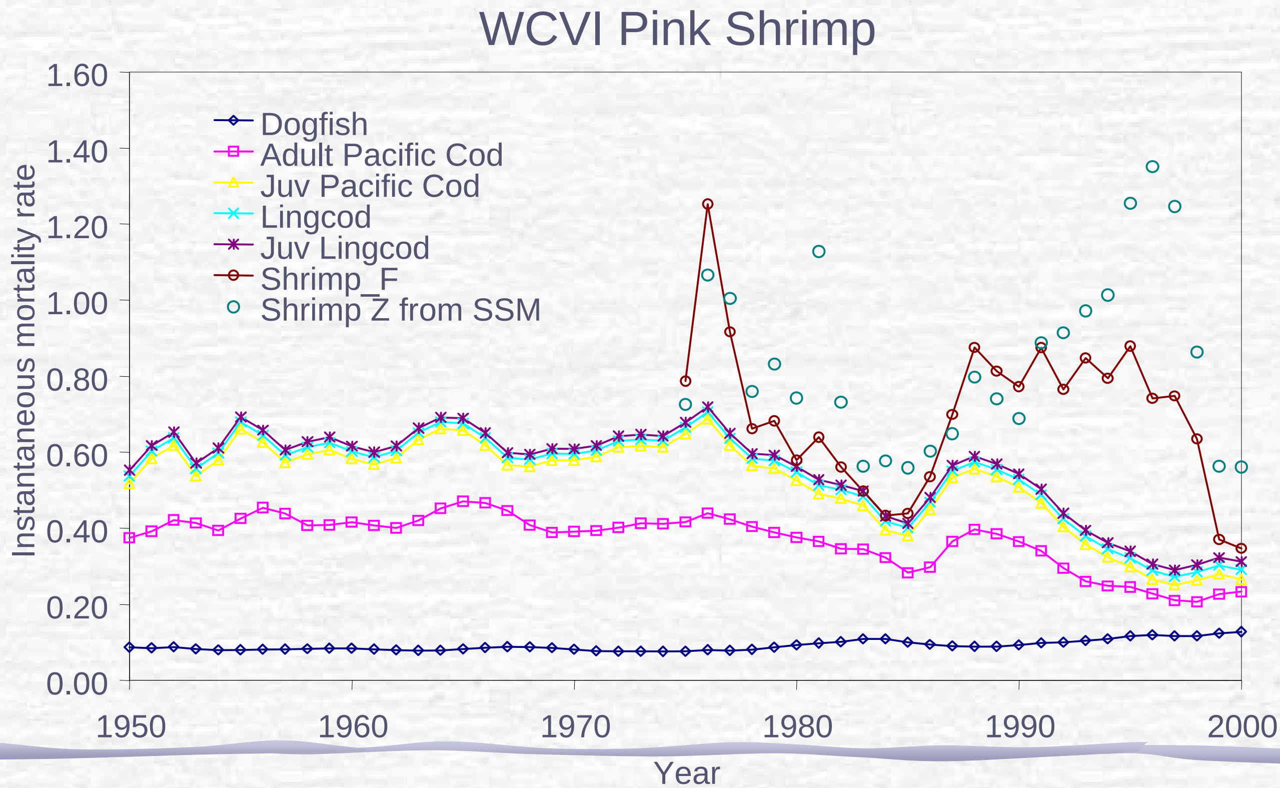
Information requirements for assessing trophic impacts of fisheries on ecosystems

Steve Martell[1]
Sean Cox[2]
And a cameo appearance by George Watters

[1] Center for Limnology, 680 North Park Street, Madison, WI, 53706, U.S.A.
[2] School of Resource and Environmental Management, Simon Fraser University, 8888 University Drive, Burnaby, BC, V5A 1S6

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. $Z=-\ln[N_{t+t}/N_t]$)
  - Cannot partition Z into components (i.e. $Z=M_1+M_2+M_3+...+F$)



