Information requirements for assessing trophic impacts of fisheries on ecosystems

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And a cameo appearance by George Watters

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Limitations of Single Species Models

Single species models fail to capture changes in vital rates associated with changes in trophic structure.

- Possible to estimate changes in $Z$ from catch-age data (i.e. $Z=-\ln(N_{t+1}/N_t)$)
- Cannot partition $Z$ into components (i.e. $Z=M_1+M_2+M_3+\ldots+F$)

**WCVI Pink Shrimp**

Instantaneous mortality rate

- Dogfish
- Adult Pacific Cod
- Juv Pacific Cod
- Lingcod
- Juv Lingcod
- Shrimp F
- Shrimp $Z$ from SSM
Ecosystem Models

Development of Ecosystem models is an essential step for moving towards ecosystem based management.

- Explicit accounting of direct and indirect ecological interactions.
- Examine tradeoffs associated with fisheries.

But! How can we be certain ecosystem models are making reasonable predictions?

- We need methods for model validation.
  - Confronting models with data.
- Also need methods for comparing alternative models.
  - Comparing single species approaches with ecosystem approaches.
Ecopath with Ecosim

**ECOPATH**
- Initialization routine for Ecosim (Walters).

**ECOSIM**
- A set of routines for predicting:
  - Changes in biomass ($B_i$).
  - Changes in consumption ($Q_{ij}$).

**ECOSPACE**
- A spatially explicit version of Ecosim.
  - Used to evaluate spatially explicit management options such as closed areas, or effects of seasonal migrations.
Leading parameter setup

Inputs:
- biomass
- P/B
- Q/B
- catch
- diet

ECOPATH

Inputs:
- Fishing mortality
- Fishing effort
- Historical forcing data
- Mediation relationships

ECOSIM

Calculate derived variables

Inputs:
- $V_{ij}$ (min N)
- Handling time (1)
- Feeding time parameters (2)
- Predator effect parameters (2)
- S-R parameters (4-5)
The guts of Ecosim

Change in biomass predicted using:

\[
\frac{dB_i}{dt} = g_i \sum_j Q_{ji} - \sum_j Q_{ij} - (M_i + F_i)B_i
\]

Consumption \((Q_{ij})\) based on foraging arena concepts.

\[
Q_{ij}(B_i, B_j) = \frac{a_{ij} v_{ij} B_i B_j}{2v_{ij} + a_{ij} B_j}
\]
**Consumption**

Representing limited prey vulnerability in Ecosim

- **B** = Total prey biomass;
- **V** = Vulnerable prey biomass;
- **v** = Behavioral exchange rate;
- **P** = Total predator biomass;
- **a** = Predator rate of search.

Fast equilibration between **B-V** and **V** implies

\[ V = \frac{vB}{2v + aP} \]
Consumption equation

Given estimate of $v_{ij}$ and inputs $(B_i, B_j, Q_{Bj}, D_{cij})$, calculate $a_{ij}$

$$Q_{ij} = \frac{a_{ij} v_{ij} B_i B_j}{2v_{ij} + a_{ij} B_j}$$

solve for $a_{ij}$

$$a_{ij} = \frac{-2Q_{ij} v_{ij}}{B_j (Q_{ij} - v_{ij} B_i)}$$

Unknown parameter for each trophic interaction link is $v_{ij}$
Main Criticisms of the approach

Reliance on input parameters for estimating derived variables

- Mass-balance constraint limits our ability to estimate leading parameters.
- Although convenient, consumption equations are sensitive to diet inputs and user specified exchange rates ($v_{ij}$’s).
- No real way, yet, to validate functional responses.
Questions?

Are typical fisheries data sufficient for estimating parameters in Ecosim, specifically:

- are relative abundance data sufficient for estimating vulnerabilities ($v_{ij}$)?
- again, are these data sufficient for estimating both $v_{ij}$ and environmental variation (a mixed error model)?
Methods

Steve:
- Create artificial ecosystems using Ecosim.
- Use Ecosim to generate time series data with errors and pass them onto George.
  - Data included relative abundance, fishing effort, catches, and total mortality rate estimates

George:
- Received an Ecopath model from Steve and time series data.
- Estimate Ecosim parameters from time series data (Blind).

Steve:
- Compare Georges estimates with true states, then determine how these policy recommendations would differ from the optimal state.
Data Quality & Observation Errors

Three Replicate Ecosystems, all with the same parameter values, different exploitation histories, and different observation errors. No process errors (primary-productivity anomalies).

- All vulnerabilities = 0.3, except Epipelagics $v = 0.45$, increasing observation errors.

![Graphs showing biomass over simulation year for different CV values](image-url)
Process & Observation Errors

- CV in observation errors = 0.05
- CV in process errors = 0.2 (the oceanographic index is proportional to primary production with some variability).

![Graphs showing OCGY Index and Primary Production over years compared to each other.](image)

![Histogram showing distribution of OCGY Index over years.](image)
Time Series Data (OTM 1.4)

- Relative abundance (incomplete for epi & mesopelagics)
- Catch & Effort-by-gear data
- Total mortality for Apex Predators
Results: Data Quality

Relative differences between true and estimated states
Including PP anomalies: Over fitting!

No Primary Productivity Forcing

Forcing Primary Productivity

Relative differences between true and predicted states
Results: OTM 1.4 (mixed errors)

Well sorry to disappoint you, but George and his wife had a baby and the blind experiment has been put on hold.
Summary from the blind experiment

George had figured out that models 1-3 had increasing observation errors.

Was able to obtain a better fit to model 3 by estimating process errors (over fitting the model).

George estimated a single $v_{ij}$ parameter for all groups, and did not explore the possibility that only one group had a higher vulnerability exchange rate.

- As a consequence, slightly over-estimated $v_{ij}$ parameters for all groups
- Implications: estimates of ecosystem compensation rates increase (i.e. the ecosystem is more resilient to fishing).

Poor George!
Other Things to Try

- Use single species models, or multi species models to aid Ecosystem approaches.
- Conduct more simulation experiments where observations include changes in diet composition over time.

**Lingcod Diet**

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- A. Res. Coho
- J. Hake
- Lingcod
- Small Pelagics
- Dogfish Shark
- Eulachon
- J. Herring
- J. Res. Coho
- Predatory Invertebrates
- H. Zool plankton
- A. Hake
- C. Zool plankton
- Demersal Fishes
- A. Herring
Summary & Limitations

Prospects for estimating parameters for the dynamic model look promising, however:

- assumes Ecopath parameters are correct,
- a nasty problem of comparing alternative models (i.e. estimating one overall $v_{ij}$ versus linkage specific $v_{ij}$’s).

The reliance on the mass-balance for model initialization constrains options for estimating leading parameters.

- It can be done in a rather crude fashion!
  - Random search
  - Trial and error