“Education is the path from cocky ignorance to miserable uncertainty.”

–Mark Twain, American author and humorist (1835-1910)

“When one admits that nothing is certain one must, I think, also admit that some things are much more nearly certain than others.”

-Bertrand Russell, 1947; British author, mathematician, & philosopher (1872-1970)

“[T]here are known knowns; there are things we know we know.

We also know there are known unknowns; that is to say we know there are some things we do not know.

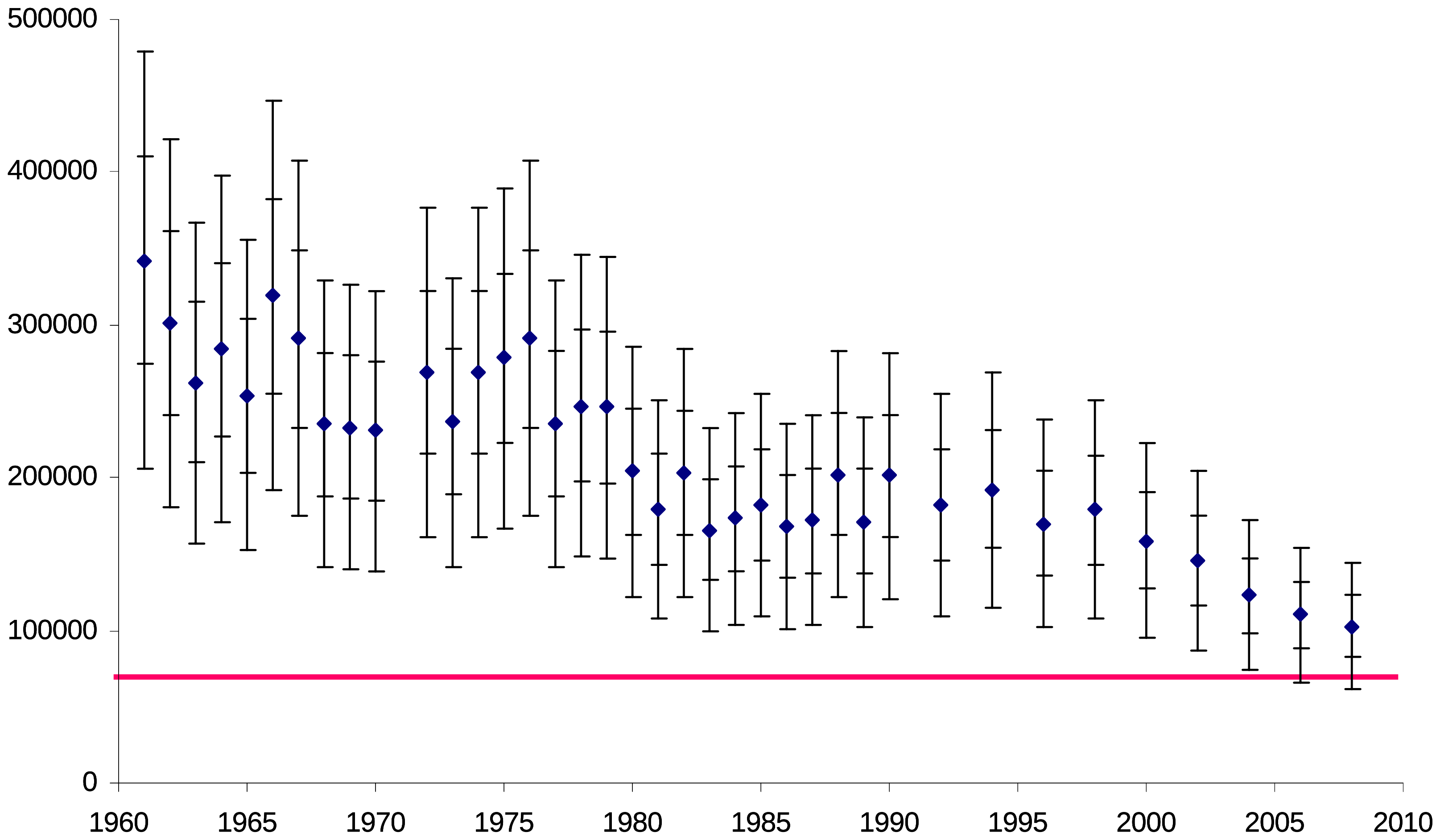
But there are also unknown unknowns – the ones we don't know we don't know.”

- Donald Rumsfeld, 2002, Former U.S. Secretary of Defense

Uncertainty in ecosystem indicators: known knowns, known unknowns, and unknown unknowns

Sarah Gaichas
Resource Ecology and Fishery Management Division
NOAA NMFS Alaska Fisheries Science Center

Uncertainty and thresholds: why we care



Classes of indicators

Rice (2003) Ocean & Coastal Management 46:235–259

- Single species
- Diversity
- Ordination
- Integrated: size spectra, dominance curves
- Emergent (model based)

  Cury et al. (2005) ICES Journal of Marine Science, 62:430-442

  - catch or biomass ratios
  - primary production required to support catch
  - production or consumption ratios and predation mortality
  - Trophic level of the catch
  - fishing-in-balance
  - mixed trophic impact

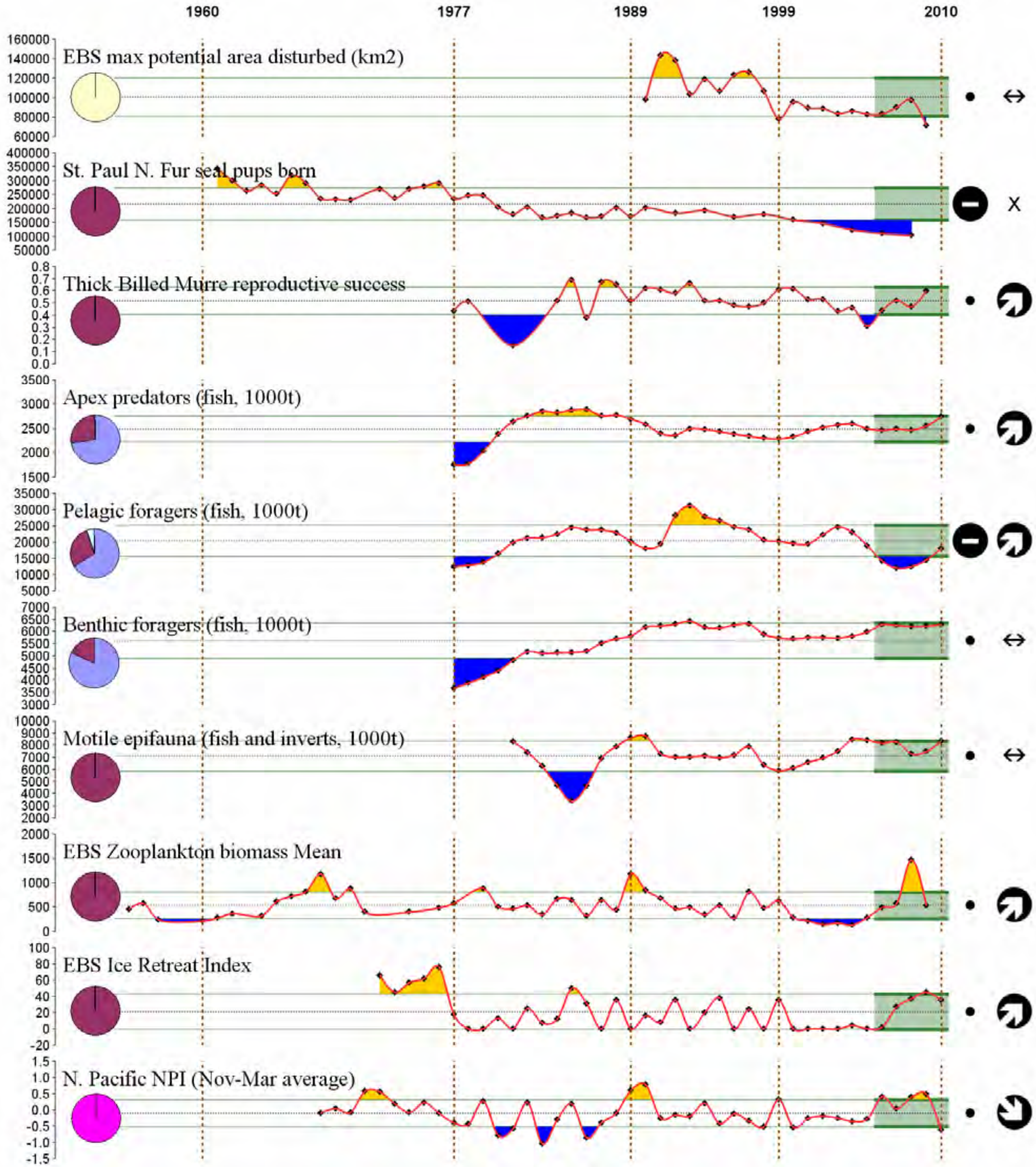
➢ Climate indicators!

➢ Combinations: aggregates, ordinations of indices...

Another indicator classification for uncertainty estimation

By indicator source:

- Field monitoring (trawl surveys, other field observations)
- Statistical model incorporating field observations
  - Climate indices
  - Abundance surveys corrected for sighting probability, q, etc
  - Ordinations of biological data by environmental factors
- Mechanistic model, maybe incorporating field observations
  - Climate or earth-system physical model
  - Population dynamics (single or multispecies) model
  - Food web model (static mass balance, dynamic)
  - Biogeochemical whole system model
- Complicated combinations of the above



Indicator sources:

- SS Model
- Survey Obs
- Catch Obs
- FW Model
- Stat Model

Types of uncertainty (Link et al. in review)

- Natural variability
  - Process noise
  - Endogenous & Exogenous factors
- Observation error
  - Missing key measurements
  - Sampling variability and bias
- Model structural complexity
  - Attempts to include endogenous/exogenous factors
  - Parameterizations rapidly outstrip data available
- Inadequate communication
  - Between scientists, scientists-managers, managers-stakeholders, etc
- Unclear management objectives
- Implementation/Outcome uncertainty

Do indicator classes imply methods to estimate uncertainty?

<table>
<tr><th>Uncertainty→

Indicator source ↓</th><th>Natural variability</th><th>Observation error</th><th>Model complexity</th><th>Communication uncertainty,
Unclear management objectives,
Implementation uncertainty</th></tr>
<tr><td>Field monitoring</td><td>Match spatial and temporal sampling to key driving processes</td><td>Sampling theory design-based estimate; resampling</td><td></td><td rowspan="4">Scientific disciplines must collaborate to provide specific information for optimal indicators, improve visualization and interpretation

Iterative stakeholder processes required to improve communication and develop/clarify management objectives

Management strategy evaluation (MSE) within stakeholder process may clarify the above, and can estimate effects of implementation uncertainty</td></tr>
<tr><td>Statistical model</td><td>Match spatial and temporal scale to key driving processes</td><td>Model-based analytical expression; resampling</td><td>Beware of overfitting the data: AIC, BIC, cross-validation</td></tr>
<tr><td>Mechanistic model</td><td>Match spatial and temporal scale, model key driving processes</td><td>Statistical fitting to data and error estimated by above methods</td><td>Above, plus: Monte Carlo approaches, Multi-model inference, MSE</td></tr>
<tr><td>Combinations</td><td colspan="3">Incorporate the above; but how to combine appropriately?</td></tr>
</table>

Easy?

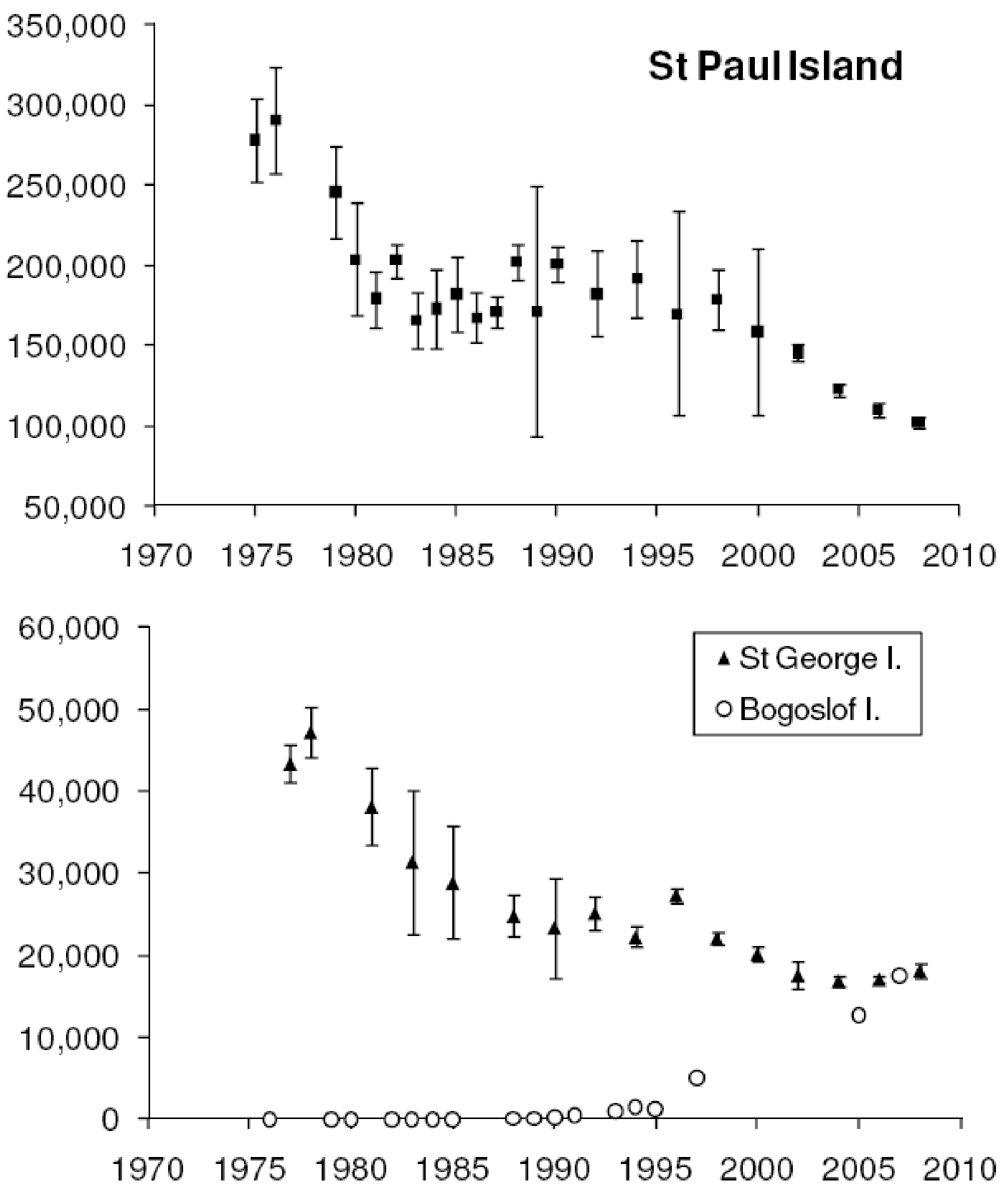
- Observation error and broad natural variability together
  - Survey-based and or single species time series indicators
  - Diversity indices
  - Consumption/diet indices
  - Can be adapted for spatial indicators

- Model based “emergent” indicators: Monte Carlo analysis

- MMI for structural uncertainty, parameter uncertainty

- Scientific communication: asking the right questions

Northern Fur Seals (Fritz and Towell 2010)