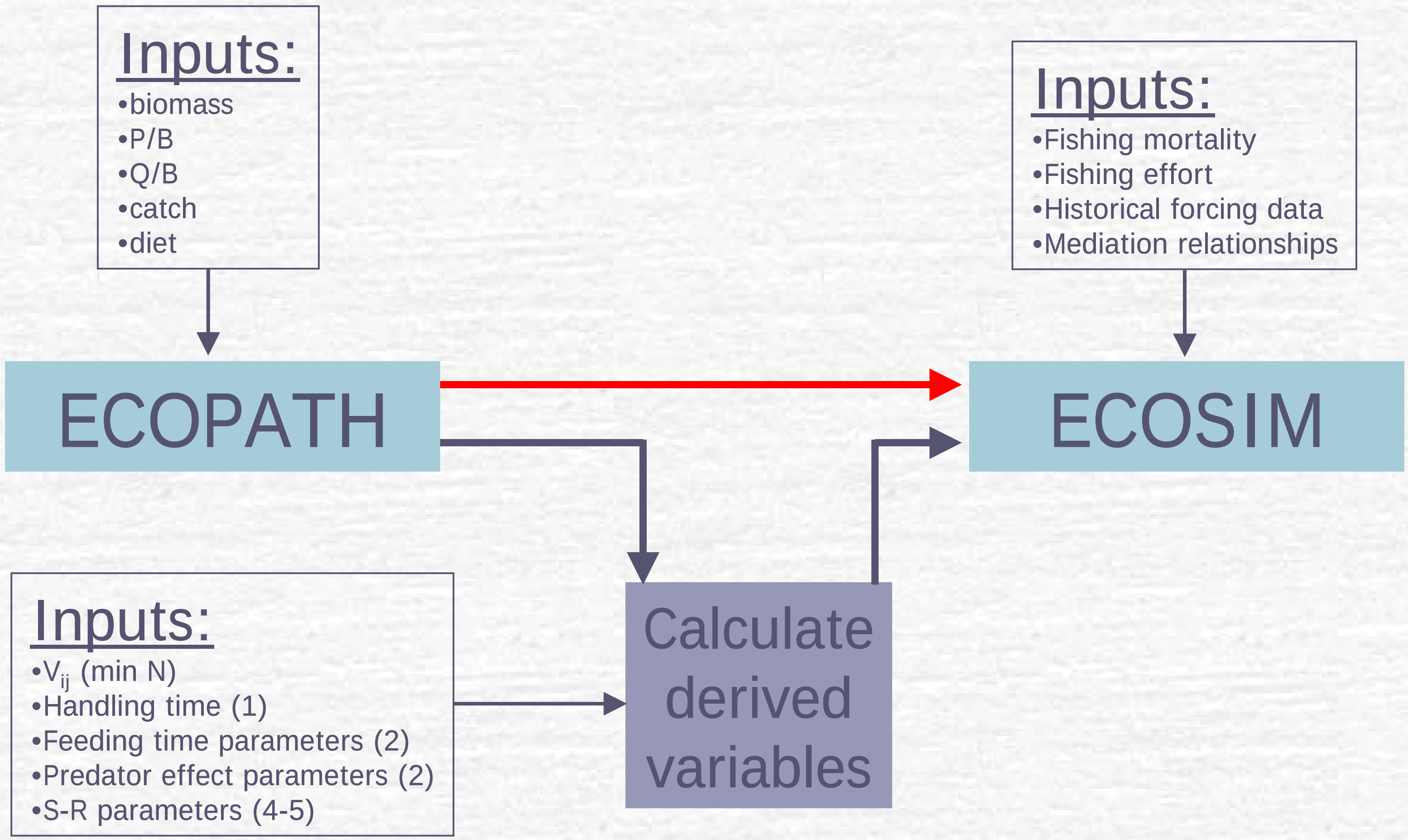
Ecosystem Models

- 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
  - Mass-balance accounting system (Polovina & Pauly).
  - Initialization routine for Ecosim (Walters).
- ECOSIM
  - A set of routines for predicting:
    - Changes in biomass (B_i).
    - Changes in consupmtion (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



The guts of Ecosim

- Change in biomass predicted using:

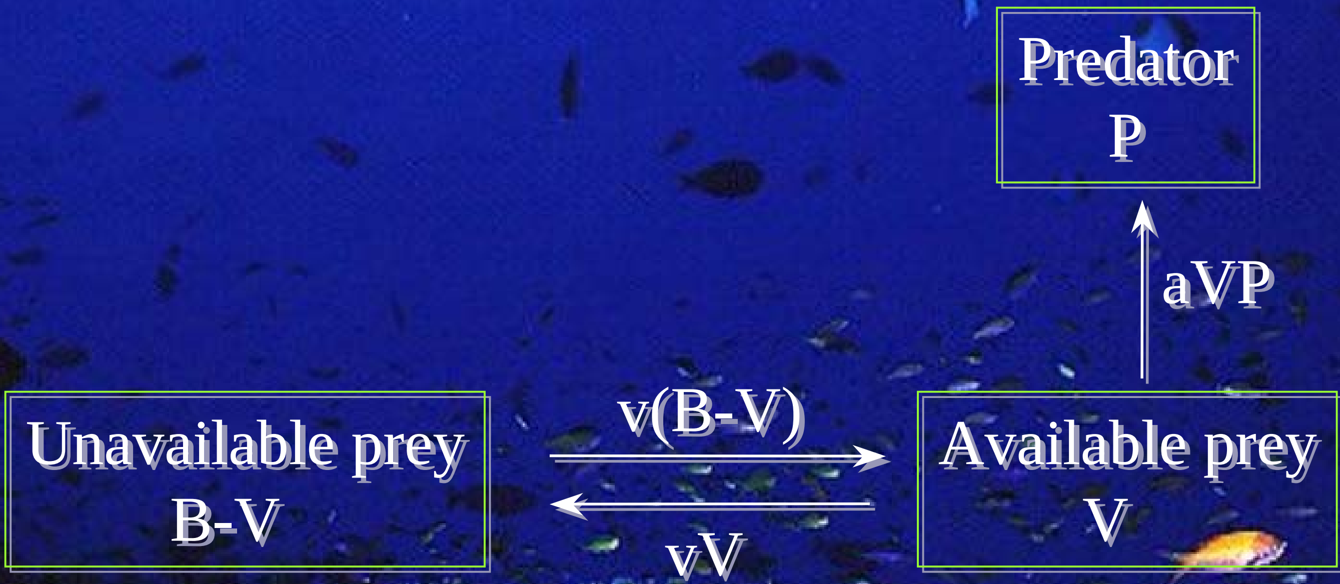
$$\frac{dB_i}{dt} = \underbrace{g_i \sum_j Q_{ji}}_{\text{Production}} - \underbrace{\sum_j Q_{ij}}_{\text{Predation losses}} - \underbrace{(M_i + F_i)B_i}_{\text{Unexplained \& fishing mortality}}$$

- 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



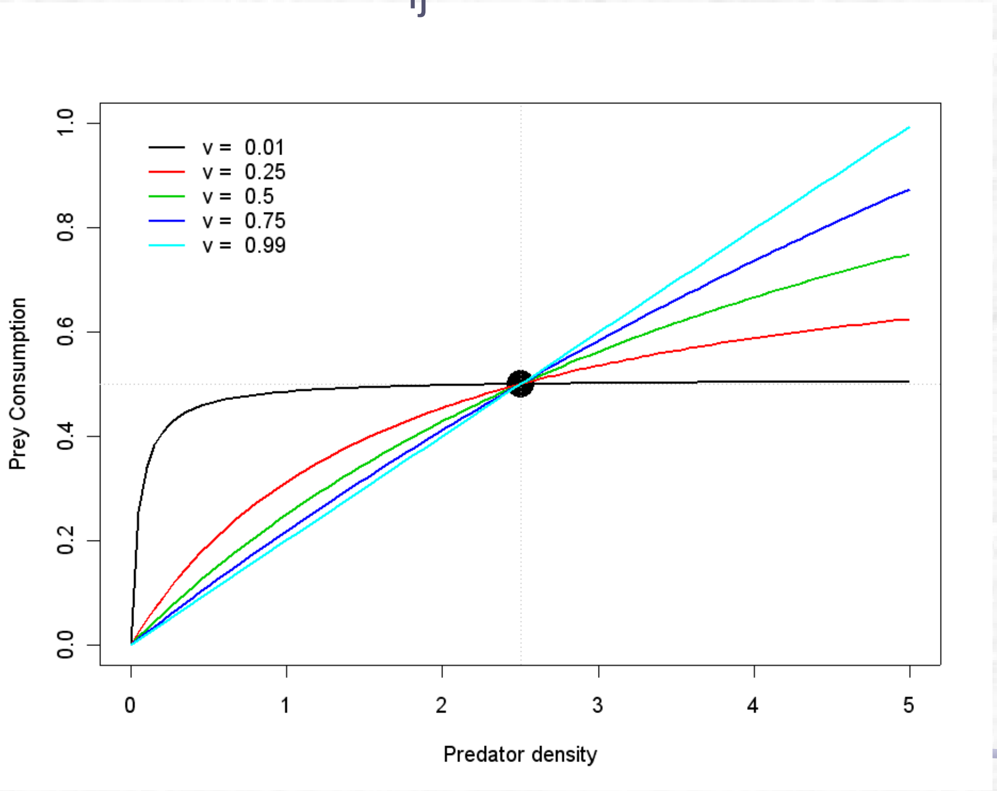
B = Total prey biomass;
V = Vulnerable prey biomass;
v = Behavioral exchange rate;
P = Total predator biomass;
a = Predator rate of search.

