# Where Do You Think You're Going? Improving the Spatial Dynamics of Stock Assessment Models by Incorporating Tagging Data

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CAPAM Workshop on Spatial Assessment Models
October 1 - 5, 2018
La Jolla, CA

# The more things change…


**INTER-AMERICAN TROPICAL TUNA COMMISSION**

**WORKSHOP ON SPATIAL ANALYSIS FOR STOCK ASSESSMENT**

**La Jolla, California (USA)**

**14-17 October 2008**

**REPORT**

spatially-explicit stock assessment models. The goals of the workshop are to provide a forum to discuss the state of the art in spatial analysis in fisheries stock assessment and how it can be improved, and to motivate more applications.

Accurately modeling yellowtail flounder, *Limanda ferruginea*, is vital, because all three U.S. stocks are rebuilding from an overfished condition, and large discrepancies have occurred between model predictions and subsequent stock assessments. Recent tagging data demonstrate movements of yellowtail among stock areas, which may be affecting the model results, as negligible immigration and emigration is assumed in all three assessments. The purpose of this study is to evaluate the sensitivity of stock assessment results to movements of fish among stock areas. To do this, a spatially-explicit forward-projection stock assessment model is being developed that includes a mark-recapture component (based on yellowtail tagging data) to the objective function to estimate movement. Future work will also include development of an external large-scale circulation model to assess the effects of egg and larval drift, both within and among stock areas, on recruitment. A simulation study will be performed on the integrated model to assess model performance, and to evaluate the types and amounts of movement that most affect the population dynamics of yellowtail flounder.

# If the coffee/lunch can't wait….

- *Ignore spatial dynamics and connectivity at your own peril*
- Flexible parametrization of movement dynamics is critical
- Spatial models without tagging information may be limited in their ability to accurately reflect movement dynamics


# Where do you think you're going?

- Spatial tag-integrated models are better equipped to estimate complex movement dynamics
- *Do not overthink the use of tagging data**

# Outline

- Background on tag-integrated models
  - What are they?
- How they have been utilized for management advice?
  - Why are spatial assessments not more prevalent?
- Explore critical research questions
  - Use simulation-estimation framework to explore performance of tag-integrated models
- Final thoughts

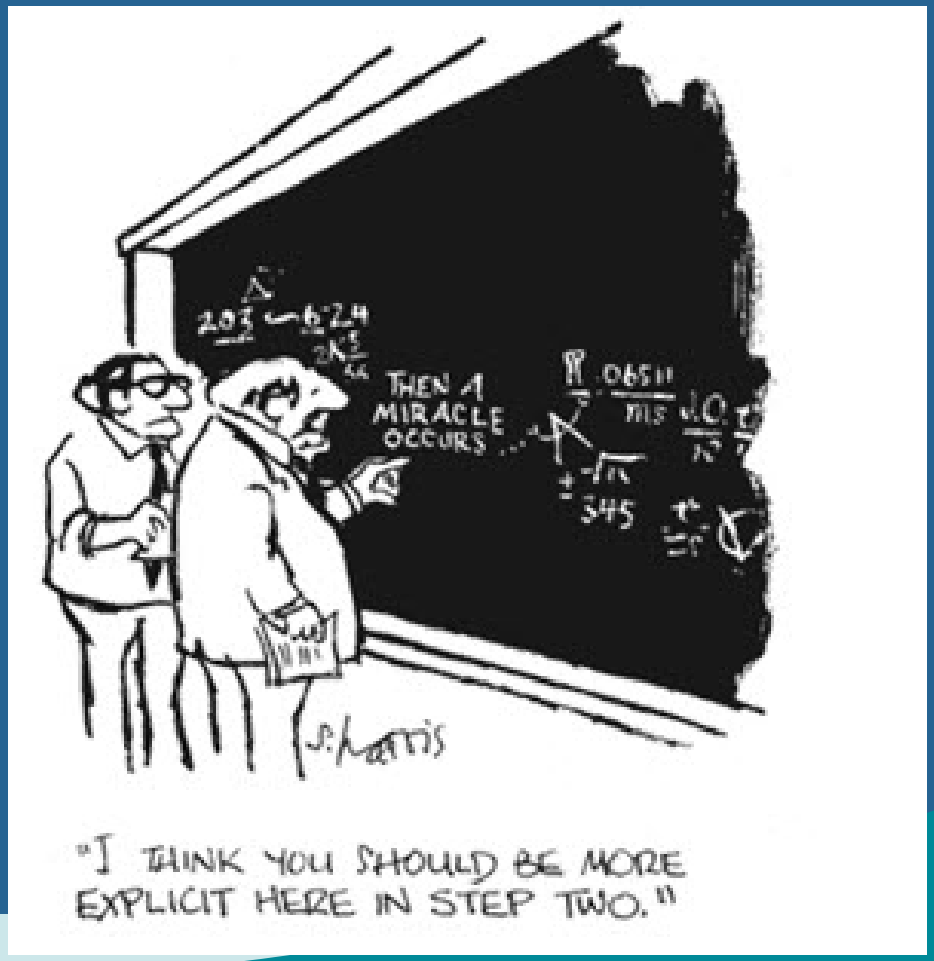
# Discussion Topics

- When are tag-integrated models needed?
- Can tagging data reduce parameter correlation in spatial models?
- Can tagging data help estimate complex movement dynamics (time/age varying)?
- Does tagging experimental design matter?
- Can reporting rate be estimated?
- Can natural mortality be estimated with tagging data?
- How can we ensure tagging assumptions are not violated (incomplete mixing, tag loss/mortality)?
- How should tagging cohorts be defined/fit when there is no information on age?
- Should tagging data be incorporated directly or processed external to an assessment?
- How do we handle data weighting issues when incorporating tagging data?
- How should electronic tagging be incorporated?
  - Balancing precision vs. representativeness
- Should fleet dynamics be accounted for (relationship among tag timing and fishing seasons)?
- How can we make better use of alternate tag types (parasites, genetics, otolith)?

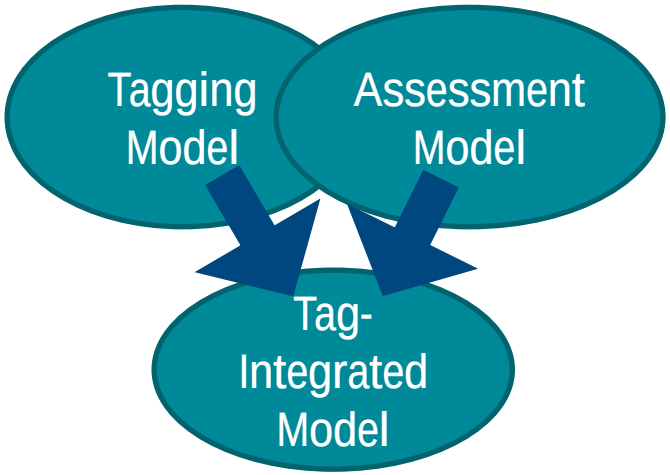
# Focus of Presentation

- Is tagging data needed to estimate complex movement patterns?
- Can simpler movement parametrizations be useful?
- Does a tagging study need to be perfectly designed?
  - Are opportunistic tagging studies useful?
  - Does timing (in relation to assessment timeseries) of a tagging study matter?
  - Can tagging designs requiring less resources be useful?

# What Are Tag-Integrated Models?



# Tag-Integrated Models




- What are they?
  - Models that incorporates tagging information directly in the objective function
    - Additional data helps inform estimation of critical population parameters
  - Focus here on spatial modeling, but can be applied in non-spatial context
    - Petersen estimates of abundance
    - Estimate growth
    - Estimate natural mortality

ELSEVIER

Fisheries Research

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A review of integrated analysis in fisheries stock assessment

Mark N. Maunder [a], André E. Punt [b]

**Incorporating Spatial Structure in Stock Assessment: Movement Modeling in Marine Fish Population Dynamics**

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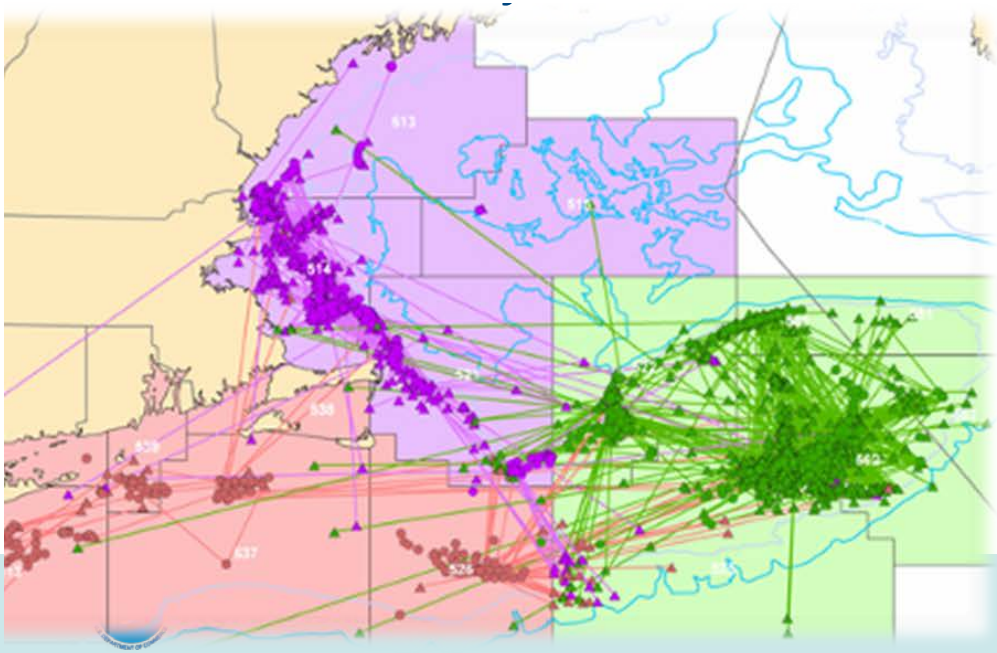
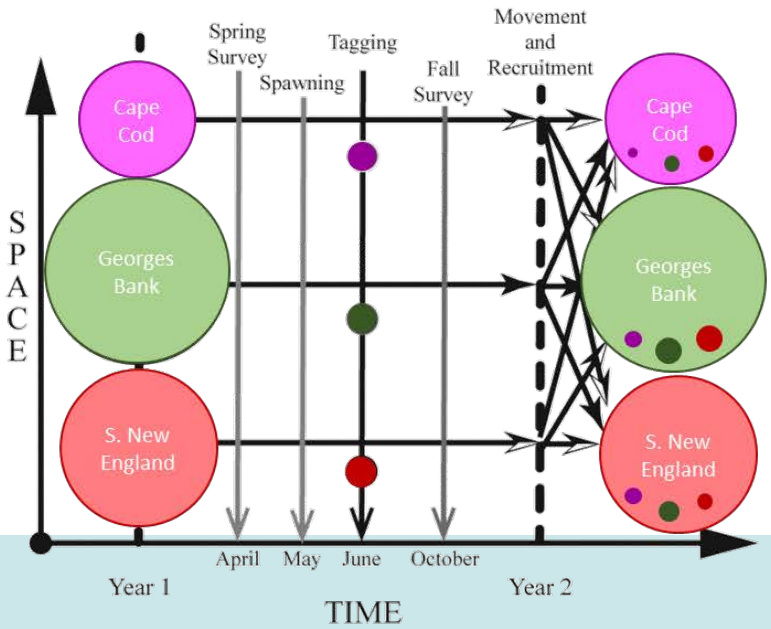
# Tag-Integrated Models

- Incorporate tagging data directly using:
  - A tagging sub-model
  - A tag component in the objective function

$$\hat{r}^{l}_{j,y+1} = n^{l}_{j,y+1}\beta_j\left(1-e^{[-(F_{j,y+1}+M)]}\right)\frac{F_{j,y+1}}{F_{j,y+1}+M}$$



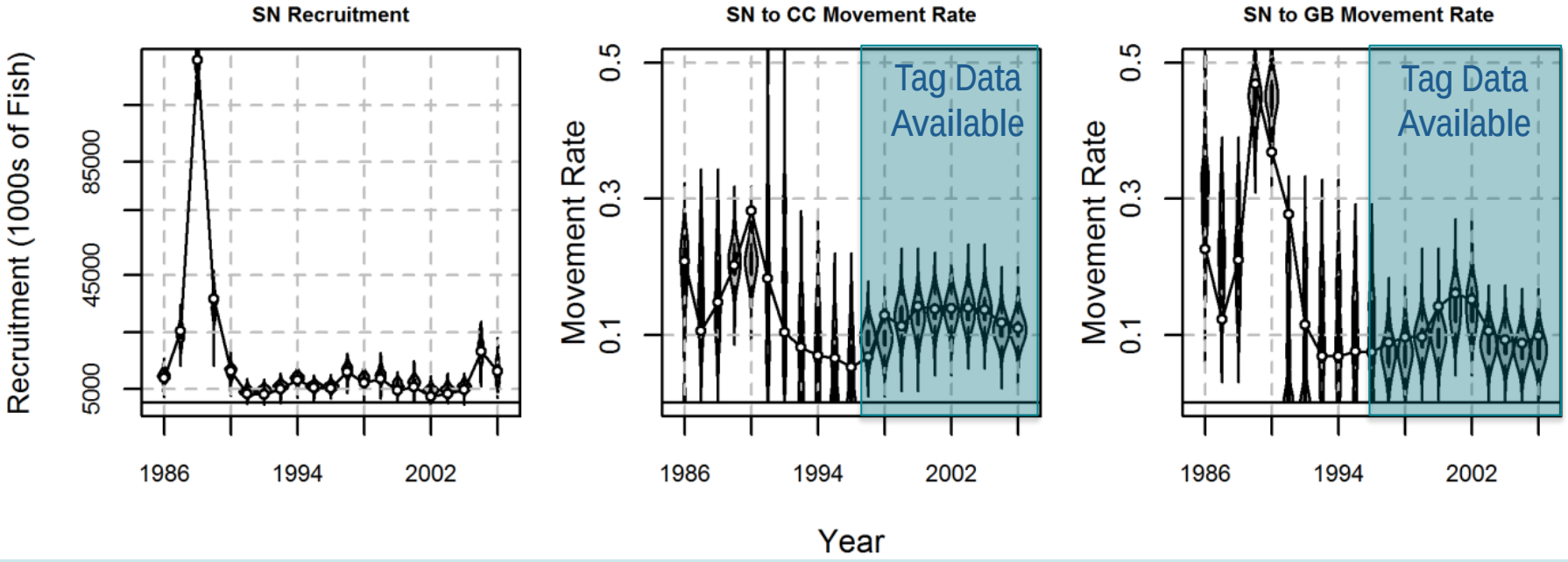


# Tag-Integrated Models

- All parameters estimated simultaneously using single objective function and shared among sub-models

