Supporting sustainable fisheries while tackling population spatial structure

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MARINE BIOLOGY AND ECOLOGY

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GUEST LECTURE MARINE CONSERVATION

Outline

Background

- What is spatial structure?
- Drivers of spatial structure
- How does it affect management?
- Ways to include spatial structure in management?

Single species assessments & incorporating space

- Example in Simulation
- Example in Reality (didn't get this far)

Large scale multispecies ecosystem models

- (next lecture)

What is spatial structure?

In fisheries spatial structure refers to inconsistencies in a population's metrics due to geographic separation

Population metrics used to identify structure include:

- Magnitude/ subpopulation size
- Size and Growth rates
- Age at which fish maturity
- Yield per unit effort (number of vessels)
- Age composition

Spatial Structure in Age Composition

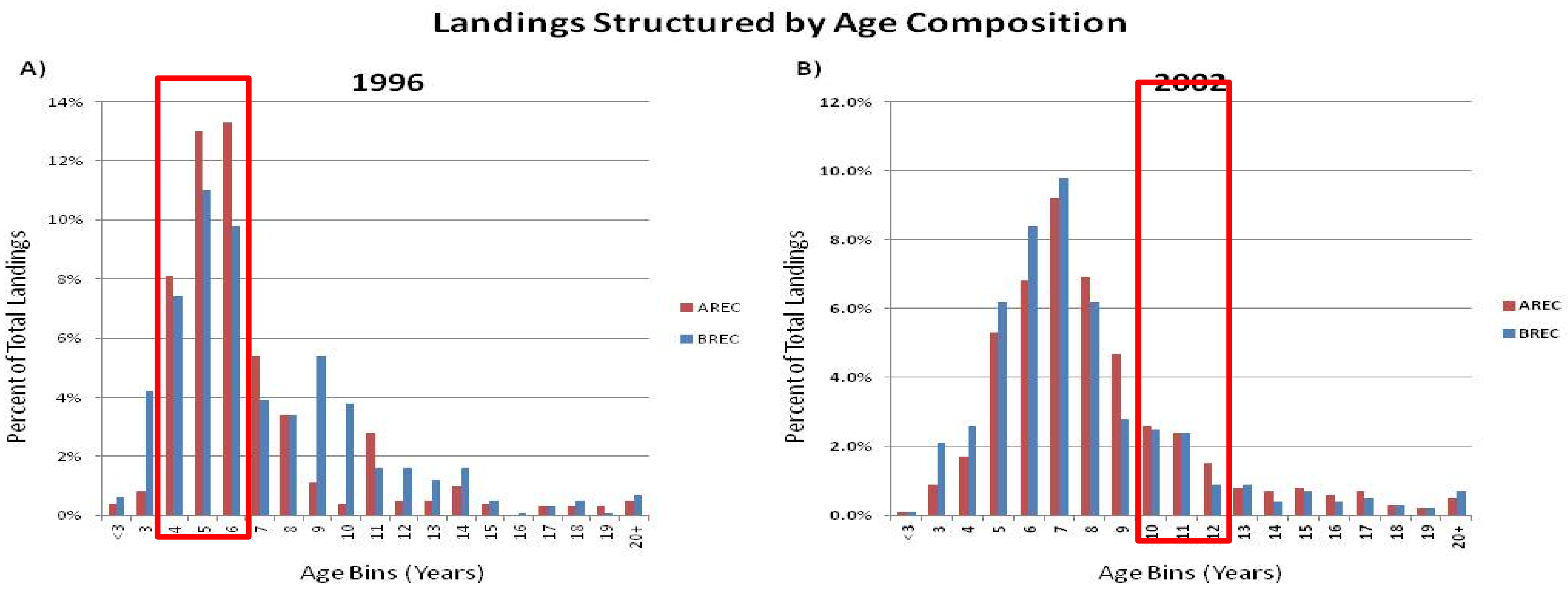


Figure 2. Age composition data from the Pacific Fisheries Information Network age standardized between years by determining the age percentage of the total landings. Data is shown for the recreational fishery in region B (Oregon South) and region A (Oregon North) for years 1996 and 2002 (Sampson 2007).

Drivers of spatial structure

Differences in fishing patterns (MPAs)

Differences in habitat suitability

- Environmental forcing
- Food and resource availability

Distribution of recruitment

Movement

- Ontogenetic shifts
- Migration

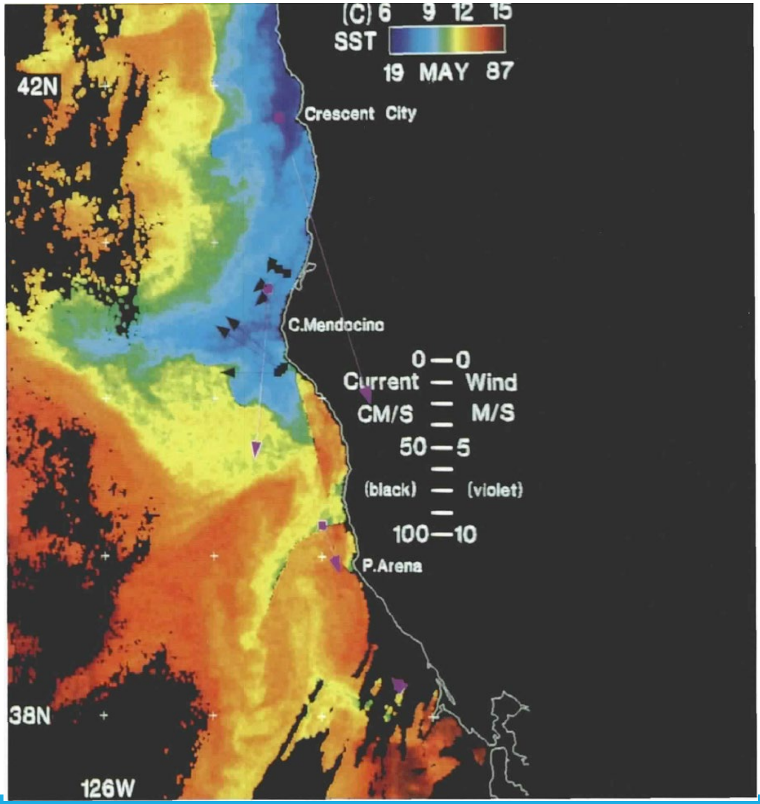


Figure 1. Oceanography off the West Coast of the United States. The wind forcing at Cape Mendecino and near-surface currents converge, resulting in a distinction between colder sea surface temperatures (SST) to the North and warmer SST to the South (Magnell et al. 1990).

Spatial structure can be a problem for management

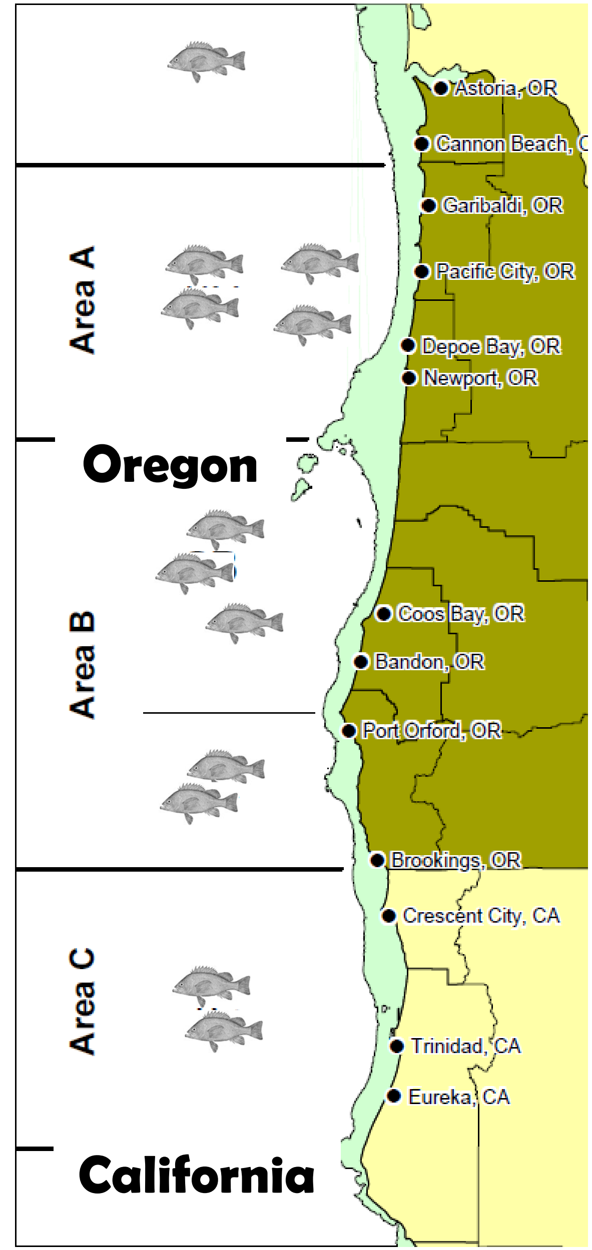
Spatial structure can distort our estimates of biomass used to manage a fishery leading to overharvesting

