Simulation testing stock assessments of spatially-structured Atlantic bluefin tuna stocks

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Spatial Stock Assessment Models

CAPAM Spatial Stock Assessment Workshop

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modified from Brian Skerry

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Contributors	Gavin Fay, Ben Galuardi, Clay Porch, Matt Lauretta, John Walter, J.-J. Maguire, Tristan Rouyer, Ai Kimoto, Dave Secor, ICCAT Bluefin Tuna Working Group
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Outline

1. Introduction

What we know about Atlantic bluefin tuna stock mixing

Assumptions of the current stock assessment and management paradigm

2. Methods

How the operating model simulates mixed Atlantic bluefin tuna stocks

How the operating model and estimation models differ structurally

3. Results

Operating model representation of the known system

Performance of estimation models

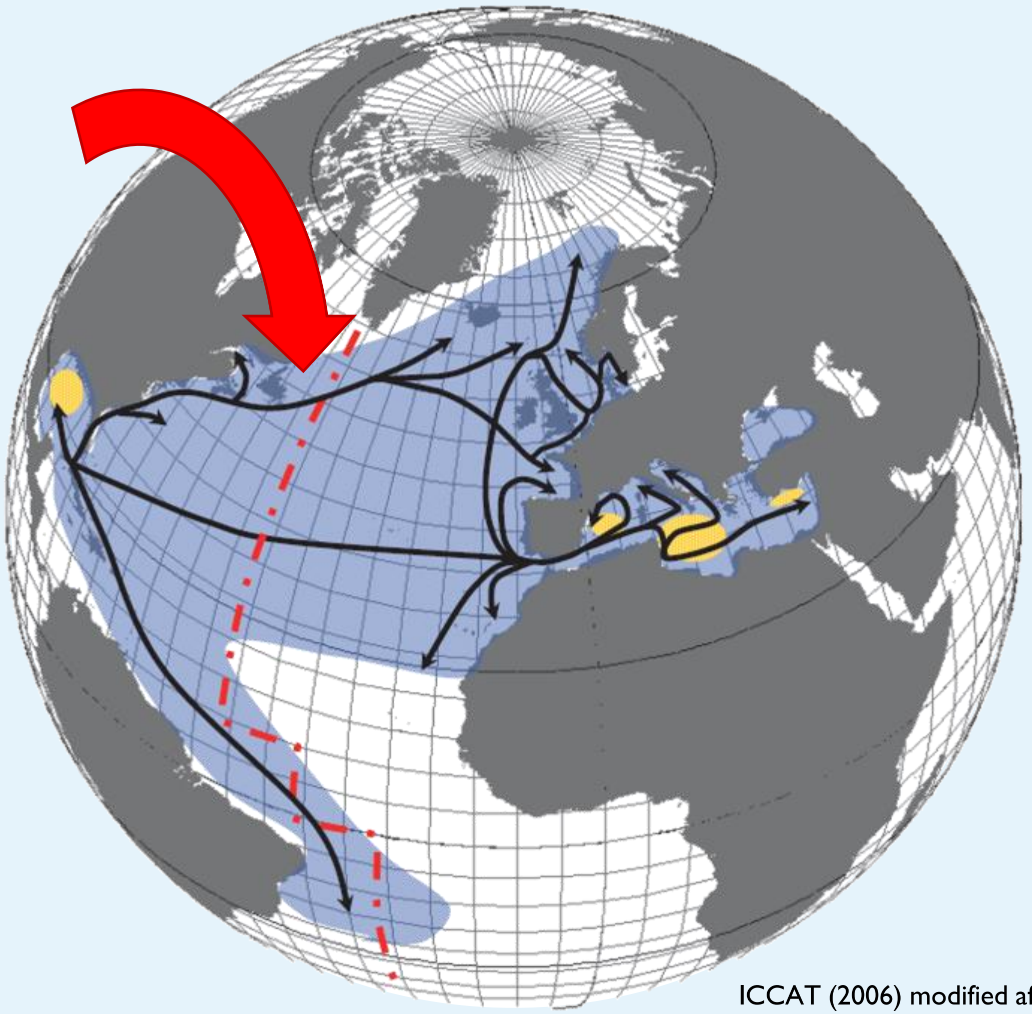
4. Discussion

Why the estimation models performed the way they did

What this means for Atlantic bluefin tuna management

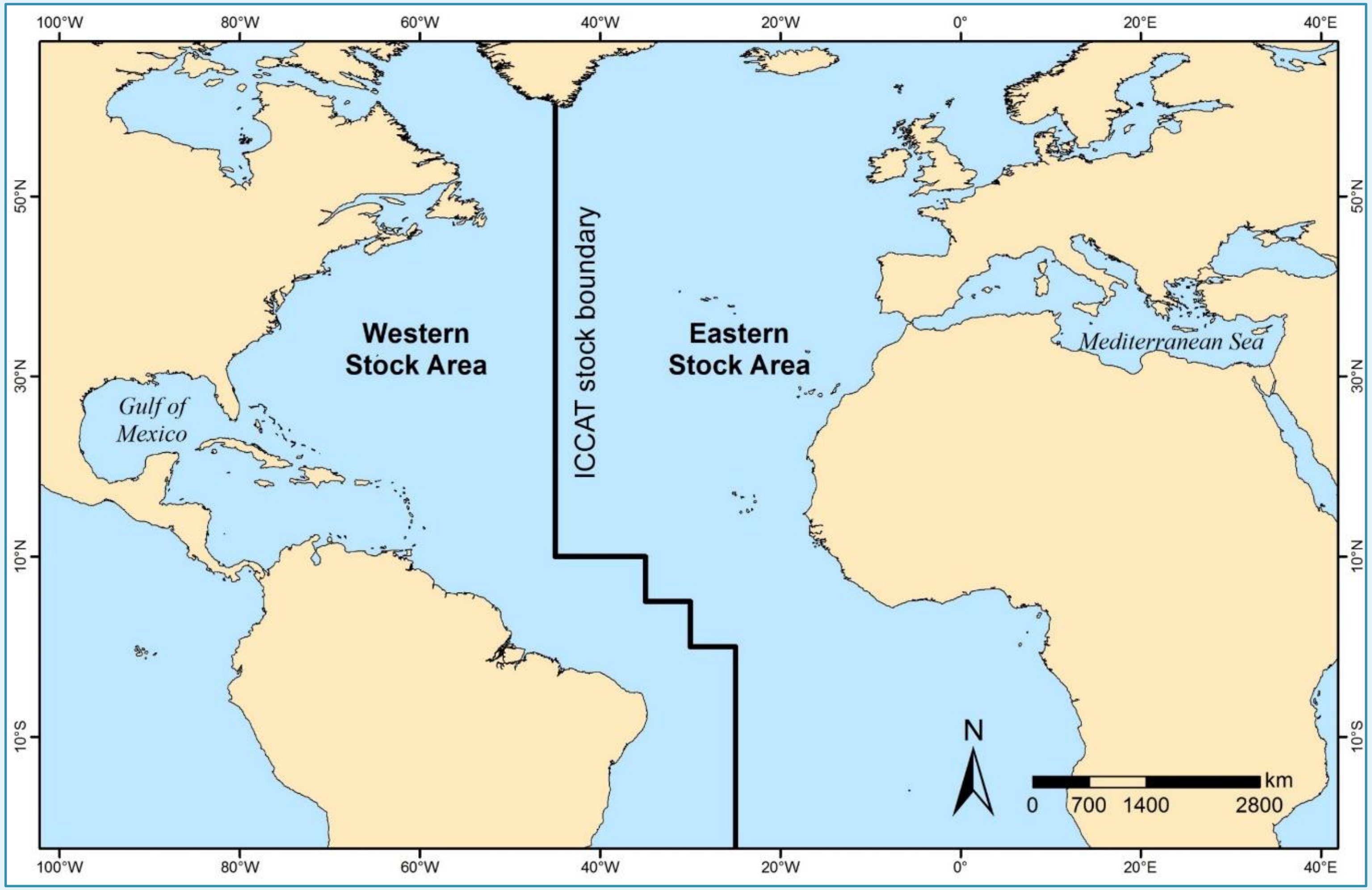
What we know about Atlantic bluefin tuna stock mixing

- Highly-migratory species
- 2 populations: west and east
- Spawning site fidelity
  - Western population: Gulf of Mexico (& Slope Sea?)
  - Eastern population: Mediterranean Sea
- Mixing of populations in North Atlantic feeding grounds (fall)
  - Varies across space, time, and demographic groups



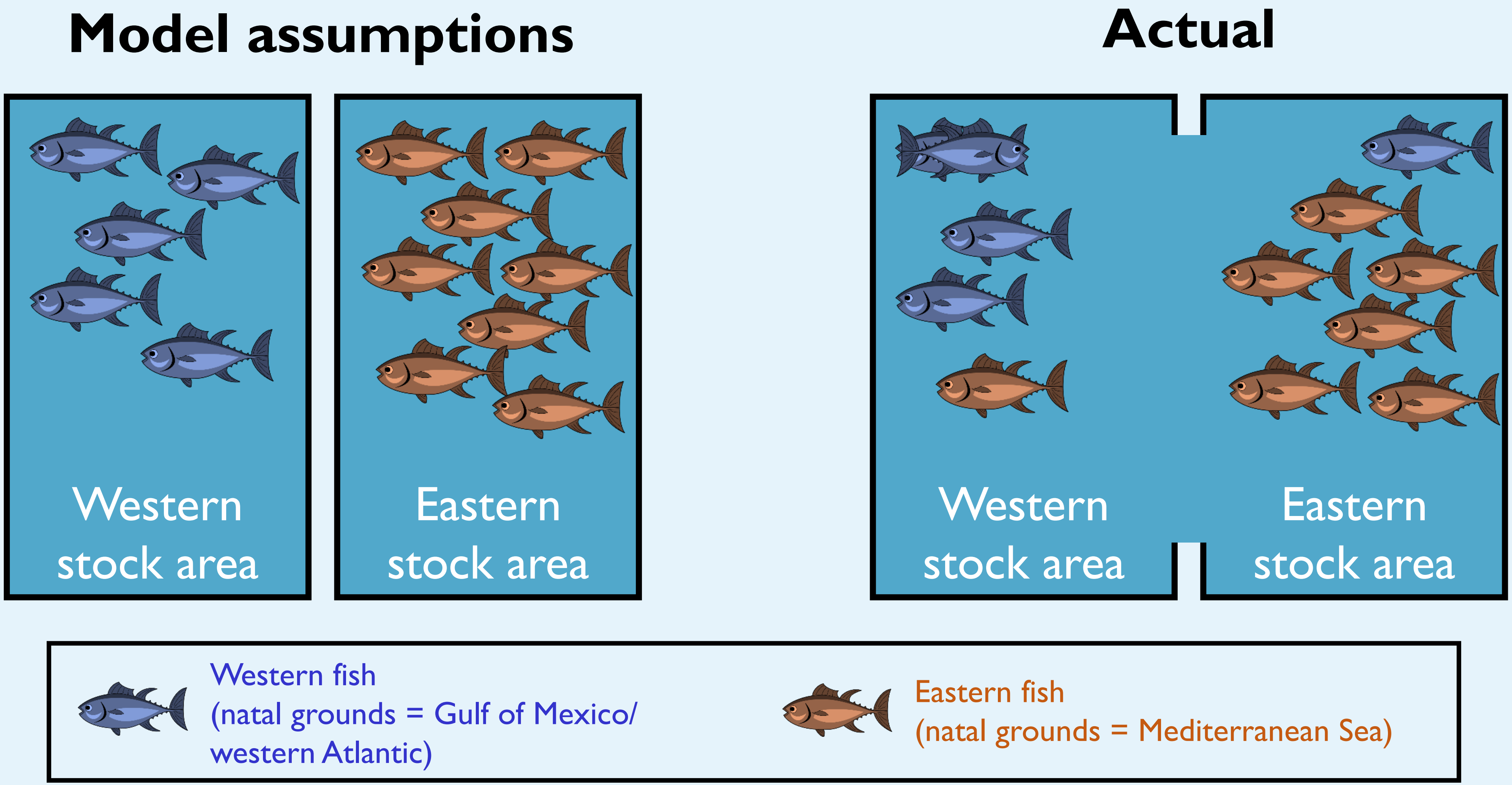
ICCAT (2006) modified after Fromentin & Powers (2005)