Fast equilibration between B-V and V implies

V=vB/(2v+aP)

Consumption equation

- Given estimate of v_{ij} and inputs (B_i, B_j, QB_j, Dc_{ij}), 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?

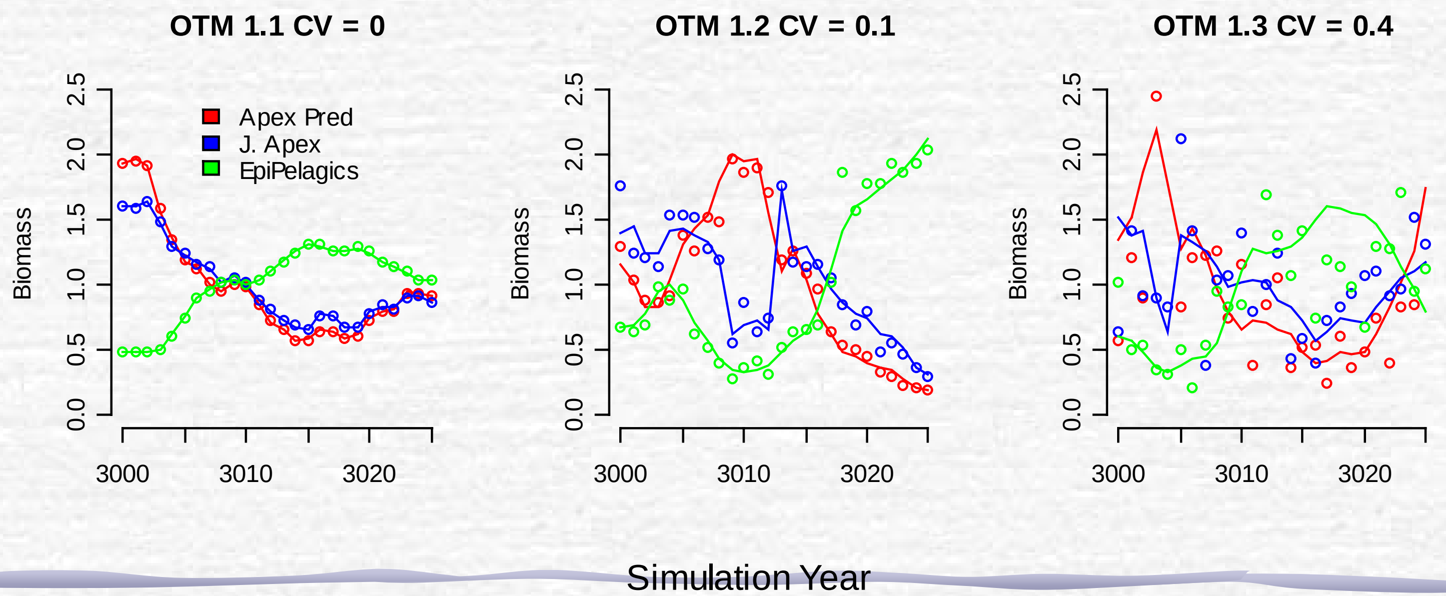
- Are typical fisheries data sufficient for estimating parameters in Ecosim, specifically:
  - are relative abundance data sufficient for estimating vulnerabilities (v_{ij})?
  - again, are these data sufficient for estimating both v_{ij} and environmental variation (a mixed error model)?

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.

