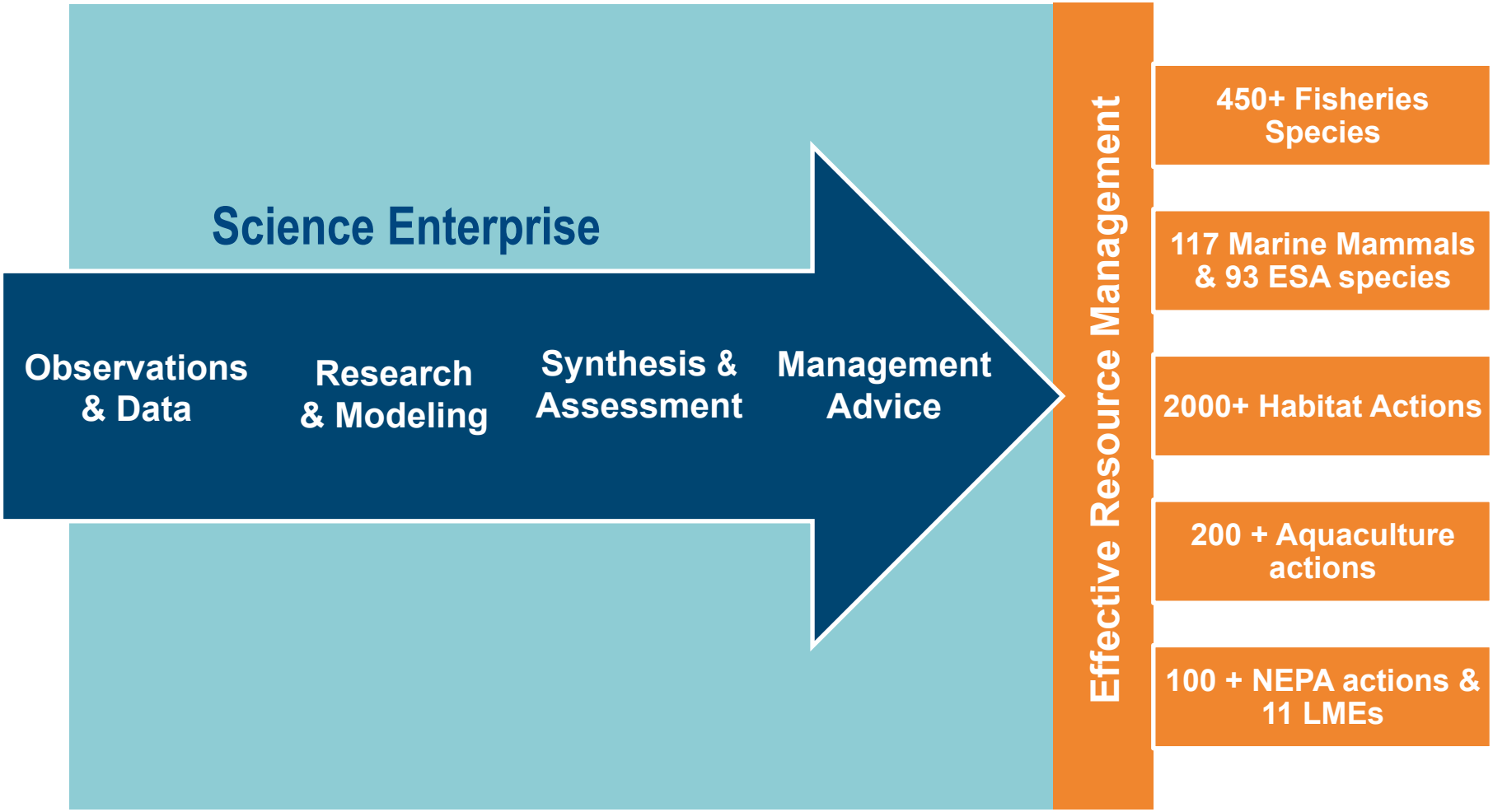
Incorporating climate into ecosystem-based fishery management

Sarah Gaichas
Jason Link
NMFS

Application of Seasonal to Decadal Climate Predictions for Marine Resource Management Workshop
Princeton, NJ

June 3, 2015

Context: Management decisions made now



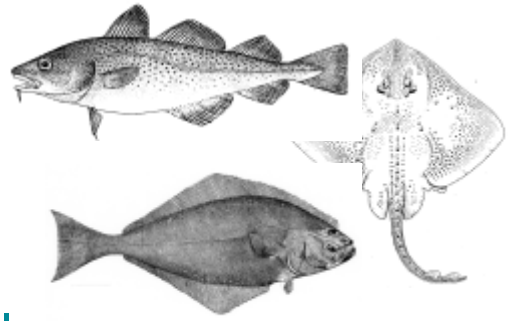
A spectrum of tools, a spectrum of uses

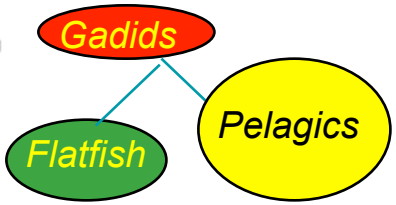
Stock/Single Species

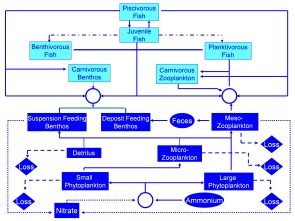
Multi-species

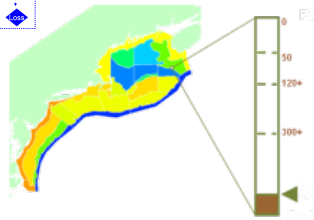
Aggregate Biomass

Ecosystem









Single stock models

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

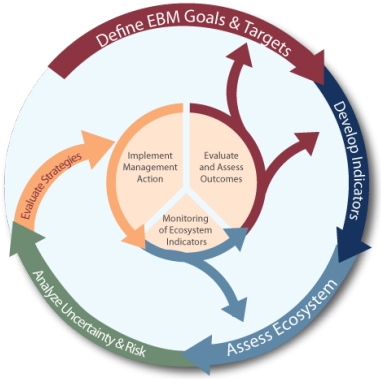
Multiple stock assessments in “harmony”