The current stock assessment and management paradigm



- Two-stock management since 1980s
- Separate stock assessments using age-based models (VPA, SS)
  - Assume closed unit stocks (negligible mixing)

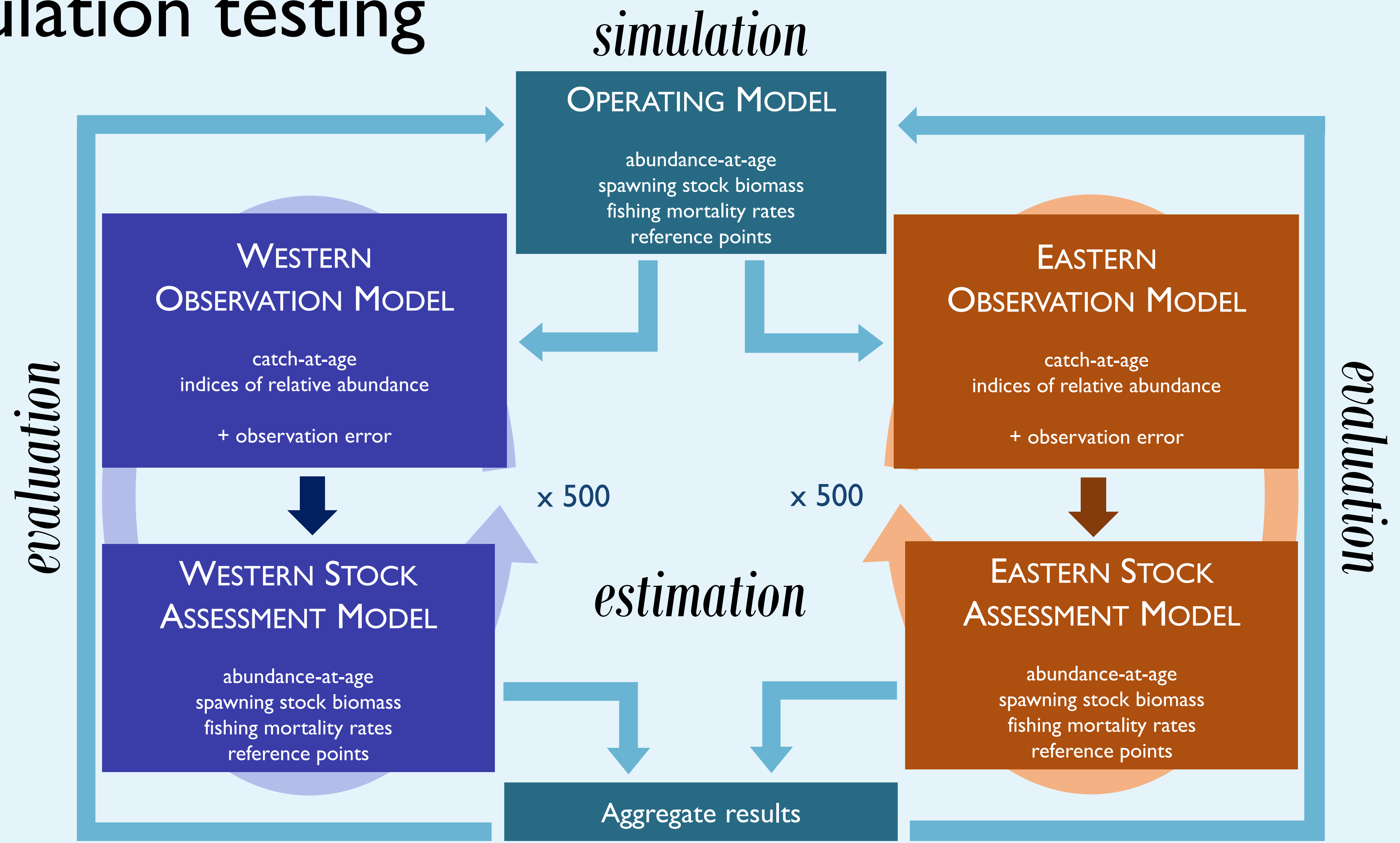
The current stock assessment and management paradigm



Research Question

How does model misspecification of spatial structure and mixing dynamics affect stock assessment results of Atlantic bluefin tuna?

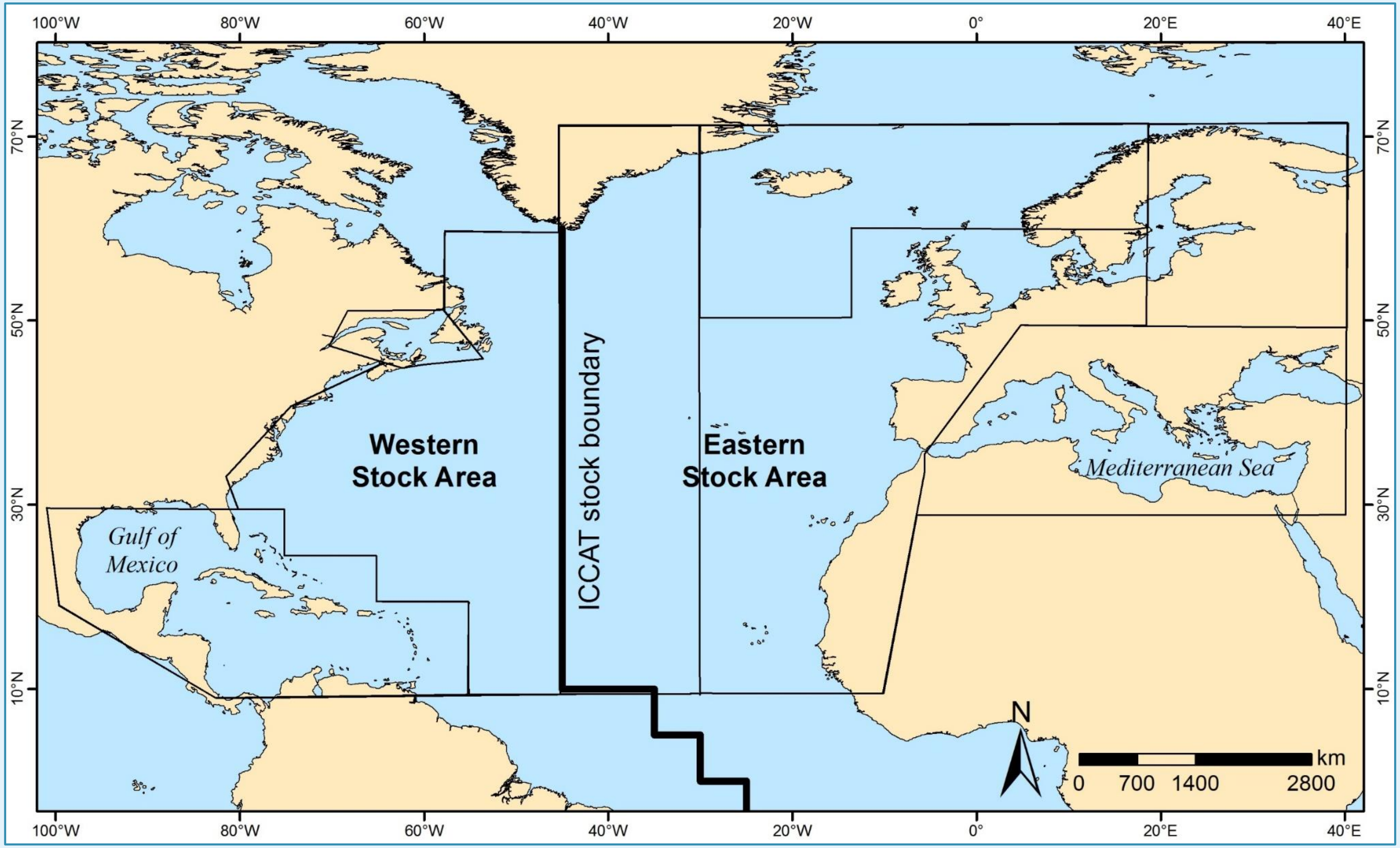
Simulation testing



Operating model (adapted from Kerr et al. 2018)

Structure
- 2 populations (west & east)
- 29 age classes
- 7 geographic zones
- 4 seasonal quarters
- 1974 to 2015
- Overlap movement

Conditioning
- Time-constant movement matrices based on telemetry data (Galuardi et al. 2018)
- Recruitment, fishing mortality, selectivity, catchability parameters from 2017 stock assessment

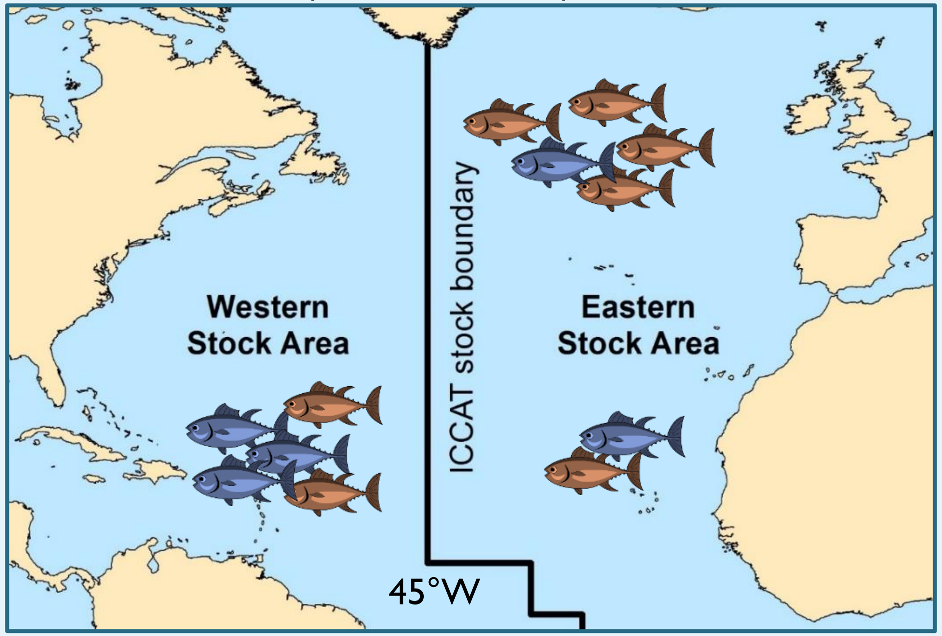


Operating Model

abundance-at-age
spawning stock biomass
fishing mortality rates
reference points

"Stock View"

