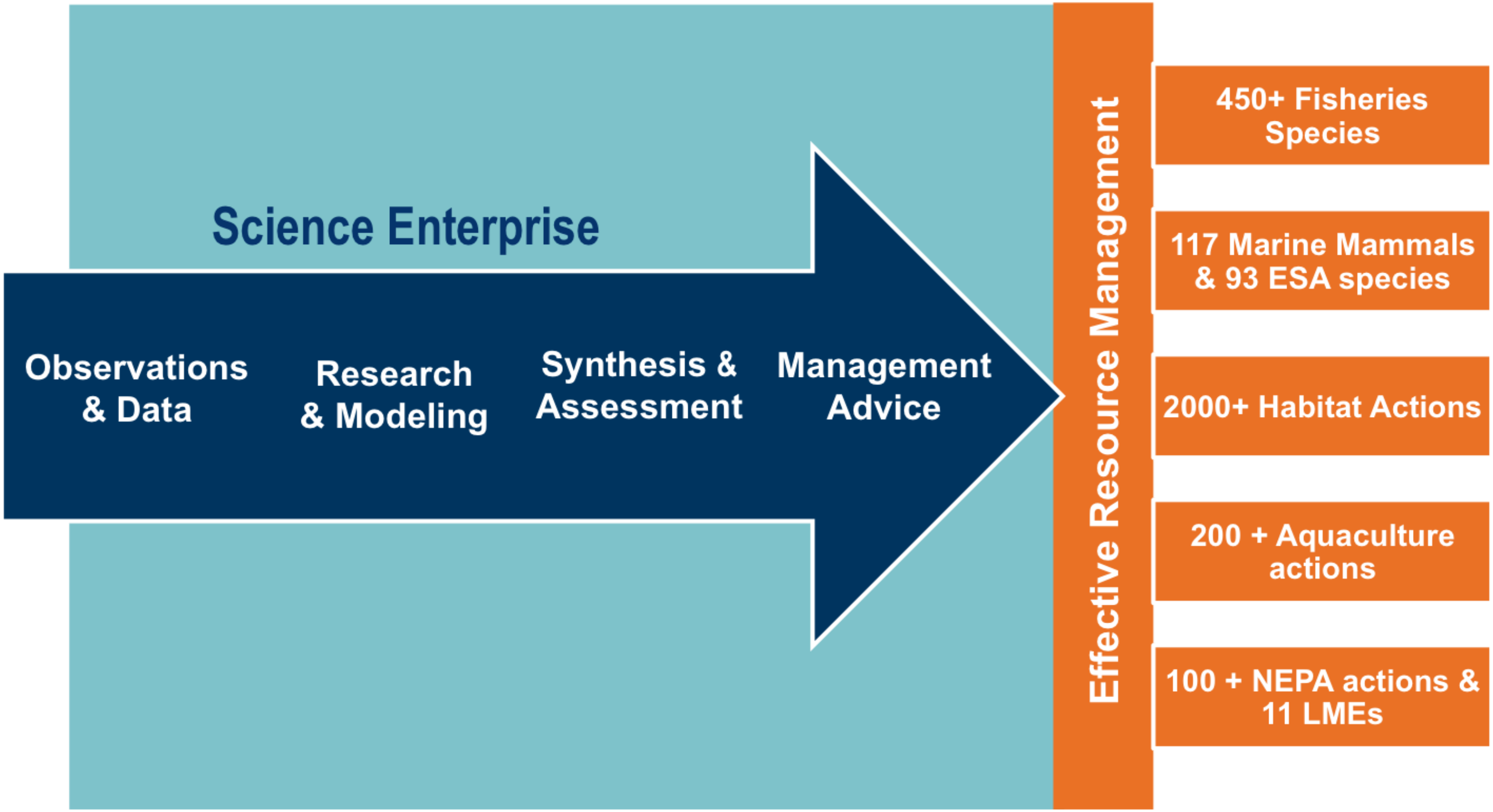
Fishing within food webs:

Modeling for management advice

Sarah Gaichas
Northeast Fisheries Science Center

What does modeling have to do with management?

NOAA FISHERIES
National Oceanic and Atmospheric Administration



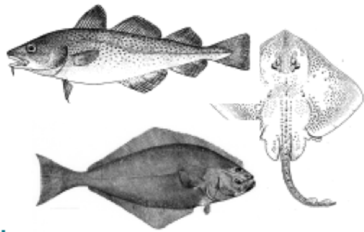
What kinds of models are there?

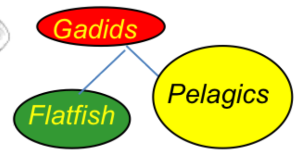
Stock/Single Species

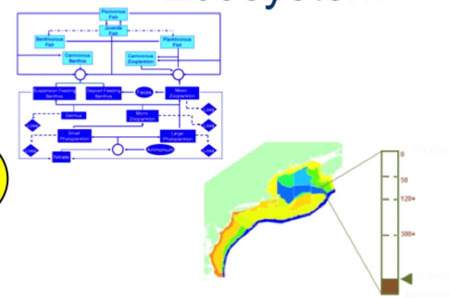
Multi-species

Aggregate Biomass

Ecosystem







Single stock models

Functional group models

Whole system models

Stock assessments with add-ons: explicit M2 or habitat or climate considerations

Multi-species assessments

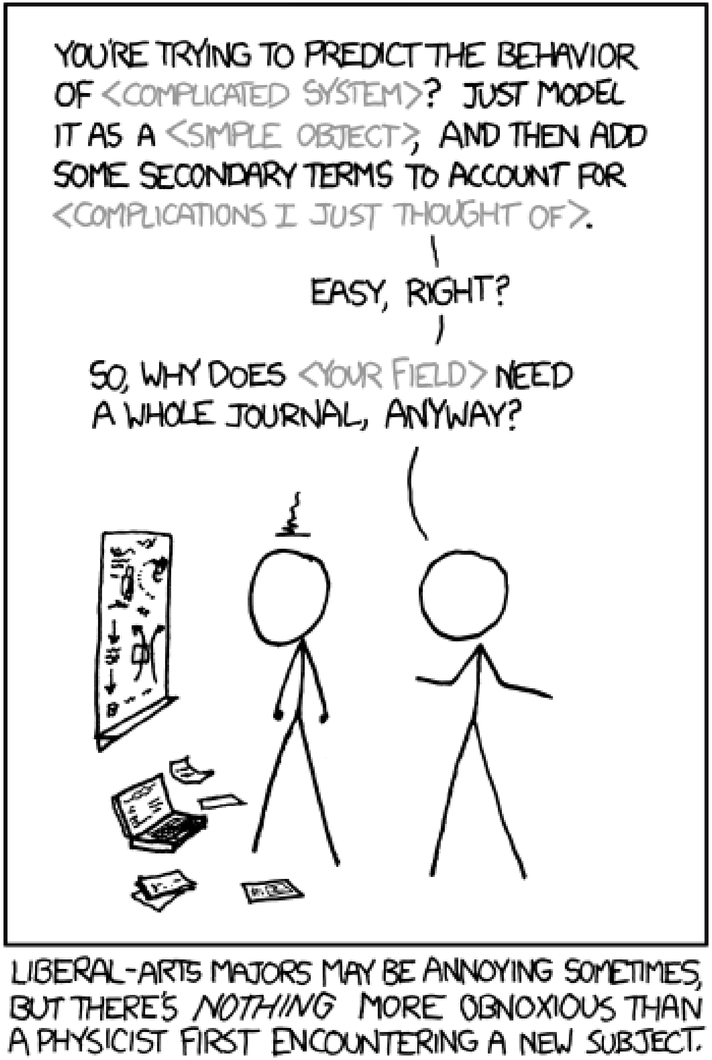
Integrated ecosystem assessments

Multiple stock assessments integrated

Economic assessments, social impacts

Which models are best for management decisions? (Conclusions!)

- Based on **clearly specified questions** (from managers/stakeholders)
- **Outputs** and **controls designed** to answer the questions
- Using **observations** directly from the ecosystem
- With clear description of **uncertainties**

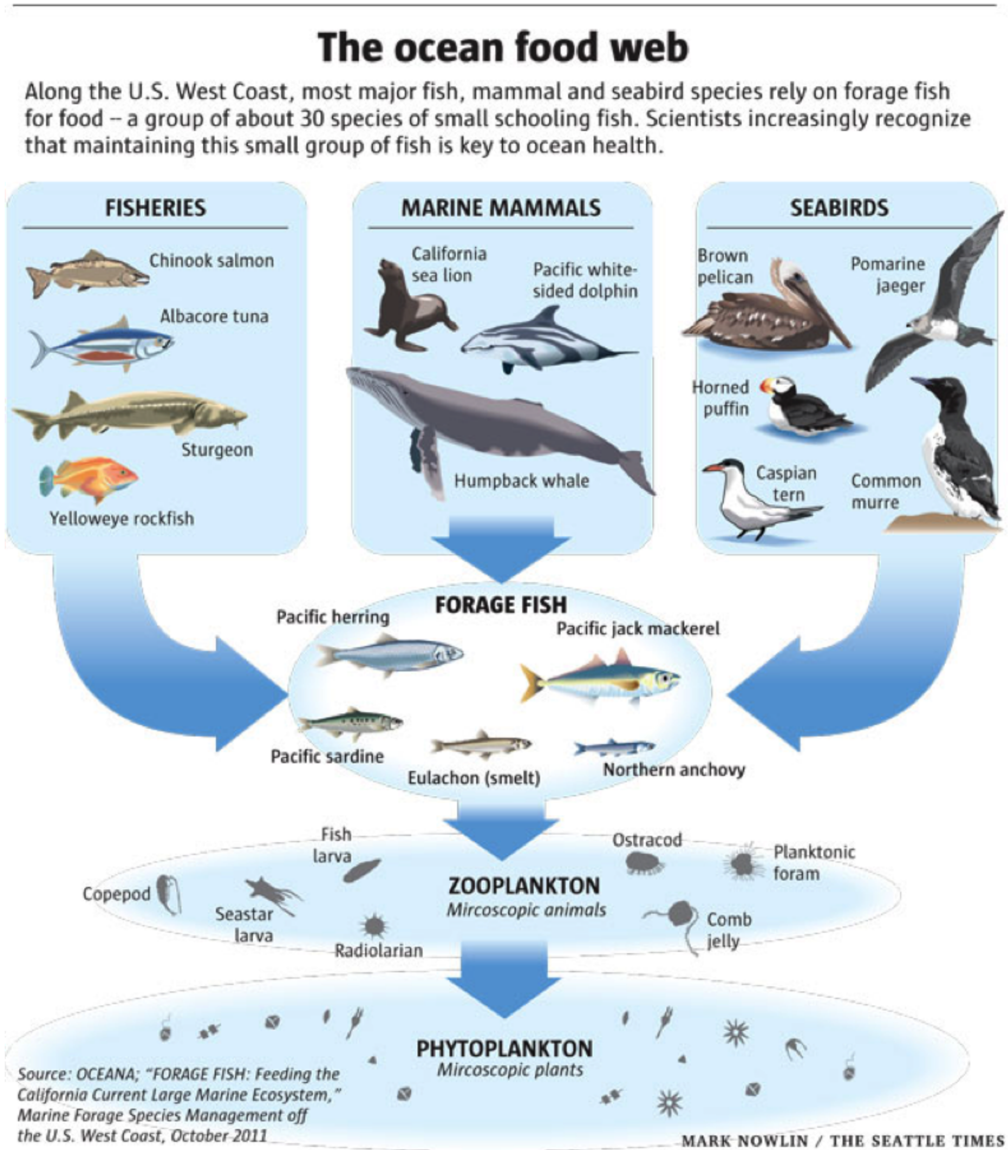


https://xkcd.com/793/

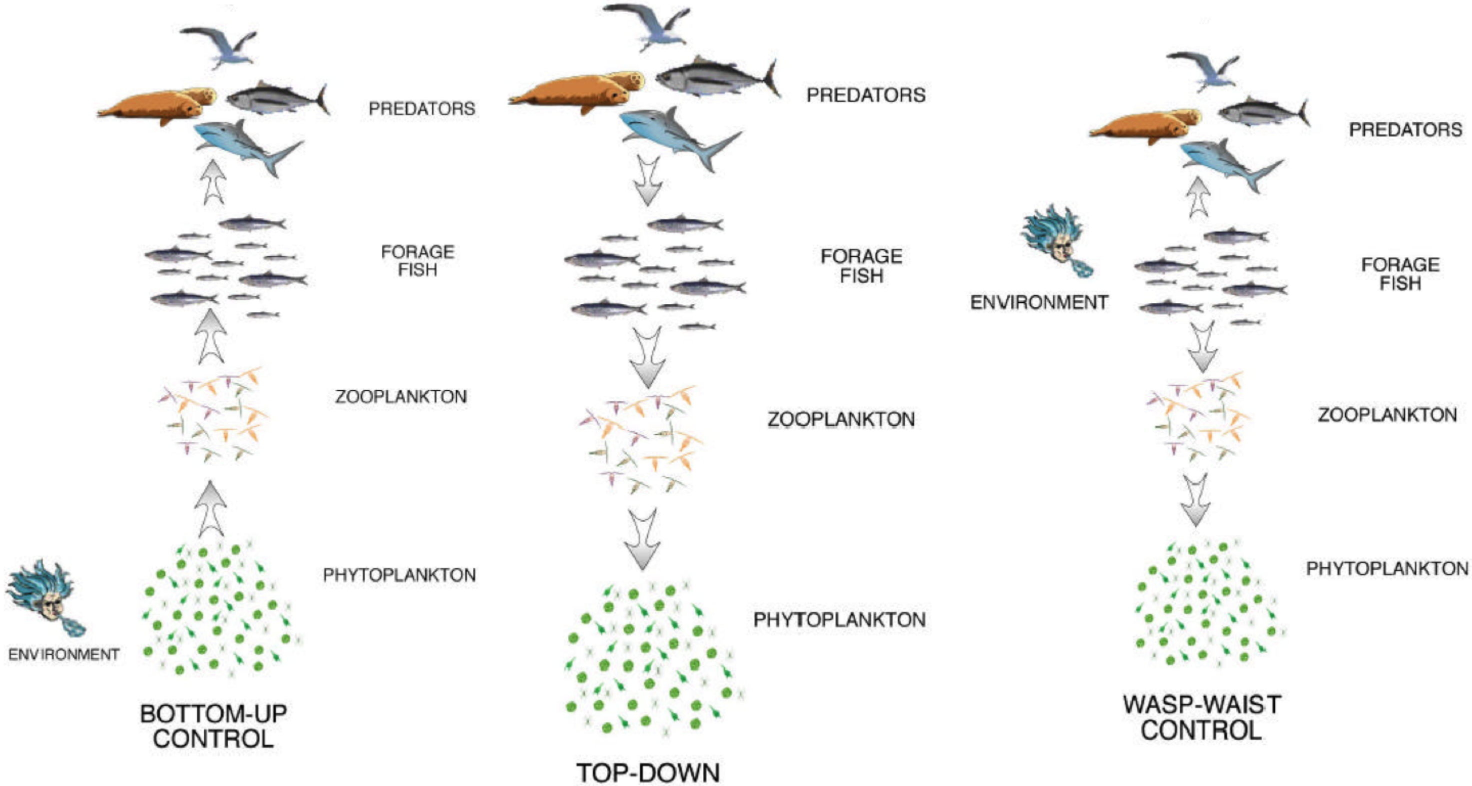
Food webs and fisheries--two examples

- Preface: What is a "forage fish"?
- Alaska pollock: ecological research with a food web model
  "How does ecosystem structure affect dynamics?"
  - Distinguishing climate, fishing, and food web interactions
  - Dealing with uncertainty
- Atlantic herring: fishery management strategy evaluation
  "Which harvest control rules best consider herring's role as forage?"
  - Balancing fishing benefits and ecological services
  - Diverse stakeholder interests
  - Needed timely answers!

