Addressing uncertainty in living marine resource modeling

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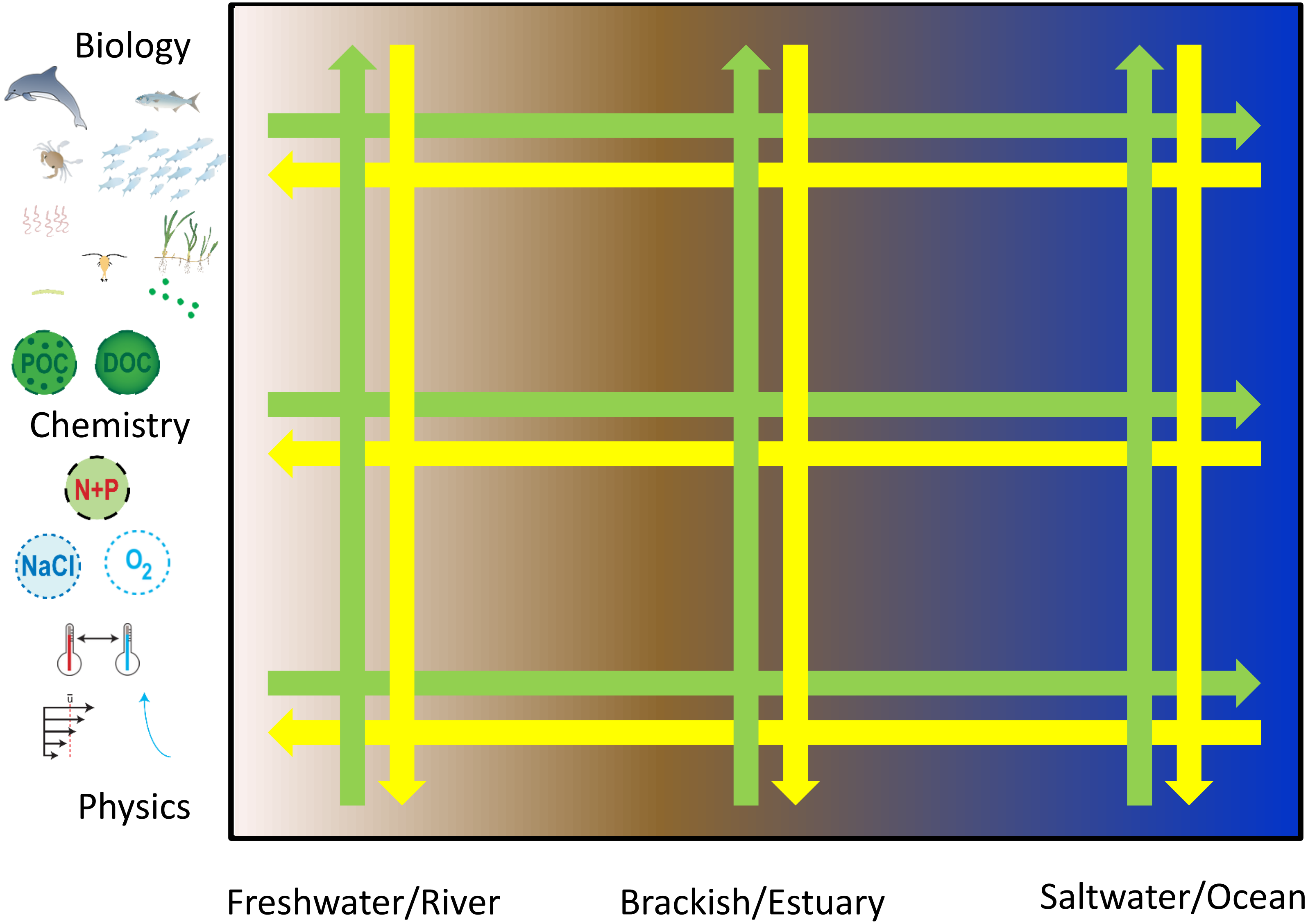
Fisheries/Living Marine Resource Mandates

	Pressures																					
	Overfishing	Bycatch	Climate Change			Ocean Acidification	Food Web Alteration	Invasive Species	Biodiversity Loss	Habitat Loss/Degradation	Disease	Eutrophication	Hypoxia	Toxic Deposition		Oil & Gas	Marine Litter	Dredging & Dumping	Food Security	Economic Security	Social Impacts
Focal LMR Area, Main Mandates, Main Focal Efforts			Thermal Habitat	Flow Regime	Sea Level									POPs	Metals						
Target Stocks																					
MSA, etc.																					
Stock Assessments																					
Protected Species																					
MMPA, ESA, etc.																					
SRGs, Section 7																					
Aquaculture																					
NAA, CZMA, etc.																					
Permitting, Siting Reviews																					
Habitat																					
CWA, CZMA, ESA, MSA, etc.																					
Permitting Reviews																					
Ecosystem and Aggregate Properties																					
NEPA, MSA, cross-mandates																					
cumulative impacts, IEAs																					