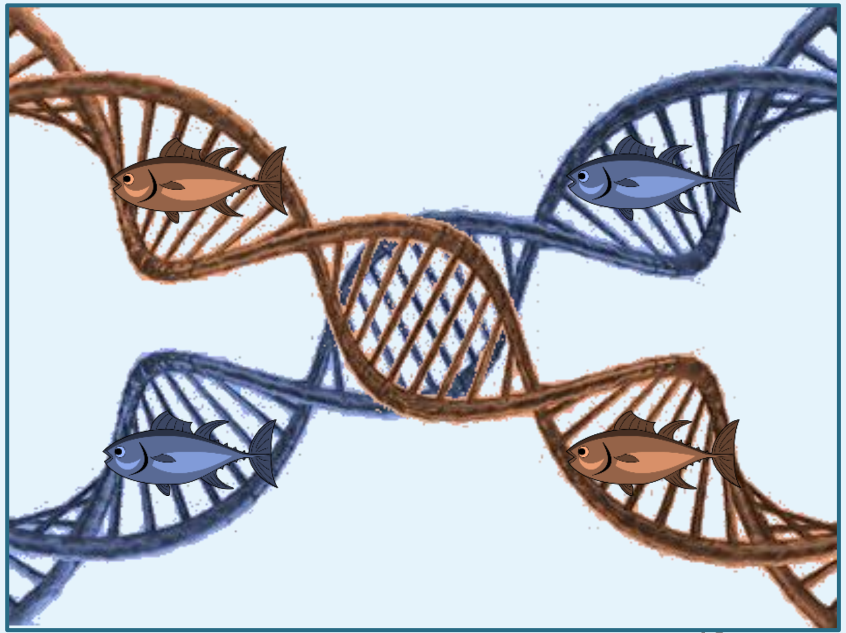
2 **geographically-distinct** fish groups (ICCAT 1981)



Note: the **stock** view contains fish from *both* **populations**

"Population View"

2 **genetically-distinct** fish groups



Observation model

Catch-at-age

$$C_{y,a,s} = \left(\sum_{\substack{West\ z=1:3 \\ East\ z=4:7}} \sum_{q=1}^{4} \sum_{p=1}^{2} N_{y,a,z,q,p} \frac{F_{y,a,z,q}}{F_{y,a,z,q} + M_{a,q,p}} \left[1 - e^{-\left(F_{y,a,z,q} + M_{a,q,p}\right)} \right] \right) e^{\varepsilon_{y,a,s}}$$

Indices of relative abundance

$$I_{y,g} = \left(\sum_{\substack{West\ z=1:3 \\ East\ z=4:7}} \sum_{a=1}^{29} \sum_{p=1}^{2} S_{a,g} N_{y,a,z,q,p} W_{a,p} Q_g \right) e^{\varepsilon_{y,g}}$$

Relative age composition of indices

$$P_{y,a,g,s} = \left(\sum_{\substack{West\ z=1:3 \\ East\ z=4:7}} \sum_{q=1}^{4} \sum_{p=1}^{2} N_{y,a,z,q,p} \frac{E_{y,g} Q_g S_{a,g}}{E_{y,g} Q_g S_{a,g} + M_{a,q,p}} \left[1 - e^{-\left(E_{y,g} Q_g S_{a,g} + M_{a,q,p}\right)} \right] \right) e^{\varepsilon_{y,a,s}}$$

Observation error $\varepsilon \sim N(0, \sigma^2)$

where $\sigma = \sqrt{\frac{1}{Y} \frac{1}{A} \sum_{y}^{Y} \sum_{a}^{A} [\ln x_i - \ln \hat{x}_i]^2}$

C	catch	W	weight
N	abundance	y	year
F	fishing mortality rate	z	zone
M	natural mortality rate	g	fleet
E	effort	q	seasonal quarter
S	selectivity	p	population
Q	catchability		

Estimation model

- VPA-2BOX (Porch 2003, Porch et al. 2001)
- Single stock calibrated VPA
- Same model configuration as 2017 benchmark stock assessment

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+-----------------------------------------------------------------------------+
| Program VPA-2BOX.F90, Version 4.01 (April 15, 2017)                          |
|                                                                             |
| A virtual population analysis tool that uses catch-at-age, indices of      |
| abundance, indices of mortality rates, and tag-recoveries to estimate      |
| the abundance and mortality of one or two (intermixing) populations.       |
|                                                                             |
| based on the methods of                                                     |
|   Porch, C. E., Turner, S. C., and Powers, J. E. 2001                       |
|   Virtual population analyses of Atlantic bluefin tuna with alternative    |
|   models of transatlantic migration: 1970-1997. Int. Comm. Conserv. Atl.   |
|   Tunas, Coll. Vol. Sci. Pap. 52: 1022-1045                                 |
|                                                                             |
| programmed by                                                               |
|   Clay E. Porch                                                             |
|   NOAA Fisheries                                                            |
|   75 Virginia Beach Drive                                                   |
|   Miami, Fl 33149 (USA)                                                     |
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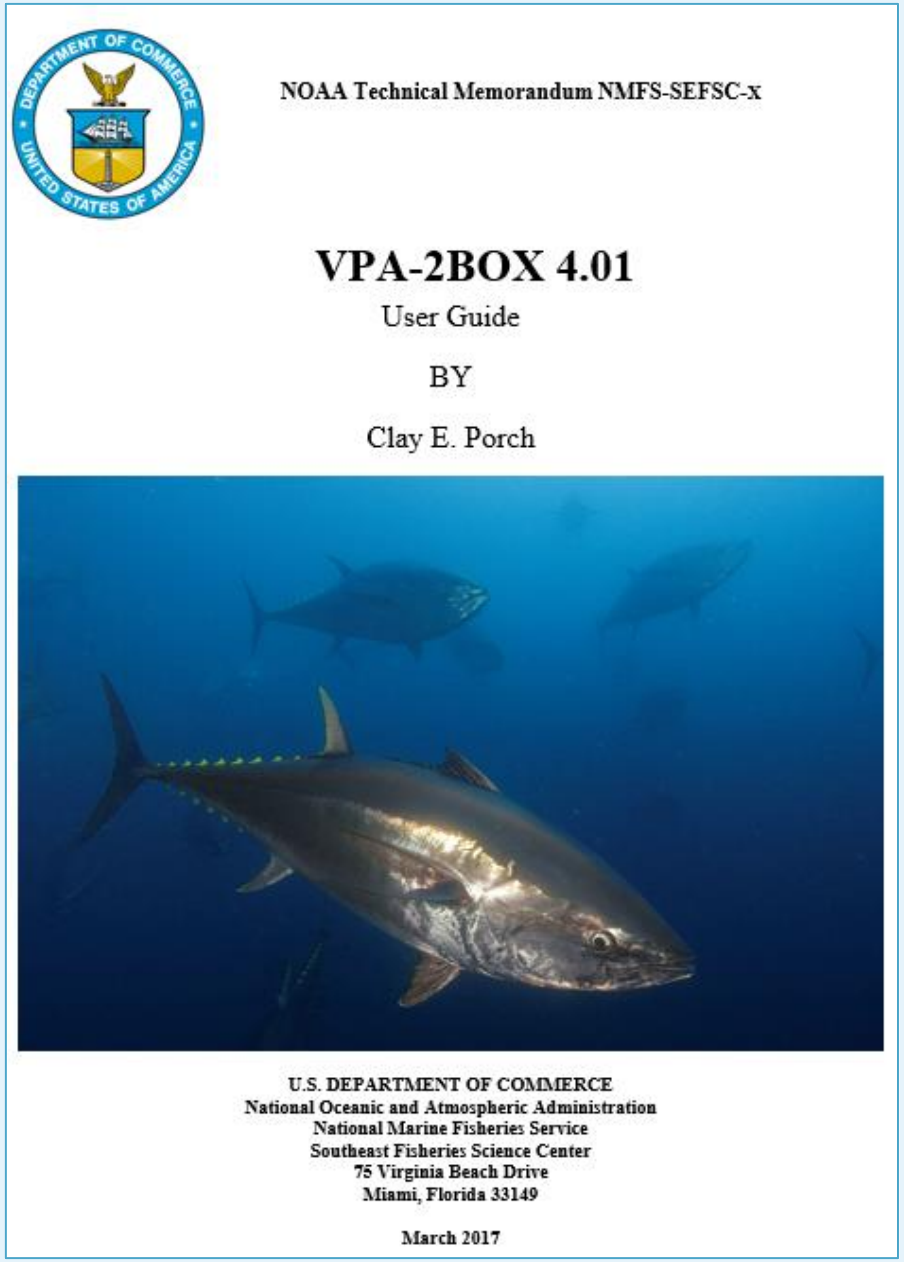
NOAA Technical Memorandum NMFS-SEFSC-x

VPA-2BOX 4.01

User Guide

BY

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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Science Center
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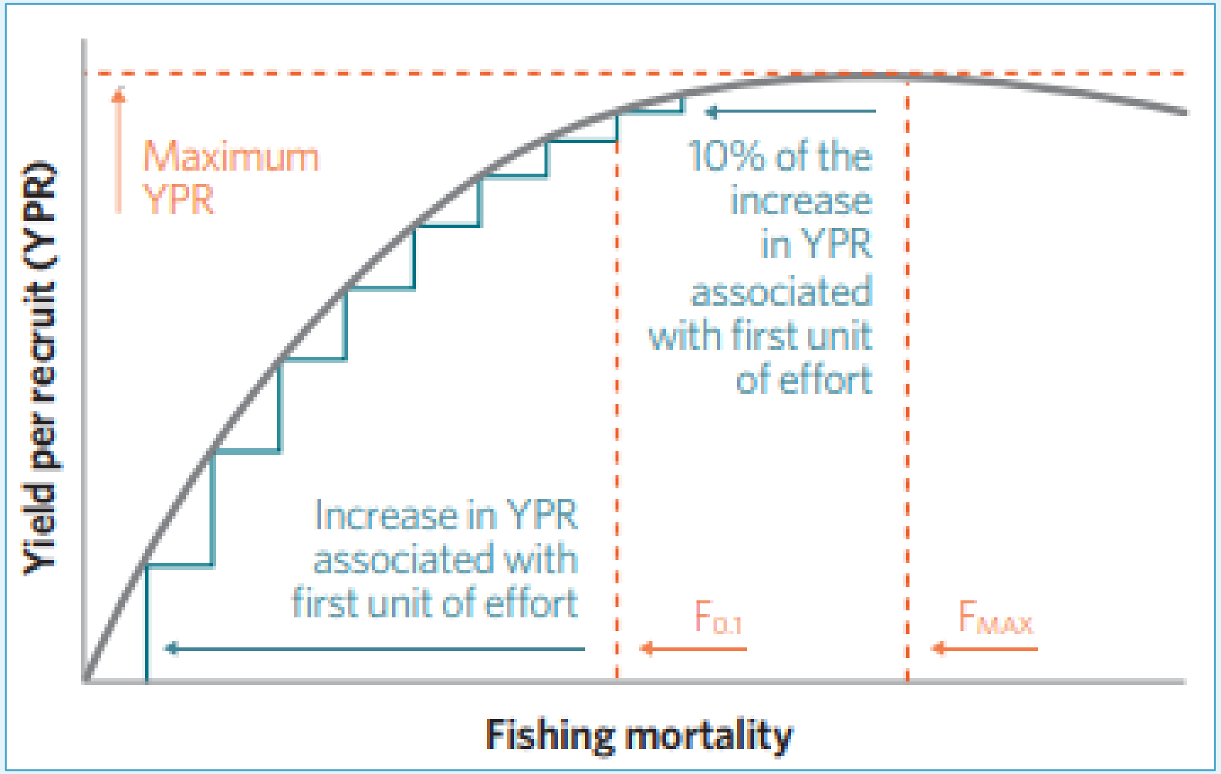
March 2017

