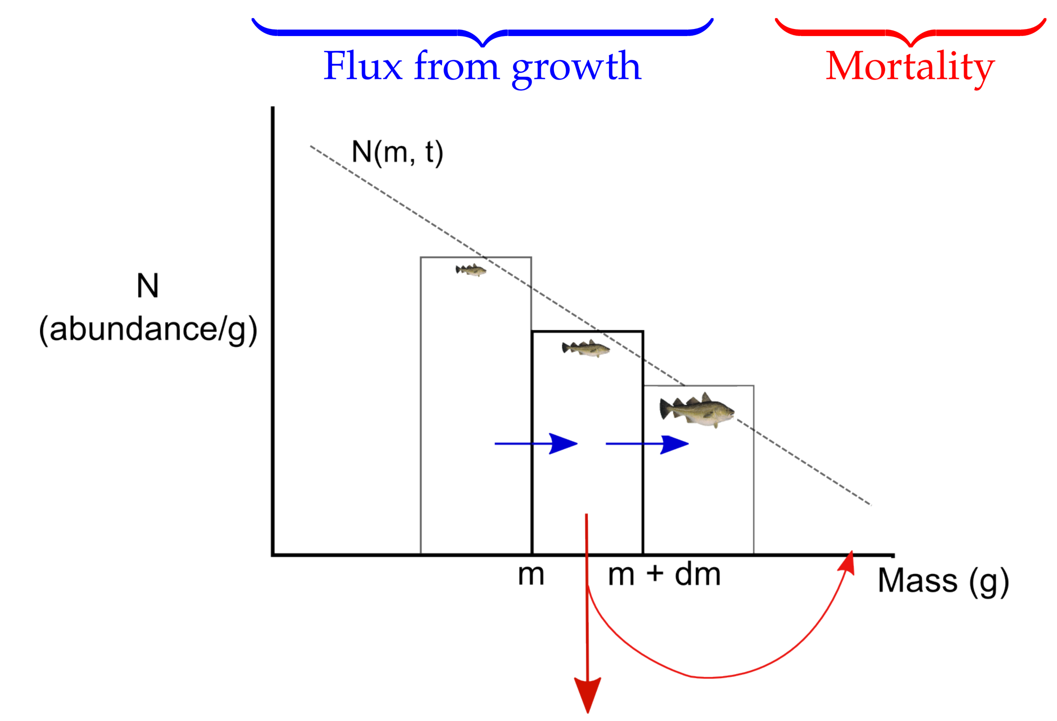

Figure 3: Schematic of size-structured PDE model[3].

We apply this model to a tri-trophic community where size-independent food web structure is modeled through coupling matrix θ.

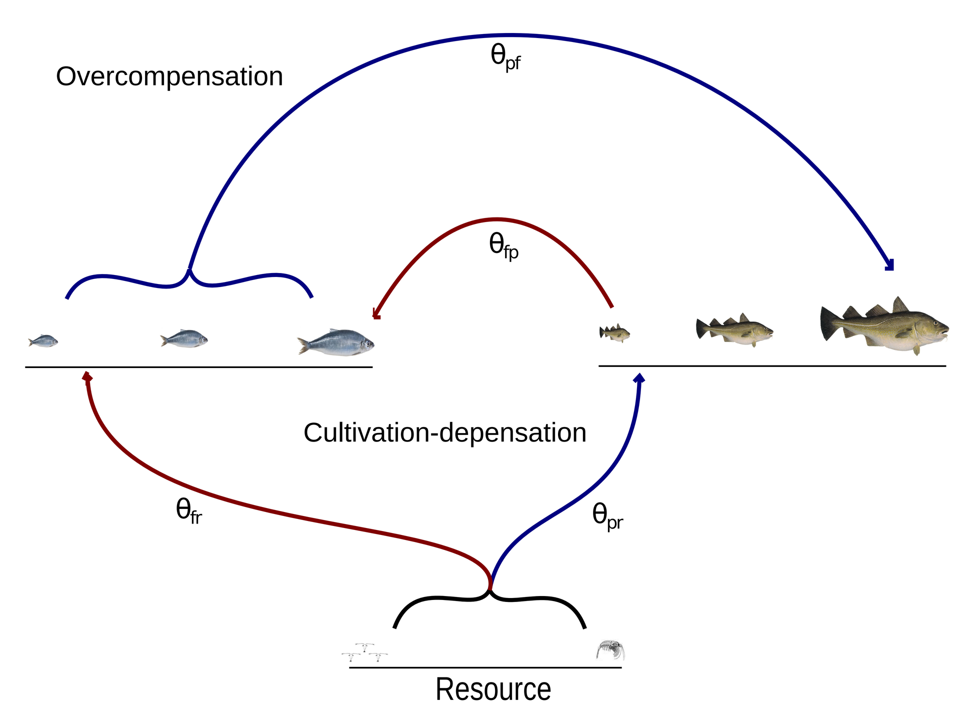

Figure 4: Size-structured interactions between cod and forage fish.