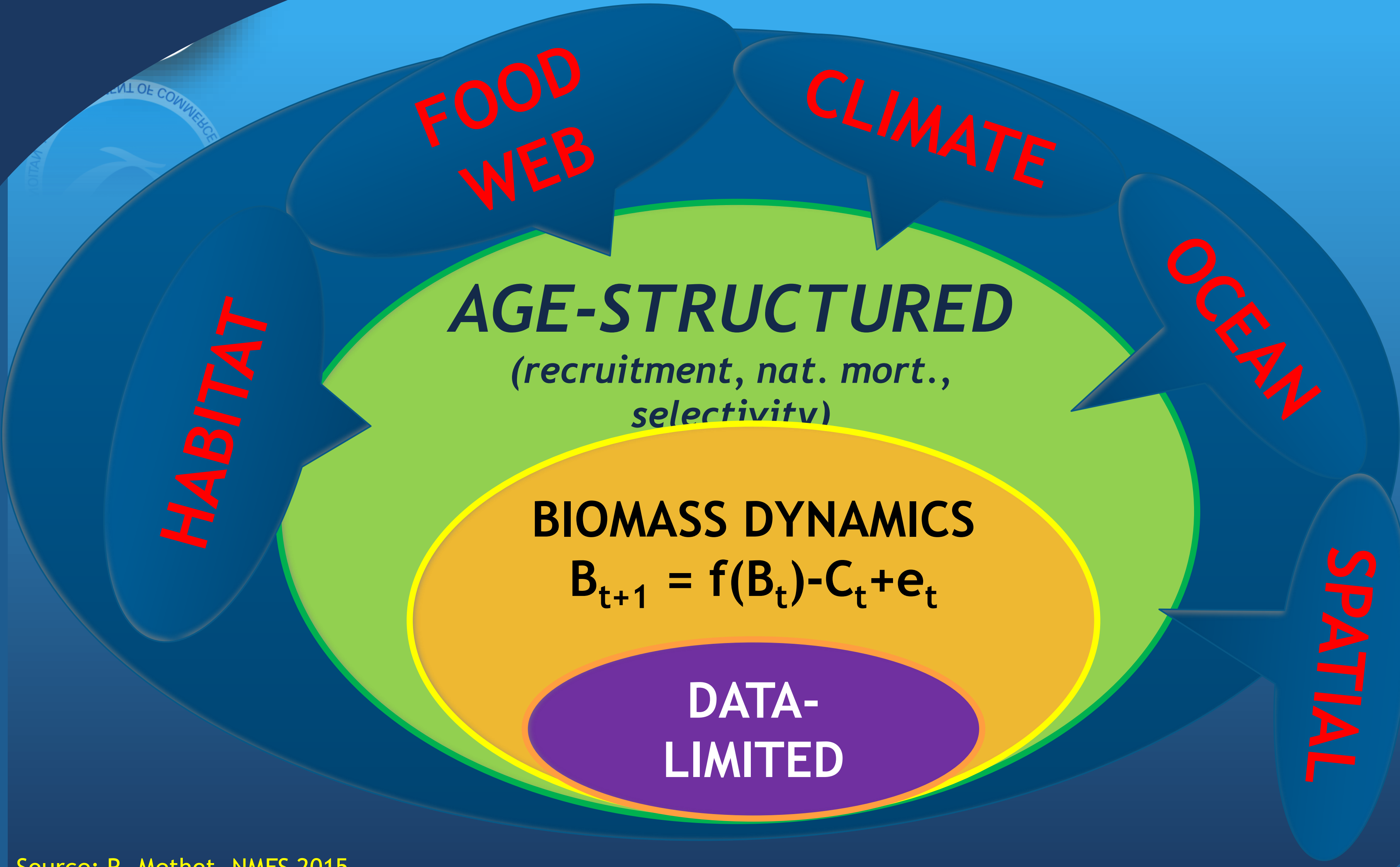
RED indicates areas of high activity

Ideal Ecological Modeling System



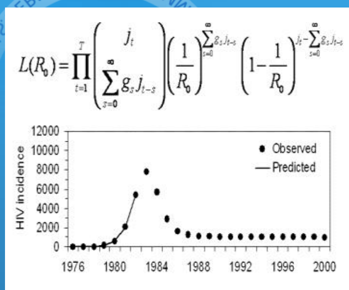
Icons from: Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/)

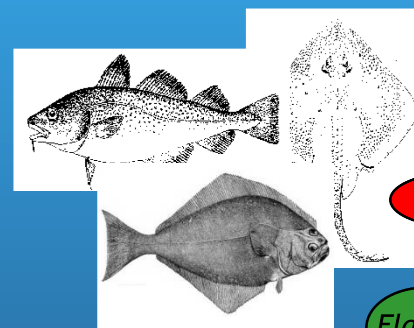
Onion of Model Simplifications

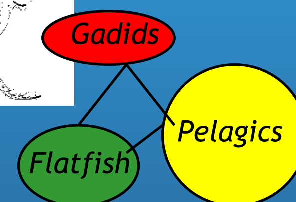


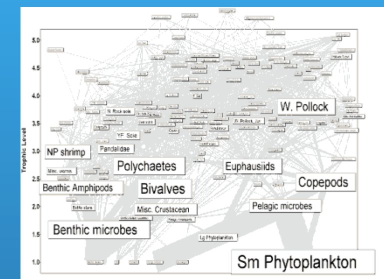
Source: R. Methot, NMFS 2015

Spectrum of Modeling For LMR Management Process









Data-limited Calculations — Biomass dynamics models — Age/Size Structured Models — Age/size Models w/ external factors — Multi-species Models — Biophysical Models — Aggregate Biomass Models — Food Web Models — Biogeo-chemical Models — Full System Models

Stock Assessment/Single Species Models

Ecosystem Assessment/Multi-species model

Z = F + M

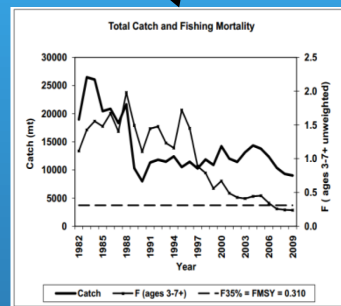
Natural mortality

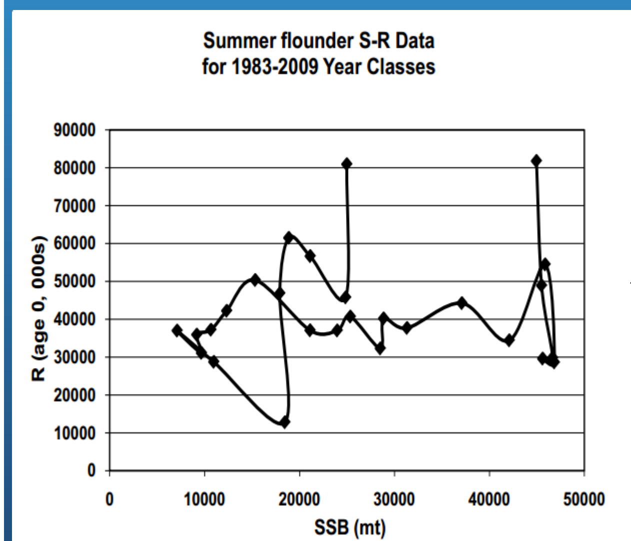
Recruitment

Growth

Fishing mortality

M=0.2





Population model equations

(T2.2.1) $N_{1,a} = \bar{R}e^{-\sum_{a=1}^{a=1} Z_{1,a} + \gamma_a}; \gamma \sim N\left(0, \sigma_\gamma^2\right)$