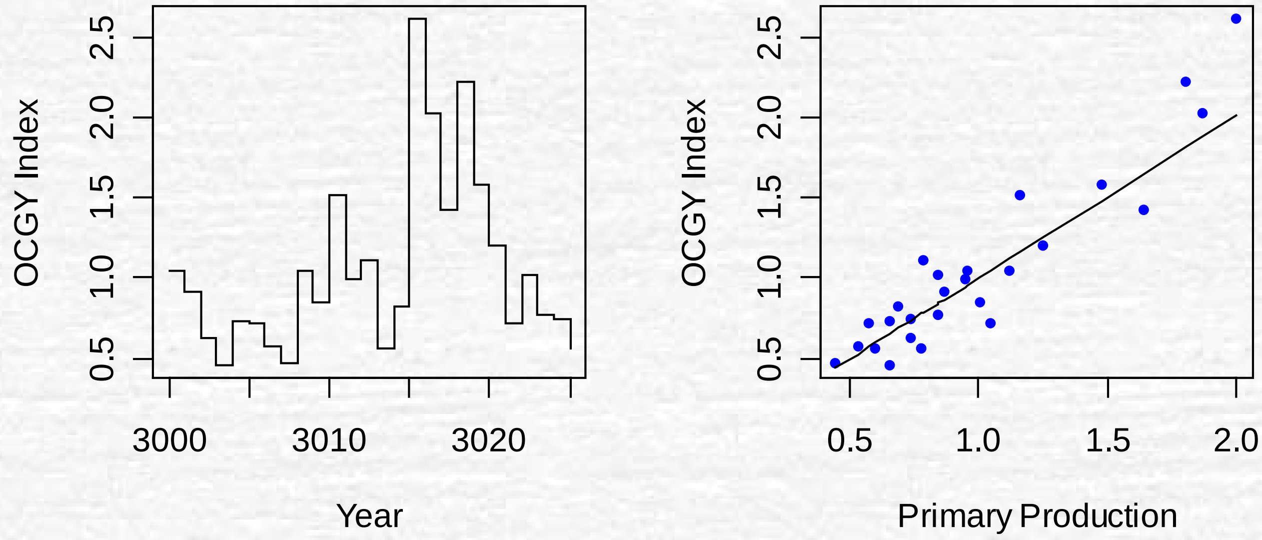
Data Quality & Observation Errors

- 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.



