# Exploratory spatially-structured models for bigeye tuna in the eastern Pacific Ocean

Juan L. Valero, Mark. N. Maunder, Haikun Xu, Carolina Minte-Vera, Cleridy Lennert-Cody and Alexandre Aires-da-Silva

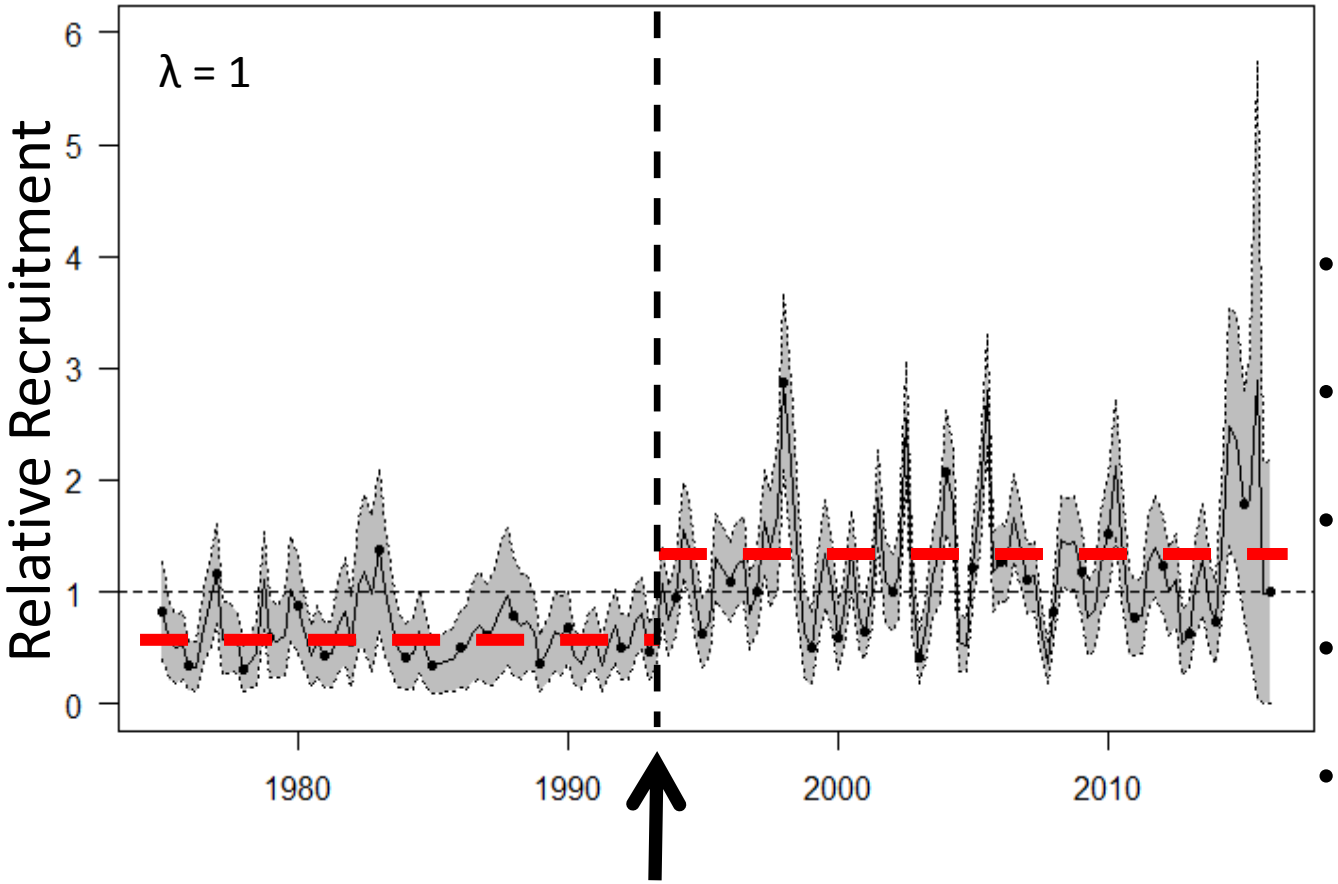
CAPAM

CAPAM Spatial Assessment Models Workshop
Oct. 02, 2018, La Jolla, CA

# Outline

- Motivation for this work
  - Resolve BET stock assessment model misspecifications (Spatial mismatch)
    - Improve BET stock assessment
    - Develop more realistic operating models for ongoing Management Strategy Evaluation (MSE)
- Approach
  - Age-structured production models (ASPM) for alternative spatial sub-areas of the EPO
  - Integrated model for EPO's Central area (largest spatial mismatch between PS catch and LL index)
  - Spatial Integrated model of 4 EPO areas
    - Spatial structure as defined by Lennert-Cody et al and Minte-Vera et al. (this workshop)
    - Movement scenarios as defined by Xu et al. (this workshop)
- Results
- Summary of work so far

# The two-regime BET recruitment pattern

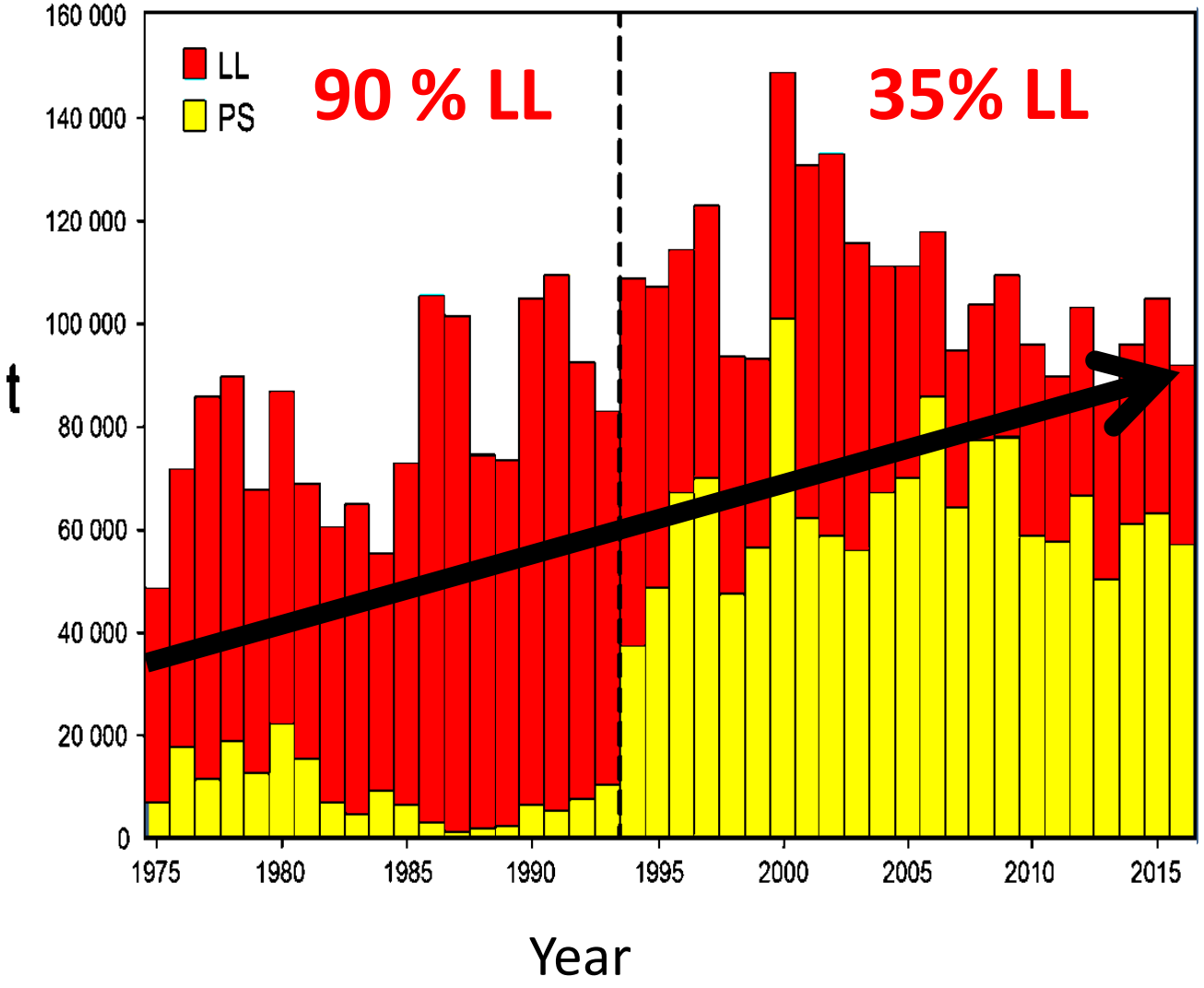



Recurs in BET assessments since 2003

Alternative hypotheses:

- **Environmental shift** (Fonteneau and Ariz, 2008)
- **Underestimated early FAD catch** (Idem)
- **Higher natural mortality** (Idem)
- **Density-dependent growth** (Hoyle, SPC)
- **Migratory pattern changes** (Harley, SPC)
- **Artifact due to large catches of small individuals** by the purse-seine fishery (Maunder et al., 2010)
- **Spatial mismatch** between PS catch and LL CPUE index (Aires-da-Silva and Maunder, 2010)

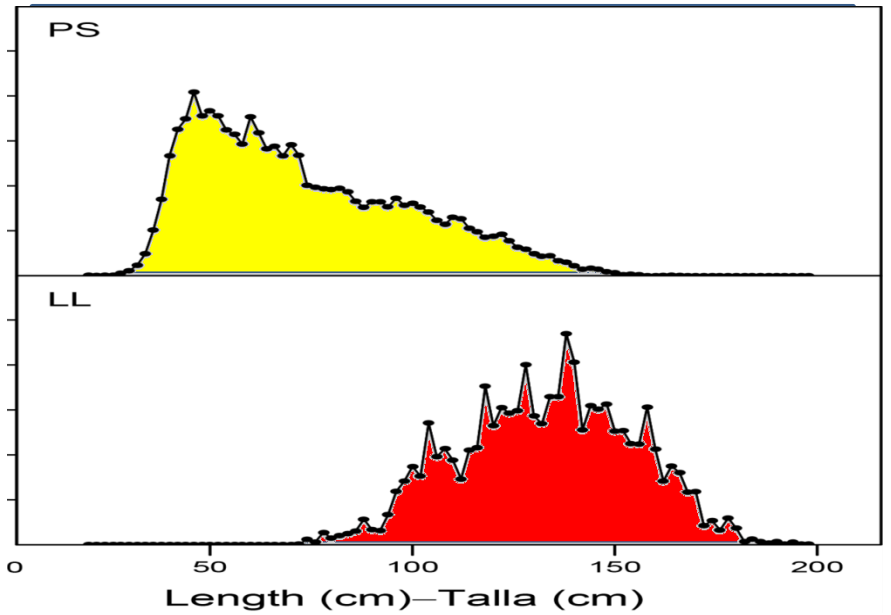
# Expansion of FAD fishery



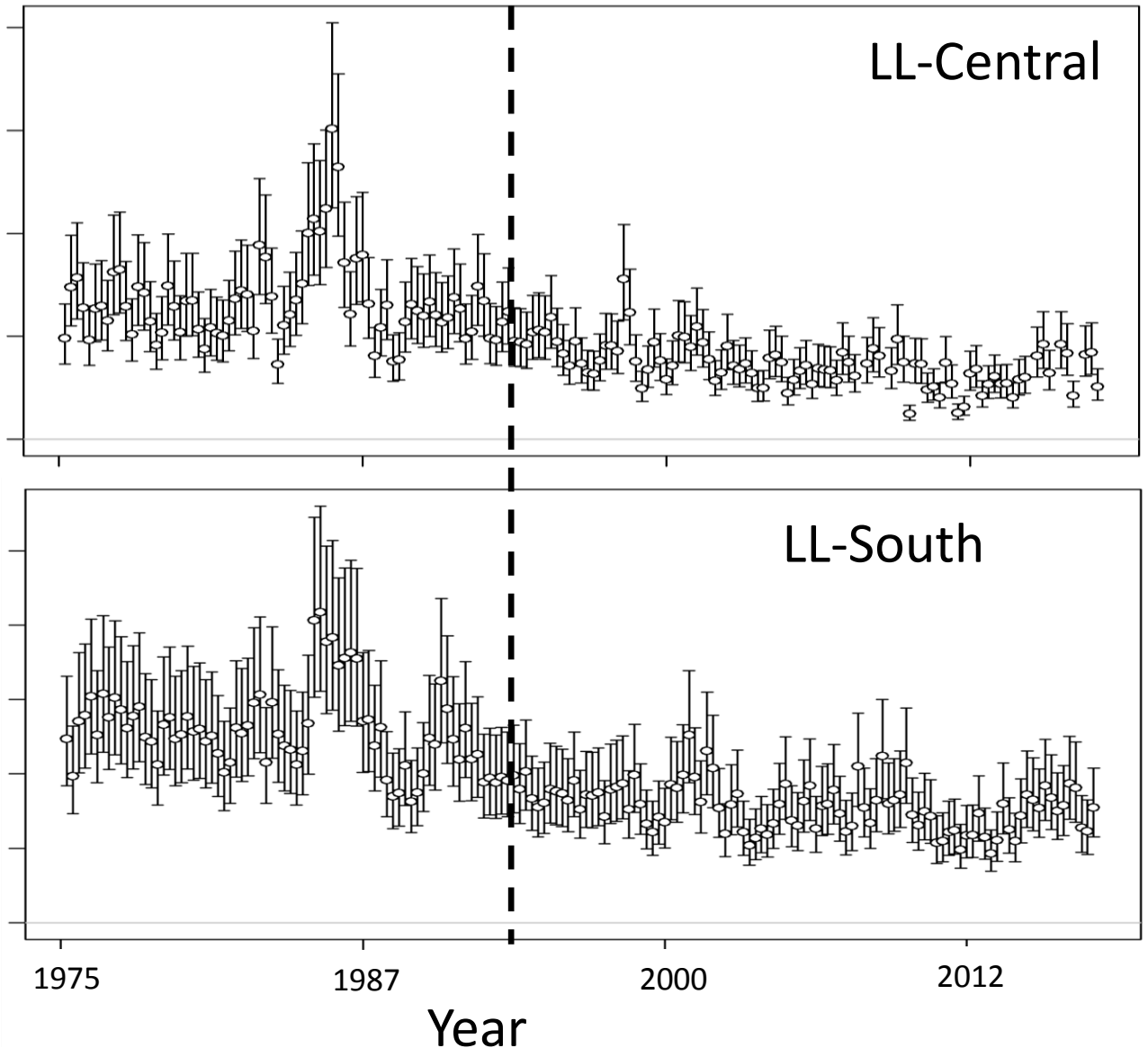

Expansion of **Purse Seine** fishery

Increased **TOTAL** catch

Smaller fish in **Purse Seine** fishery



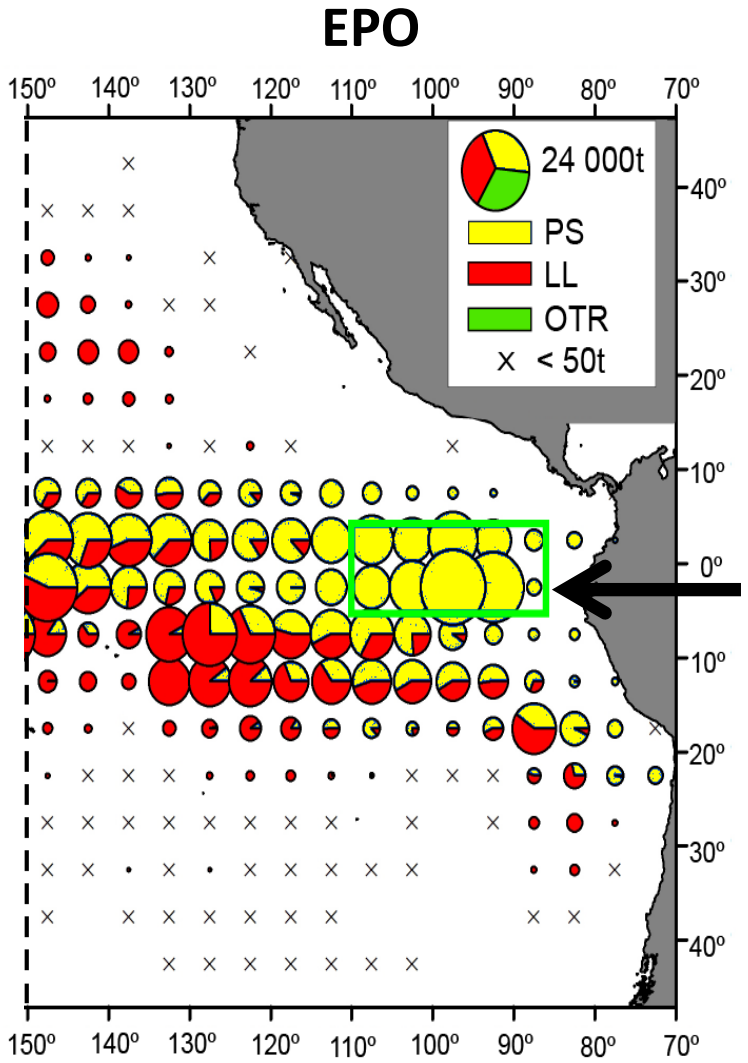
# Longline CPUE main source of information




## Current BET assessment

- Longline CPUE indices are the main source of information in the BET stock assessment
  - Purse seine CPUE indices are not used in the assessment
  - Size composition data is greatly down weighted (0.05 of original weight)

# Spatial heterogeneity among fishery catches

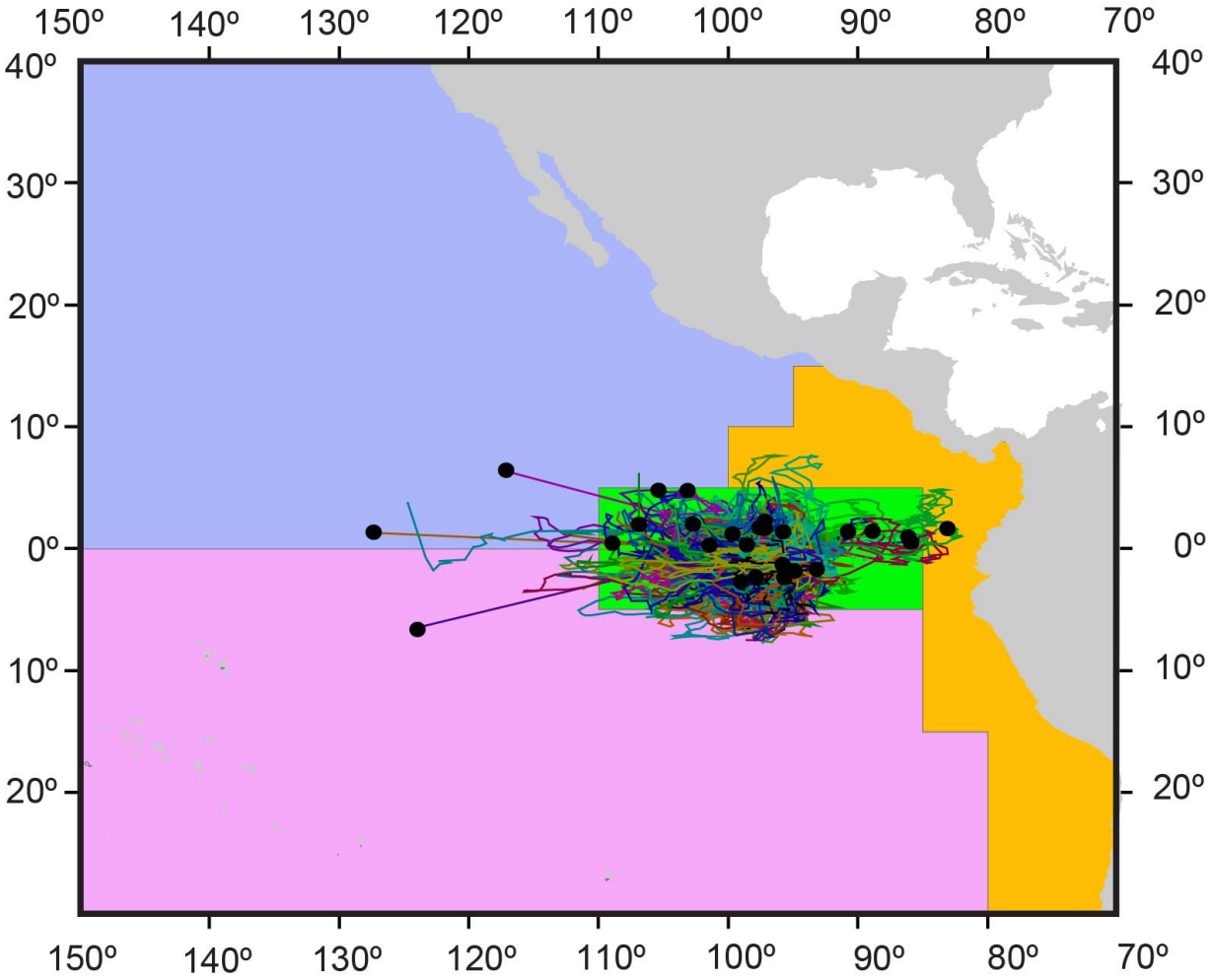



- Most of PS catches from Equatorial area
  - Between 5°N and 5°S
- Little LL catch in Equatorial area
  - Between 5°N and 5°S from 110°W to 85°W

**Central Area**

BET catch during 2008-2012 (modified from Schaefer et al. 2015)

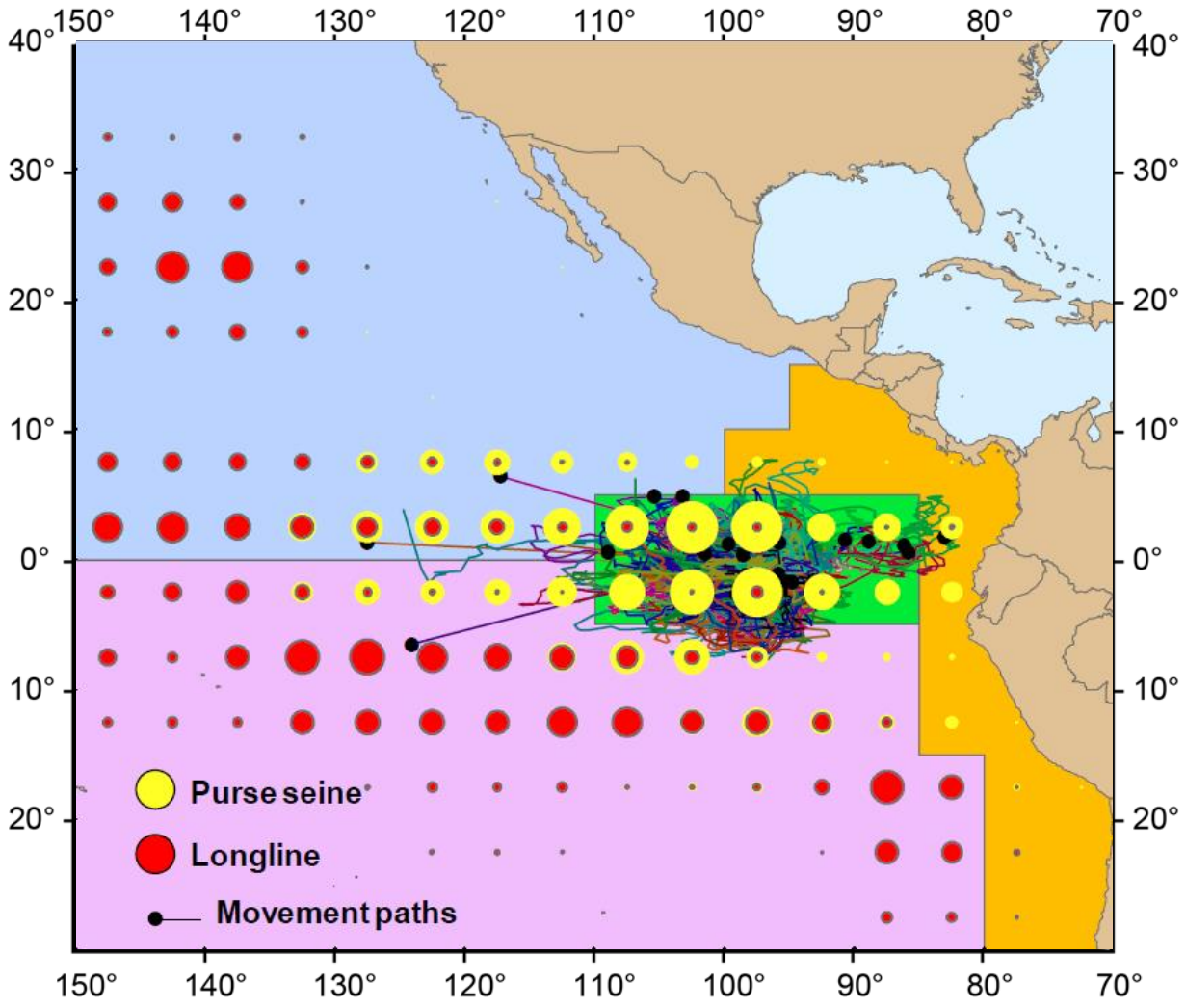
# Spatial heterogeneity in BET movements