What is a forage fish?



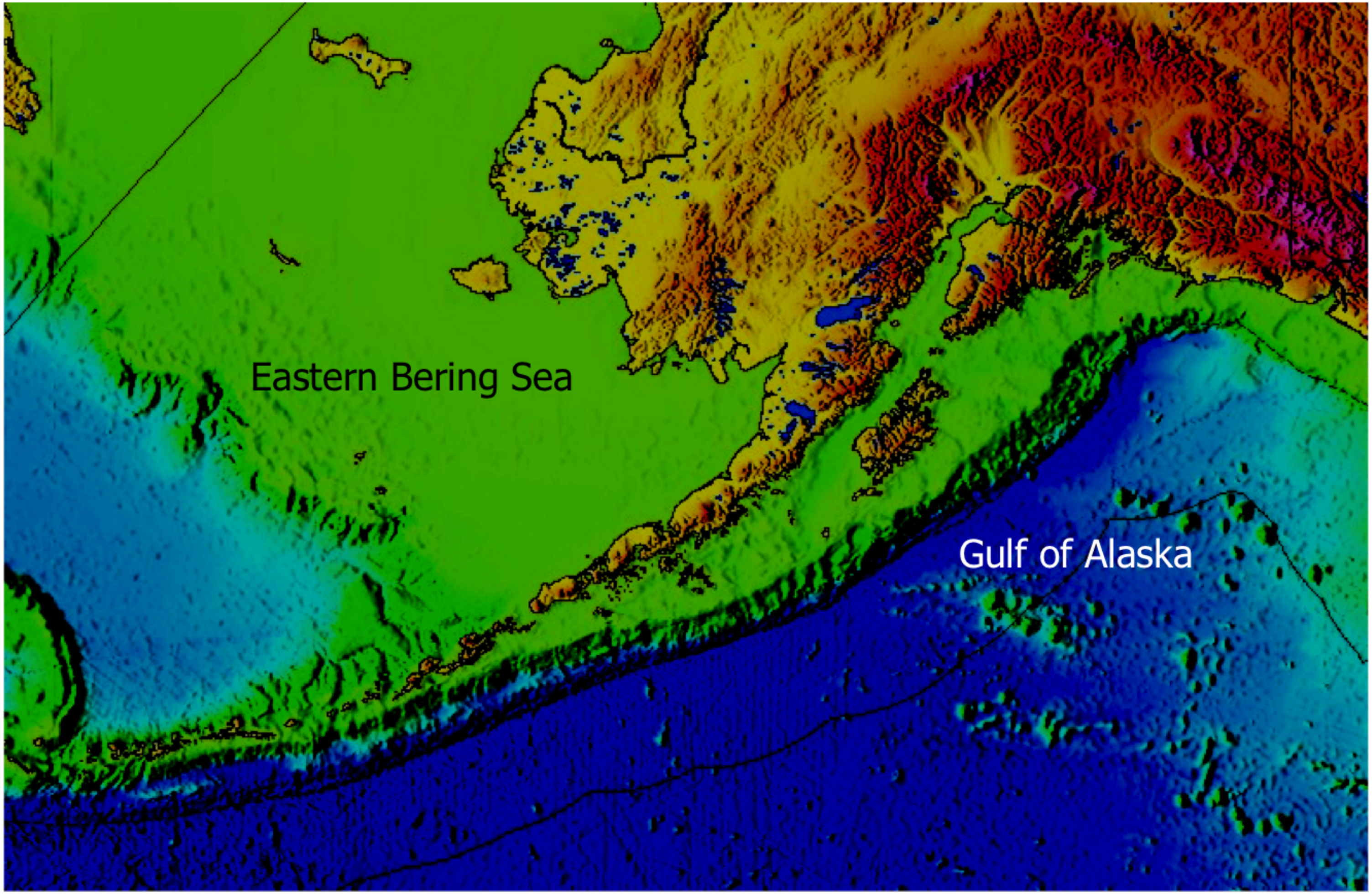
How does ecosystem structure affect dynamics?



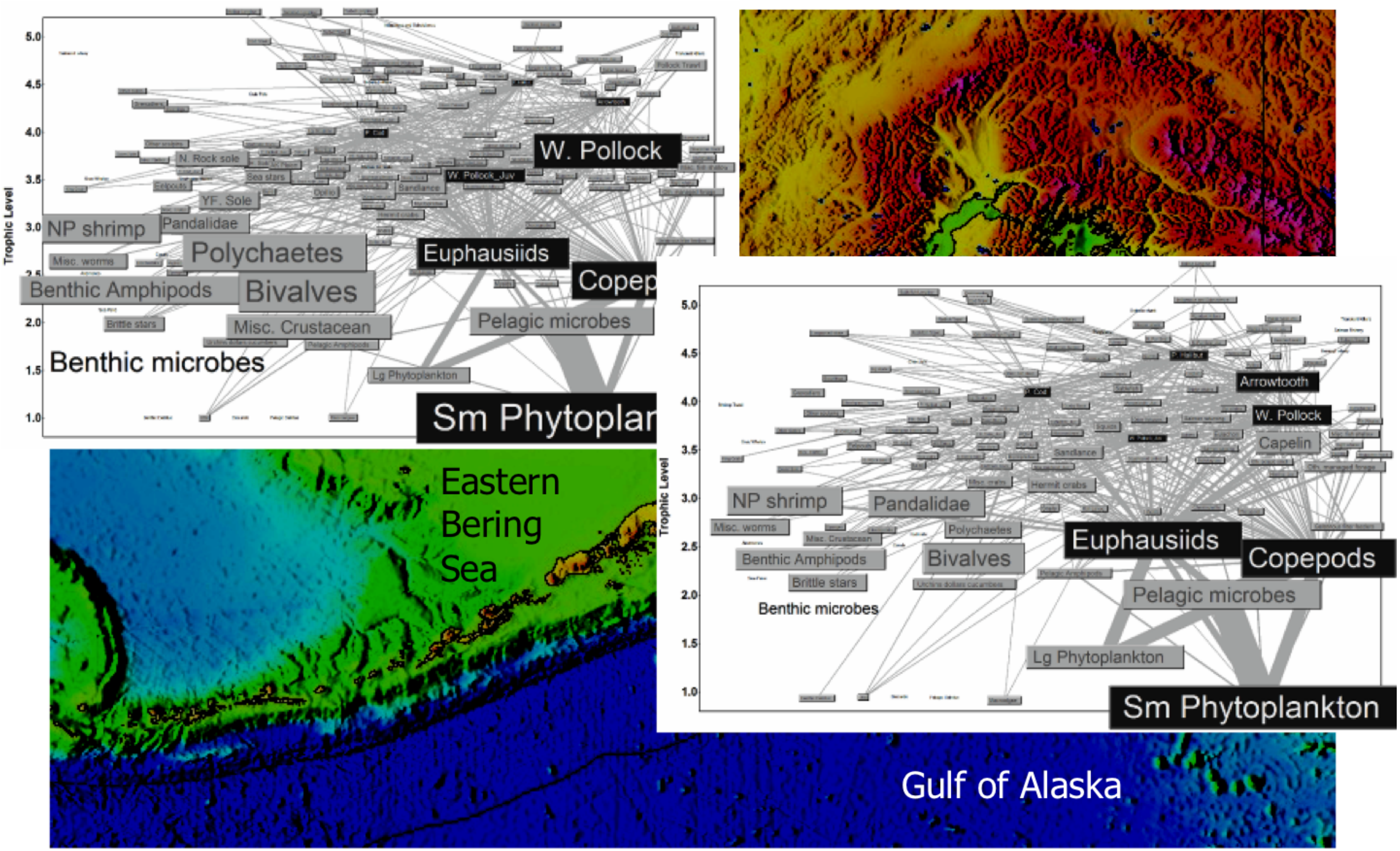
The functioning of marine ecosystems
P. Cury, L. Shannon, and Y.-J. Shin

Reykjavik Conference on Responsible Fisheries in the Marine Ecosystem
Reykjavik, Iceland, 1-4 October 2001

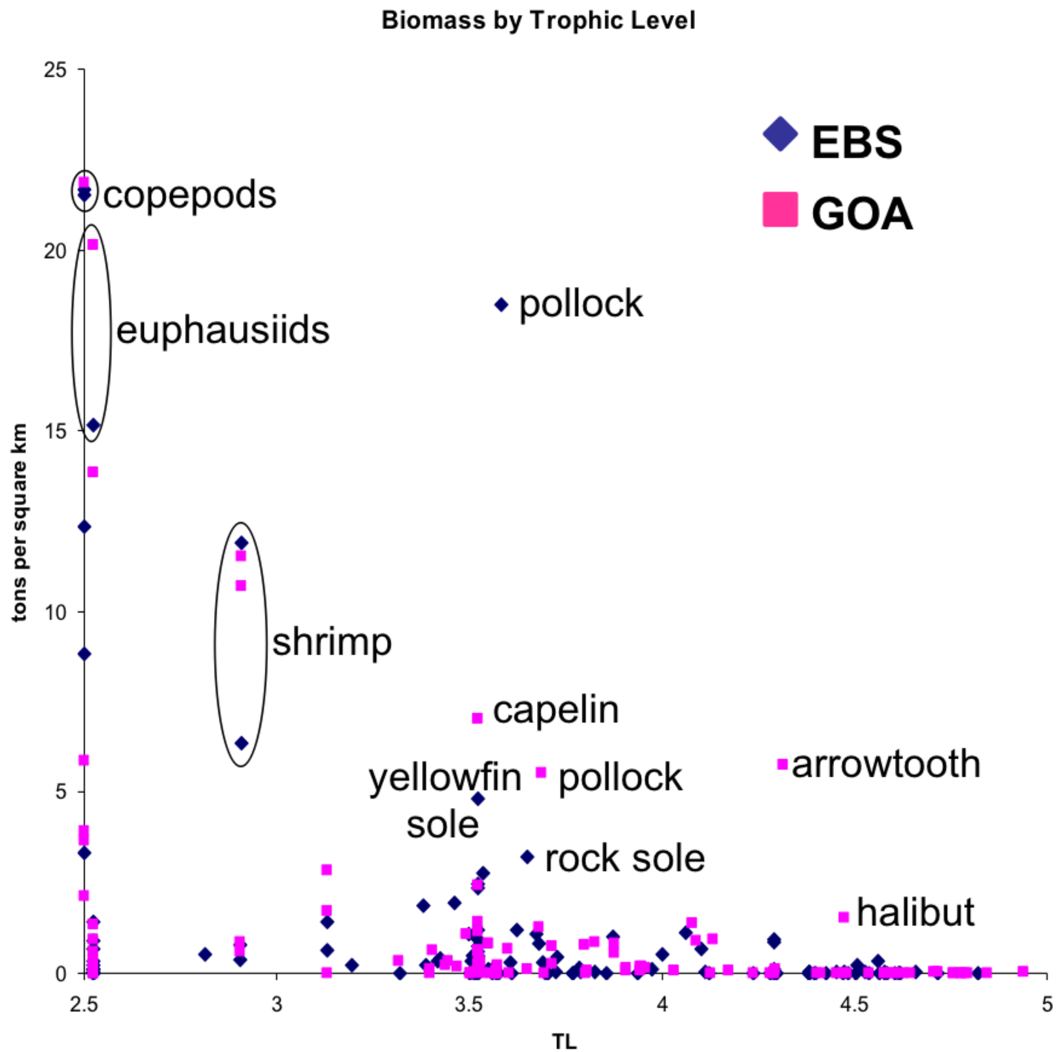
Alaska pollock: a tale of two ecosystems