Multi-species assessments

Functional group models

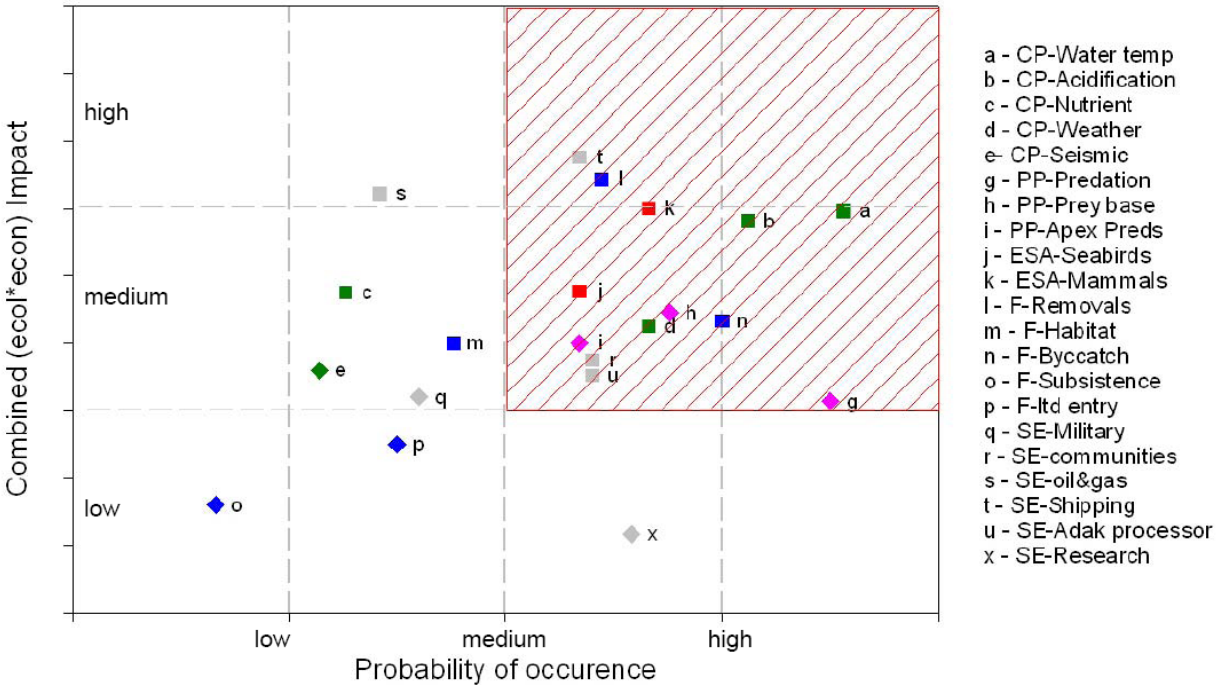
Integrated ecosystem assessments

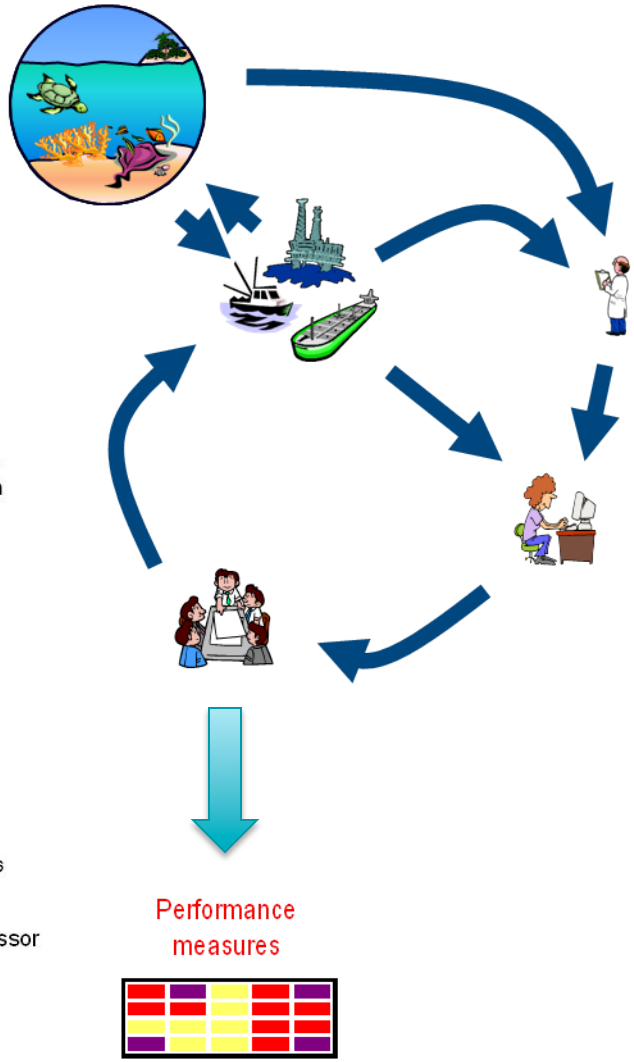
Whole system models



Powerful strategic tools

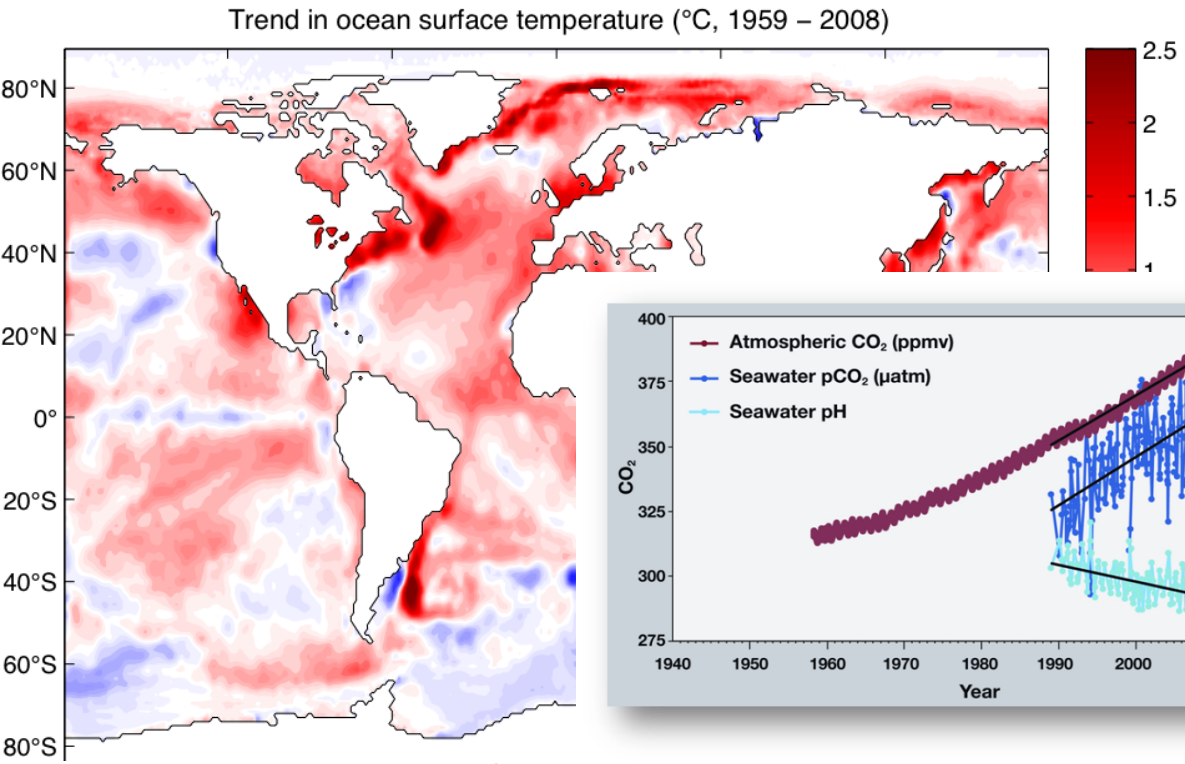
- Risk assessment methods
- Management strategy evaluation

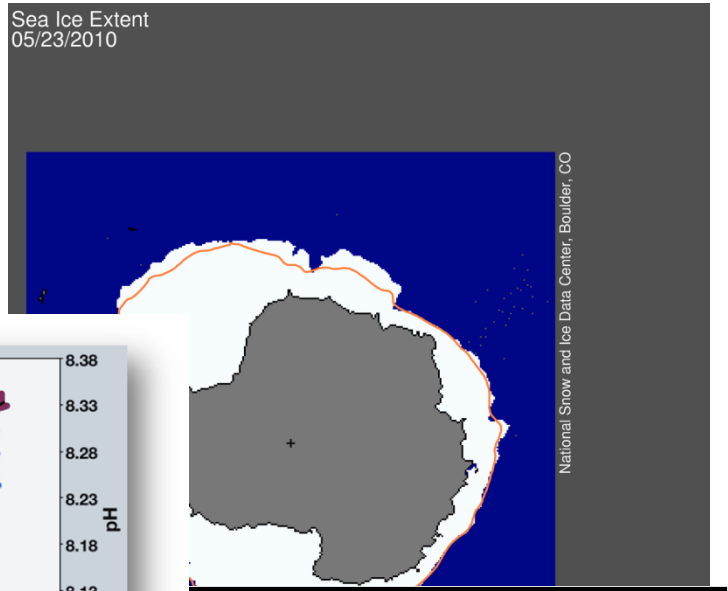


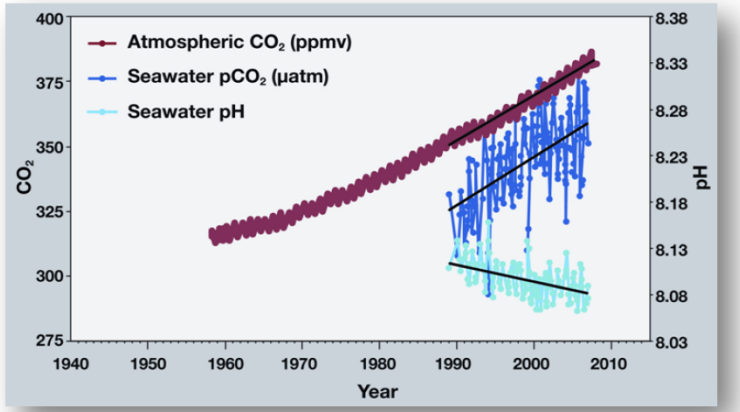


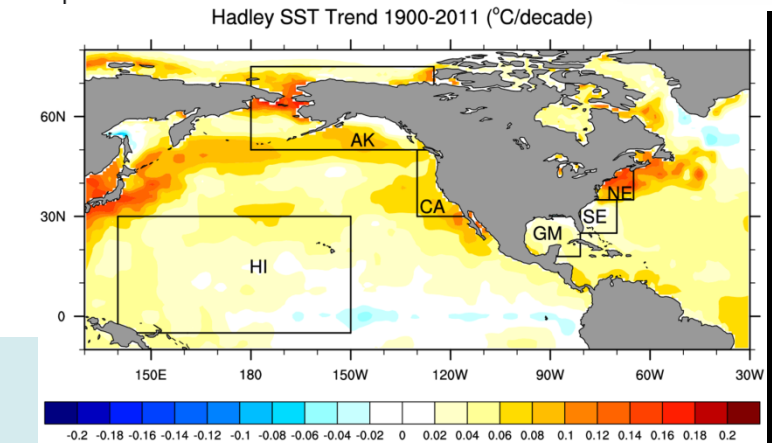
Redrawn with permission of Beth Fulton

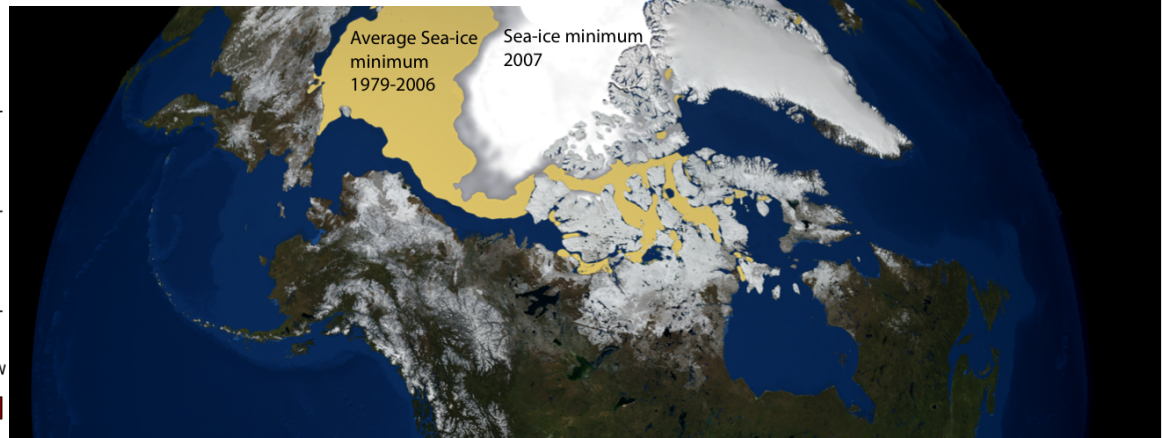
Climate Change Occurring in Global Ocean Systems