Spatial Example:

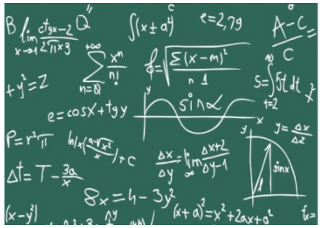
Black rockfish (Sebastes melanops) U. S. West coast

Regional differences in age composition

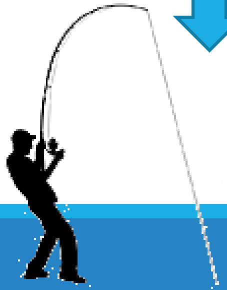
Possible regional differences in exploitation

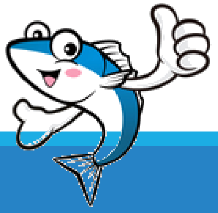


We estimate biomass using Stock Assessments



1. Mathematical models & population information
2. Estimates of population size
    - Spawning Stock Biomass (SSB)
3. Help setting management regulations
4. Maintain fish populations and fisheries





Stock assessment methods for estimating biomass: pros and cons

Biomass based methods

- ***Catch only models***
  - Only needs catch
  - Doesn't take into account changes in population dynamics
- ***Production models***
  - Assumes simple population dynamics, logistic growth (Schaefer 1954)
  - No difference in life stages (recruits vs. adults)

ICES. 2012. Report on the Classification of Stock Assessment Methods developed by SISAM. ICES CM2012/ACOM/SCICOM: 01. 15 pp.

Stock assessment methods for estimating biomass: pros and cons

Age and size based methods

- ***Virtual population analysis***
  - Begins to consider differences in fishing temporally
  - Needs highly precise catch at age data (not often available)
- ***Statistical catch-at-age***
  - Allows for flexibility in data quality
  - External estimation of spawner-recruit relationship
- ***Integrated analysis models (length- or age-based)***
  - Allows for flexibility in data types and quality
  - Incorporate advanced population dynamics such as regional differences in natural mortality and fishing mortality (fleets-as-areas), recruitment distribution and other factors (Methot and Wetzel 2013. Stock Synthesis)
  - Can take on the characteristics of any of the above models

ICES. 2012. Report on the Classification of Stock Assessment Methods developed by SISAM. ICES CM2012/ACOM/SCICOM: 01. 15 pp.

Recap

So now you know:

- What is spatial structure?
- Drivers of spatial structure
- How does it affect management?
- Ways to include spatial structure in management?

Choose a method …

Many stock assessors in the US use Integrated Analysis methods to estimate the biomass of a spatially structured stock but there are still many questions:

When do we do it?

- When there is evidence of spatial structure?

How do we do it?

- Have different values for mortality?
- Add movement parameters?

What information is needed?

- Do we need spatially structured data?
- Can environmental or habitat data help ?
- What happens when we don’t have that?

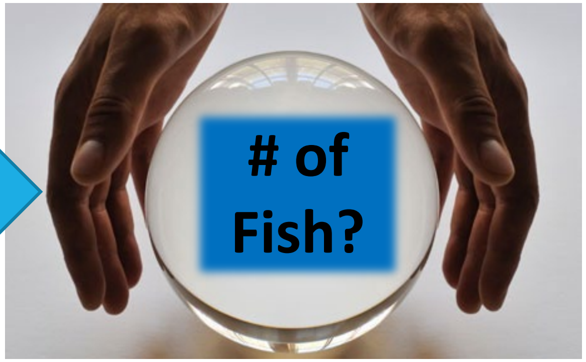
The way we attempt to answer some of these questions or test our hypotheses is through simulation

What is a simulation in fisheries?

Virtually create fish & figure out ways not to kill them all

VIRTUAL FISH POPULATION

BEST WAYS TO ESTIMATE BIOMASS OF FISH IN THE POPULATION



Virtually create fish & figure out ways not to kill them all

VIRTUAL FISH POPULATION

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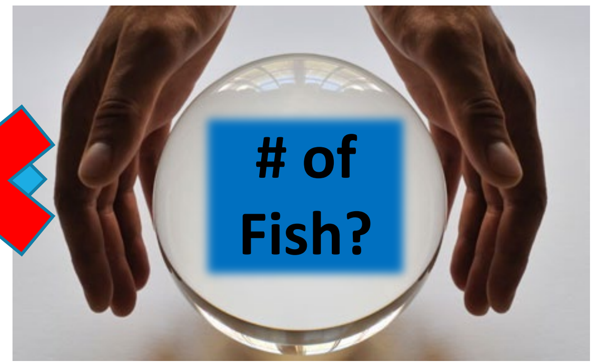
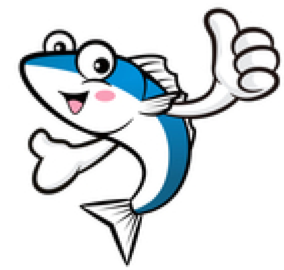


Real world fish populations



Impacts on estimates

Choose a method …

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The way we attempt to answer some of these questions or test our hypotheses is through simulation

Single species assessments & incorporating space

A SIMULATION EXAMPLE

Denson et. al 2017 Canadian Journal of Fisheries and Aquatic Science

Revisiting the management problem

Spatial structure can distort our estimates of biomass used to manage a fishery leading to overharvesting

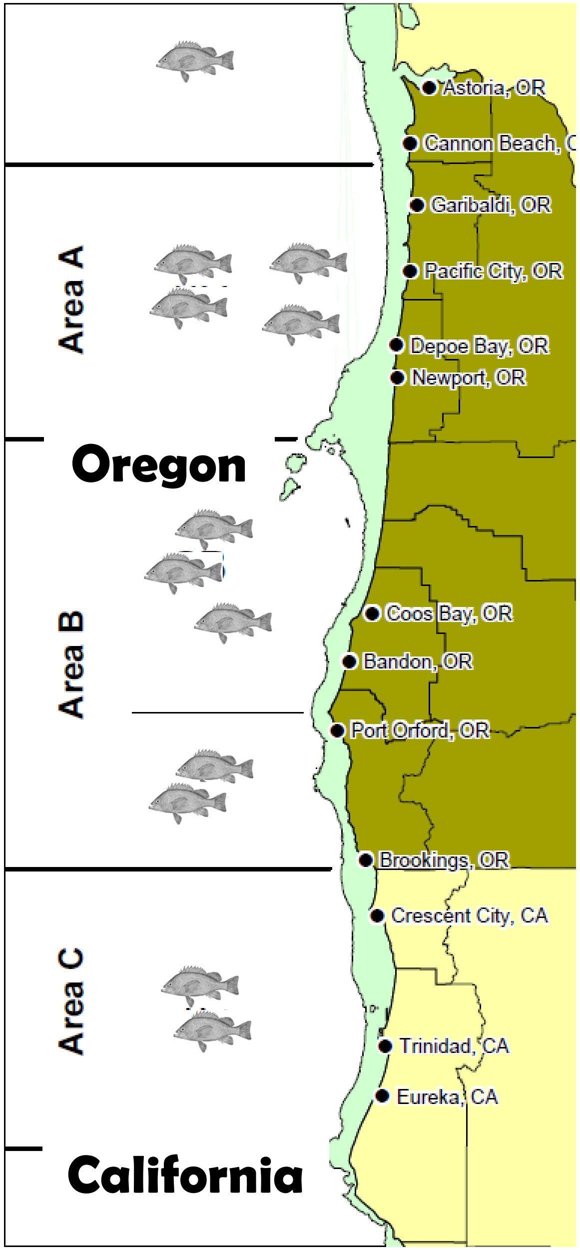
Spatial Example:

Black rockfish (Sebastes melanops) U. S. West coast

Regional differences in age composition

Possible regional differences in exploitation

Lack of informative data in spatial assessment to distribute larval fish

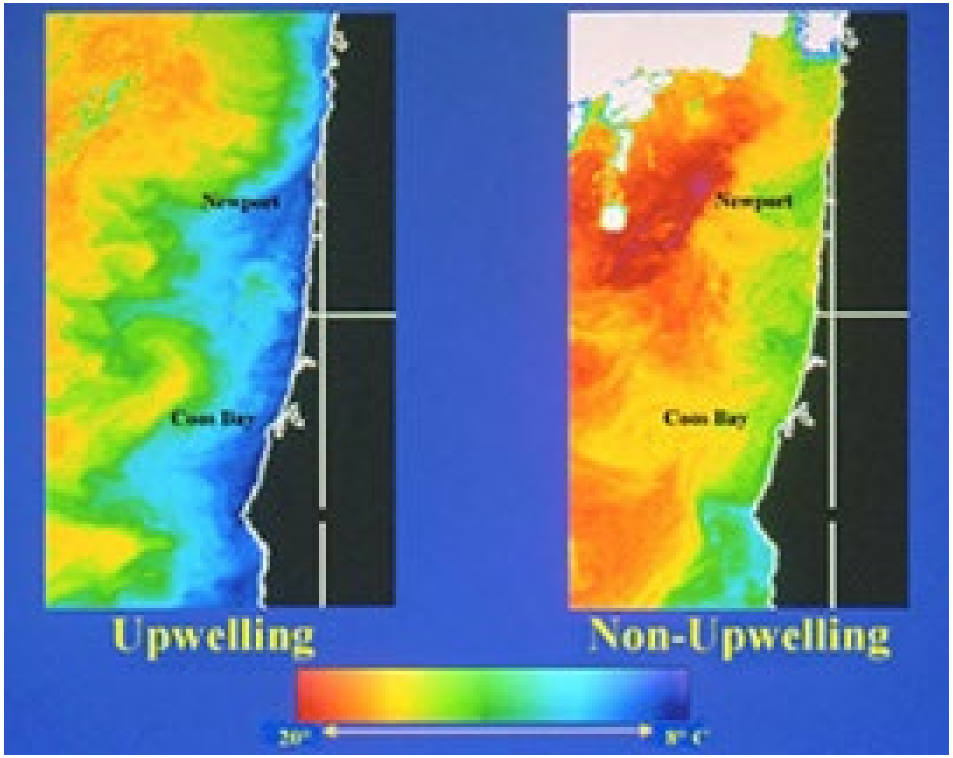


The environment can help

Features of the environment may provide support for recruitment distribution

Current assessments ignore environmental influences

Spatial and Temporal Differences in Temperature

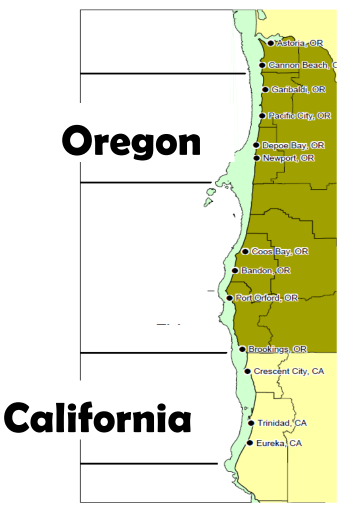


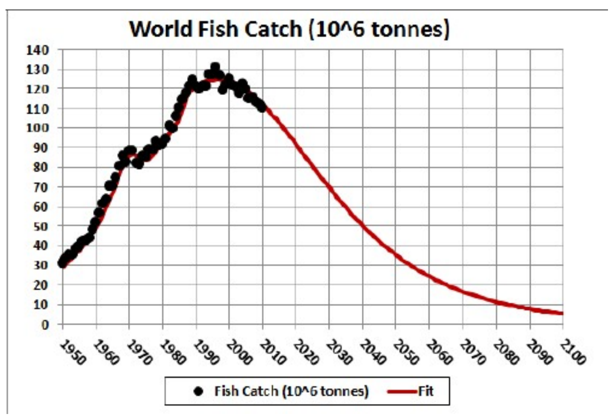
http://www.oregon.gov/lcd/ocmp/pages/ocean_phys.aspx

Research Question 1 and Hypothesis

What information and model structure are needed to produce reliable estimates of biomass from spatially explicit stock assessments?

Hypothesis: Stock assessment models with the **spatial structure** matching that of the population, and utilizing all **available data** will produce the most reliable estimates of spawning biomass.



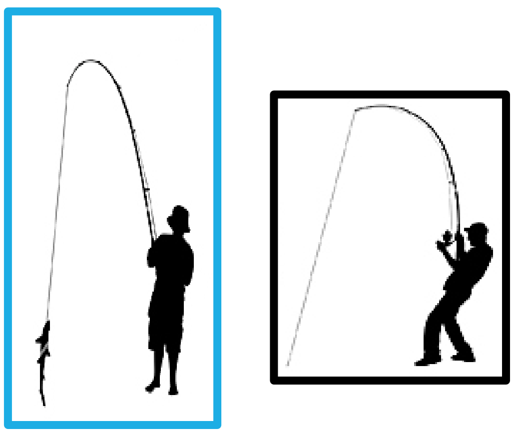


Spatial Structure + **Available Data** = **Reduced Bias**

Research Question 2 and Hypothesis

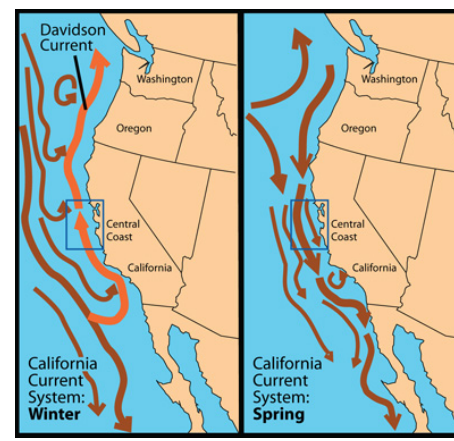
Do regional differences in exploitation rate and environmental forcing on recruitment distribution influence the spatially explicit stock assessment accuracy?

Hypothesis: Regional differences in both **exploitation** and **environmental forcing** on recruitment distribution will influence estimates of biomass.



Exploitation

Influence Bias



Environmental Forcing

Methods: Simulation Approach

1. **Create an Operating Model (OM)**

   Simulate an age and spatially structured stock

   Generate data and calculate “true” SSB

2. **Apply Estimation Models**

   Integrated Analysis Method (Stock Synthesis)

   Multiple model configurations to estimate quantities

3. **Compare Outputs from the Models**

   Estimates vs. “true” SSB from the OM

4. **Analysis of Comparisons**

   Identify patterns and statistical support for changes in bias

Operating Model (OM)

Virtual Population Dynamics

Long lived

Regional differences in fishing mortality & percentage of recruits distributed to the regions (*%Recruit*)