(T2.2.2a) $N_{y+1,a+1} = N_{y,a}e^{-Z_{y,a}}$

(T2.2.2b) $N_{y+1,8} = N_{y,7}e^{-Z_{y,7}} + N_{y,8}e^{-Z_{y,8}}$

(T2.2.3) $B_y = \sum_a N_{y,a} w_a$

(T2.2.4) $Z_{y,a} = M + F_{y,a}$

(T2.2.5) $F_{y,a} = q_y E_y s_a$

Catchability model equations

(T2.2.6) *White noise*

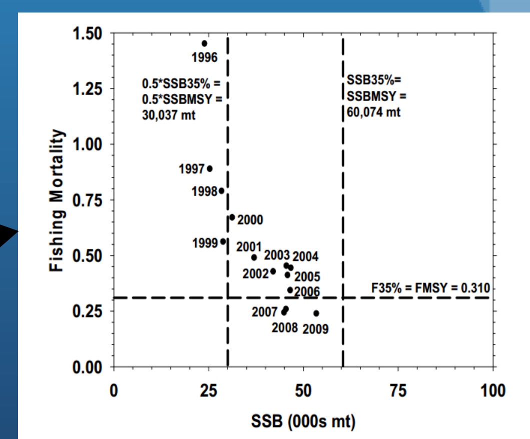
$$\log_e q_{y,f} = \log_e \bar{q}_f + \delta_y; \delta_y \sim N\left(0, \sigma_\delta^2\right)$$

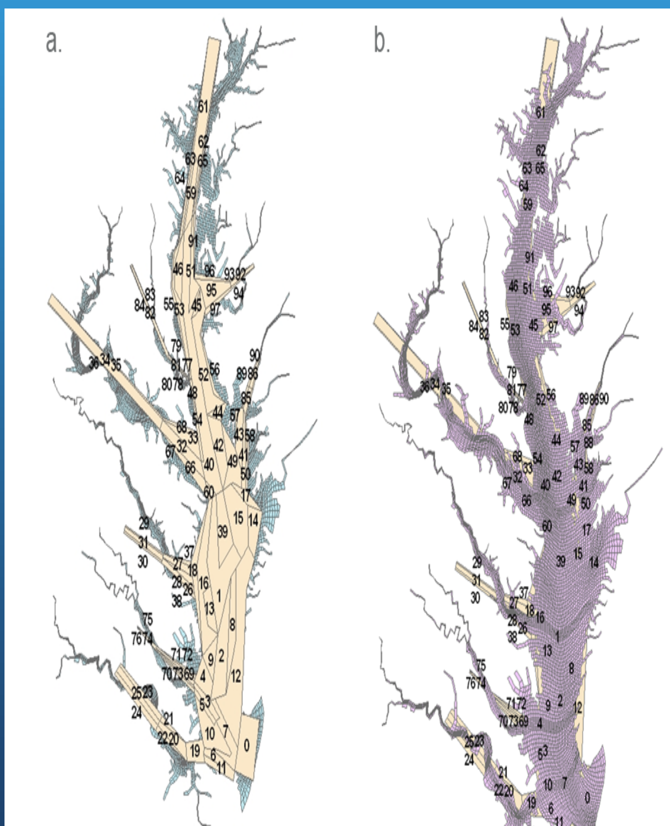
(T2.2.7a) *First order autoregressive*

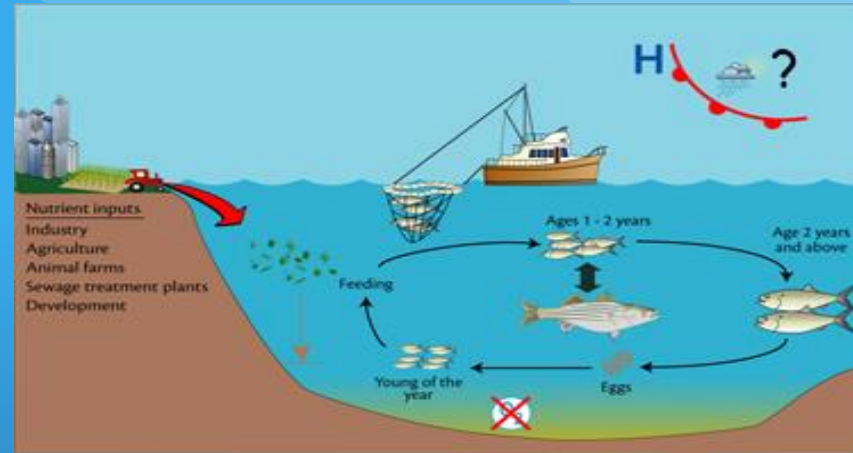
$$\log_e q_{1,f} \sim N\left(\log_e \bar{q}_f, \frac{\sigma_\varepsilon^2}{1-\rho^2}\right)$$

(T2.2.7b) $\log_e q_{y+1,f} = \log_e \bar{q}_f + \rho\left(\log_e q_{y,f} - \log_e \bar{q}\right) + \varepsilon_y$

$$\varepsilon_y \sim N\left(0, \sigma_\varepsilon^2\right)$$







Ecosystem based fisheries management aims to manage fisheries in a manner that considers a variety of interactions with the fishery of interest. Ecosystem based fisheries management is now strongly advocated and in some cases even mandated. Some of the main ecological interactions affecting menhaden biomass and recruitment are availability of food (plankton), level of predation from fish such as striped bass , and habitat quality such as dissolved oxygen , nutrient input , and weather pattern variability .

Credit: Caroline Wicks, UMCES

$$\frac{d(NH_w)}{dt} = -\sum_{i=PX_w} A_{NH_w i} - A_{NH_w,DF} - A_{NH_w,MB_w} - A_{NH_w,MA} - A_{NH_w,PFB} + \sum_{i=CX_w,BF} E_i + \sum_{i=FX} E_i + \sum_{\substack{i=pelagic\\bacteria}} E_i - S_{NIT,PAB} + R_{NET_w}$$

$$dA/dt = G_A - M_{A,lys} - M_{A,lin} - M_{A,quad} - \sum_{j=1}^{n} M_{A,\Pr ed_j}$$

$$dV_{i,a}/dt = T_{Im,Vi} - T_{Em,Vi} - \sum_{j=1}^{n} M_{Vi,\mathrm{Pred}_j} - M_{Vi,F} - M_{Vi,lin} - M_{Vi,quad}$$