Movements of BET for >30 days, archival tagging data from 2000-2006 (Schaefer and Fuller 2009)

- Current BET assessment uses a single area, **assuming stock is randomly mixed** within the EPO, with no localized spatial dynamics
- However, tagging indicate restricted movements for some areas, **regional fidelity** in particular in the Central area
- Restricted movements in some areas, combined with spatial heterogeneity of catches, suggest that **localized depletion** of BET sub-stocks may exist in the EPO

# The “spatial mismatch” hypothesis

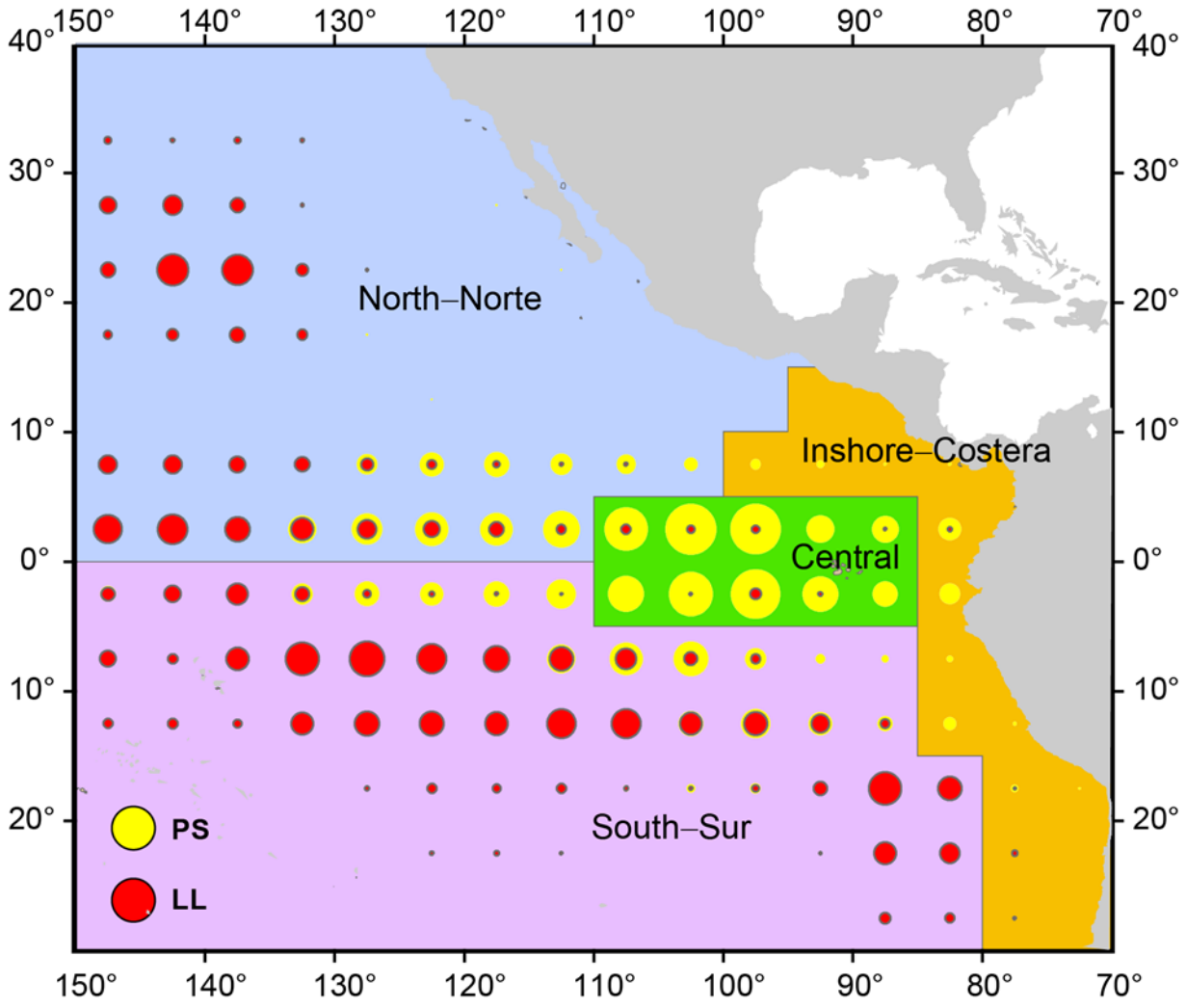



BET catch during 2000-2006 (From Aires-da-Silva and Maunder, 2010)

## This hypothesis postulates that:

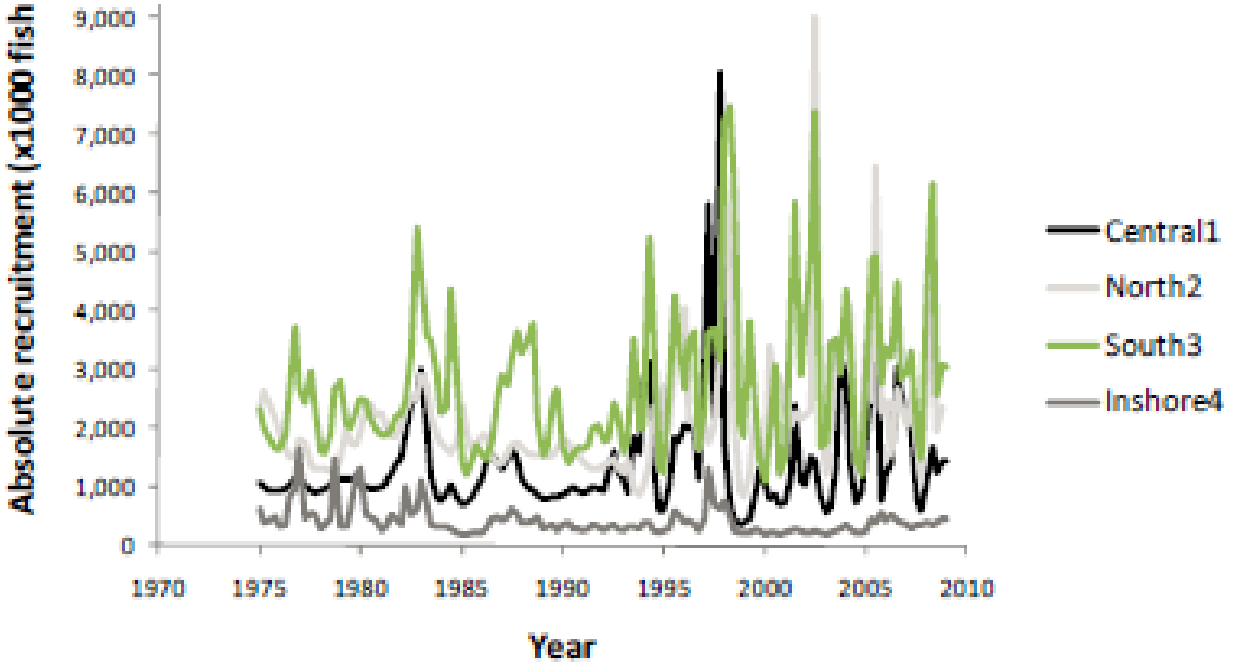
- The two-recruitment pattern results from **spatial misspecification in the assessment**
- The increase in equatorial purse seine-catch not reflected in reductions in longline CPUE due to:
  - Restricted BET movements, leading to **local depletion**, and
  - The **longline CPUE corresponding to a wider, or different**, area than where the increased purse-seine catch occurred

# The “spatial mismatch” hypothesis

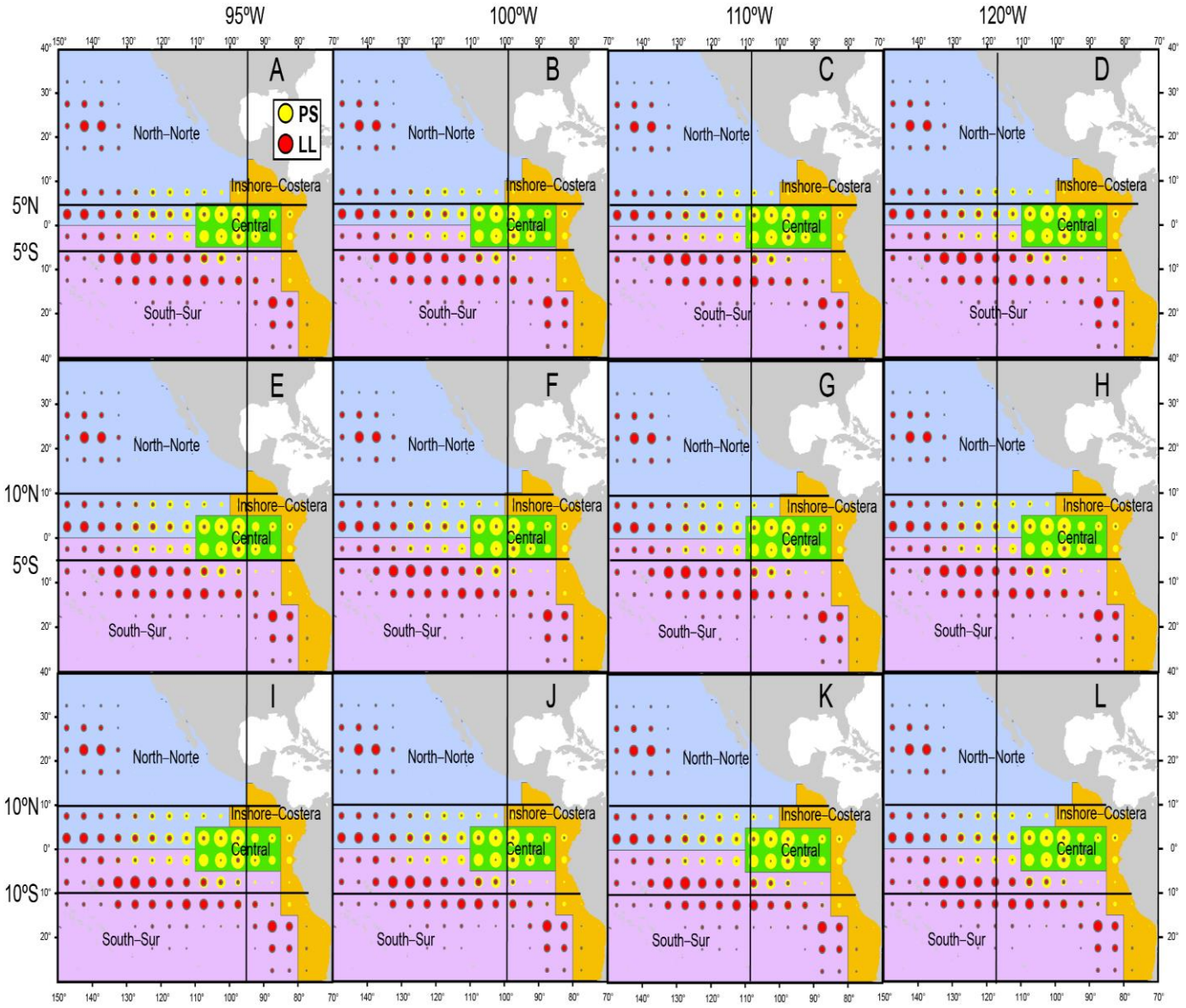



2000-2006 BET catch (From Aires-da-Silva and Maunder, 2010)

- If hypothesis correct, a **spatially-structured BET** assessment should **correct** the two-regime recruitment pattern
- Aires-da-Silva and Maunder (2010) fitted spatially independent models for four EPO areas, resulting in **different trends and depletion levels among areas** and a partial correction of the recruitment pattern



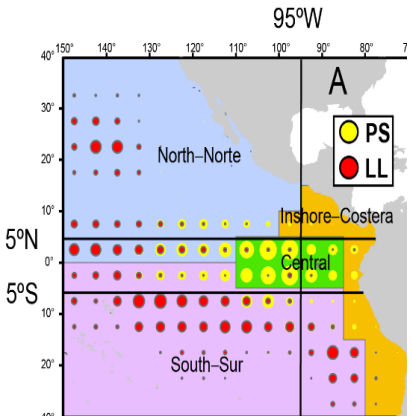
# Age-structured production model (ASPM)

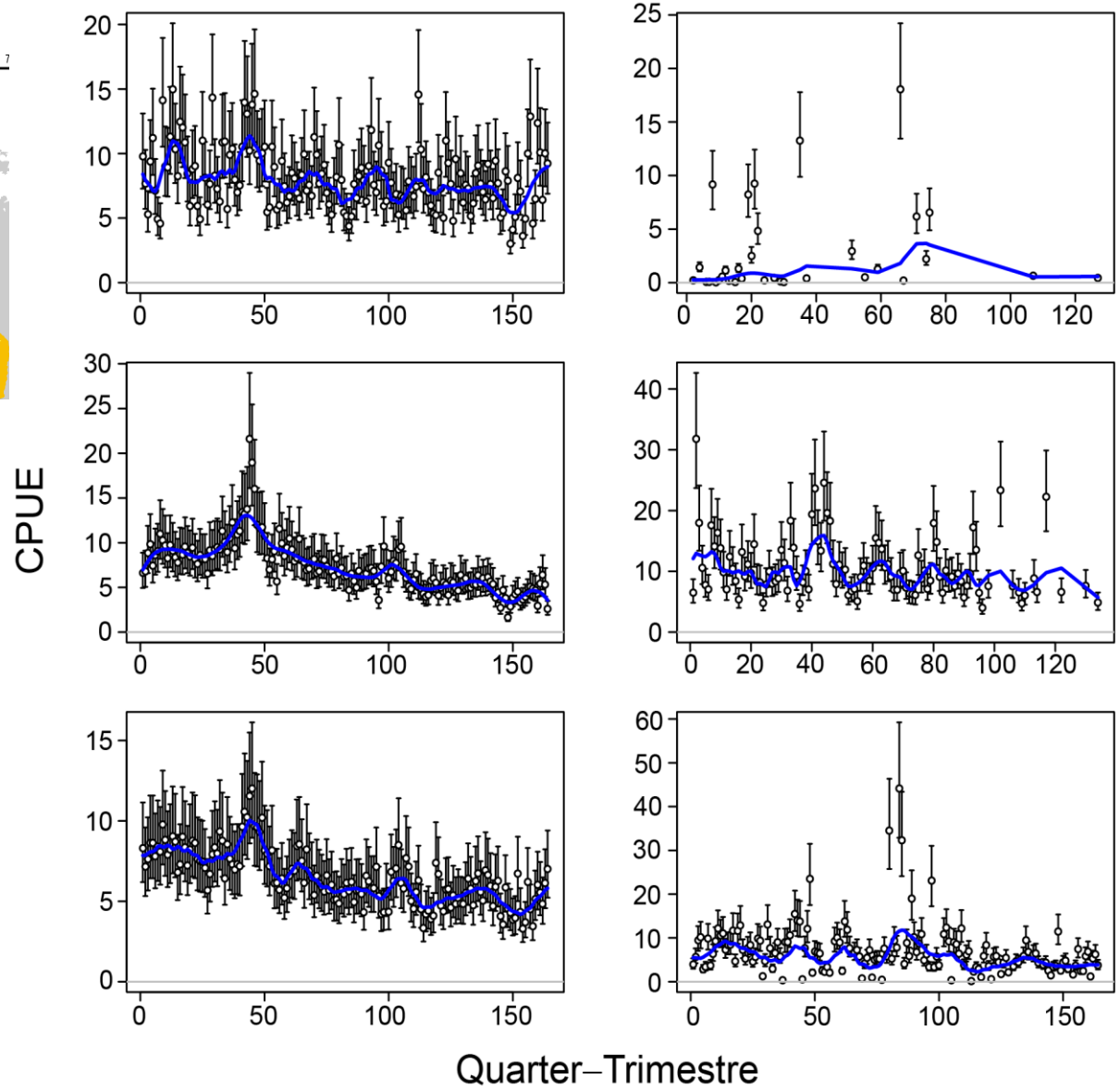



**Evaluates consistency between catch & CPUE**

- Systematically divide the EPO into 12 grids of 6 areas each (72 total areas)
- Fit an independent ASPM to each area's total catch by fleet and LL CPUE
- Estimate quarterly biomass, fishing mortality, (with and without recruitment deviates)

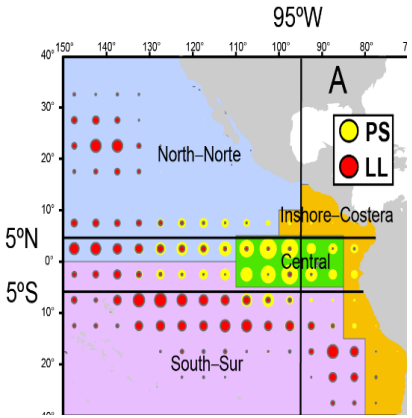
# Age-structured production model (ASPM)

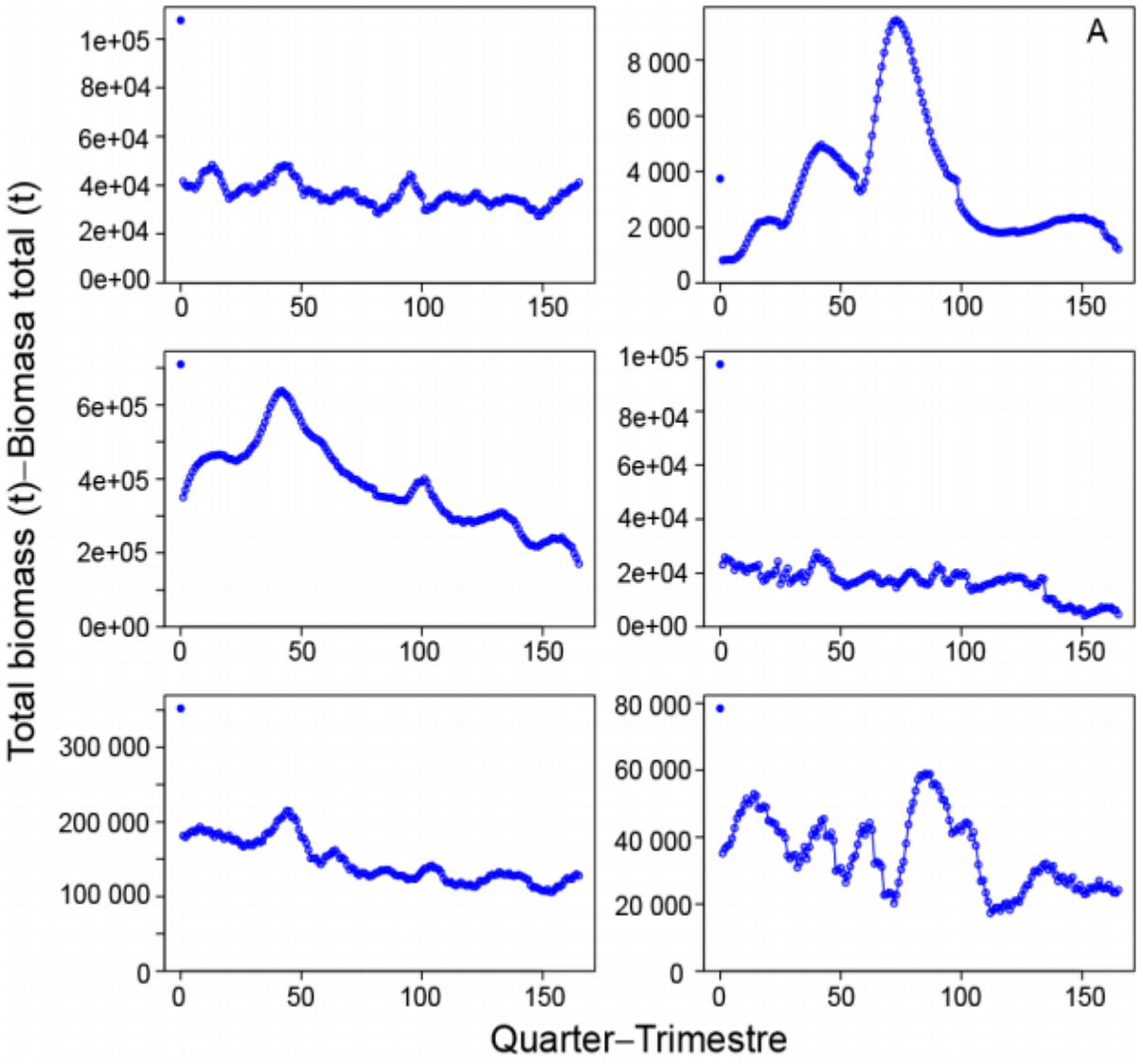



- Runs **with** recruitment deviates produce better fits to the longline CPUE
- **Recruitment is driving abundance** more than catch is. **Problematic** when relying on the effect of catch on CPUE to inform absolute abundance

# Age-structured production model (ASPM)

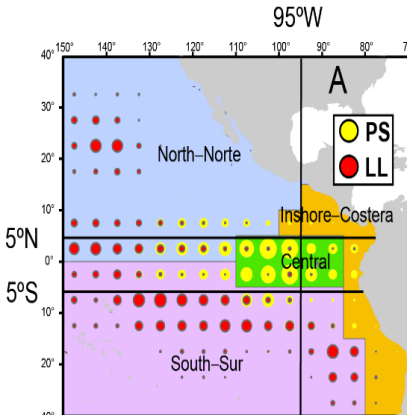


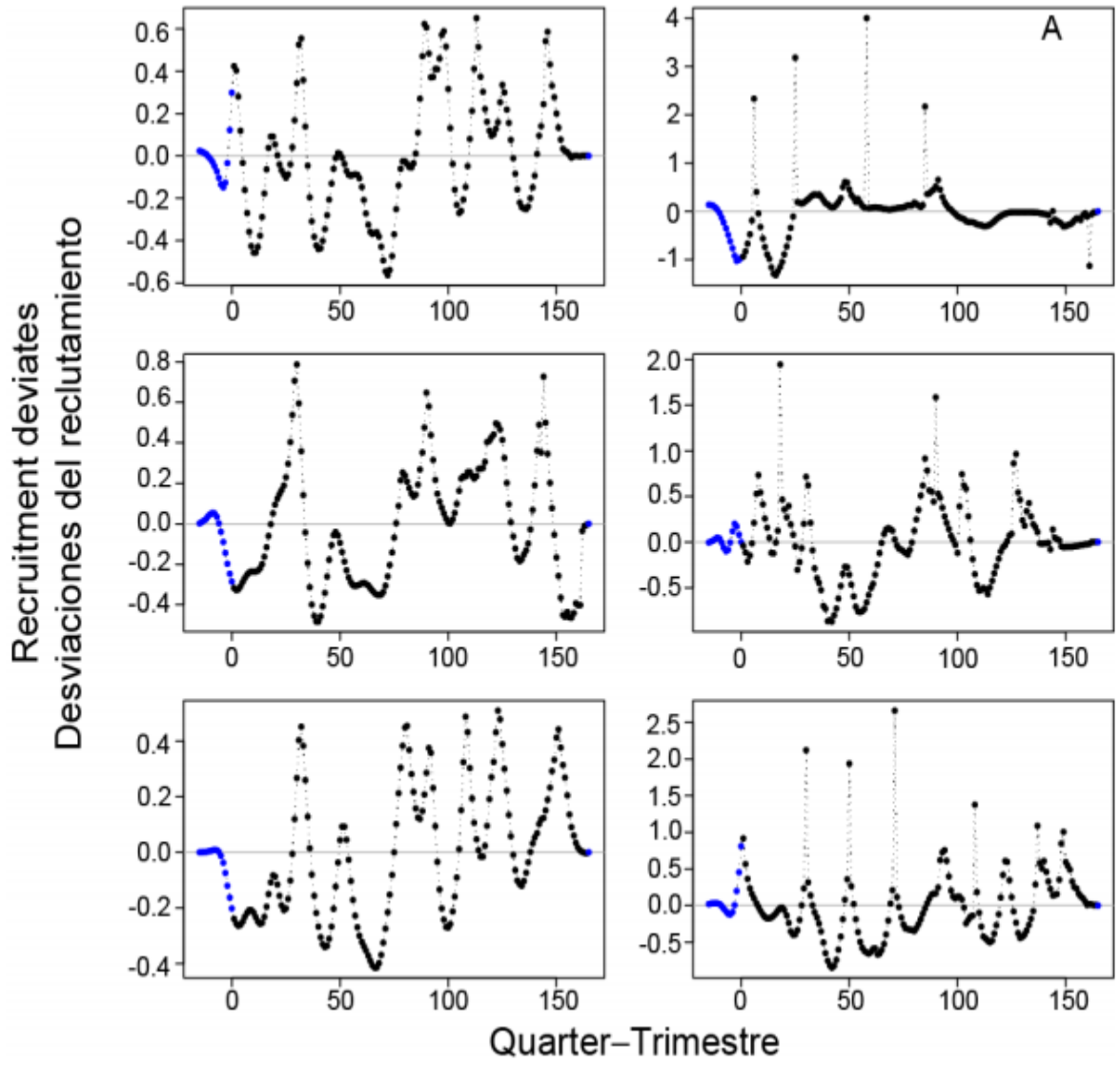




## General ASPM results

- Largest estimated biomass **declines in Equatorial areas**
- Some area combinations have too sparse data for meaningful results
  - **Fewer areas and alternative divisions**