Data Needed for the Stock Assessment Models

Annual Catch biomass

Survey of Abundance

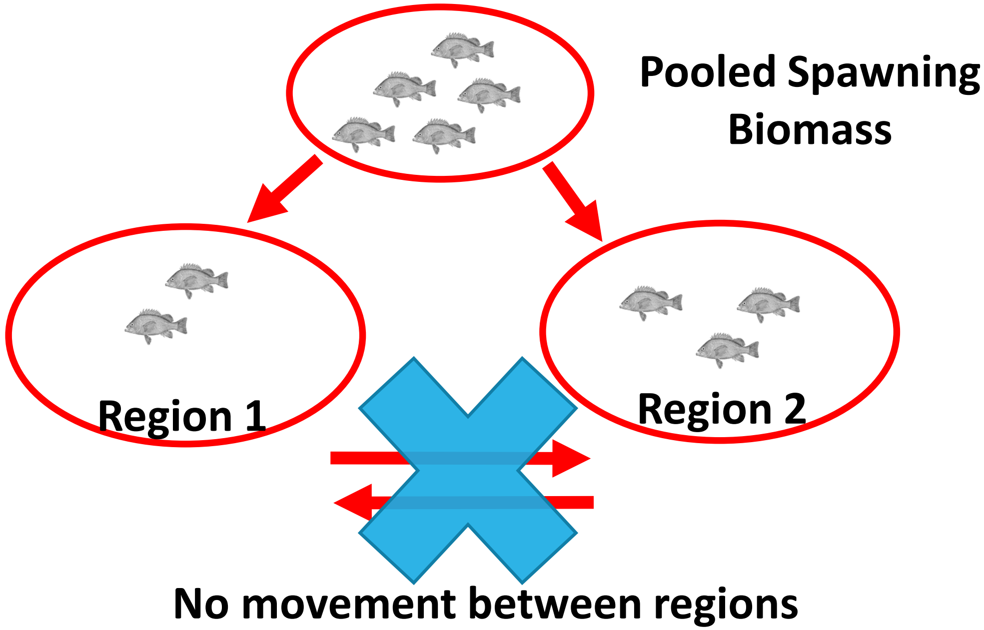
Environmental Index

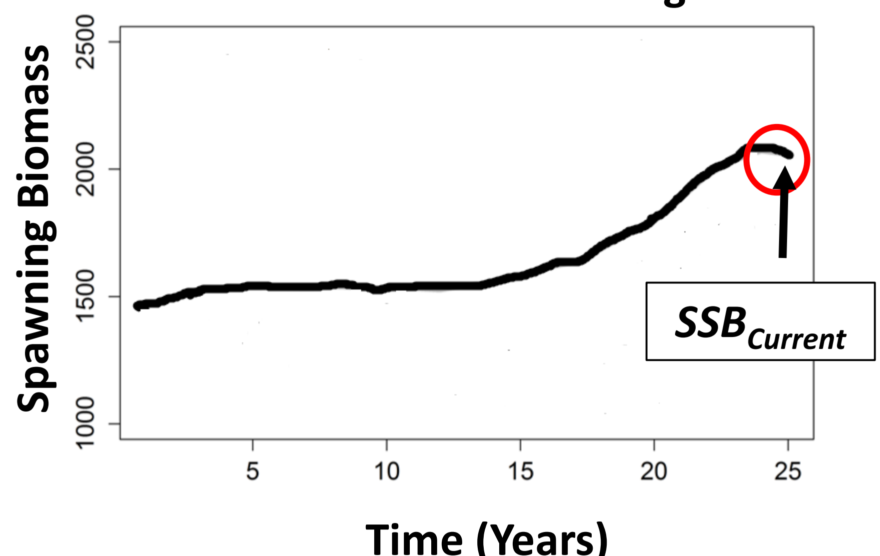
Age composition

Calculate “true” quantities

Spawning Stock Biomass in the 25th year ($SSB_{Current}$)

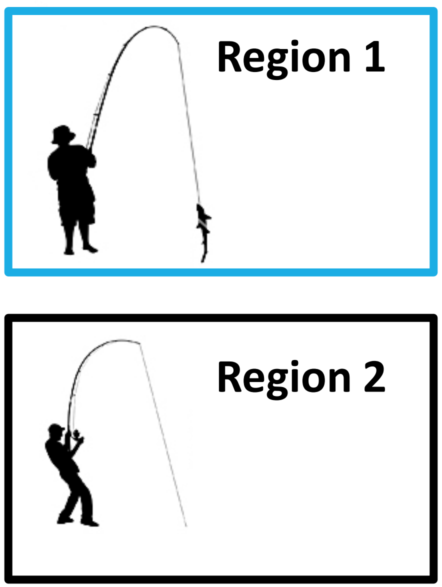
For 100 replicates



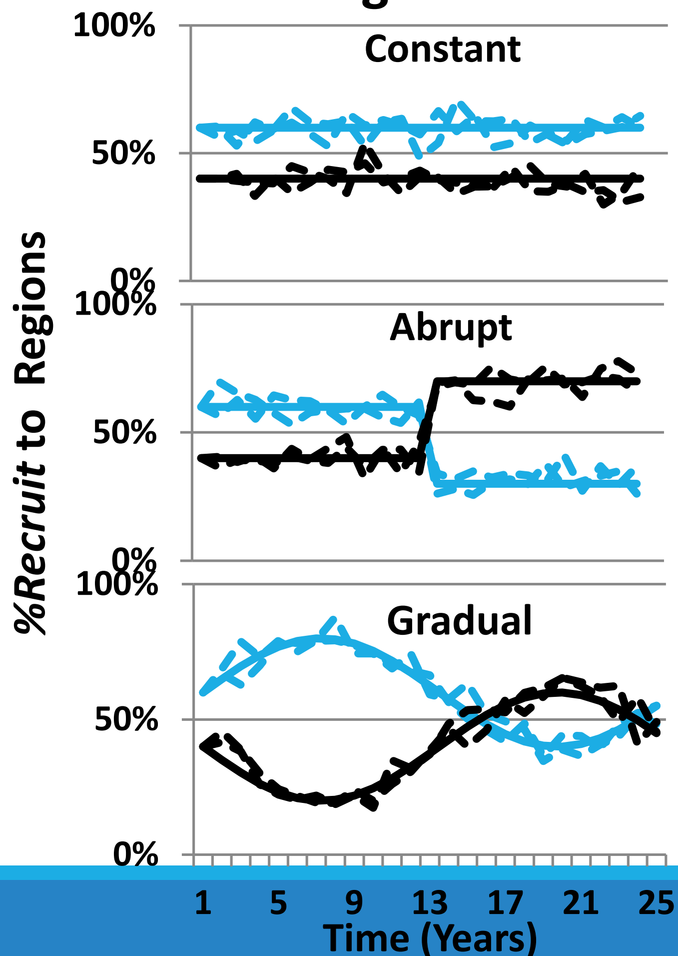


Experimental Design:
Operating Model Factors

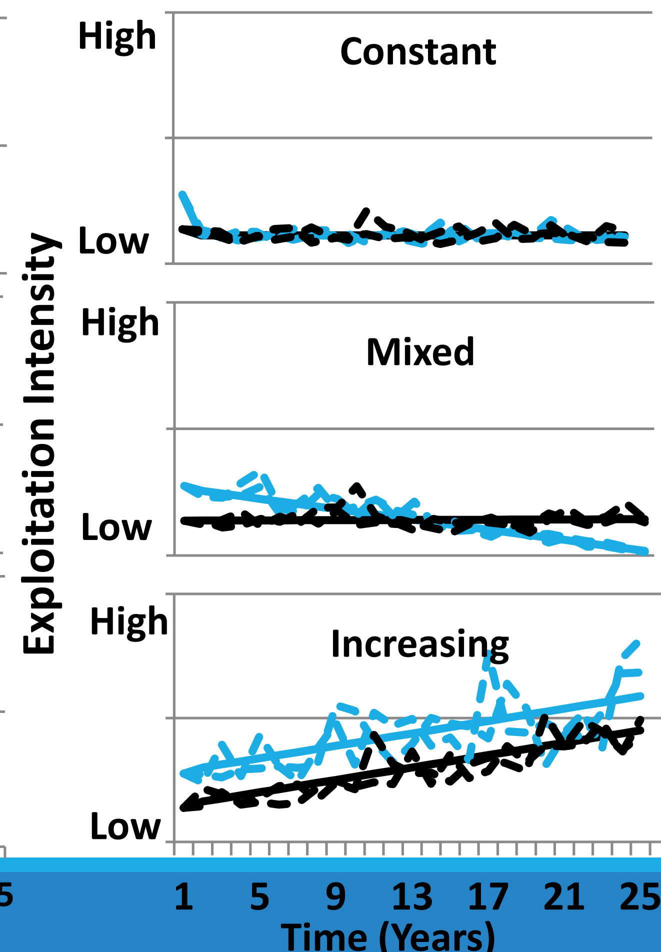
EnvirP (E) ***Exploit (F)***



Environmental patterns influencing *%Recruit*



Exploitation Histories



Experimental Design:
Stock Synthesis Model Factors

Factors			
Space	***Survey***	***E. Index***	**Model Configurations**
2 regions	X	X	2.S.E
2 regions	-	X	2.nS.E
2 regions	X	-	2.S.nE
2 regions	-	-	2.nS.nE
1 region	X	NA	1.S
1 region	-	NA	1.nS