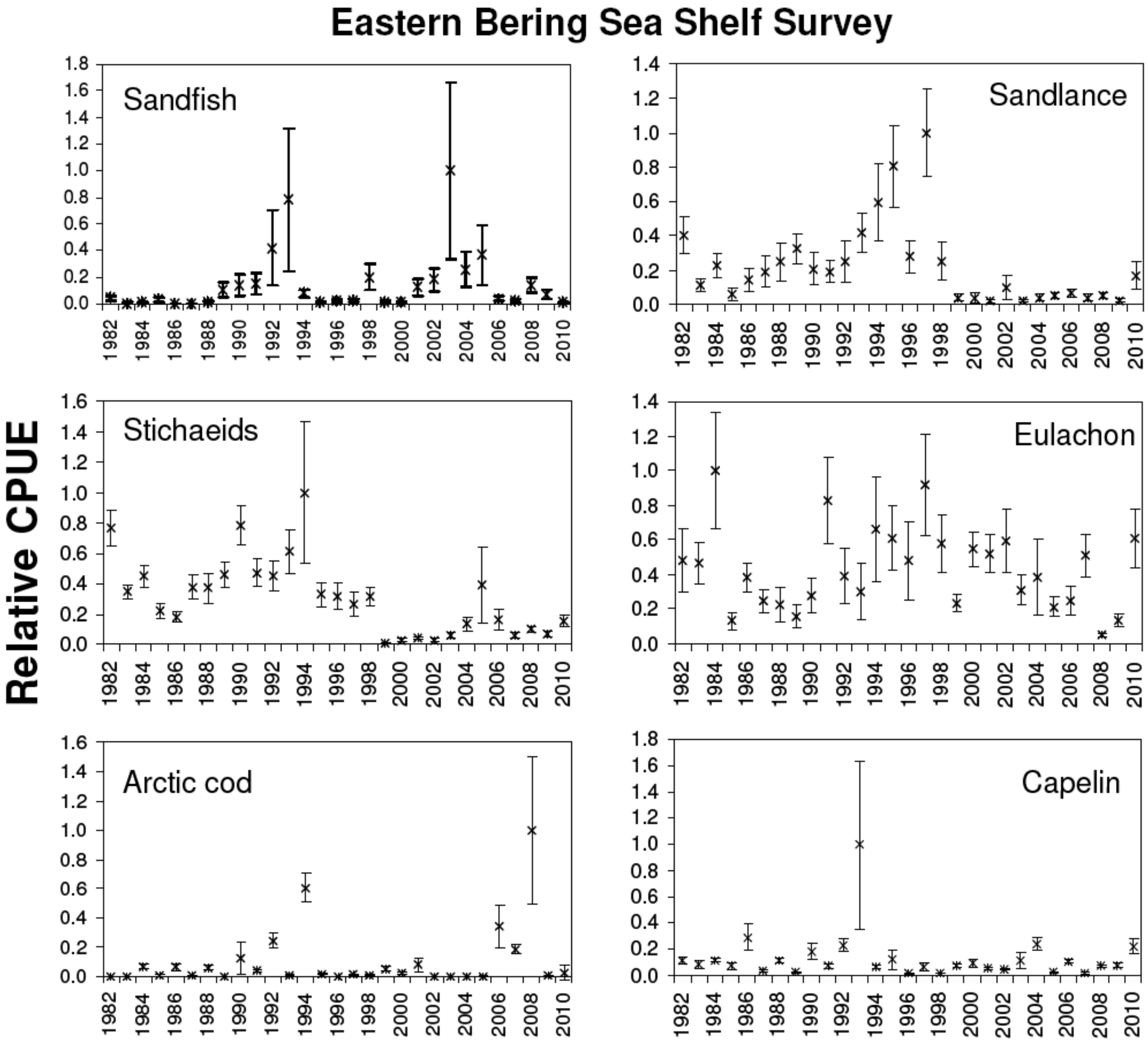


"Field Monitoring": Total pup estimates from mark-recapture method; multiple observation days to estimate standard deviation.

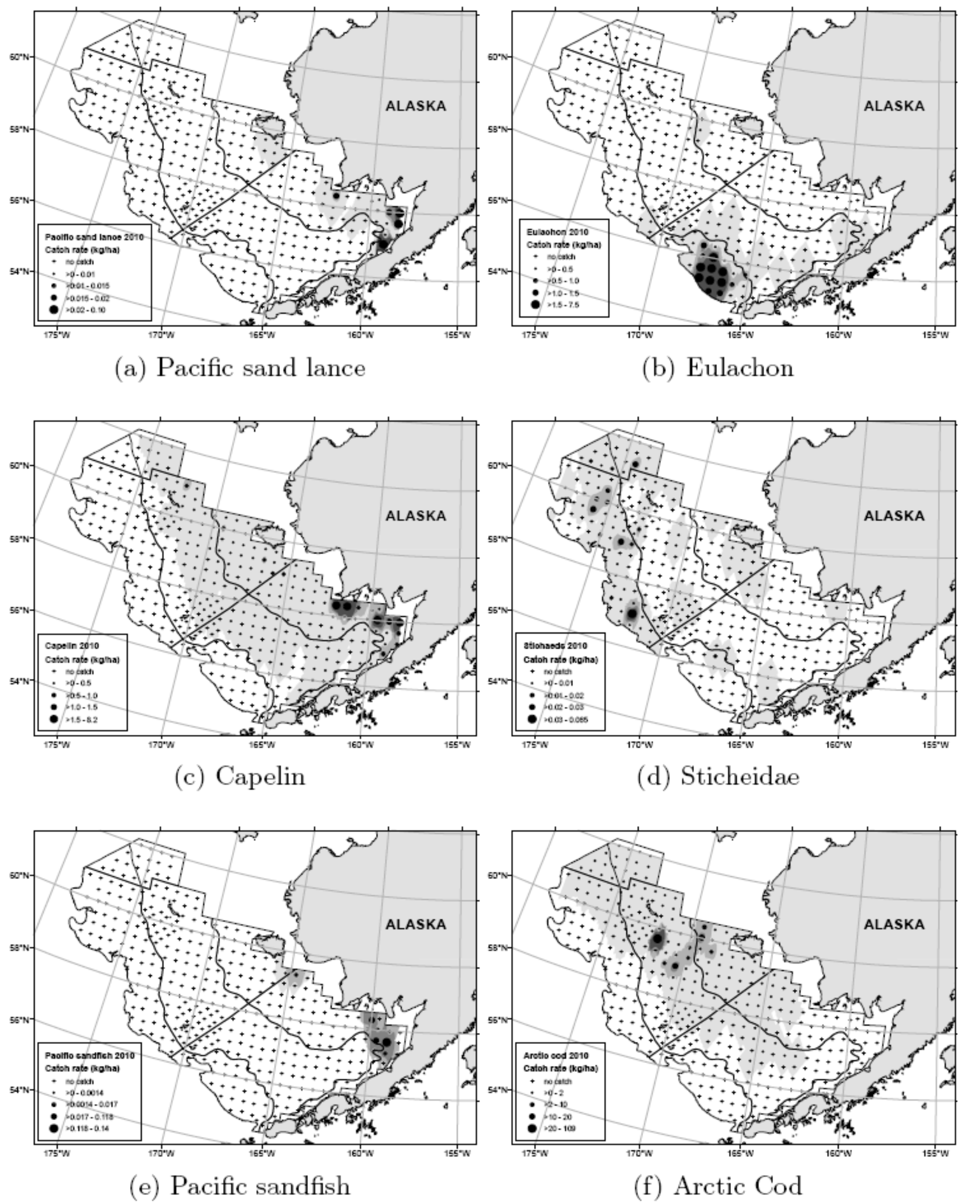
Forage Species EBS (Lauth and Hoff 2010)

"Field monitoring":

Standardized bottom trawl survey for groundfish, relative CPUE and standard error from stratified systematic survey design.



Forage Species EBS (Lauth and Hoff 2010)



(a) Pacific sand lance (b) Eulachon

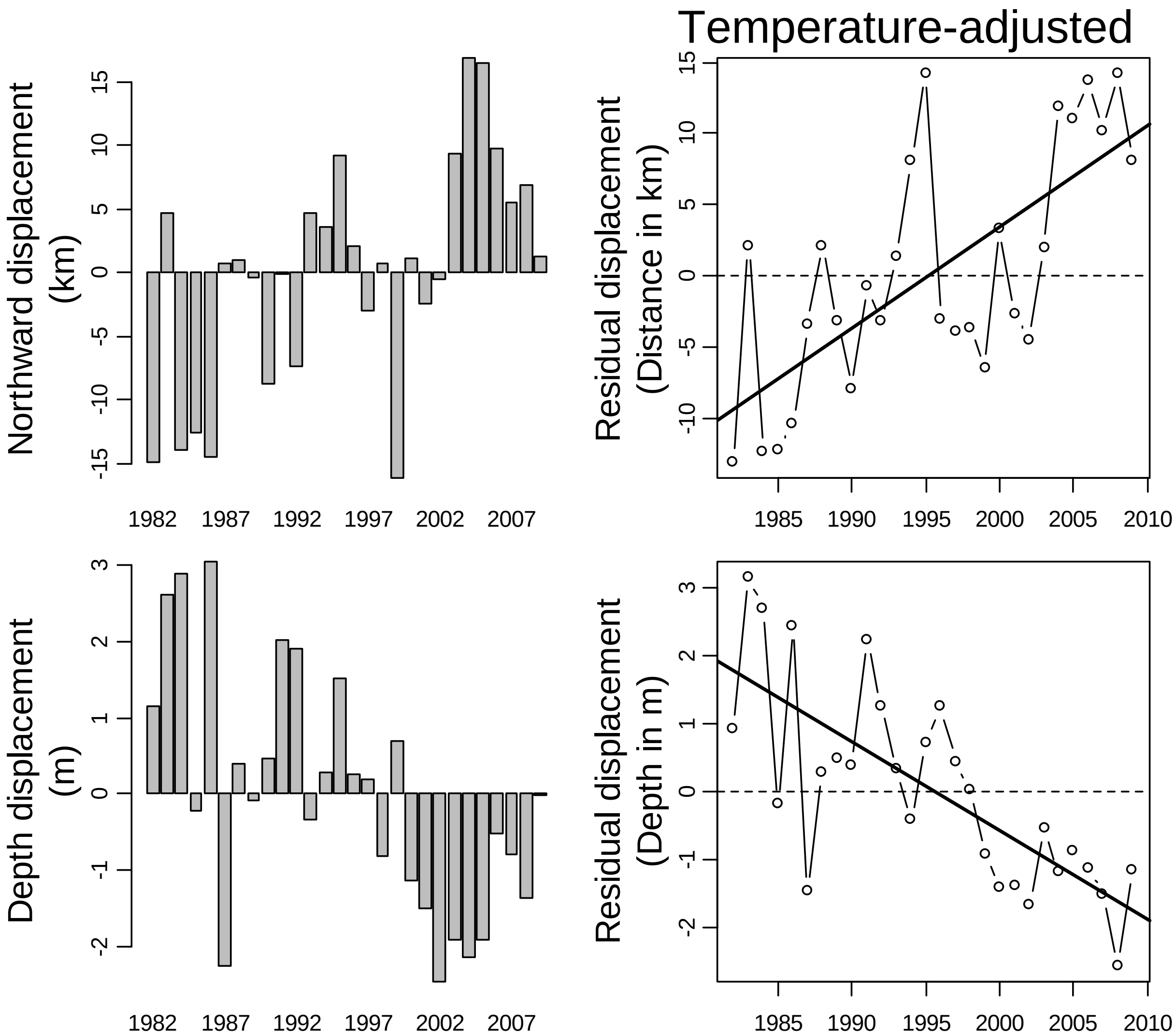
(c) Capelin (d) Sticheidae

(e) Pacific sandfish (f) Arctic Cod

Distribution and relative abundance during 2010: uncertainty by several possible methods...

Spatial Distribution of EBS Groundfish

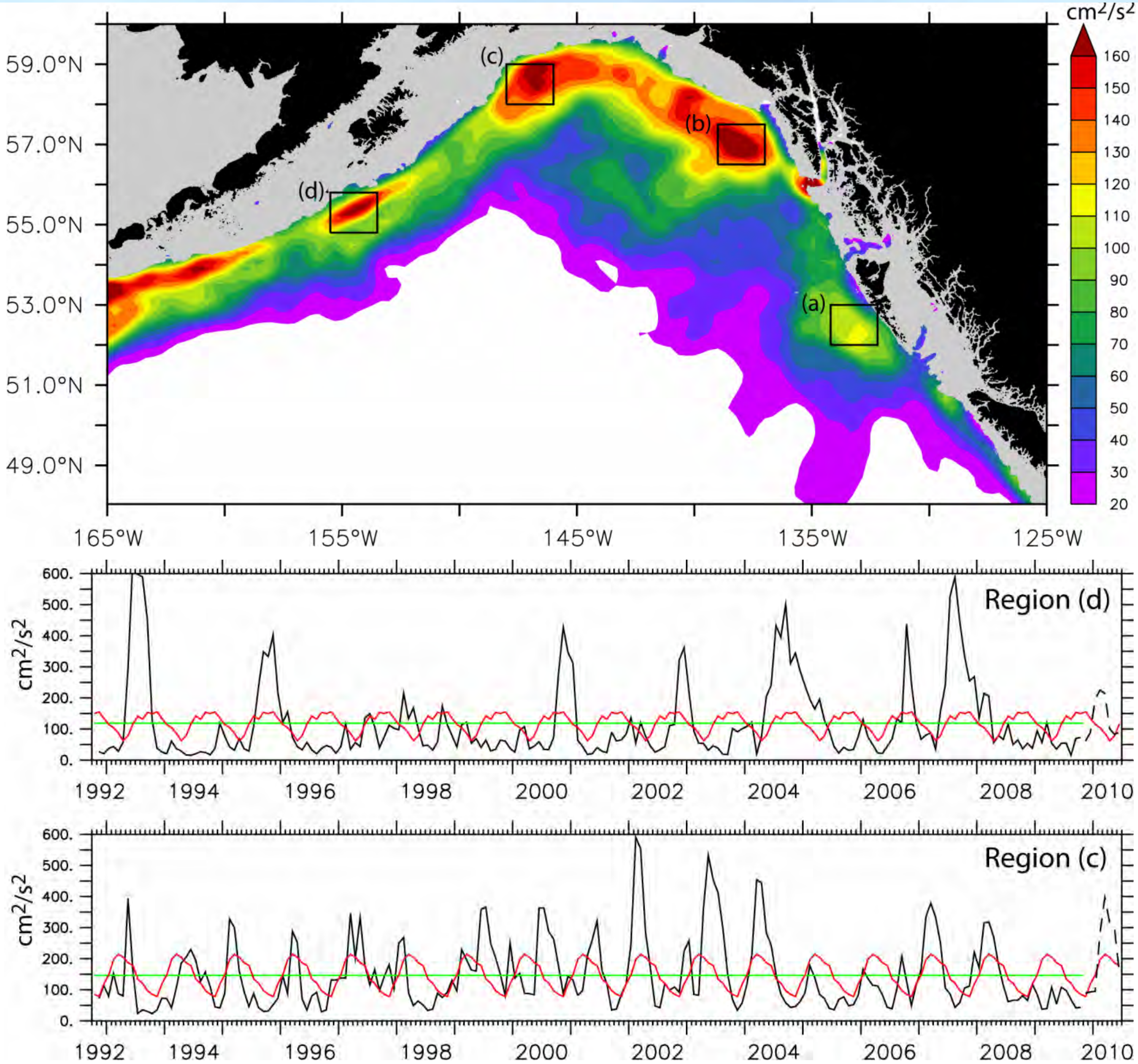
(Mueter, Litzow, & Lauth 2010)



"Statistical model":

annual anomaly from CPUE weighted mean bottom trawl survey lat/depth 1982-2008, variance could be estimated.