# Age-structured production model (ASPM)

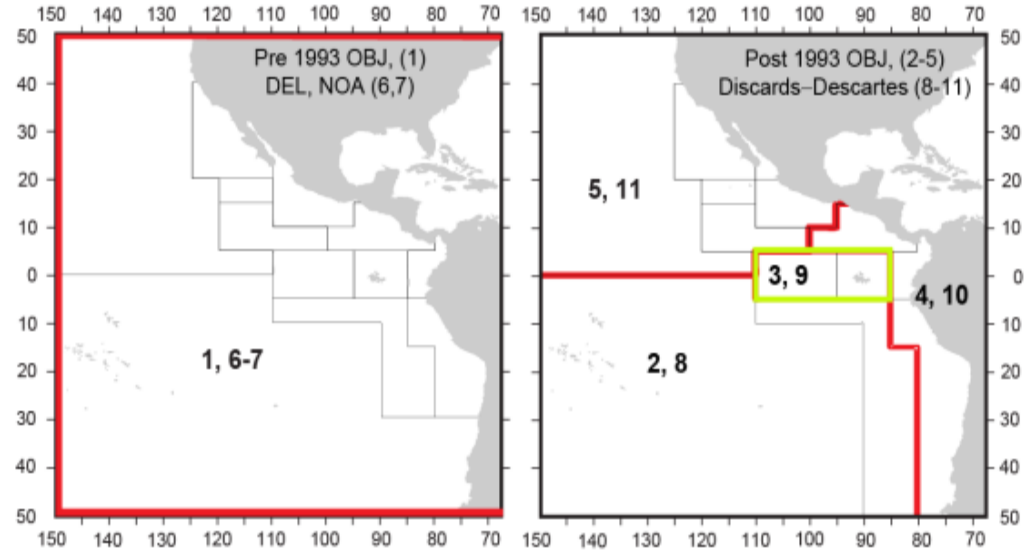


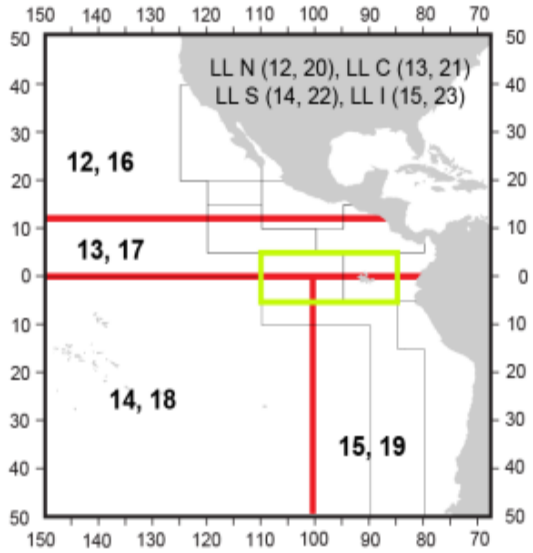




## General ASPM results

- **Two-regime recruitment** pattern **estimated** in several area combinations
- Pattern **independent of length compositions**, which are not used in the ASPM

# Integrated model (Central area)



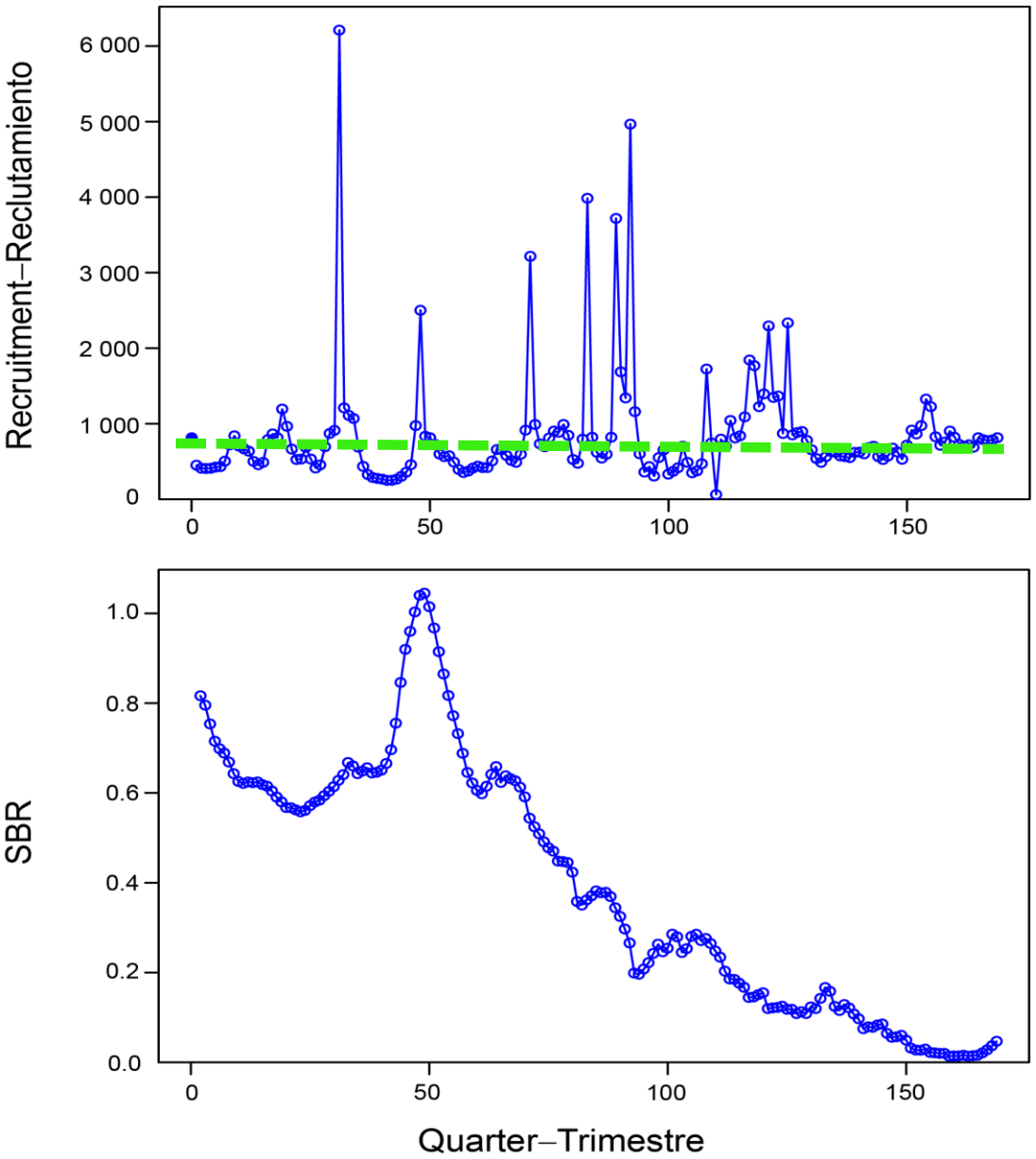




**Similar to BET base model but restricted to the Central Area, where the increased purse-seine catch occurred**

- Fisheries redefined on spatial overlap with Central area

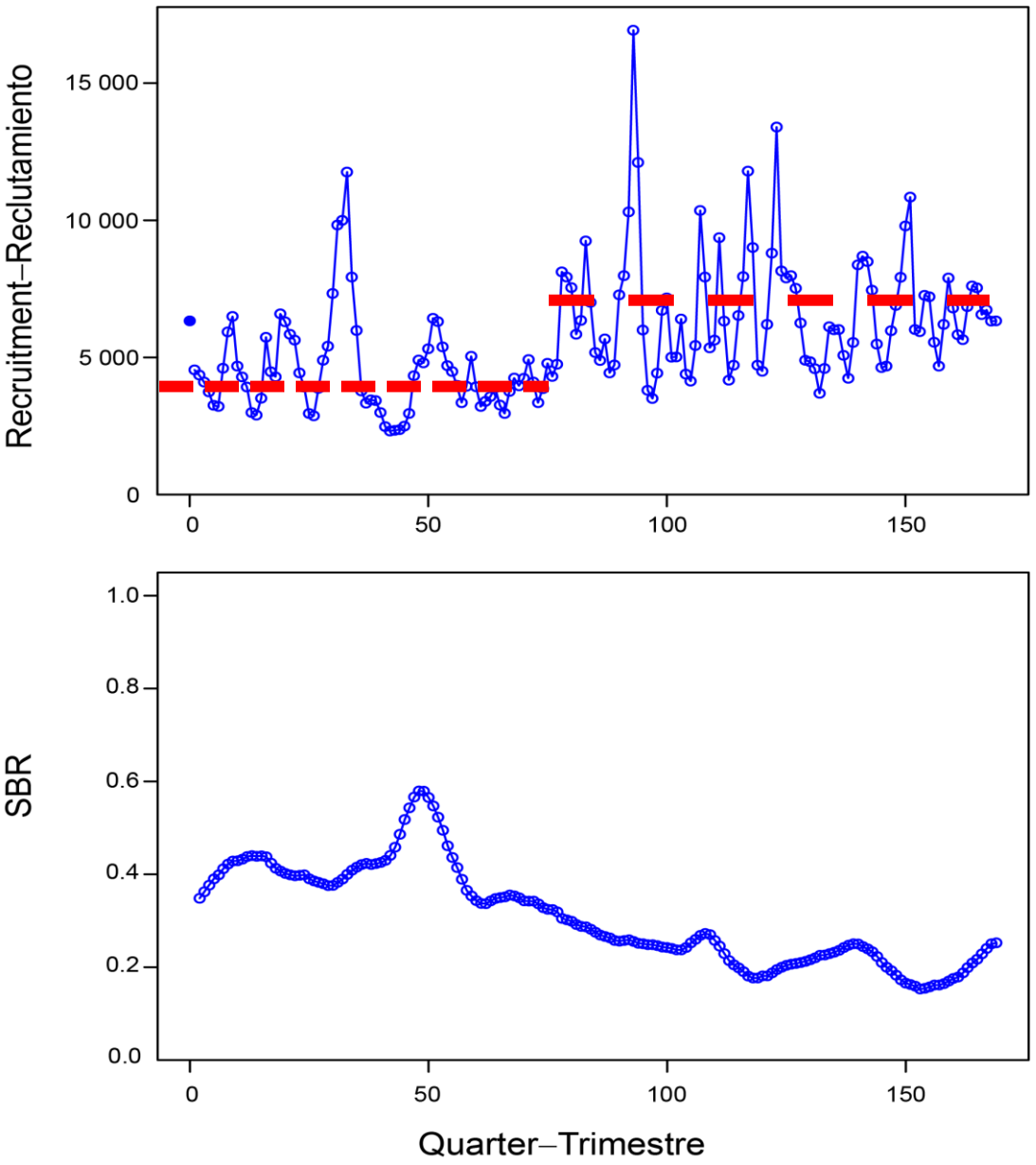
- Three alternative weightings of the composition data: ($\lambda = 0.05$, $\lambda = 1$, and Francis (2011) iterative weighting)

# Integrated model (Central area)



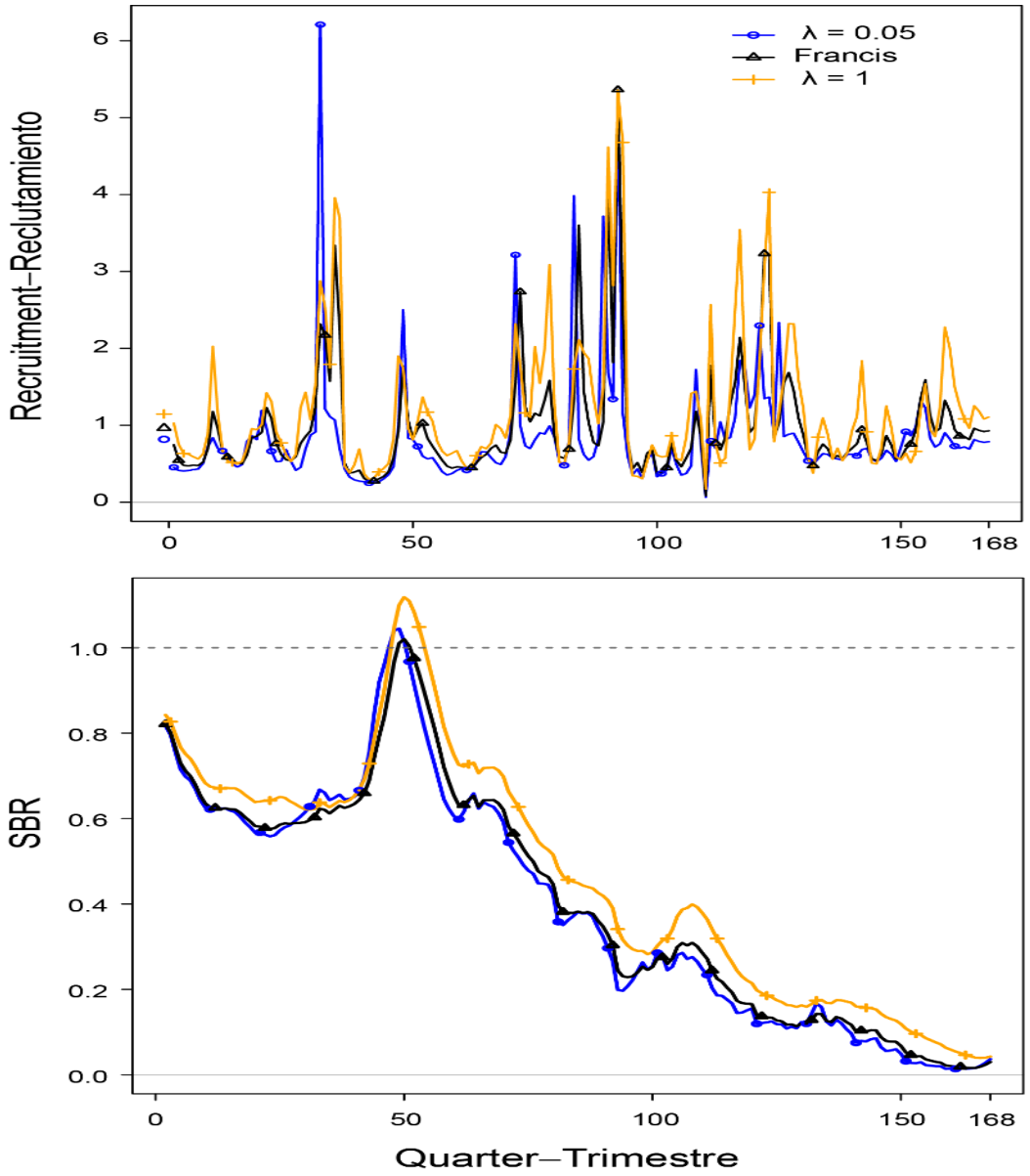

- The integrated model estimates a steeper **declining trend** in the spawning biomass ratio (SBR), and a **more depleted stock status** in the Central area than is estimated by the base case stock assessment for the whole EPO
- Recruitment estimates for the Central area **do not show the two-regime** pattern typical of previous models
- Results are consistent with those of Aires-da-Silva and Maunder (2010)

# Integrated model (Base case SAC 08 )



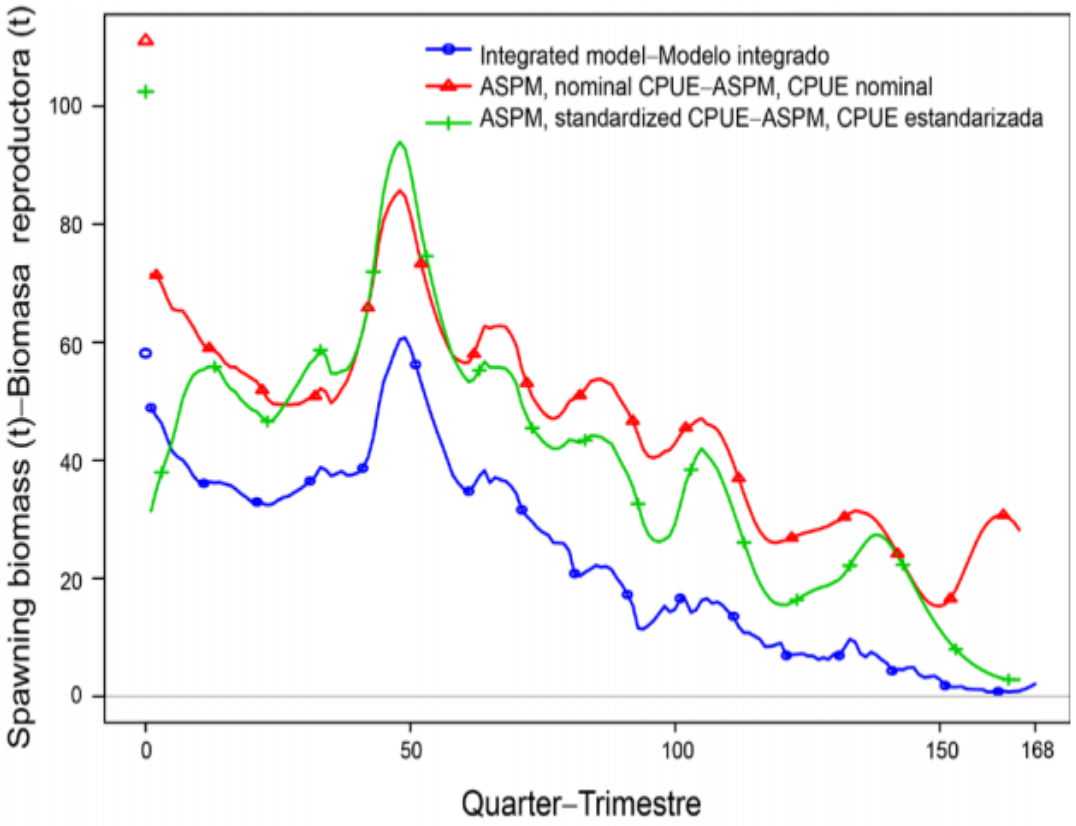

- The integrated model estimates a steeper **declining trend** in the spawning biomass ratio (SBR), and a **more depleted stock status** in the Central area than is estimated by the base case stock assessment for the whole EPO
- Recruitment estimates for the Central area **do not show the two-regime** pattern typical of previous models
- Results are consistent with those of Aires-da-Silva and Maunder (2010)

# Integrated model (Central area, data weighting)



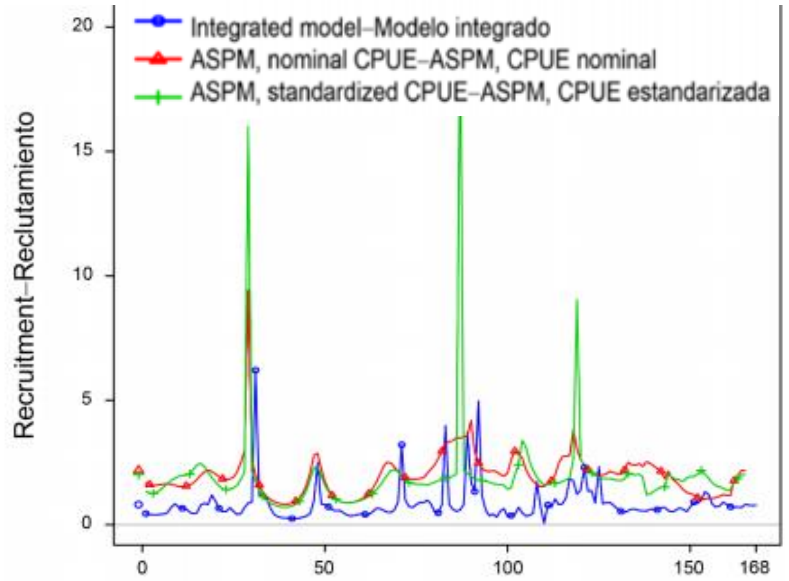

- Alternative length-composition **data-weighting does not change overall results** in the Central area model
- In contrast, length-composition data are down-weighted (λ=0.05) in the **base case assessment. Up-weighting (λ =1) worsens the two-regime** pattern and leads to a more pessimistic stock status
- Francis (2011) method **suggests increasing λ for all fisheries**, to around 0.5 for purse-seine fisheries and to between 0.8 and 2.5 for longline fisheries

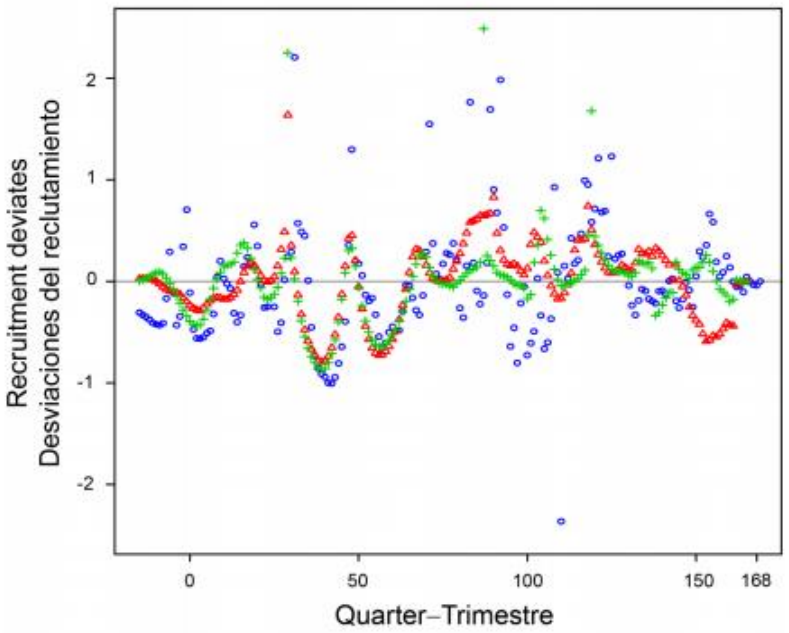
# Integrated model (Central Area) and ASPM




- Declining biomass trends are similar between the Integrated model and ASPM (both with and without standardization), **the biomass scale is lower for the Integrated model**

# Integrated model (Central Area) and ASPM




- Although the two-regime pattern is not evident in the integrated model, it is evident in the ASPM, whether standardized or nominal CPUE is used
- Using smaller areas to resolve the spatial mismatch between purse-seine catches and longline CPUE may be only partially successful unless length-composition data are included

# Conclusions (up to last week)

- Spatially disaggregating the BET assessment removed the recruitment two-regime pattern, **consistent with the spatial mismatch hypothesis**