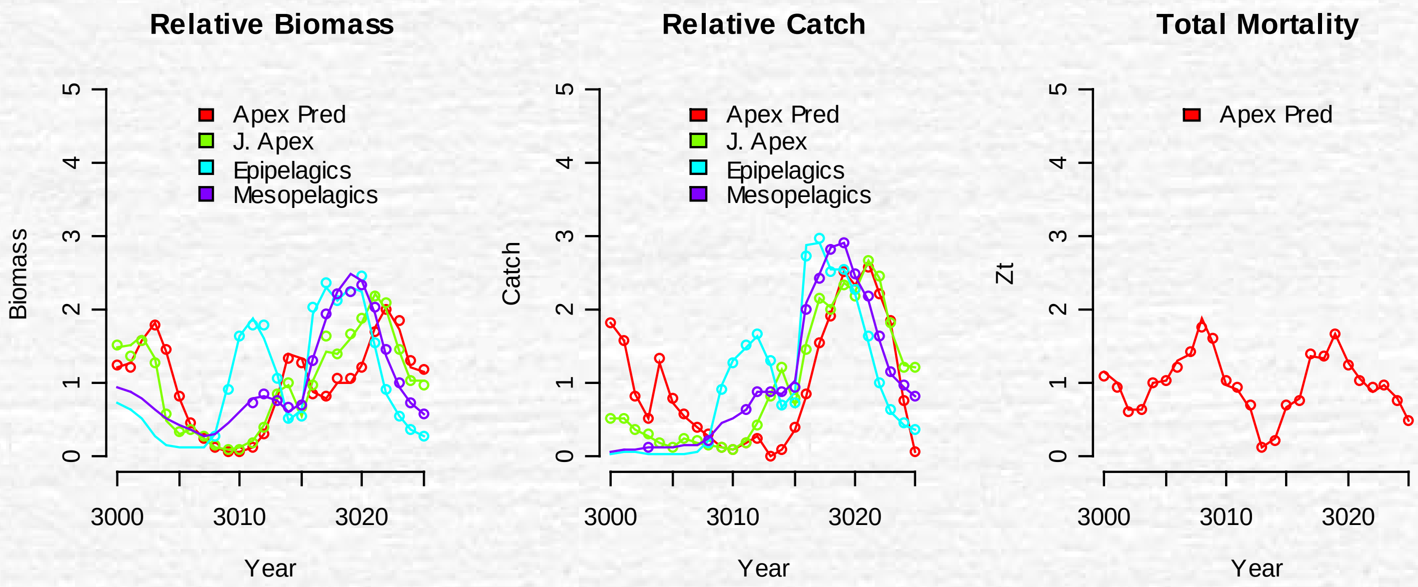
Process & Observation Errors

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

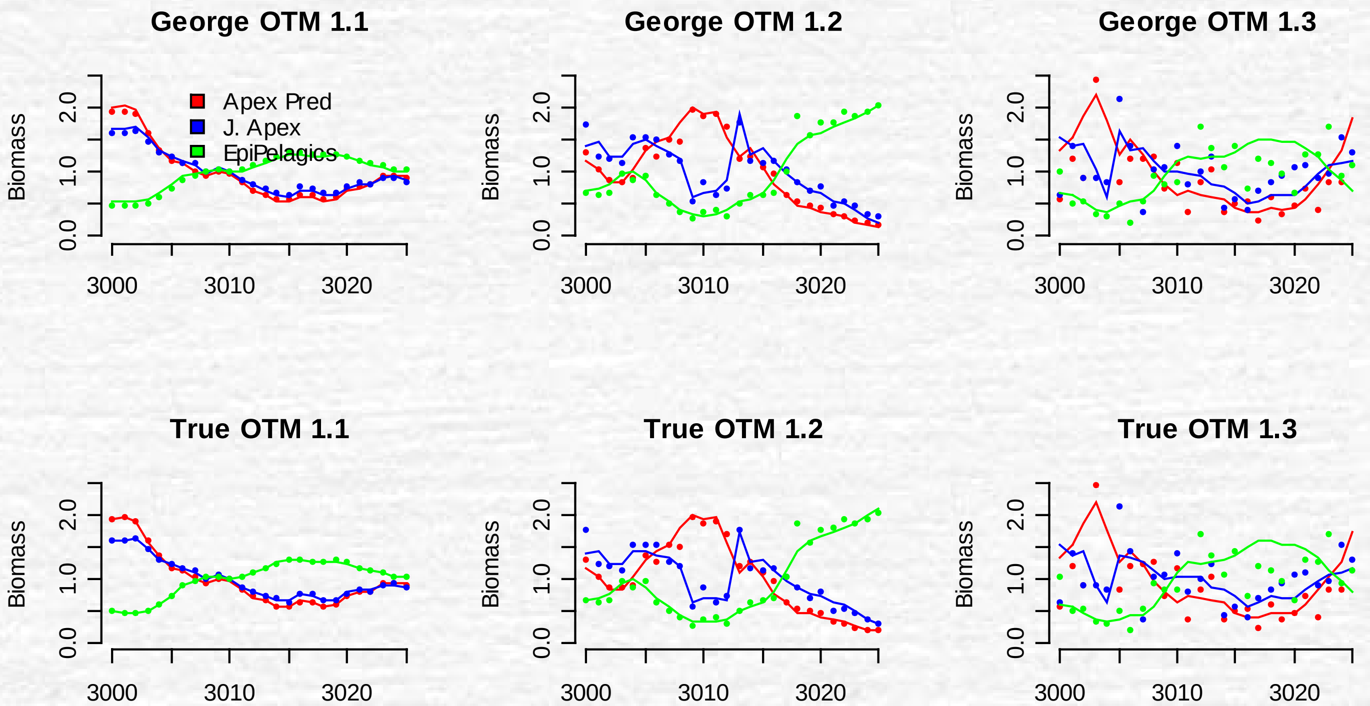


Time Series Data (OTM 1.4)