Alaska pollock: a tale of two ecosystems

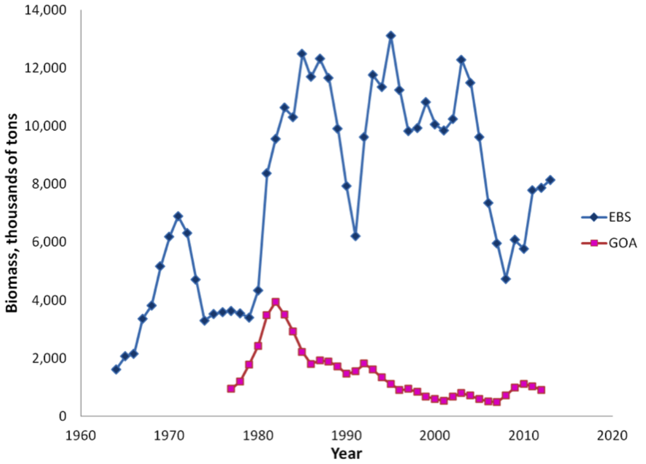


Alaska pollock: a tale of two ecosystems



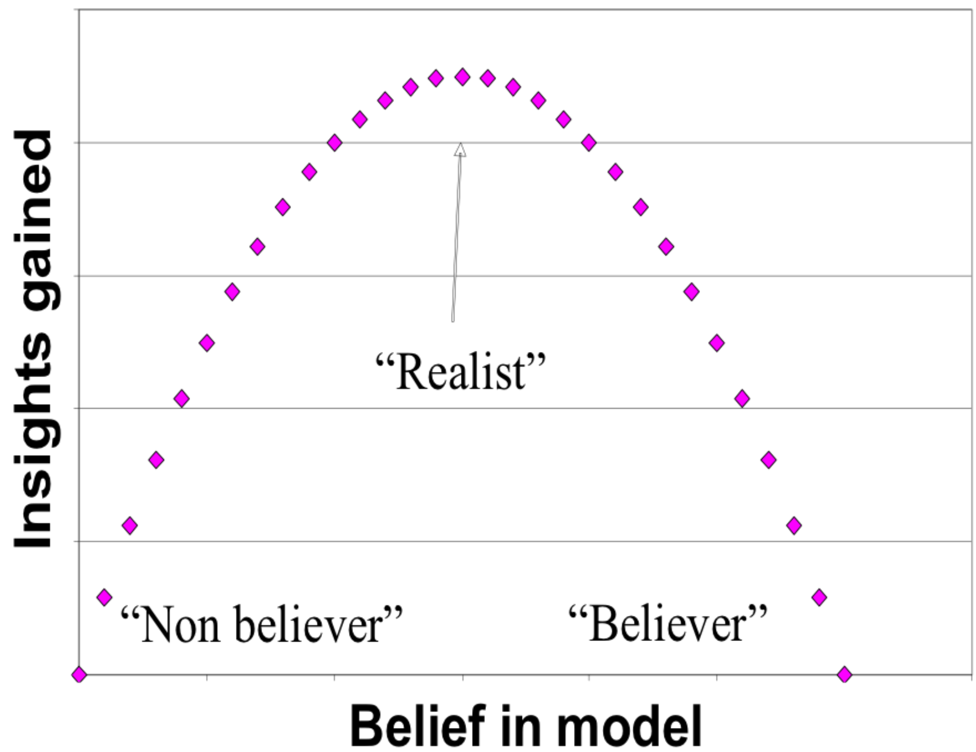
Alaska pollock: a tale of two ecosystems

- Different pollock trajectories
- Different pollock diets, mortality sources

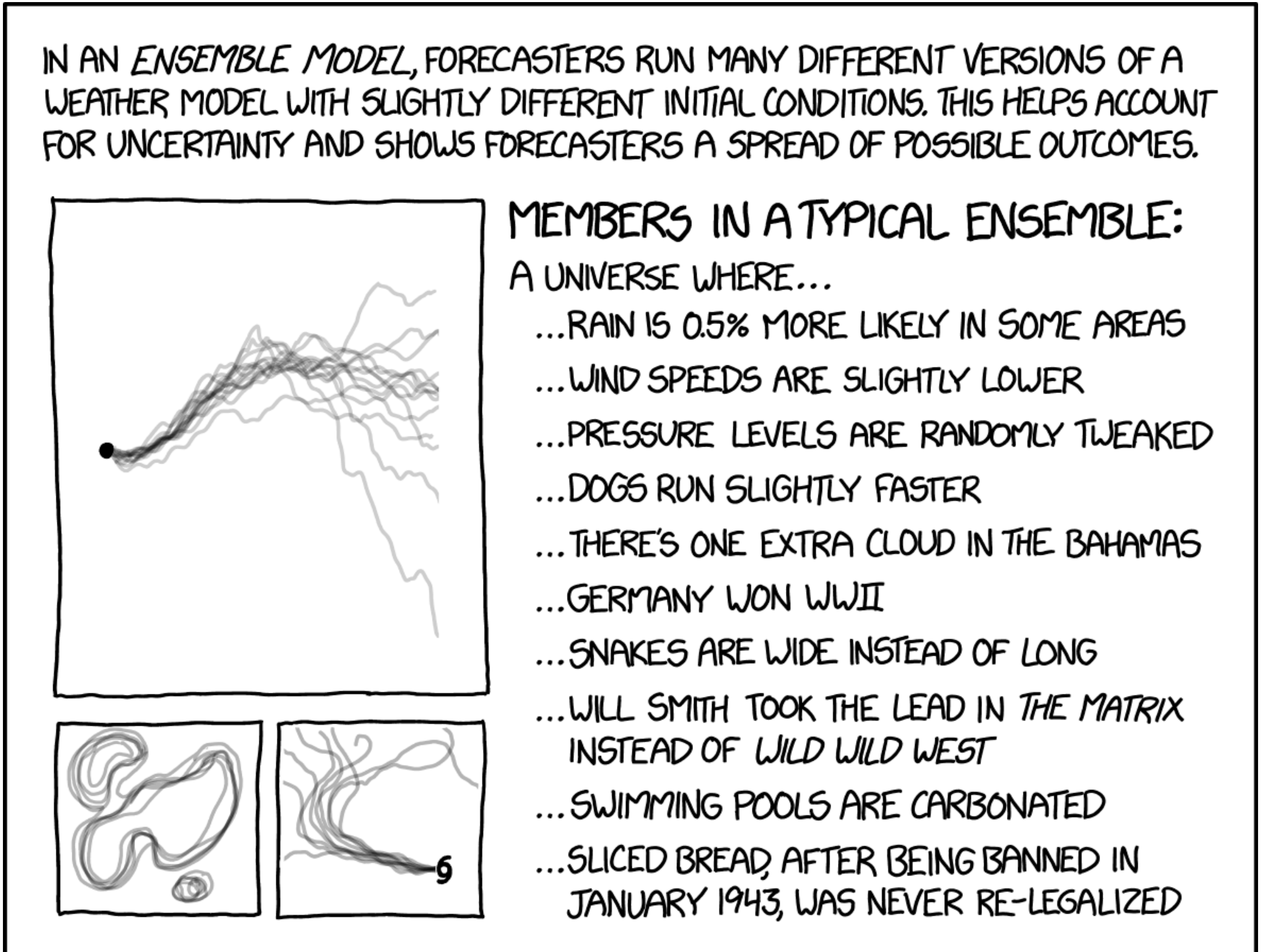


Ecosystem models and uncertainty

Aydin's Modelling
Yield Curve



Model ensemble https://xkcd.com/1885/



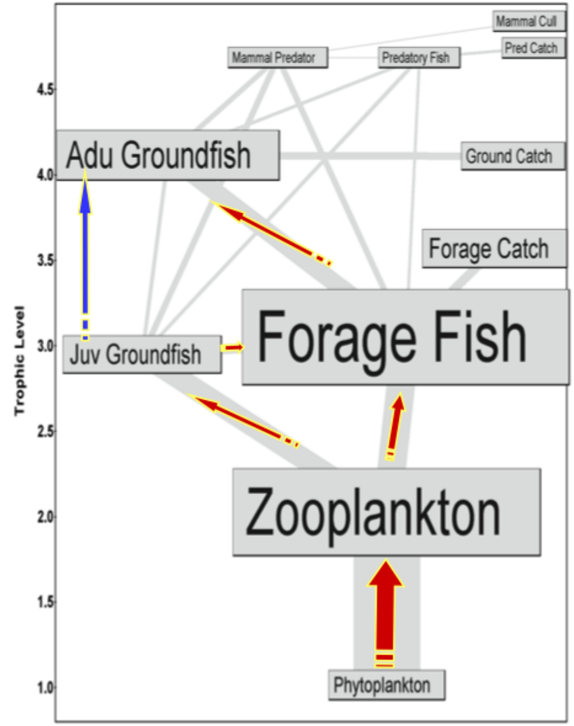
What is a food web model?

A system of linear equations

For each group, i, specify:

Biomass B [or Ecotrophic Efficiency EE]
Population growth rate $\frac{P}{B}$
Consumption rate $\frac{Q}{B}$
Diet composition DC
Fishery catch C
Biomass accumulation BA
Im/emigration IM and EM

Solving for EE [or B] for each group:



$$B_i\left(\frac{P}{B}\right)_i * EE_i + IM_i + BA_i = \sum_j \left[B_j\left(\frac{Q}{B}\right)_j * DC_{ij}\right] + EM_i + C_i$$

Ecosystem models and uncertainty: grading inputs

Group	Biomass	Prod/Bio	Cons/Bio	Diet
Trans Kill	0.80	0.30	0.60	0.80
Sperm bk	0.80	0.60	0.60	0.80
Resident K	0.50	0.30	0.60	0.80
Porpoises	0.50	0.60	0.60	0.80
Gray Wha	0.50	0.60	0.60	0.80
Humpback	0.50	0.20	0.60	0.80
Fin Whale	0.50	0.60	0.60	0.80
Sei whales	0.80	0.60	0.60	0.80
Right whal	0.80	0.60	0.60	0.80
Minke wha	0.50	0.60	0.60	0.80
Sea Otters	0.50	0.60	0.60	0.80
N. Fur. Sea	0.50	0.40	0.70	0.70
N. Fur. Sea	0.50	0.40	0.80	0.70
Central S.S	0.10	0.40	0.70	0.60
Central S.S	0.10	0.40	0.80	0.60
West S.S.I	0.10	0.40	0.70	0.60
West S.S.I	0.10	0.40	0.80	0.60
Resident s	0.50	0.60	0.60	0.70
Shearwate	0.80	0.60	0.60	0.80
Murre	0.50	0.60	0.60	0.80
Kittiwake	0.50	0.60	0.60	0.80
Auklet	0.50	0.60	0.60	0.80
Puffin	0.50	0.60	0.60	0.80
Fulmar	0.50	0.60	0.60	0.80
Storm Pet	0.50	0.60	0.60	0.80
Cormoran	0.50	0.60	0.60	0.80
Gulls	0.50	0.60	0.60	0.80
Albatross	0.80	0.60	0.60	0.80
Sleeper Sl	0.50	0.70	0.70	0.60
Salmon Sh	0.50	0.70	0.70	0.80
Dogfish	0.80	0.70	0.70	0.80
W. Polloc	0.80	0.40	0.40	0.10
W. Polloc	0.10	0.40	0.40	0.10
P. Cod Ju	0.80	0.40	0.40	0.10
P. Cod Ad	0.10	0.30	0.30	0.10
Herring J	0.80	0.40	0.40	0.80
Herring A	0.50	0.60	0.60	0.70
Arrowtoot	0.50	0.40	0.40	0.10
Arrowtoot	0.10	0.30	0.30	0.10
P. Halibut	0.50	0.40	0.40	0.10
P. Halibut	0.10	0.30	0.30	0.10
YF. Sole	0.10	0.60	0.60	0.10
FH. Sole	0.80	0.40	0.40	0.10
FH. Sole	0.10	0.30	0.30	0.10

Group	Biomass	Prod/Bio	Cons/Bio	Diet
N. Rock s	0.50	0.60	0.60	0.10
S. Rock sc	0.50	0.60	0.60	0.10
AK Plaice	0.10	0.60	0.60	0.70
Dover Sol	0.50	0.60	0.60	0.30
Rex Sole	0.50	0.60	0.60	0.30
Misc. Flat	0.50	0.60	0.60	0.30
Bathyraja	0.10	0.70	0.70	0.80
Bathyraja	0.50	0.70	0.70	0.80
Bathyraja	0.50	0.70	0.70	0.80
Bathyraja	0.50	0.70	0.70	0.80
Bathyraja	0.10	0.70	0.70	0.80
Raja rhina	0.50	0.70	0.70	0.80
Raja binoc	0.50	0.70	0.70	0.80
Black Skat	0.10	0.70	0.70	0.80
Sablefish	0.80	0.60	0.60	0.60
Sablefish	0.50	0.50	0.80	0.60
Eelpouts	0.80	0.70	0.70	0.80
Giant Gre	0.50	0.70	0.70	0.30
Pacific Gr	0.10	0.70	0.70	0.70
Other Mac	0.50	0.70	0.70	0.70
Prickle sq	0.80	0.70	0.70	0.80
POP Juv	0.50	0.40	0.40	0.10
POP Adu	0.10	0.30	0.30	0.10
Sharpchin	0.80	0.60	0.60	0.30
Northern I	0.10	0.60	0.60	0.30
Dusky Ro	0.50	0.60	0.60	0.30
Shortraker	0.50	0.60	0.60	0.30
Rougheye	0.50	0.60	0.60	0.30
Shortspine	0.80	0.40	0.40	0.30
Shortspine	0.50	0.30	0.30	0.30
Other Seb	0.80	0.60	0.60	0.70
Atka Juv	0.80	0.60	0.60	0.80
Atka Adu	0.50	0.50	0.80	0.70
Greenling	0.10	0.70	0.70	0.70
Bigmouth	0.10	0.70	0.70	0.70
Other scul	0.80	0.70	0.70	0.70
Pricklies	0.80	0.70	0.70	0.70
Octopi	0.80	0.70	0.70	0.80
Squids	0.80	0.70	0.70	0.80
Salmon re	0.80	0.50	0.80	0.70
Salmon ou	0.80	0.60	0.60	0.80
Bathylagid	0.80	0.70	0.70	0.80
Myctophid	0.80	0.70	0.70	0.80
Capelin	0.80	0.70	0.70	0.80

Group	Biomass	Prod/Bio	Cons/Bio	Diet
Sandlance	0.80	0.70	0.70	0.80
Eulachon	0.80	0.70	0.70	0.80
Managed F	0.80	0.70	0.70	0.80
Oth pel. sr	0.80	0.70	0.70	0.80
Bairdi	0.80	0.60	0.80	0.80
King Crab	0.50	0.60	0.80	0.80
Opilio	0.10	0.60	0.80	0.80
Pandalidae	0.80	0.50	0.80	0.80
NP shrimp	0.80	0.60	0.60	0.80
Sea Star	0.50	0.60	0.70	0.80
Brittle Sta	0.50	0.60	0.70	0.80
Urchins de	0.50	0.60	0.70	0.80
Snail	0.80	0.60	0.70	0.80
Hermit cra	0.80	0.60	0.70	0.80
Misc crab	0.80	0.60	0.70	0.80
Misc. Cru	0.80	0.60	0.70	0.80
Benth. Am	0.80	0.60	0.70	0.80
Anemones	0.50	0.60	0.70	0.80
Corals	0.10	0.60	0.70	0.80
Benth. Hy	0.80	0.60	0.70	0.80
Benth. Urc	0.50	0.60	0.70	0.80
Sea Pens	0.10	0.60	0.70	0.80
Sponge	0.50	0.60	0.70	0.80
Clam	0.80	0.60	0.70	0.80
Polychaete	0.80	0.60	0.70	0.80
Misc. Wo	0.80	0.60	0.70	0.80
Scypho Je	0.50	0.60	0.60	0.80
Fish Larva	0.80	0.70	0.70	0.80
Chaeteg et	0.80	0.70	0.70	0.80
Euphausiid	0.80	0.60	0.60	0.80
Mysid	0.80	0.70	0.70	0.80
Pel Amph	0.80	0.60	0.60	0.80
Pel. Gel. F	0.80	0.70	0.70	0.80
Pteropod	0.80	0.70	0.70	0.80
Copepod	0.80	0.70	0.60	0.80
Microzoo	0.80	0.70	0.70	0.80
BenthicBa	0.80	0.70	0.70	0.10
Algae	0.80	0.70	0.70	0.00
Lg Phytop	0.80	0.50	0.00	0.00
Sm Phytop	0.80	0.50	0.00	0.00
Outside Pr	0.80	0.70	0.00	0.00