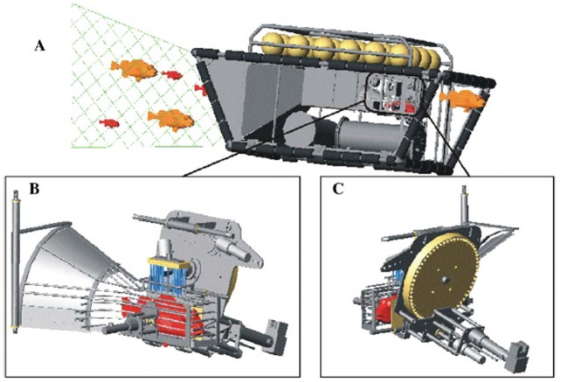
$$N_{j,y,a} = \sum_{k} T_{k,j,y} N_{k,y-1,a-1} e^{[-(v_{k,y-1,a-1} F_{k,y-1} + M)]}$$

- May improve parameter estimates



# Tag-Integrated Models

- Limitations
  - Collecting tagging data
  - Validating tagging data assumptions
    - Incomplete mixing
    - Tag loss
    - Tag induced mortality
  - Estimating ‘nuisance’ parameters
    - Reporting rate
  - Data weighting
  - Combining data from multiple tag types




Sigurdsson et al. 2006

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Evaluation of tag mixing assumptions in western Pacific Ocean skipjack tuna stock assessment models

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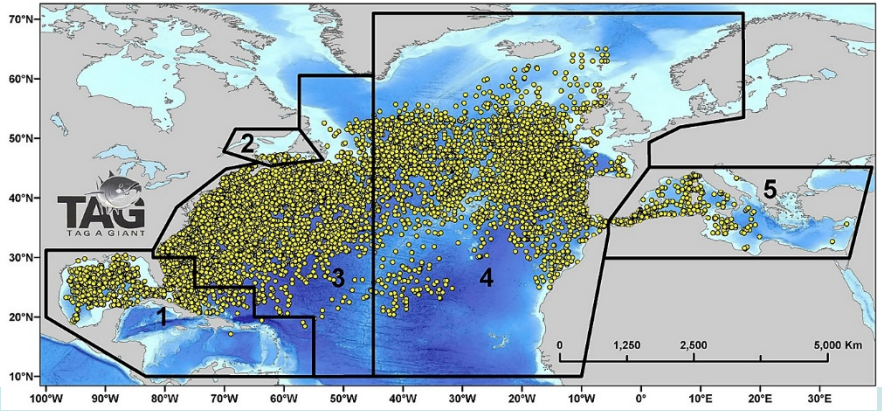
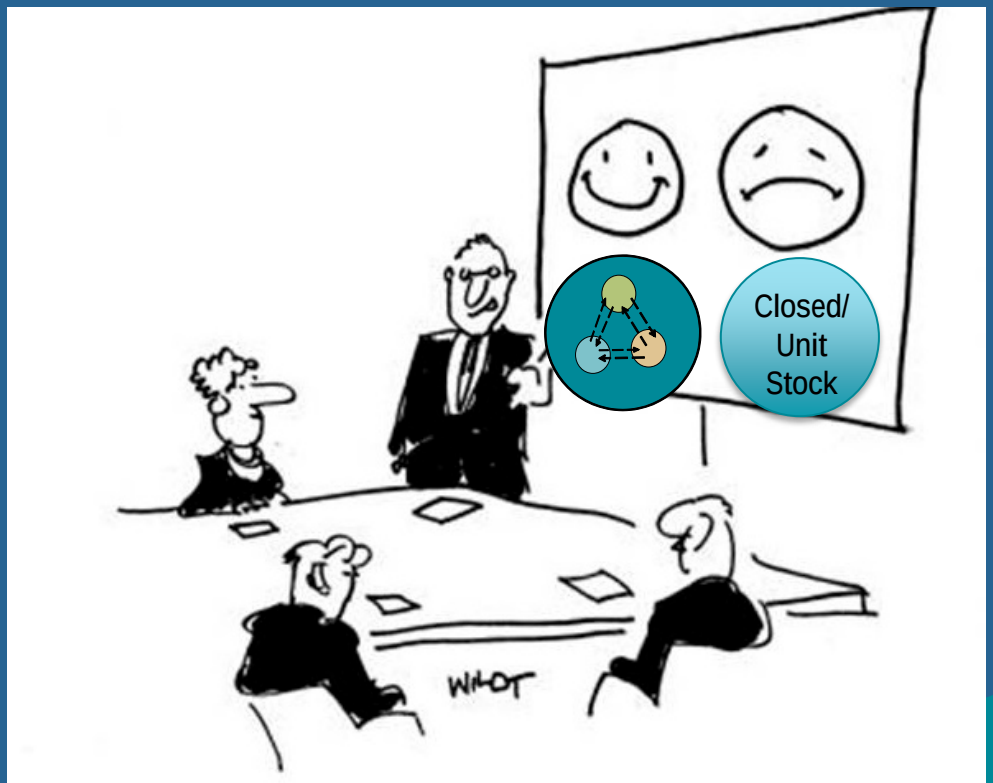



Taylor et al. 2012

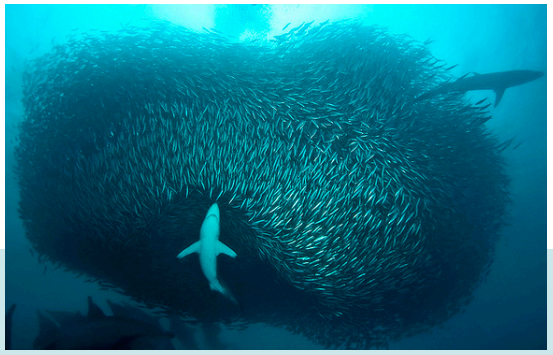
# How Have Tag-Integrated Models been Utilized for Management Advice?



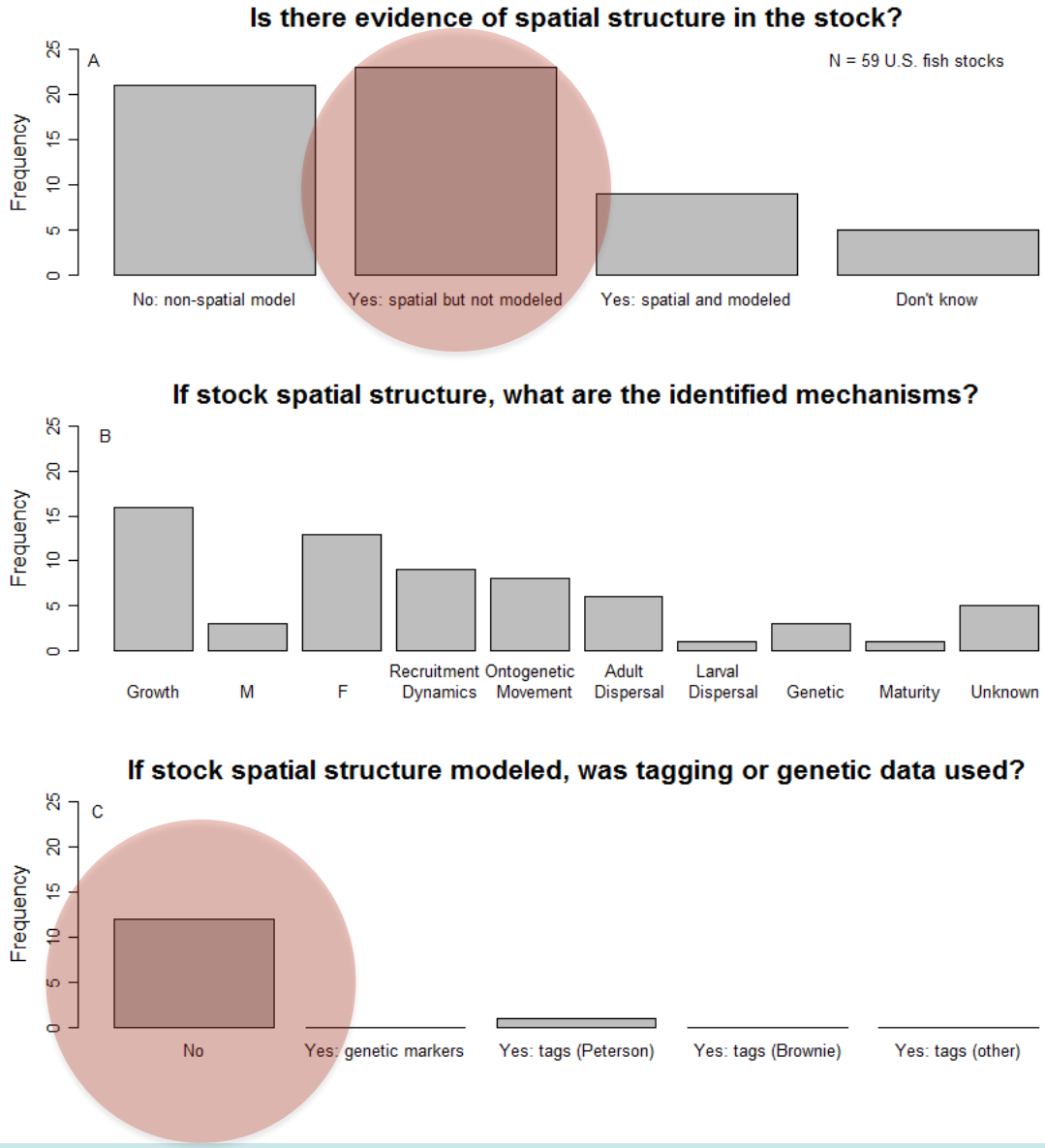

"Sure, we can spend all day nitpicking specifics but aren't sweeping generalities so much more satisfying?"

# Use of Tag-Integrated Models for Management

- Use of tag-integrated models as the basis of management advice is extremely RARE
  - South Pacific (Multifan-CL for Pacific tunas)
  - New Zealand (snapper, toothfish)
  - Australia (school shark, toothfish)
  - Canada (Northern cod; nonspatial)
  - South Africa (sardine; parasite tags)
  - North Atlantic (Fin whales!)

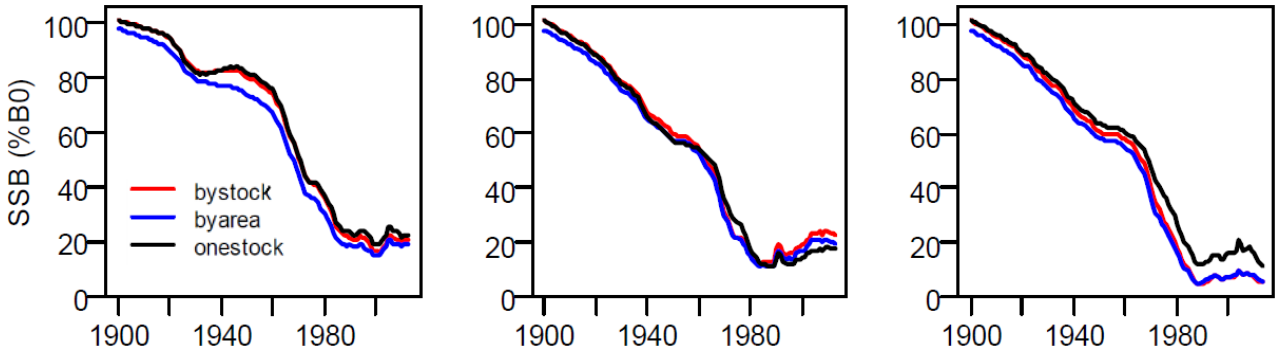



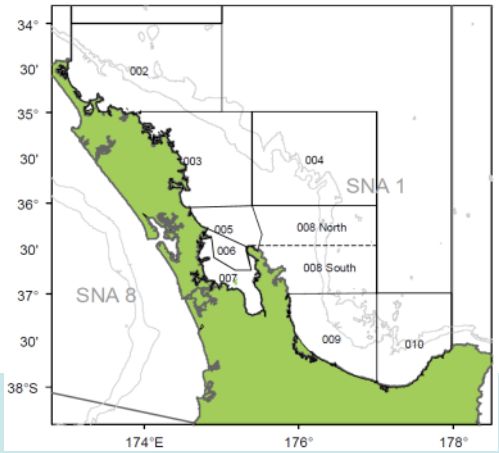
# Use of Tag-Integrated Models for Management