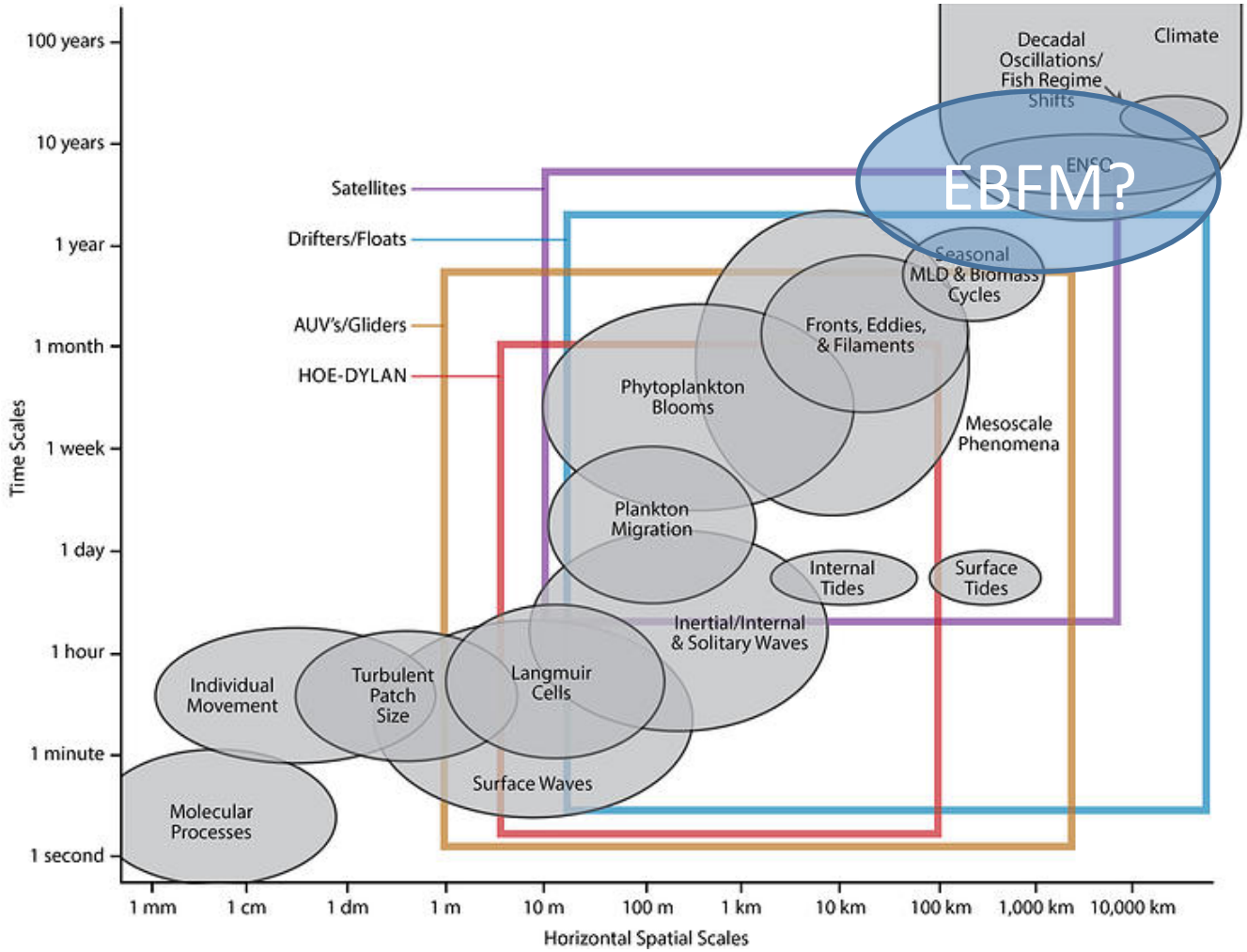








What scales are important for living marine resource management?

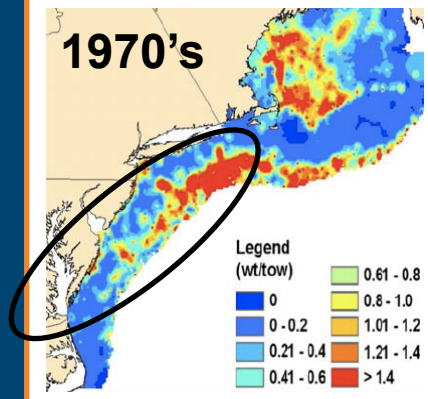


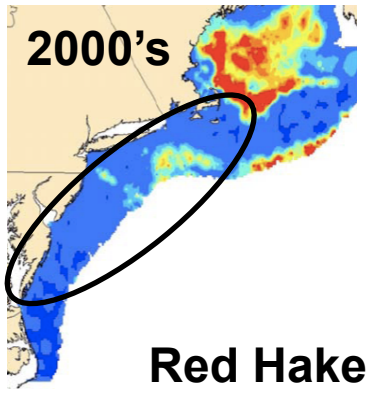
- Seasonal-decadal
- Large Marine Ecosystem (LME)
- Regional management (States-LMEs)
- Fish stock to community range
- Oceanographic features (boundary currents)
- Key habitats

Wilson and Karl 2013. Current - the Journal of Marine Education. 28: 20-21.

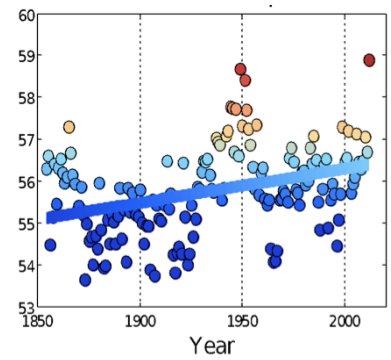
Key Information Requirements

WHAT IS CHANGING?

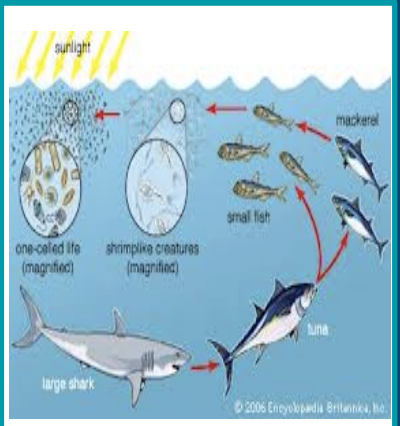




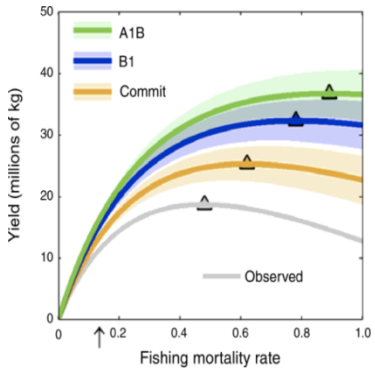
WHY IS IT CHANGING?



West Atlantic SST



HOW WILL IT CHANGE?



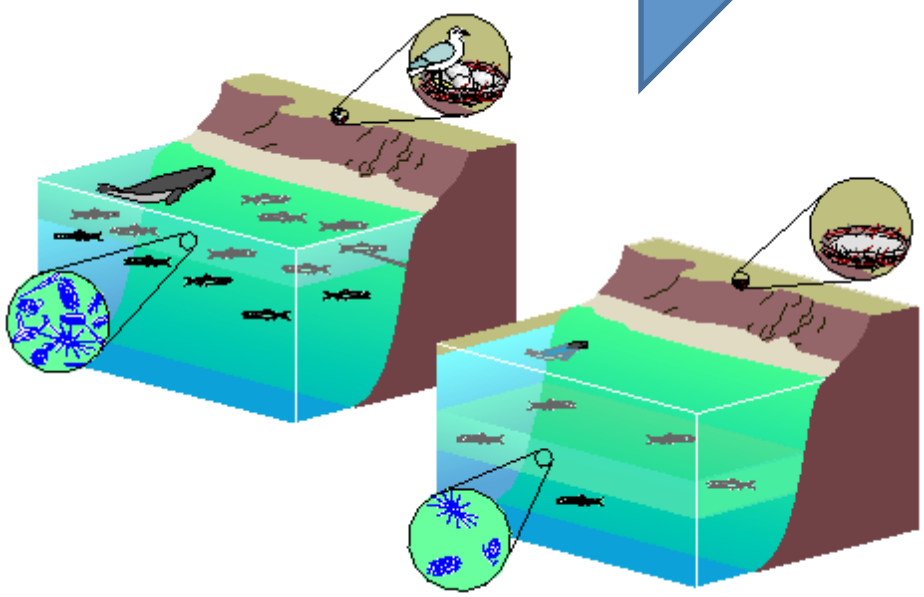
HOW TO RESPOND?