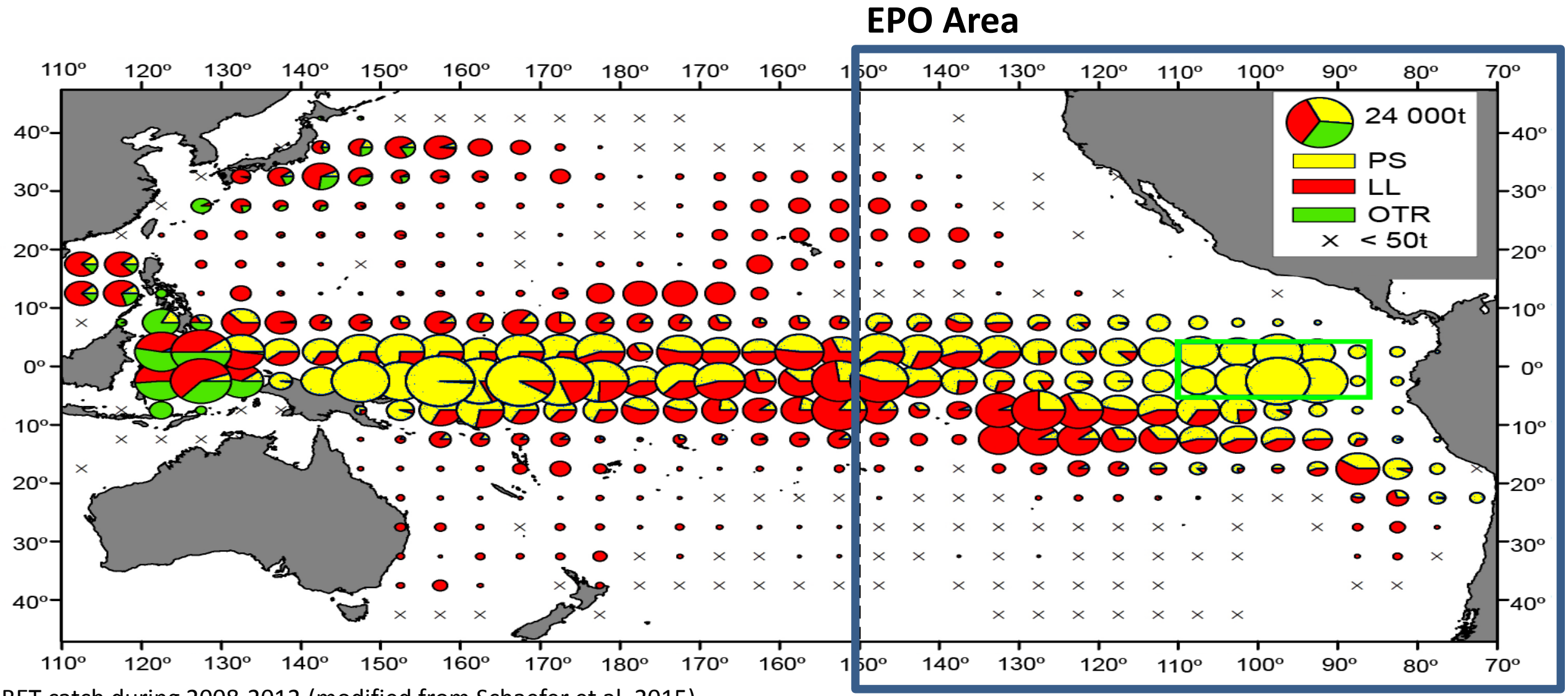
- The **two-regime pattern seems to be an artifact** of treating the EPO as a single homogeneous area when in fact there are **localized dynamics** of the stock and the fisheries that should be taken into account to remove model misspecification

- **Alternative spatial management measures should be evaluated for BET in the EPO**

# More recent work

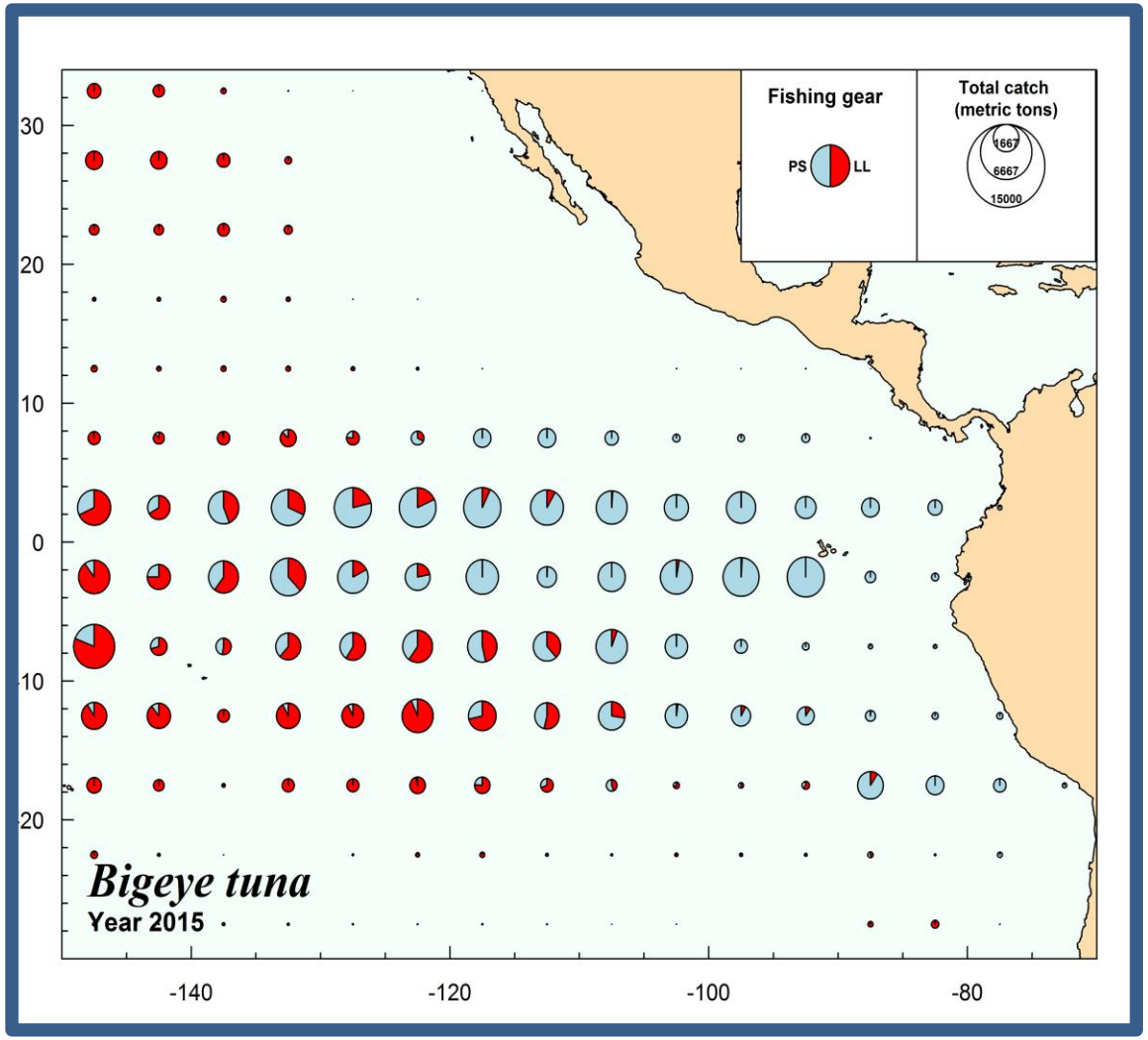
- Spatial Integrated model in Stock Synthesis dividing the EPO into four areas
  - **Spatial structure** as defined by Lennert-Cody et al and Minte-Vera et al. (this workshop)
  - **Movement scenarios** as defined by Xu et al. (this workshop)
  - Alternative spatiotemporal **standardization of CPUE** indices (Xu et al.)

# Pacific wide BET catches

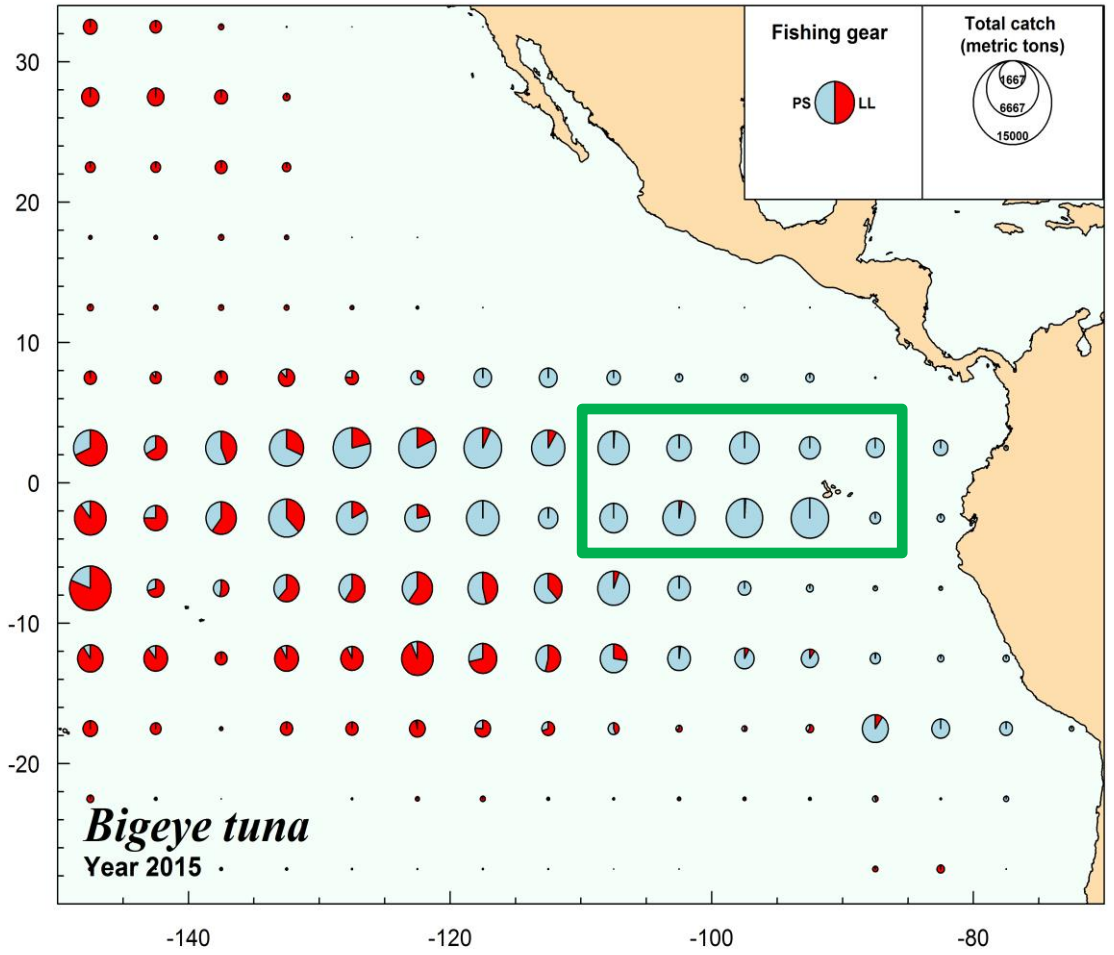



BET catch during 2008-2012 (modified from Schaefer et al. 2015)

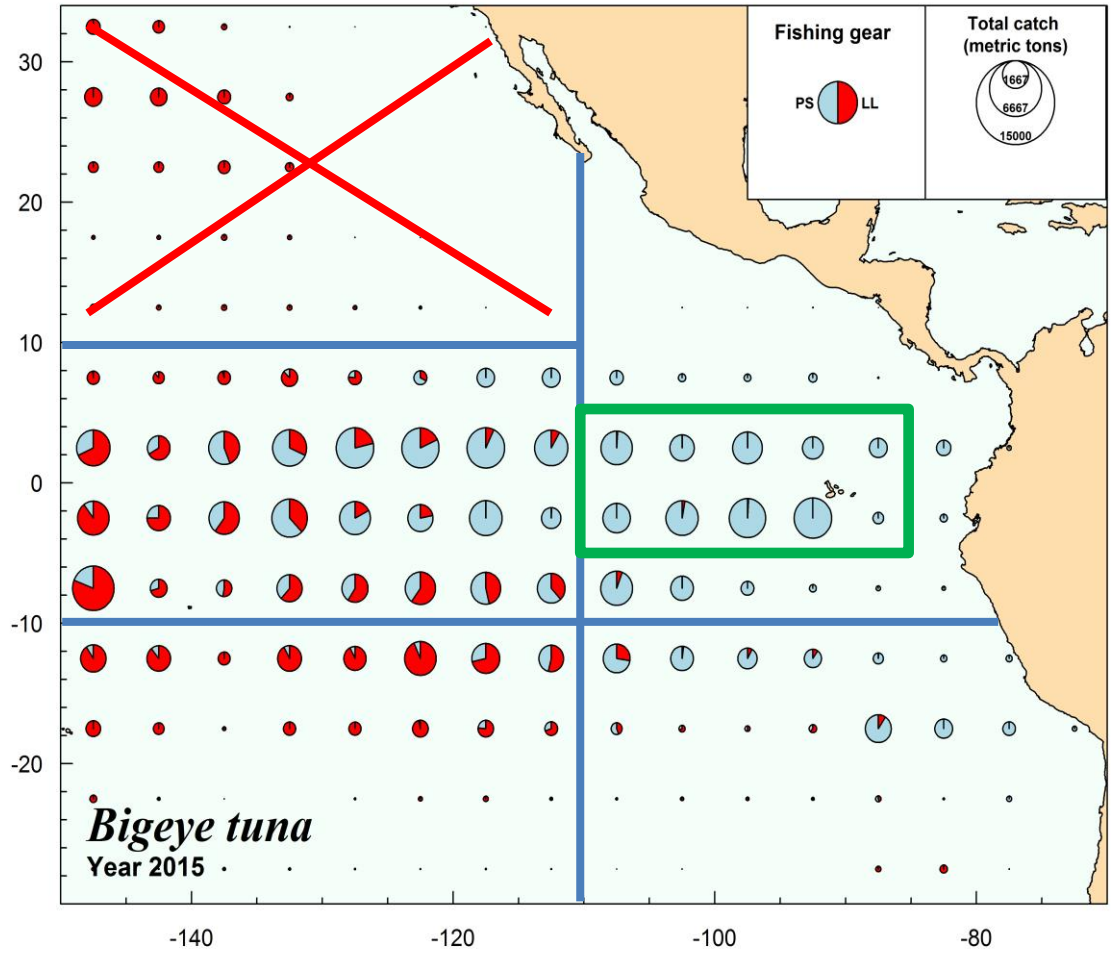
# EPO BET catches



# EPO BET Spatial Structure assumptions



# EPO BET Spatial Structure assumptions



# EPO BET Spatial Structure assumptions

Spatial structure as defined by Lennert-Cody et al and Minte-Vera et al. (this workshop)

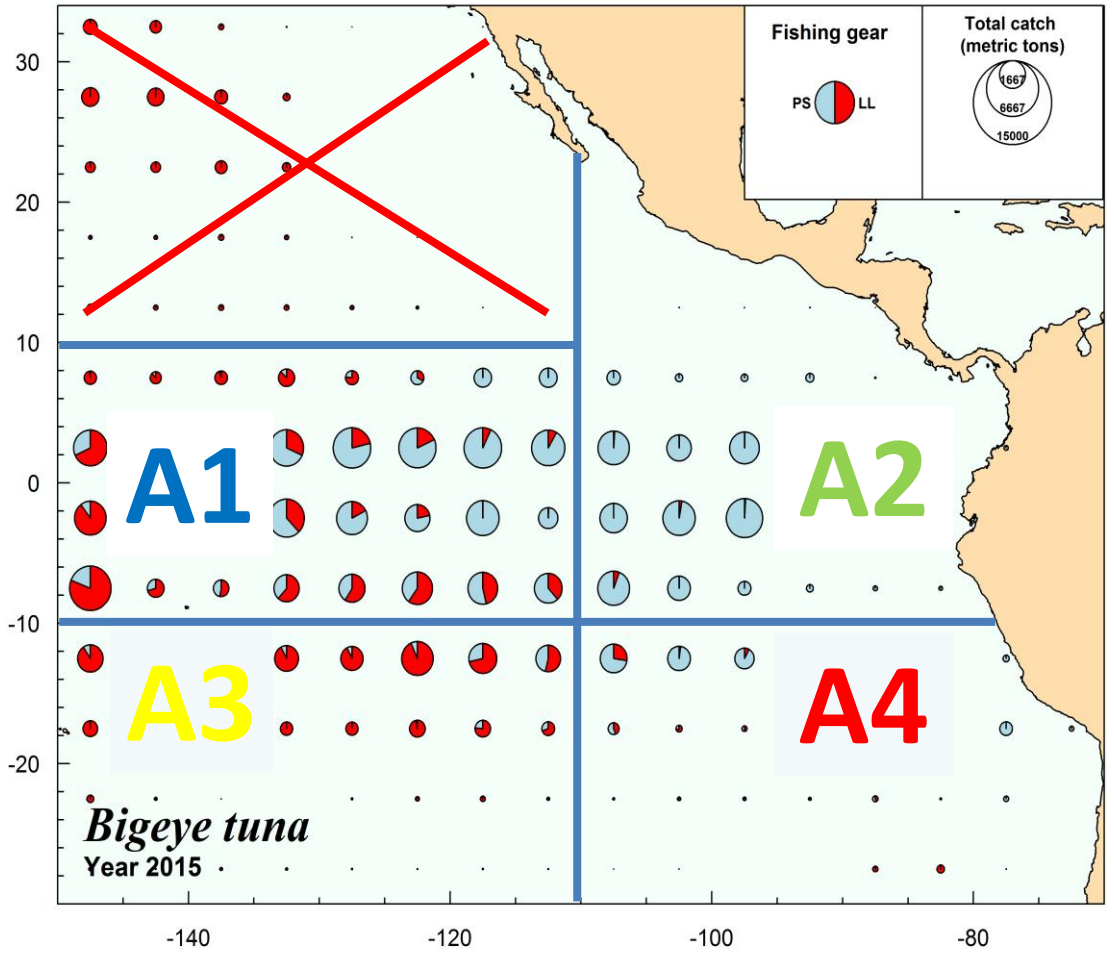
Four Areas (excluding north of 10°N)

**A1**

**A2**

**A3**

**A4**



# EPO BET Spatial Structure assumptions

Spatial structure as defined by Lennert-Cody et al and Minte-Vera et al. (this workshop)

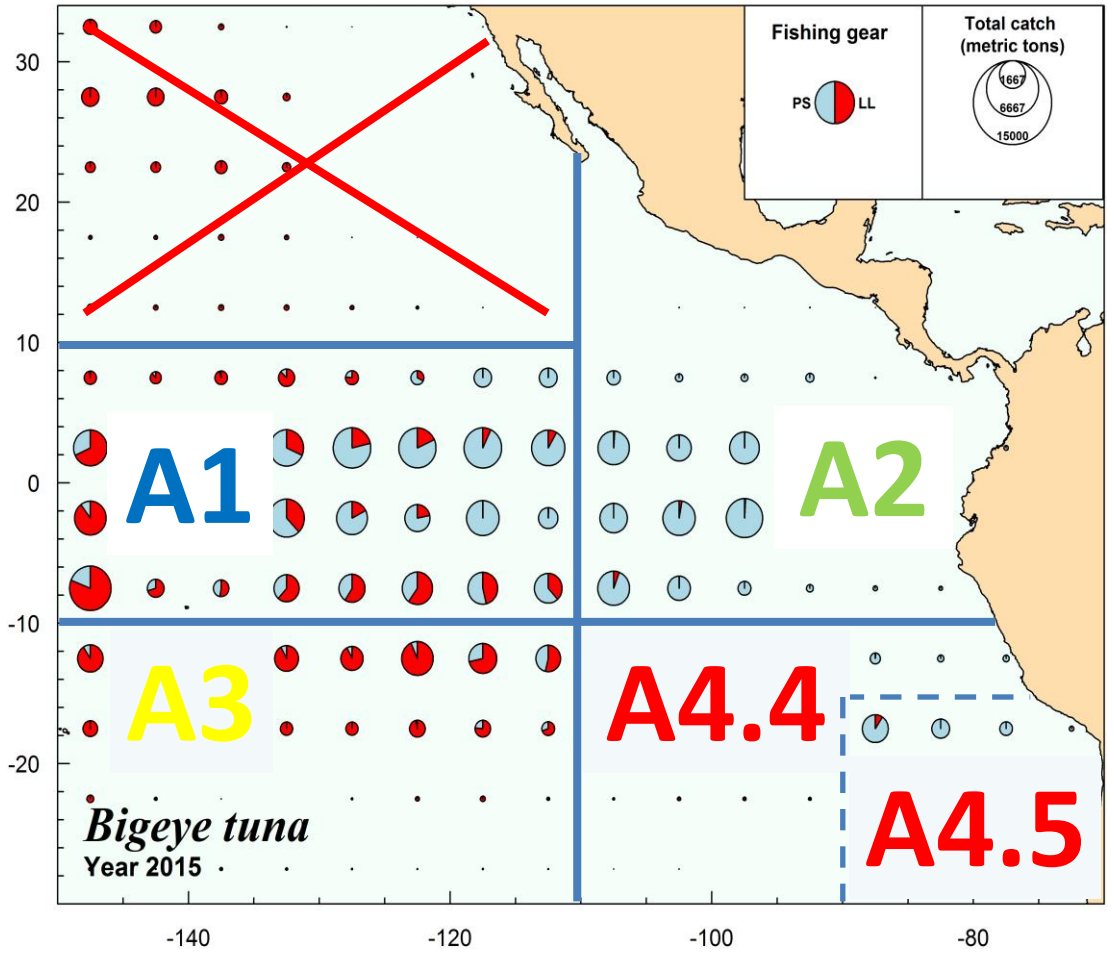
Four Areas (excluding north of 10°N)

**A1**

**A2**

**A3**

**A4** (split fisheries into **A4.4** and **A4.5**)



# Bigeye tuna models

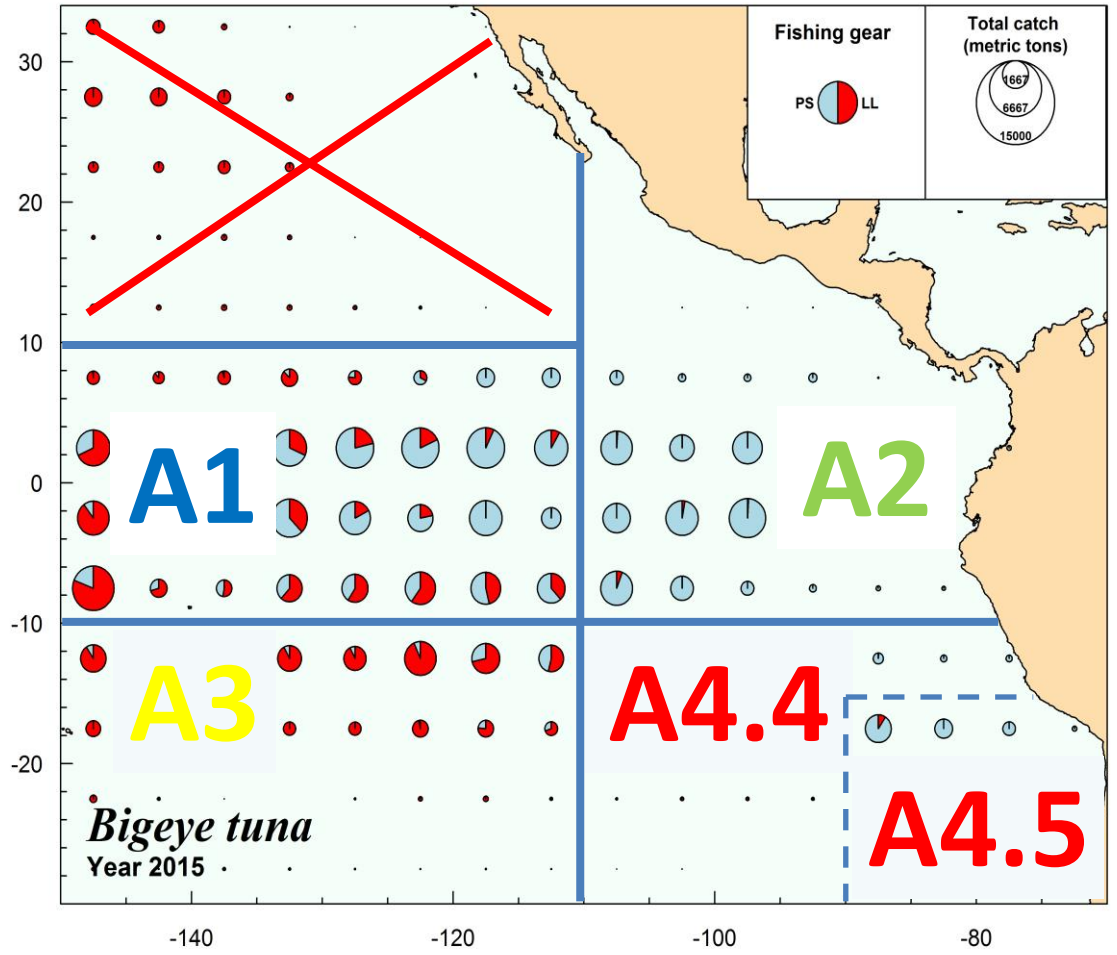
## Current base case

- SS version 3.23b
- Years as Quarters approach
  - Years 1975 to 2017 as Quarters 1 to 168
- Max age 40 quarters (10 years)
- 2-sex model
- Growth is a fixed Richards function
- Fixed age/sex specific natural mortality
- Steepness *h*=1
- 1 Area
- 27 fleets
- 245 parameters
- 3 to 8 hours run time