# Use of Tag-Integrated Models for Management

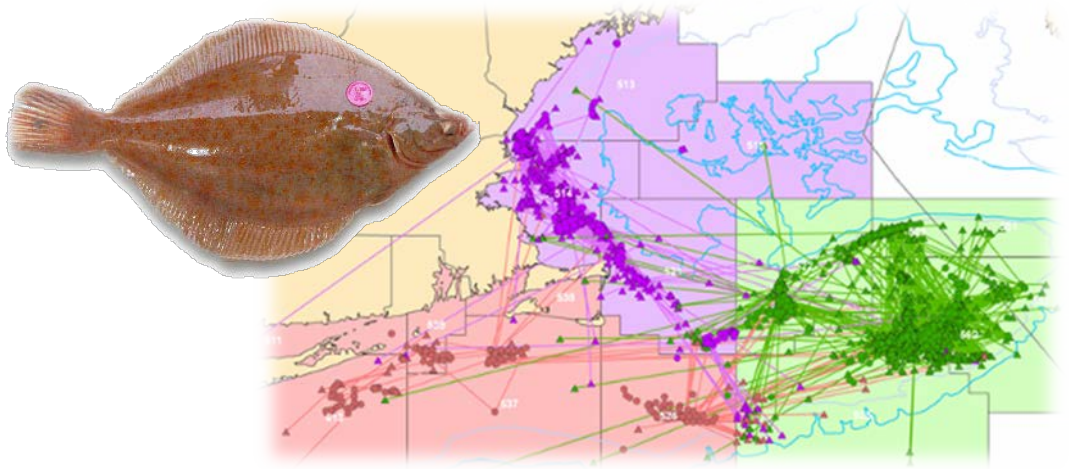
- Uncertainty in movement dynamics is often utilized to delay implementation of advice from spatial models
  - For *NZ SNA1* snapper the diffusion of fishing mortality across populations due to natal homing complicated regional management decisions
  - Uncertainty in spatial dynamics resulted in use of a combined quota while a tagging program is implemented

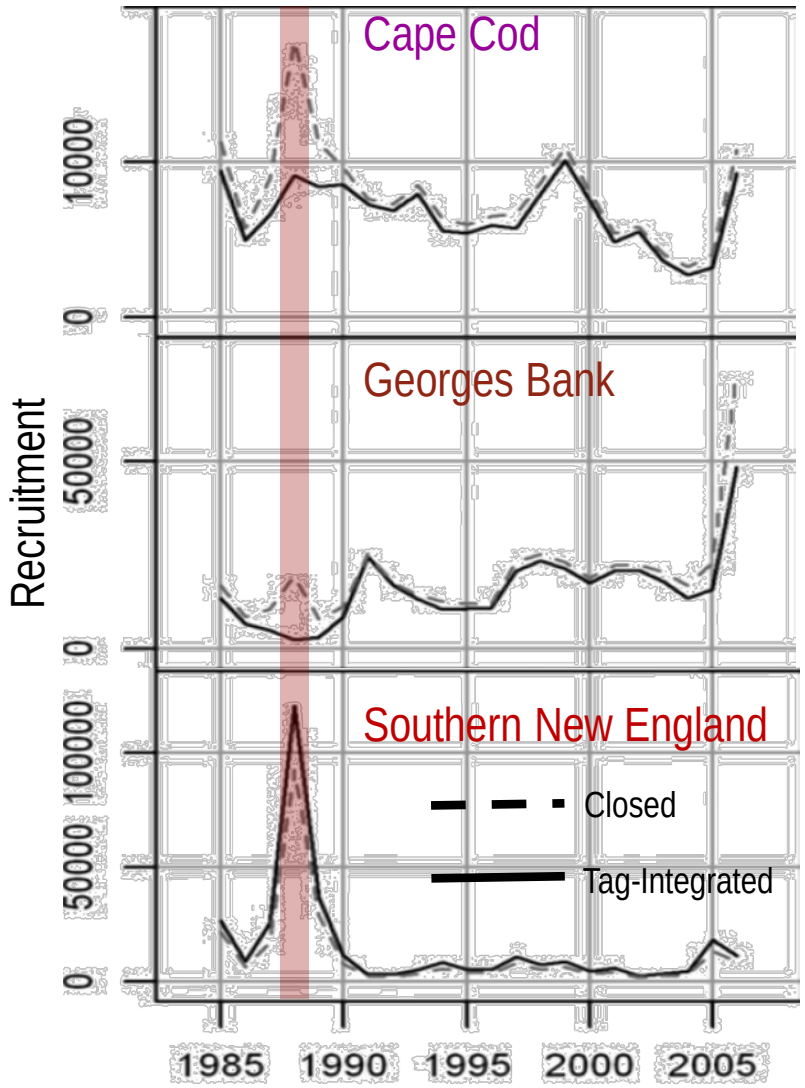


# Use of Tag-Integrated Models for Management

- OR results from spatial models are used to validate closed population models
  - New England yellowtail flounder (Goethel et al. 2015)

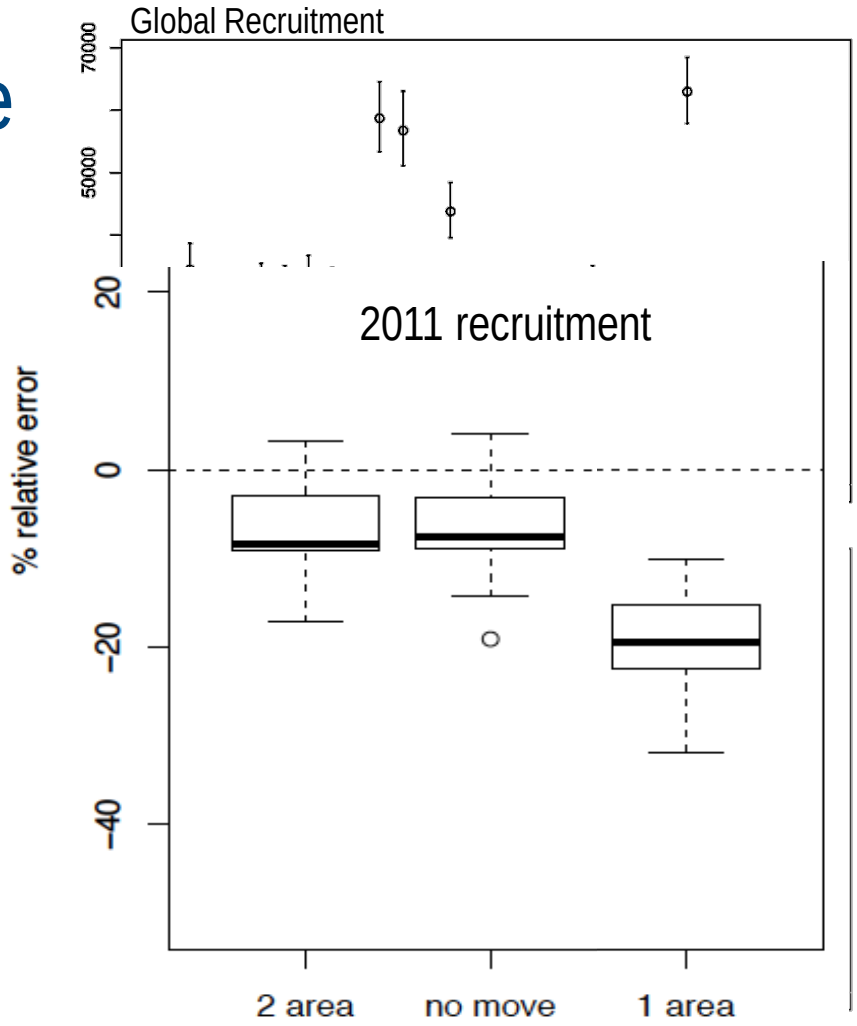




# Use of Tag-Integrated Models for Management

- OR results from spatial models are used to validate closed population models
  - Southern New England black sea bass (Fay et al. 2016)

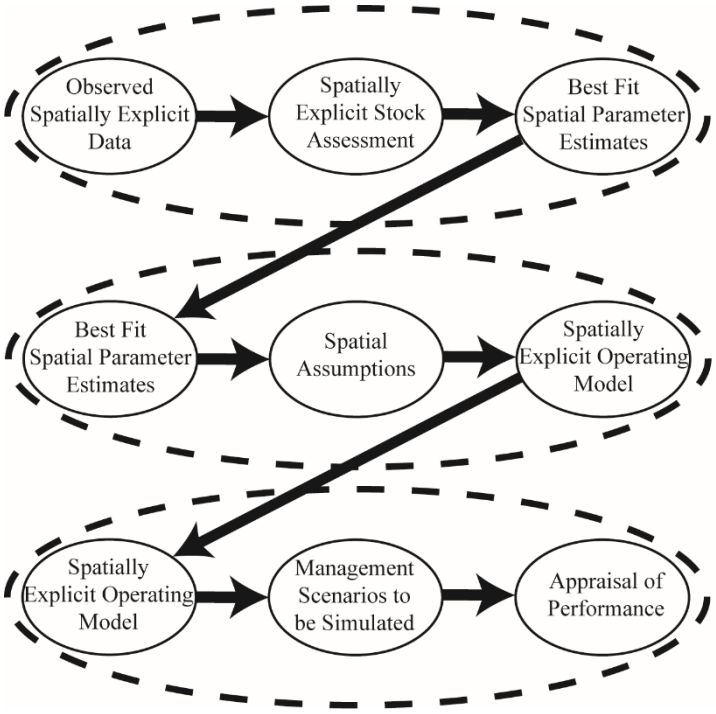




# Use of Tag-Integrated Models for Management

- BUT…spatial models are increasingly used to parametrize operating models that test the robustness of alternate assessment types and management strategies
  - New England yellowtail flounder
  - Atlantic bluefin tuna (in progress)
  - Pacific halibut (in progress)
  - Pacific hake (in progress)

3 Tier Approach for Evaluating the Importance of Spatial Structure in Stock Assessment




Goethel et al. (2016)

# Use of Tag-Integrated Models for Management

- Why have spatial models not been more widely adopted?

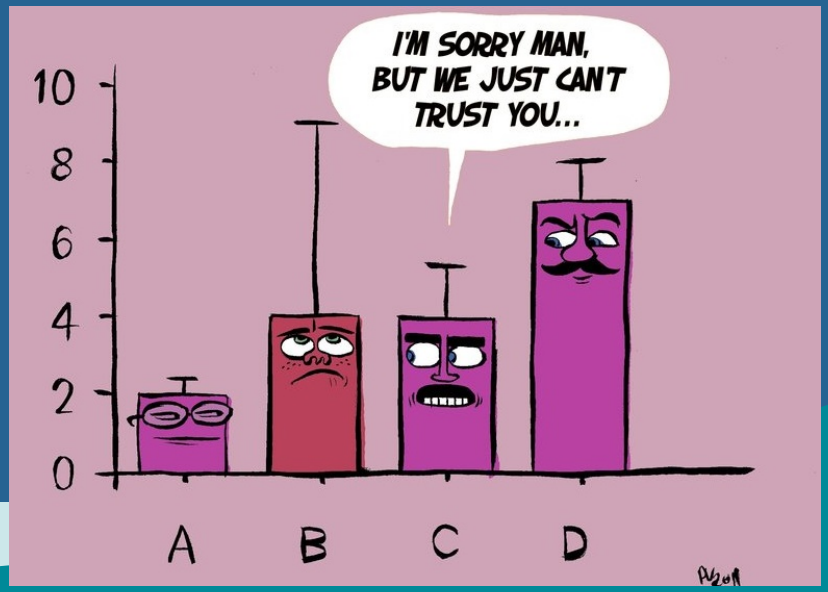
| | Hindrance | Future Needs |
|---|---|---|
| **Data** | Lack of Spatially-Resolved Data | Continued Spatially-Explicit Data Collection |
| | Uncertain Population Structure | Genetic and Otolith Data/Analysis |
| | Unresolved Connectivity Dynamics | Improved Tagging Information |
| **Models** | Performance Uncertainty | Ongoing Simulation Testing |
| | Ability to Make Operational | Time to Apply within Assessment Cycles |
| | Limited Forecasting Ability | MSE[1] to Evaluate Robust Assessment-Management Frameworks |
| **Management** | Mismatch with Assessment Spatiotemporal Scale | Communication of Ideal Spatial Scales from Managers to Scientists |
| | Limited Understanding | Communication of Model Structures from Scientists to Stakeholders |
| | Institutional Inertia | → Increased Exposure ← |

- Or is it a lack of faith in tagging data?