Possible Impacts of a Changing Climate

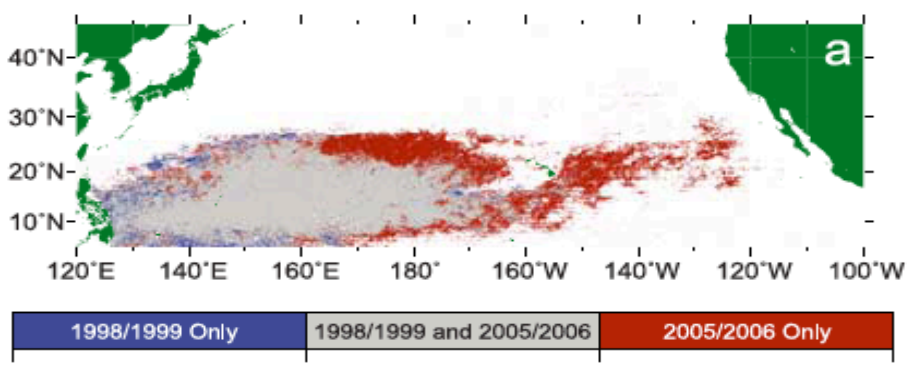
Climate Changes	Physical Chemical Impacts	Biological Impacts	Social Economic Impacts
↑ Temperature	↑ Ocean temperature	Δ Productivity	Δ Fishing activities
Δ Precipitation	↓ Sea ice	Δ Phenology & survivorship	Δ Revenues & economies
↑ Atmospheric Carbon Dioxide	↑ Sea level	Δ Species distribution	Δ Industries
	Δ Freshwater	Δ Species abundance	Δ Subsistence use
	↑ Ocean Acidification	Δ Community composition	Δ Community health

Changing productivity

Physical and fluid habitat change
Thermal conditions
pH conditions



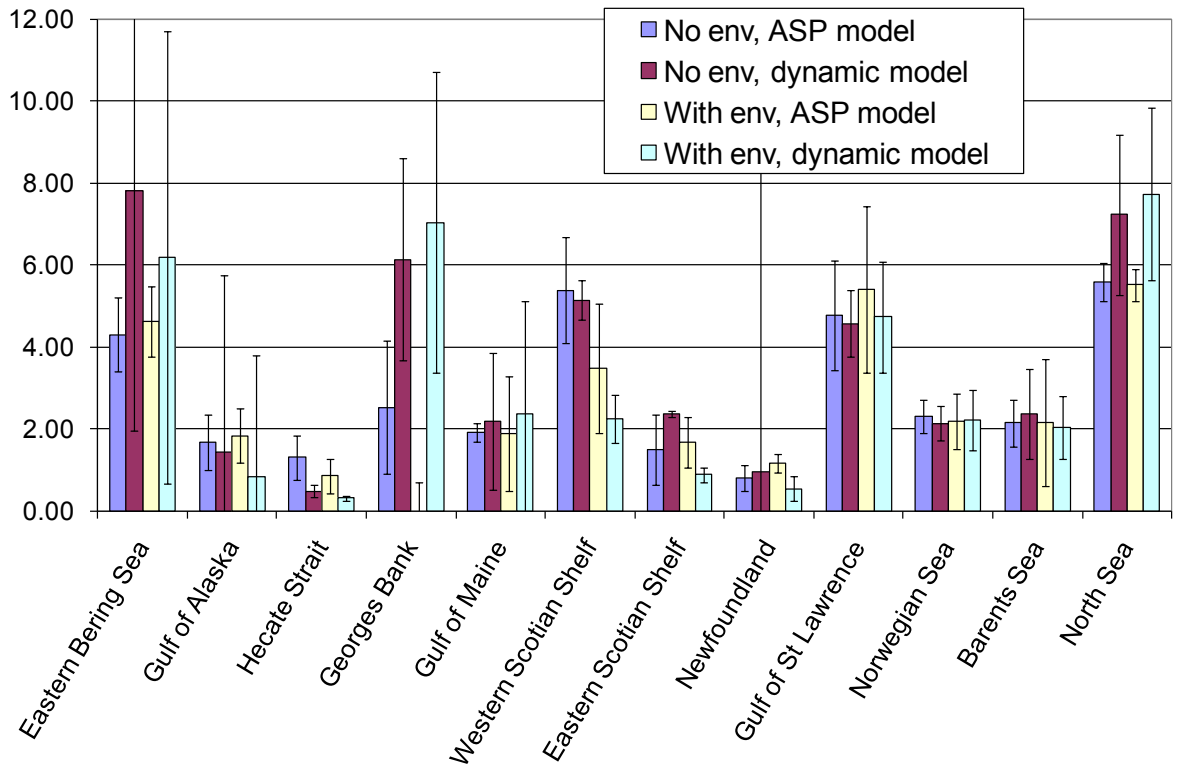
- Full ecosystem level
- Community level
- Species level
- Identify:
  - Production regimes
  - Production potential



Polovina et al. 2008 Geophys Res Lett

Modeling: total system production

- Total system MSY averages ~1-5 t km^{-2} yr^{-1}
  - May be a fundamental feature of marine ecosystems
  - Holds across multiple models for 12+ ecosystems
- B_{MSY}, or B tot, or B by group also in similar ranges (5-20) of t km^{-2}



Bundy et al. 2012 MEPS

Modeling: environmental covariates

- Including environmental covariates improved model fits—fundamental feature—but impact differs by system
- Different covariates important in different systems
- Magnitude of response also varies, but direction often lowers MSY

System	MSY w/o Cov (mt/km^2)	MSY w/ Cov (mt/km^2)
EBS	4.3	3.98
GOA	1.67	0.88
HS	1.3	0.04
GB	2.53	-
GOM	1.91	0.29
WSS	5.38	0.51
ESS	1.49	0.38
NL	0.81	0.9
GOSL	4.77	0.8
NS	2.31	3.19
BS	2.14	3.23
NORT	5.57	5.52

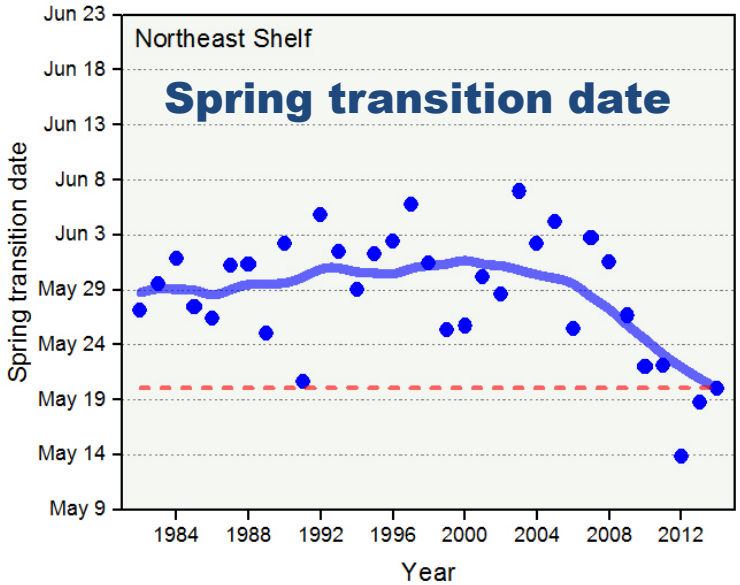
Bundy et al. 2012 and Holsman et al. 2012 MEPS

Changing phenology and survivorship

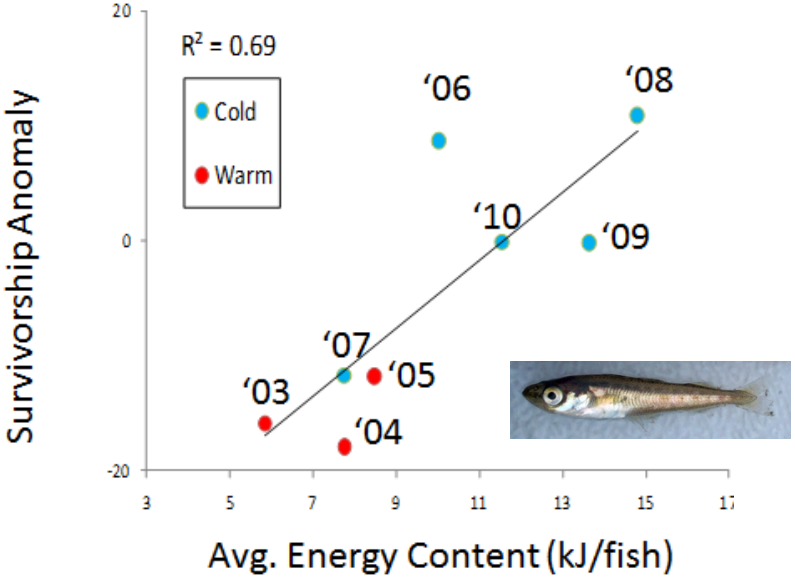
Thermal conditions
pH conditions

- Changes in phenology/timing
- Changes in physiology
- Impacts on vital rates
  - Consumption, Growth
  - Maturity, Reproduction
  - Survival/Mortality

Ecosystem Advisory
for the Northeast Shelf
Large Marine Ecosystem



http://www.nefsc.noaa.gov/ecosys/advisory/current/



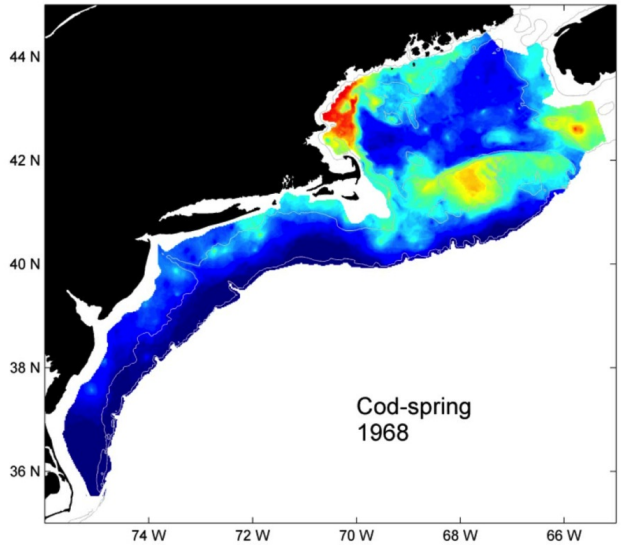
http://www.afsc.noaa.gov/Quarterly/amj2011/amj11divrpts.pdf