Compare

Estimates from Stock Synthesis (SS) w/ “true” SSB from Operating Model (OM)

$$Relative\ Error(RE) = \frac{SS\ Estimate\ - OM\ "True"}{OM\ "True"}$$

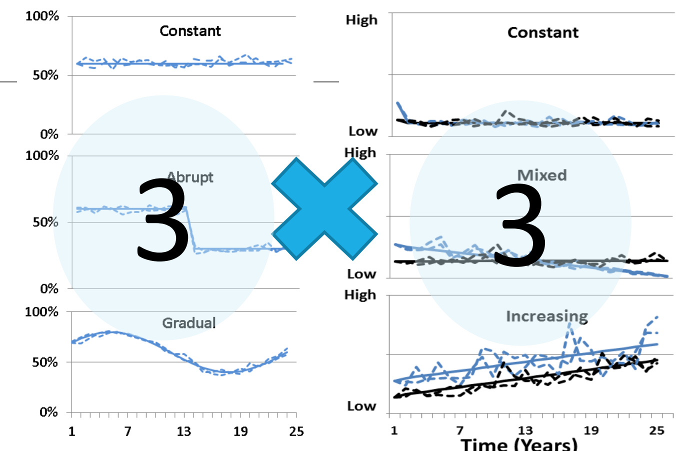
Bias - Median Relative Error (MRE)