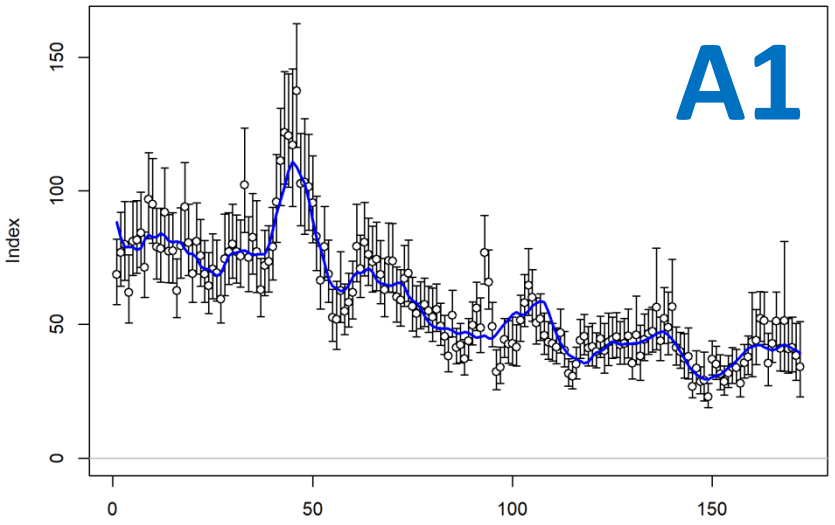
## Exploratory spatial

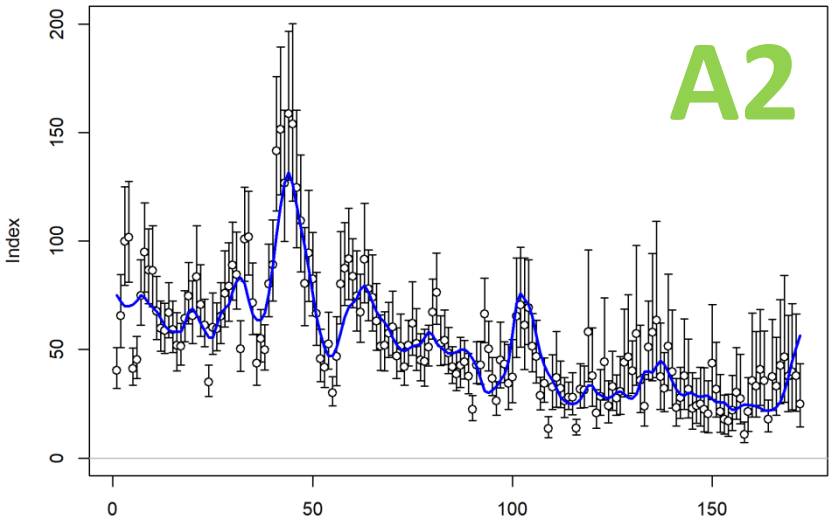
- **SS version 3.3.12**
- Years as Quarters approach
  - Years 1975 to 2018 as Quarters 1 to 172
- Max age 40 quarters (10 years)
- 2-sex model
- Growth is a fixed Richards function
- Fixed age/sex specific natural mortality
- Steepness *h*=1
- **4 Areas**
- **20 fleets**
- **230 to 800 parameters**
- **1 to 3 hours run time**