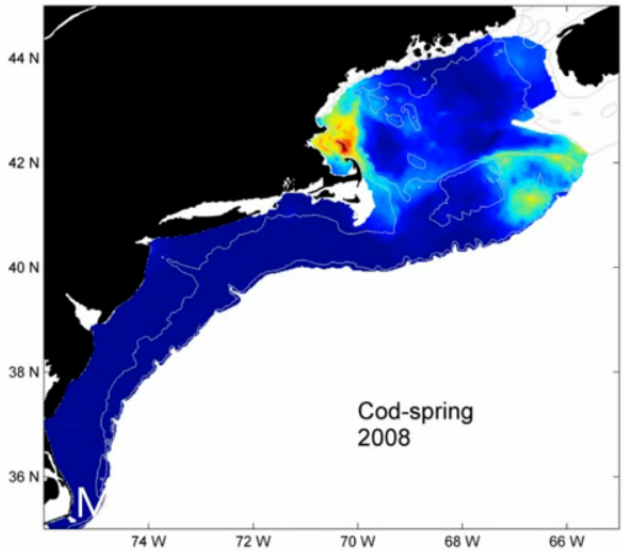
Changing species distributions

Thermal conditions
pH conditions
Ocean circulation
Large scale currents
Local hydrography

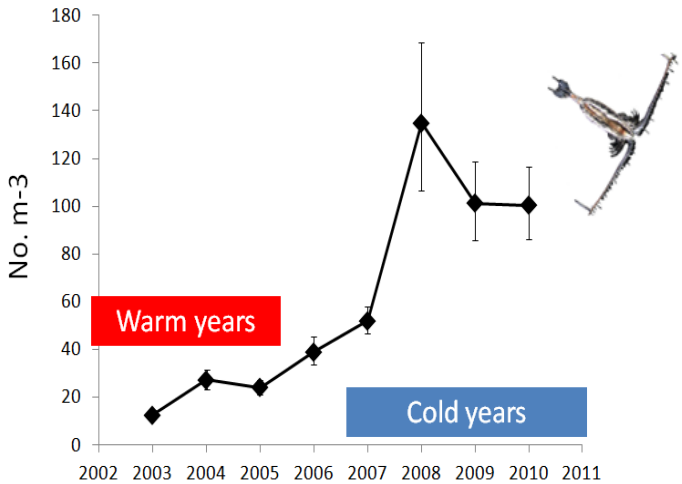
- Altered habitat
- Changes to
  - Seasonal migrations
  - Frontal aggregations
- Distributional shifts

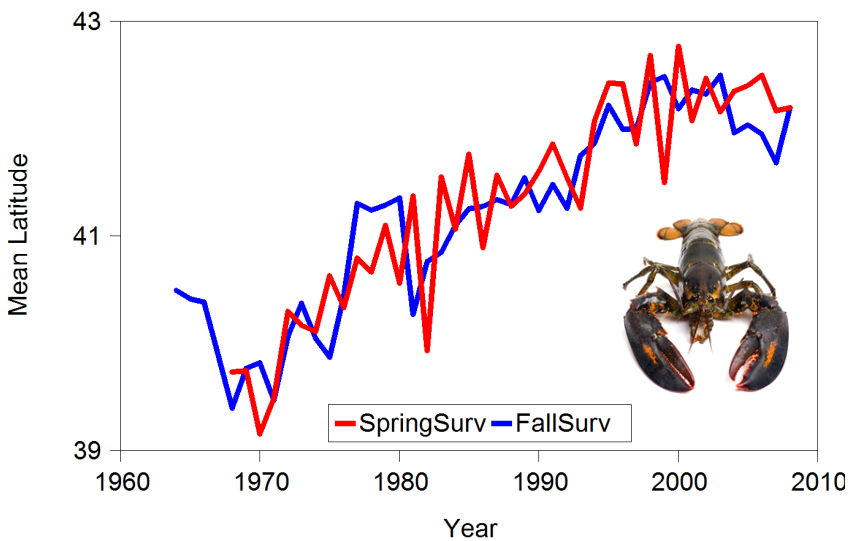
http://www.nefsc.noaa.gov/ecosys/climate_change/movie4.html





Changing species abundances

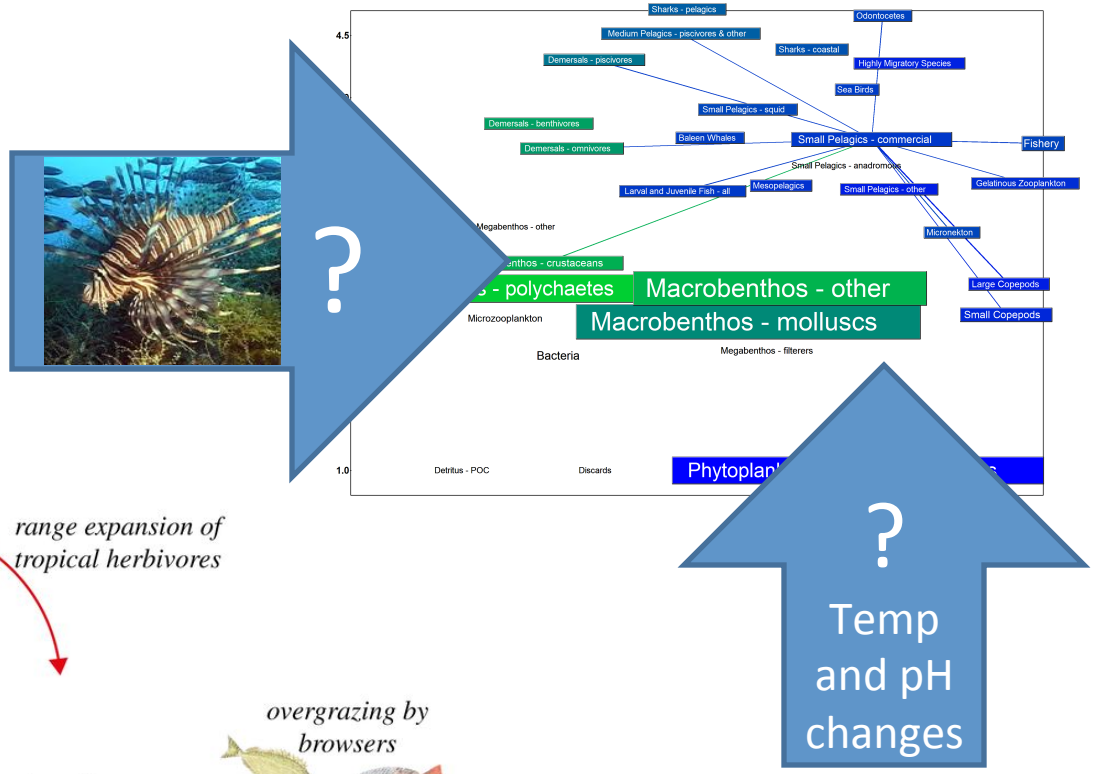


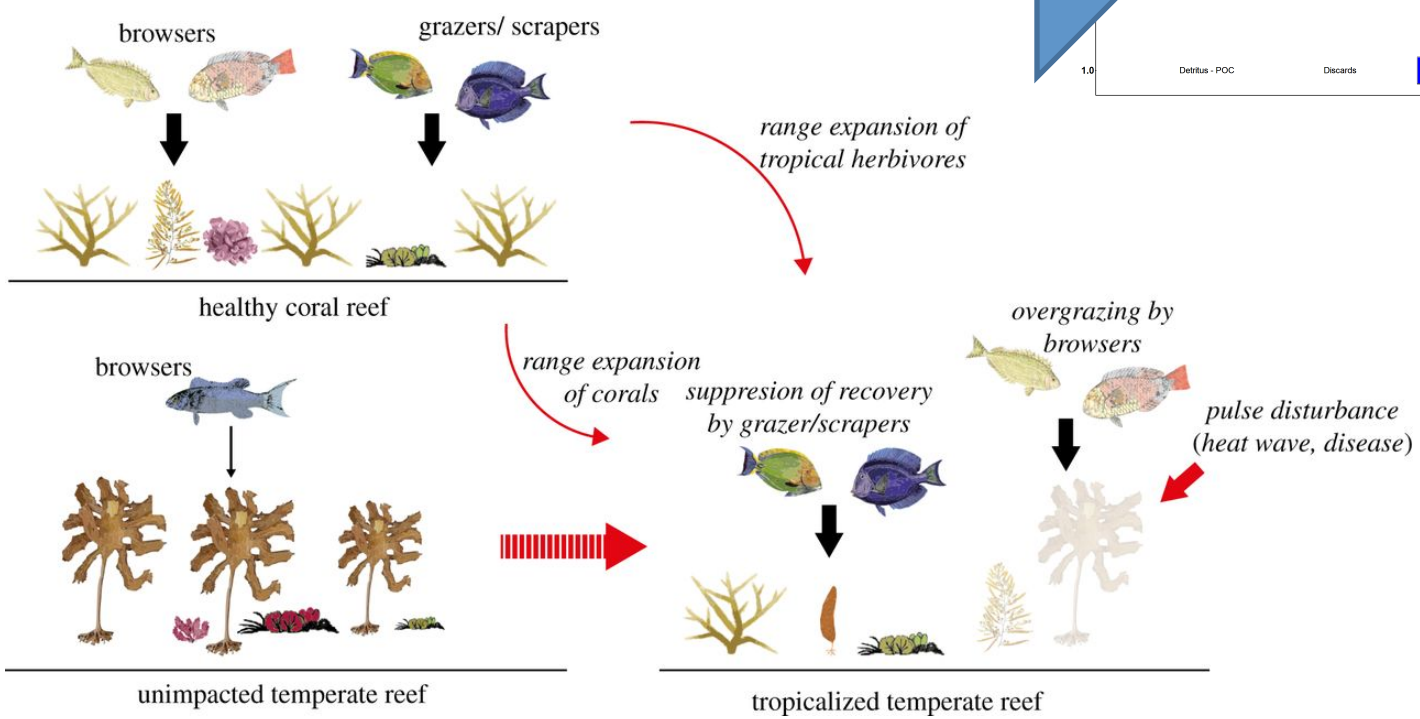


- Related to changes in
  - Productivity
  - Phenology/survivorship
  - Distributional shifts
- Related to ecological interactions (next slide)