Parameter Estimation

- Measurement process on deterministic model:
$$\log y_{ijt} \sim \mathcal{N}(\log N_{ijt}, \sigma^2)$$
- Maximum likelihood estimation of:
  - θ: food web coupling matrix
  - κ: scaling factor for resource carrying capacity
- Fit to post-collapse data (1993 - 2003)
- Optimization carried out using `TMB` package in R.

Results

- The stability of the smallest cod and the decline of the largest more consistent with either overcompensation or increased seal predation.

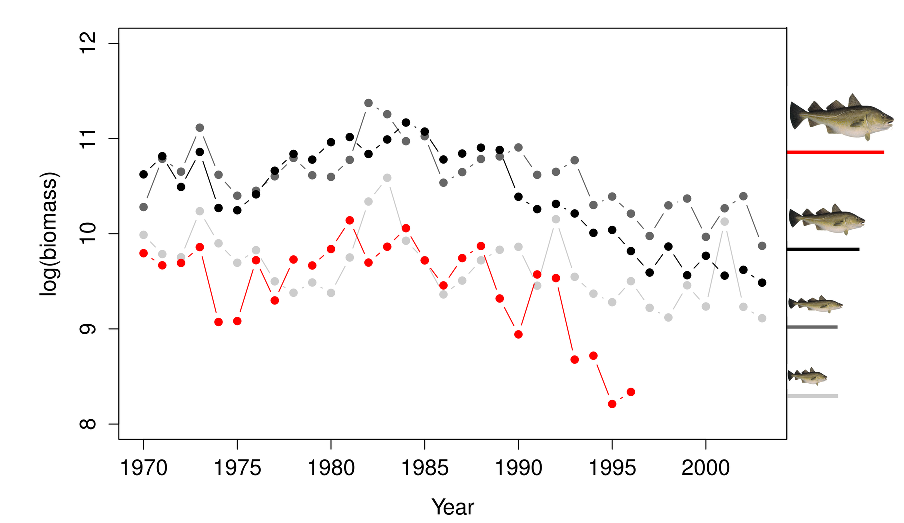

Figure 5: Changes in cod population structure over time.

- The best fit model able to capture major features of the data.
- But there are many local optima – likelihood surface difficult to traverse.

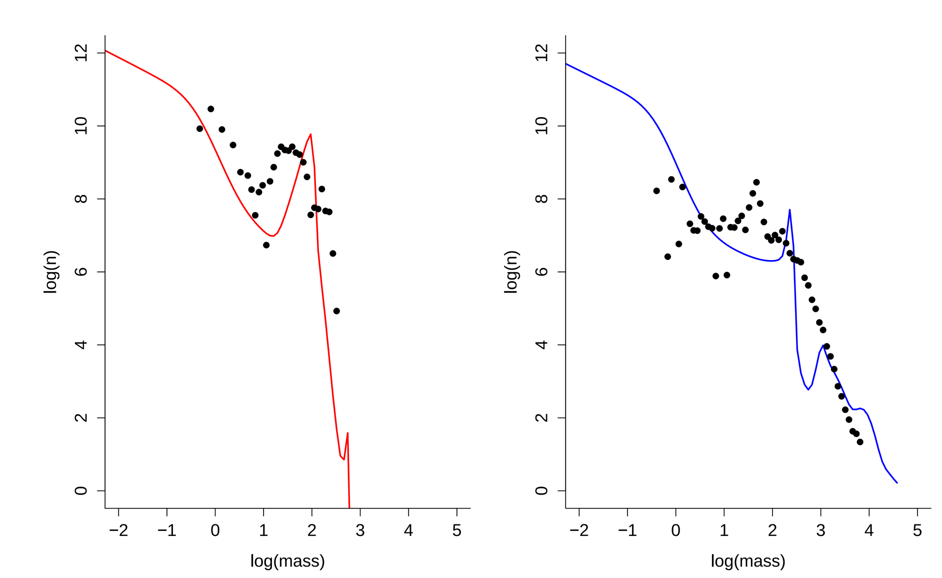

Figure 6: Model predicted size spectra (colored lines) for forage fish (left) and predators (right) for 2003. Observed abundances shown with points.

Conclusions

- The data suggest that recovery likely inhibited by forces acting on larger cod:
  - Limited growth and/or high starvation mortality from lack of suitable prey.
  - Increased mortality from seal predation.
- Can tease apart these mechanisms with the help of the size-structured model and a more robust statistical framework.

Future work

Biological questions

- Incorporate size-at-age data in model fitting to better separate growth from mortality.
- Better explore the influence of other (currently fixed) parameters that may control/distinguish the possible mechanisms.
  - e.g. growth rate and max size of resource
- What role do other species play in mediating the cod-herring interaction?
- How can this work be expanded to fit into a true trait-based framework?

Statistical questions

- Generally, how to approach the problem of fitting large mechanistic models to data?
  - Start with simplest reasonable model on simulated data
  - Incorporate process noise/uncertainty – can help to smooth likelihood surface

References

(1) Fisher et al. (2010) *Ecology*: 2499 – 2505.
(2) Gårdmark et al. (2014) *Phil. Trans. R. Soc. B* 370: 20130262.
(3) Hartvig et al. (2011) *JTB*: 113 – 122.

Acknowledgements

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