$F_{0.1}$ reference point

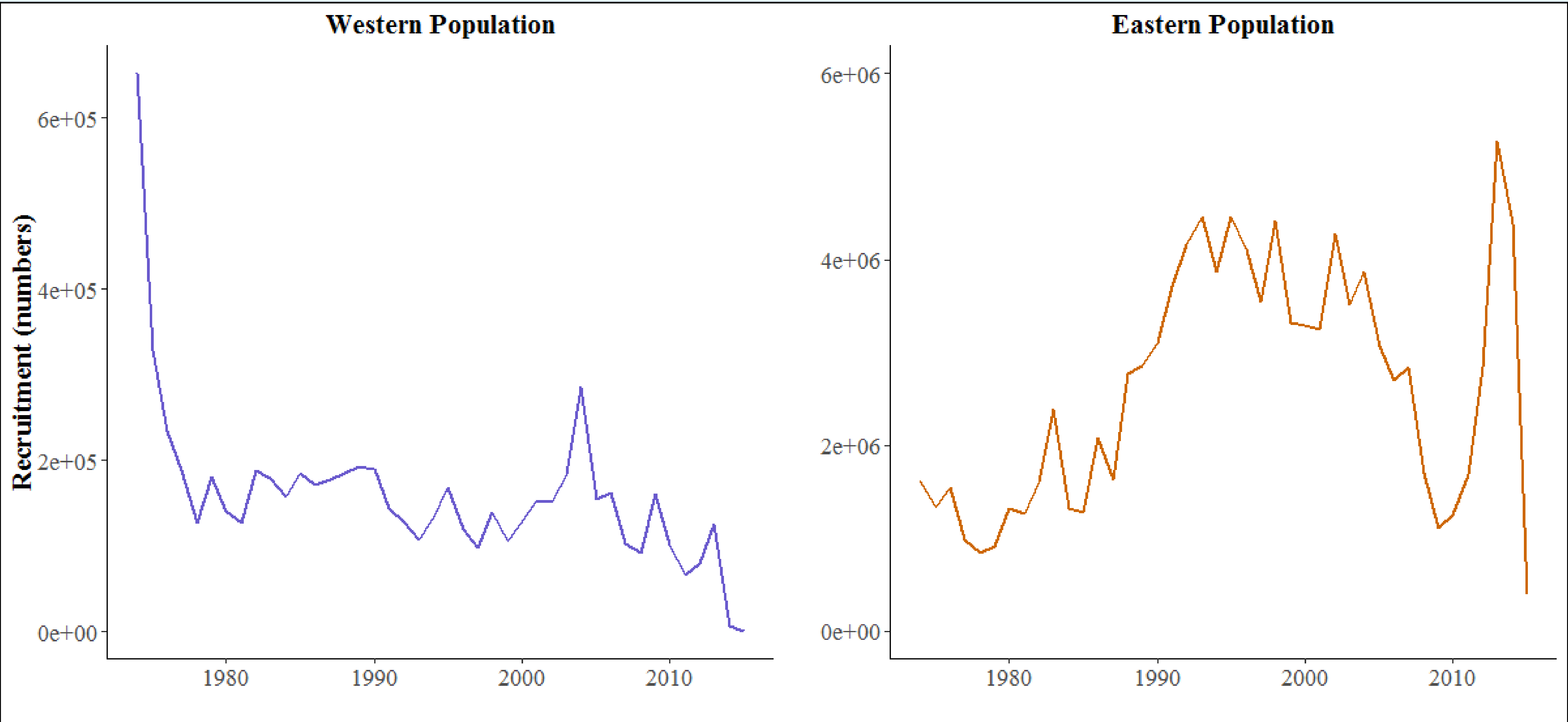
- $F_{0.1}$ calculated using partial recruitment P_a from operating model and estimation models
- Compared to $F_{current}$ (2012-2014) of reference ages (ages where $P_a \geq 0.8$)

$$\frac{F_{current}}{F_{0.1}} \quad \begin{array}{l} > 1 = \textit{overfishing occurring} \\ < 1 = \textit{overfishing NOT occurring} \end{array}$$