Eddy Kinetic Energy (Ladd 2010)

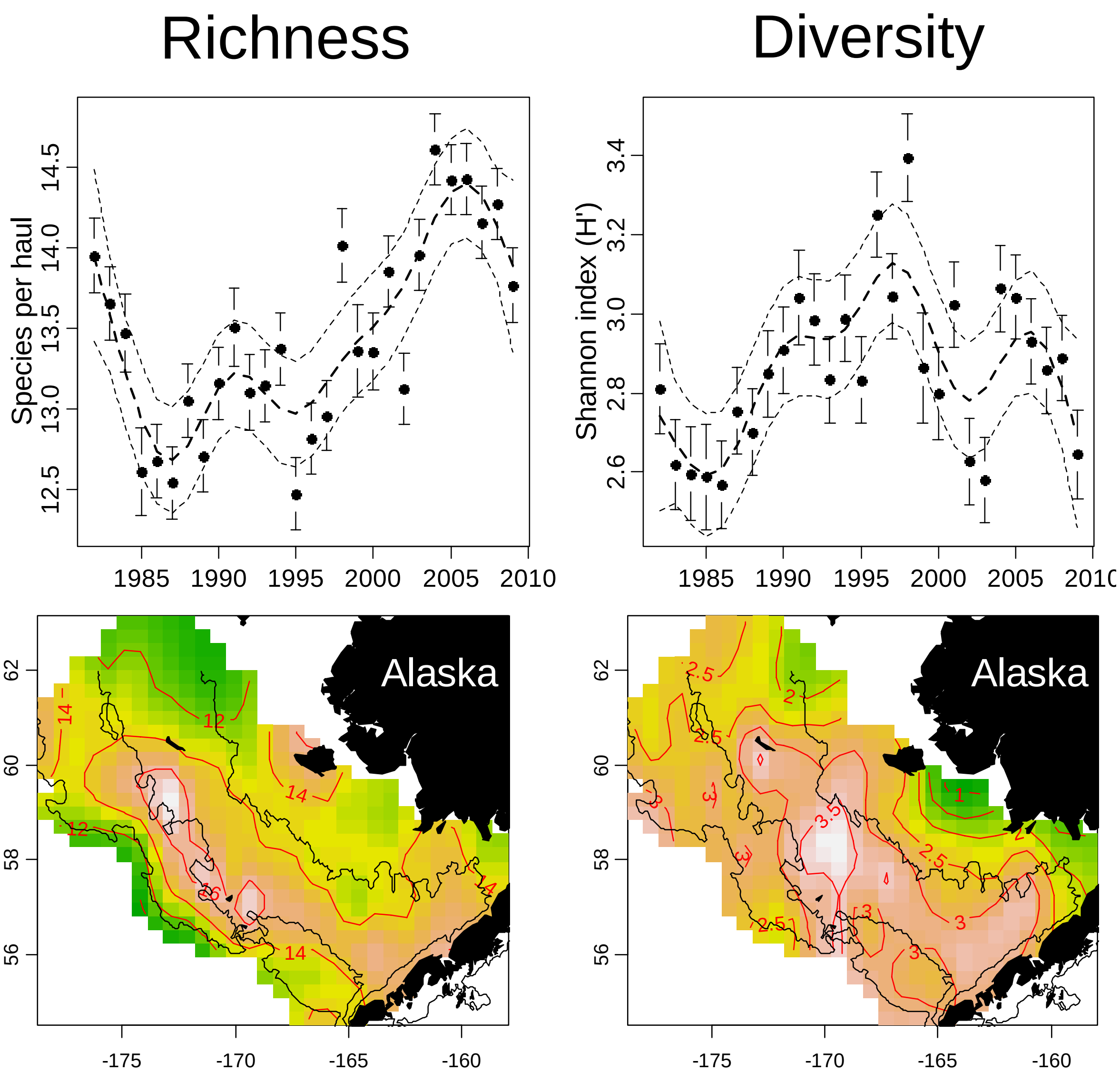


"Field monitoring":

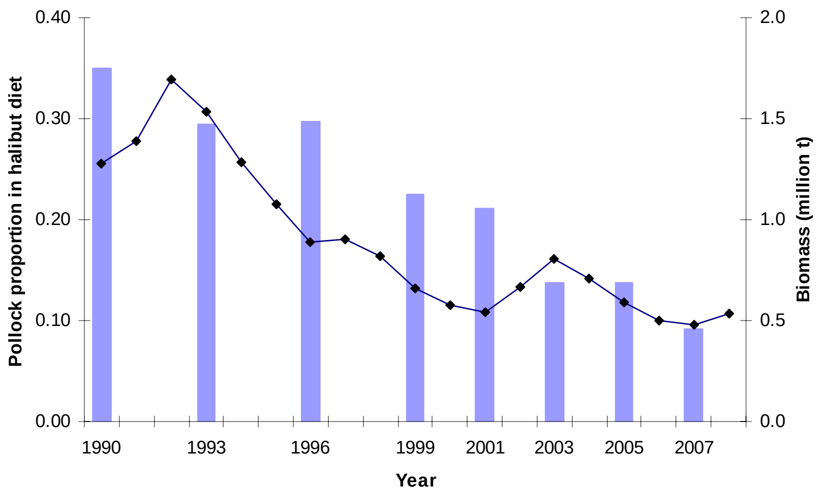
Gridded altimetry data, time series calculated as mean of boxed areas, variance of this could be estimated

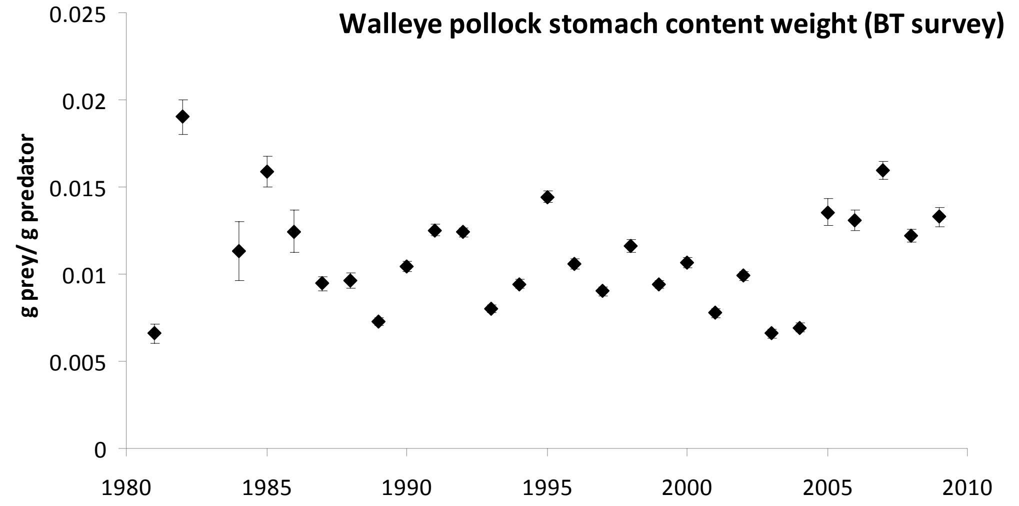
EBS Richness and Diversity (Mueter & Lauth 2010)

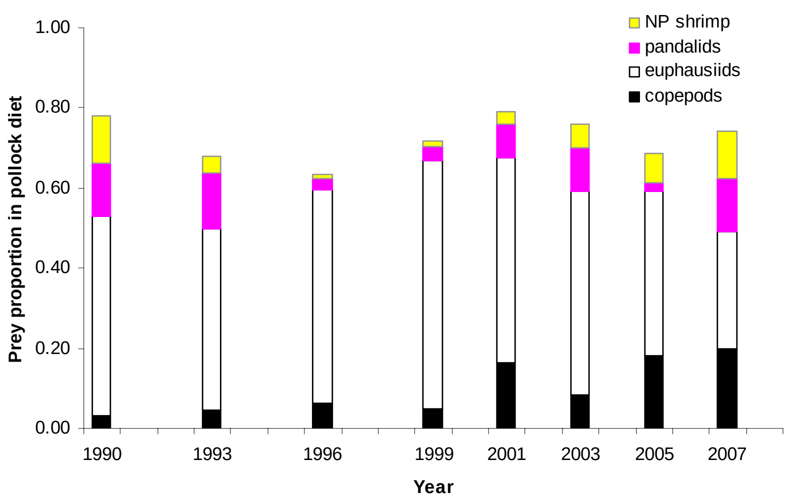
"Statistical model":
Bottom trawl survey haul-specific indices averaged for each year within a GAM accounting for area swept, date, location, and depth; uncertainty from GAM output

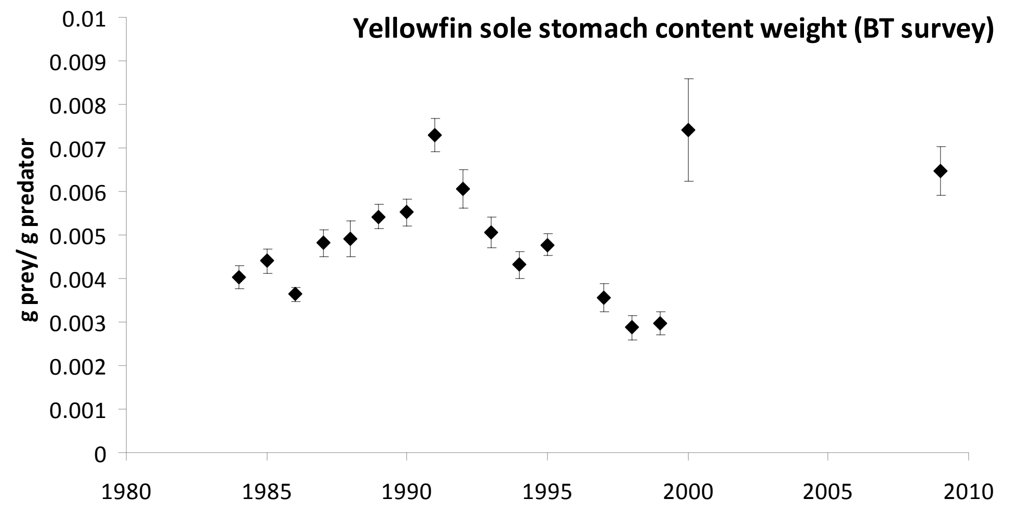


Time series of diet data: add bootstrap









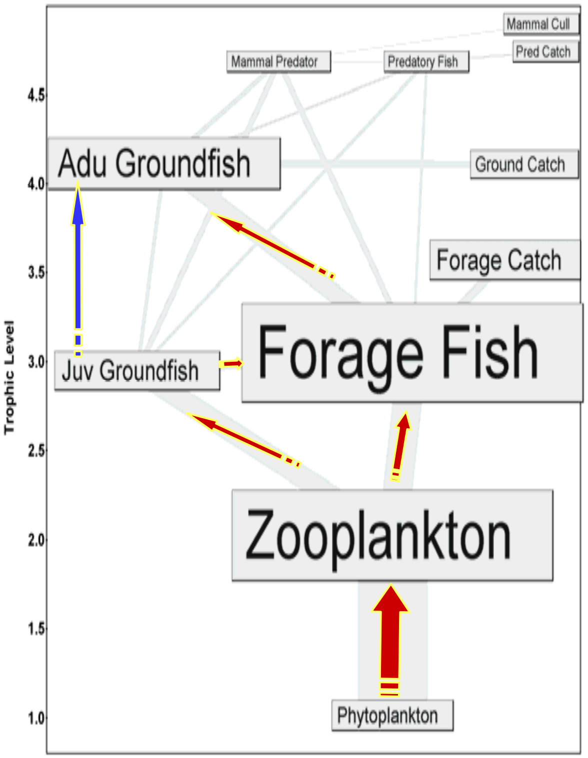
Incorporating uncertainty in mass balance models

System of linear equations

For each group, i, specify:

- Biomass (B) [or Ecotrophic Efficiency (EE)]
- Population growth rate (P/B)
- Consumption (Q/B)
- Diet composition (DC)
- Fishery catch (C)
- *Biomass accumulation (BA)*
- *Im/emigration (IM and EM)*

Solving for EE [or B] for each group



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

Data uncertainty rating → distributions for parameters

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 Sh	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 sc	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 R	0.10	0.60	0.60	0.30
Dusky Roc	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 S	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. sm	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 do	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 Phyto	0.80	0.50	0.00	0.00
Outside P	0.80	0.70	0.00	0.00