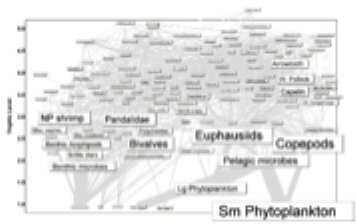
Good

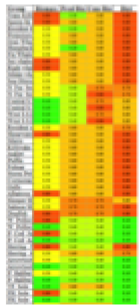
OK

Bad

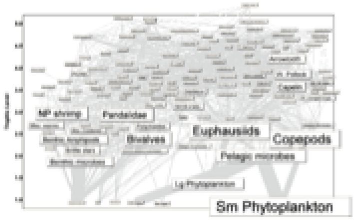
Ugly

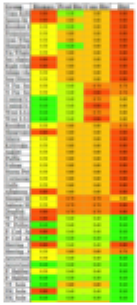
Ecosystem models and uncertainty: run a scenario

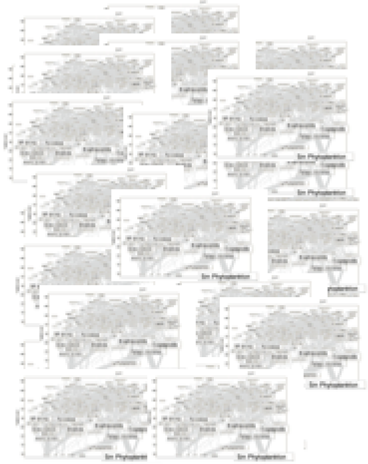




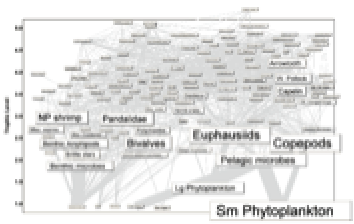
Ecosystem models and uncertainty: run a scenario

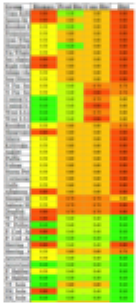




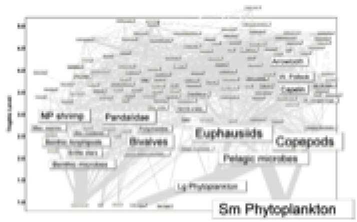


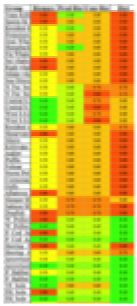
Ecosystem models and uncertainty: run a scenario

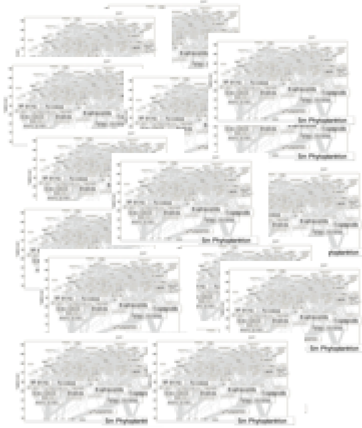


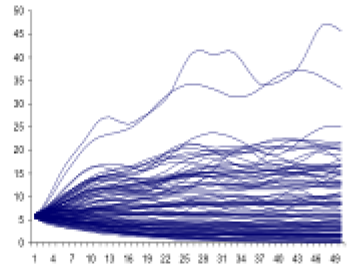


Ecosystem models and uncertainty: run a scenario in an ensemble

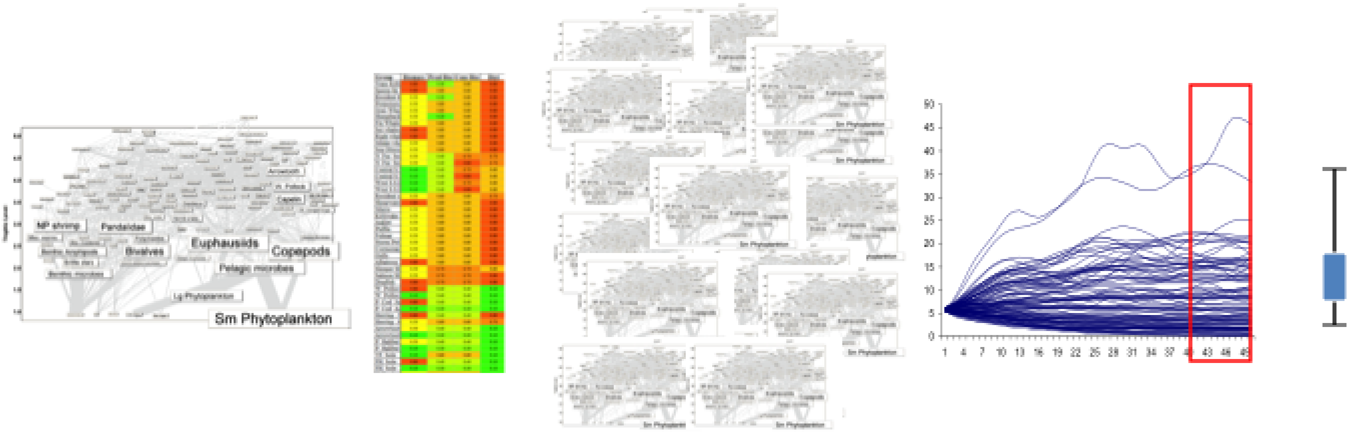




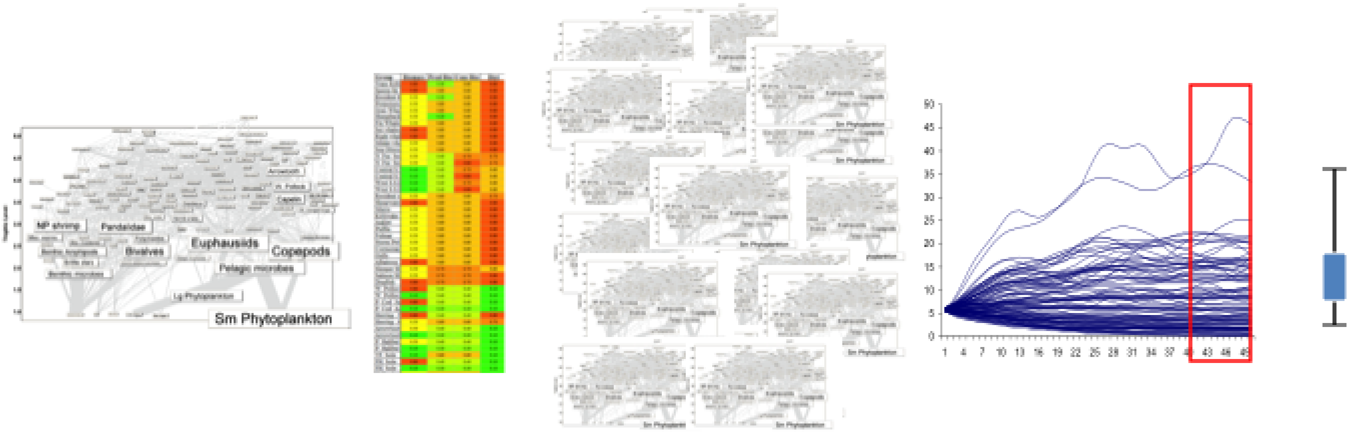


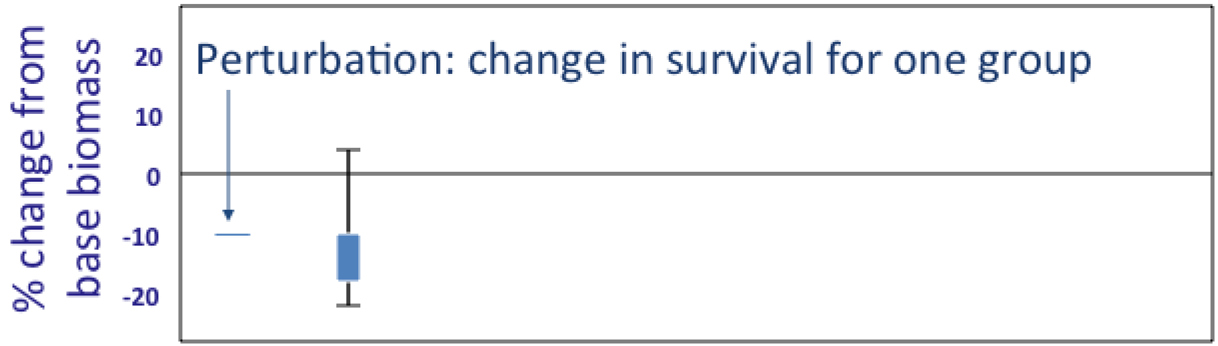


Ecosystem models and uncertainty: run a scenario in an ensemble

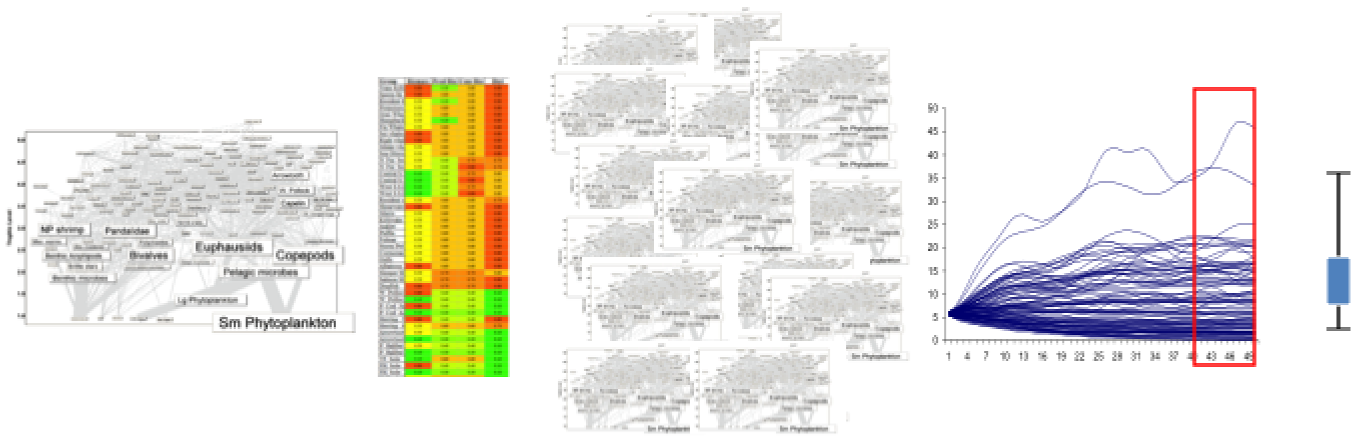


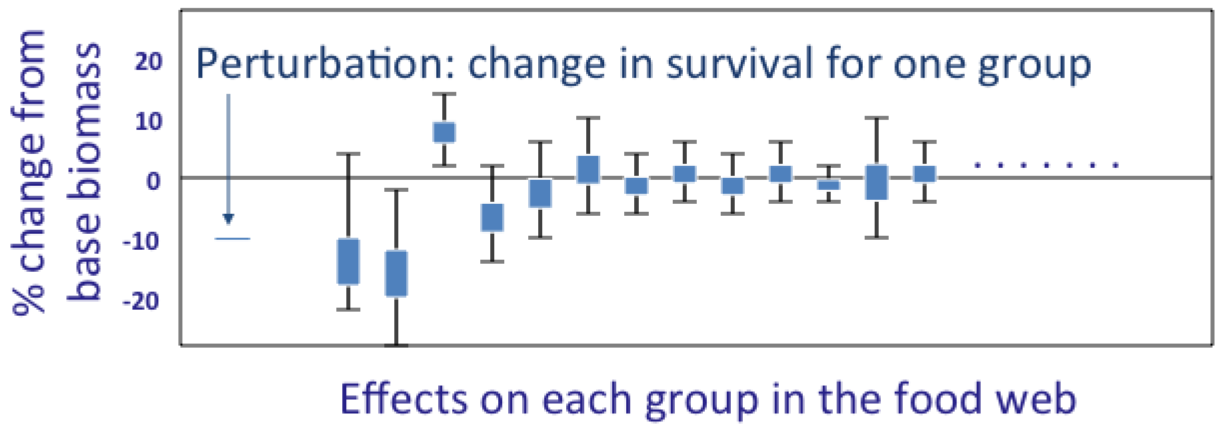
Ecosystem models and uncertainty: run a scenario in an ensemble





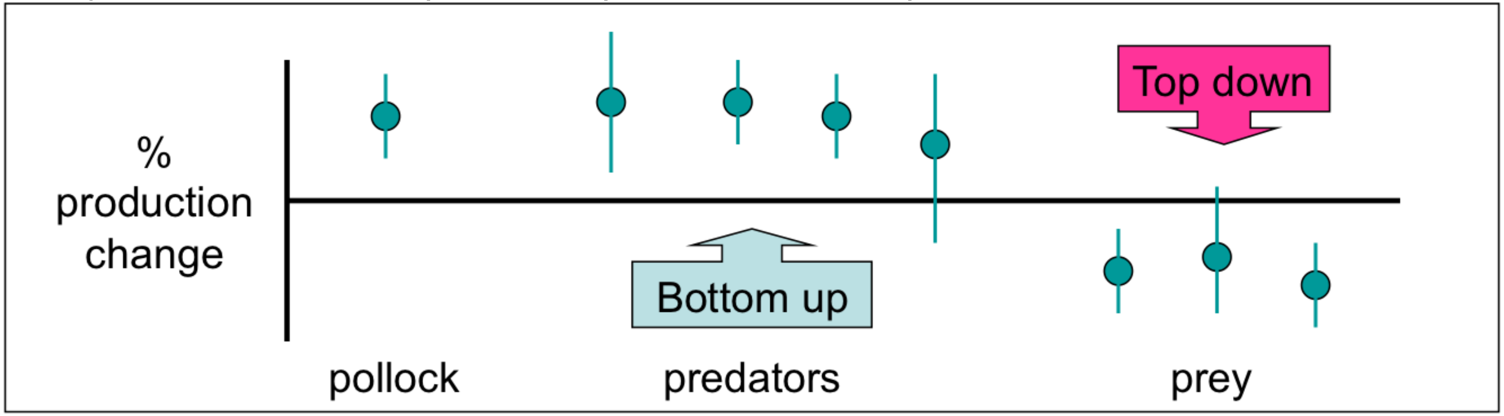
Ecosystem models and uncertainty: run a scenario in an ensemble