Levels of Model Use to Inform LMR Management

Tactical

- Fish Stock Assessments
  - Harvest Policy: strategy for %take
  - Status: Overfishing? Overfished?
  - Forecast: What catch would implement the policy
  - Account for scientific uncertainty
- Specific Impacts on Non-Target Species, Habitat
- Specific "What If" Scenarios and Gaming
- BINDING ON REGULATORY PROCESS
- Time-scale: 1-5 years

Heuristic

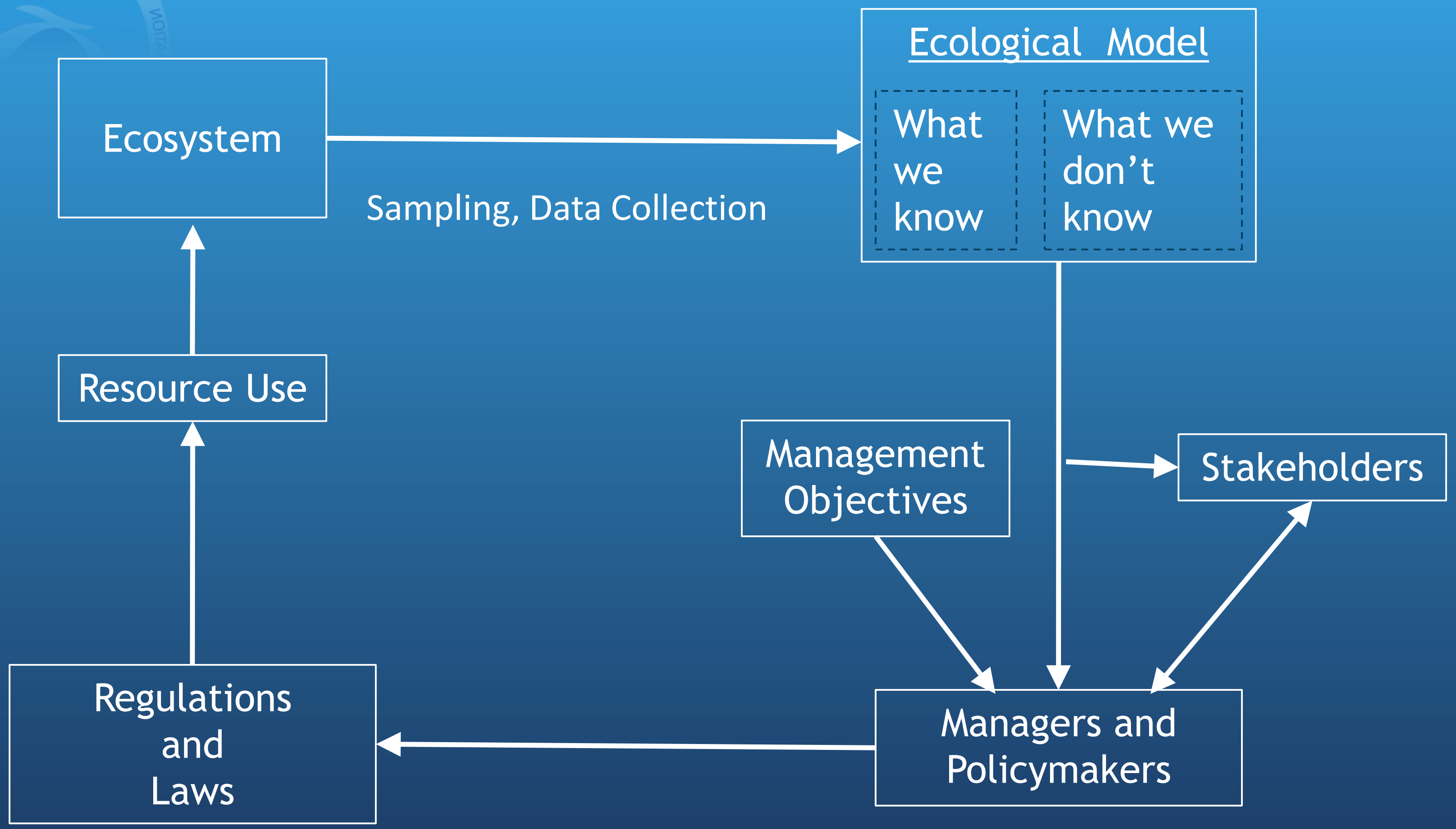
- Understanding Ecosystem Functioning
- Relative Importance of Different Processes
- Advancing Scientific Theory