# What Have We Learned from Simulation Testing Spatially-Explicit Tag-Integrated Models?

AKA

Death by Boxplot

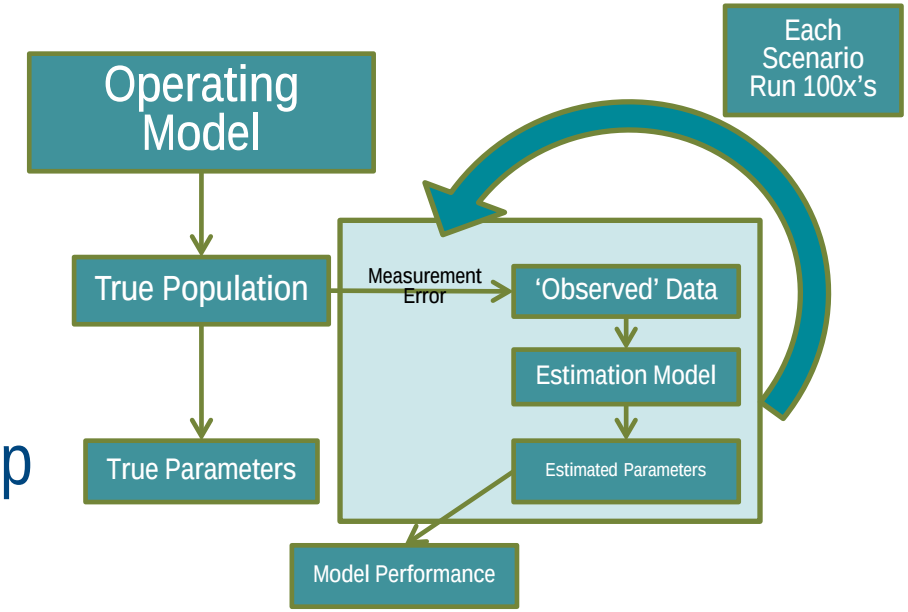


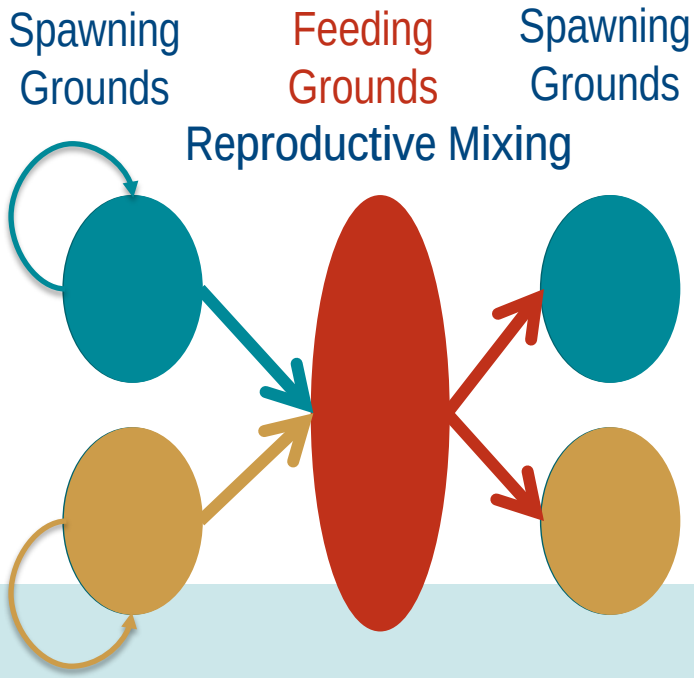
# Study Design

# RESULTS ARE PRELIMINARY!!!

# Methodology

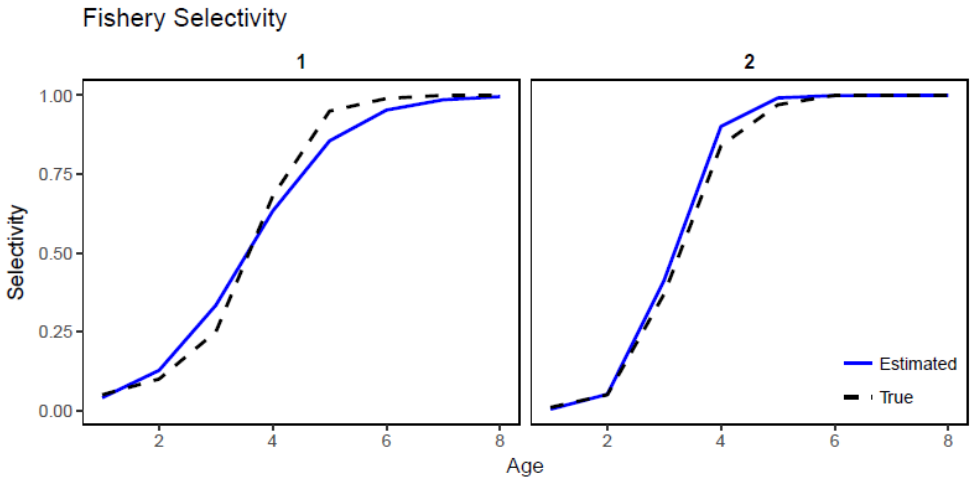
- Operating model setup
  - 2 areas assuming metapopulation structure
  - 8 ages including a plus group
  - Each population has unique stock-recruit relationship
    - Average recruitment with a 60/40 split (pop 1/pop 2) in productivity
    - Random yearly deviations
  - 1 fishery and 1 survey per population assuming a 30 year timeseries

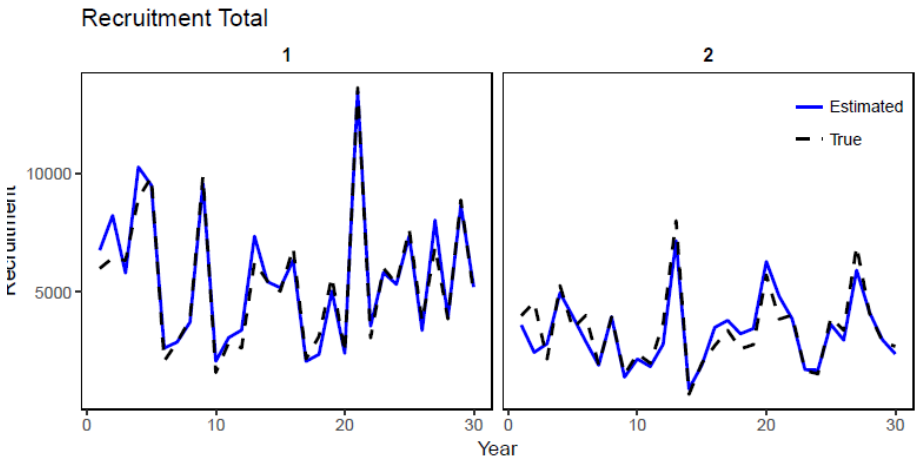


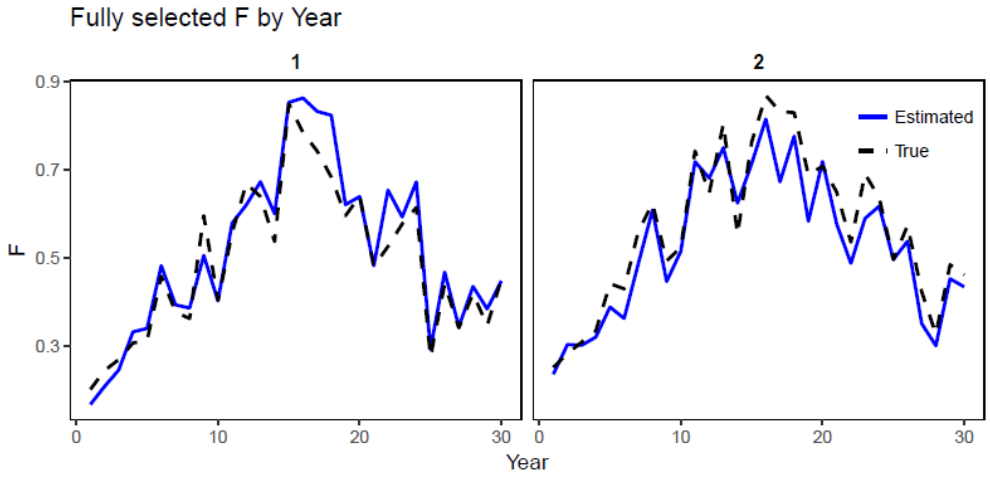



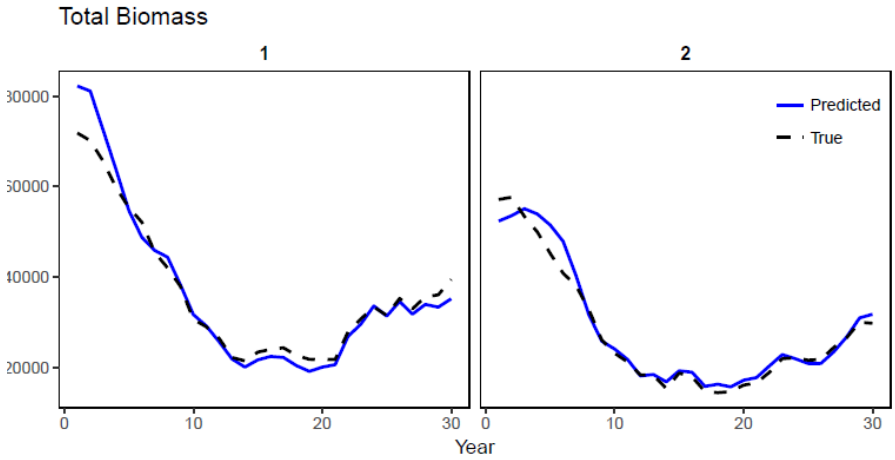
# Methodology

- Operating model population parameters
  - Natural mortality is 0.2 and 0.25 (pop 1/pop 2)



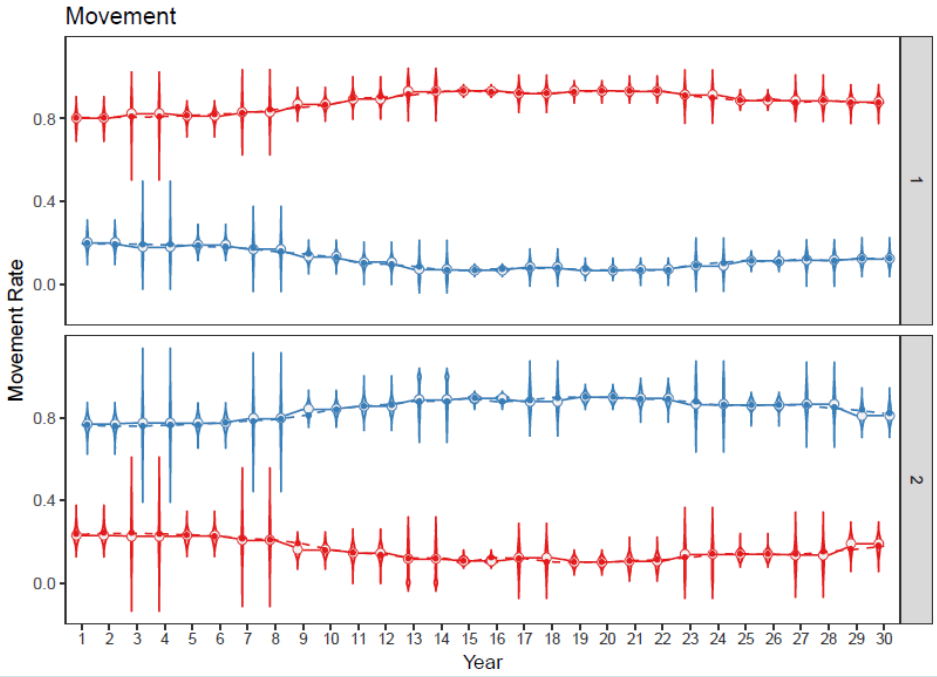



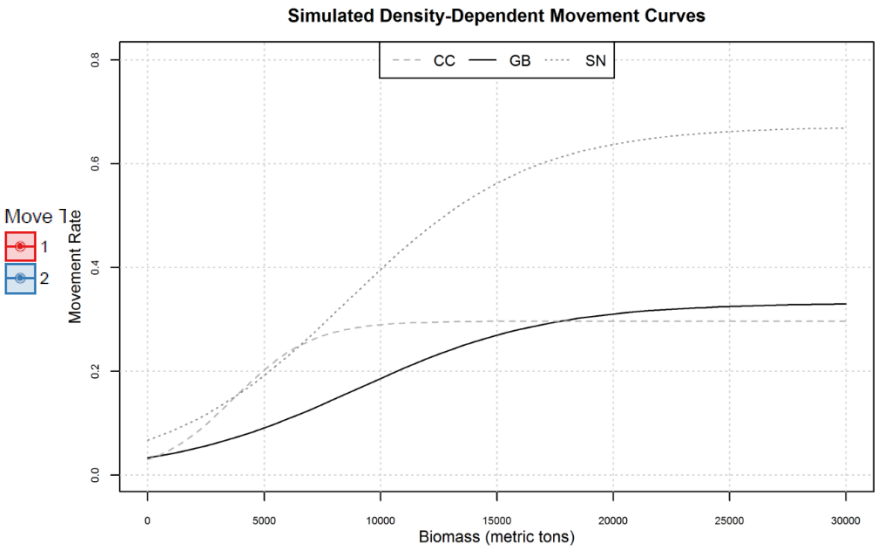



# Methodology

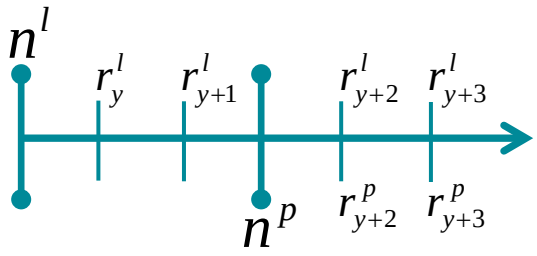
- Operating model movement
  - Time-varying, density-dependent movement
  - Minimum residency of 80/75 (pop1/pop2)
  - Based on logistic preference functions and relative biomass among areas



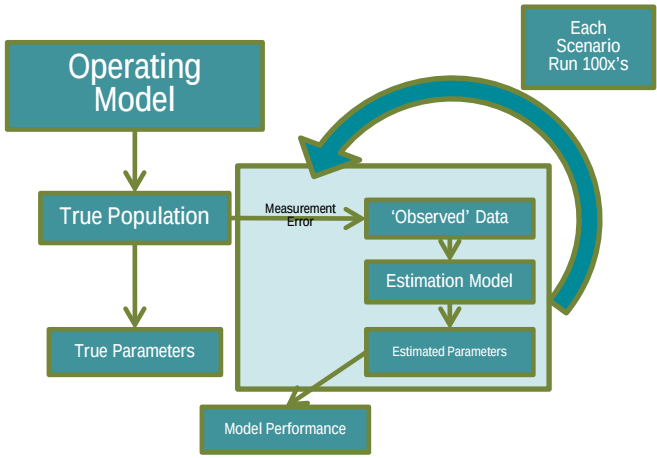
# Methodology

- Operating model tagging dynamics (except for alternative tagging scenarios)
  - Tag cohort is combination of release year, location, and age
  - Age is known
  - Number of tags is proportional to total abundance, ~3000-6000 tags/year
  - Regional distribution is proportional to survey abundance
  - Tags are distributed across ages based on survey selectivity
  - Tagging occurs every 5 years
  - Yearly recaptures for life of a tag (5 years)
  - Reporting rate is 0.7/0.8 (pop 1/pop 2)
  - Tags fully mix, no tag loss, and no tag mortality