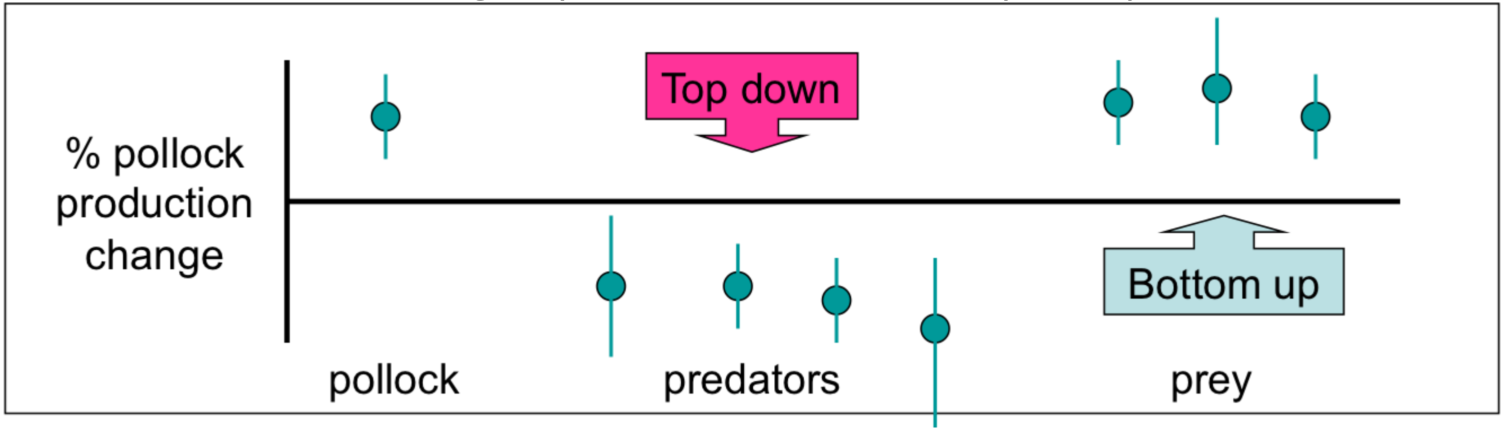


Defining ecosystem structure in the EBS and GOA: expectations

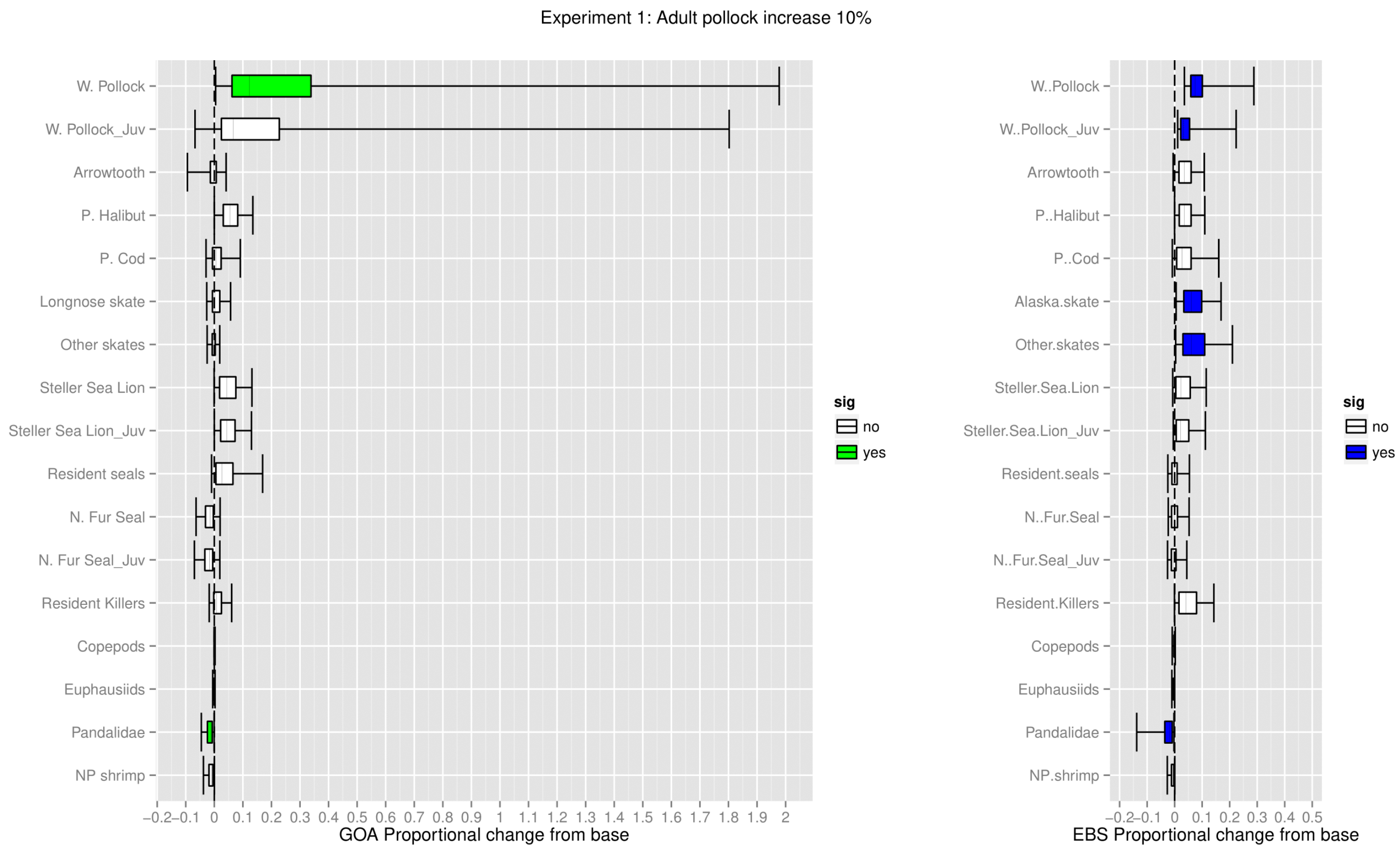
Ecosystem reaction to pollock if pollock is a "wasp waist":



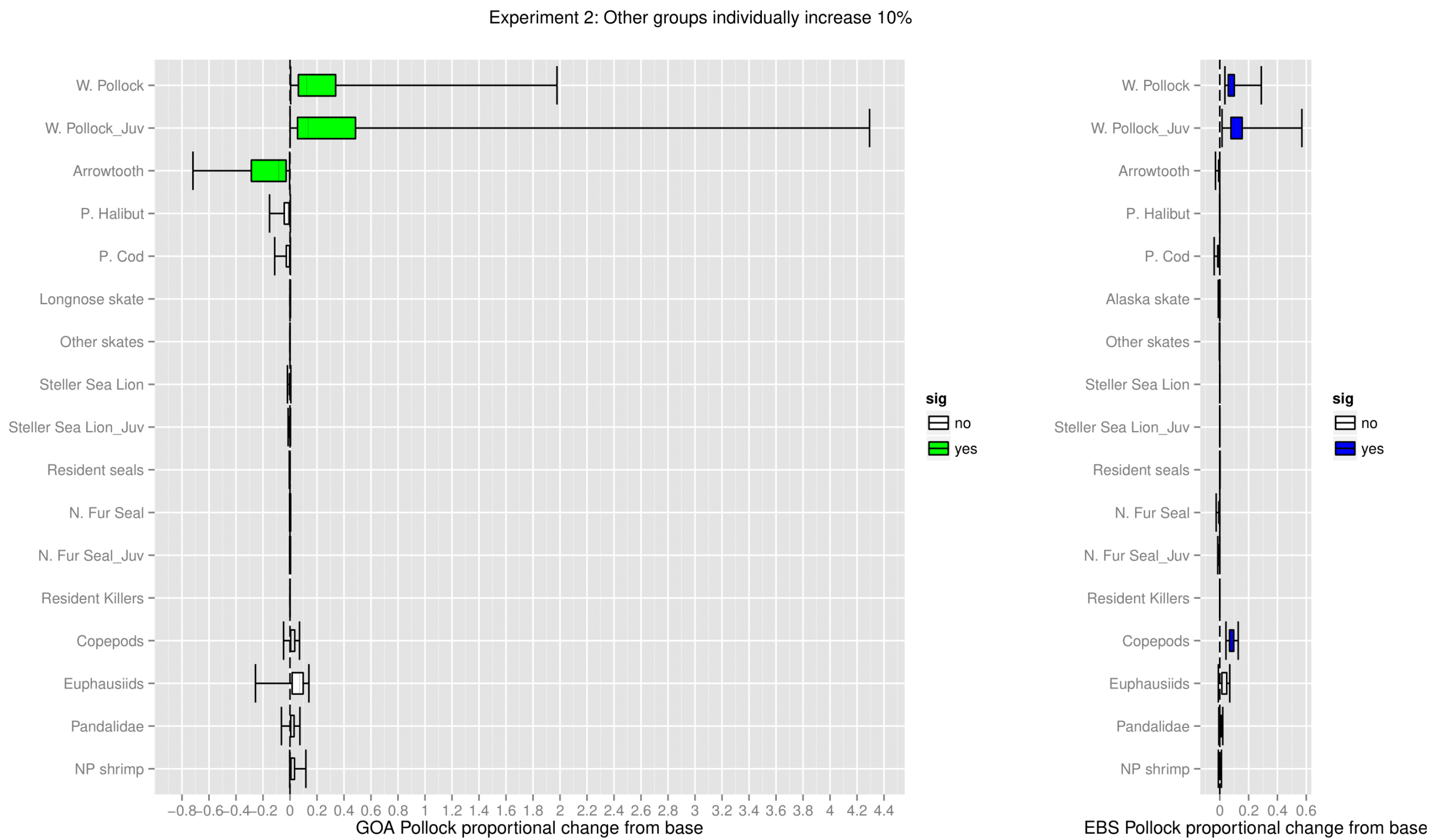
Pollock reaction to other groups if control is bottom up or top down:



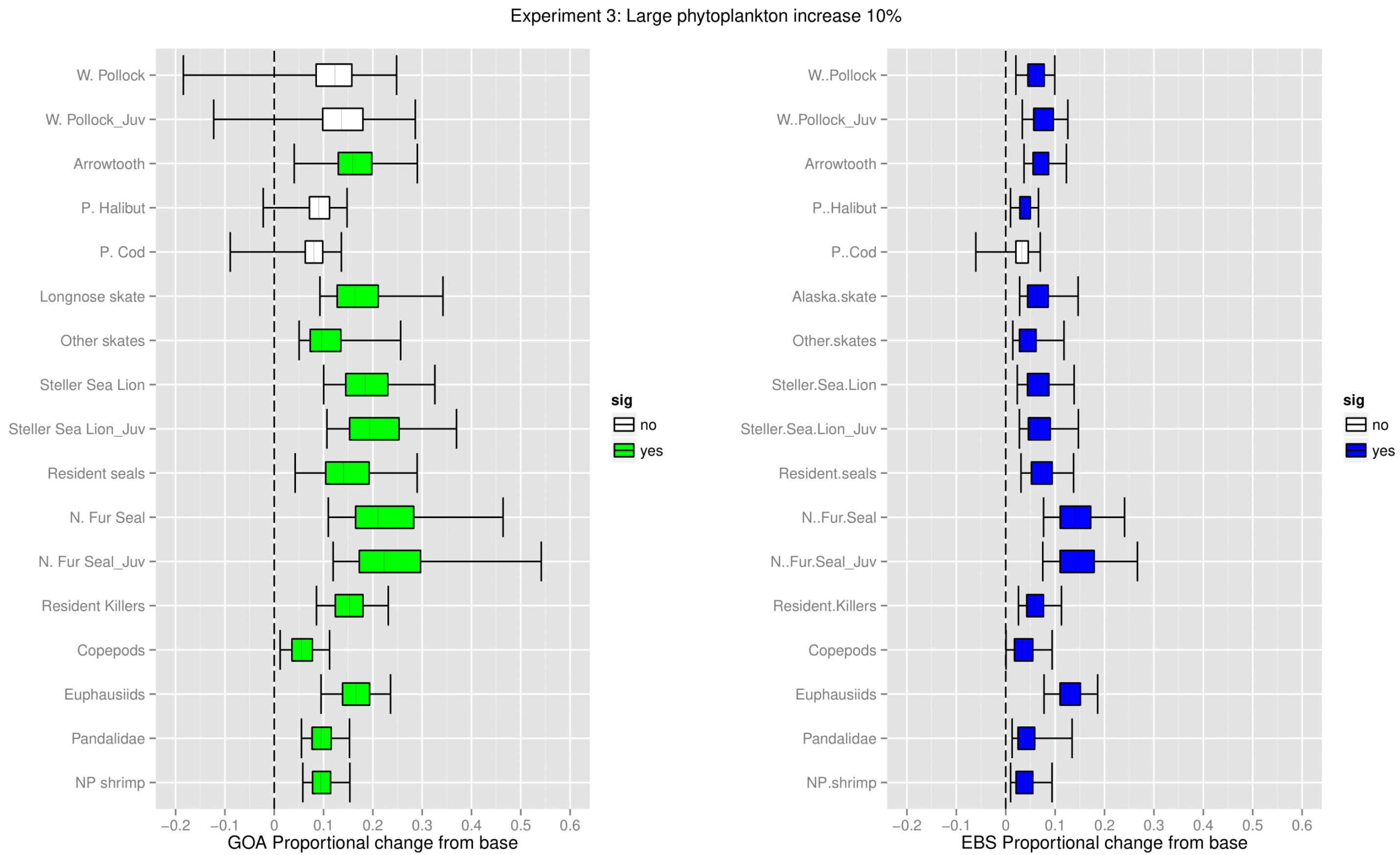
Perturbation results: ecosystem reaction to 10% pollock increase