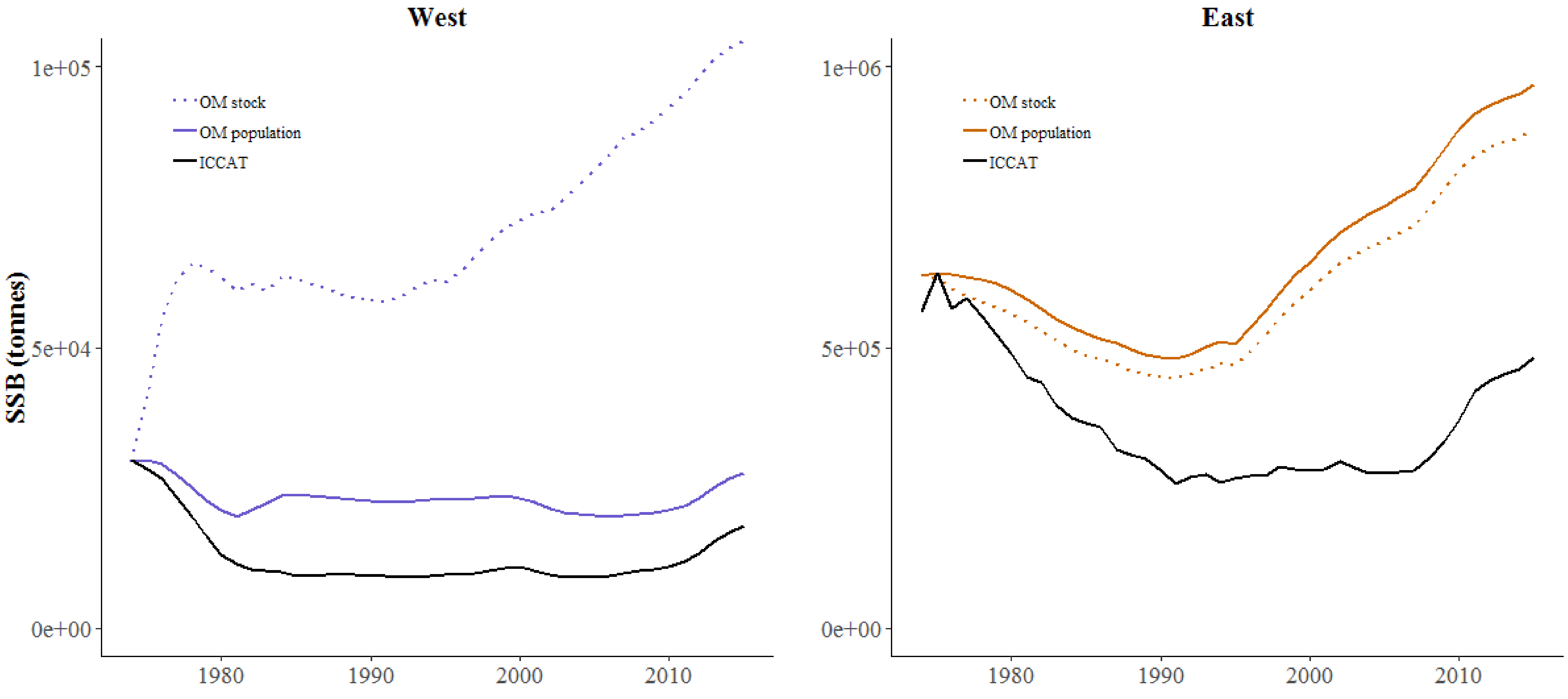


Pew Charitable Trusts, Cooper 2006

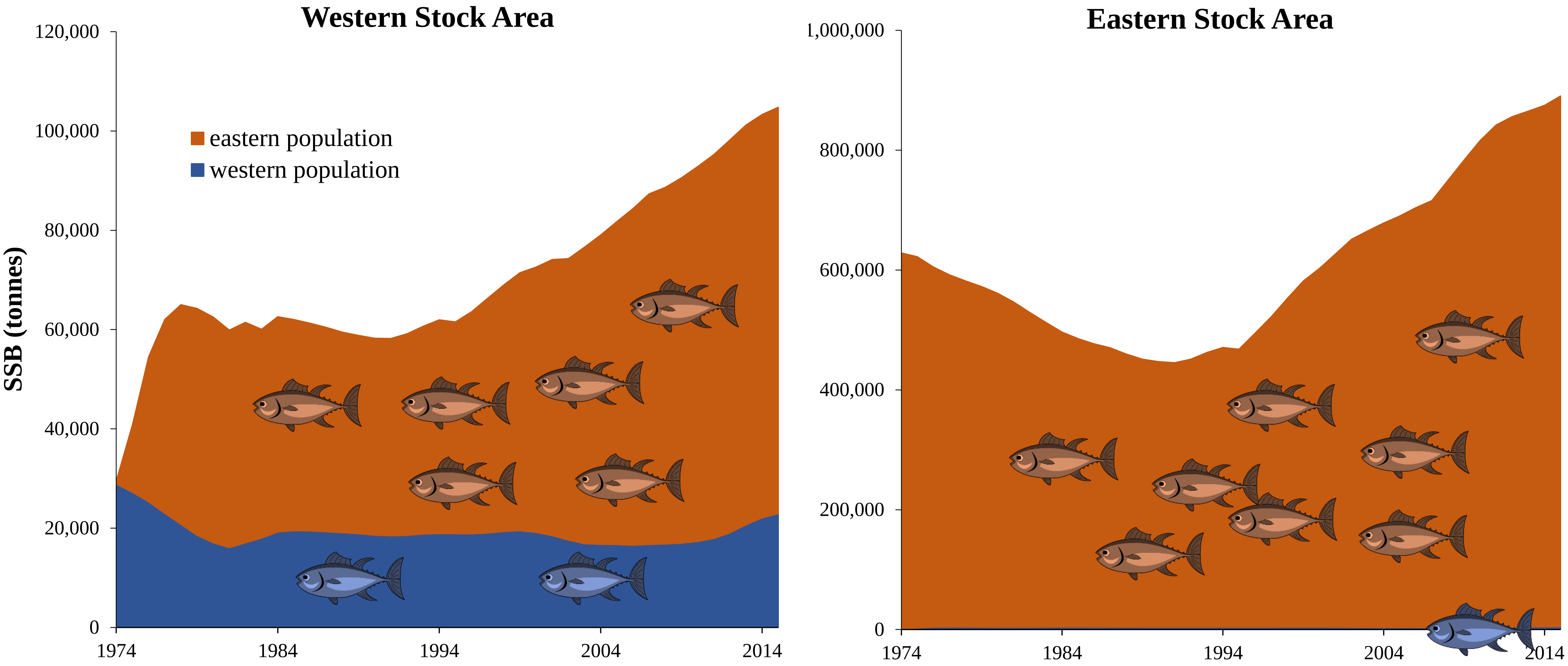
Operating model: Recruitment



Operating model: Spawning stock biomass



Operating model: Population mixing

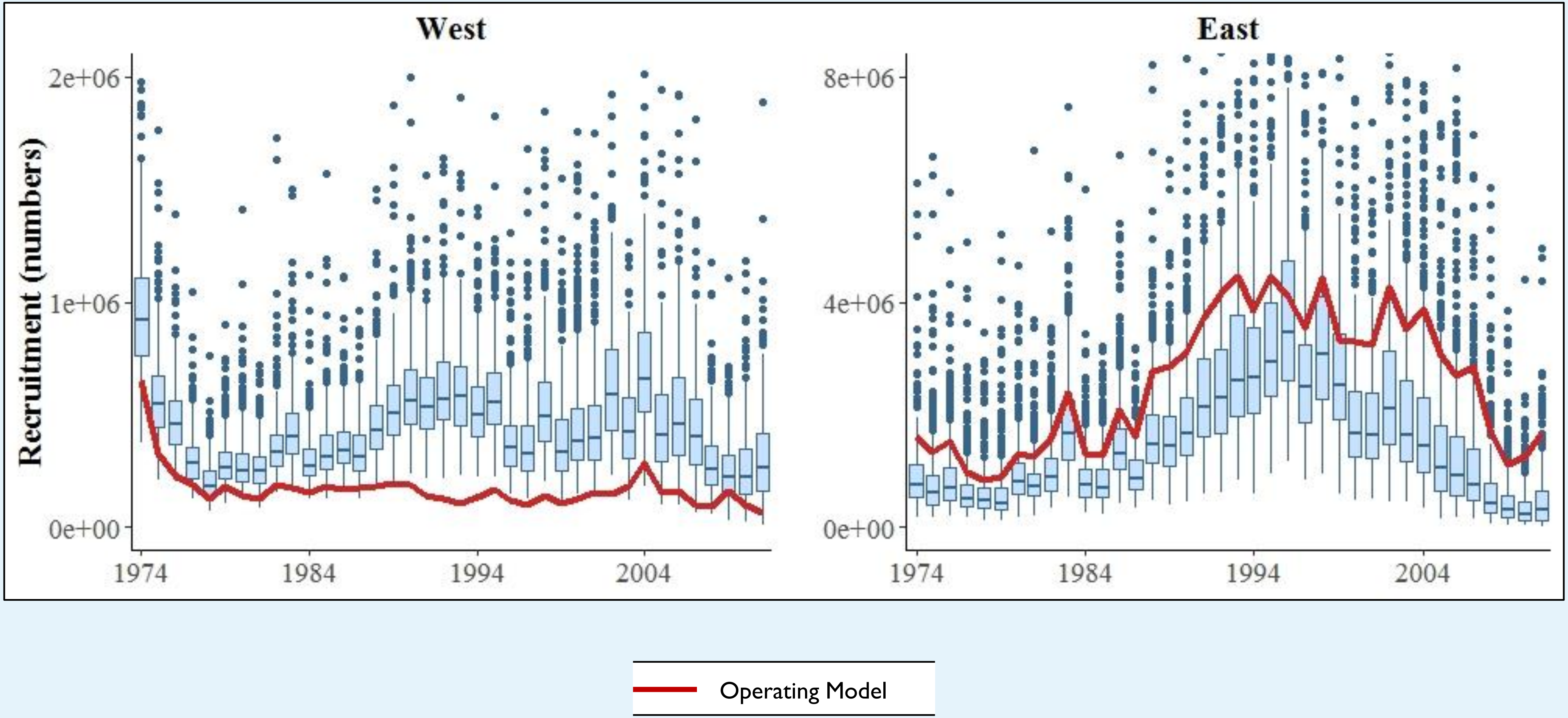


Estimation model: Convergence challenges

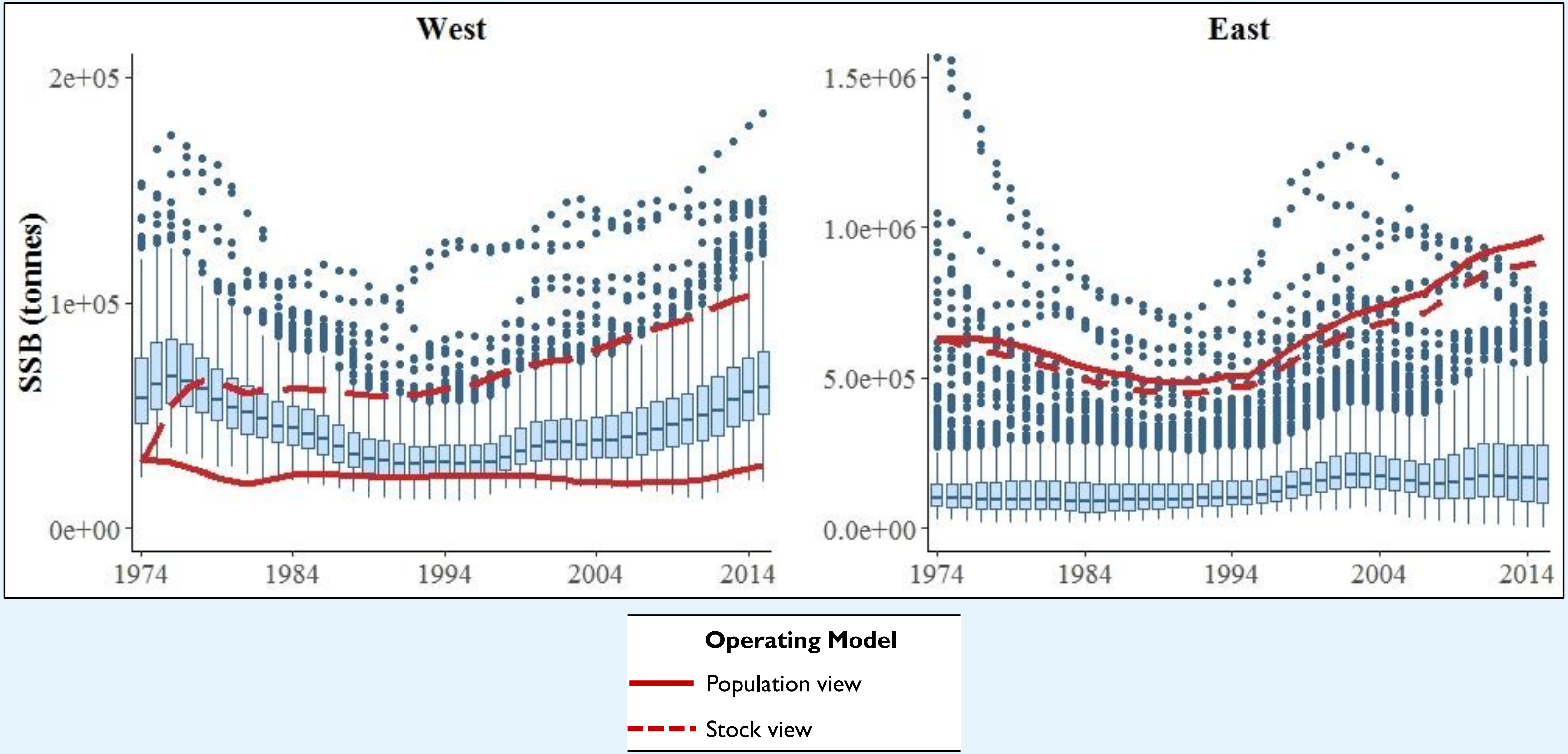
- Poor parameter estimation:
  - terminal F (west)
  - index variance scaling parameters (east)
- Similar problems as ICCAT Bluefin Tuna Working Group (Zarrad et al. 2018)
- Tested revised estimation model configurations

Stock	Estimation Model Configuration	Convergence Rate
West	ICCAT 2017	6%
	Revised	81%
East	ICCAT 2017	95%
	Revised	96%