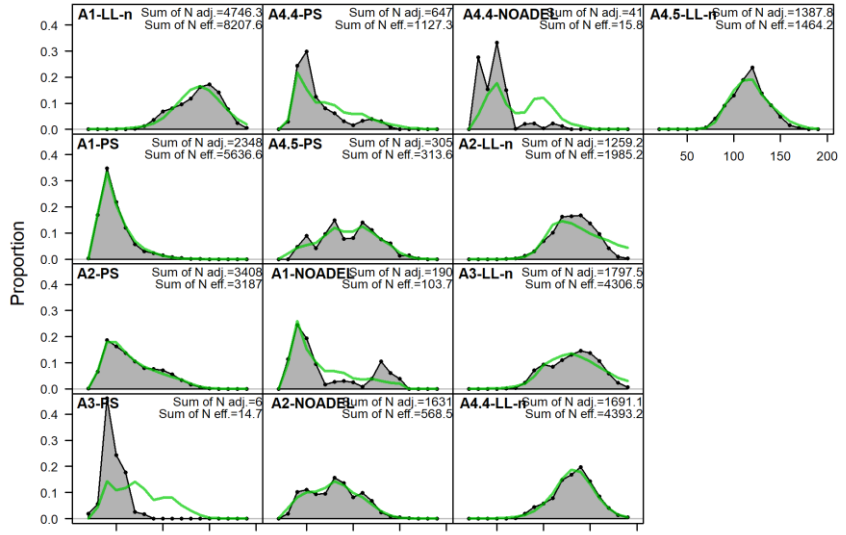
# 4 Areas, No movement

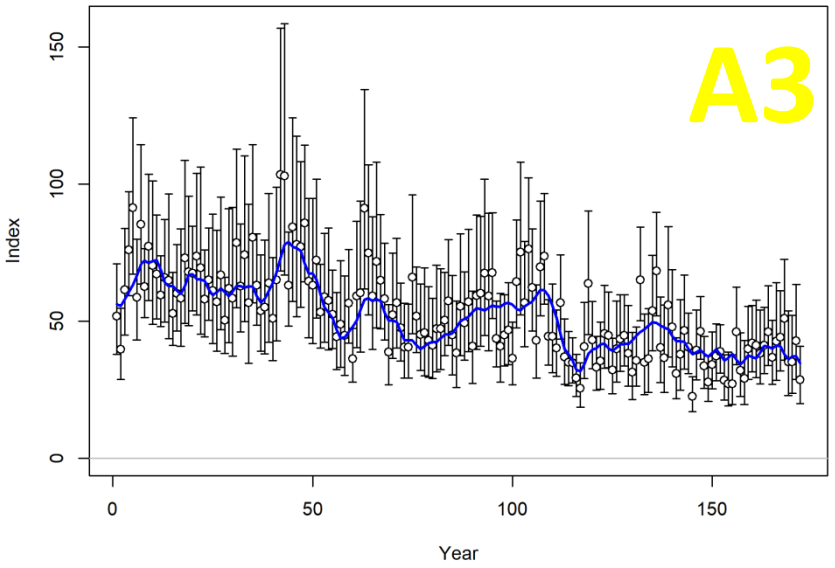


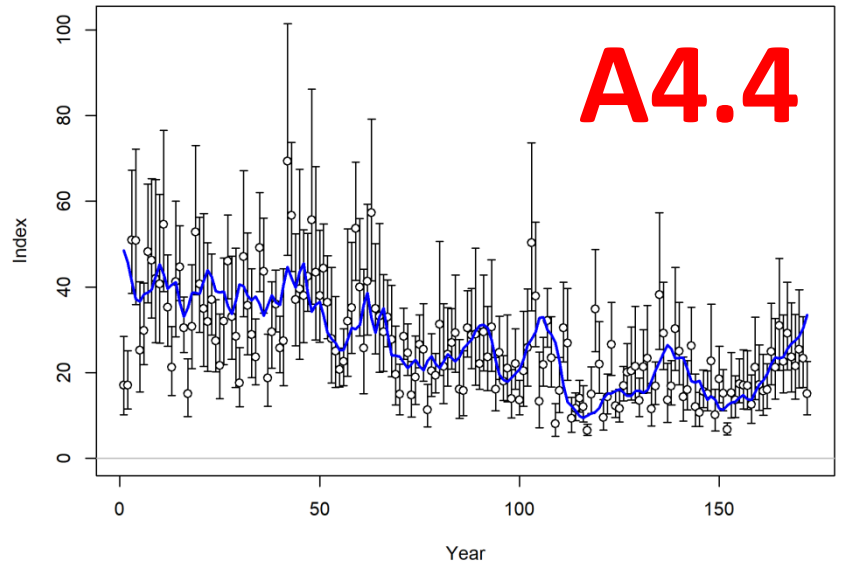
# 4 Areas, No movement

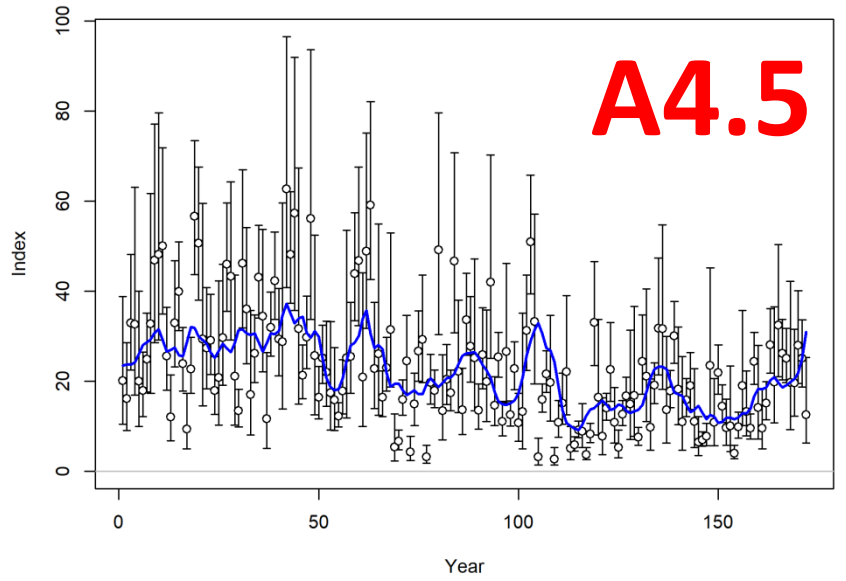


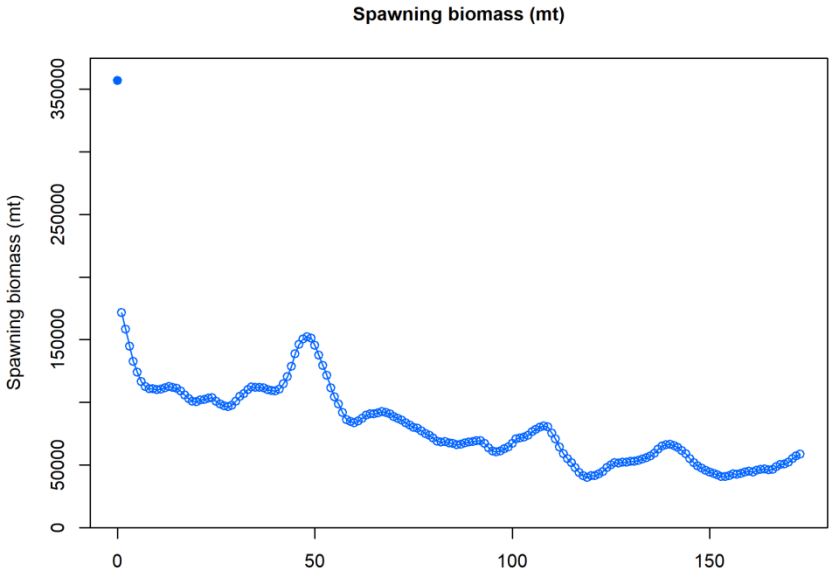



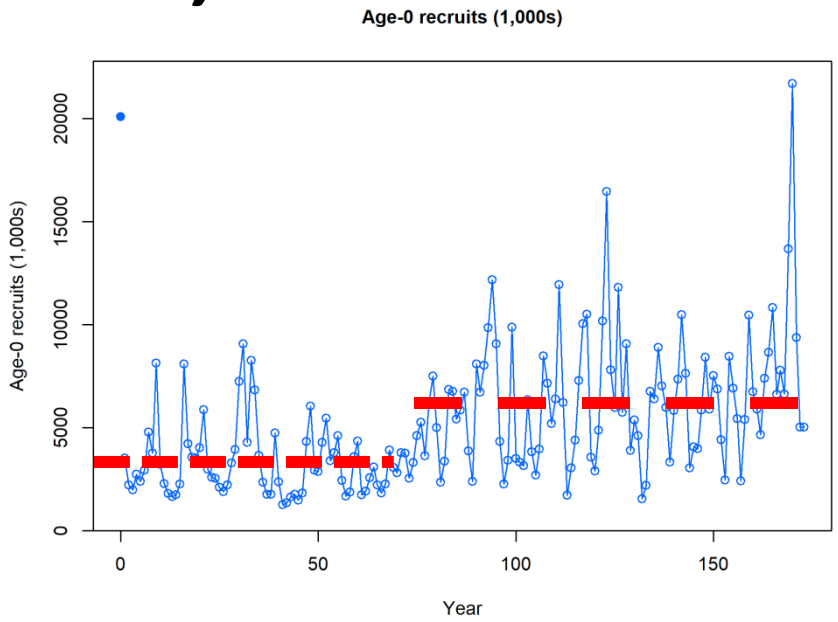



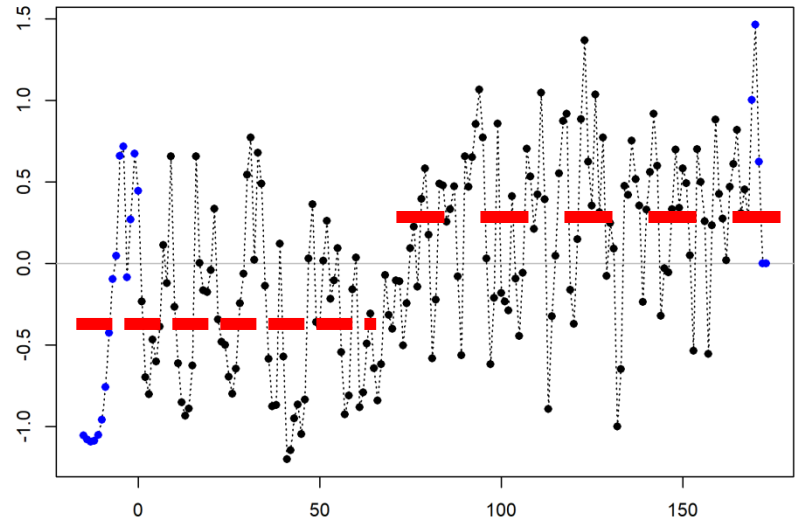



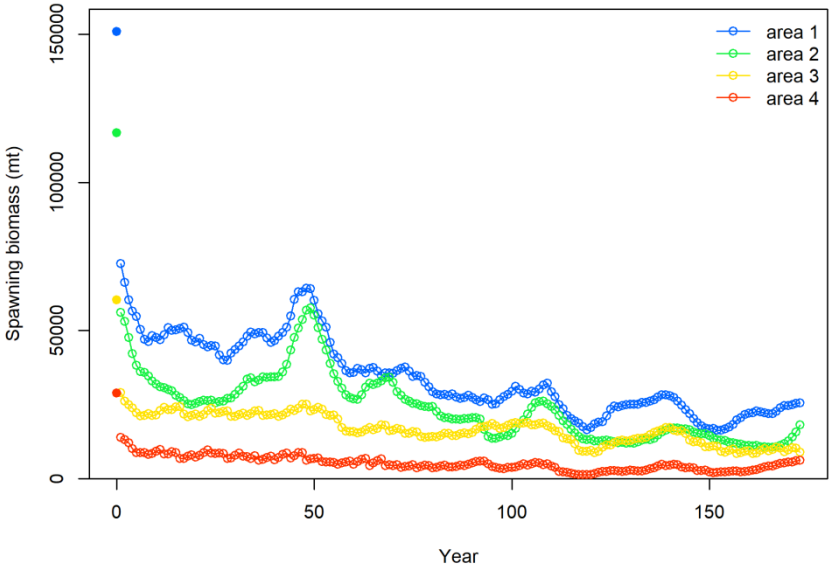



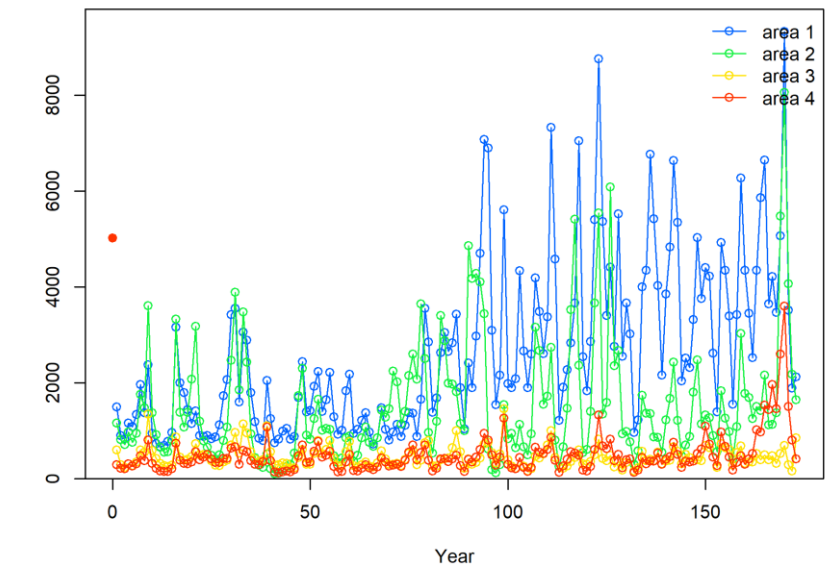
# 4 Areas, No movement

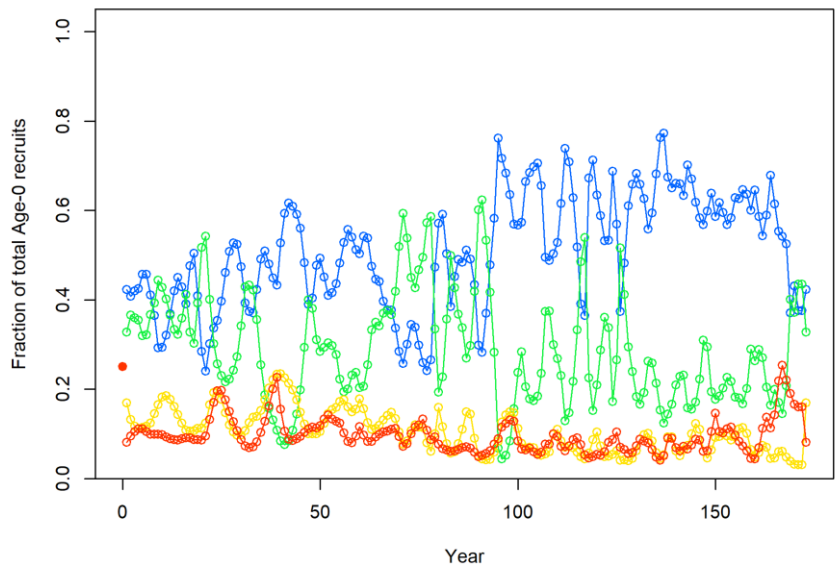


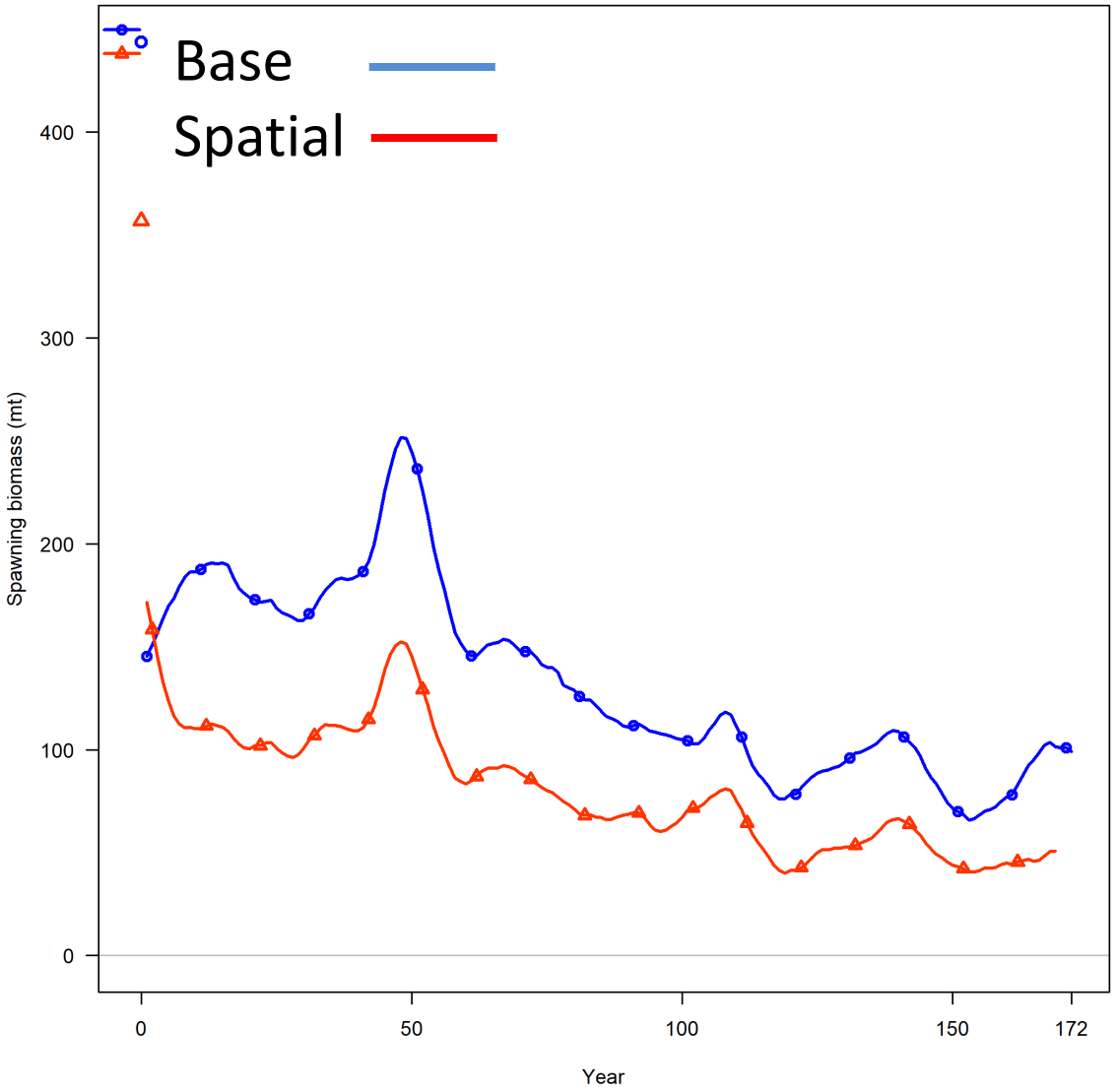



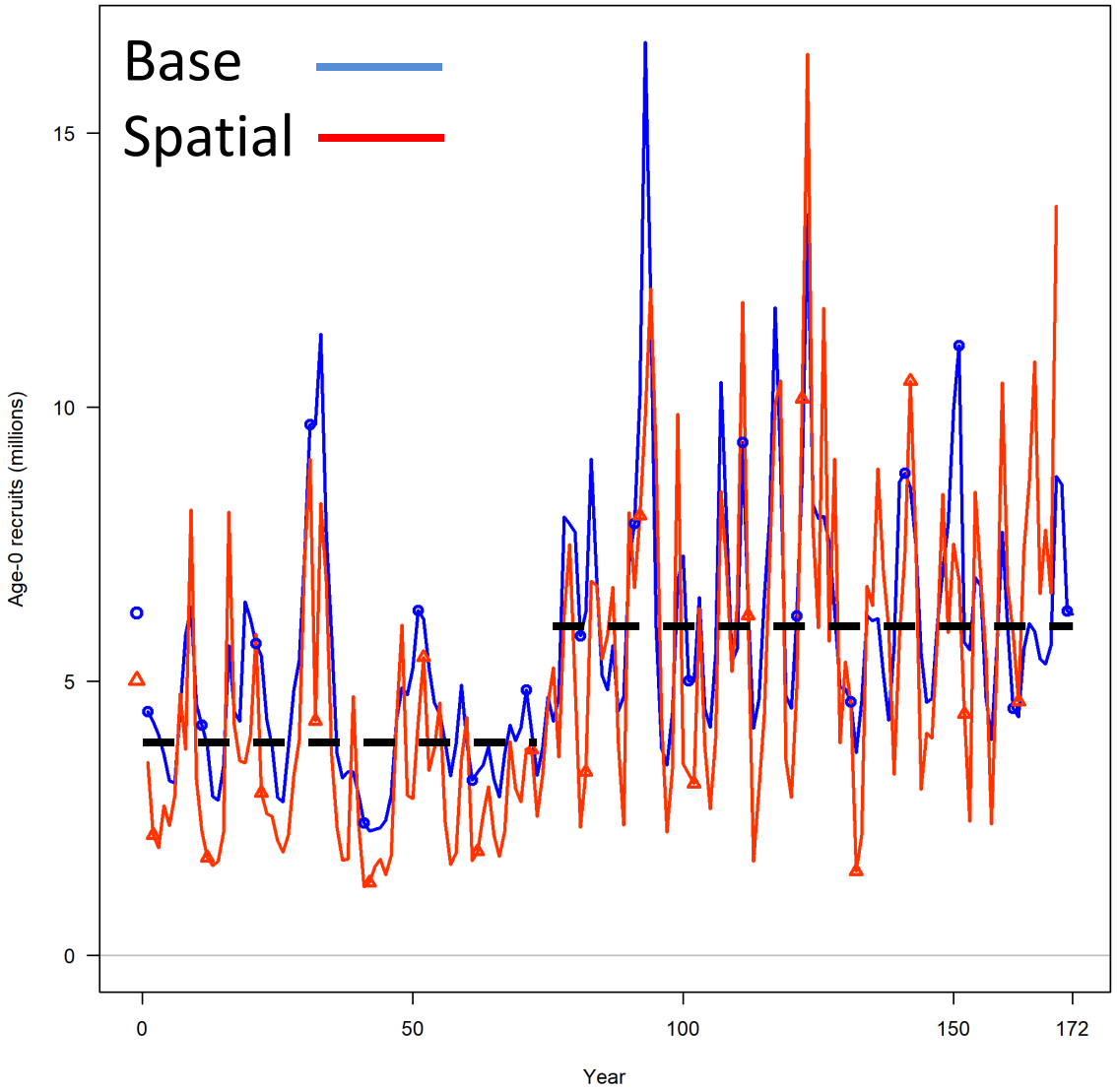



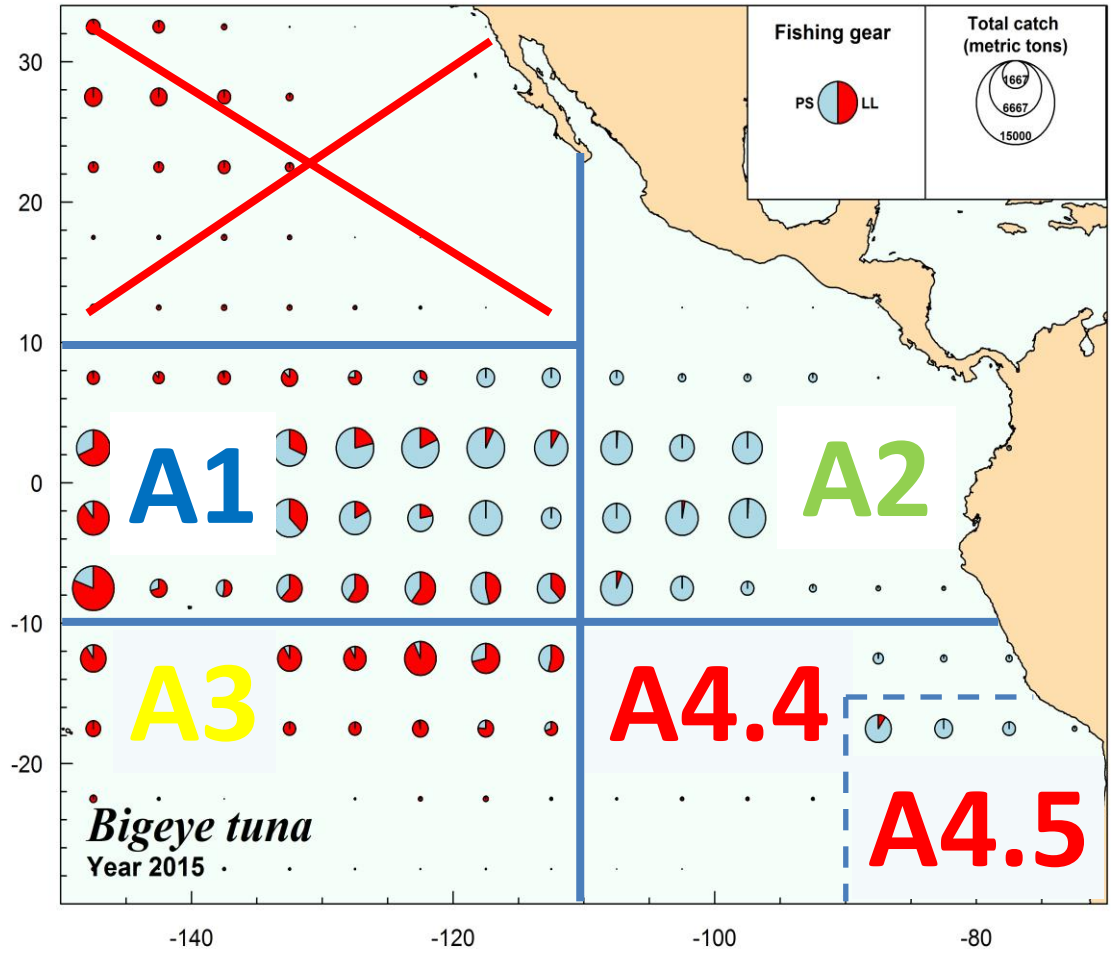



# 4 Areas, No movement vs. 1 area Base

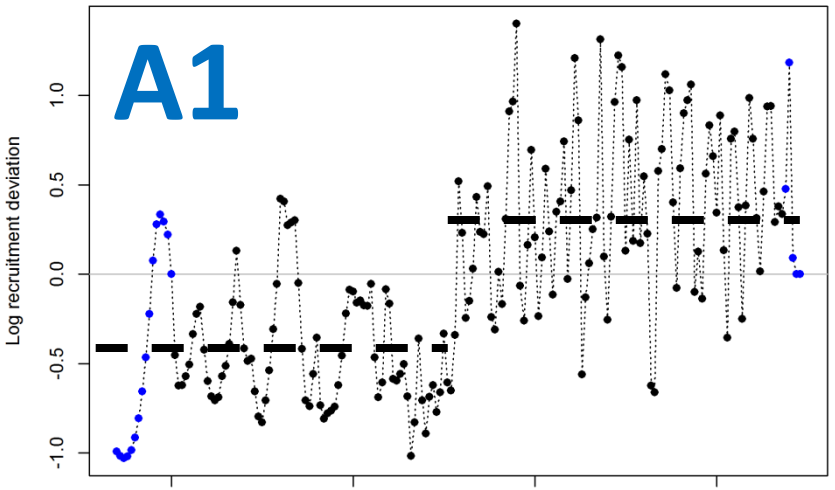


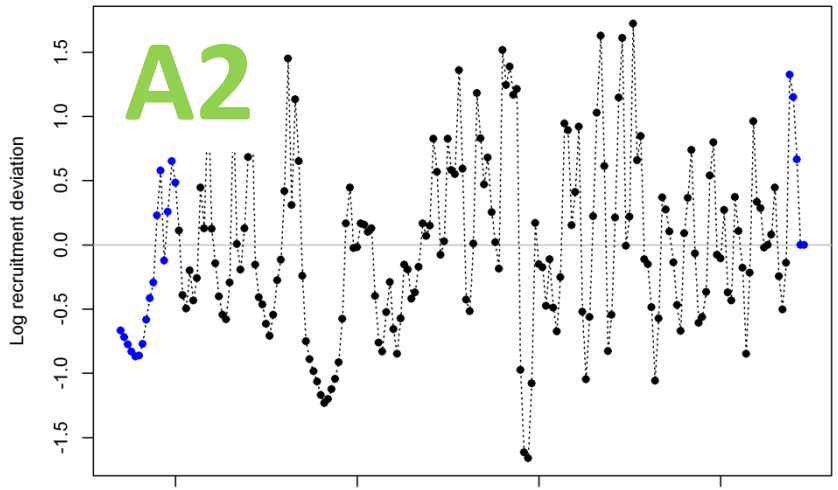



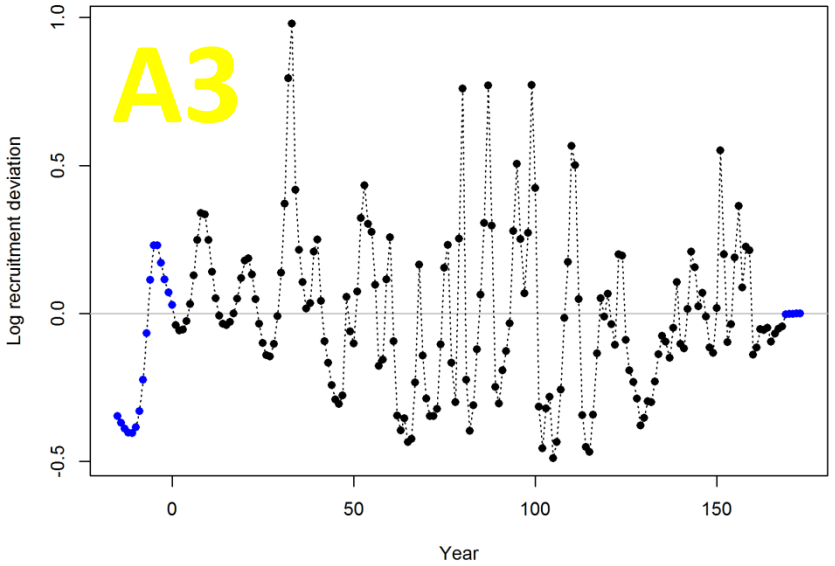
# 4 Areas, independent assessments

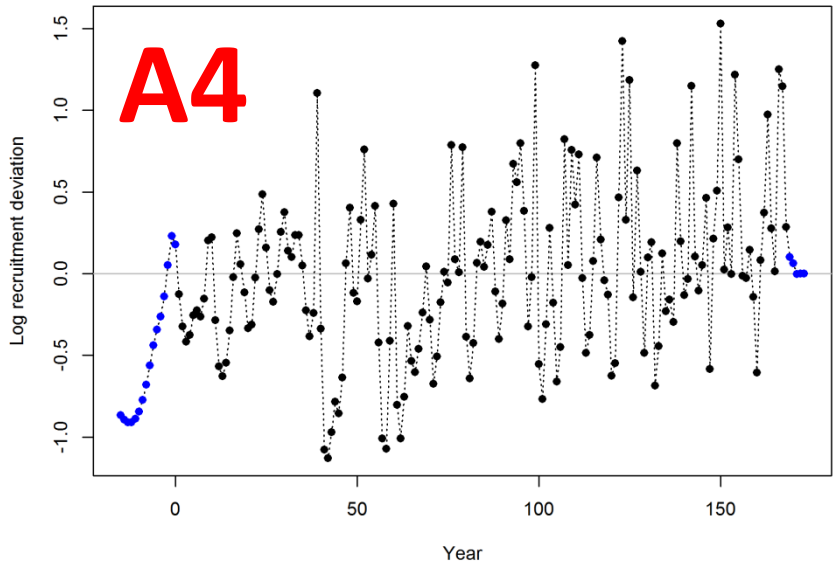


# 4 Areas, independent assessments

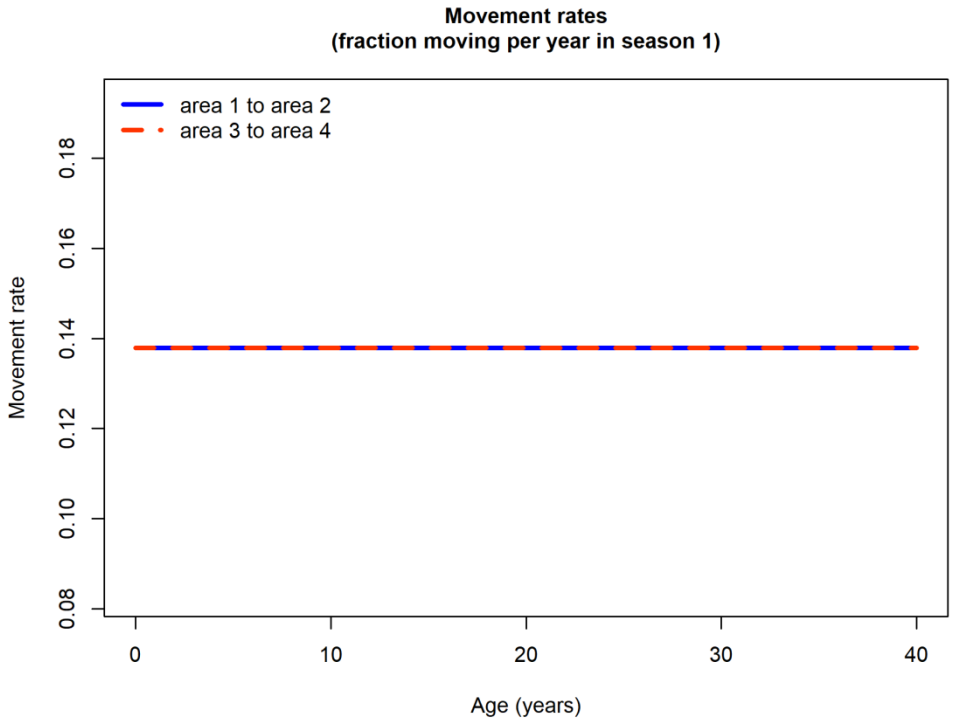


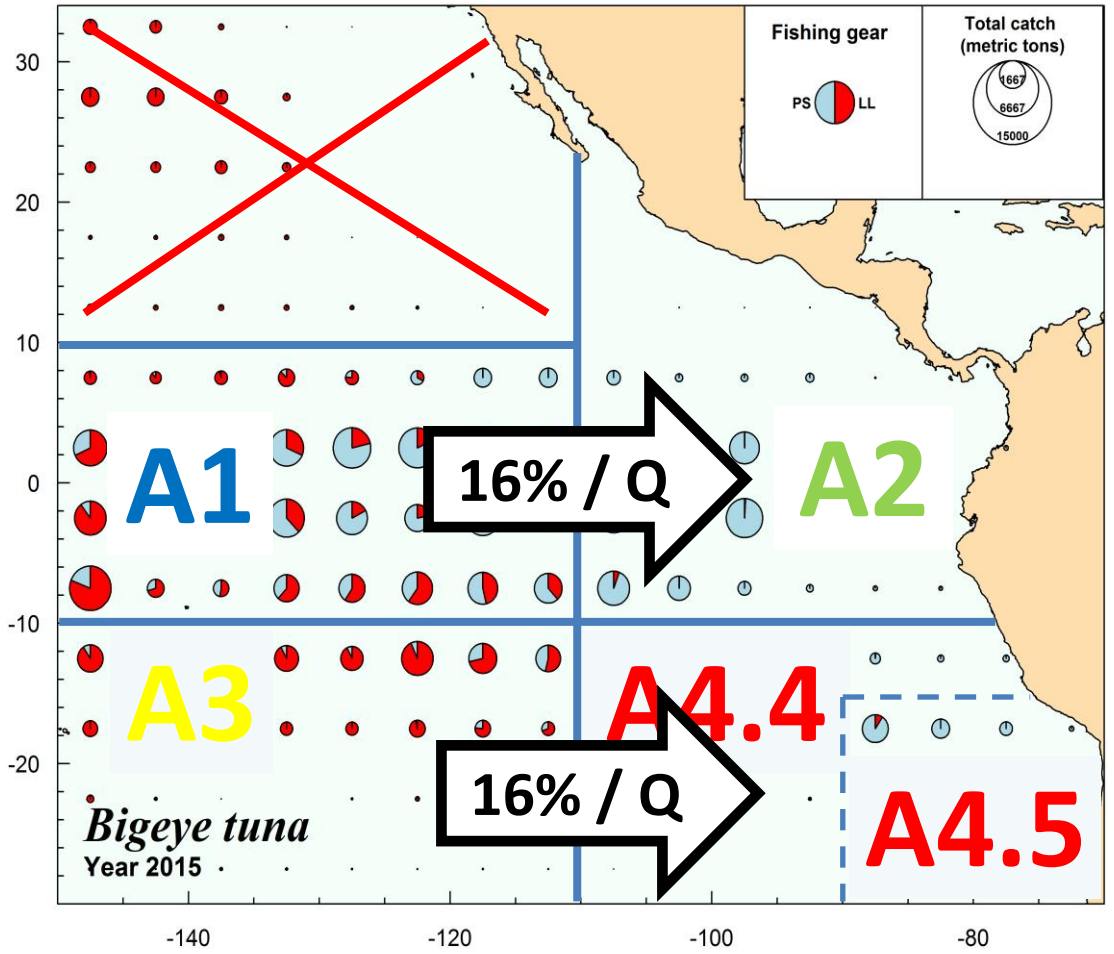



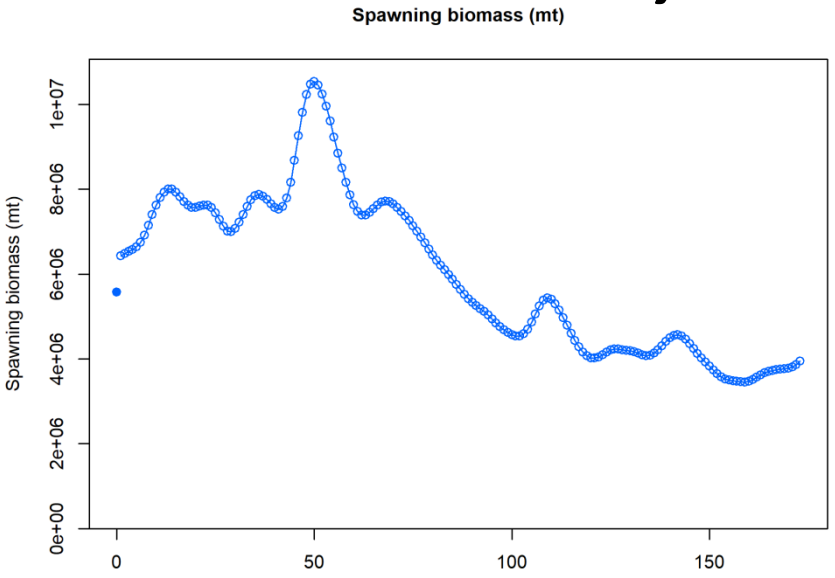



# 4 Areas, Movement (age invariant)

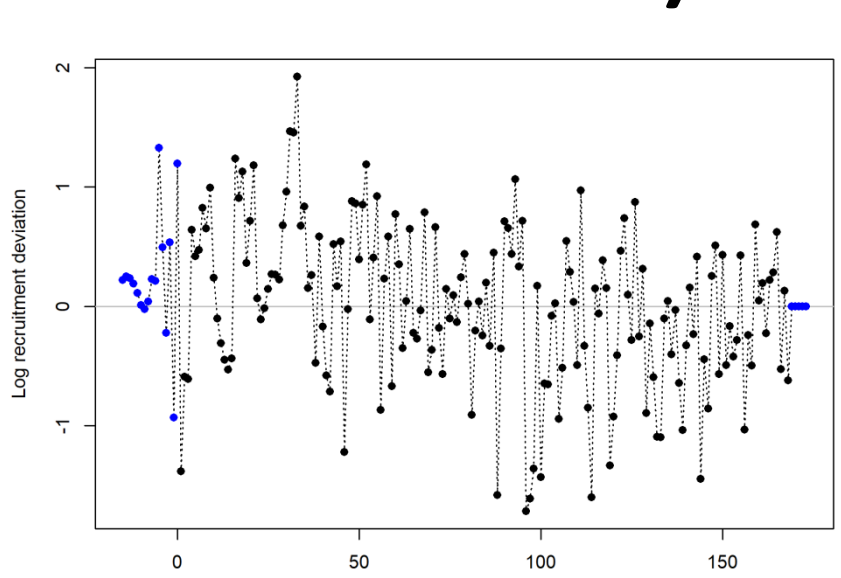


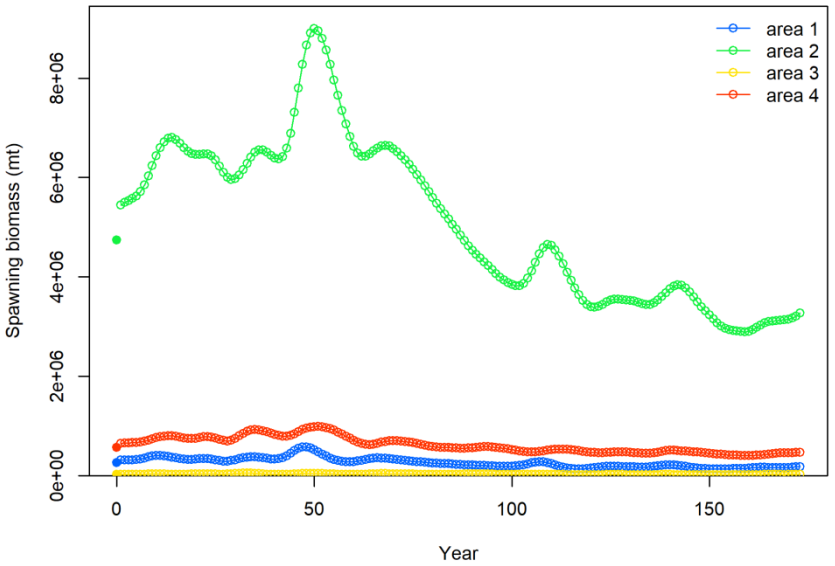



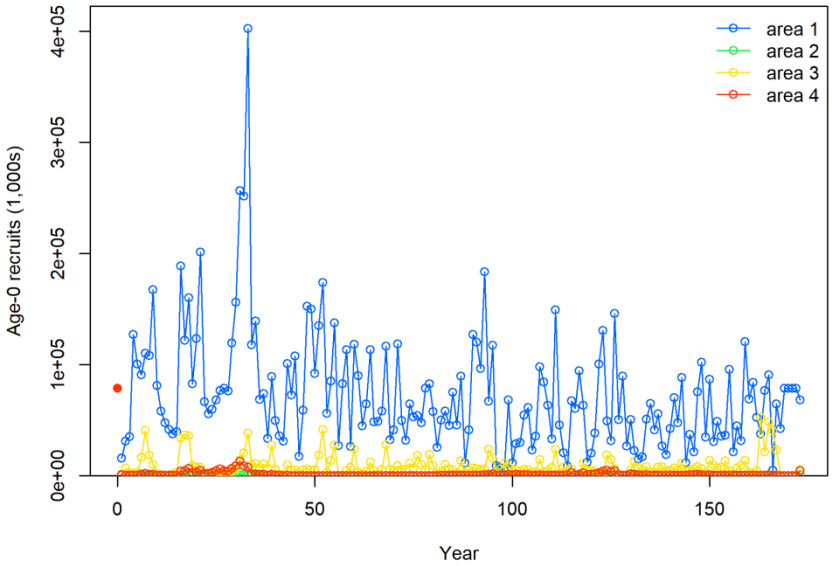
# 4 Areas, Movement (age invariant)