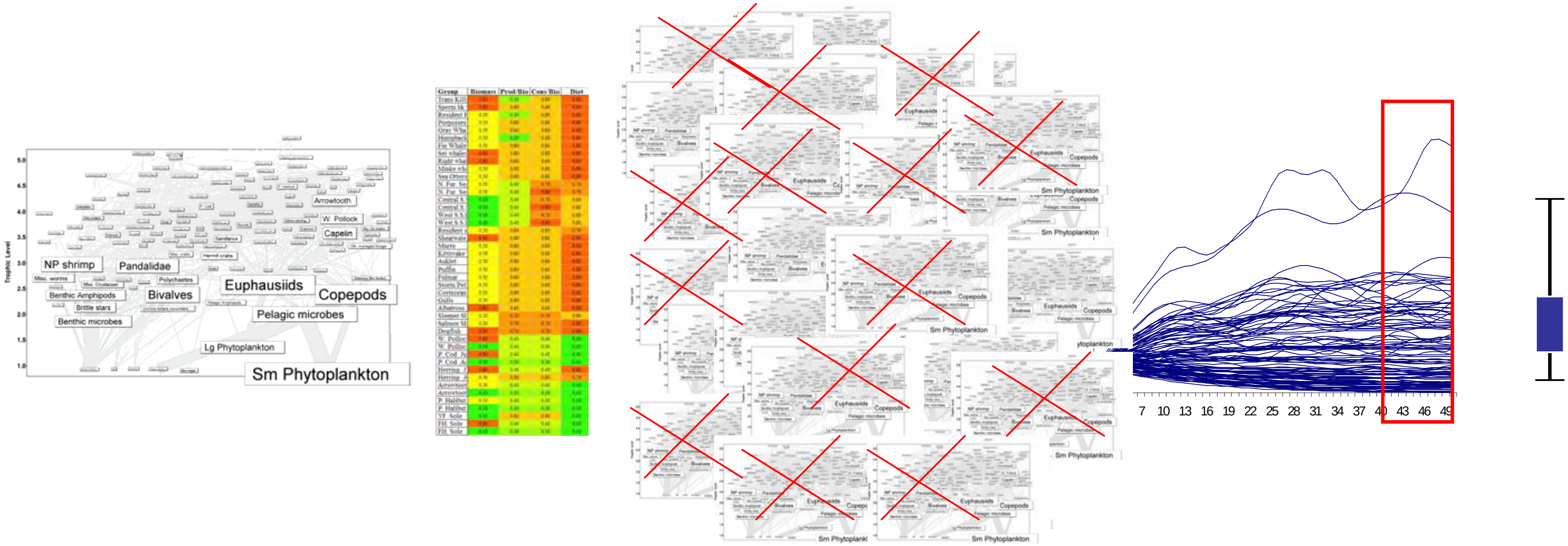
Good

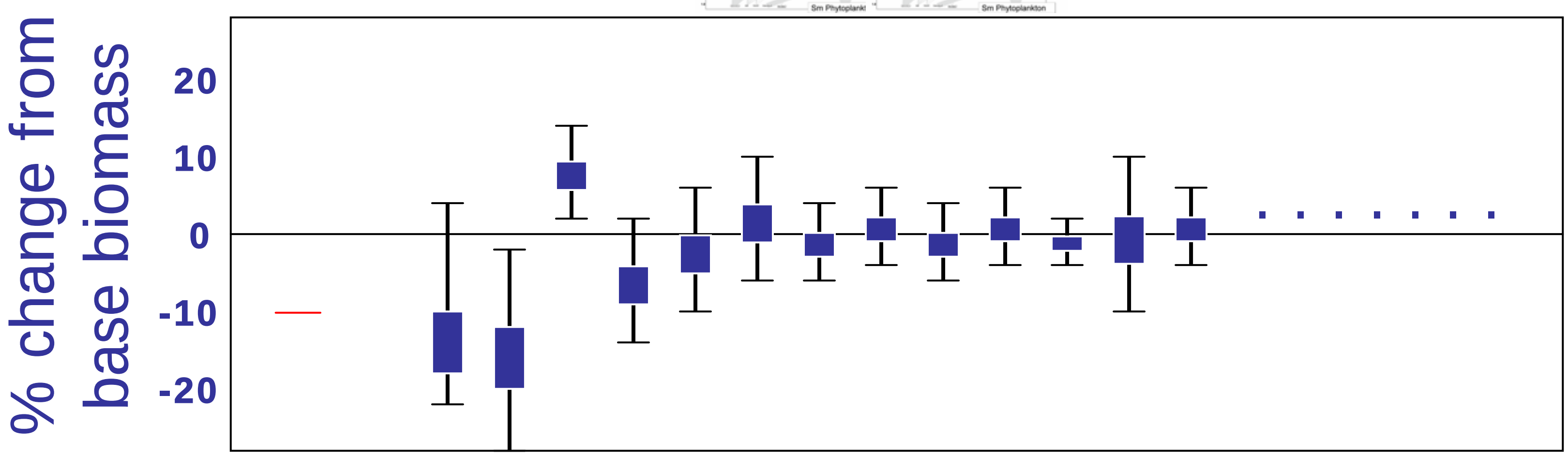
OK

Bad

Ugly

Monte carlo approach simulating pertubations

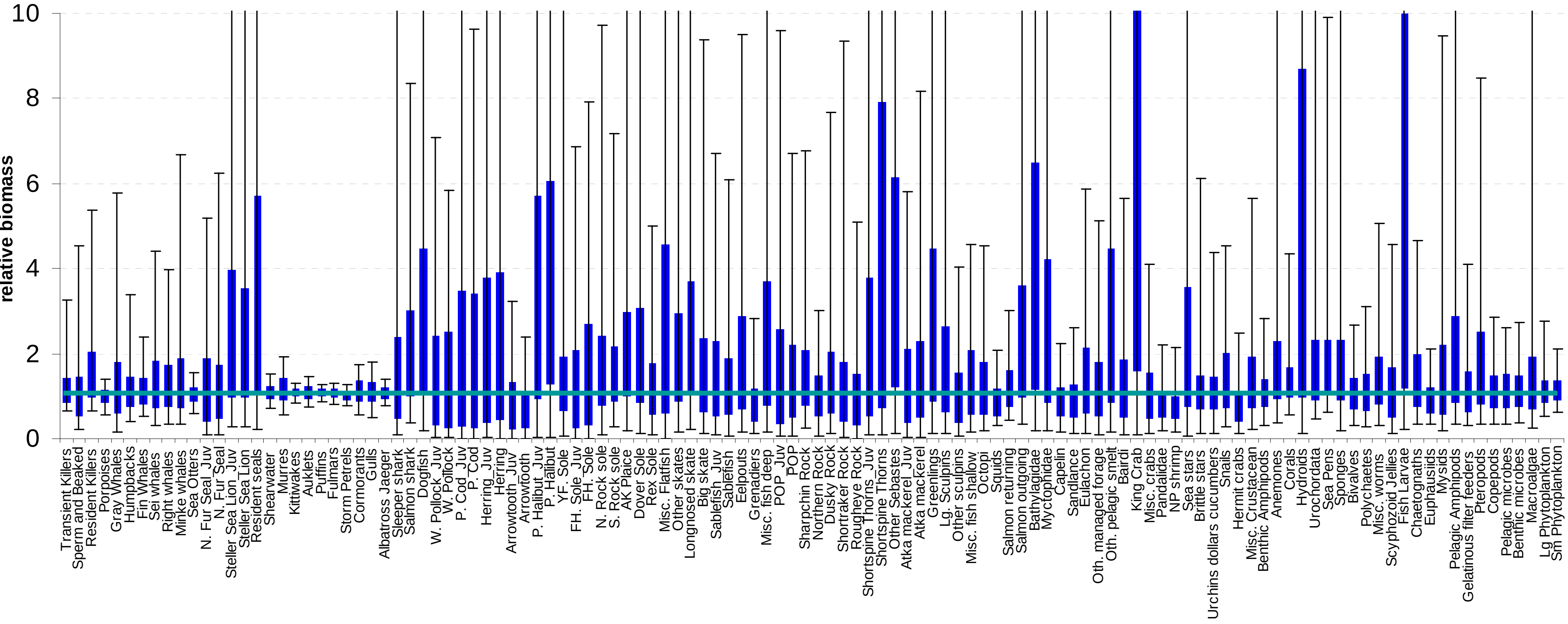




Effects on each group, sorted by median

Results: “Base trophic uncertainty”

- Bars show 5%-95% interquantile range for year-50 biomasses in accepted ecosystems; boxes are 25%-75% interquantile range
- Limited confidence of exactly where system will be in 50 years, but patterns do emerge…



Functional response parameters (dynamic)

- Vulnerability:

  how much prey biomass is available to predators?

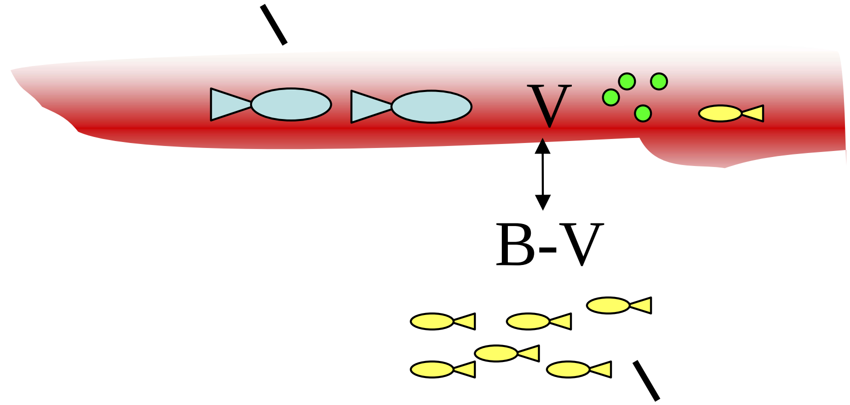
- Foraging Time:

  if I'm hungry, should I spend more time vulnerable?

- Handling Time:

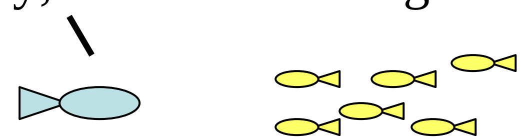
  at some point, my consumption is limited even if there are more prey

"It's cold down there!"



"Our food is up there, but so are those big guys!"

"Don't worry, I'm still chewing."



$$c(B_{pred}, B_{prey}) = Q^*_{link}\left(\frac{X_{link}\cdot Y_{pred}}{X_{link}-1+Y_{pred}}\right)\left(\frac{D_{link}\cdot Y_{prey}^{\theta_{link}}}{D_{link}-1+Y_{prey}^{\theta_{link}}}\right) \qquad Y = TB_t / B^*$$

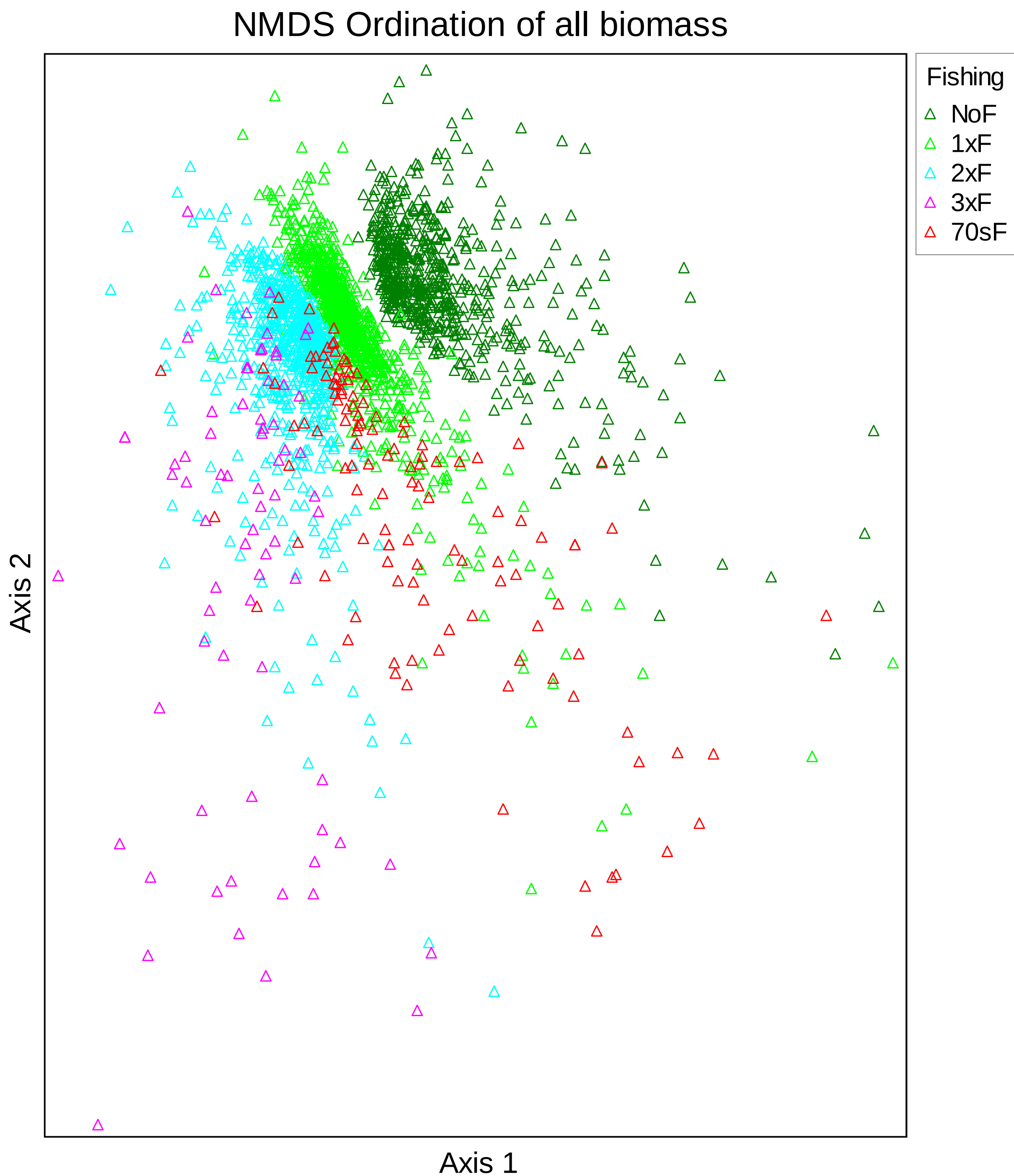
Structural uncertainty and fishing

Parameterizations are random draws

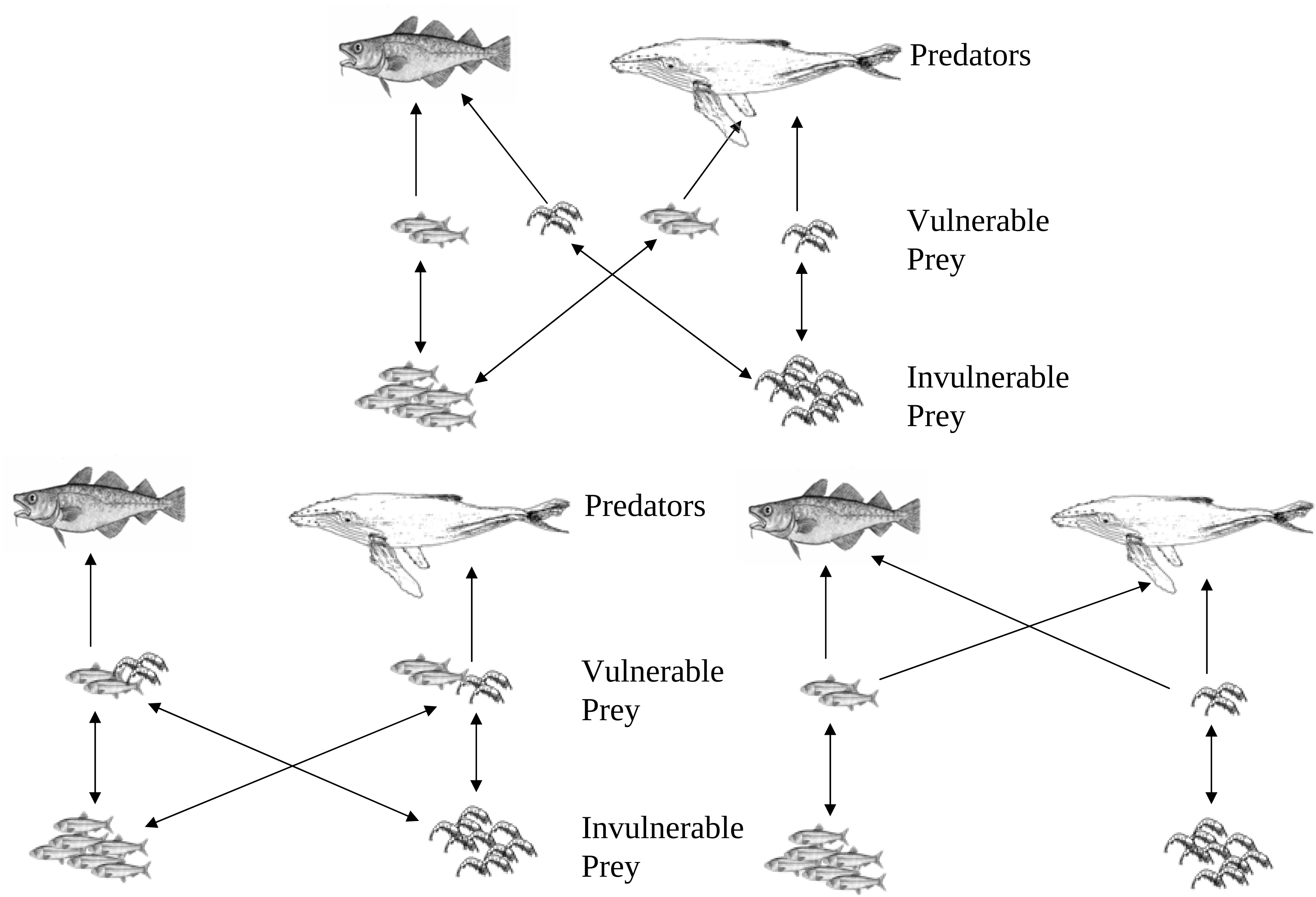
Unfished systems different from fished systems

No, light, and moderate fishing produce mostly similar ecosystems

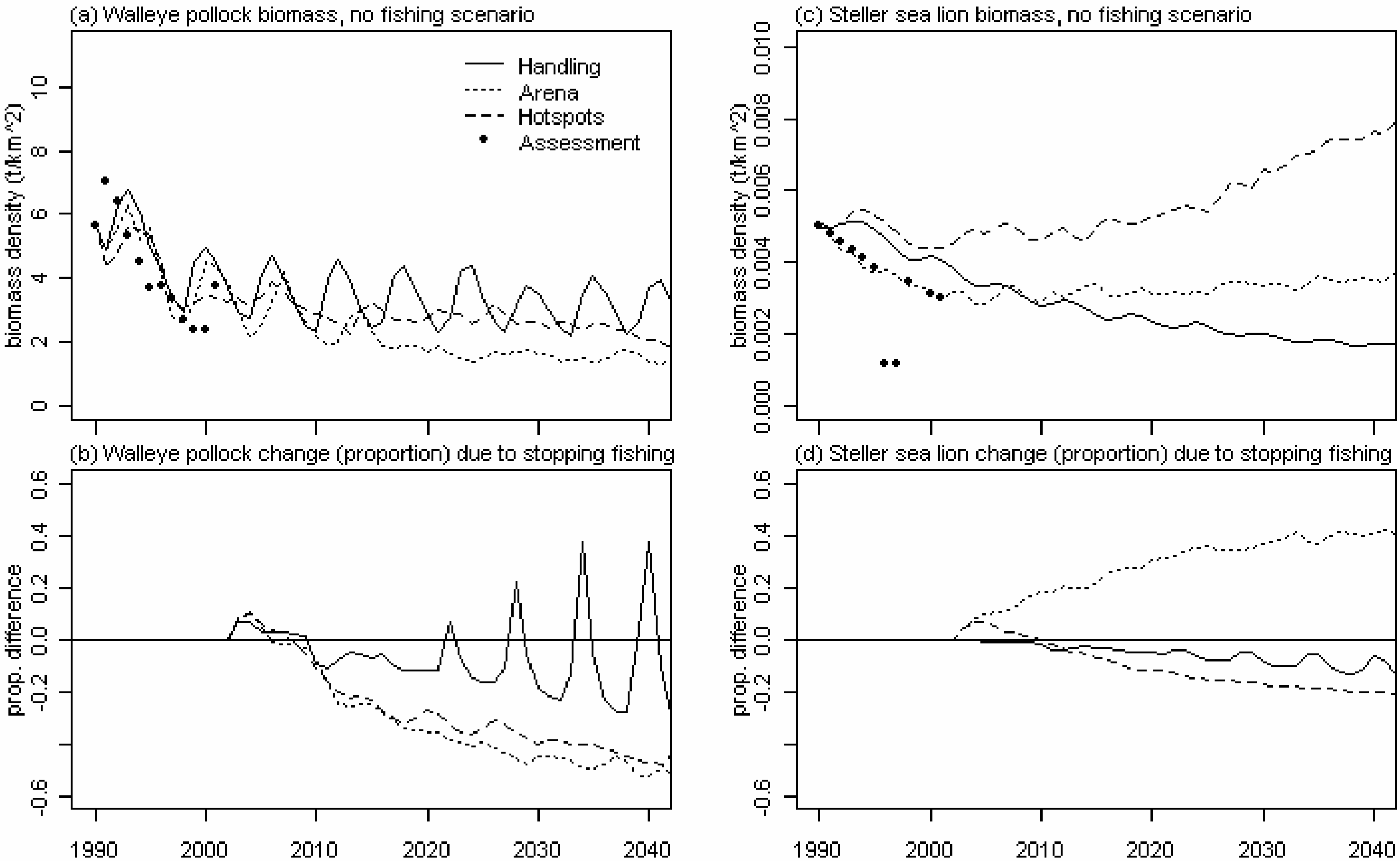
Heavy system wide fishing and heavy rockfish fishing produce mostly different, *reorganized* ecosystems