Estimation model performance: Recruitment

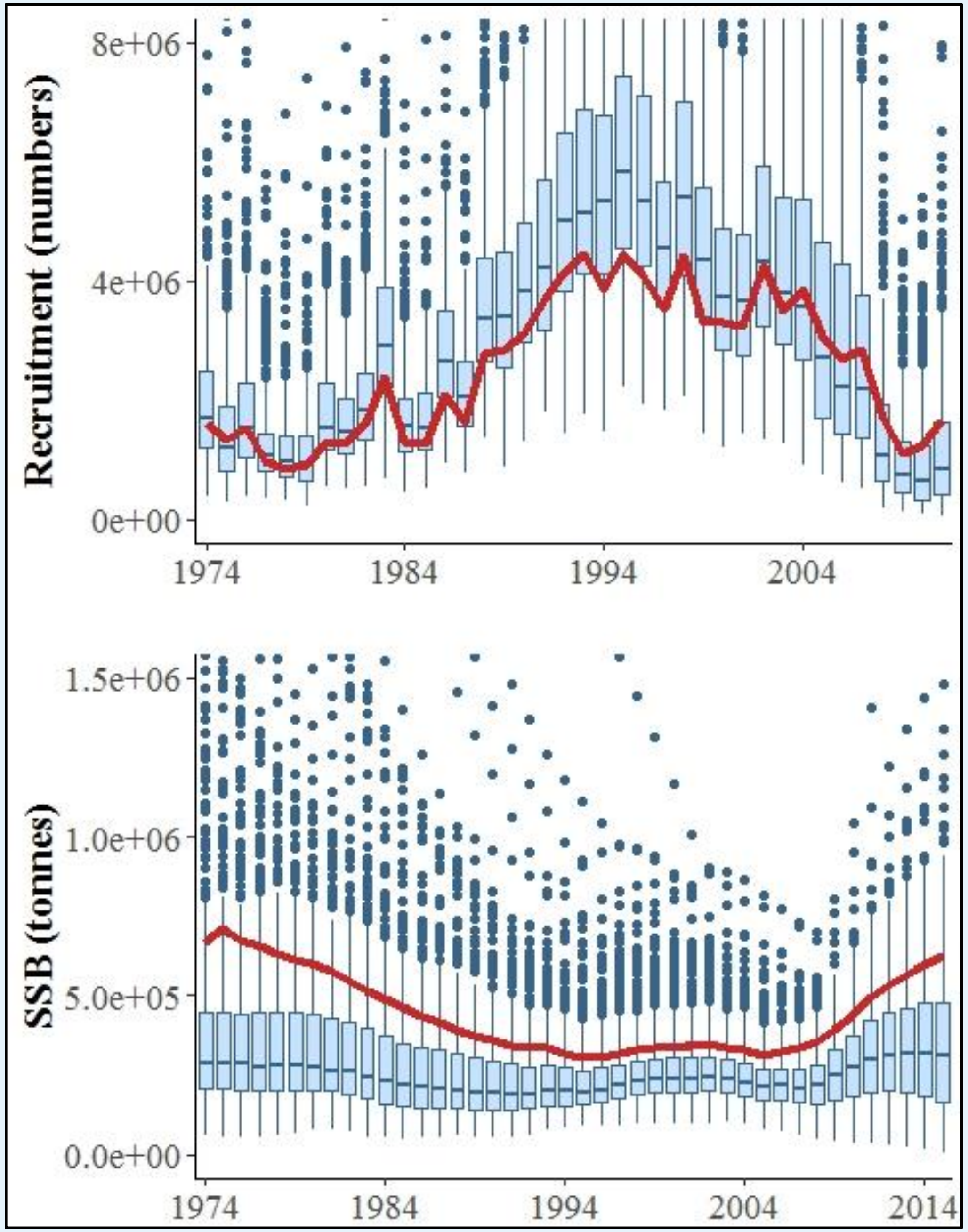


Estimation model performance: Spawning stock biomass



Eastern estimation model: Self-test

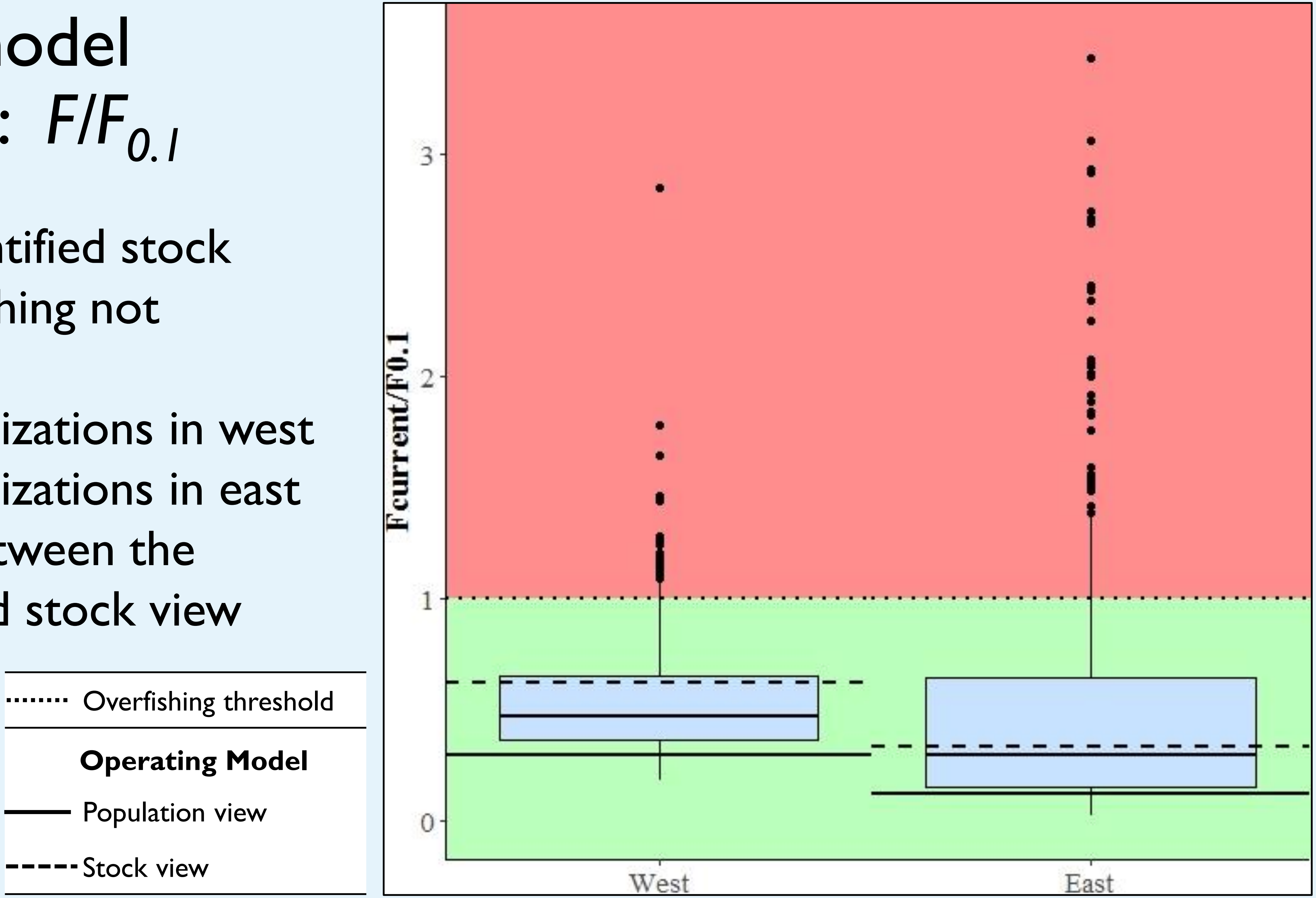
- Modification of operating model to eliminate spatial structure, seasonal structure, and fish movement for a "self-test" (Deroba et al. 2015)
- Percent relative estimation bias:
  - Recruitment: 60%
  - SSB: -30%
- Revealed additional limitations of VPA-2BOX
  - Poor estimation of terminal F for youngest ages
  - Supports previous findings on model instability (Zarrad et a. 2018)



Operating Model

Estimation model performance: $F/F_{0.1}$

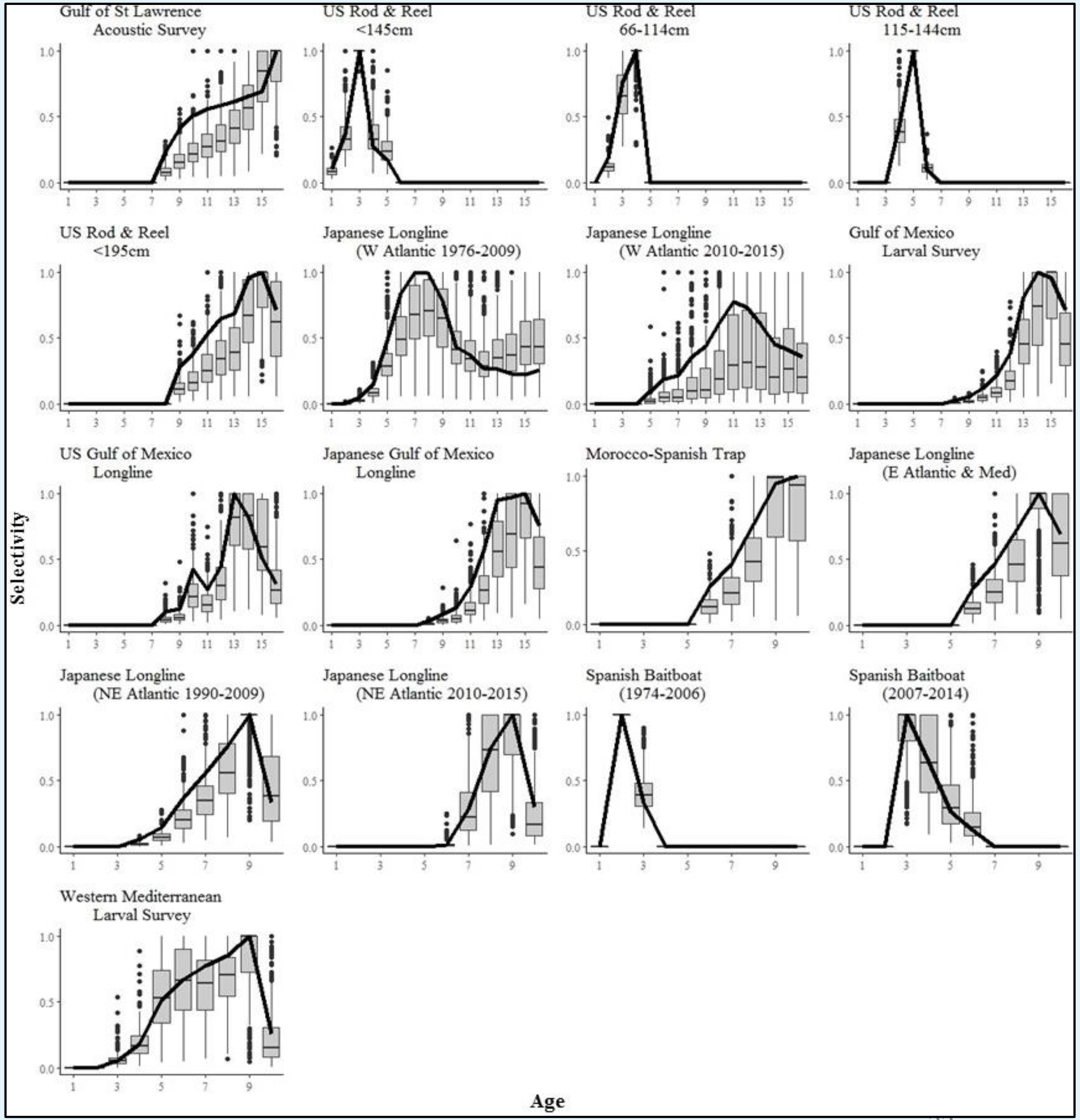
- Correctly identified stock status (overfishing not occurring) for
  - 94% of realizations in west
  - 85% of realizations in east
- Median fell between the population and stock view true values



Estimation model performance: $F/F_{0.1}$

- Problems with using F to evaluate model performance
  - Poor estimation of index selectivities-at-age
  - Apical F and age-averaged F incomparable between OM and EM

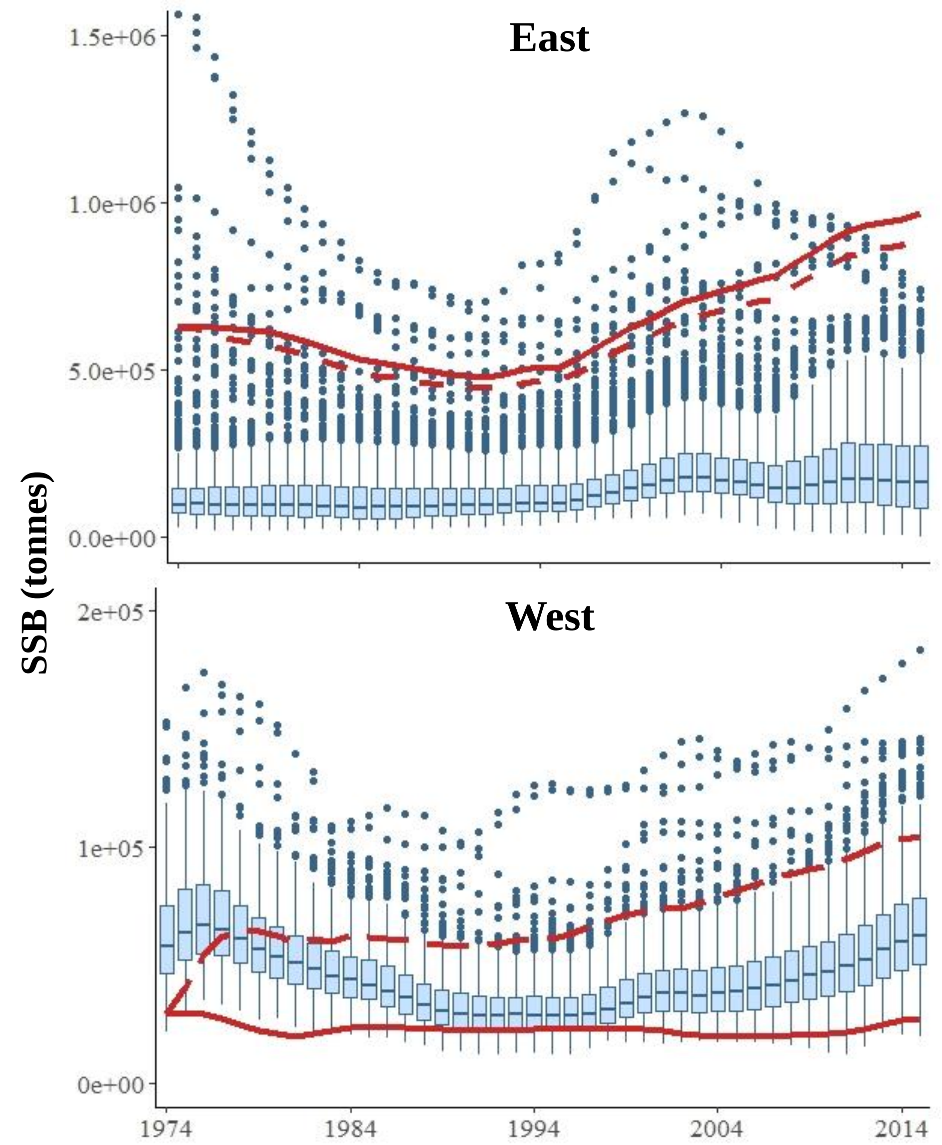
- Alleviated with ratio $F_{current}/F_{0.1}$
  - Same perception of selectivity in $F_{current}$ and $F_{0.1}$



Key findings

"Only the most naïve stock assessment biologist would actually believe he [or she] ever correctly specifies a model."