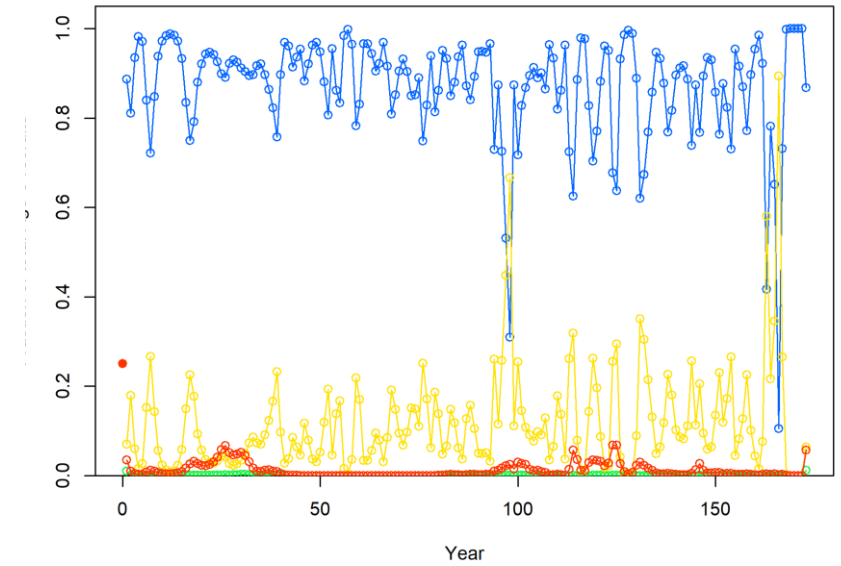




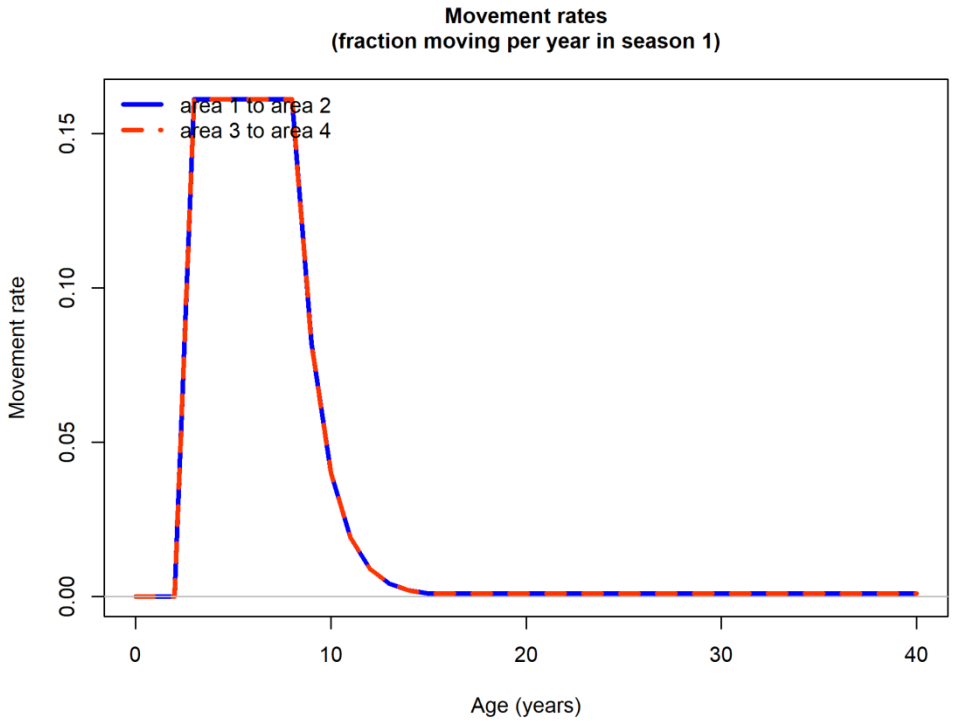


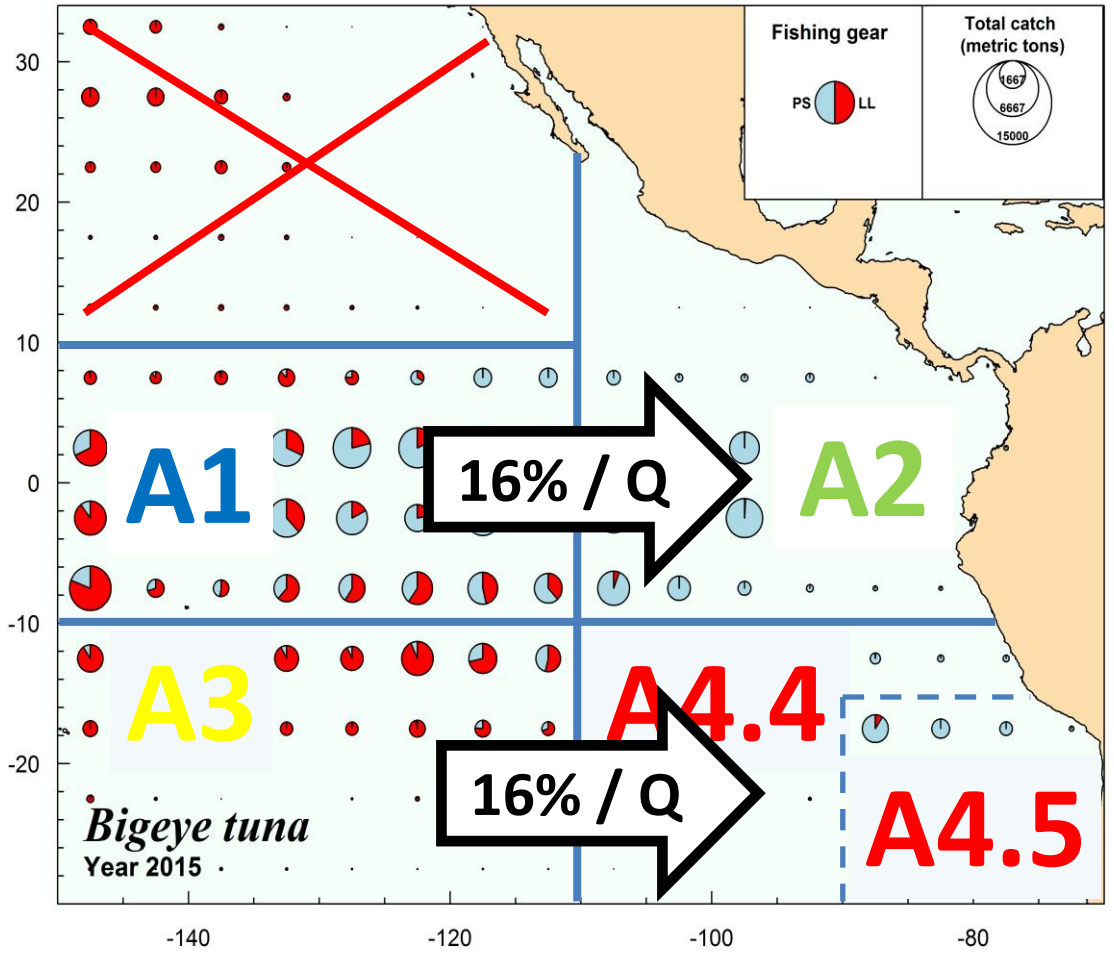



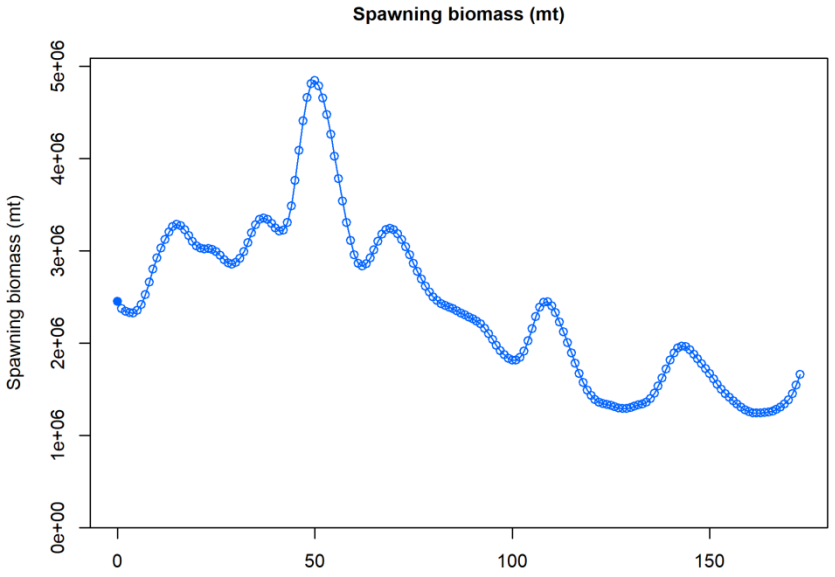



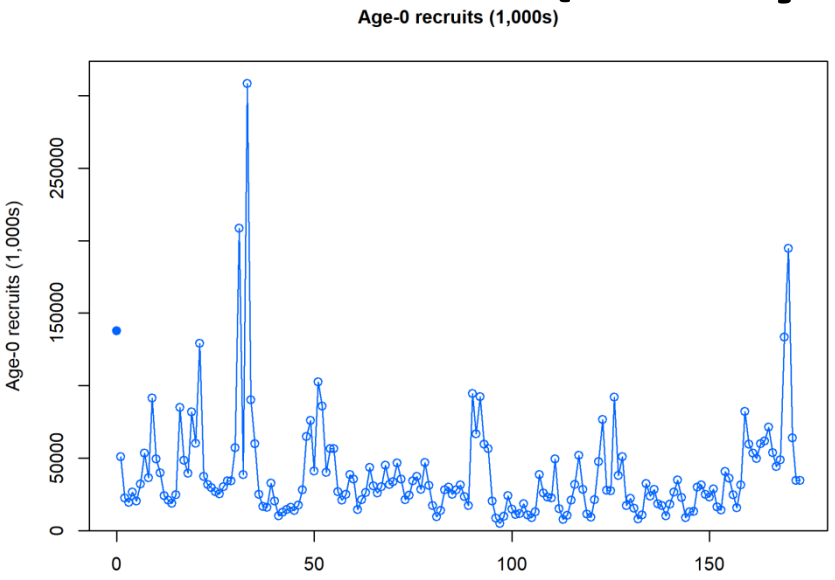
# 4 Areas, Movement (only ages 3 to 8)

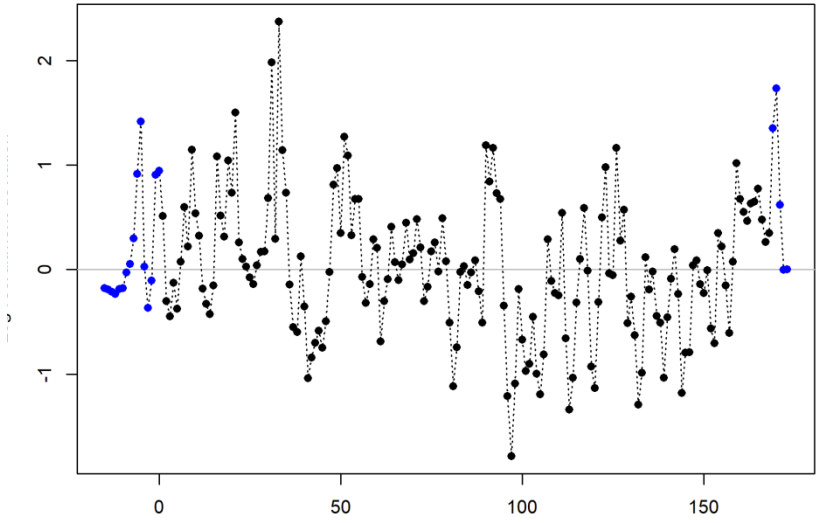


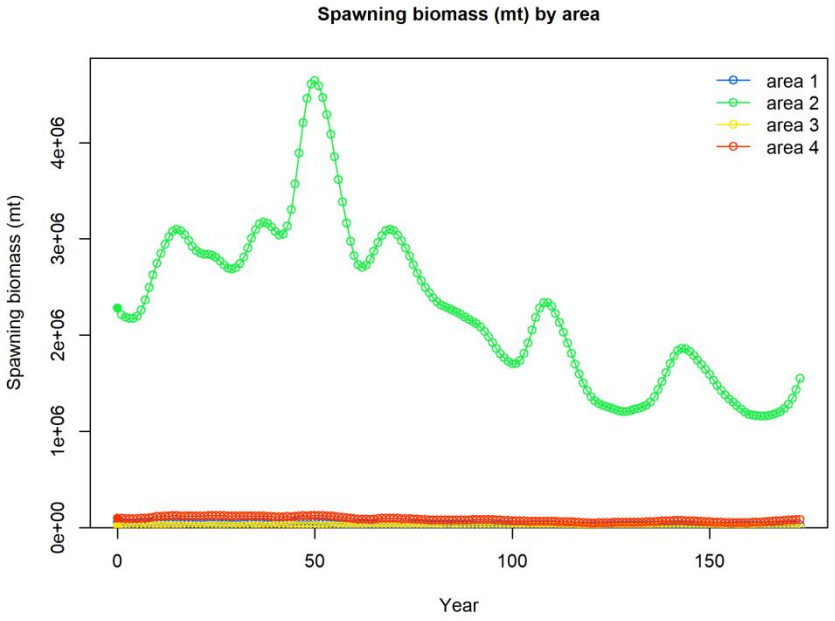



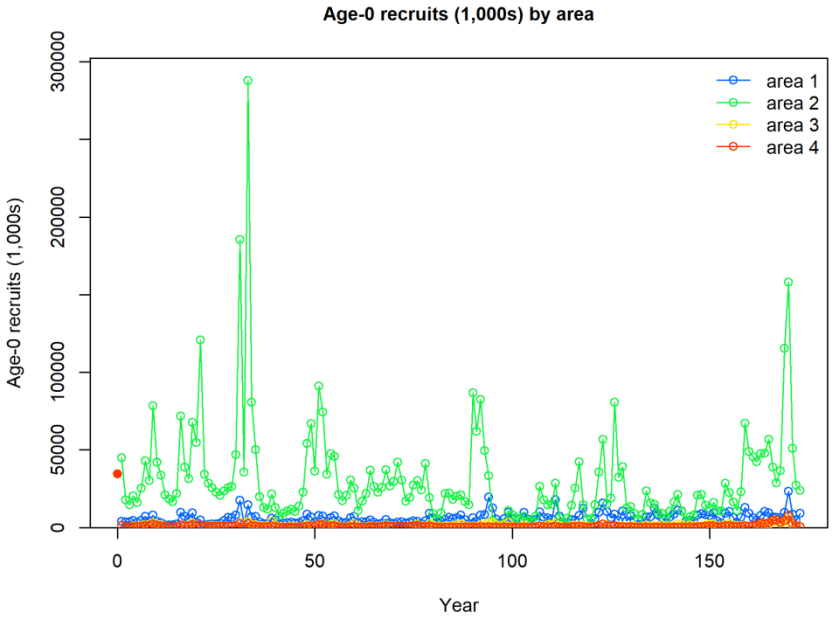
# 4 Areas, Movement (only ages 3 to 8)

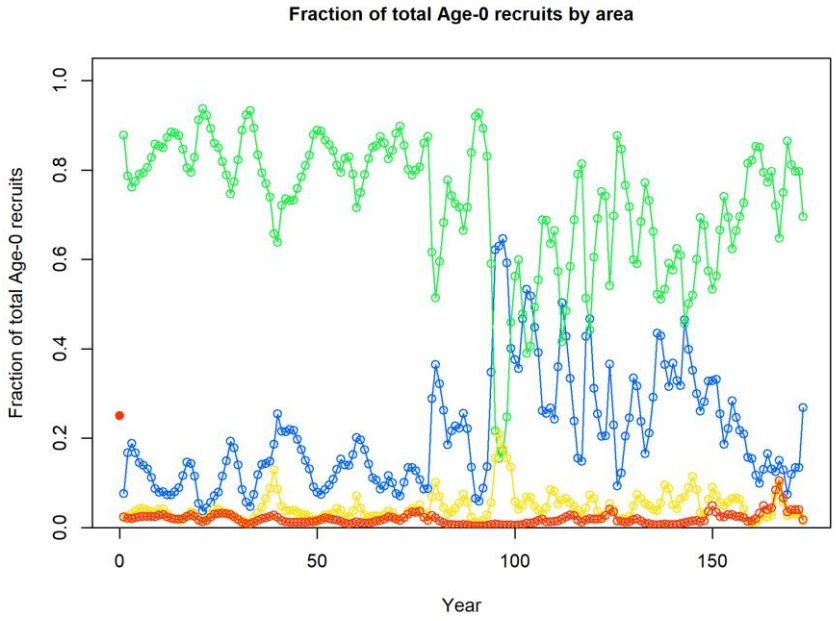


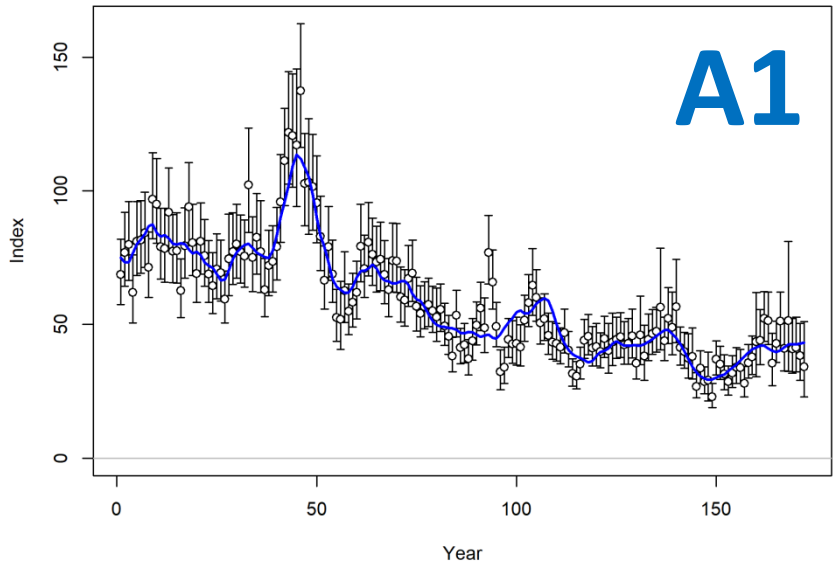



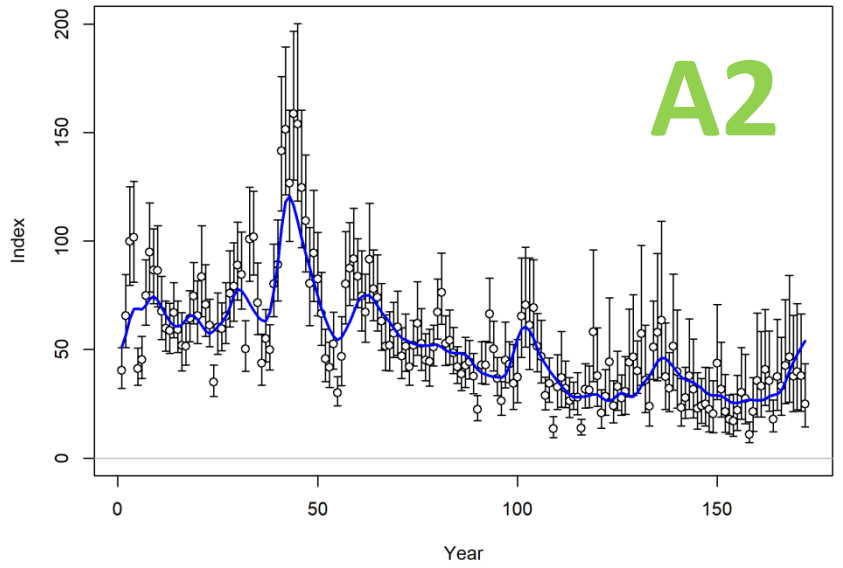



# 4 Areas, Movement (only ages 3 to 8)

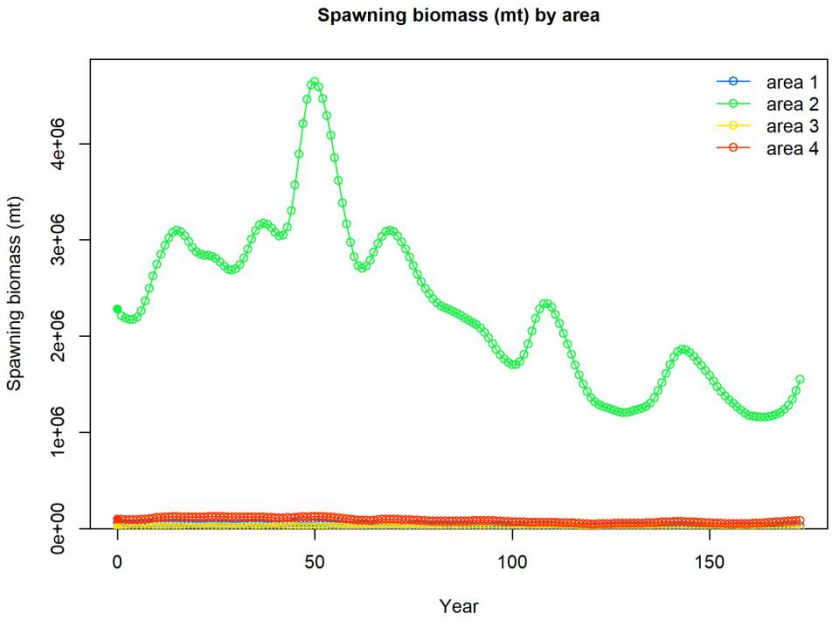
Area specific q and selectivities for longline