Alternate structures for functional response



Multiple model structures fitted to data



Asking the right questions (PICES Rept 34)

Table 2.1 Continued

Species	Index	Mechanism	Month 1	2	3	4	5	6	7	8	9	10	11	12
Bering Sea – Aleutian Islands														
Snow crab	ROMS drift tracks from start locations in area	Survival depends on successful advection to the northeast, shallower waters	–	–	–	–	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	–	–
	SST	Temperature in upper water column affects rate of development and settlement time	–	–	–	–	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	–	–
	ROMS output of snow crab advection relative to Pacific cod geographic distribution in area	Larval settlement in areas occupied by cod adversely affects survival	–	–	–	–	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	–	–
	Timing of spring bloom	Match/mismatch of crab larvae and spring bloom	–	–	–	56.5-62N, 168-175W	56.5-62N, 168-175W	–	–	–	–	–	–	–
	Abundance of immature snow crabs	Settling snow crabs are cannibalized by juveniles already occupying the nursery areas	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W	56.5-62N, 168-175W
Korean coastal waters														
Chub mackerel	Spring currents and salinity from about 50 m depth to the surface for the same areas as described above	Transport to nursery areas	–	32-35N, 123-131E	32-35N, 123-131E	32-35N, 123-131E	32-35N, 123-131E	32-35N, 123-131E	–	–	–	–	–	–
Jack mackerel	Probability that a surface particle would land in the 'touch down zone' where larval jack mackerel settle out of the planktonic larval stage	Recruitment is related to success of settlement in nursery ground transported by the Kuroshio Warm Current	–	–	–	32-35N, 125-131E	32-35N, 125-131E	32-35N, 125-131E	–	–	–	–	–	–
	Temperature and salinity at the surface and 50 m layer depth	Growth is a function of metabolic rate	–	–	–	32-35N, 125-131E	32-35N, 125-131E	32-35N, 125-131E	–	–	–	–	–	–
	Zooplankton abundance April–June	Growth is a function of prey availability	–	–	–	32-35N, 125-131E	32-35N, 125-131E	32-35N, 125-131E	–	–	–	–	–	–

More difficult

- Ordination-based indicators?
- Aggregate indicators? (survey+model information)?
- Models too computationally expensive for Monte Carlo?
- And, we have few quantitative reference points (unclear management objectives)

EOF uncertainty?

Polovina and Howell 2005

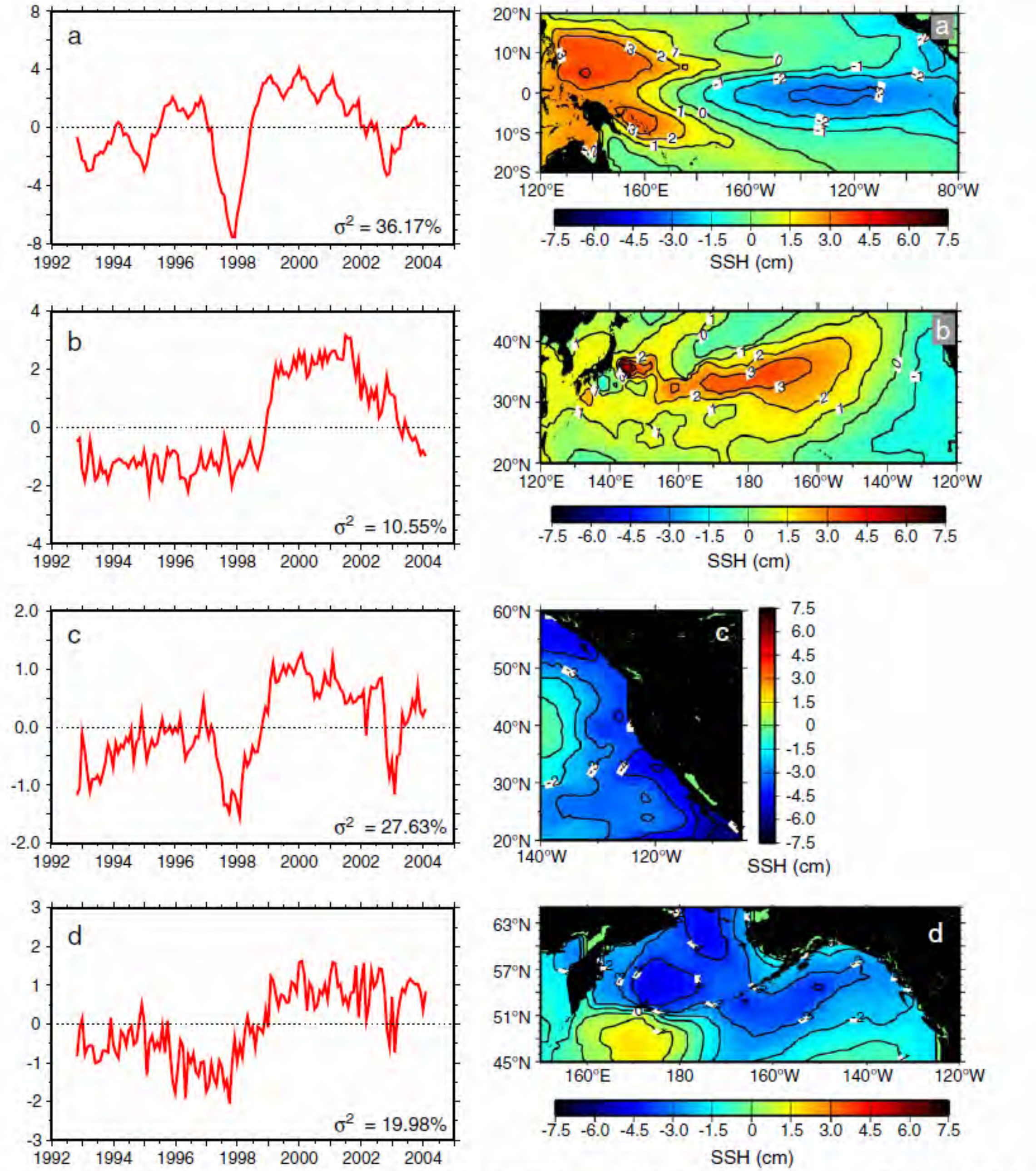
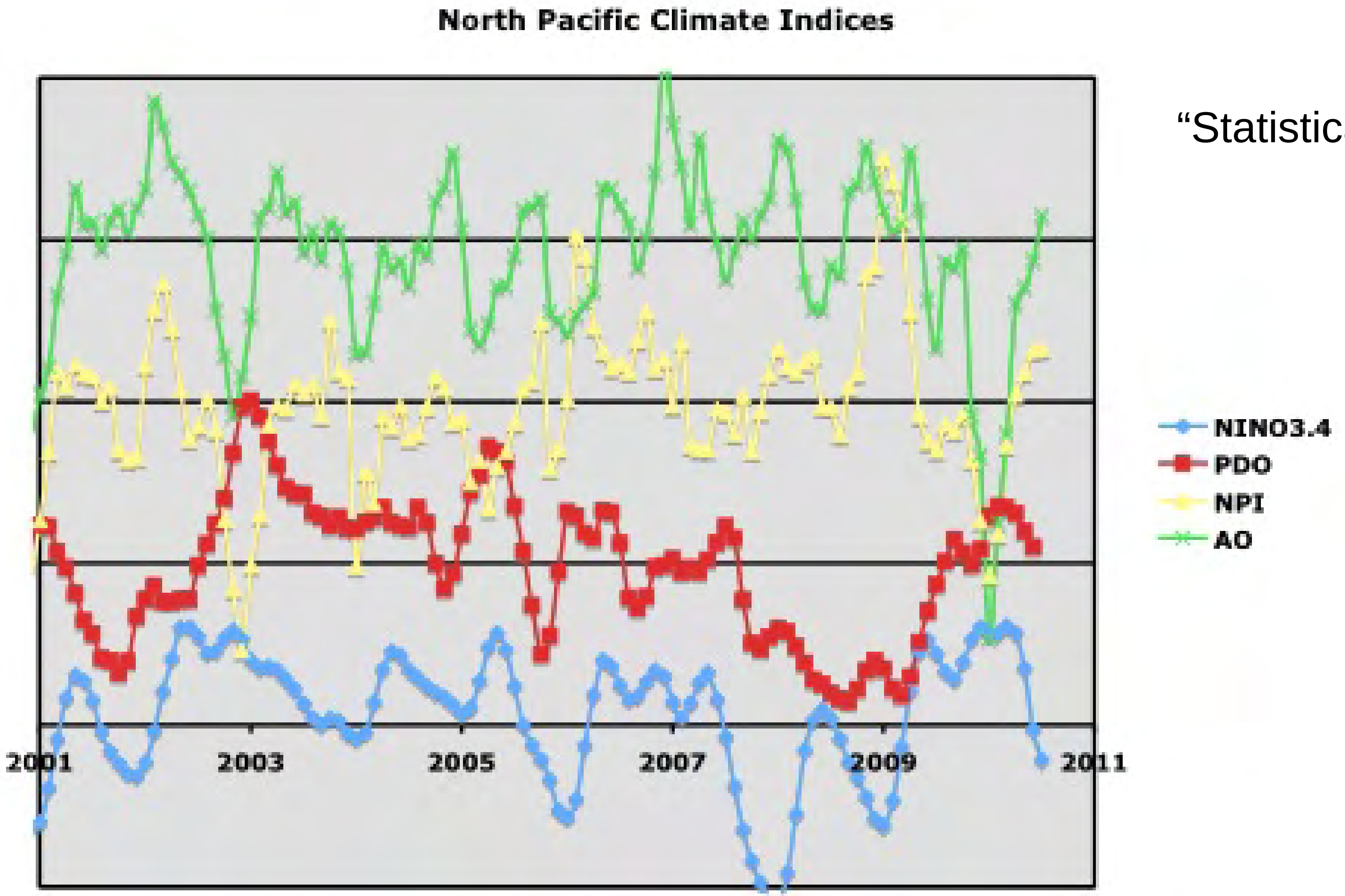


Figure 1. The first EOF modes of SSH for (a) the equatorial Pacific, (b) the central North Pacific, (c) the eastern Pacific, and (d) the Alaskan Gyre. Left panels, weighting functions expressed as time-series (with annotation of the variance explained); right panels, corresponding spatial patterns.

Climate Indices (Bond and Guy 2010)



“Statistical model”

Ordination of indicators (NEFSC 2009)

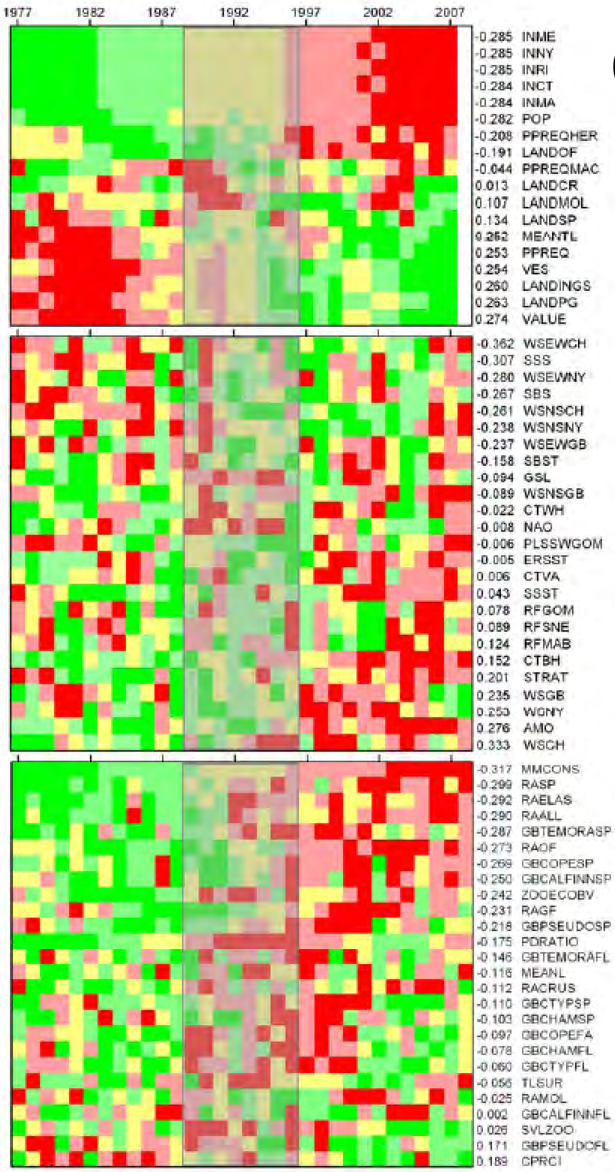


Figure 8.1 Human-related (top panel), climate and physical forcing (middle panel) and biotic ecosystem (bottom panel) indicators of change. The series have been ordered using a Principal Components Analysis to group variables showing similar patterns. Shaded box indicates transition period.

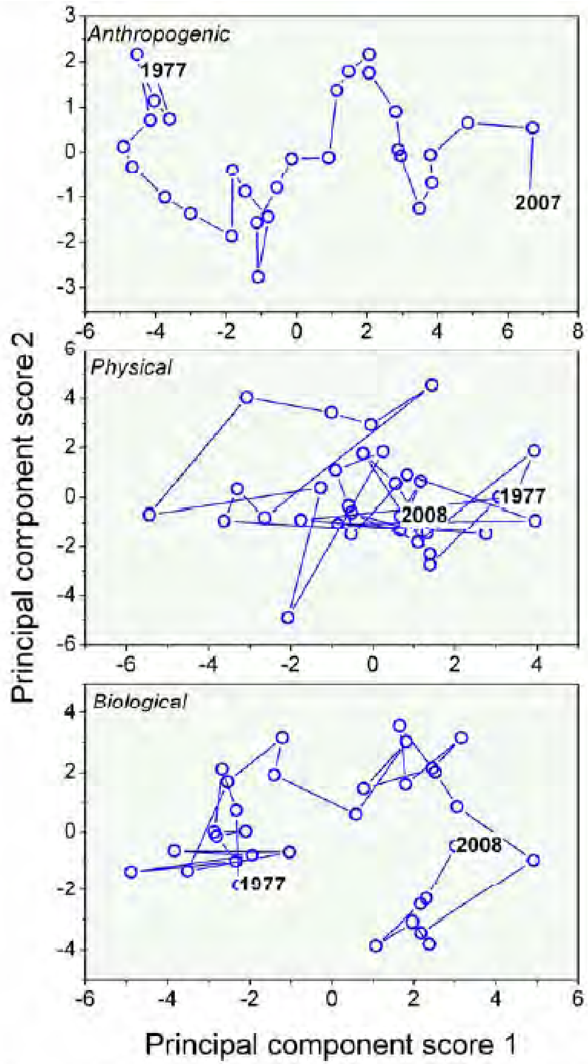


Figure 8.2 Time trajectories of change in canonical phase space for anthropogenic, physical, and biotic indicator variables.

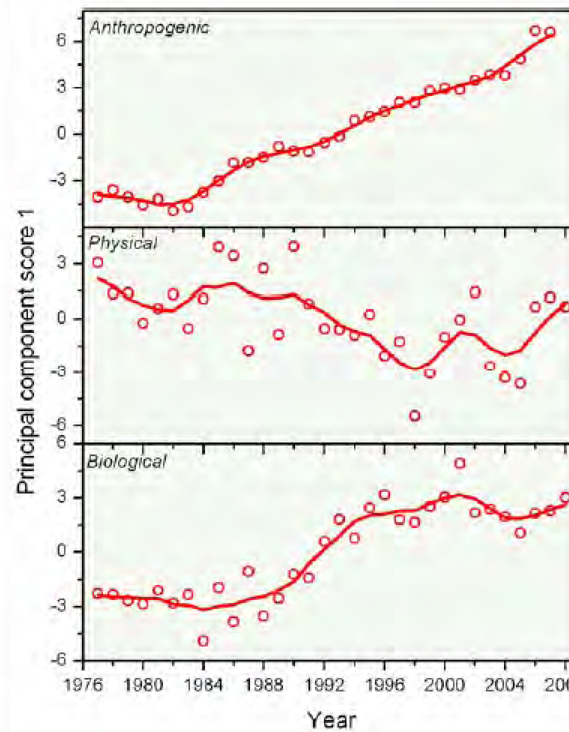


Figure 8.3 Time trends for the first principal components for anthropogenic, climate/physical, and biotic indicators.

http://www.nefsc.noaa.gov/publications/crd/crd0911/crd0911.pdf

Methods are out there...