-Hilborn and Walters (1992), modified by M. Morse



Misspecification in **spatial structure** of operating and estimation models produces **structural error**, resulting in

Resilience:

underestimation of eastern population size may protect it from overfishing, but limit maximum sustainable exploitation

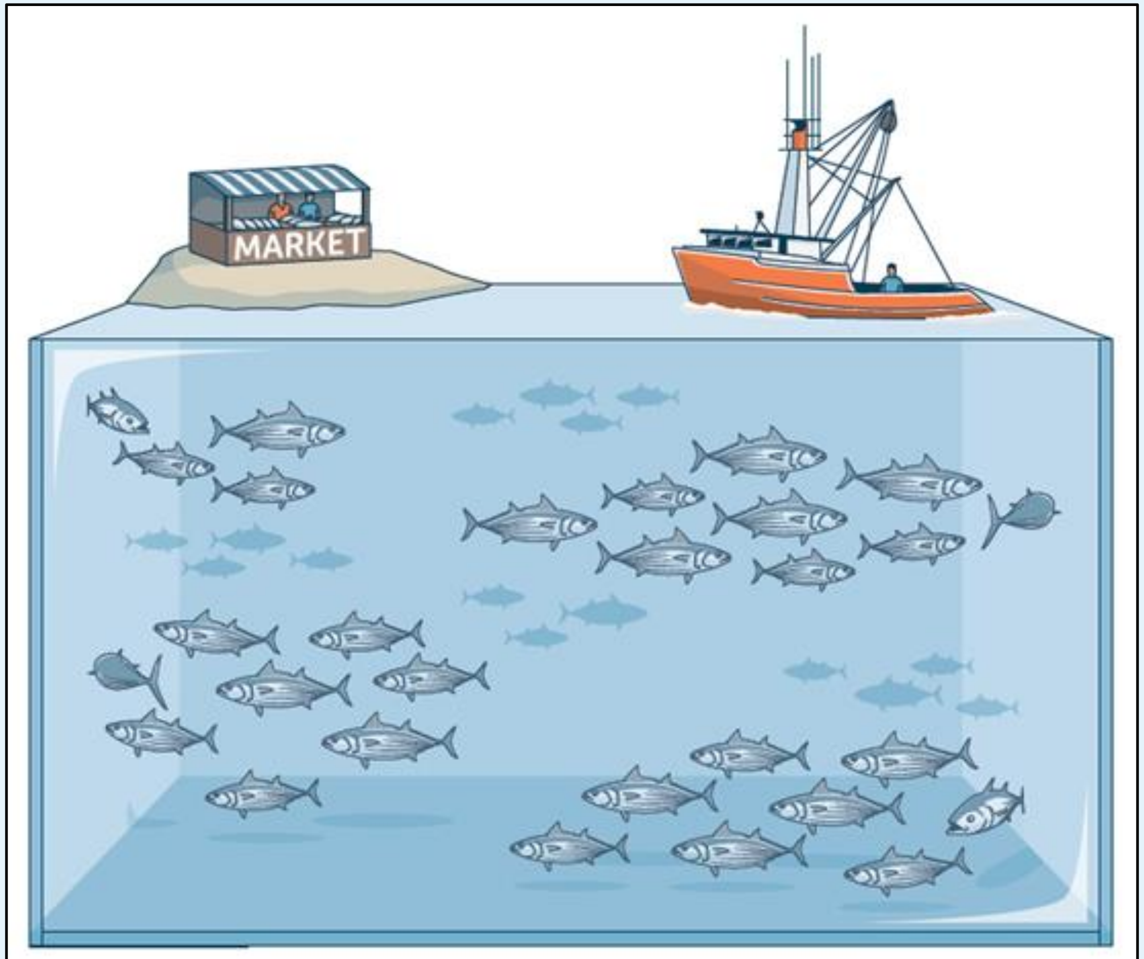
Vulnerability:

overestimation of western population size may increase risk of overfishing

Management implications

The VPA captures the stock size and stock status better than the population size

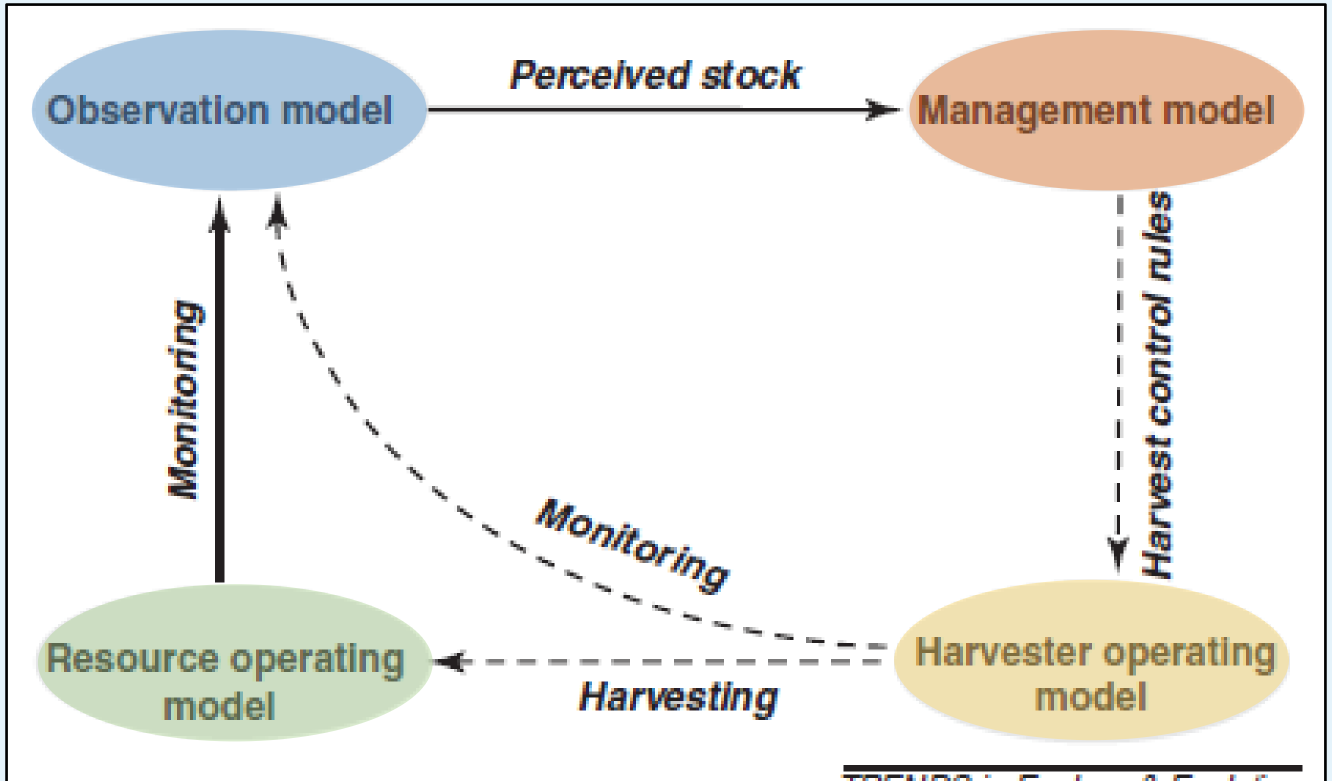
- *Effective* for understanding **current** and **short-term trends** in the resource available to fisheries (e.g., setting near-term quotas)
- *Effective* for understanding **current overfishing status** based on $F/F_{0.1}$ ratio
- *Ineffective* for **long-term projections, rebuilding,** or **population conservation** (requires accurate estimates of production)



Pew Charitable Trusts

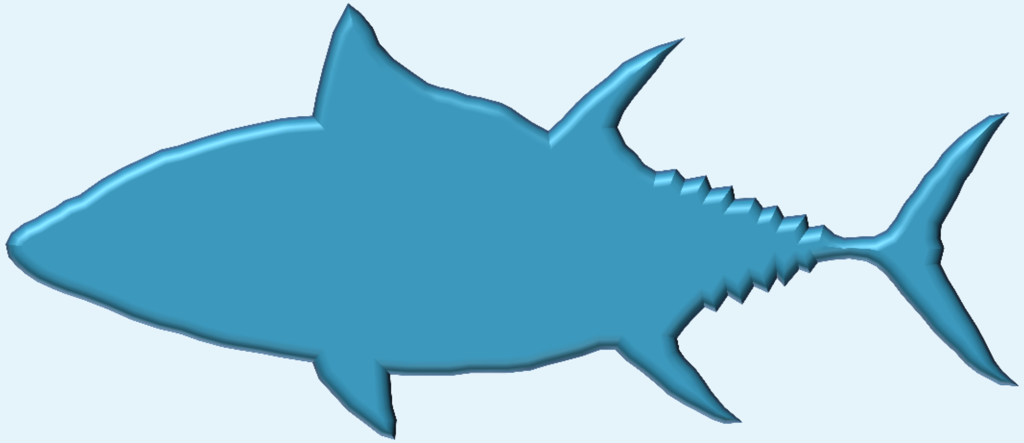
Next Steps

- Testing additional reference points (F_{max}, SSB_{Fmax}, $F_{30\%}$, $SSB_{F30\%}$, etc.)
- Management Strategy Evaluation (MSE)
  - Stakeholder input on defining management procedures
- Continued development of stock assessment models that explicitly incorporate mixing data



Bunnefeld et al. (2011)

Thank you!
Questions? Comments?