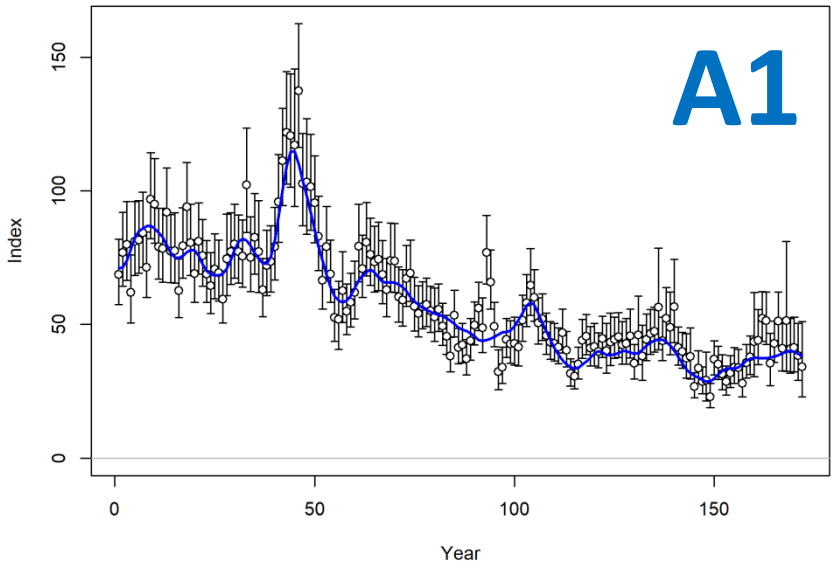

**q = 0.06**

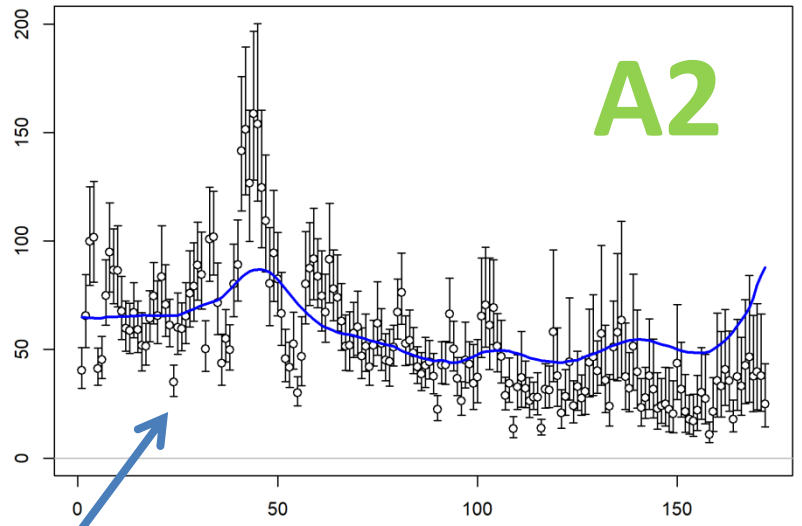
**q = 0.0006**

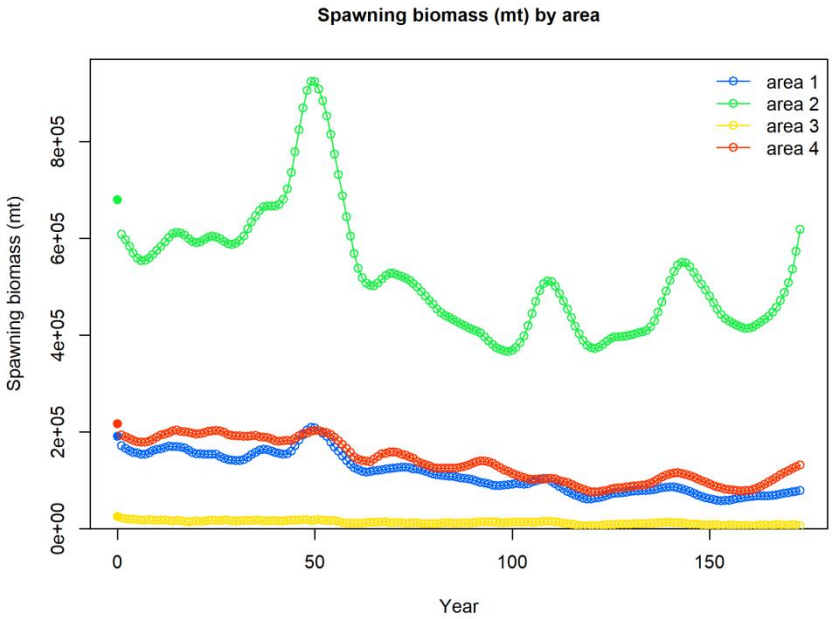


# 4 Areas, Movement (only ages 3 to 8)

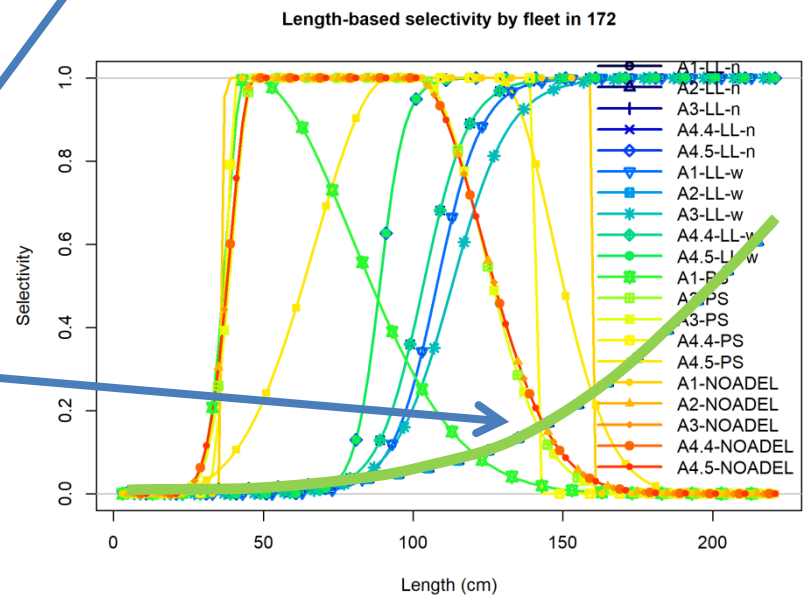
Mirror q, BUT area specific selectivities for longline



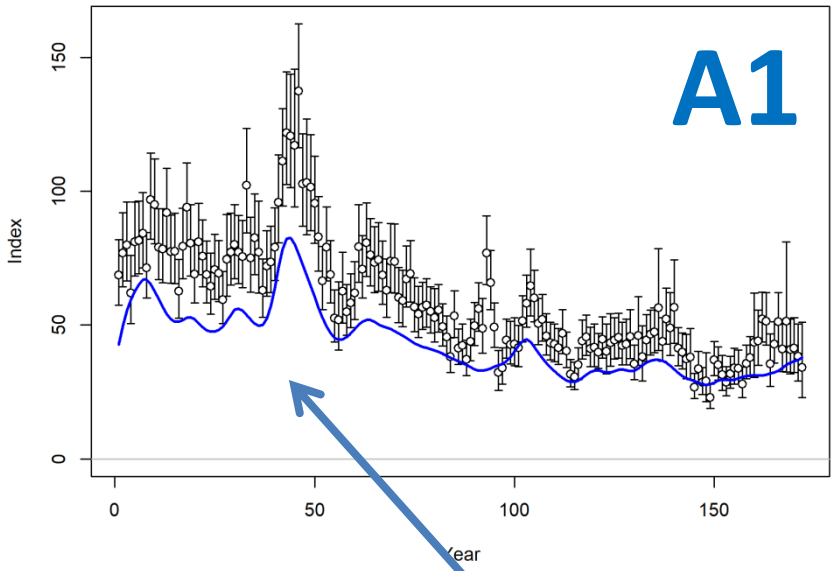



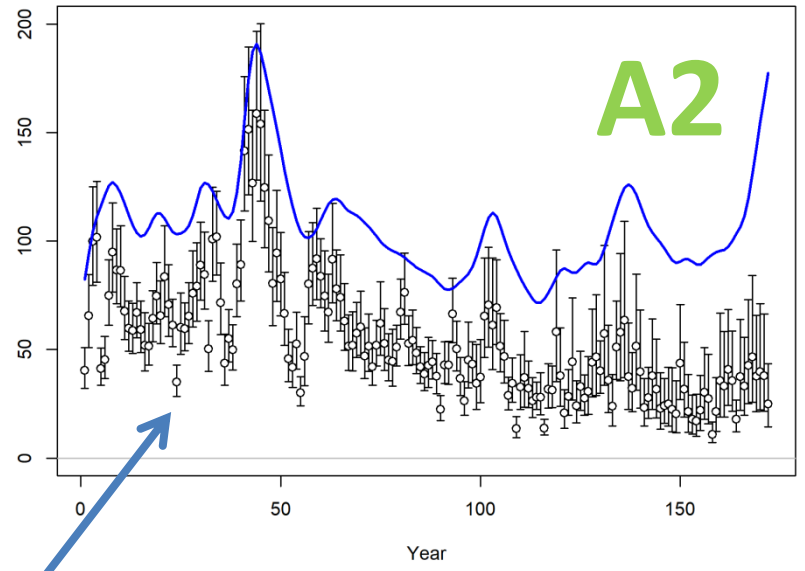

- Degraded fits to indices
- Unrealistic LL selectivities

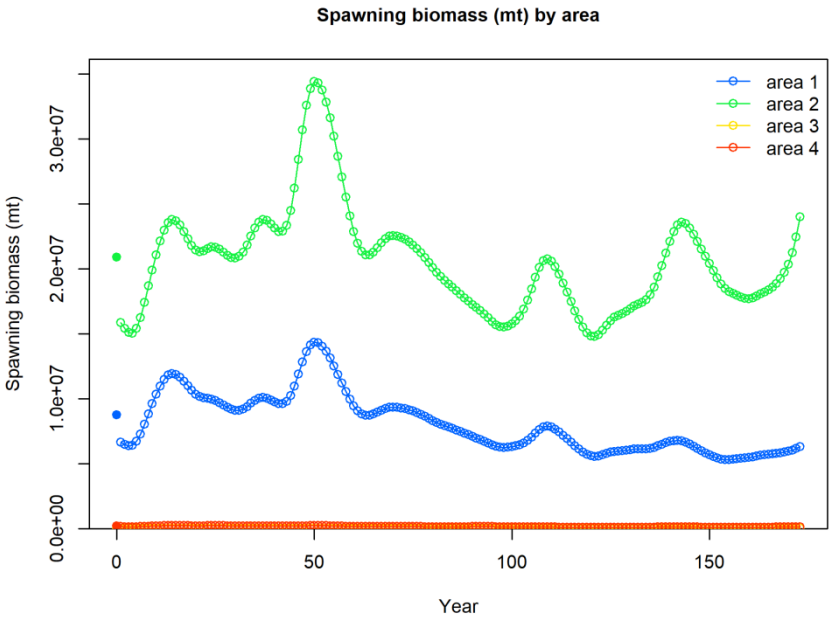


# 4 Areas, Movement (only ages 3 to 8)

Mirror q, AND selectivities for longline

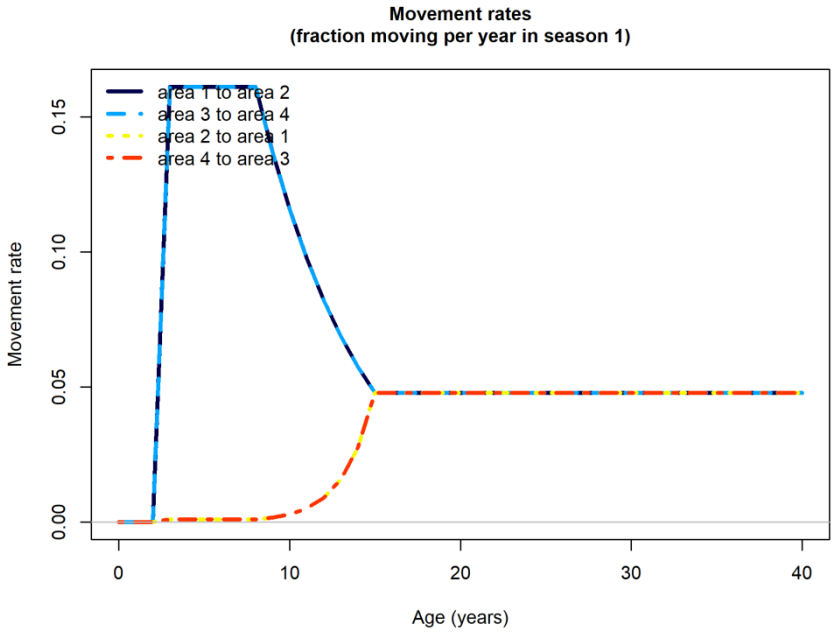


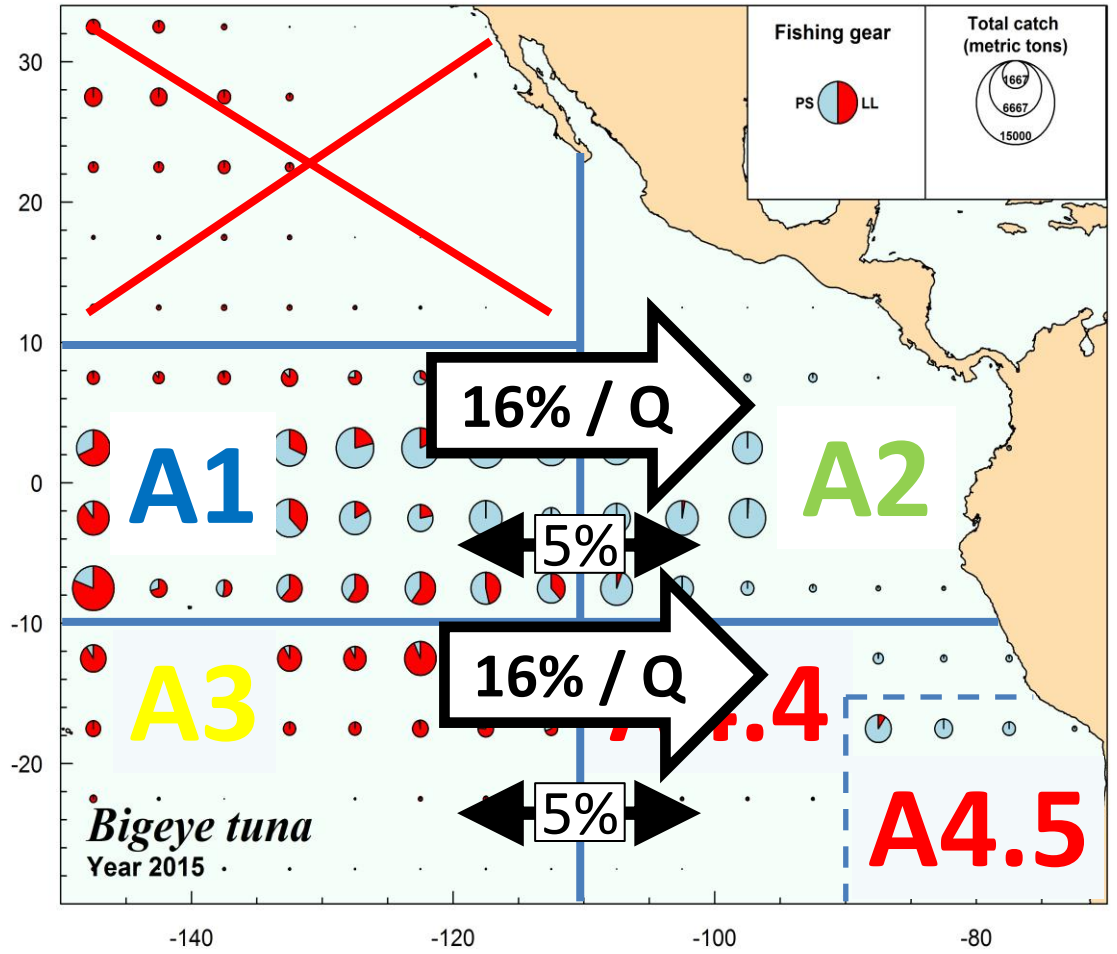



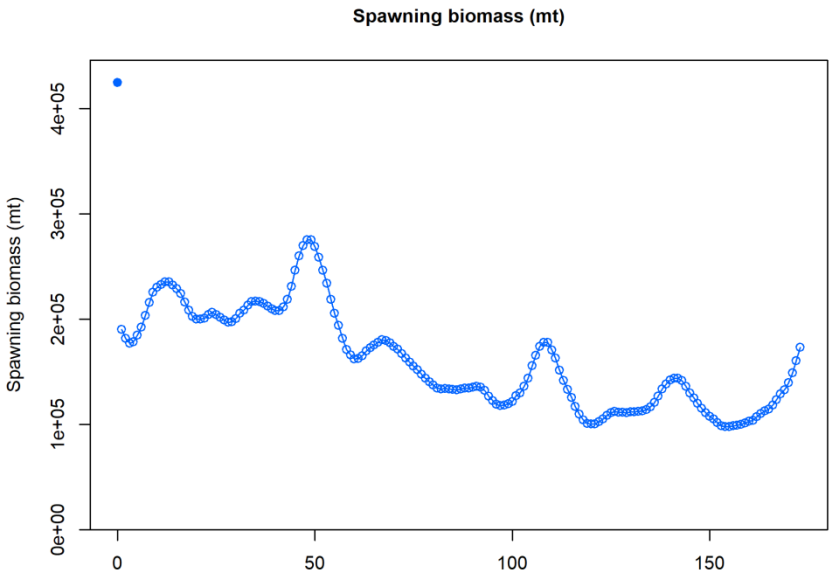

- Severely degraded fits to indices!
- Non-convergence

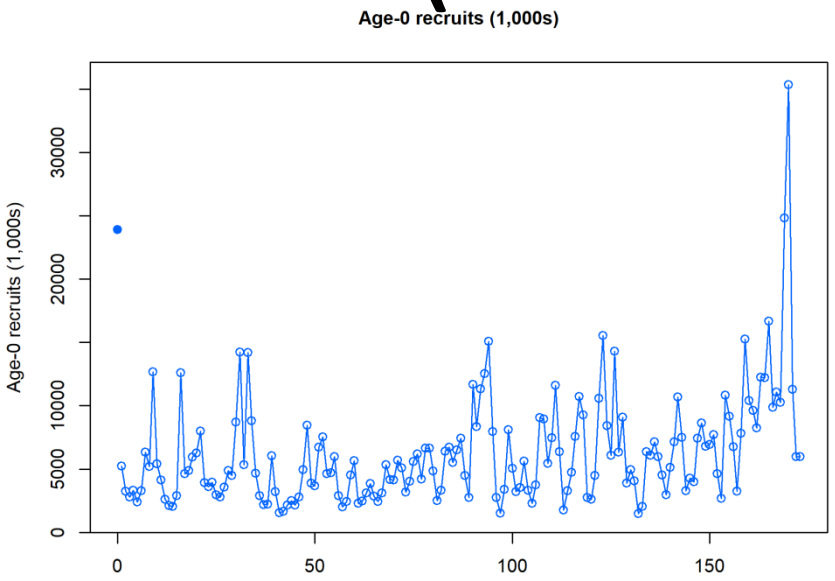
# 4 Areas, Movement (3-8 to E, 15+ diffuse)

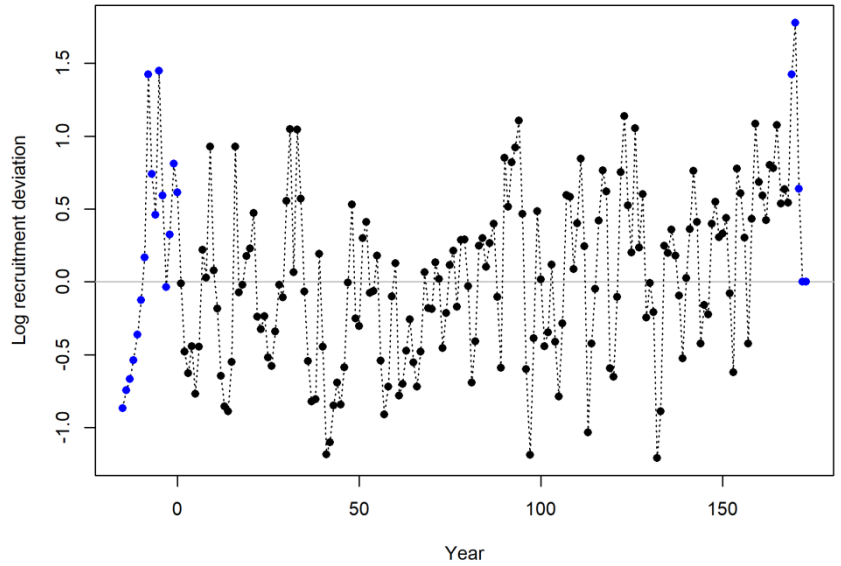


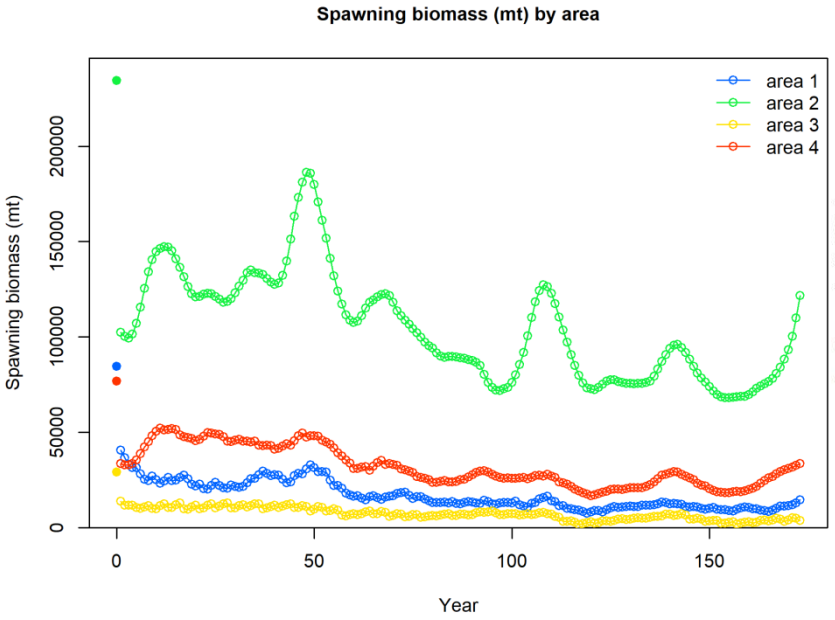



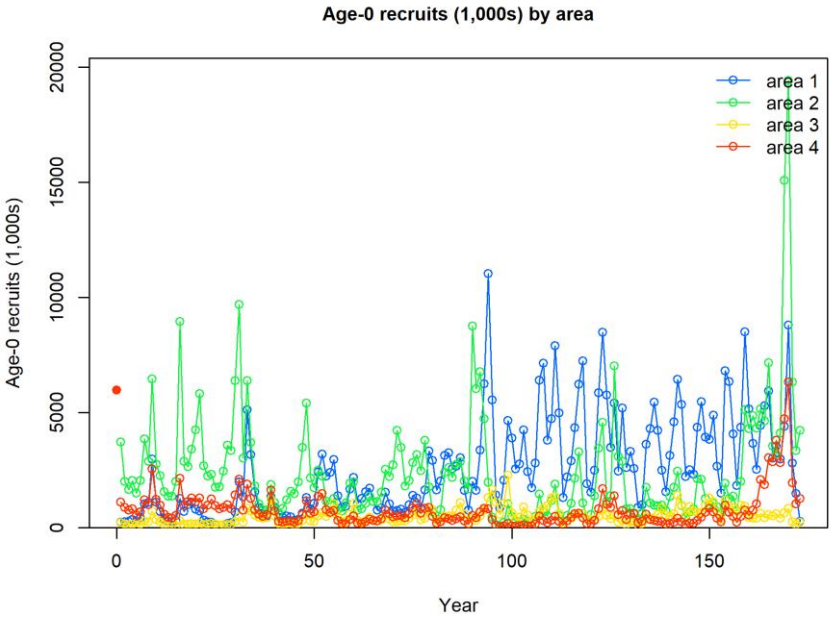
# 4 Areas, Movement (3-8 to E, 15+ diffuse)

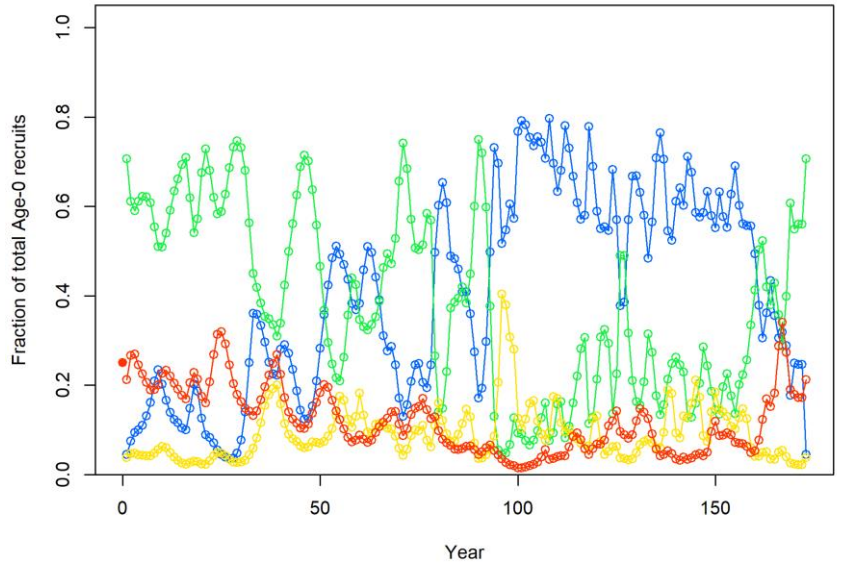


# Summary

- Spatial models of the EPO with no movement do not remove the recruitment regime shift
- Movement at 16% /Q seems too high, even if just for juveniles
- Including East-West diffusion of adults removes the recruitment shift, however we do not know what are reasonable movement rates for adult BET

# Future work

- **Alternative movement scenarios** based on existing archival data
- **Pacific-wide** assessment with SPC
- Better understanding of BET **spatial structure** and dynamics will improve not only stock **assessments**, but also operating models for **ongoing MSE** work.

# That’s all  we have so far!

## Questions? Comments?