- Confidence intervals for principal components analysis loadings are calculable
  - Analytically if multivariate normality is assumed
  - Using resampling methods if that assumption is violated
  - e.g. Timmerman et al. 2007, British J Math Stat Psychology

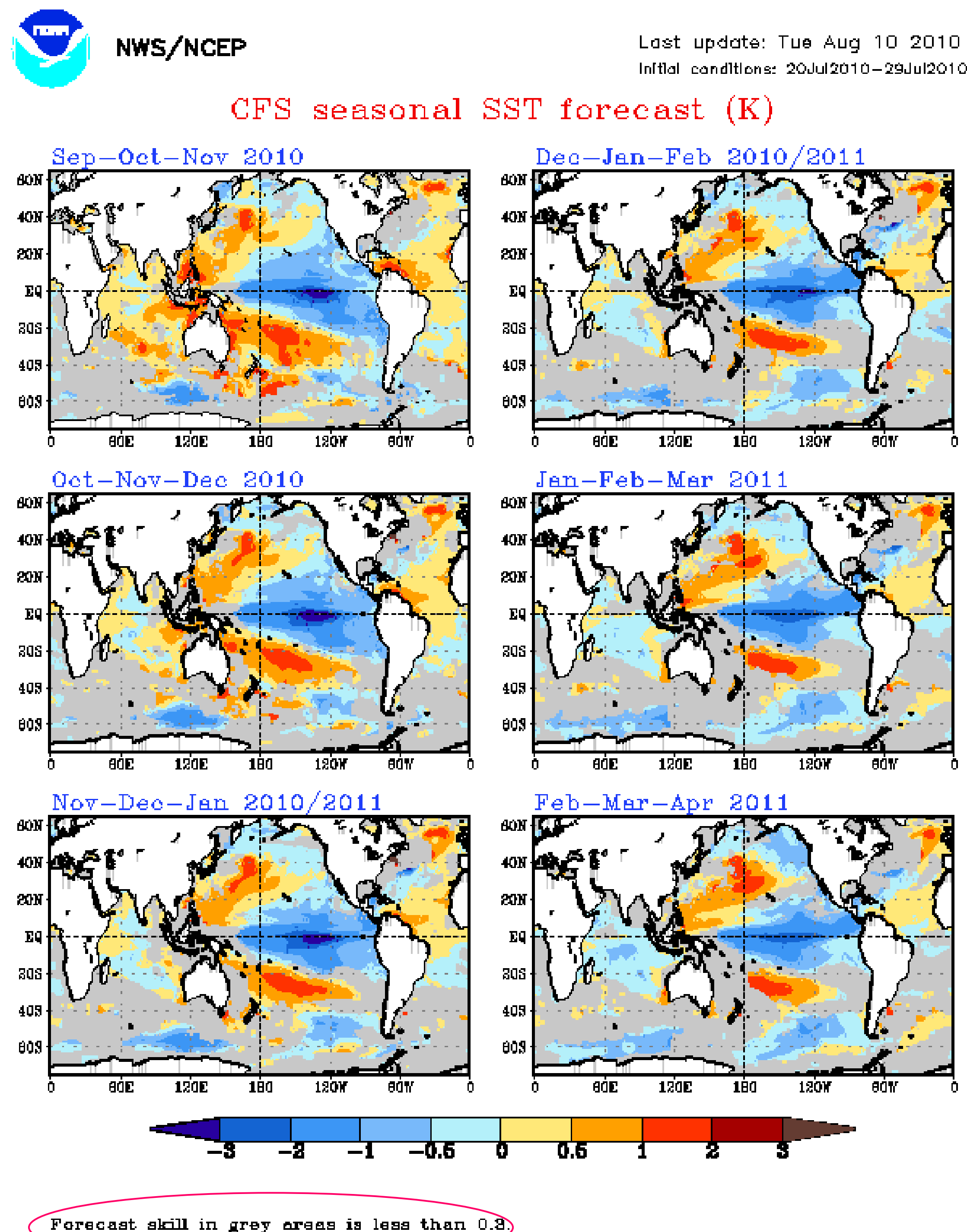
- Applicable to EOFs?
- Applicable to indicator reduction?

Sea Surface Temperature Predictions
(Bond & Guy 2010)

"Mechanistic model":

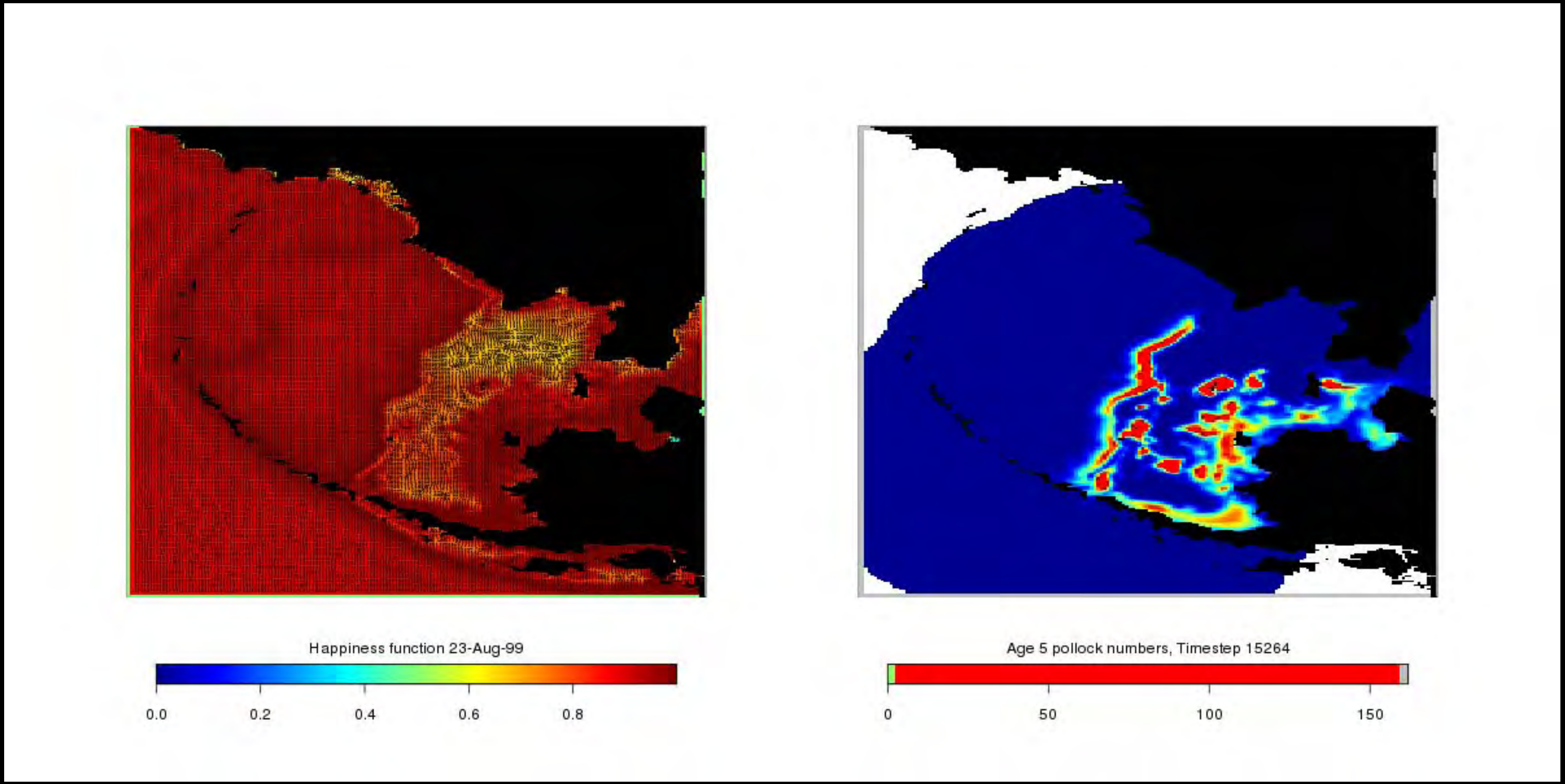
NCEP coupled forecast system model (CFS). Model skill indirectly reported, and uncertainty reported verbally:

"Regionally it is not clear whether the Bering will remain cool or become milder due to storm tracks from ocean instead of land."



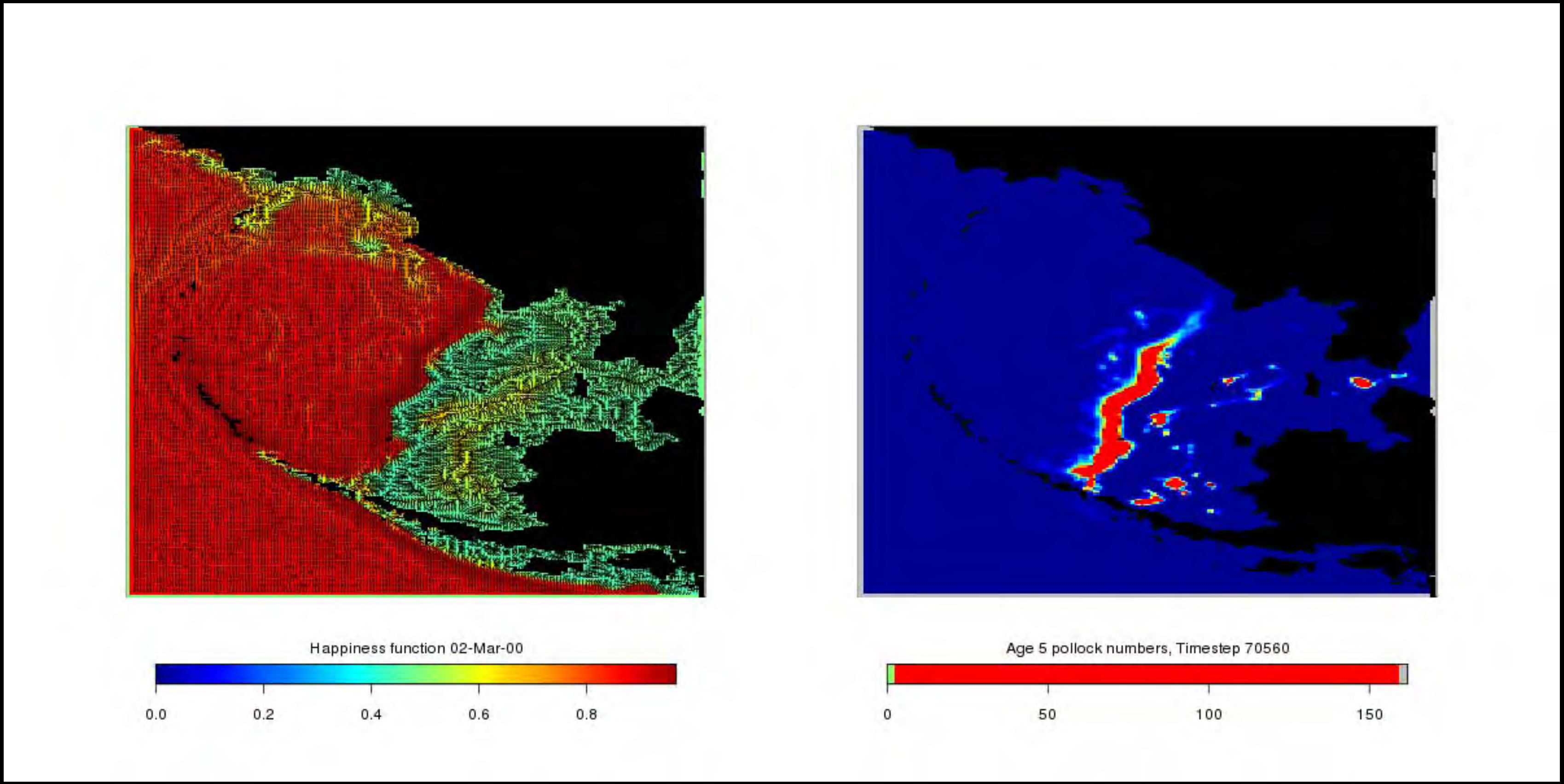
Mechanistic model: FEAST

This happiness function is a bioenergetic function of prey supply (including zoop/fish size preference) and temperature



Mechanistic model: FEAST

Fish move according to the function in reasonable ways.
Multiple runs of this model VERY computationally expensive.



Communicating uncertainty (Anderson 2001)

Evolved abilities	Examples	Related cognitive tasks that are difficult	Examples
Packaging information •Recognizing things or events as discrete units •Classifying and naming categories	•Observing predation events •Defining units of habitat •Politically-defined populations •Taxonomy		
Focusing on frequencies •Counting instances of a class, things, events •Interpreting counts as frequencies	•Number of extinct Hawaiian birds since European arrival out of the number of original Hawaiian birds		
Telling stories •Sharing experience •Using cases for decision making, problem solving, learning	•Short presentation as a story at a professional meeting •Lessons from past policies/practices predict future change		

Communicating uncertainty (Anderson 2001)

Evolved abilities	Examples	Related cognitive tasks that are difficult	Examples
Packaging information •Recognizing things or events as discrete units •Classifying and naming categories	•Observing predation events •Defining units of habitat •Politically-defined populations •Taxonomy	**Dealing with continuous processes** •Working across scales •Managing problems without clear boundaries or definitions	•Metapopulations •Ecosystems •Biodiversity •Evolutionarily significant units
Focusing on frequencies •Counting instances of a class, things, events •Interpreting counts as frequencies	•Number of extinct Hawaiian birds since European arrival out of the number of original Hawaiian birds	**Using decimal probabilities** •Single event probabilities •Probability theory	•Probability that a Hawaiian bird will become extinct in the next 10 years
Telling stories •Sharing experience •Using cases for decision making, problem solving, learning	•Short presentation as a story at a professional meeting •Lessons from past policies/practices predict future change	**Decision making without experience** •Solving unique problems involving uncertainty •Communicating theory, abstractions	•Global climate change •Explaining how processes at different temporal and spatial scales interact in ecosystems

What to do? (Anderson 2001)

- Package information in discrete units
- Focus on frequencies to maintain correct definition
  - Chance: "Probability" is the chance or frequency of a given outcome among all outcomes of a truly random process.
  - Tendency: "Probability" is the tendency of a particular outcome to occur, or how "close" it is to occurring.
  - Knowledge: "Probability" is allocated among the set of known hypotheses.
  - Confidence: "Probability" is the degree of belief in a particular hypothesis.
  - Control: "Probability" is the degree of control over particular outcomes.
  - Plausibility: "Probability" is the believability, quantity, and quality of detail in a narrative or model.

- Tell stories and count cases
- Use cases to solve problems
- Develop common indices to use across systems that are

  "Both easy to assess in the field and reasonable indicators of important ecosystem variables. In general, such variables are easier to use if they are constrained to only a few levels—qualitative states or ranges of data values."

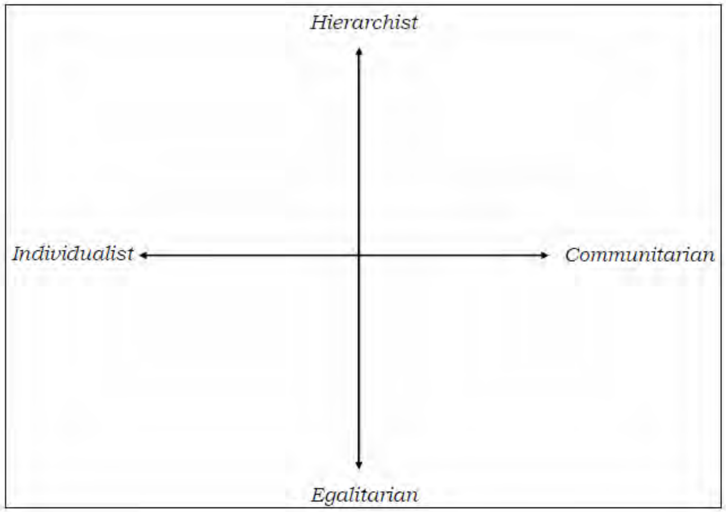
Communicating with diverse stakeholders

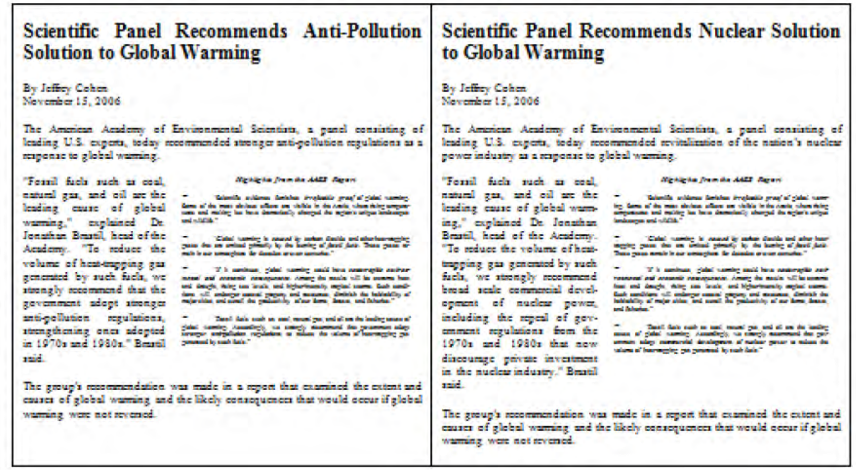
- Humans have much quicker emotional responses than rational responses to information; can communicating differently help?