# Methodology

- Estimation model structure
  - Same structure as OM with M and reporting fixed
  - Maximum likelihood estimation assuming same error structure as OM
  - Biennial emigration rate (blocked in 2 year timeblocks)
- Error levels
  - 100 runs per scenario
  - Constant measurement error across scenarios




OM Error Parameters

| | Parameter | 1 | 2 |
|---|---|---|---|
| 1 | Sigma_Rec | 0.55 | 0.5 |
| 2 | Sigma_Rec_Apport | 0.2 | 0.2 |
| 3 | Sigma_F | 0.3 | 0.35 |
| 4 | Rec_Index_sigma | 0.5 | 0.5 |
| 5 | Survey_Sigma | 0.2 | 0.2 |
| 6 | Catch_Sigma | 0.05 | 0.05 |
| 7 | SIM_N_Catch | 150 | 150 |
| 8 | SIM_N_Survey | 150 | 150 |

ESSTags= 200

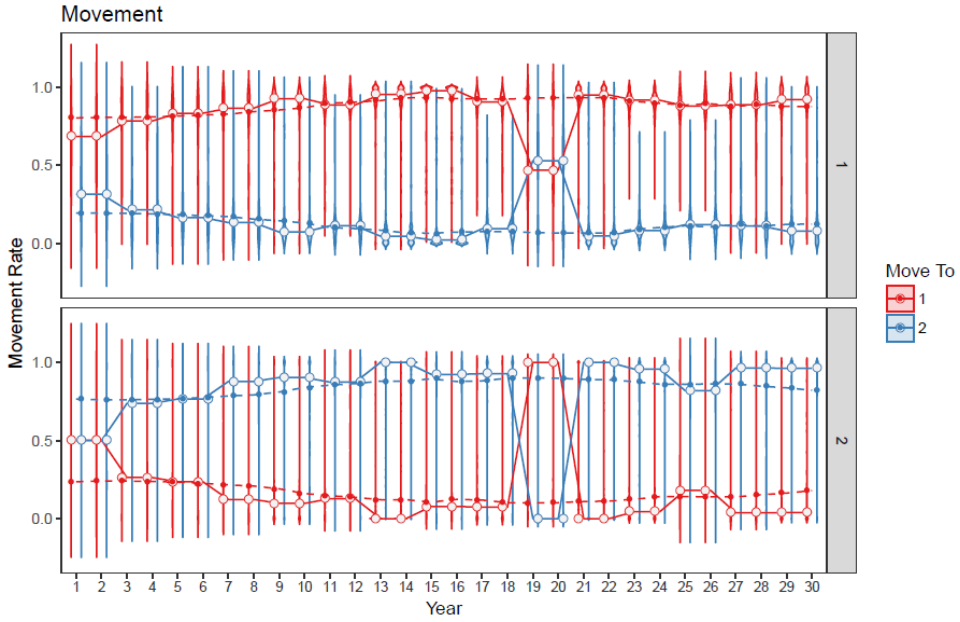
# Importance of Tagging Data

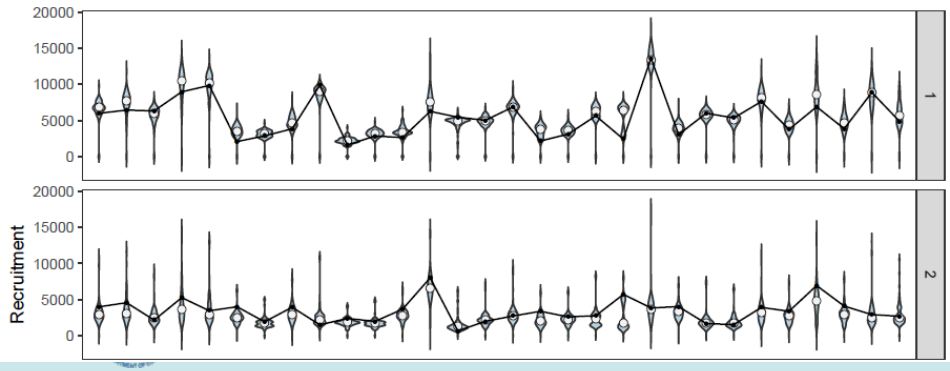
- Is tagging data needed to estimate complex movement patterns?
  - Compare tag-integrated models to spatial models without tagging data
    1. When movement is time-varying (base model)
    2. When age composition data is of poor quality
       - Effective sample size = 50

# Importance of Tagging Data

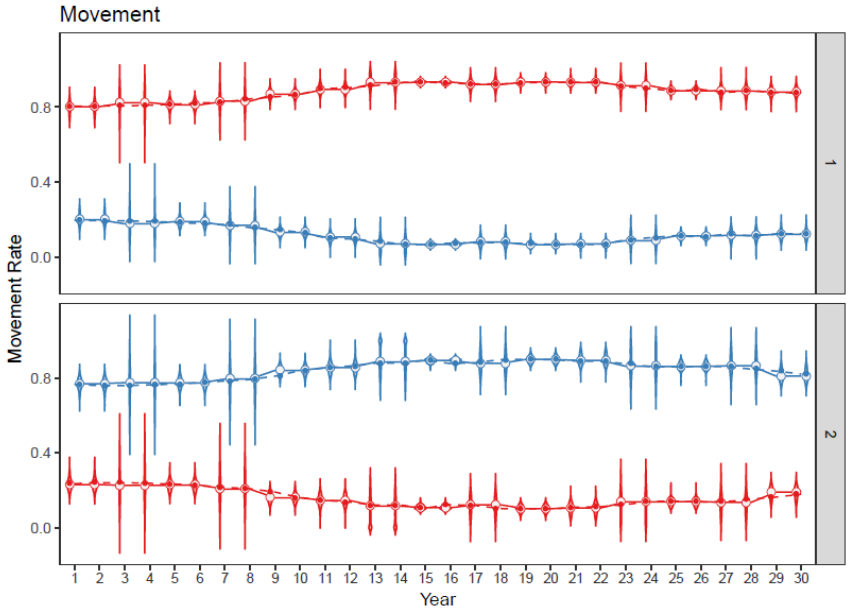
- When movement is time-varying (base model)

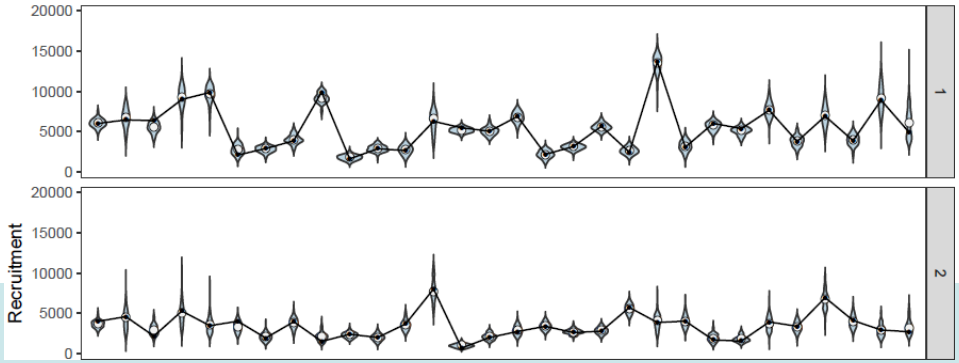
## Spatial, No Tagging



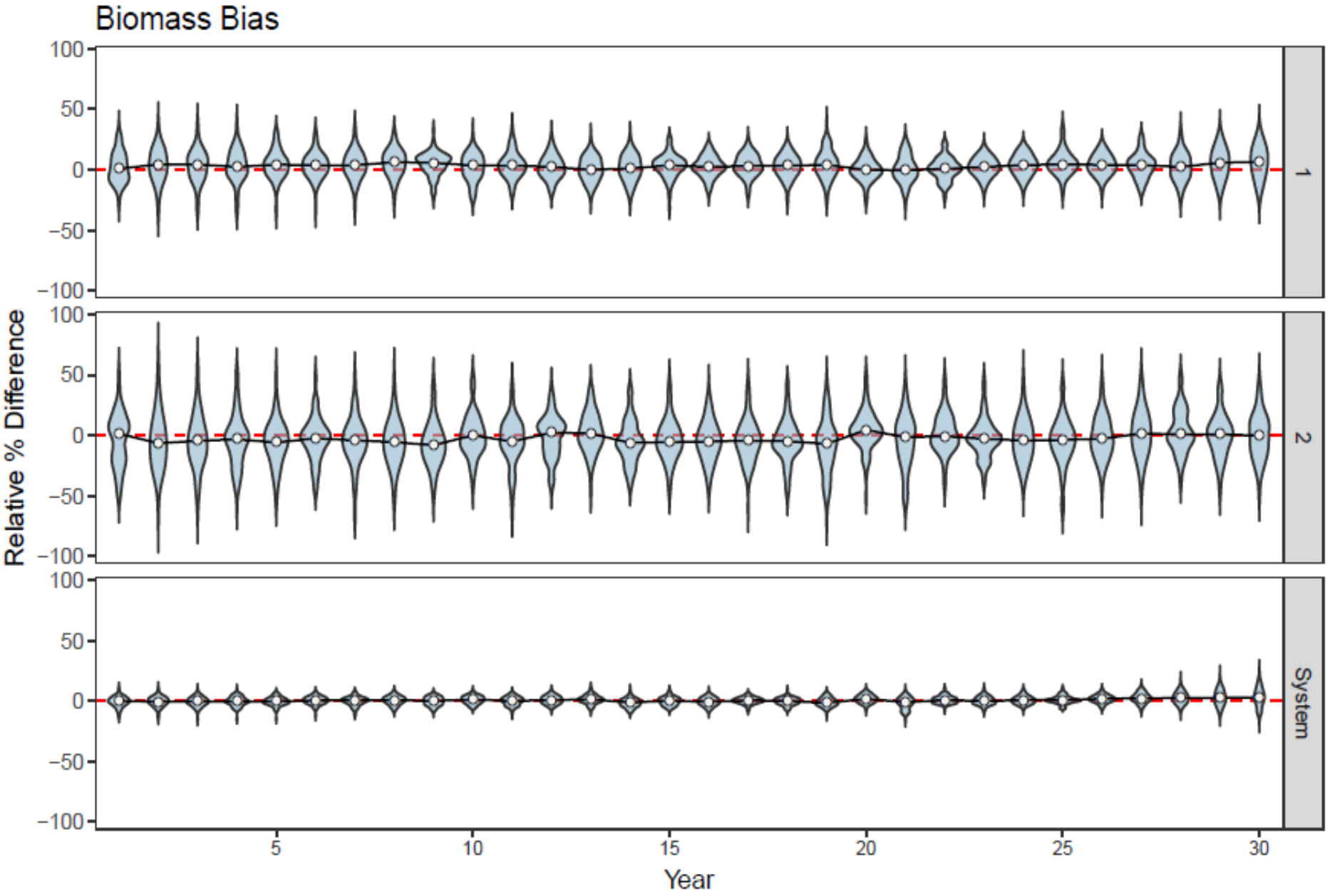




## Tag-Integrated



# Importance of Tagging Data



# Movement Process Error

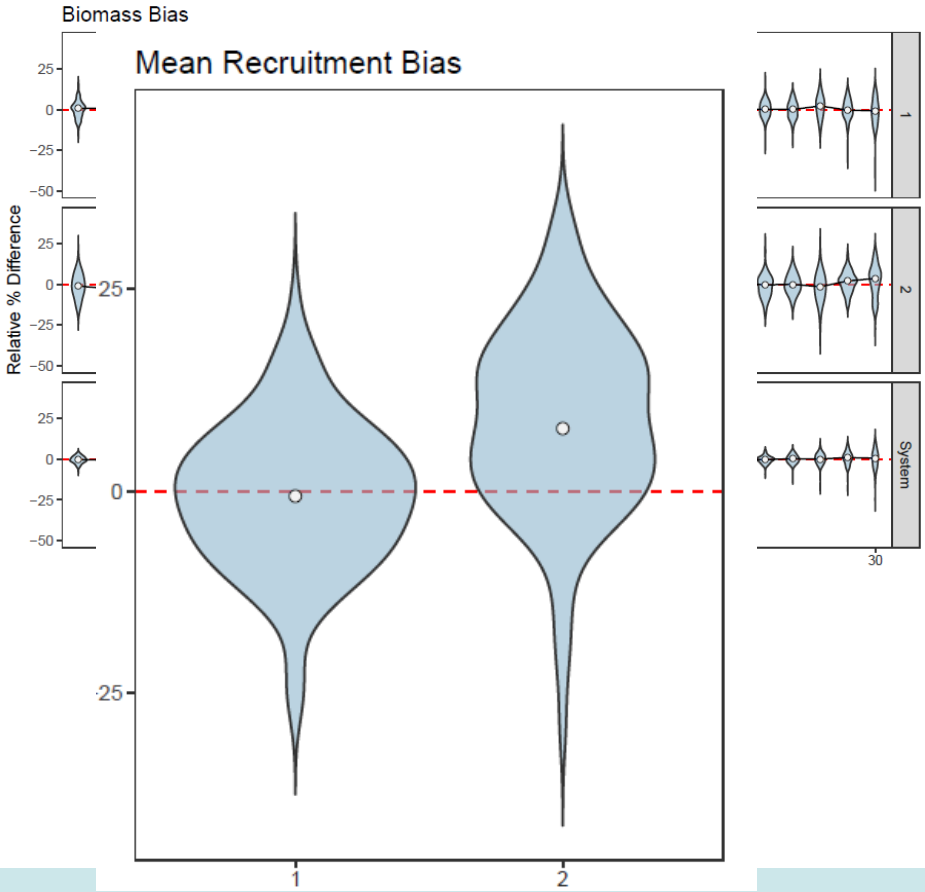
- Can simpler movement parametrizations be useful?
  1. What is process error resulting from ignoring movement
     - Estimation model assumes 100% residency
  2. What is process error from ignoring time-varying movement
     - Estimate time-invariant movement
  3. Is time and/or age blocking useful?
     - Compare Base model to that estimating yearly movement

# Movement Process Error

- What is process error resulting from ignoring movement?