Experimental Design Data Flow

9 population scenarios

100 replicates per scenario

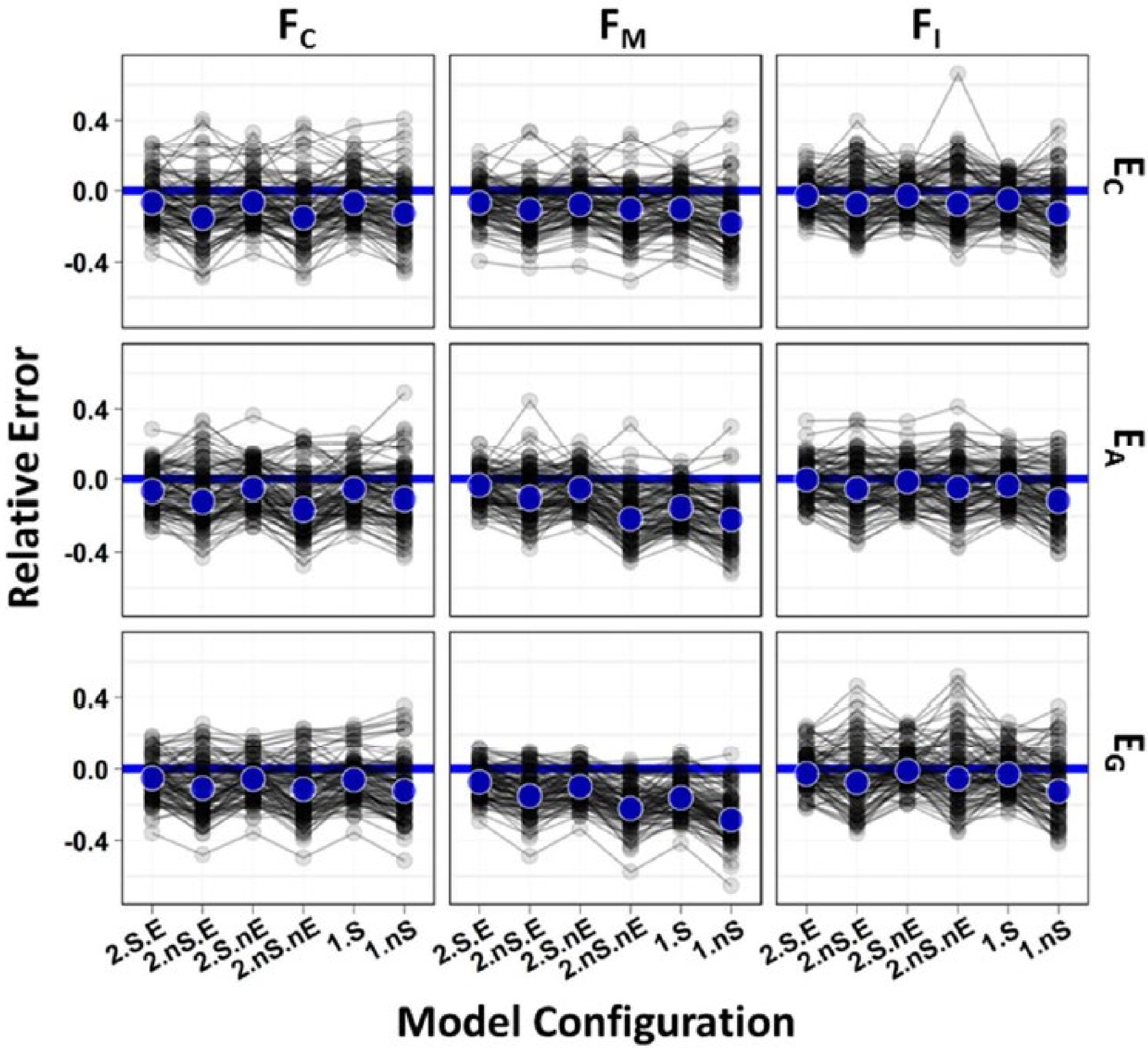
Each rep used in 6 Model Configurations



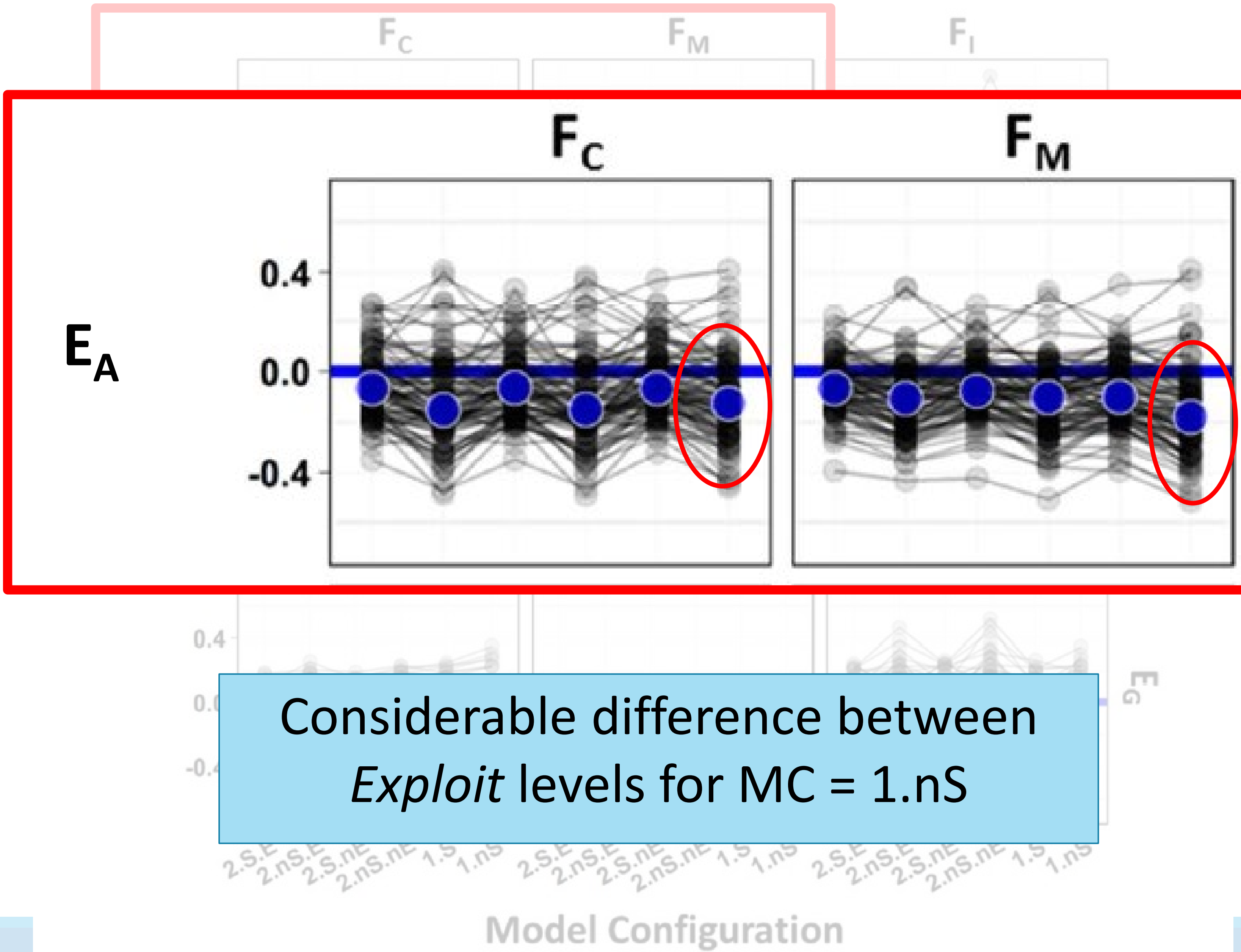
100 reps

6 MCs

Variability Between and Within Groups

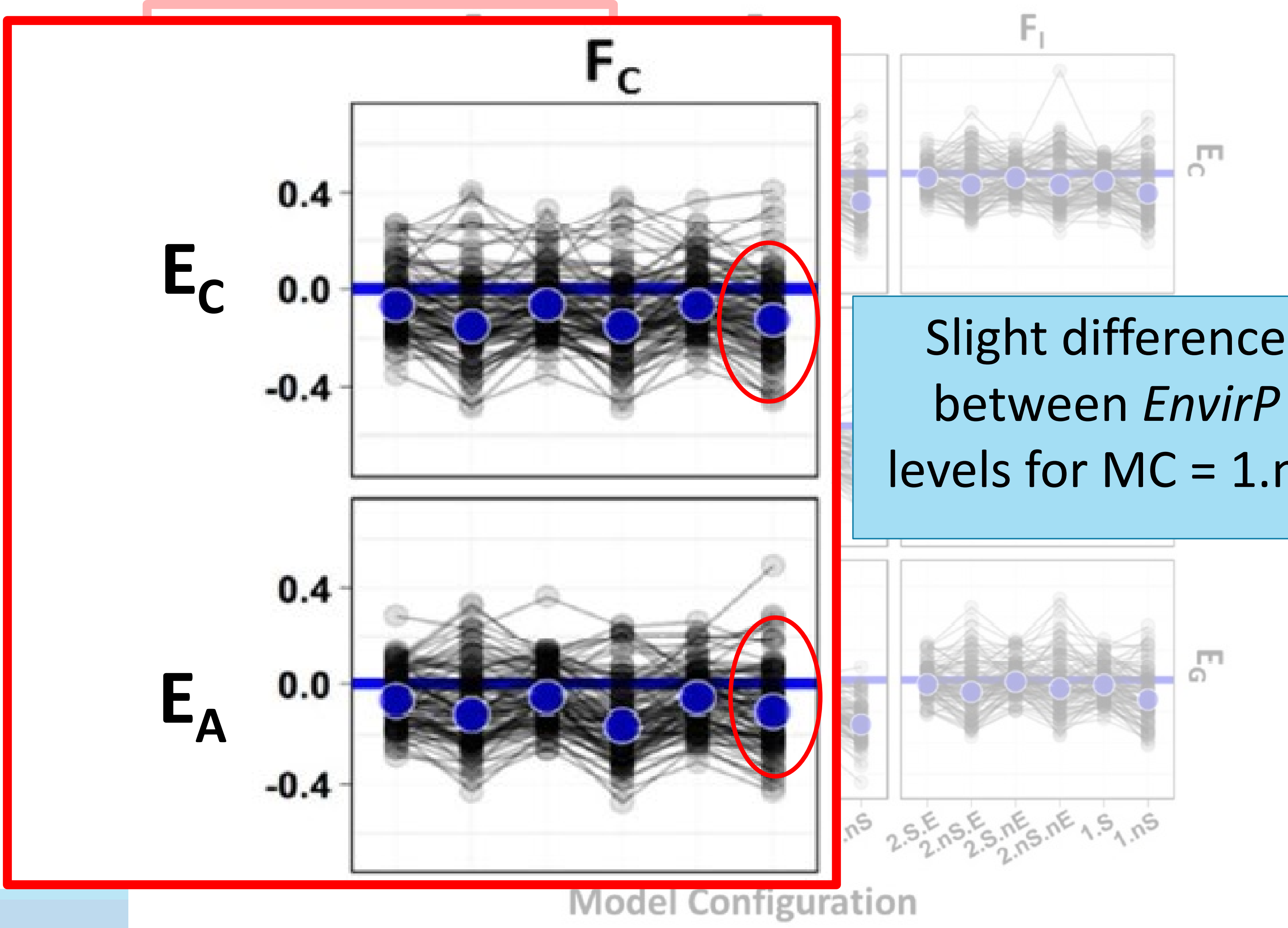


Variability Between *Exploit (F)* Levels



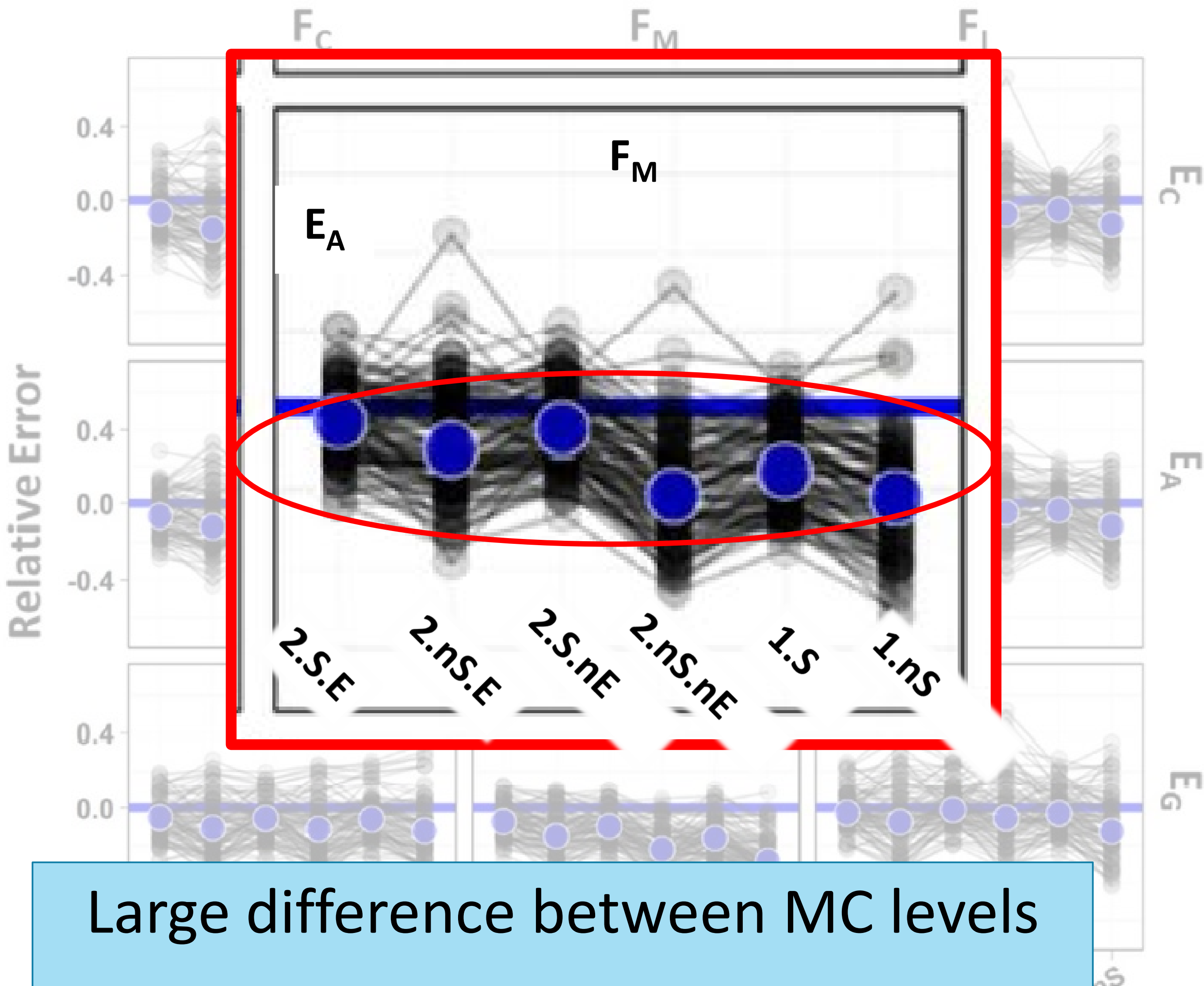
Considerable difference between *Exploit* levels for MC = 1.nS