"If you want someone to accept new evidence, make sure to present it to them in a context that doesn't trigger a defensive, emotional reaction.... paradoxically, you don't lead with the facts in order to convince. You lead with the values—so as to give the facts a fighting chance."

--Mooney, April 18 2011, Mother Jones
http://motherjones.com/politics/2011/03/denial-science-chris-mooney

Values, risk, communication (Kahan et al. 2007)





Scientific Panel Recommends Anti-Pollution Solution to Global Warming

By Jeffrey Cohen
November 15, 2006

The American Academy of Environmental Scientists, a panel consisting of leading U.S. experts, today recommended stronger anti-pollution regulations as a response to global warming.

"Fossil fuels such as coal, natural gas, and oil are the leading cause of global warming," explained Dr. Jonathan Brautl, head of the Academy. "To reduce the volume of heat-trapping gas generated by such fuels, we strongly recommend that the government adopt stronger anti-pollution regulations, strengthening ones adopted in 1970s and 1980s." Brautl said.

The group's recommendation was made in a report that examined the extent and causes of global warming and the likely consequences that would occur if global warming were not reversed.

Scientific Panel Recommends Nuclear Solution to Global Warming

By Jeffrey Cohen
November 15, 2006

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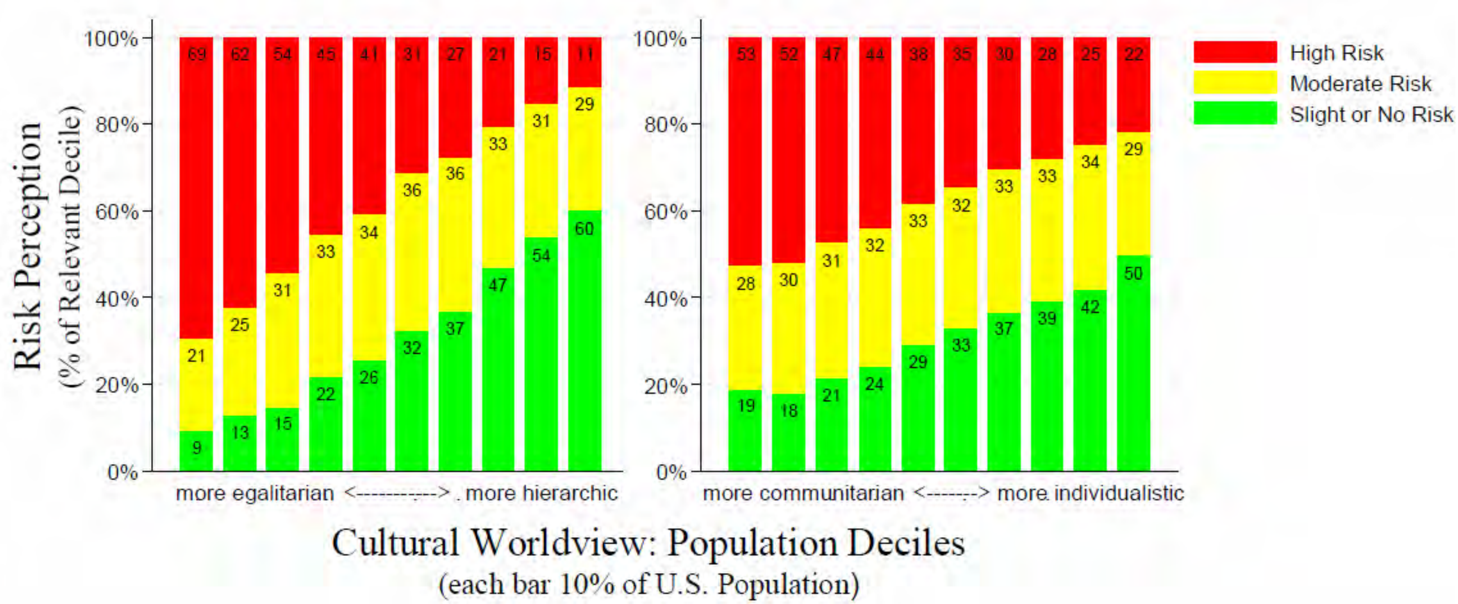
"Fossil fuels such as coal, natural gas, and oil are the leading cause of global warming," explained Dr. Jonathan Brautl, head of the Academy. "To reduce the volume of heat-trapping gas generated by such fuels, we strongly recommend broad scale commercial development of nuclear power, including the repeal of government regulations from the 1970s and 1980s that now discourage private investment in the nuclear industry." Brautl said.

The group's recommendation was made in a report that examined the extent and causes of global warming and the likely consequences that would occur if global warming were not reversed.

How much risk does global warming pose for people in our society?



Promising work

- Trophic level as biodiversity indicator—uncertainty in TLs
- Uncertainty in model-based simulations: qualitative results from quantitative inputs
- Indicator performance testing and utility threshold estimation incorporating uncertainty

Ecosystem-based Management Indicators

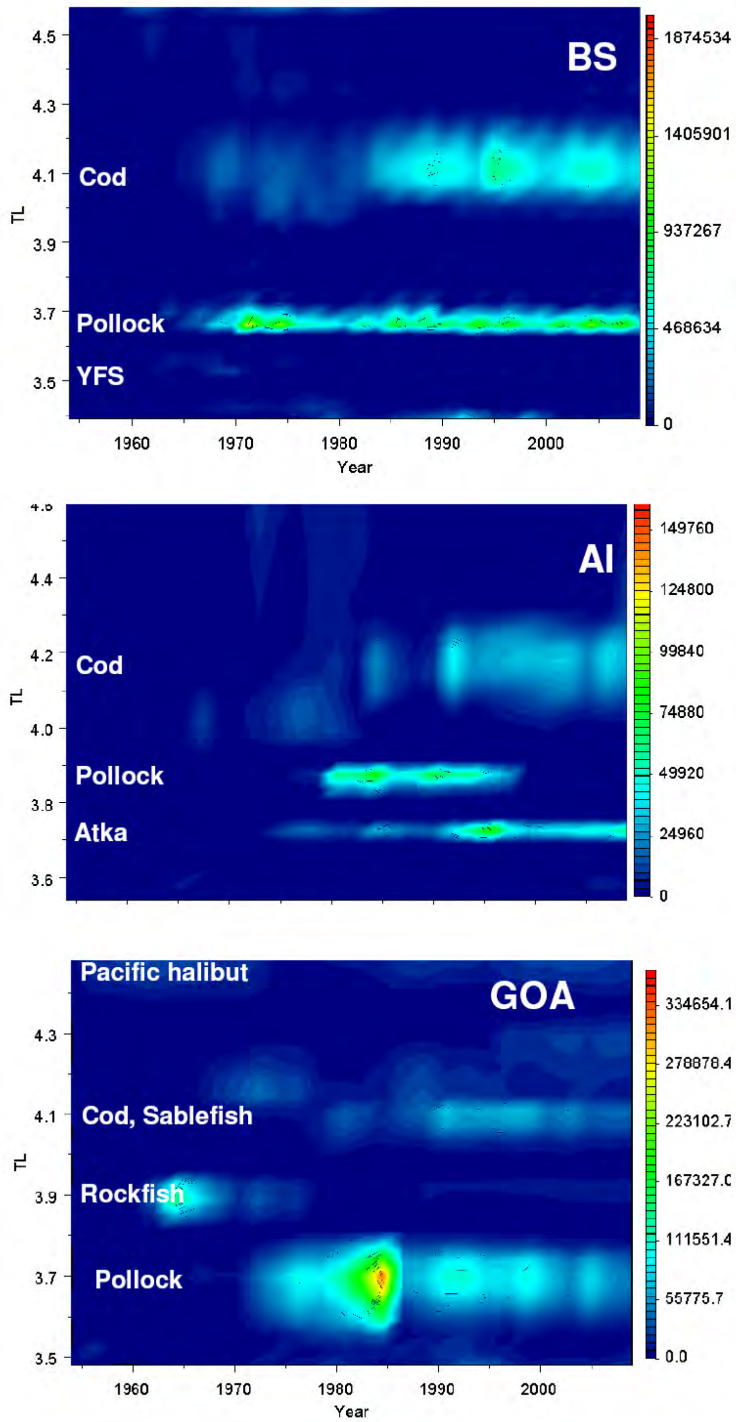
Trophic Level of the Catch (Livingston and Boldt 2010)

“Combination”:

Catch data with trophic levels from food web structural model. Presentation shows underlying process well:

- Fishing events episodic in AI and GOA
- Pollock steadily dominates in EBS

Uncertainty?



Uncertainty in trophic levels? (Branch et al.)

$$T_i = 1 + \sum_{j=1}^{N_p} p_{ij} T_j$$

Trophic level definition

$$MTI = \frac{\sum_i C_{y,i} T_i}{\sum_i C_{y,i}}$$

Marine Trophic Index

$$OI_i = \sum_{j=1}^{N_p} p_{ij} \left(T_j - \bar{T}_j \right)^2, \qquad \bar{T}_j = \sum_{j=1}^{N_p} p_{ij} T_j$$

Old SEs in FishBase

$$SE(T_i) = \sqrt{OI_i}$$

Slide courtesy T. Branch

Stats consulting: Roopesh Ranjan

$$\text{var}(T_i) = \text{var}\left(1 + \sum_{j=1}^{N_p} p_{ij} T_j\right) = \text{var}\left(\sum_{j=1}^{N_p} p_{ij} T_j\right)$$

Ranjan Wizardry

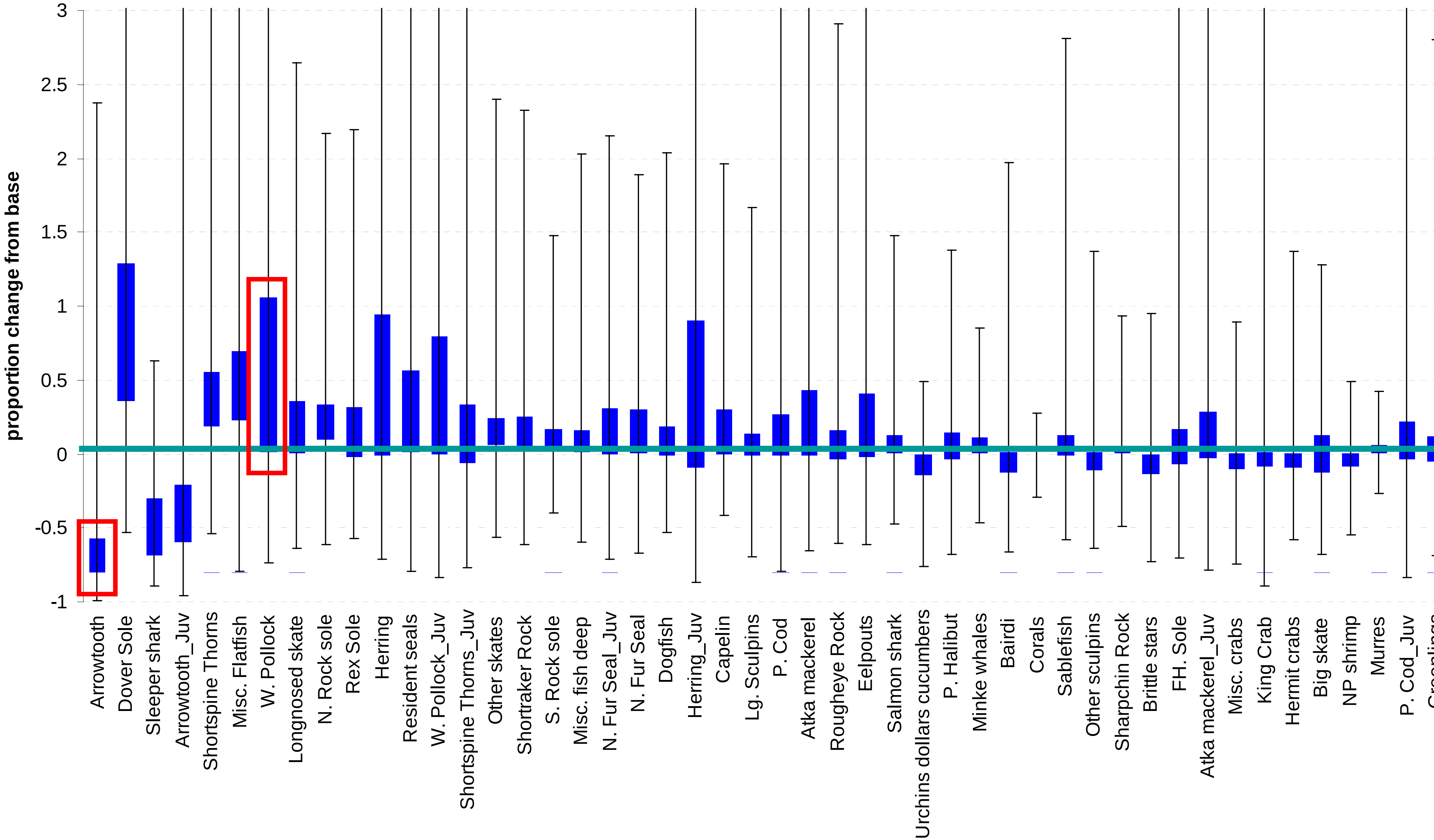
$$\text{SE}(T_i) = \sqrt{\text{var}(T_i)} = \sqrt{\sum_{j=1}^{N_p}\left[\frac{p_{ij}(1-p_{ij})\sigma_j^2}{N_s} + \frac{p_{ij}\mu_j^2}{N_s} + p_{ij}^2\sigma_j^2\right] - \frac{1}{N_s}\left(\sum_{j=1}^{N_p} p_{ij}\mu_j\right)^2}$$

where N_p is the number of prey, N_s is the number of predator i stomachs sampled, p_{ij} is the proportion of prey j in the diet of predator i, μ_j is the mean trophic level of prey j, and σ_j is the standard error of the trophic level of prey j

As $N_s \rightarrow \infty$ $\qquad \text{SE}(T_i) = \sqrt{\sum_{j=1}^{N_p} p_{ij}^2 \sigma_j^2}$