Perturbation results: pollock reaction to 10% increase in others



Perturbation results: ecosystem reaction to 10% phytoplankton increase

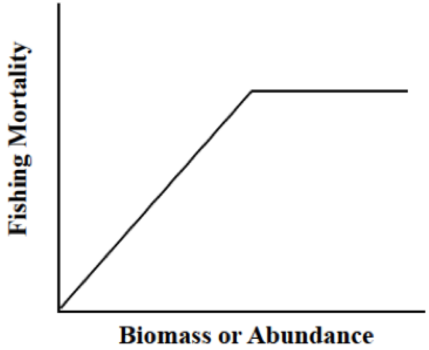


Simulated increased pollock fishing (significant changes only)

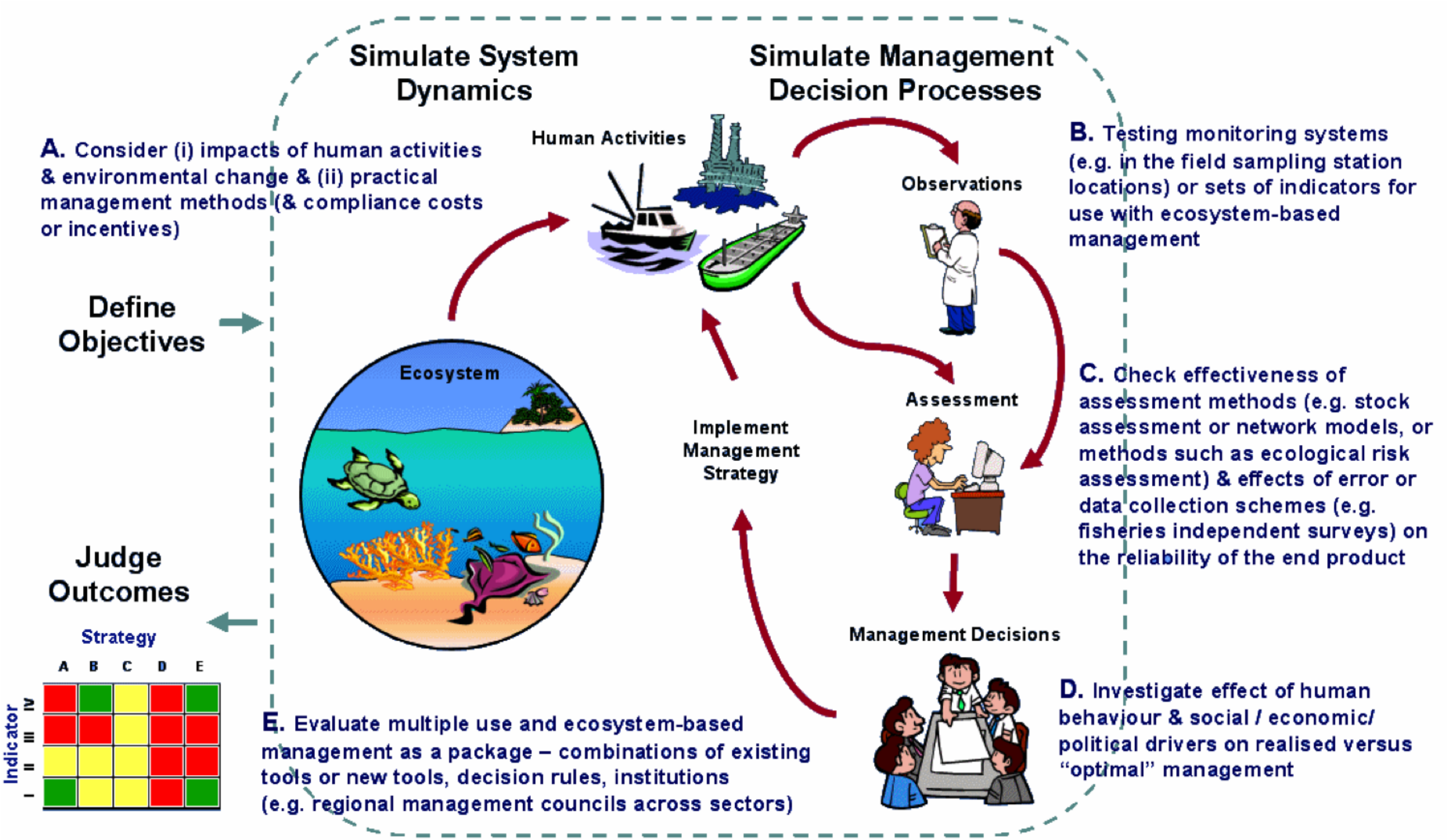
Insights for fishery management

- Differences in food web structure between two adjacent ecosystems with similar biological communities and fishery management
    - Which species respond to the same perturbation
    - Level of uncertainty / predictability in response
- EBS: Influential group at mid trophic levels
    - Wasp waist transmits signal to other groups (neither AK system)
    - Self regulating dominant group (beer belly) absorbs signals
    - Beer belly systems are more predictable, stable as long as the beer belly maintains itself?
- GOA: Influential groups at high trophic levels
    - Magnifies bottom up signals and top down?
    - A less predictable system?
    - Subject to more radical change?
- Structure of a food web may determine how predictable a system is under perturbation, and how changes in primary production propagate through systems

Are any Atlantic herring harvest control rules good for both fisheries and predators?



What is Management Strategy Evaluation?



Source: CSIRO, Australia

The Dream and The Reality

2016

January – May

Planning with Council	Stakeholder Workshop 16-17 May

May – November

Model develop ment	Analysis	Visualiza tion (I)	Planning with Council

December

Stakeholder Workshop 7-8 Dec.	Analysis to Council

2017

January – March

Reporting to Council	Peer Review 13-15 March

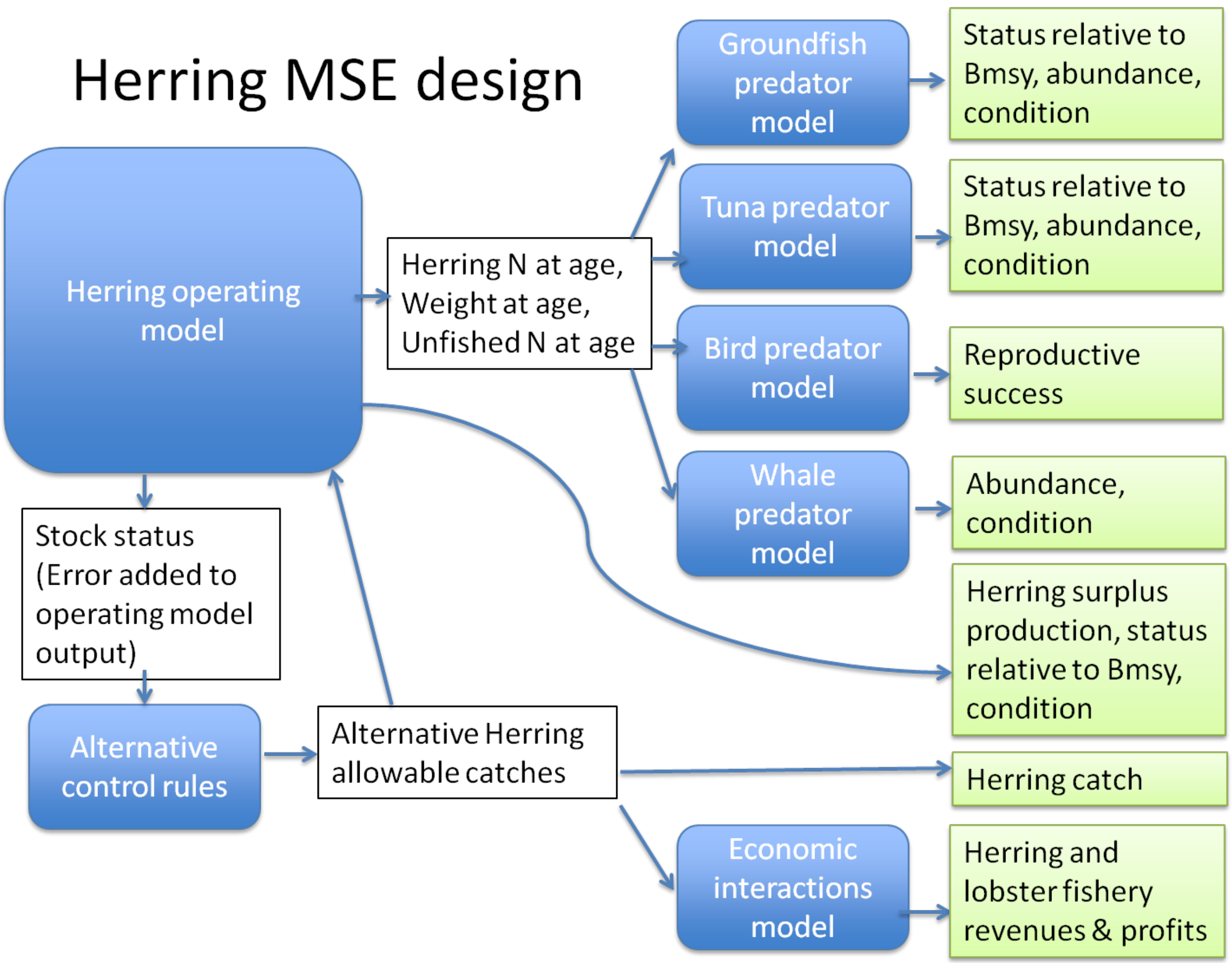
March - September

Narrow Options	Visualization (II)	Council Review

October - January

Public Comment	Council Decision

Design: link models matching stakeholder-identified objectives



Design: multiple (herring) operating models spanning uncertainty

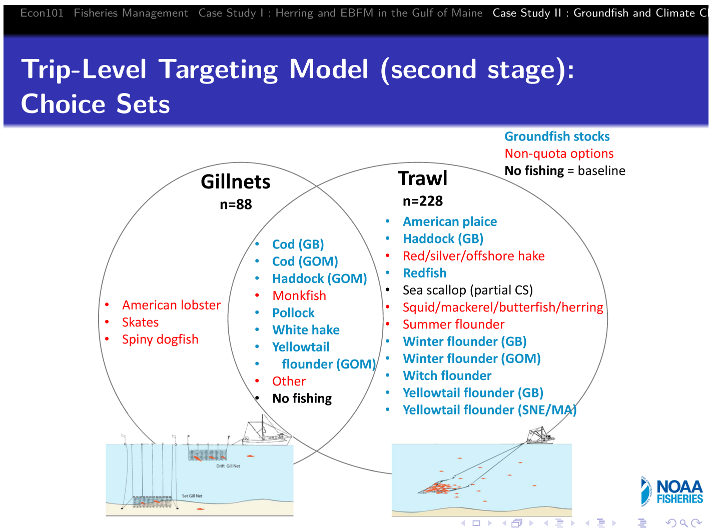
Operating Model Name	Herring Productivity	Herring Growth	Assessment Bias
LowFastBiased	Low: high M, low h (0.44)	1976-1985: fast	60% overestimate
LowSlowBiased	Low: high M, low h (0.44)	2005-2014: slow	60% overestimate
LowFastCorrect	Low: high M, low h (0.44)	1976-1985: fast	None
LowSlowCorrect	Low: high M, low h (0.44)	2005-2014: slow	None
HighFastBiased	High: low M, high h (0.79)	1976-1985: fast	60% overestimate
HighSlowBiased	High: low M, high h (0.79)	2005-2014: slow	60% overestimate
HighFastCorrect	High: low M, high h (0.79)	1976-1985: fast	None
HighSlowCorrect	High: low M, high h (0.79)	2005-2014: slow	None

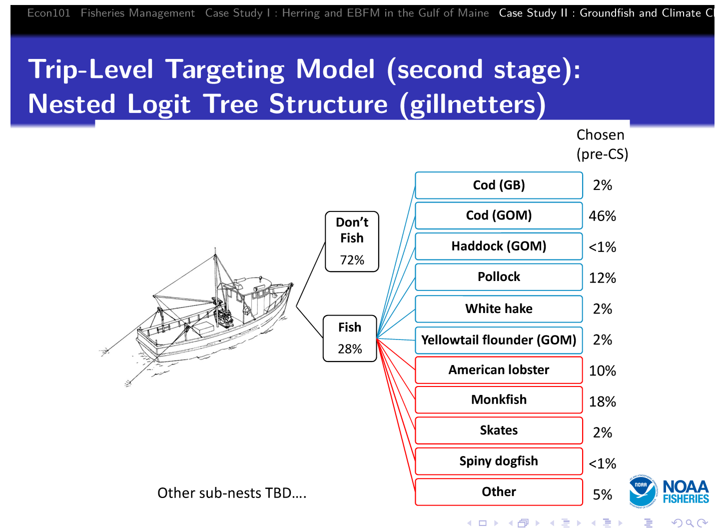
Harvest control rules: Fishing mortality (F) based on:

- Biomass (SSB) (1, 3, and 5 year blocks of catch)
- Biomass with a 15% restriction on interannual change
- Constant Catch (proportion of MSY)
- Conditional Constant Catch (not to exceed max F)