Variability Between *EnvirP (E)* Levels



Slight difference between *EnvirP* levels for MC = 1.nS

Variability Between *MC* Levels



Large difference between MC levels

MC = 2.S.E has the least bias

Linear Model & Contrasts Quantify Variability

***SSB*$_{Current}$ RE =** *Exploit +EnvirP + MC + Exploit*MC*

Linear Model & Contrasts Quantify Variability

$$\boldsymbol{SSB_{Current}}\ \textbf{RE} = Exploit + EnvirP + MC + Exploit*MC$$

Contrast =

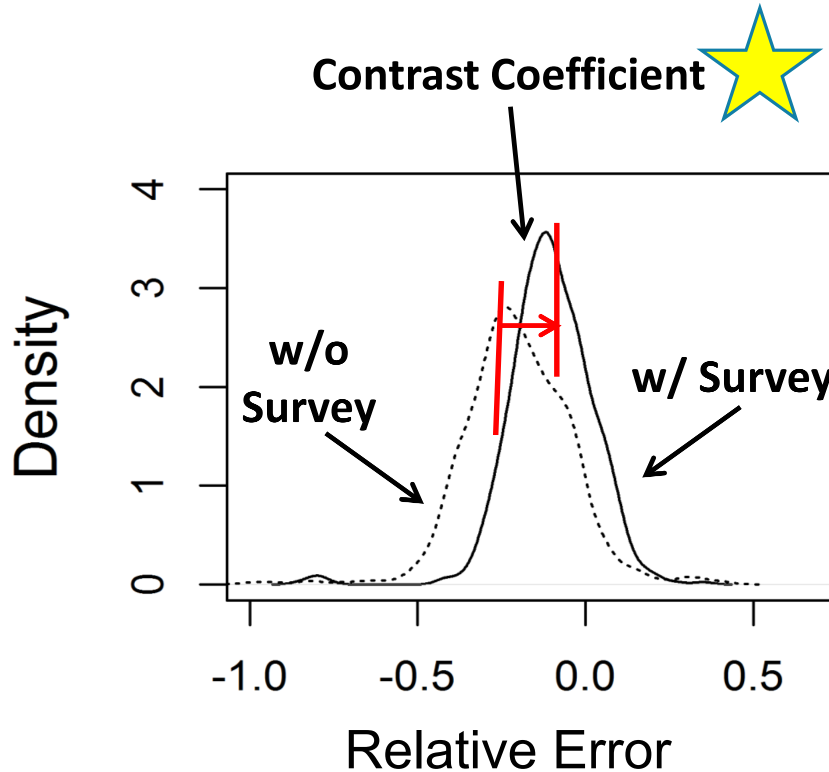
difference between factor effects on RE values

Benefit =

test specific hypothesis

Example hypothesis

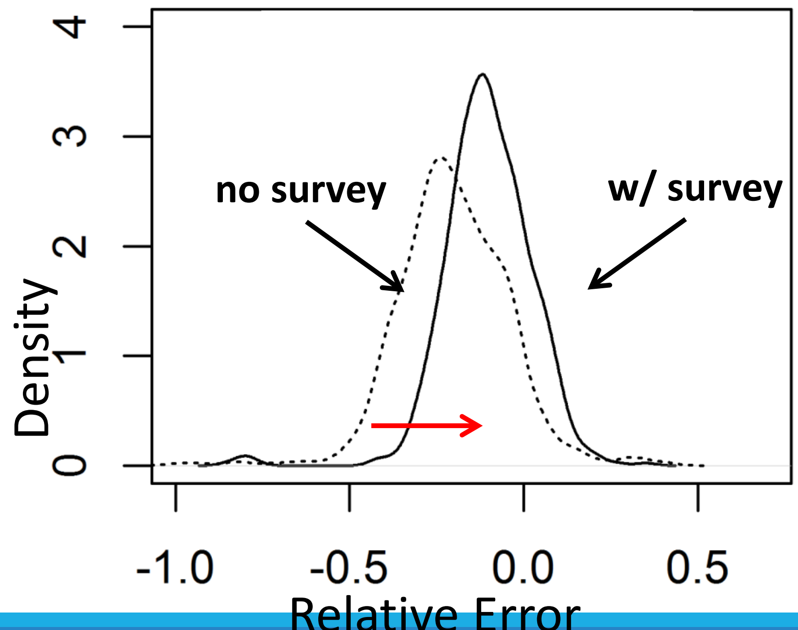
- MCs with survey data have less bias than those without
- How big and what direction is the contrast coefficient?



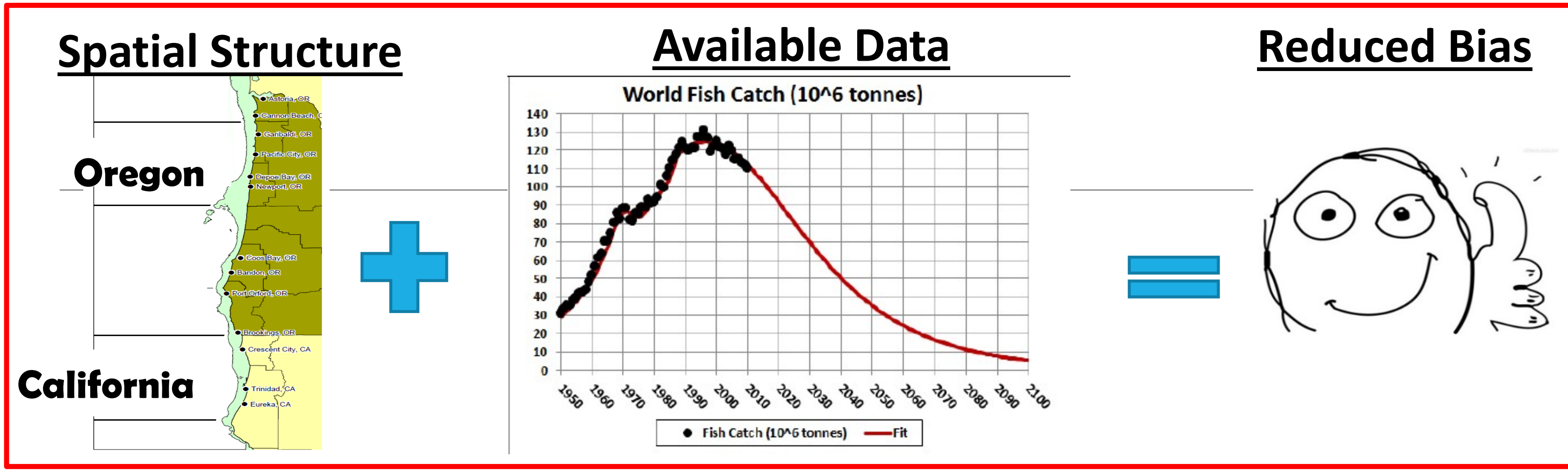
Contrast Table

Table 3. Top 20 contrasts for model coefficients for the relative error of $SSB_{Current}$ estimates.