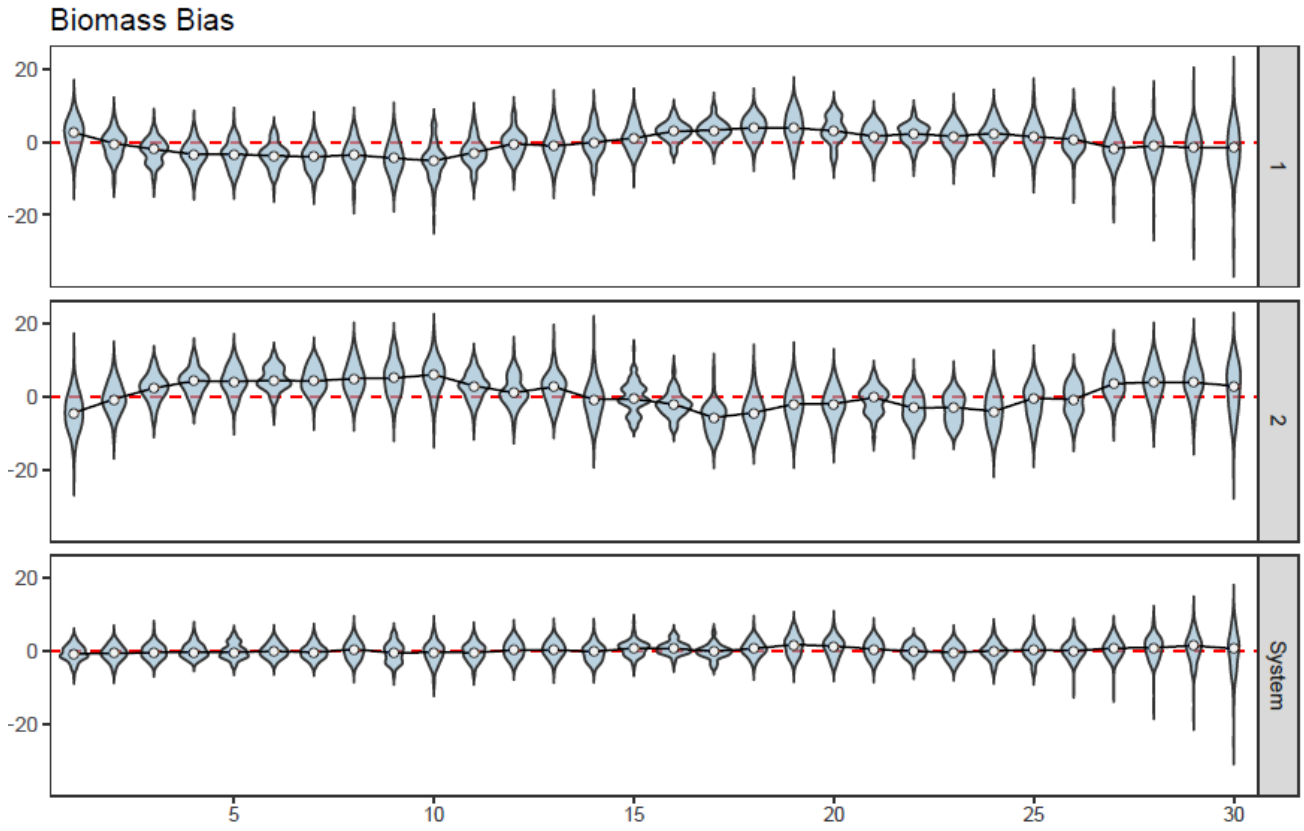
Closed Populations

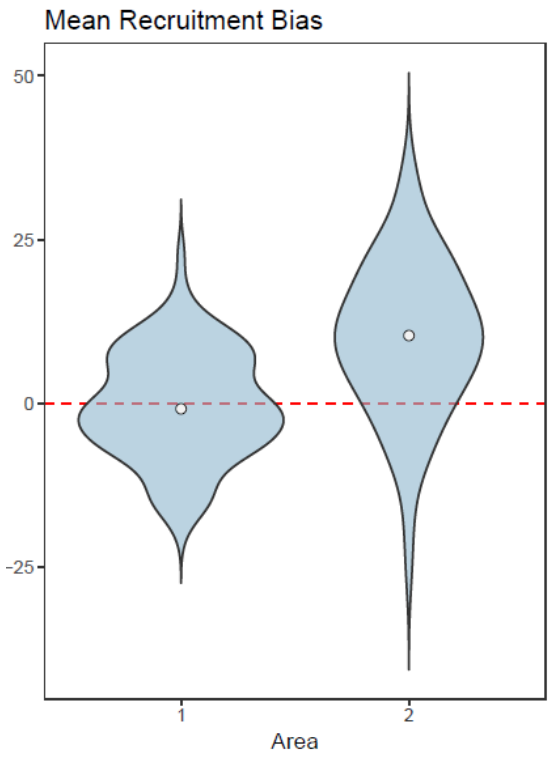

Tag-Integrated



# Movement Process Error

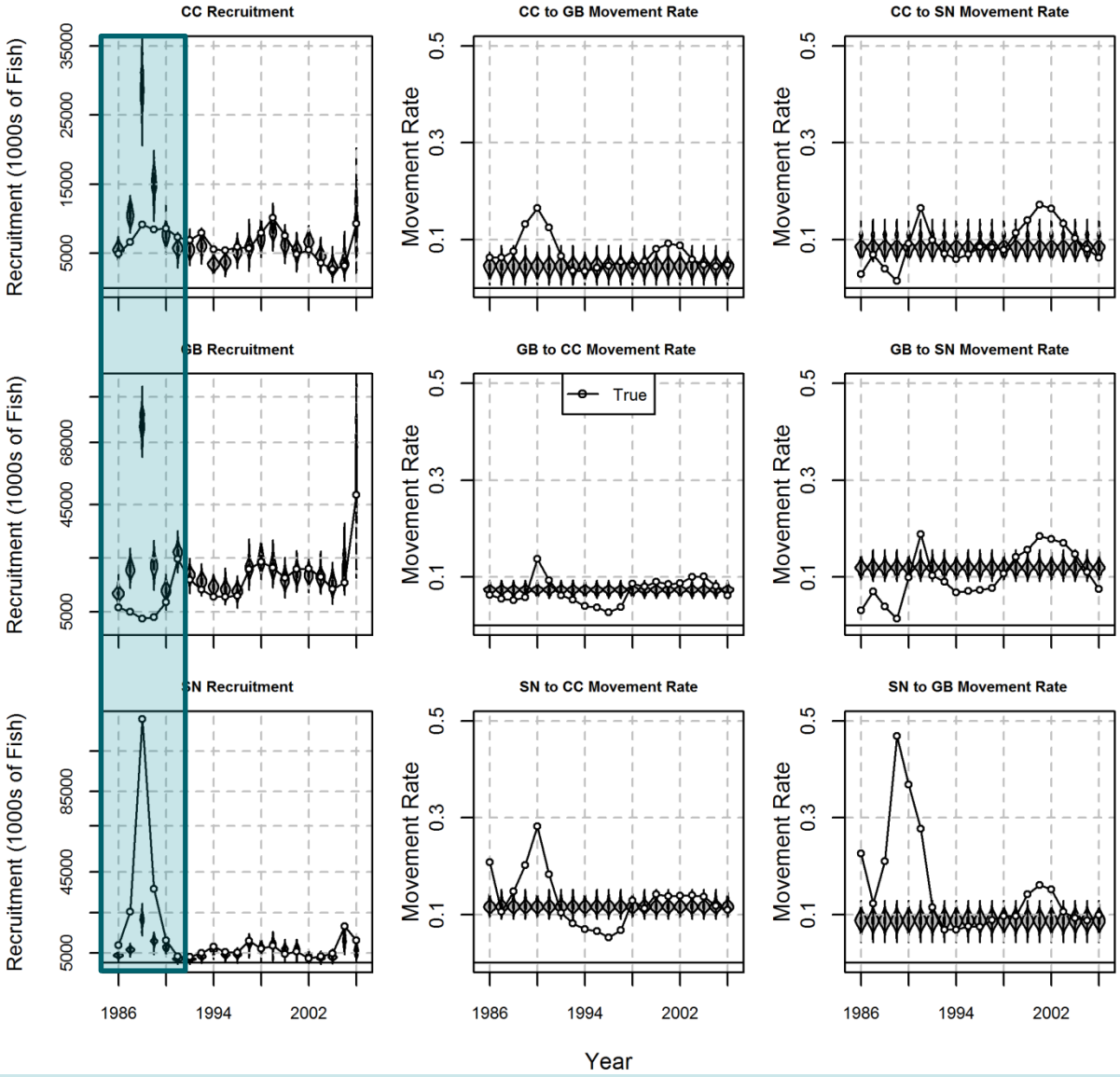
- What is process error from ignoring time-varying movement (estimating constant movement)?



# Movement Process Error

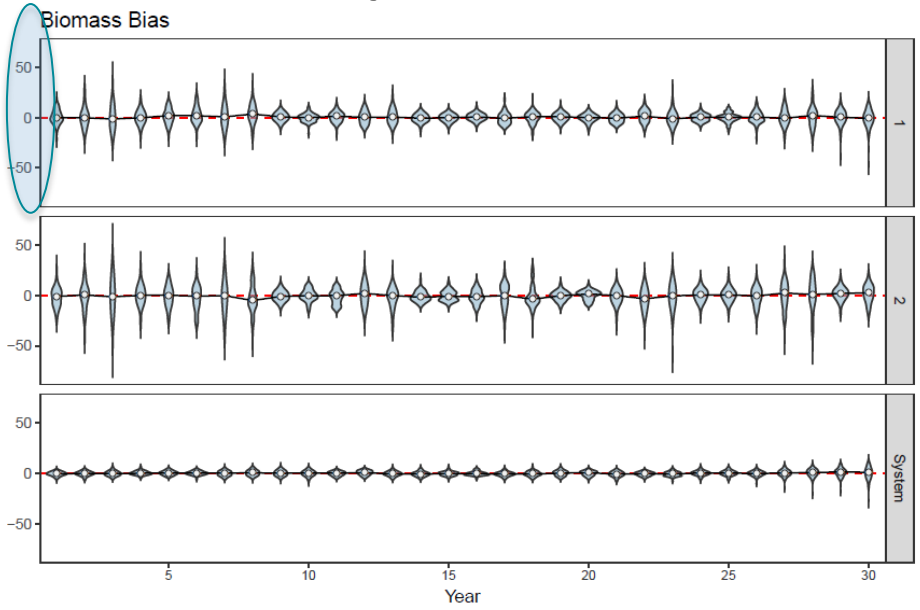
- Misdiagnosing connectivity may be worse than assuming no movement



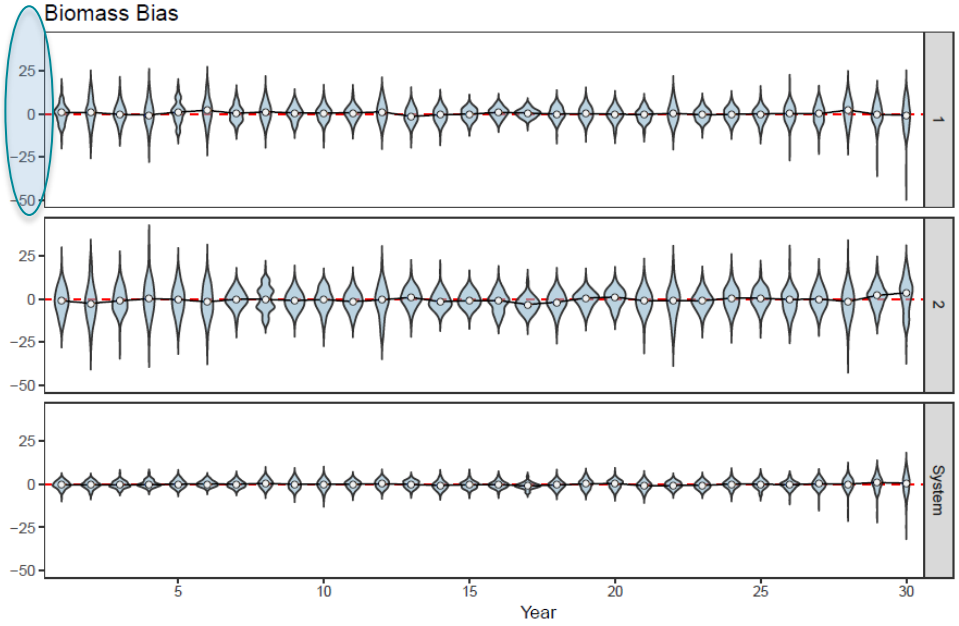
# Movement Process Error

- Is time and/or age blocking useful?