Strategic

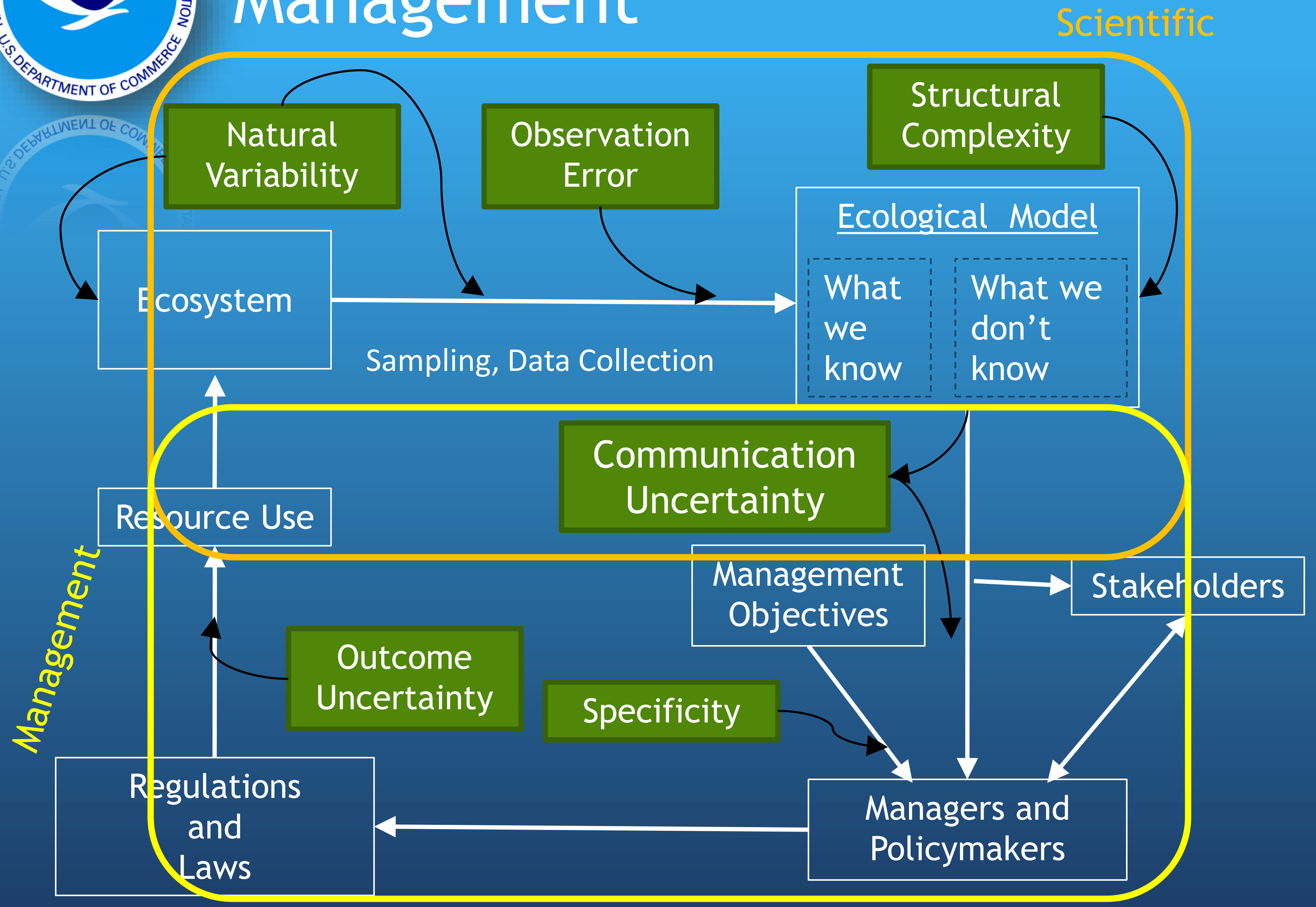
- Assessing Biomass Tradeoffs
- System Level Emergent Properties & RPs
- Evaluating Alternate Stable States
- Cumulative Impacts on Non-Target Species, Habitat
- General "What If" Scenarios and Gaming, Long Term Trends
- Time-scale: Decades

Dealing with uncertainty

Resource Management Cycle



Uncertainty in Resource Management



Dealing with Scientific Uncertainty

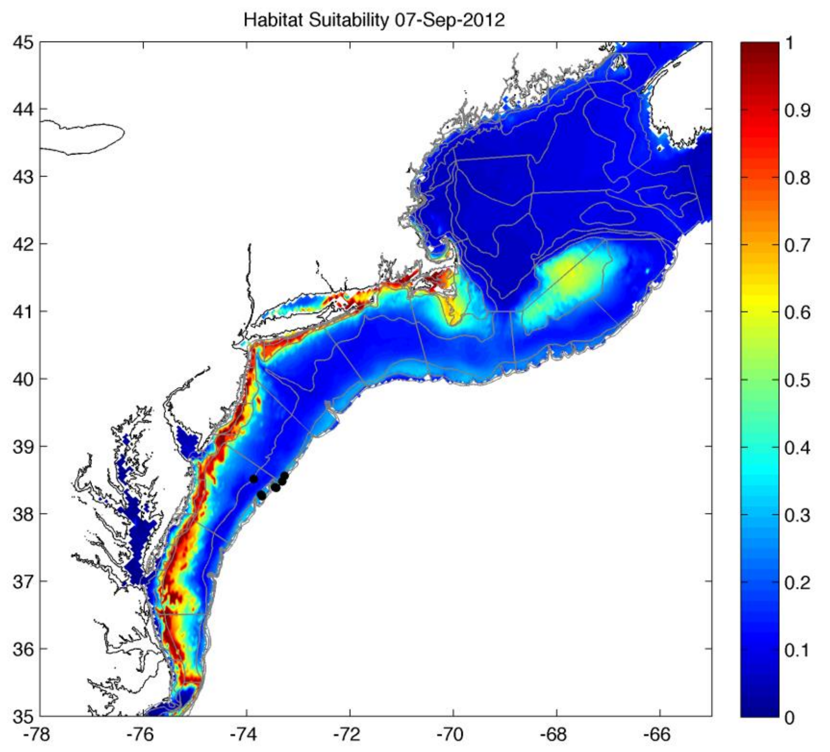
Source	Solution
Natural variability	- Single model ensemble/sensitivity analysis - Add parameters to model
Observation error	- Improve sampling gear - Increasing sample size (and spatiotemporal coverage)
Structural Uncertainty	- Run multiple models

Solutions are easy to state but often difficult or costly to implement

Progress on improving scientific uncertainty

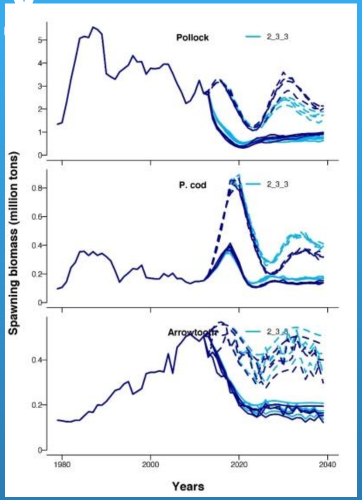
Atlantic Butter fish

- Used ROMS model to hindcast temperatures to identify habitat
- Improved estimates of catchability and reduce uncertainty around biomass estimates
- ~5 years to develop, ~2 years to implement in management model



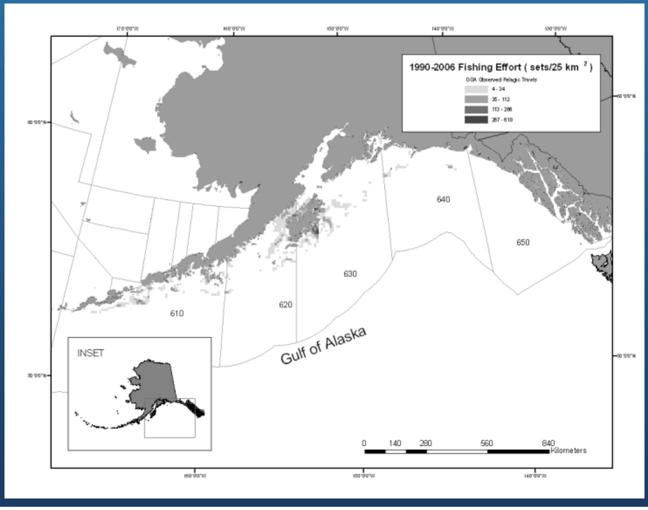
Source: http://www.nmfs.noaa.gov/stories/2014/10/butterfish_science.html