Changing community composition

- Ecological interactions
- Invasives + range shifts
- Food webs



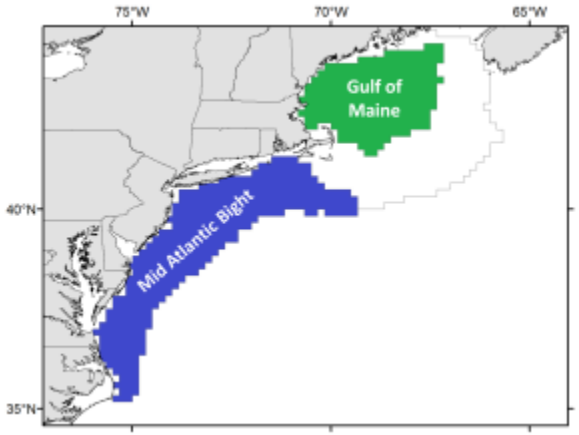


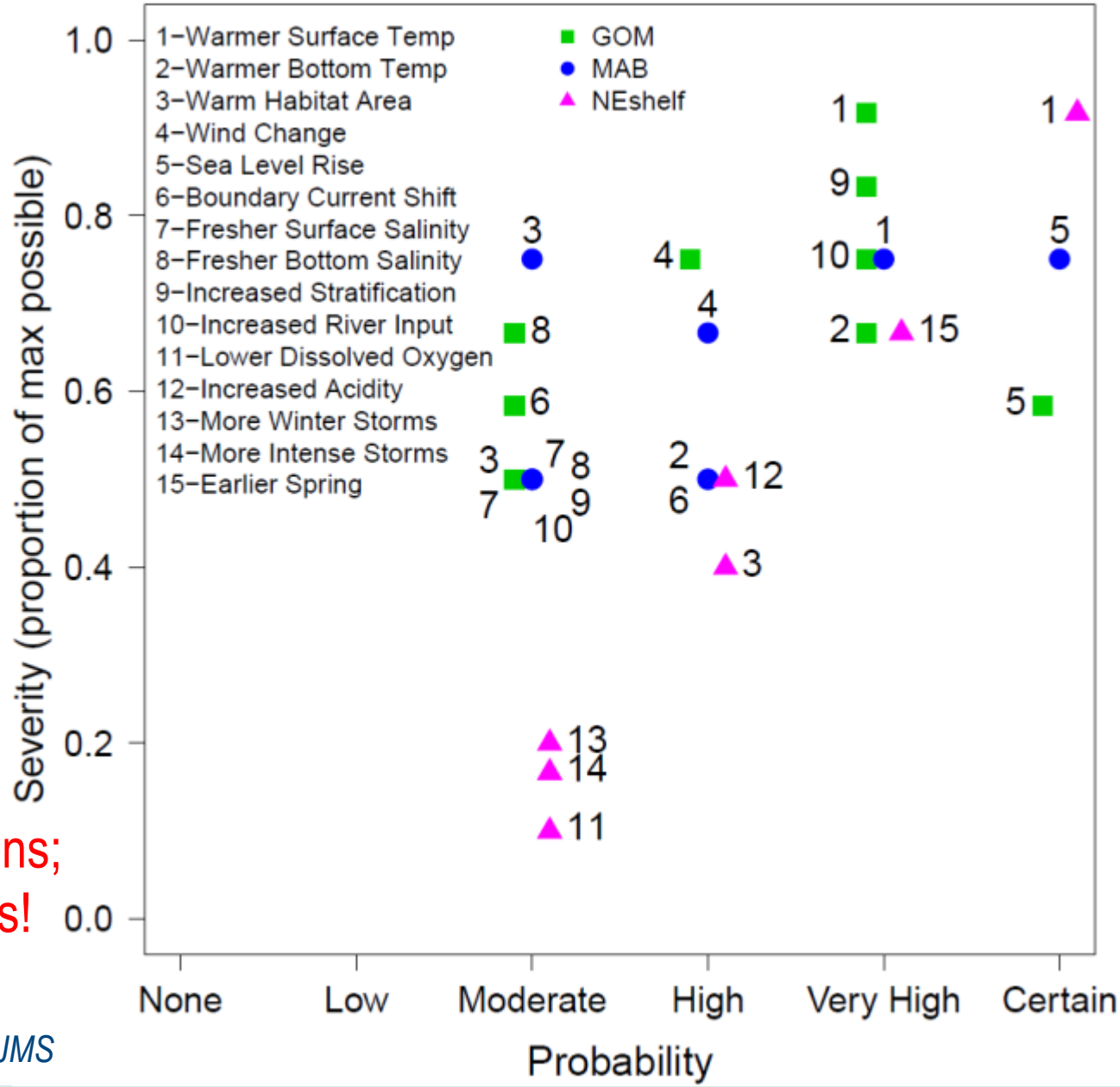
Verges et al., 2014. Proc. R. Soc. B 281: 20140846

Regional illustrations

Right here off this coast

Climate risks vary at the regional scale



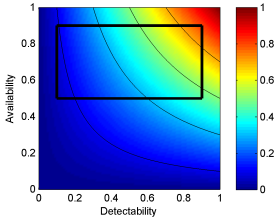


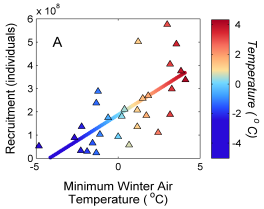
Derived from observations; need model projections!

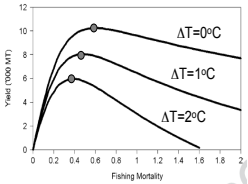
Gaichas, Link, and Hare 2014 ICES JMS

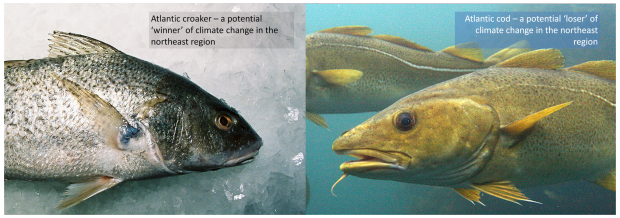
Examples of climate/environmental factors impacting stock assessments, Northeast US

- Butterfish & thermal, oceanographic habitat for environmentally driven survey catchability
- MA-SNE yellowtail flounder & cold pool volume for recruitment
- Northern shrimp & thermal considerations for distribution and productivity
- Atlantic croaker & thermal relationship to recruitment, productivity and projected distribution
- Atlantic cod & thermal relationship to recruitment, productivity and projected distribution
- Cusk & thermal and habitat features for distribution
- Distribution change noted for 30+ spp., but not yet incorporated into models
- Does not include ecological interaction examples









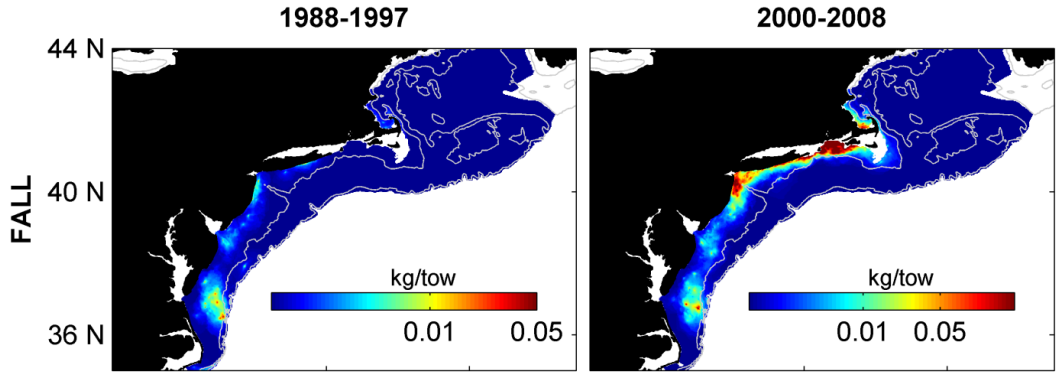
Environment → multispecies assessment models

- Covariate on process(es)
  - Growth
  - Mortality
  - Recruitment

$$l_{i,k,a,t} = \psi_{i,k} a_{i,k}^{\kappa_{i,k}} e^{\sum \phi_{p,k} X_{p,k,t}}$$

$$N_{i,1,k,t} = \alpha_{i,k} E^{\gamma_{i,k}}{}_{i,k,t-r} e^{-\beta_{i,k} E_{i,k,t-r} + \sum \zeta_{pk} X_p}$$