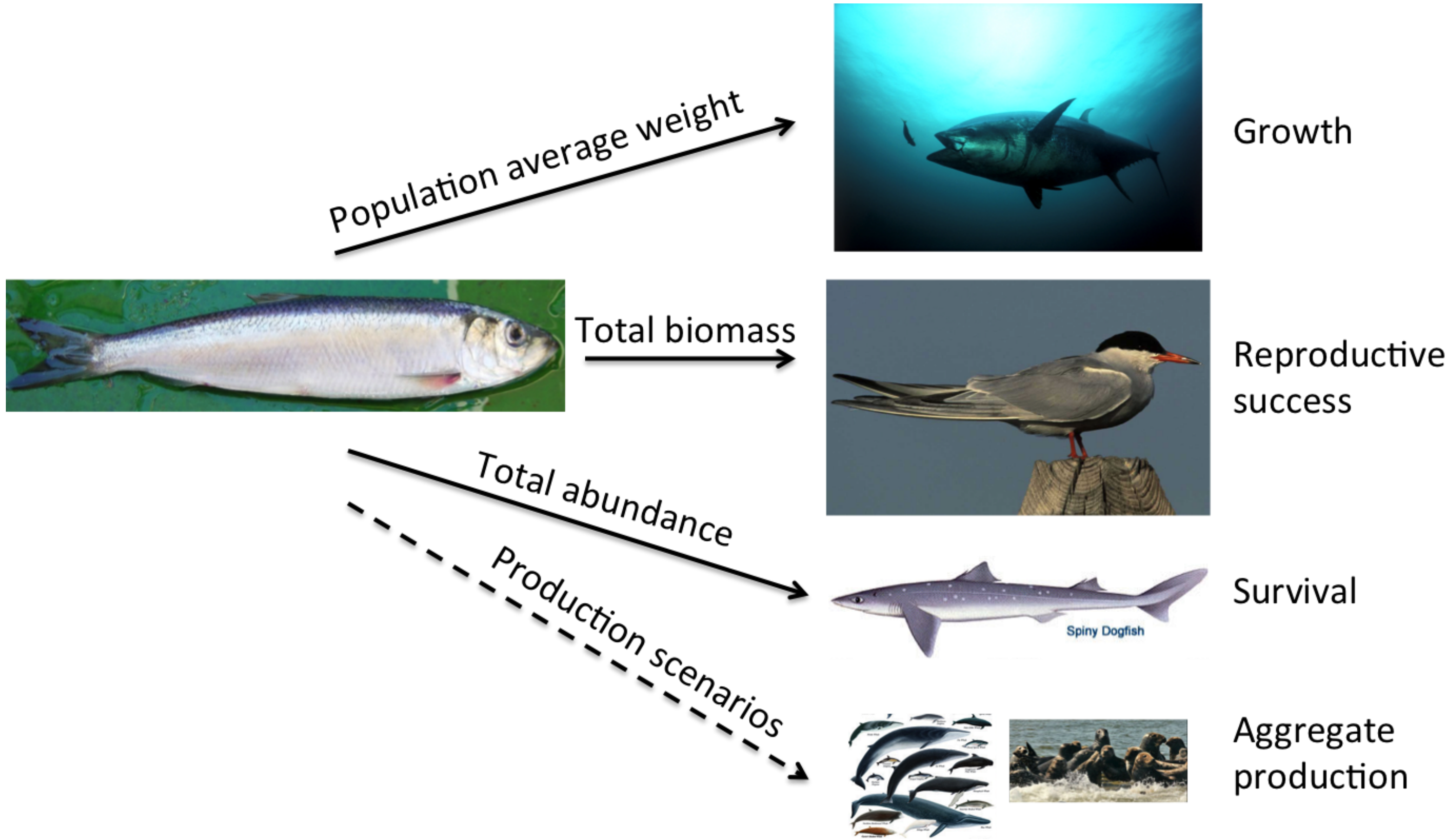
Economics: Min-Yang Lee's talk last week

- Some modeling, limited by project timeline
- The dream: predator response links to ecosystem services, human well being
- Fishery complexity rivals or exceeds that of food webs!

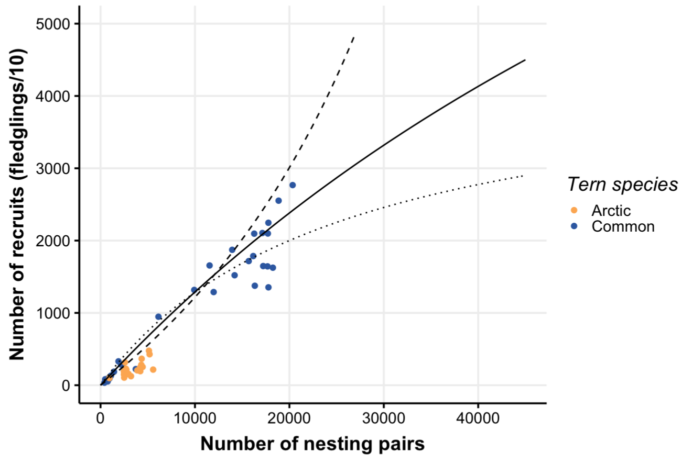


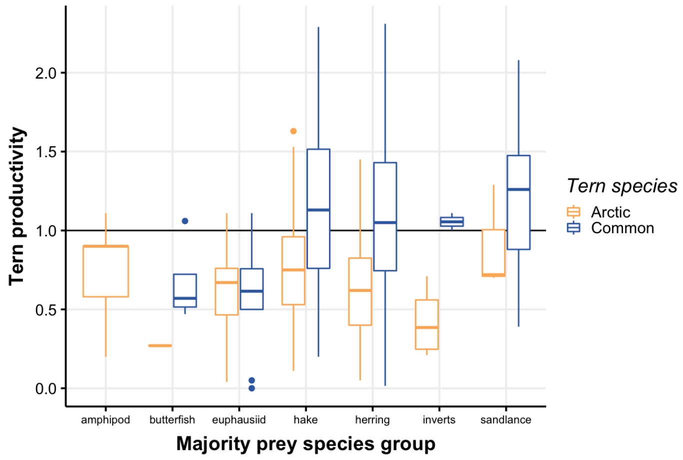


Predators


Population average weight
Total biomass
Total abundance
Production scenarios
Growth
Reproductive success
Survival
Spiny Dogfish
Aggregate production

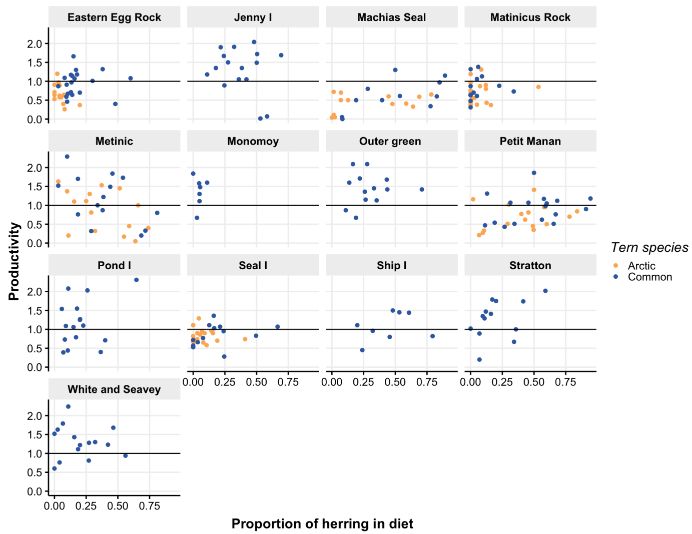
Seabirds: data collected here! (and throughout Gulf of Maine)

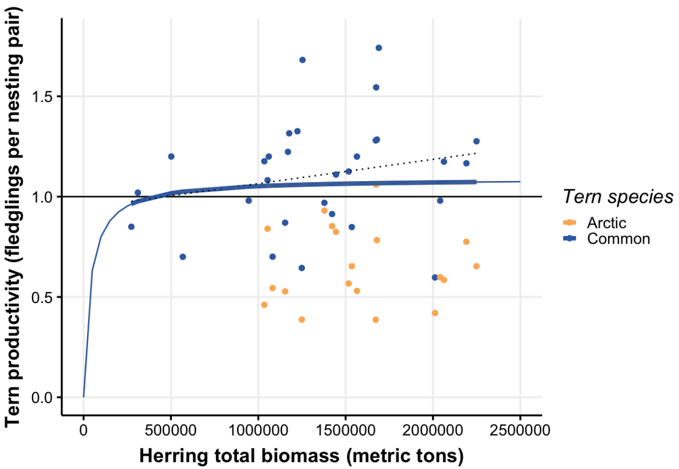




- Colony adult and fledgling count data used to develop population model
- Chick diet observations examined in relation to fledgling success

Terns and herring–developing a modeled relationship

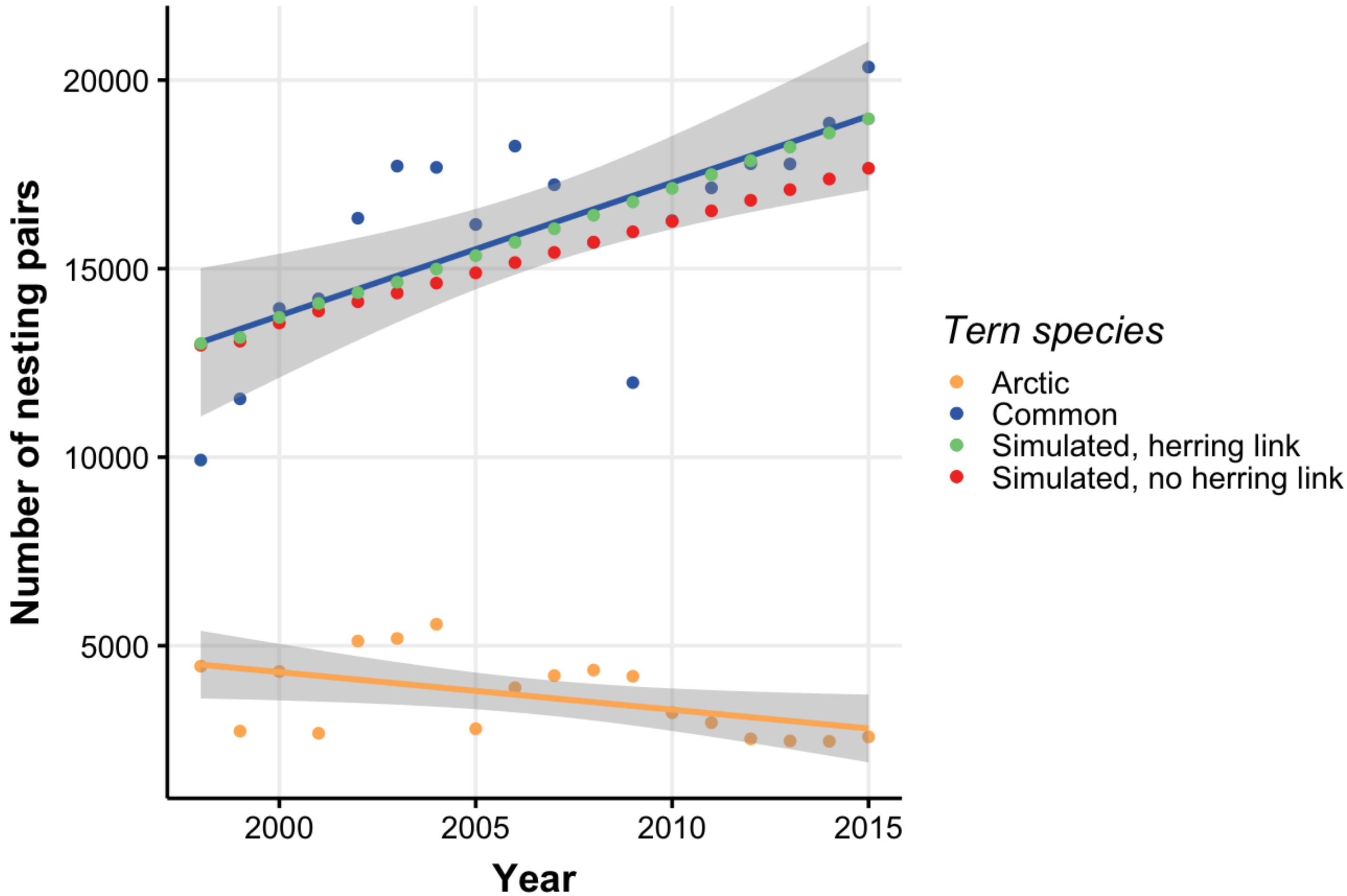




Although there were no clear significant relationships of common tern productivity and the proportion of herring in diets across all colonies, there were some correlations between herring total biomass and tern productivity.

Hence, the relationship on the right was developed to relate herring biomass to common tern productivity.

Testing the model--does it work?



Predator results summary

Similar growth response across all control rules (but differed with herring growth!)

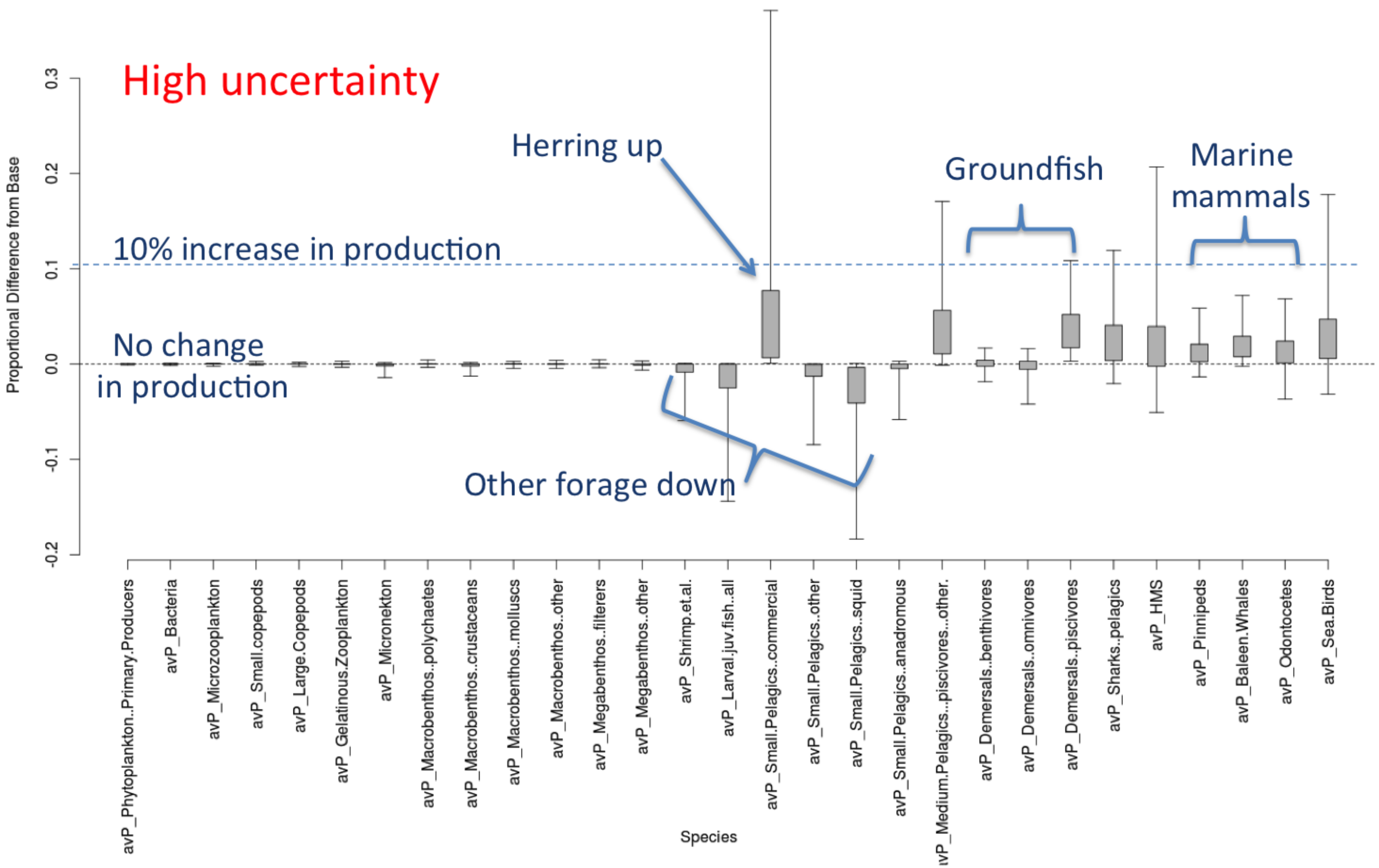
Poorer reproductive success for three control rule types