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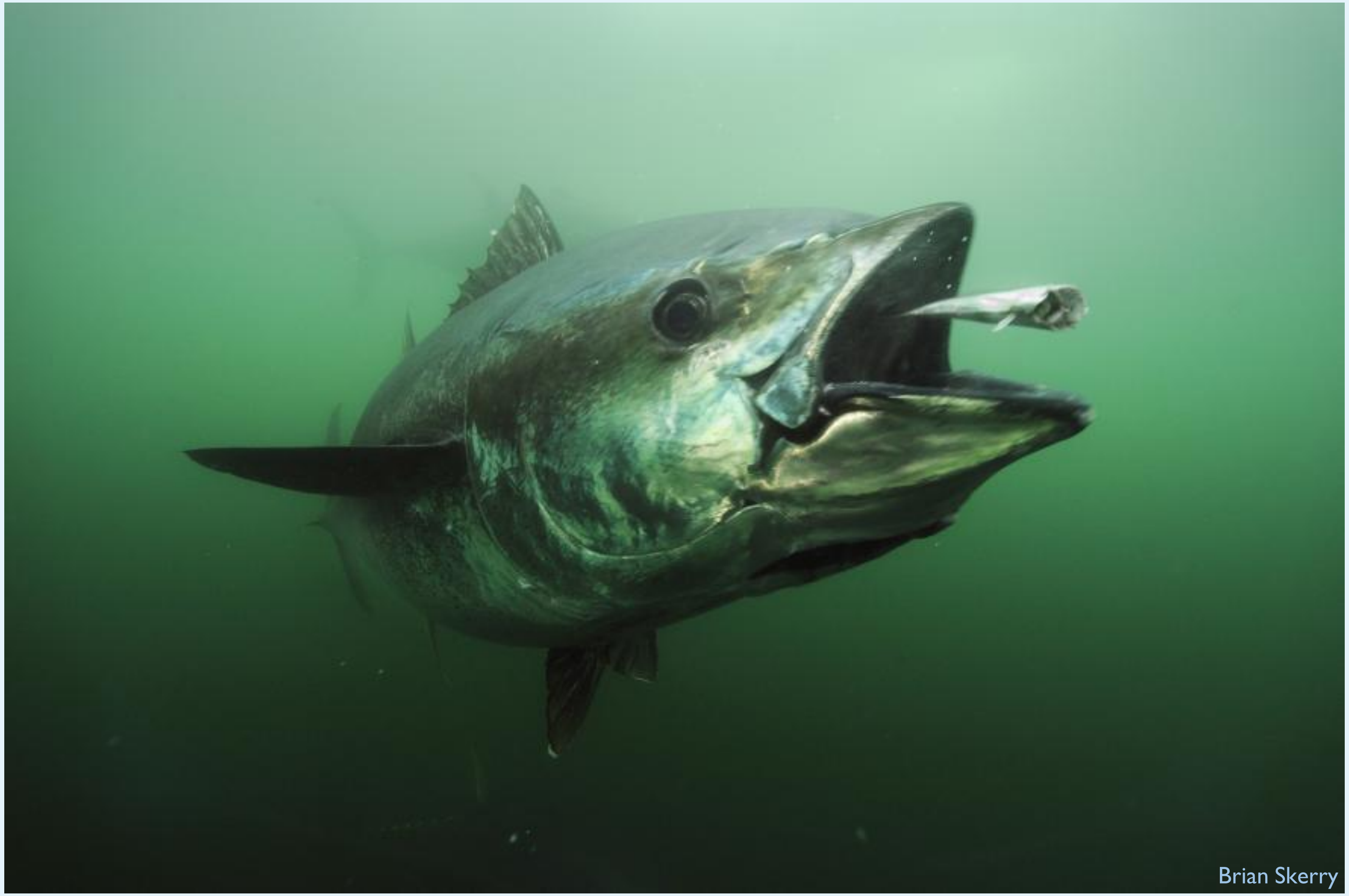
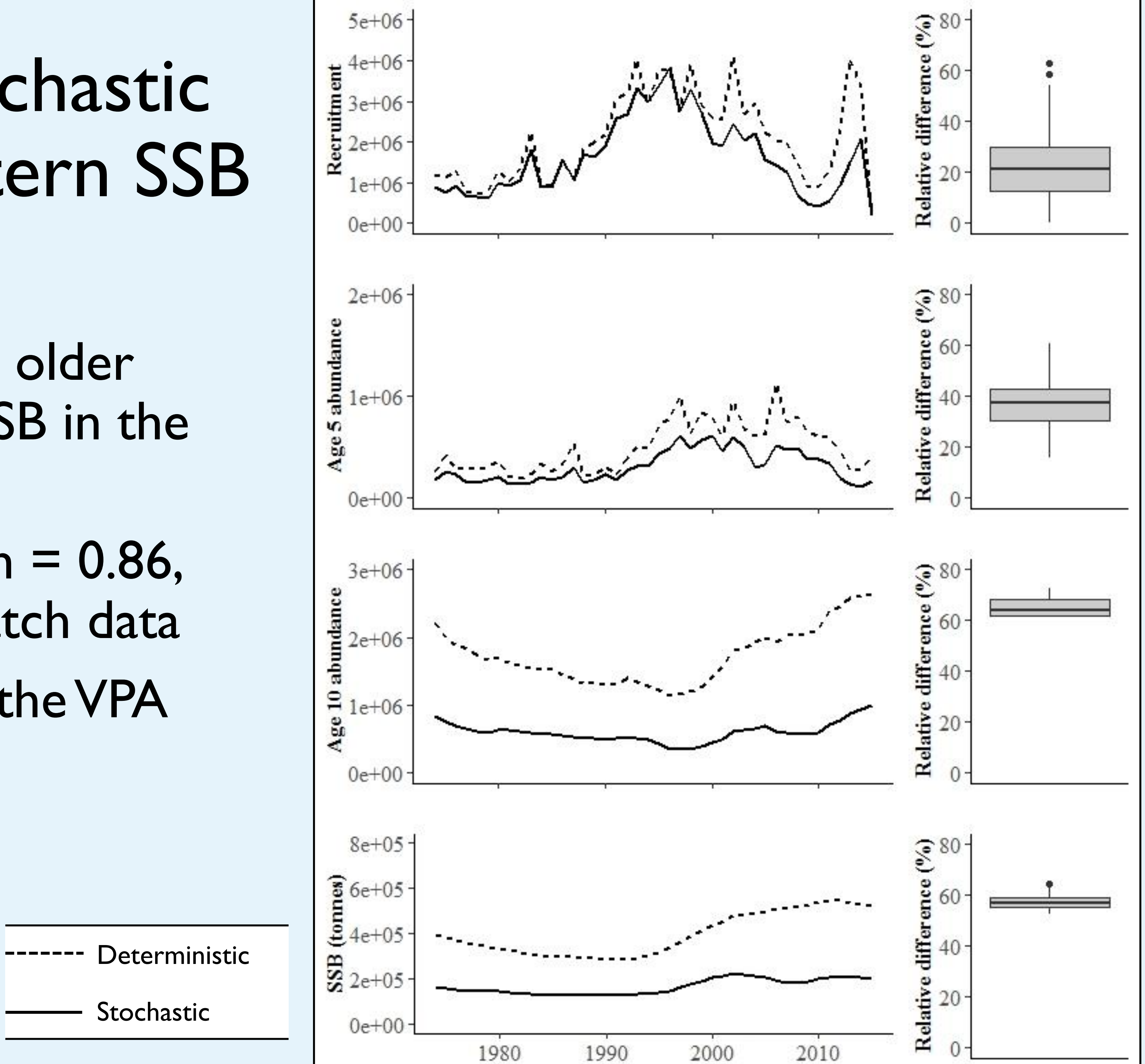
Appendix



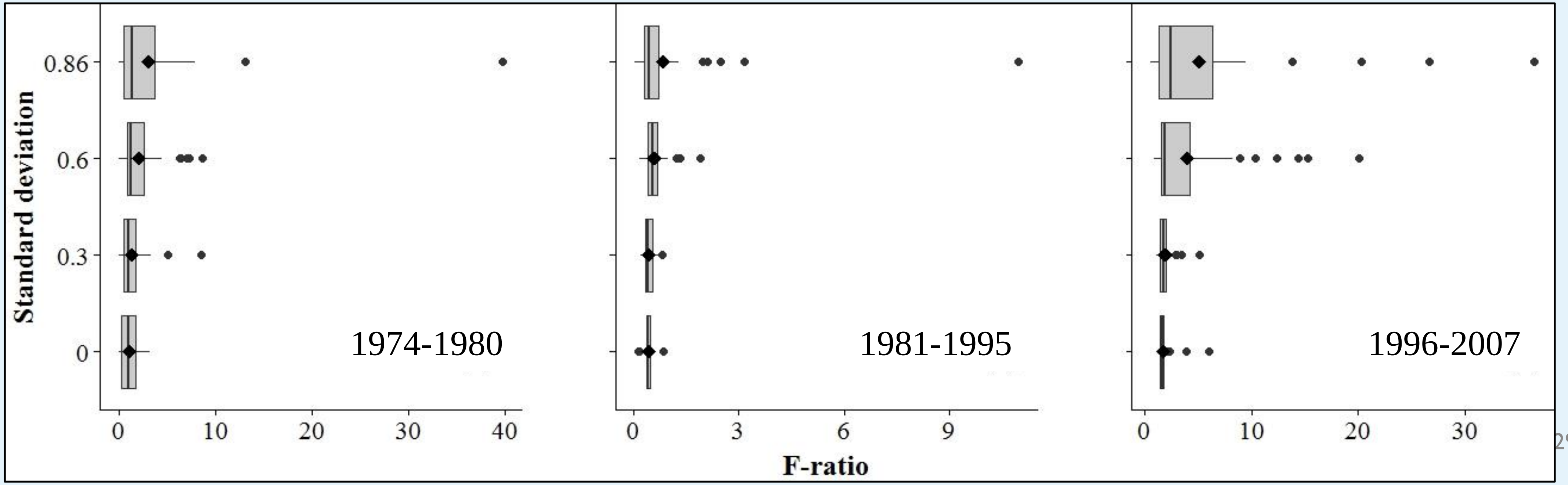
Deterministic/Stochastic divergence in eastern SSB estimates

- Divergence observed at older abundance-at-age and SSB in the eastern stock
- Large standard deviation = 0.86, large scale of eastern catch data
- Lack of identifiability in the VPA



Deterministic/Stochastic divergence in eastern SSB estimates

- Testing effect of large sigma:
  - Eastern F-ratio values estimated at four levels of standard deviation ($\sigma = 0, 0.3, 0.6, 0.86$) for the observation error term on the catch-at-age pseudodata.
  - Higher σ → higher average F-ratios and greater occurrence of extreme values
    → higher F on plus group and lower SSB



Testing additional reference points (preliminary)

Reference point values from the operating model (population and stock views) and estimation models (geometric mean across realizations).

Population/Stock	Reference Point	Operating Model Population view	Operating Model Stock view	Estimation Model
West	$F_{0.1}$	0.11	0.11	0.17
East	$F_{0.1}$	0.16	0.11	0.38
West	$SSB_{0.1}$	18,681	19,424	42,954
East	$SSB_{0.1}$	491,413	528,324	80,017
West	$F_{30\%}$	0.12	0.12	0.19
East	$F_{30\%}$	0.21	0.15	0.40
West	$F_{40\%}$	0.09	0.09	0.15
East	$F_{40\%}$	0.15	0.11	0.30
West	F_{max}	0.17	0.18	0.26
East	F_{max}	0.24	0.16	0.59
West	SSB_{Fmax}	11,308	11,227	33,027
East	SSB_{Fmax}	330,141	348,093	53,339