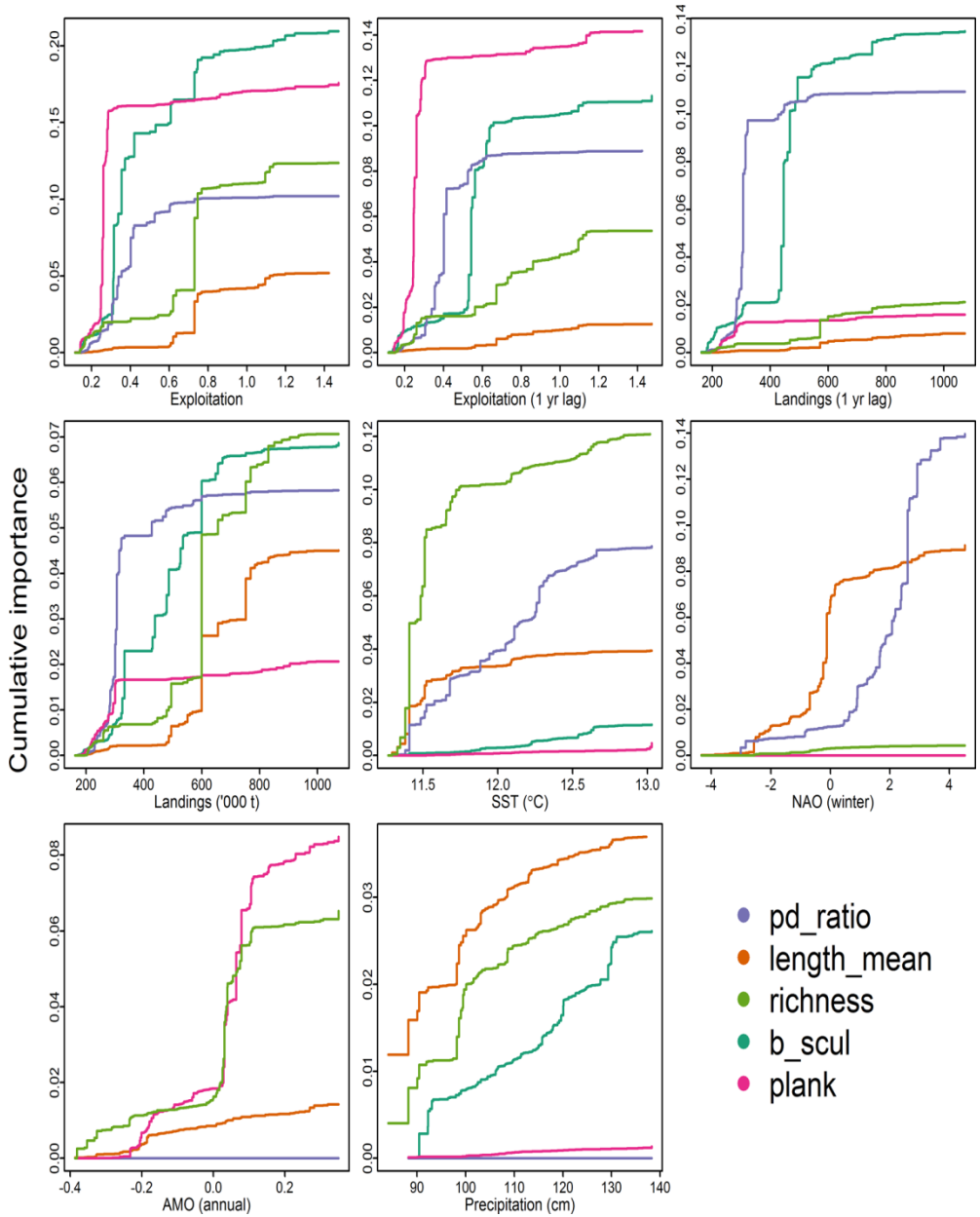
- Shifts in distribution or overlap



Black sea bass distribution

Full system responses to climate and fishing

- Energy flow indicators most sensitive to fishing
- Diversity most sensitive to SST and precipitation
- Potential ecosystem level thresholds related to climate and fishing



PLOS | ONE

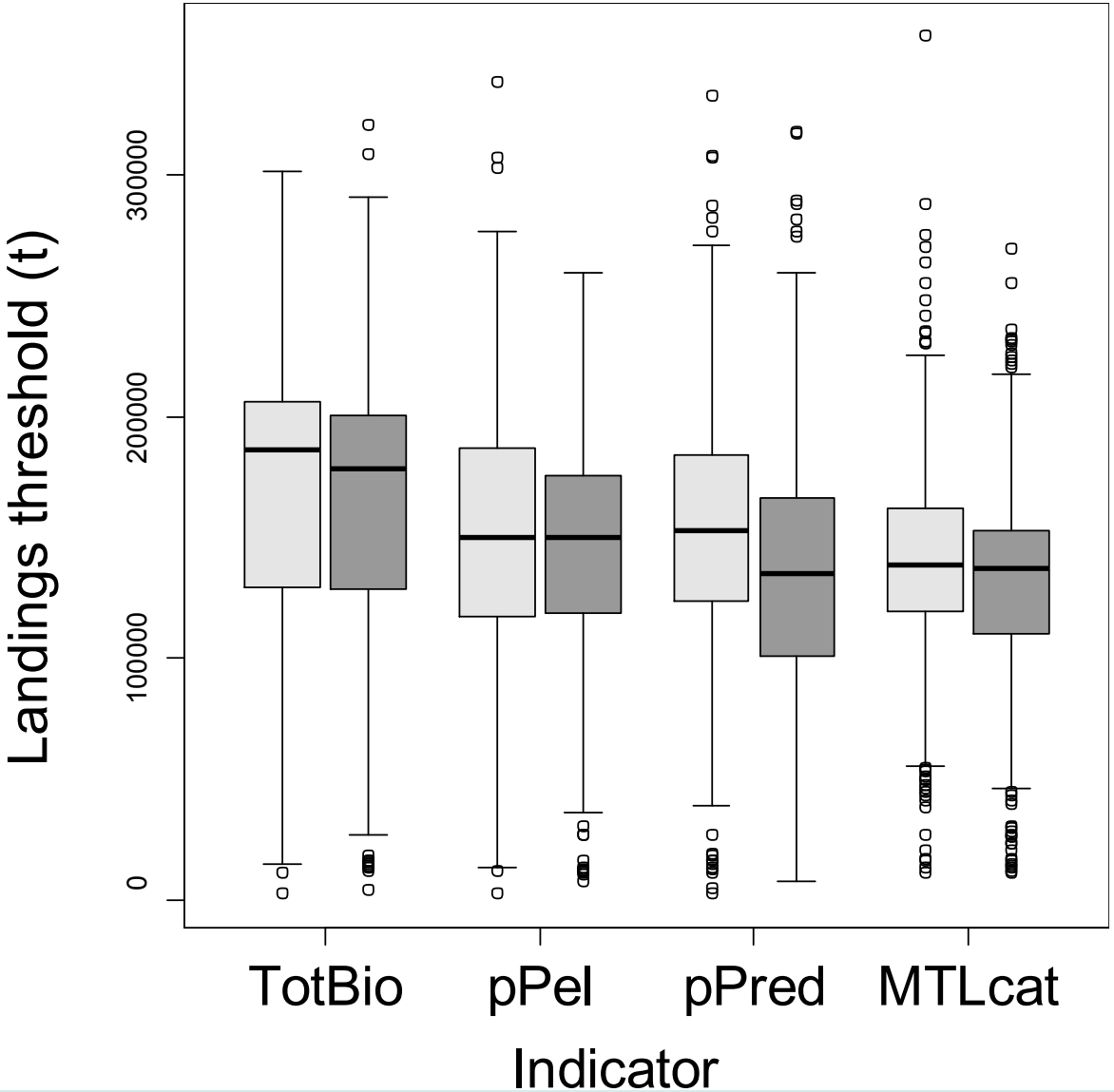
RESEARCH ARTICLE

Quantifying Patterns of Change in Marine Ecosystem Response to Multiple Pressures

Scott I. Large[1¤a]*, Gavin Fay[1¤b], Kevin D. Friedland[2], Jason S. Link[1]

PLOS ONE | DOI:10.1371/journal.pone.0119922 March 17, 2015

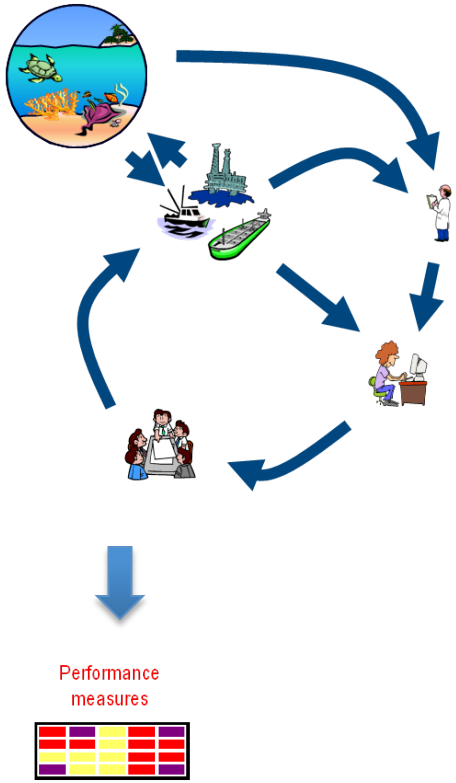
Sensitivity of thresholds to climate impact