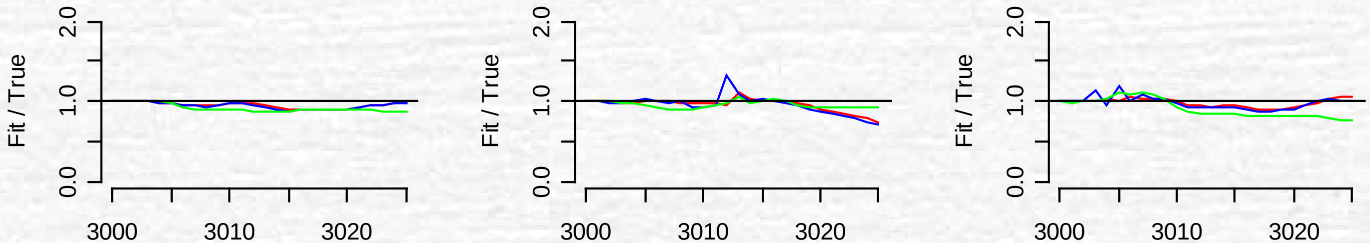
- Relative abundance (incomplete for epi & mesopelagics)
- Catch & Effort-by-gear data
- Total mortality for Apex Predators



Results: Data Quality

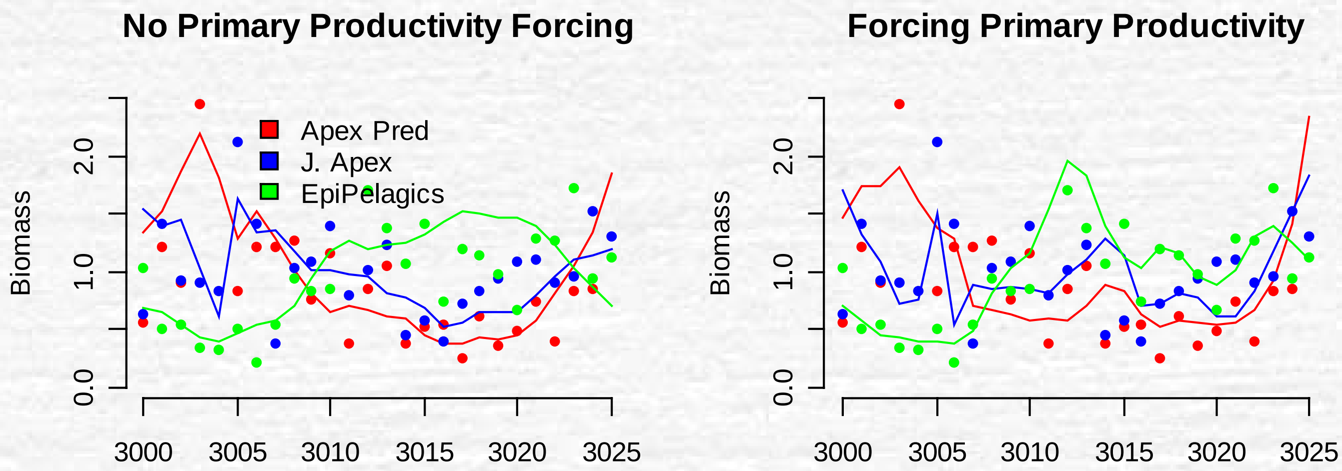


Relative differences between true and estimated states

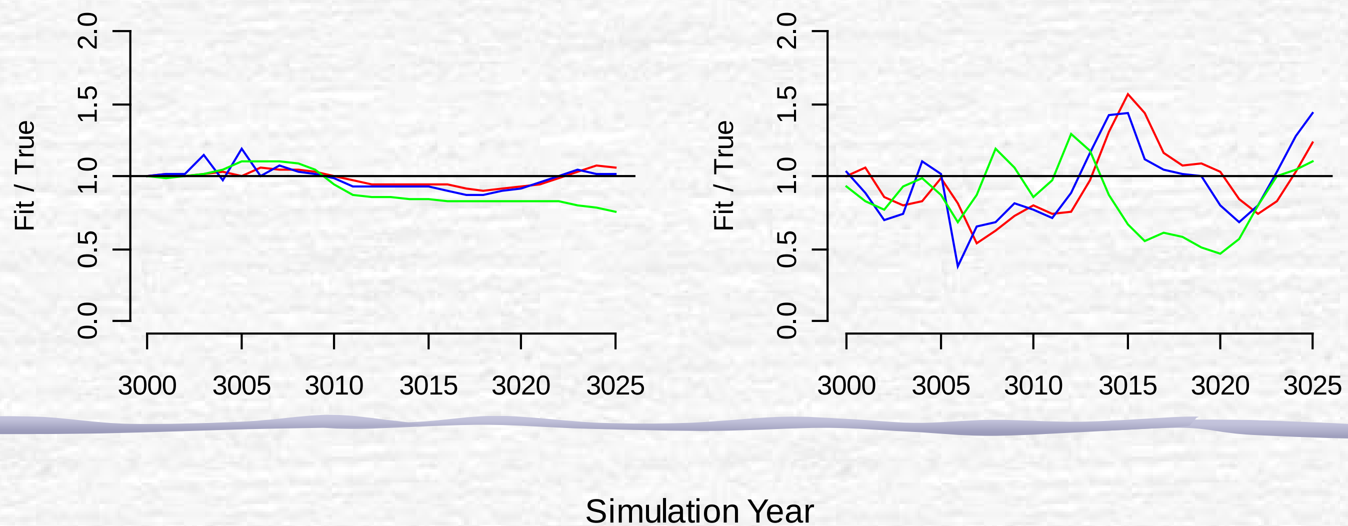


Simulation Year

Including PP anomalies: Over fitting!