Rank	Contrast	Factor level	ExpRate	SpStru	EnvInd	SurData	Coefficient
1	2.S.nE : 1.S – 2.nS.nE : 1.nS	F_M				A	0.1984
2	2.S.E : 2.nS.E – 1.S : 1.nS	F_M		A	A		0.1820
3	$F_I - F_M$	$MC_{2.nS.nE}$	×				0.1394
4	2.S.nE : 1.S – 2.nS.nE : 1.nS	F_C				A	0.1348
5	$F_I - F_M$	$MC_{1.nS}$	×				0.1158
6	$F_M - F_C$	$MC_{1.nS}$	×				0.1134
7	2.S.nE – 2.nS.nE	F_M				A	0.1052
8	2.S.nE : 2.nS.nE – 1.S : 1.nS	F_M		A			0.1046
9	2.S.nE : 1.S – 2.nS.nE : 1.nS	F_I				A	0.0967
10	$F_I - F_M$	$MC_{1.nS}$	×				0.0954



Statistical Support for Hypothesis 1:



Percentage of contrasts that reduce bias when testing the different estimation model factors

	$SSB_{Current}$
2-Regions SS Models	56 %
Having Survey Data	89 %
Having an E. Index	66 %

Having survey data tends to reduce bias more often than other factors

Contrast Table: Effect of *Exploit (F)* on Bias

Table 3. Top 20 contrasts for model coefficients for the relative error of $SSB_{Current}$ estimates.

Rank	Contrast	Factor level	ExpRate	SpStru	EnvInd	SurData	Coefficient
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3	$F_I - F_M$	$MC_{2.nS.nE}$	×				0.1394
4	2.S.nE : 1.S – 2.nS.nE : 1.nS	F_C				A	0.1348
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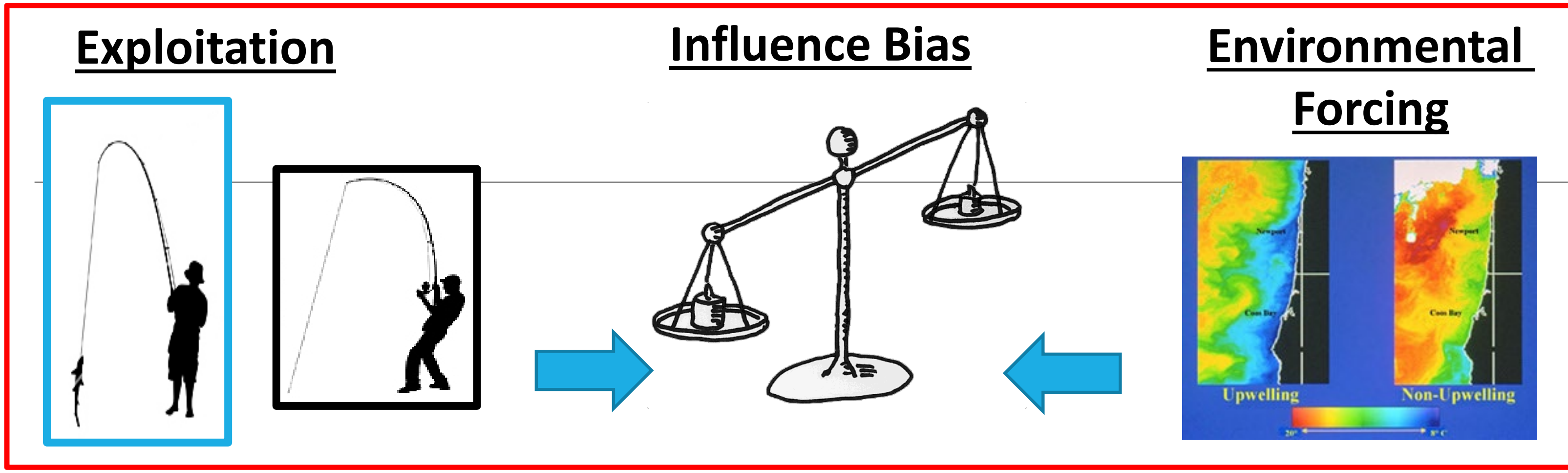
7	2.S.nE – 2.nS.nE	F_M				A	0.1052
8	2.S.nE : 2.nS.nE – 1.S : 1.nS	F_M		A			0.1046
9	2.S.nE : 1.S – 2.nS.nE : 1.nS	F_I				A	0.0967
10	$F_I - F_M$	$MC_{1.nS}$	×				0.0954

Statistical Support for Hypothesis 2:



Number of top ranked contrasts involving population dynamics factors

	$SSB_{Current}$
# of Top Contrast Examined	20
# of *Exploit* Contrasts	6
# of *EnvirP* Contrasts	0

* *EnvirP* is relatively unimportant compared to *Exploit* *

Overall Summary
Support for Hypotheses

Hypothesis 1: Spatial Structure and Data Availability

- Having survey data & an environmental index within a spatially structured stock assessment will produce the least biased estimate.

Hypothesis 2: Exploitation and Environmental Forcing

- Exploitation histories have some effect on bias
- Environmental forcing has little effect on bias

Simulation Conclusions

1. Ignoring spatial structure and environmental influences when estimating biomass for a spatially structured stock may result in bias and imprecise assessment results

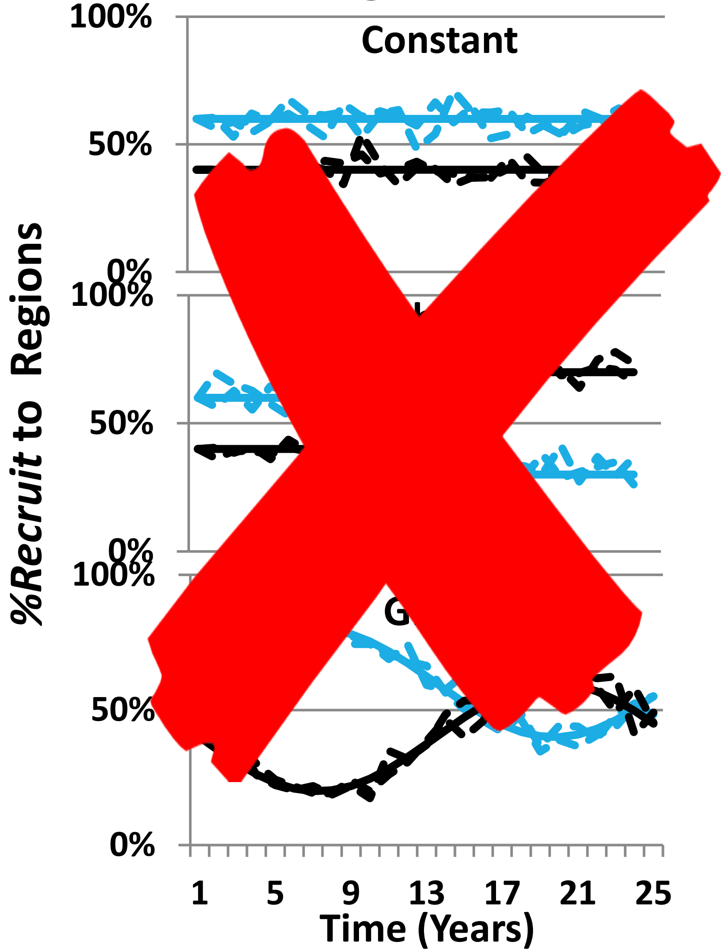
2. More precise biomass estimates can increase the effectiveness of sustauinable management

3. Findings support the importance of spatially structured survey data collection and usage in an assessment

4. **In the real world, data is out there but population dynamics relationships need to be explored and the effect quantified before it can be used in management**

EnvirP (E)

Environmental patterns influencing *%Recruit*



Not so easy to get this relationship in the real world, things are always changing!

Recap

So now you know:

- What is spatial structure?
- Drivers of spatial structure
- How does it affect management?
- Ways to include spatial structure in management?

Single species assessments & incorporating space

- Example in Simulation

Want to read up on this stuff?

Cope, J.M., and Punt, A.E. 2011. Reconciling stock assessment and management scales under conditions of spatially varying catch histories. Fisheries Research **107**(1–3): 22-38.

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Space Oddity: Recent advances incorporating spatial processes in the fishery stock assessment and management interface. Canadian Journal of Fisheries and Aquatic Sciences, 2017, 74:iii-iii, https://doi.org/10.1139/cjfas-2017-0401 (this is an entire special issue of articles)

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Interested in learning more? Want to Chat?

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Check out my website:

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