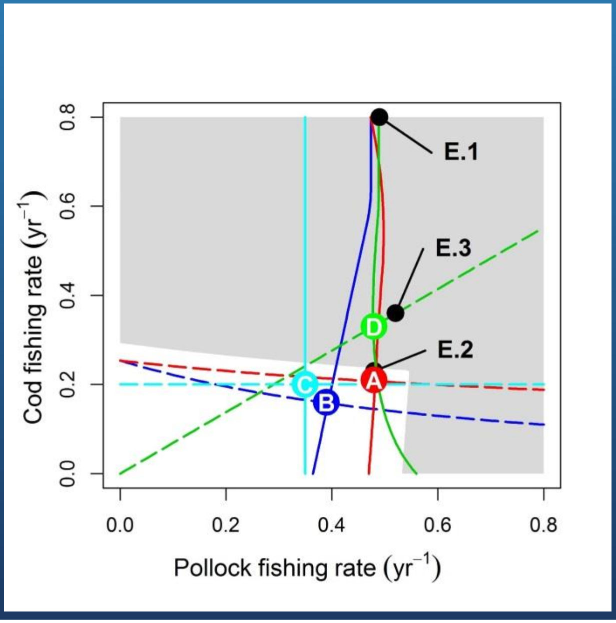
Progress on improving scientific uncertainty



Alaskan Fisheries Management

- Using sensitivity analysis
- Using multiple models (to incorporate ecosystem considerations)





Dealing with Management Uncertainty

Source	Solution
Communication uncertainty	- "iterative two-way flow" (Peterman 2004) - new ways of visualizing complex information
Specificity	- "iterative two-way flow" (Peterman 2004) - Multiple preliminary model runs to explore options in objectives
Outcome uncertainty	- Explicitly account for it by probabilistic forecast models - information systems to expedite model development and communication of model output

Solutions are easy to state but often difficult or costly to implement

Management Uncertainty – New Paradigms Necessary

McDonald's Method

- Managers and stakeholders ask
- Scientists/Assessors go away and comeback
- Often managers don't get what they asked for or what they need

Subway Method

- Managers and stakeholders ask
- Scientist/Assessors build the analysis and interact with managers as they build
- Managers more likely to get exactly what they need

Progress on improving management uncertainty

Project FishSmart

- Iterative, Collaborative Model building with stakeholders
- At the end of the process, stakeholders recommended stricter fishing regulations for Atlantic Mackerel

http://www.umces.edu/cbl/story/2010/sep/21/improving-fisheries-management-through-science-and-understanding

Progress on improving management uncertainty

Virtual Ecosystem Scenario Viewer

- Using ecosystem modeling tools, coupled with input from stakeholders, to explore the tradeoffs inherent in natural resource management decisions

https://www.st.nmfs.noaa.gov/ecosystems/ebfm/ecosystem-modeling

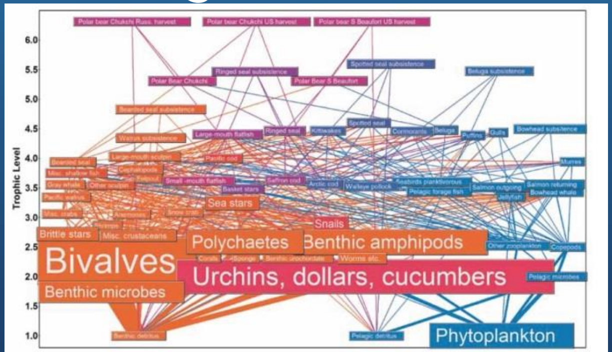
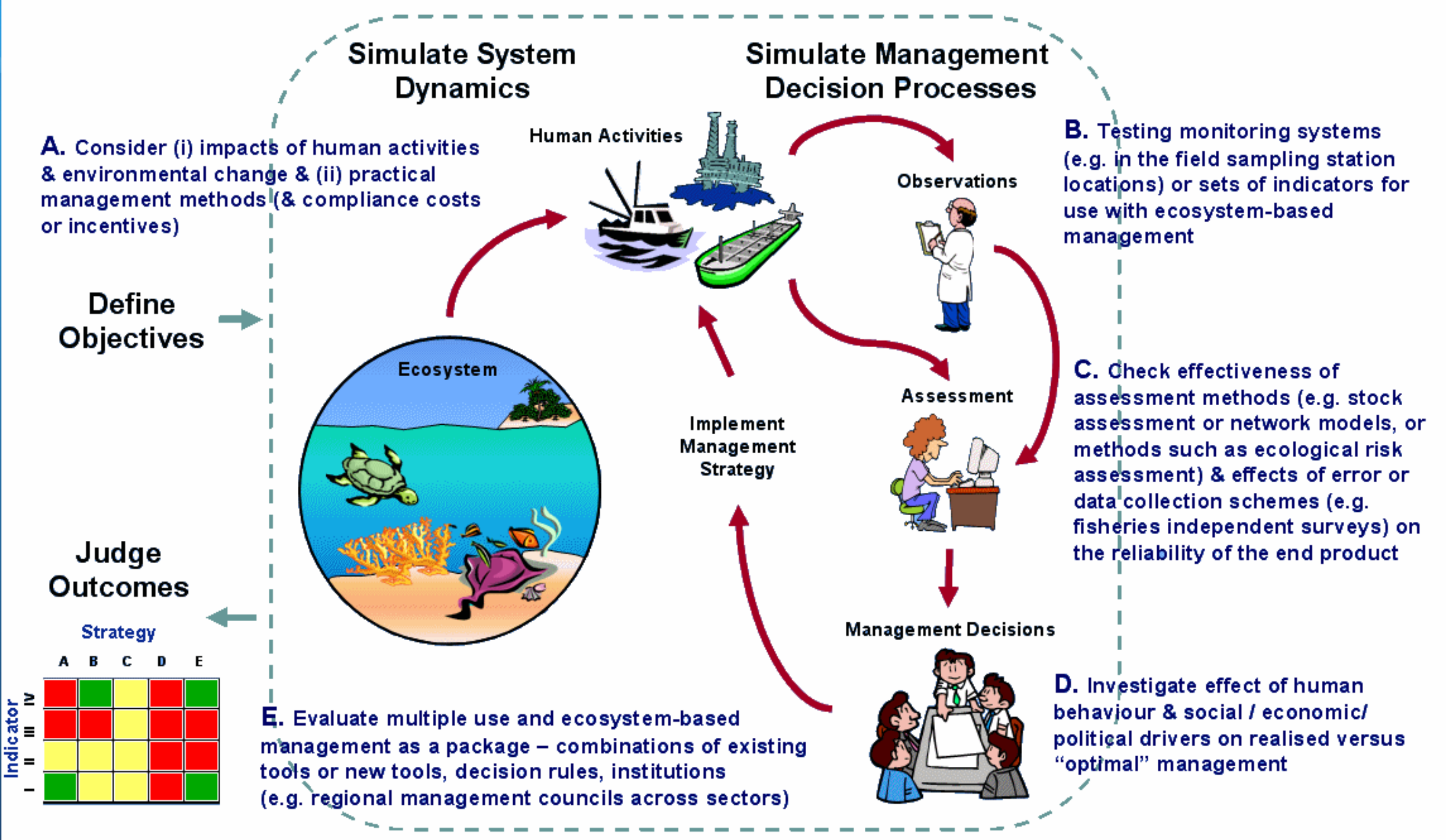