Relative differences between true and predicted states



Results: OTM 1.4 (mixed errors)

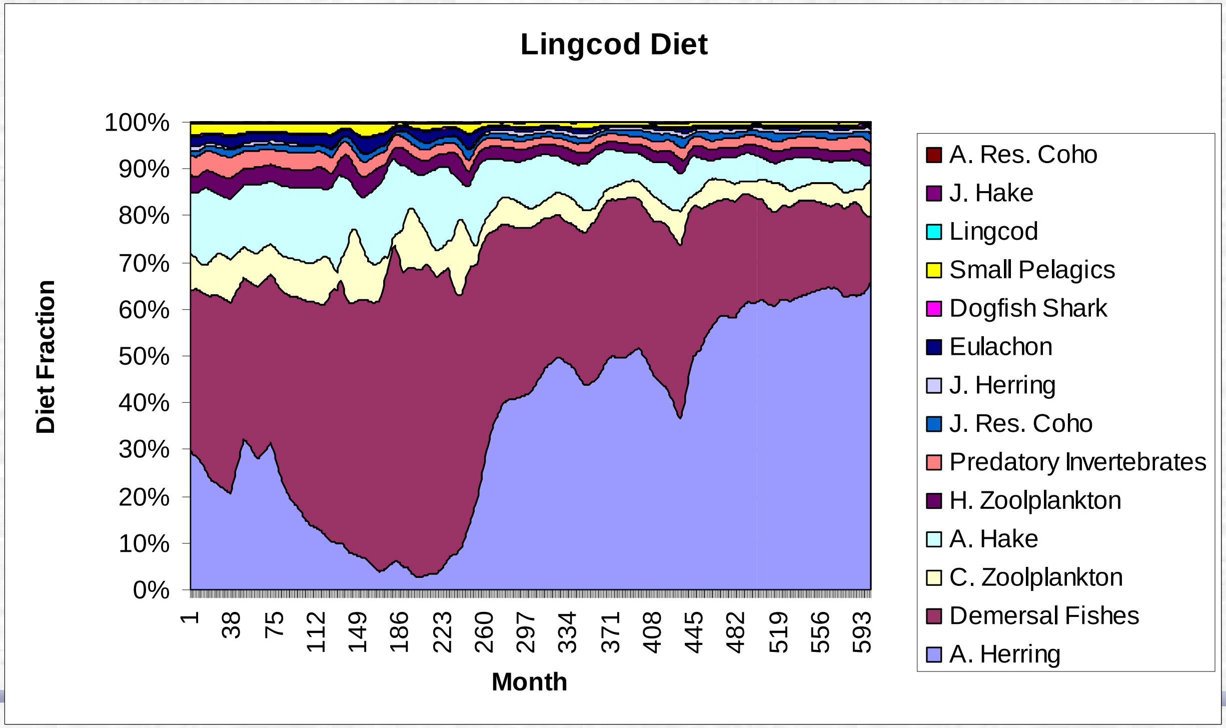
- Well sorry to disappoint you, but George and his wife had a baby and the blind experiment has been put on hold.

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.



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