Tag-Integrated,
Yearly Movement




Tag-Integrated,
2 Year Timeblocks (Base)



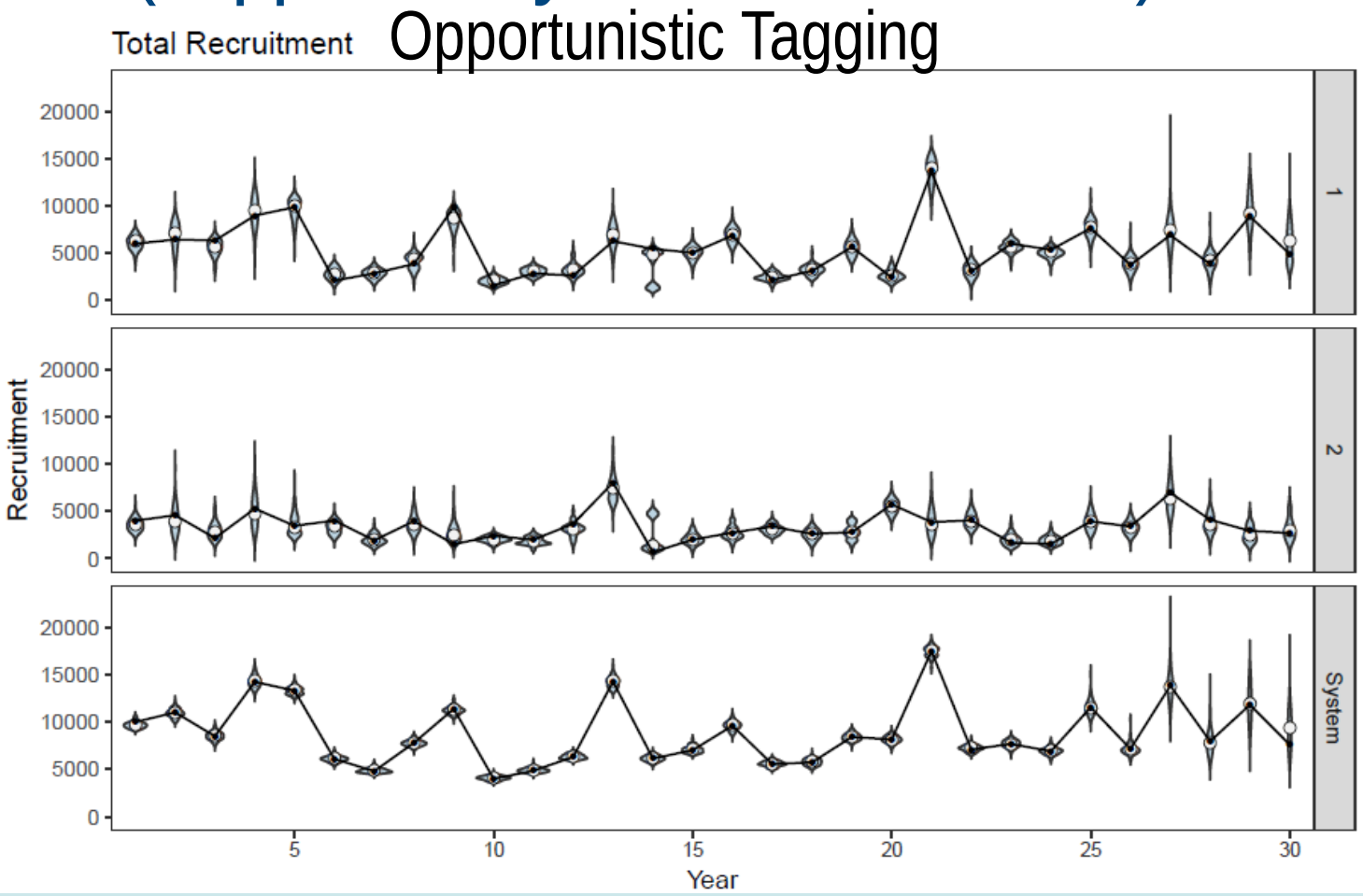

- YES!!
- Supported by Goethel et al. 2015

# Tagging Design

- Does a tagging study need to be perfectly designed?
  - Compare various tag release designs to explore robustness
    1. Does it matter how tags are released?
       - Proportional (Base), evenly, or opportunistically distributed across regions
    2. Does the timing of a tagging experiment in relation to the assessment timeseries matter?
       - Every year, Base, recent 5 years, middle 5 years

# Tagging Design

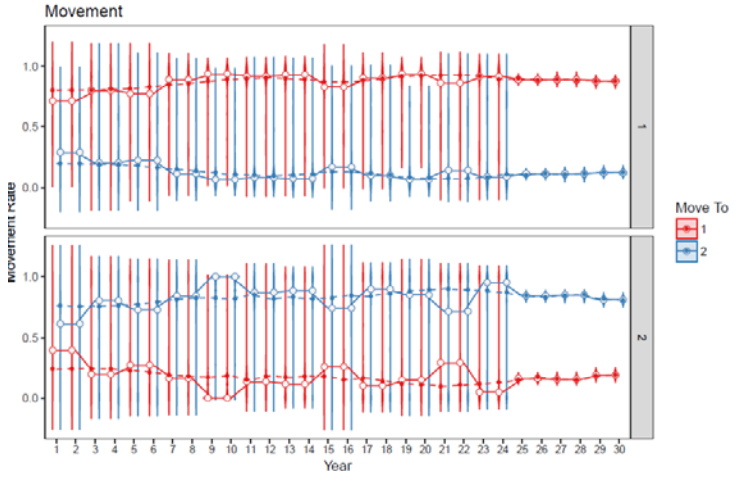
- Does it matter how tags are released?
- Even or proportional tagging provide similar results (supported by Hulson et al. 2011)



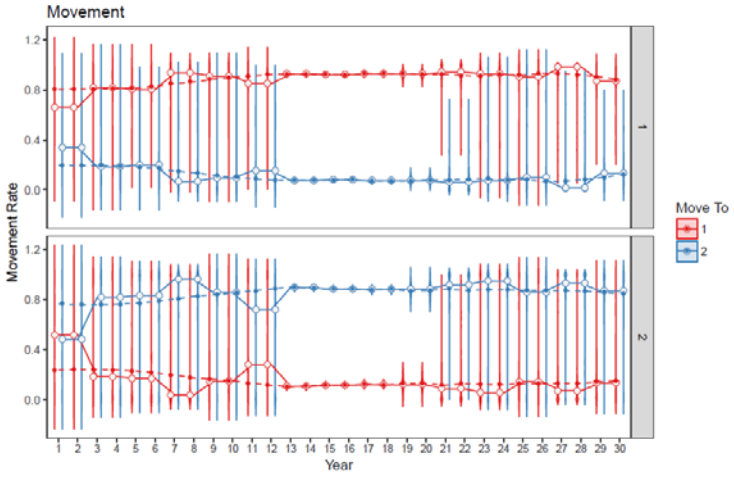
# Tagging Design

- Does the timing of a tagging experiment in relation to the assessment timeseries matter?

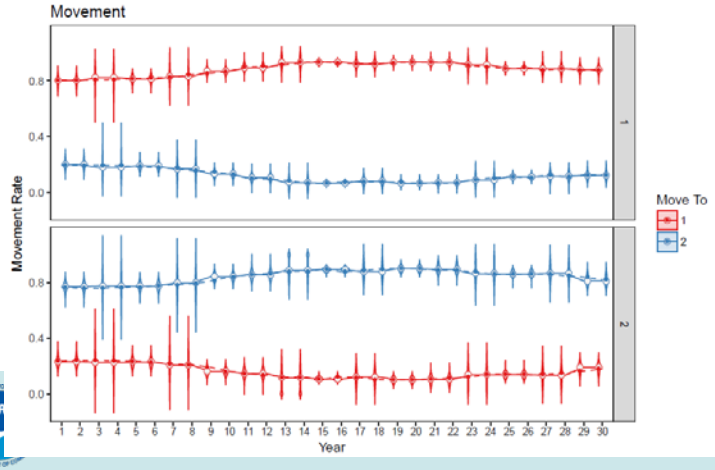
Tag Last 5 Years (~30000 tags)



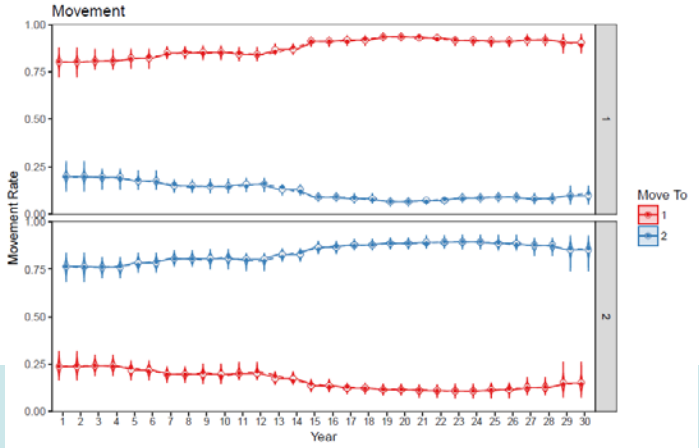

Tag Middle 5 Years (~30000 tags)




Tag Every 5 Years (Base; ~42,00 tags)



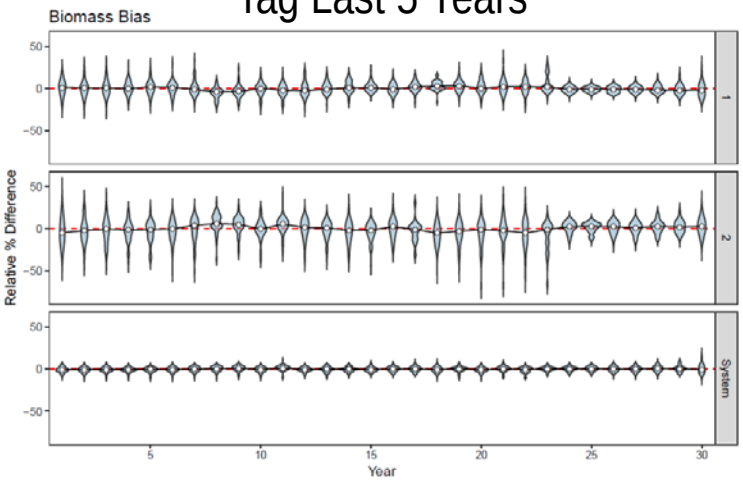

Yearly Tagging (~180,000 tags)



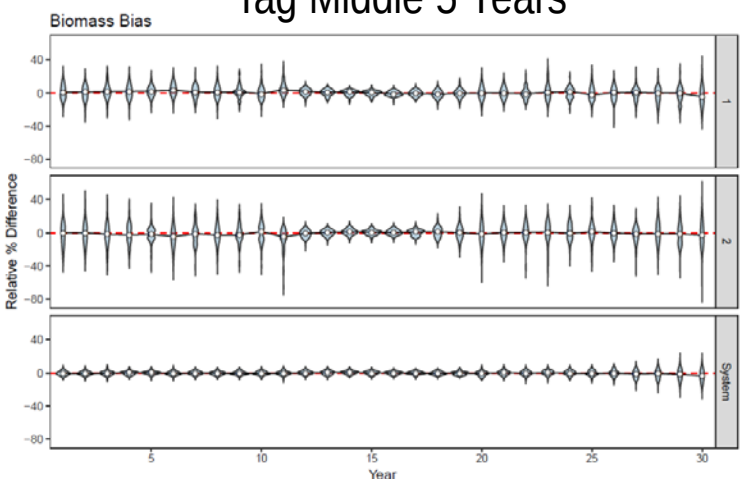
# Tagging Design

- Does the timing of a tagging experiment in relation to the assessment timeseries matter?

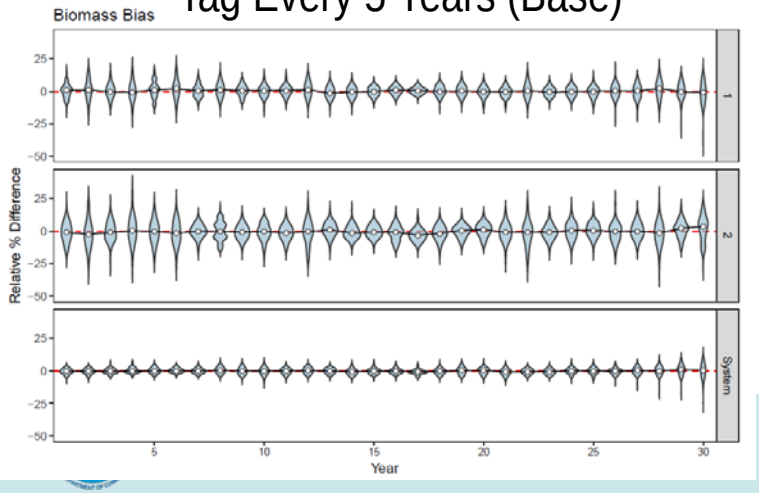
Tag Last 5 Years



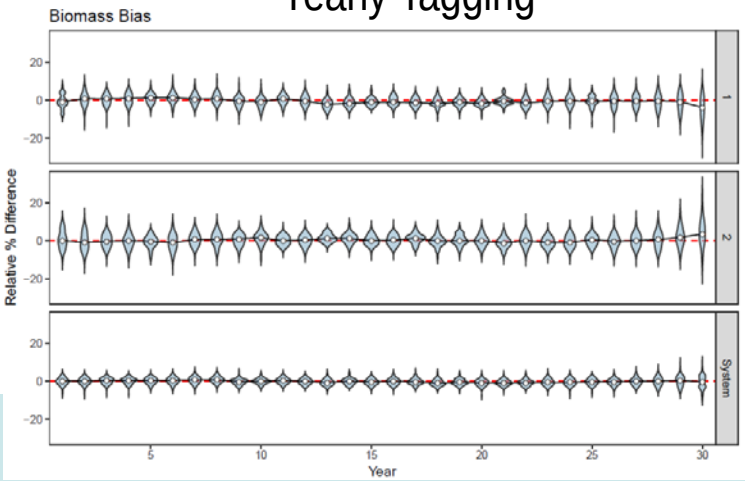

Tag Middle 5 Years




Tag Every 5 Years (Base)