Figure 2. Visualization of the eastern Chukchi Sea food web. Each box represents a functional group, and the boxes are arranged vertically by their approximate trophic level. The size of the box is roughly proportional to the biomass of the group, and the width of the lines represents the magnitude of flows between the groups. Groups highlighted in blue have a pelagic orientation, while groups highlighted in red have a benthic orientation, with varying shades in between.

https://web.sfos.uaf.edu/wordpress/arcticeis/?page_id=450

Progress on improving uncertainty in general



http://www.cmar.csiro.au/research/mse/

Uncertainty in Resource Management: Parting Thought

"Far better an approximate answer to the right question, which is often vague, than an exact answer to the wrong question, which can always be made precise".

Tukey, J.W. 1962. The future of data analysis. Annals of Mathematical Statistics, 33: 1–67.

"Doing statistics is like doing crosswords except that one cannot know for sure whether one has found the solution"

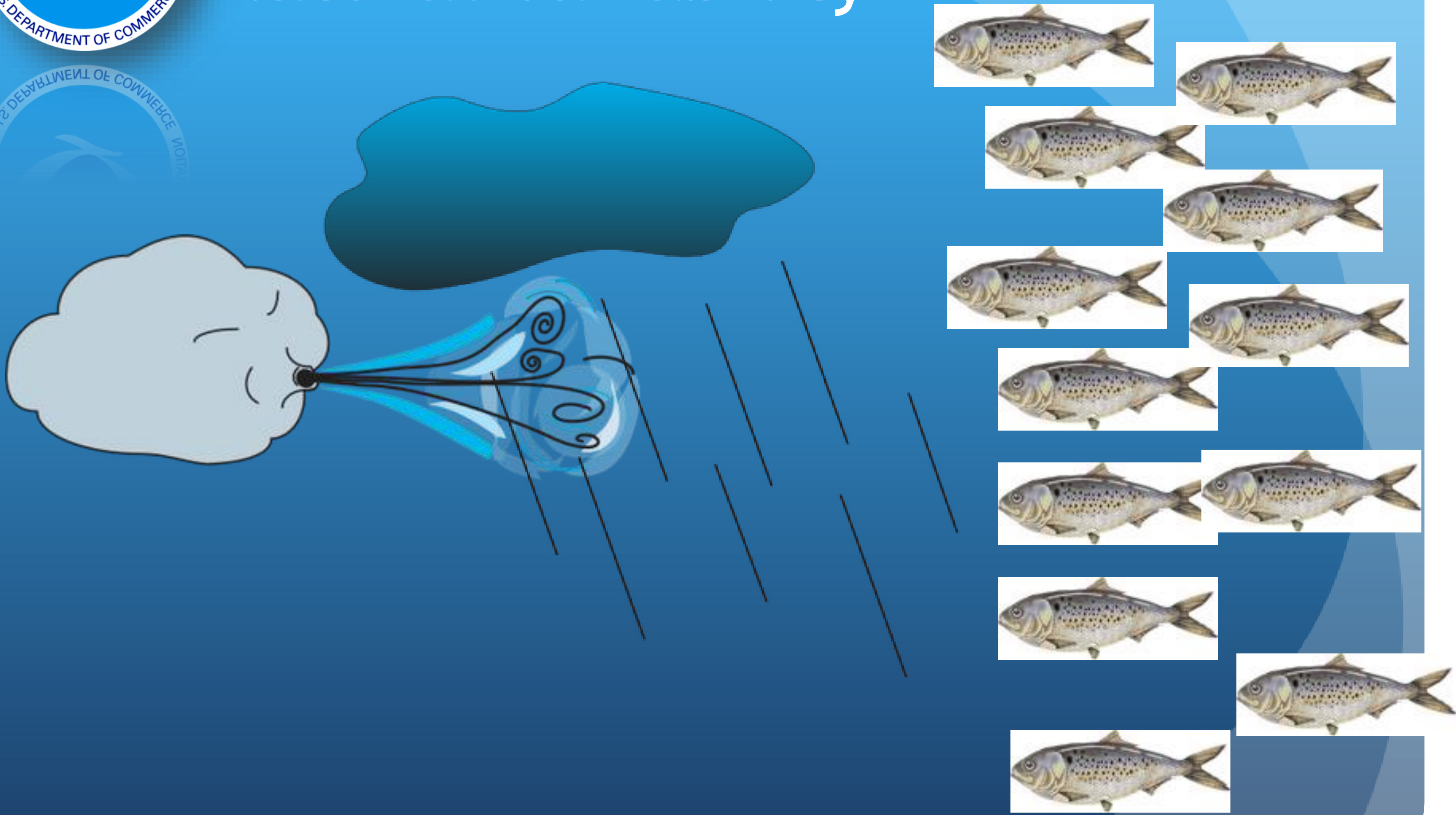
-J.W. Tukey

Extra Slides

Why uncertainty in is problematic for resource management?