Poorer stock status for three control rule types

Unable to test specific control rules

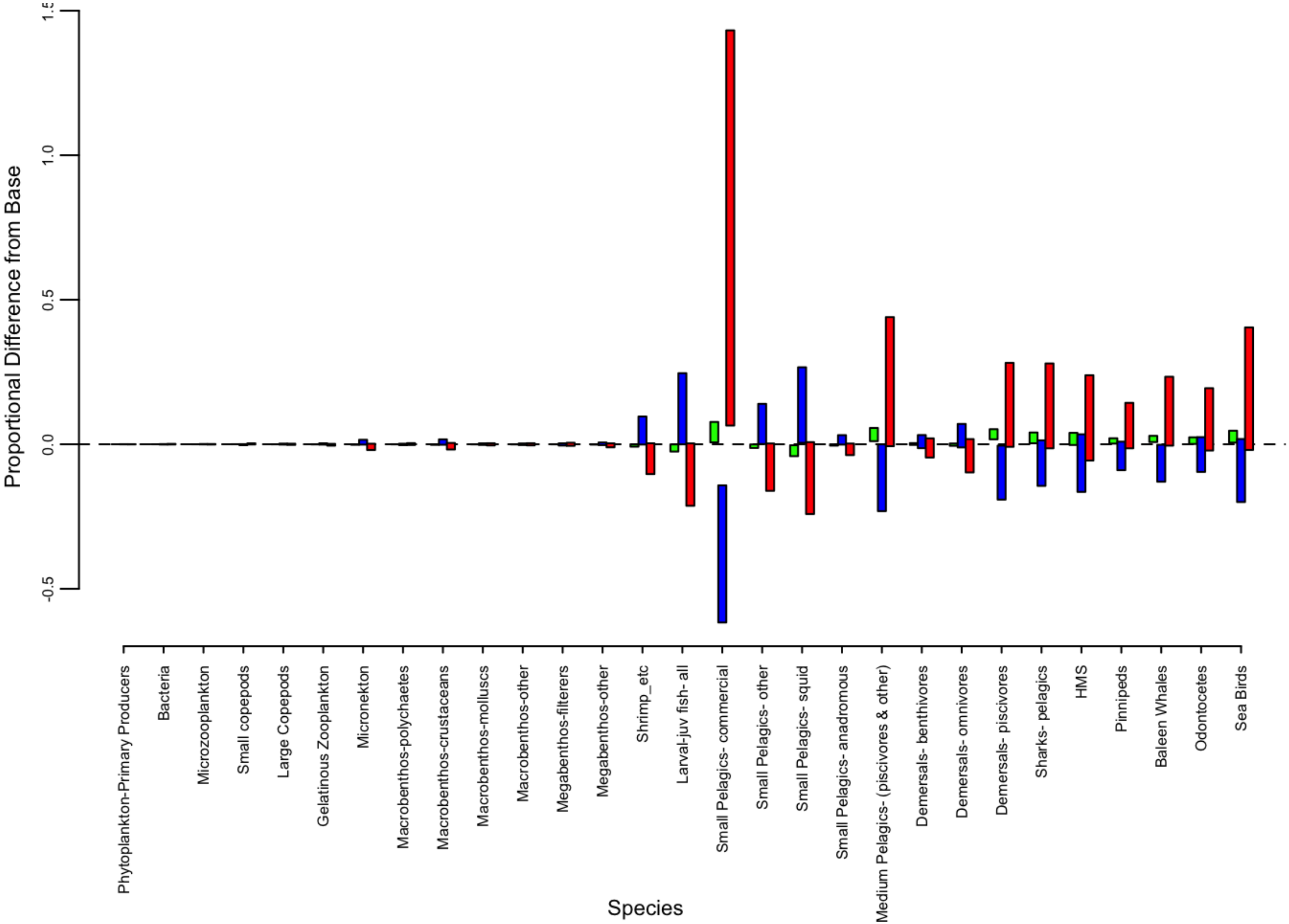
Three control rule types--Constant catch, conditional constant catch, and 15% restriction on change--were rejected at the second stakeholder meeting for poor fishery and predator performance.

Food web modeling; supplemental results



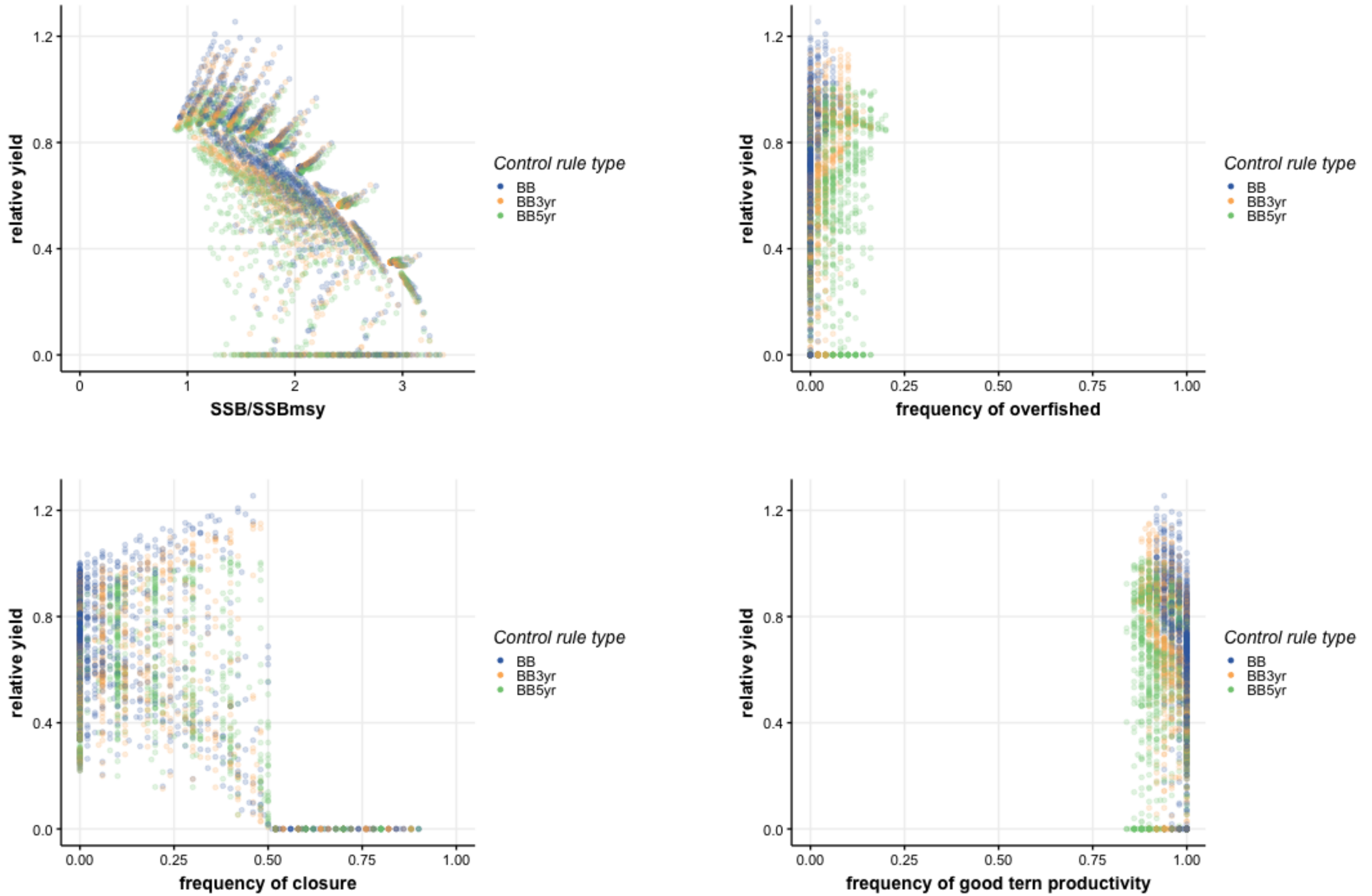
Tradeoffs between forage groups apparent

Compare 10% change with more extreme "herring" biomass



More uncertainty with increased herring biomass?

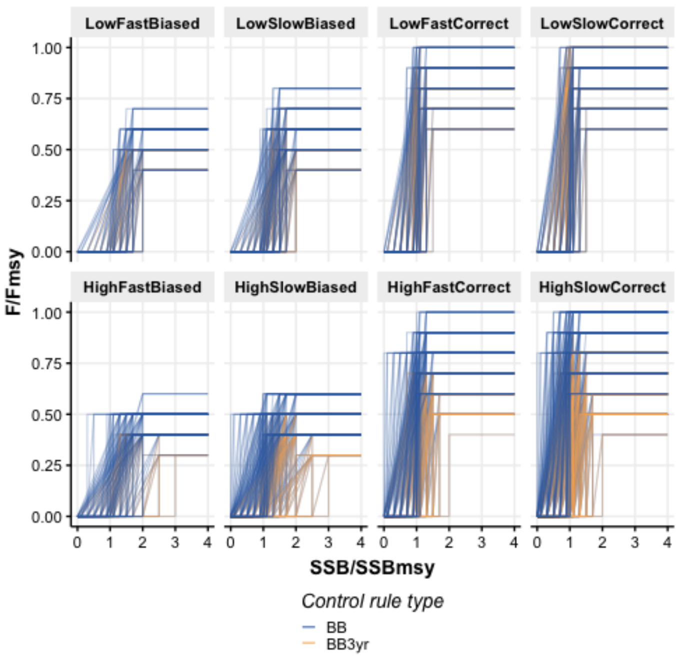
Tradeoffs in Remaining Control Rules

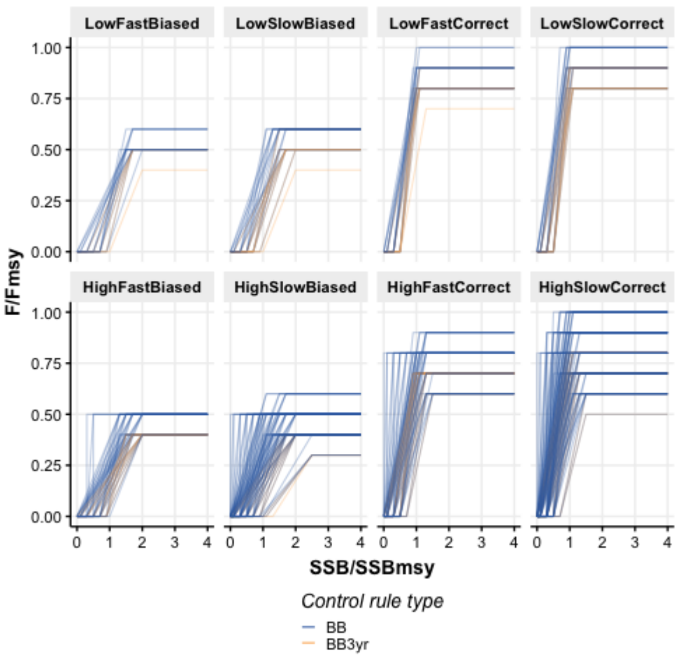


What control rules give us 90% of everything we want?

- Tern productivity at 1.0 or above more than 90% of the time
- Herring biomass more than 90% of SSBmsy
- Fishery yield more than 90% of MSY

- AND fishery closures (F=0) less than 1% of the time (second plot).

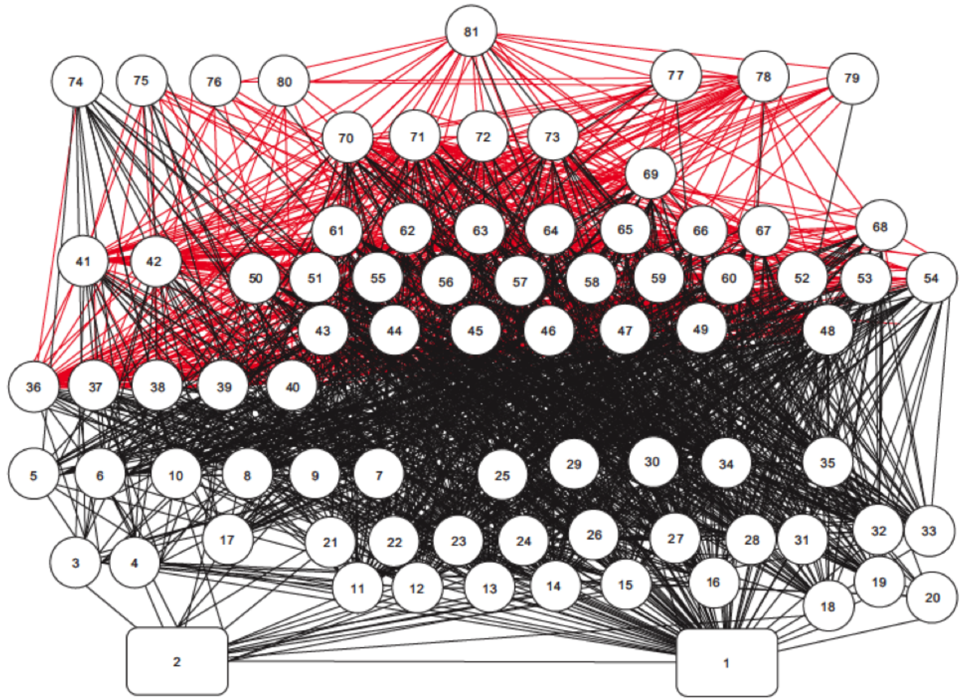




What have we learned? Modeling allows us to test options

Complex food web, generalist predators

- Herring is one of several important prey
- Assessing multiple prey together will likely show stronger effects on predator productivity



- Tern/Tuna/Groundfish/Mammal productivity is also affected by predators, weather, and other factors not modeled here
- Even relatively weak relationships still showed which herring control rules were poor
- Managers did select a harvest control rule considering a wide range of factors!

External Resources

- Wasp Waist or Beer Belly?
- New England Atlantic herring management
- New England herring MSE stakeholder process paper
- New England herring MSE modeling paper
- Rpath codebase
- Slides available at https://noaa-edab.github.io/presentations

Questions?

Thank you!