Yearly Tagging



# Tagging Design

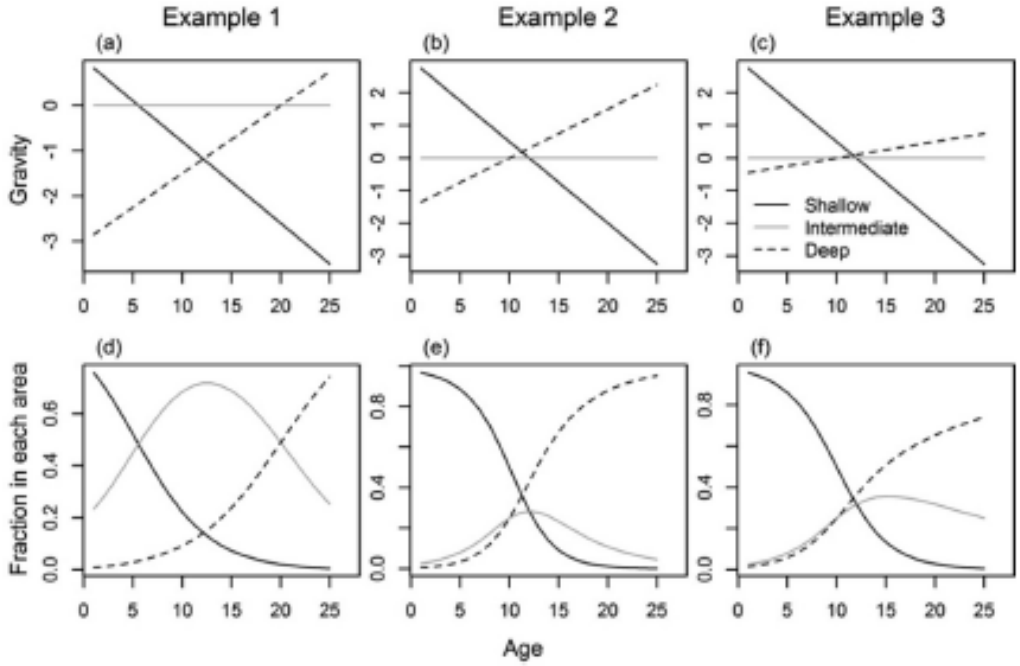
- Other findings regarding tagging design
  - Threshold levels exist where improvement in accuracy/precision is limited for:
    - Number of tags released per year
    - Number of years with releases
  - Weighting of tagging data is problematic
  - Reduced tagging data quality reduces precision/ accuracy
  - Overlap of tag release age/length comp with true age comp is important
  - M and reporting may be estimable parameters

# Final Thoughts

# Conclusions

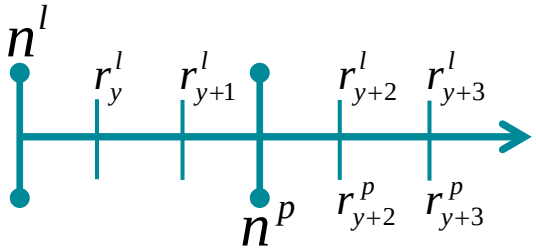
- Is tagging data needed to estimate complex movement patterns?
  - Yes, if….
    - Recruitment/movement confounding is extreme
    - Reduced precision in assessment outputs is desired
    - Age composition data is limited or of poor quality
  - Likely dependent on life history and connectivity
- Can simpler movement parametrizations be useful?
  - Yes, but be weary of oversimplifying
  - Intermediate complexity is probably warranted
    - Time- or age-blocking
    - Functional forms

Carruthers et al. 2015

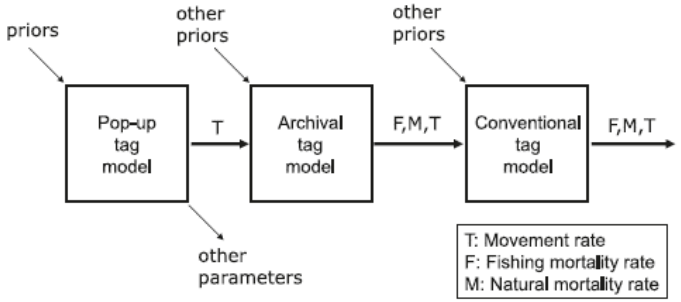


# Conclusions

- Does a tagging study need to be perfectly designed?
  - No, but cannot be completely haphazard
    - More work needed on testing violations of tagging assumptions
  - Simulation studies can identify optimal design to maximize cost-benefit
    - BUT, do not use lack thereof to postpone tagging
    - Matching tag release frequency to longevity/tag life may work well, but retain flexibility
  - Combination of conventional and electronic tagging can help ground-truth and validate each other

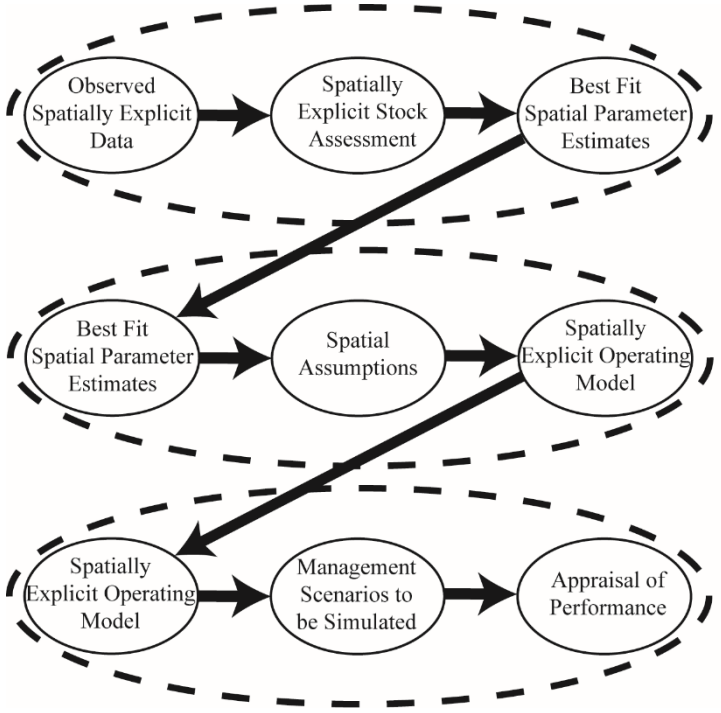



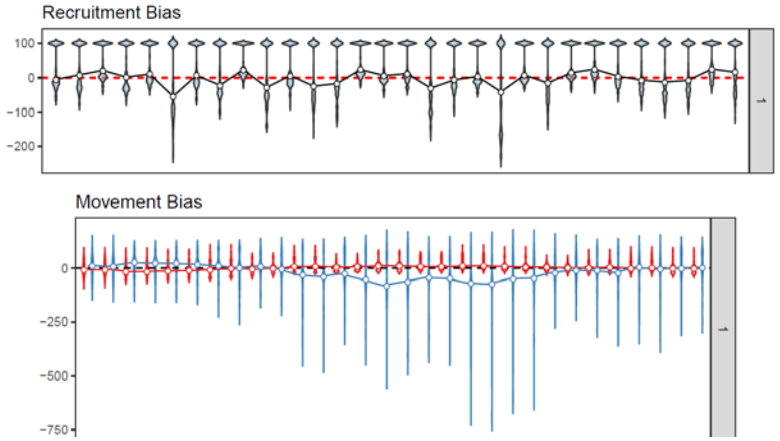

Kurota et al. 2009



# Conclusions

- Usefulness of tag-integrated and/or spatial assessment models is context specific (and dependent on movement rates and patterns)
- First step is correctly specifying spatial population structure
- Movement can be estimated without tagging data, but parameter correlation will likely occur

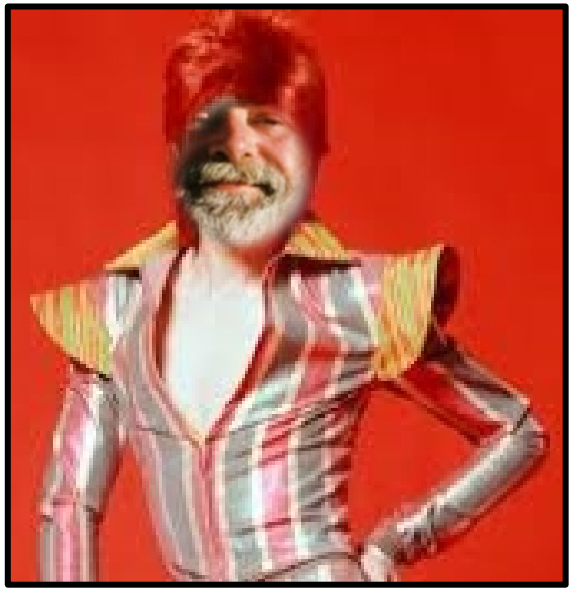



Results for spatial model w/o tagging, but higher movement rates than Base Model

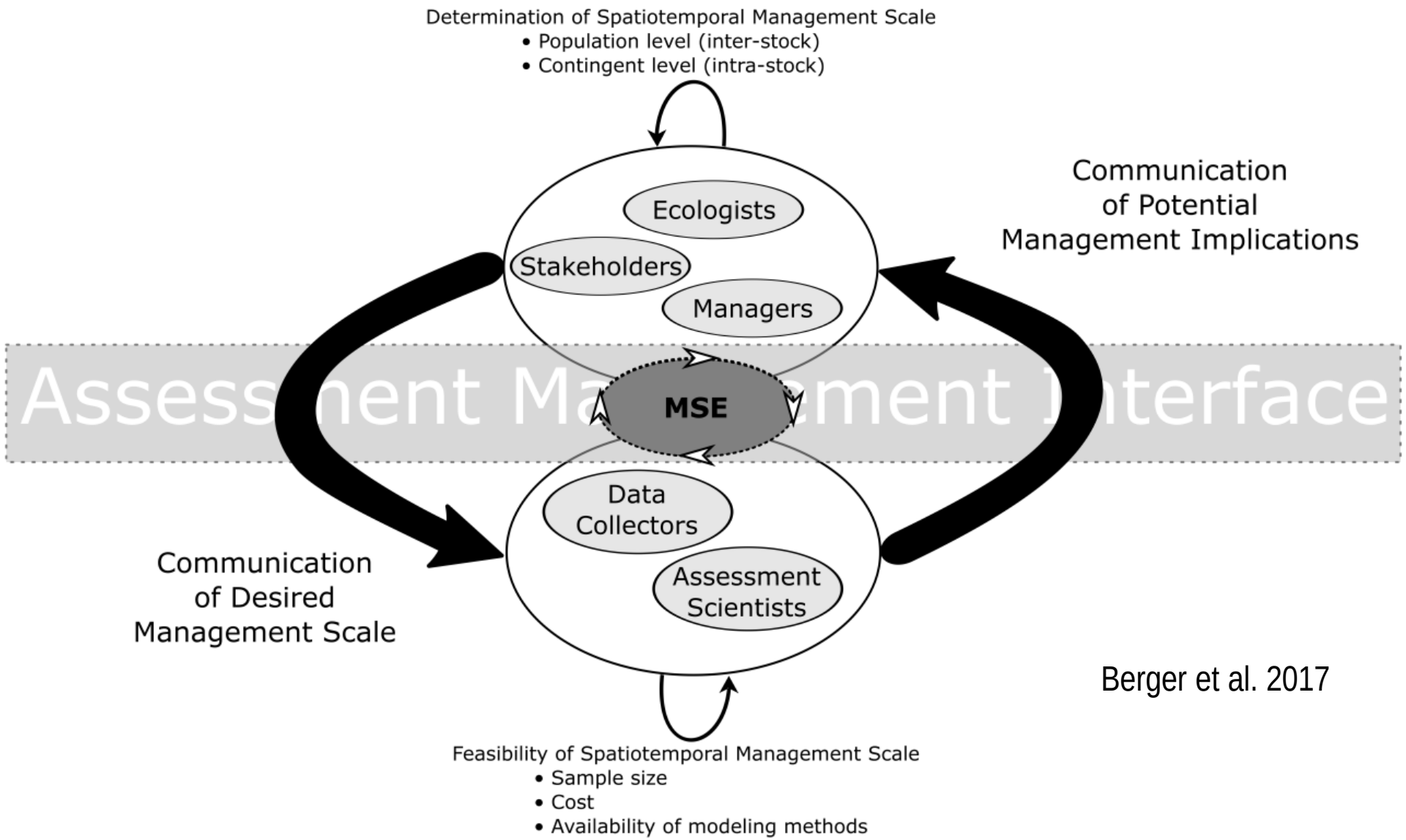
# Mission of Integration

- Words from Ground Control (Terry Quinn)
- It will happen!
  - Movement towards models that integrate all relevant datasets
  - Spatial models often perform better
  - Spatial models are plausible and realistic
  - Spatial issues are too important to ignore
- Tag-integrated models maintain consistency of model assumptions and propagation of uncertainty and can be useful even with limited tagging data

# Communication

*'Now It's Time to Leave the Capsule if You Dare'*




Berger et al. 2017

# Shameless plug

Canadian Journal of Fisheries and Aquatic Sciences

- Special issue on spatial modeling in CJFAS
  - *Space Oddity: recent advances incorporating spatial processes in the fishery stock assessment and management interface*

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# Acknowledgements

Spatial Processes And Stock Assessment Methods (SPASAM) Group
Funding provided by a grant from the NOAA Stock Assessment Analytical Methods (SAAM) RFP

# Discussion Topics

- When are tag-integrated models needed?
- Can tagging data reduce parameter correlation in spatial models?
- Can tagging data help estimate complex movement dynamics (time/age varying)?
- Does tagging experimental design matter?
- Can reporting rate be estimated?
- Can natural mortality be estimated with tagging data?
- How can we ensure tagging assumptions are not violated (incomplete mixing, tag loss/mortality)?
- How should tagging cohorts be defined/fit when there is no information on age?
- Should tagging data be incorporated directly or processed external to an assessment?
- How do we handle data weighting issues when incorporating tagging data?
- How should electronic tagging be incorporated?
  - Balancing precision vs. representativeness
- Should fleet dynamics be accounted for (relationship among tag timing and fishing seasons)?
- How can we make better use of alternate tag types (parasites, genetics, otolith)?