- Natural Variability, Observation Error and Structural Complexity lead to parameter uncertainty
- Outcome Uncertainty leads to imperfect forecasts
- Unclear Objectives and Communication Uncertainty lead to poorly informed decisions

Natural Variability



Natural Variability

Source/Cause

- variability in a state variable that is observed in nature but not necessarily well captured in a model
- also known as process error
- e.g., climate

How to Handle

- Use additional parameters to capture as much variability as possible
  - Too few → bias
  - Too many → over-parameterization
- Solution: Sensitivity analysis to weed out parameters
  - However, with large parameter sets this is difficult

Observation Error

<u>Source/Cause</u>

- error as a result of imperfect methods of observing and quantifying natural phenomenon and human activities
- includes sampling error

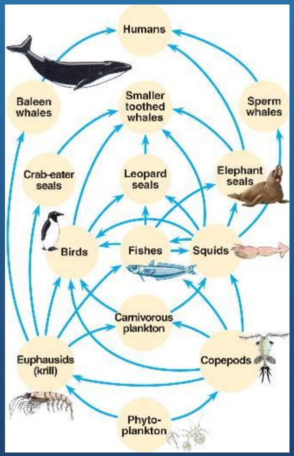
<u>How to Handle</u>

- Gear efficiency studies
- Improving catch reporting and surveys
- Increasing sample size (and spatiotemporal coverage) (reduces sampling error)

Model Structural Complexity

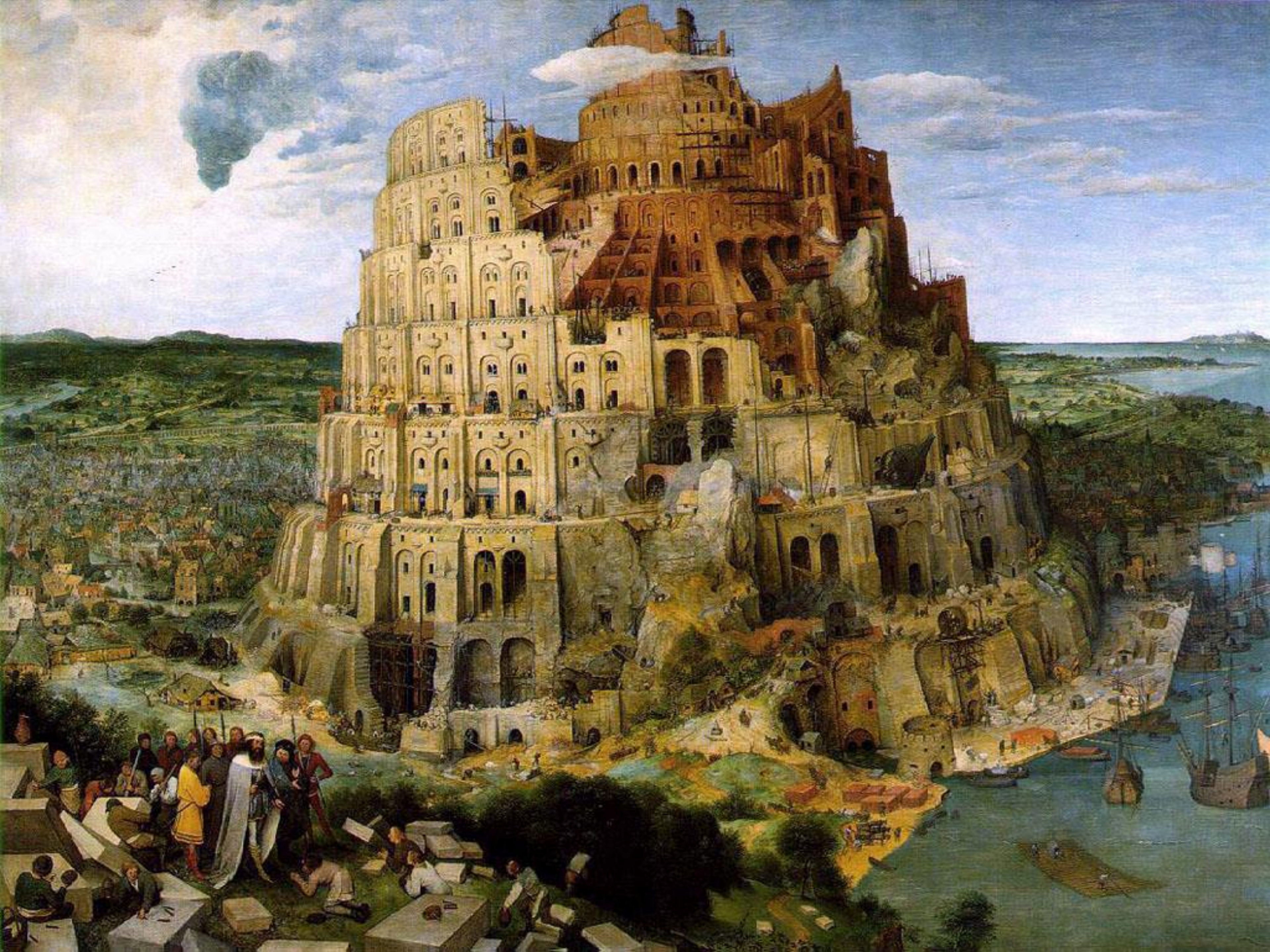
<u>Source/Cause</u>

- The extent to which natural phenomena are implicitly described in a model
- Includes the spatial and temporal resolution



<u>How to Handle</u>

- More phenomena requires more parameters and more uncertainty with each (because of previous sources)
- However, more complex can also reduce bias
- Use multiple framework, with different assumptions and levels of complexity, multiple scenarios



Specificity

<u>Source/Cause</u>

- Objectives that are poorly conceived, vaguely expressed, or difficult to quantify

- Leads to ambiguous targets, performance measures and decision rules, and inability to properly characterize important tradeoffs

<u>How to Handle</u>

- Early and ongoing engagement of scientists, managers and stakeholders, where objectives are carefully scoped and prioritized

Multiple preliminary model runs to explore options in objectives

Outcome Uncertainty

Source/Cause

- Deviation of a realized value from a target value (actual vs. expected)
- the difference between a scientific recommendation and an implemented management level
- May result from non-compliance, inadequate reporting, lags in communication assessment/forecast and implementation

How to Handle

- Explicitly account for it by probabilistic forecast models
- Develop information systems to expedite model development and communication of model output

Outcome Uncertainty