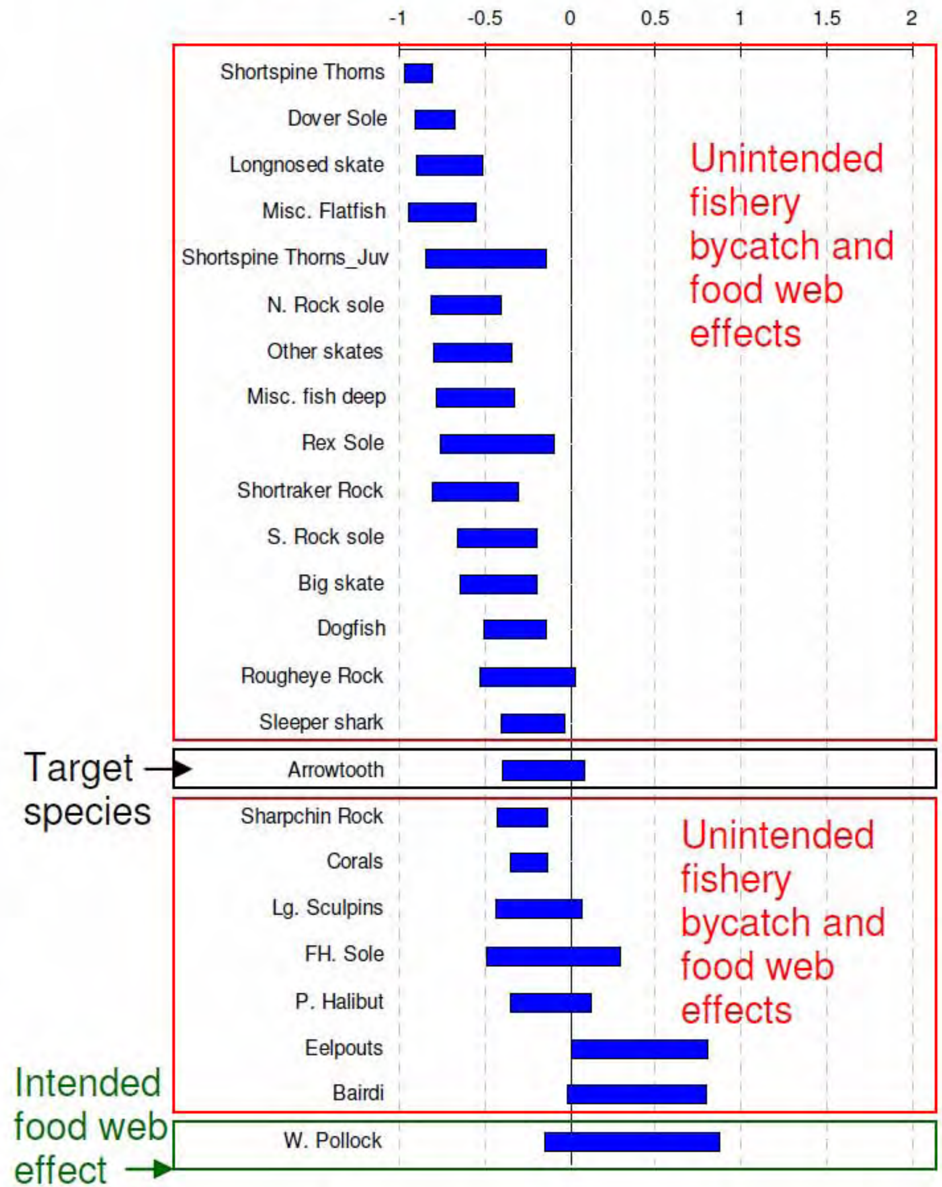
Slide courtesy T. Branch

Qualitative results from quantitative model simulations



Target F only simulation

Fishery effort simulation



Adopt standard qualitative terminology?

The standard terms used in the IPCC report to define the likelihood of a modeled outcome or result where this can be estimated probabilistically. (Adapted from Le Treut et al. 2007).

Likelihood Terminology	Likelihood of the outcome
Virtually certain	> 99% probability
Extremely likely	> 95% probability
Very likely	> 90% probability
Likely	> 66% probability
More likely than not	> 50% probability
About as likely as not	33 to 66% probability
Unlikely	< 33% probability
Very unlikely	< 10% probability
Extremely unlikely	< 5% probability
Exceptionally unlikely	< 1% probability

From Link et al. in review

Utility thresholds (Samhouri et al. 2010 PLoS ONE)

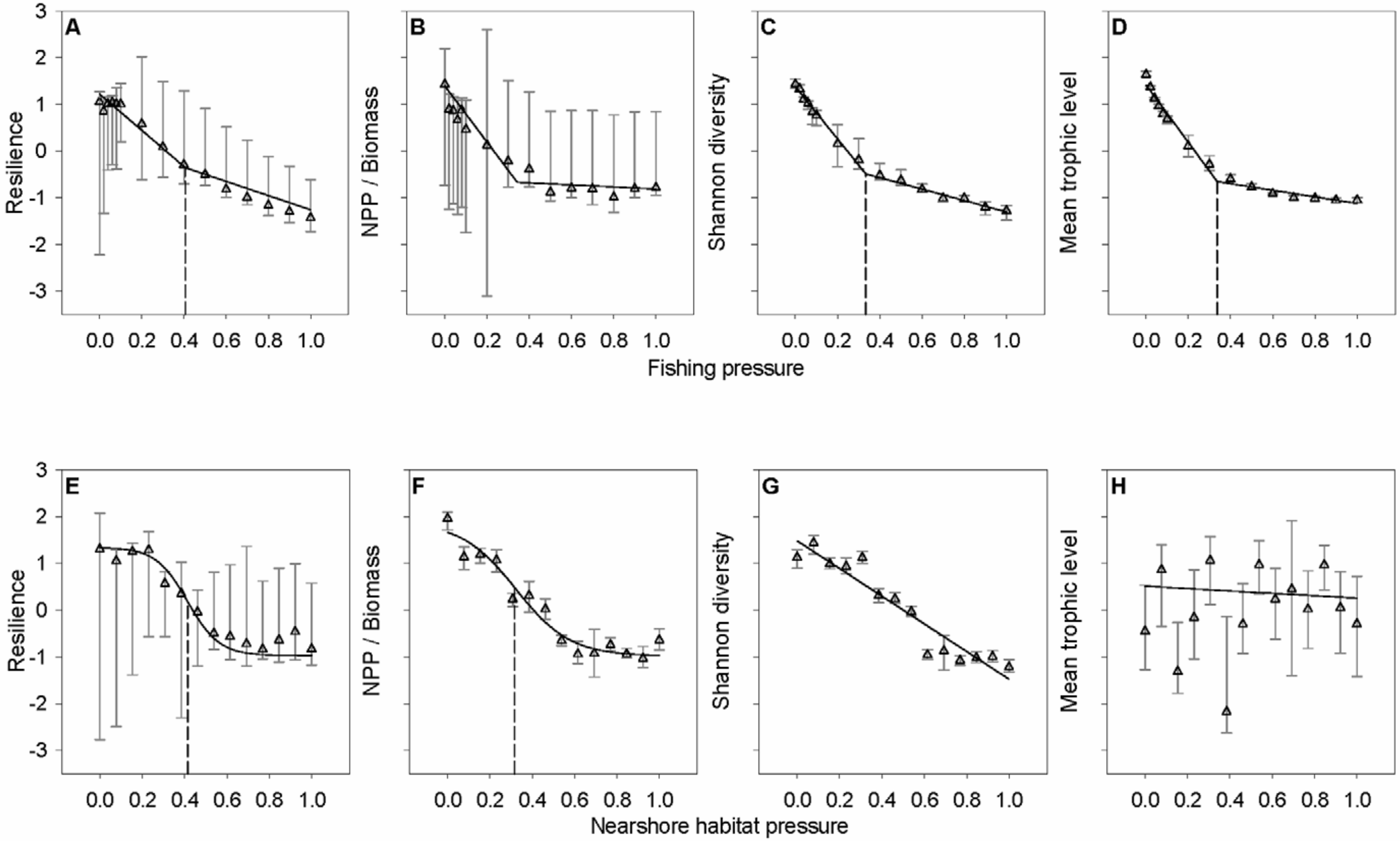


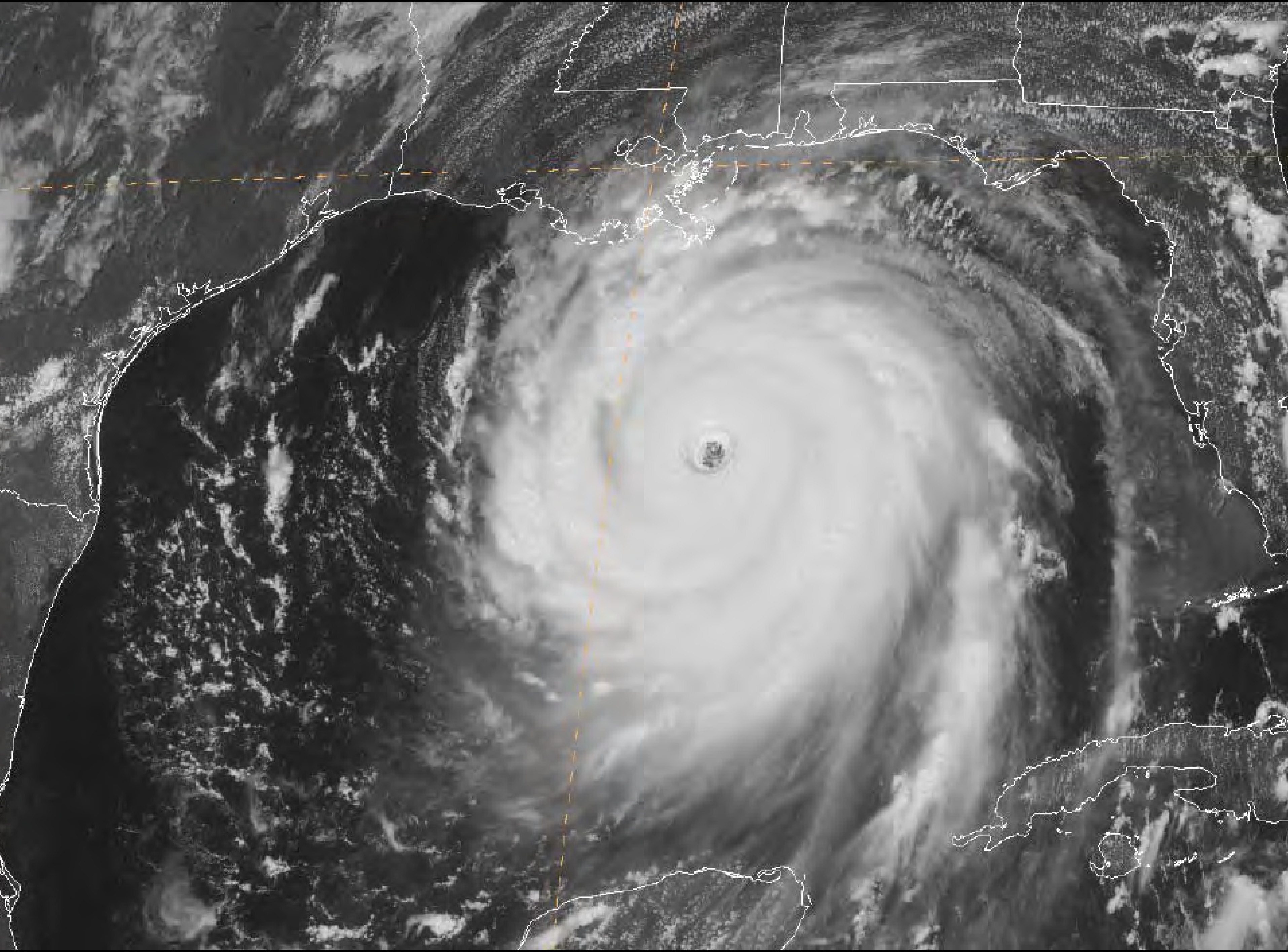
Figure 2. Model-generated relationships between 4 ecosystem attributes and increasing ecosystem-wide fishing (a-d) or nearshore habitat (e-h) pressure. Open triangles indicate median values calculated from Monte Carlo simulated Ecopath with Ecosim data (n = 100), and error bars denote 95% confidence intervals. The solid lines represent best-fit functional relationships and the dotted lines designate significant utility thresholds estimated using a nonparametric bootstrap resampling procedure (n = 10,000 for each Monte Carlo data set) (parameter values and significant utility thresholds listed in Table 2). In this and following figures, the ecosystem attributes (y-axes) have been re-scaled so that larger values are considered unstressed rather than stressed. The pressure values have been re-scaled relative to the maximum simulated pressure, and are contained within the range [0, 1].

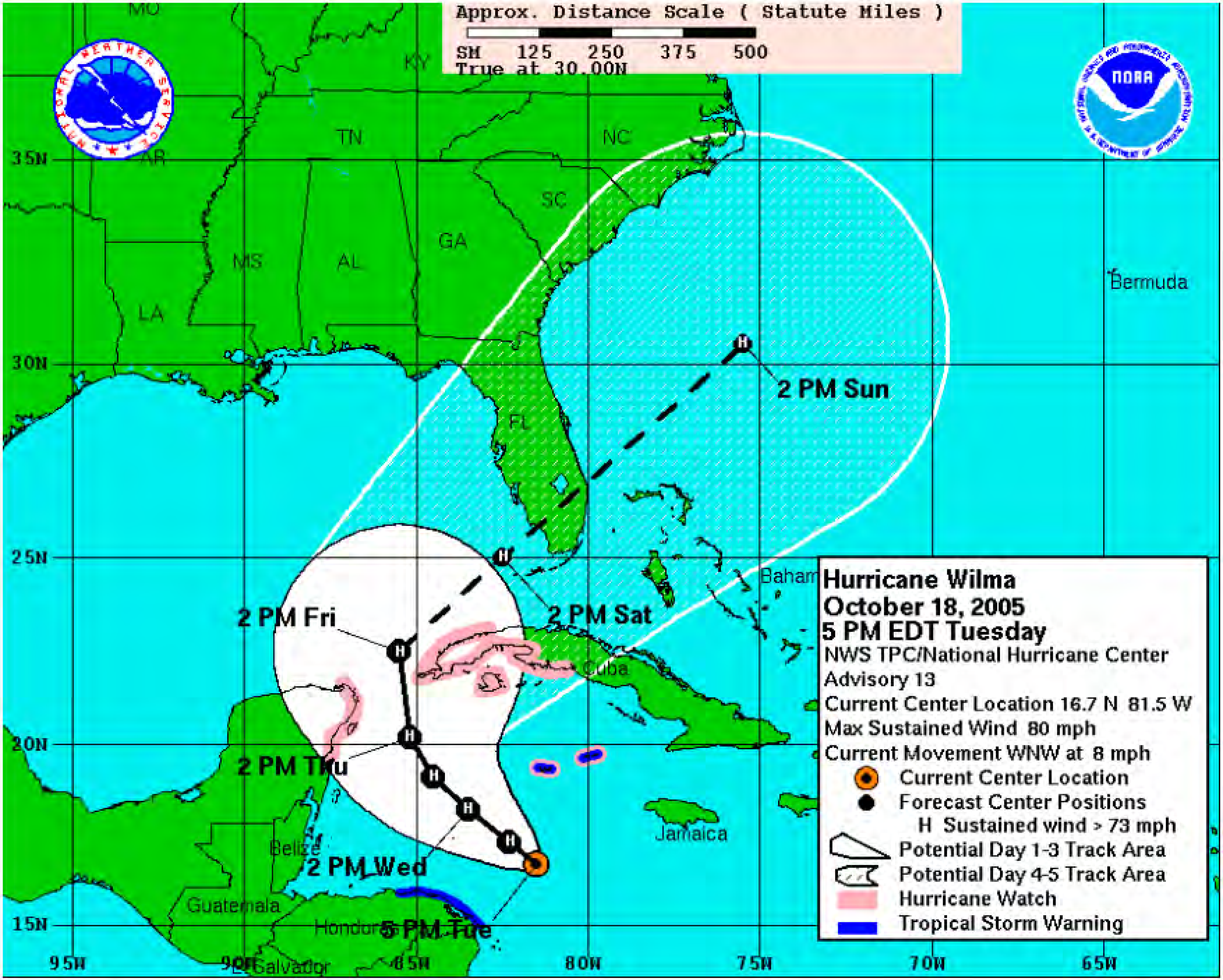
FUTURE needs?

- Indicator developers: include uncertainty
- Threshold developers: include risk tolerance levels
- All of us:
  - improve indicator specificity through communication
  - clarify management objectives with stakeholders
  - identify when and how to present uncertainty

"The future is uncertain… but this uncertainty is at the very heart of human creativity."

Ilya Prigogine, Belgian-US (Russian-born) chemist & physicist (1917 -)




Approx. Distance Scale (Statute Miles)
SM 125 250 375 500
True at 30.00N
Hurricane Wilma
October 18, 2005
5 PM EDT Tuesday
NWS TPC/National Hurricane Center
Advisory 13
Current Center Location 16.7 N 81.5 W
Max Sustained Wind 80 mph
Current Movement WNW at 8 mph
Current Center Location
Forecast Center Positions
H Sustained wind > 73 mph
Potential Day 1-3 Track Area
Potential Day 4-5 Track Area
Hurricane Watch
Tropical Storm Warning
2 PM Sun
2 PM Sat
2 PM Fri
2 PM Thu
2 PM Wed
5 PM Tue
MO
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TN
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Cuba
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