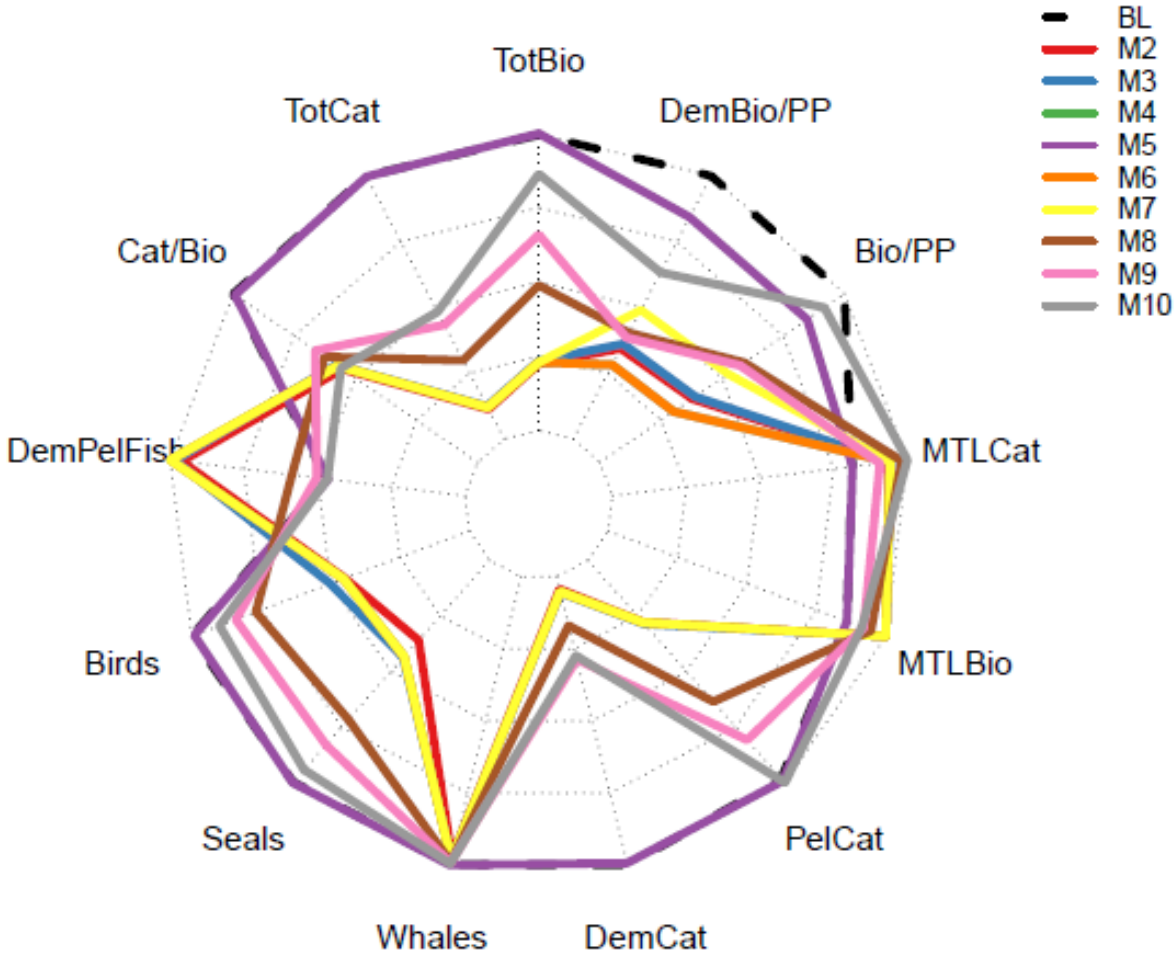


- Reduction in groundfish growth rate.
- Thresholds of response to fishing can be dependent on other system drivers.

Slide courtesy Gavin Fay

Full system climate impacts MSE





Fay, G., J.S. Link, and J.A. Hare. In Review. Assessing the effects of ocean acidification in the Northeast US using an end-to-end marine ecosystem model. Marine Ecology Progress Series.

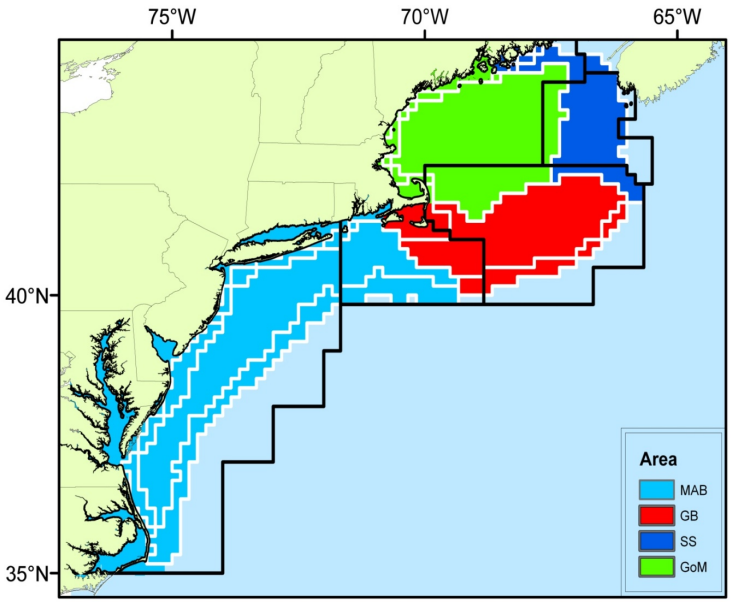
We are moving beyond previously observed ranges

NEED climate forecasts to model system responses and adjust management for the unknown

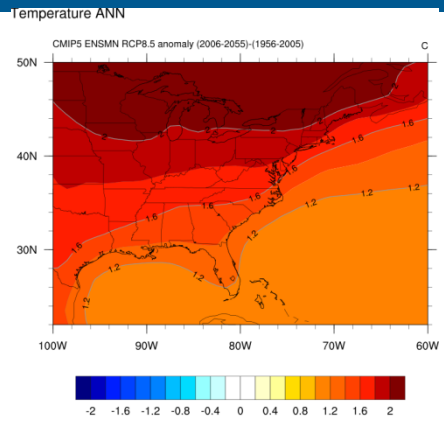
Environmental data/forecast needs: Northeast US

Assessment models (empirical, production, size/age structured)
(annual/seasonal and regional/ecological production unit scales)

- Surface Temperature
- Bottom Temperature
- Some index of stratification
- Surface Salinity
- Bottom Salinity
- Primary Production
- Chlorophyll Concentration
- Timing of Spring Bloom
- NAO
- AMO
- Gulf Stream North Wall Index
- Suitable habitat indices (percentages over time? - can include pelagic information)
- Other influential indicators (from individual metabolism to ecosystem production)



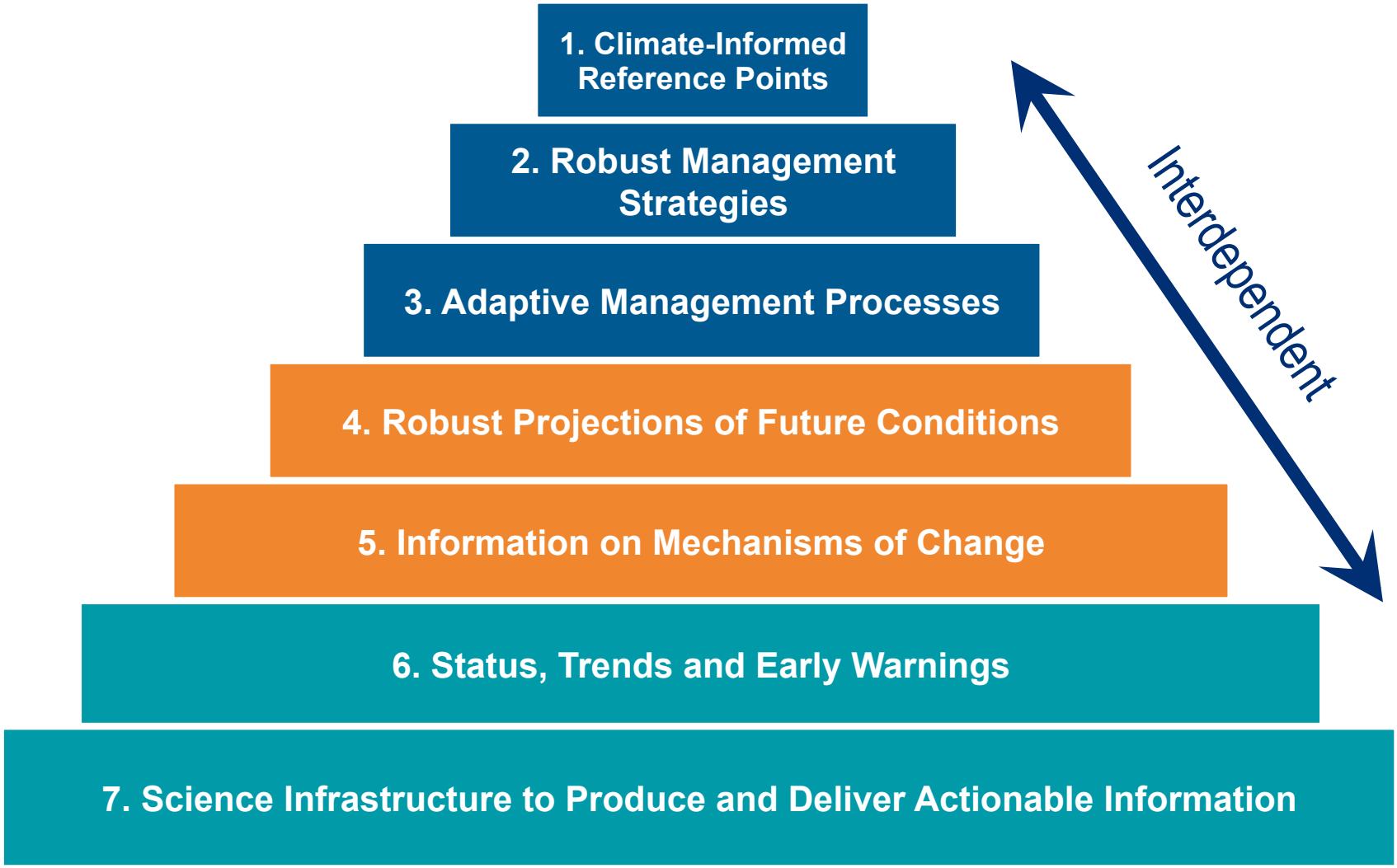
Where to go from here?



- Many general climate indices already available
- Need to adjust reference points and advice at all levels
  - Single stock → Multispecies → Ecosystem
  - Local communities → Regional economy → National policy
- Develop or improve
  - Dynamic reference points
  - Adaptive spatial management
  - Management coordination between regions

- Key will be: downscaling predictions from climate models
- AND continued monitoring

National Climate Science Strategy objectives



Thank you