Spatially-Structured Tuna Stock Assessments in the Western and Central Pacific Ocean

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Outline

- Some history
- Summary of methods and key model outputs
- Some perceived benefits of spatial assessments
- Factors to consider in defining spatial structure
- Current limitations/issues and plans for future development

History

- MULTIFAN-CL – early 1990s
- Early integrated stock assessment model, with spatial structure – Fournier et al. 1998

MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*

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Abstract: We introduce a length-based, age-structured model, MULTIFAN-CL, that provides an integrated method of estimating catch age composition, growth parameters, mortality rates, recruitment, and other parameters from time series of fishery catch, effort, and length frequency data. The method incorporates Bayesian parameter estimation, estimation of confidence intervals for model parameters, and procedures for hypothesis testing to assist model development. We apply the method to South Pacific albacore, *Thunnus alalunga*, fishery data and demonstrate the incorporation of model structure such as spatial heterogeneity, age-dependent natural mortality and movement rates, time series trends and seasonal variation in catchability, and density-dependent growth. Consistency of the results of the albacore analysis with various exogenous sets of biological and environmental data gives credence to the model results.

Résumé : Nous présentons un modèle fondé sur la longueur et structuré par l'âge, le MULTIFAN-CL, comme méthode intégrée pour l'estimation de la composition de l'âge des prises, des paramètres de croissance, du taux de mortalité, du recrutement, et d'autres paramètres, à partir de séries chronologiques de données sur les prises, l'effort et les fréquences de longueurs des captures. On y fait appel à l'estimation bayesienne de paramètres, à l'estimation des intervalles de confiance des paramètres du modèle ainsi qu'à des procédures de test d'hypothèses pour faciliter l'élaboration du modèle. Nous appliquons la méthode aux données sur la pêche du germon du Pacifique sud (*Thunnus alalunga*) et démontrons l'incorporation de structures comme l'hétérogénéité spatiale, la mortalité naturelle dépendante de l'âge et les taux de déplacement, les tendances des séries chronologiques et la variation saisonnière de la vulnérabilité à la pêche, et la croissance dépendante de la densité. La cohérence des résultats de cette analyse avec d'autres séries de données biologiques et environnementales rend crédibles les résultats obtenus avec le modèle.

[Traduit par la Rédaction]

Introduction

Age-structured models are now the method of choice for many fisheries stock assessments. Models range from simple deterministic methods, such as virtual population (or cohort) analysis (Megrey 1989), to statistical models in which variability in the data and various population processes is acknowledged (Doubleday 1976; Paloheimo 1980; Fournier and Archibald 1982; Pope and Shepherd 1982; Dupont 1983; Deriso et al. 1985; Schnute and Richards 1995; McAllister and Ianelli 1997).

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Statistical age-structured models are superior to deterministic models in that they permit the estimation of confidence intervals for the parameter estimates. This allows uncertainty in stock assessments to be incorporated into management advice through decision or risk analysis. Bayesian approaches to age-structured models (McAllister and Ianelli 1997; Punt and Hilborn 1997) now provide a powerful framework for undertaking integrated analysis of fish stocks and for expressing the full range of uncertainty in the resulting advice given to fisheries management authorities.

A second advantage of statistical age-structured models is that they provide an objective means of comparing model hypotheses regarding alternative "states of nature". In a maximum-likelihood framework, the usual frequentist approach of testing nested models using likelihood-ratio tests can be applied. In the Bayesian framework, the posterior odds of competing models can be computed. In either case, statistical guidance can be obtained regarding an appropriate model structure for the case at hand.

Both deterministic and statistical age-structured models rely on catch-at-age data. These are sometimes derived from the analysis of annuli on various body parts of individual fish. Perhaps more commonly, age composition is derived from length frequency samples using an age–length relation-

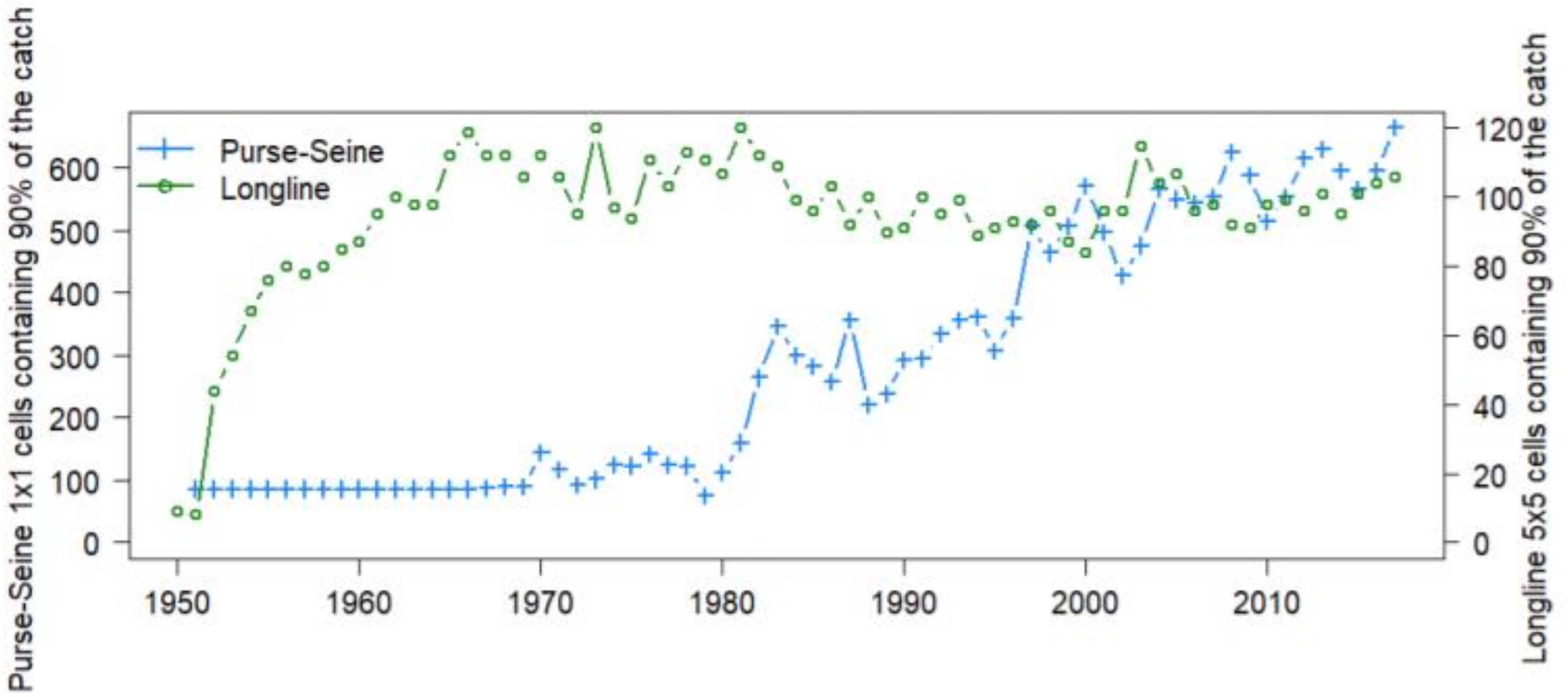
Timelines for WCPO Spatial Assessments

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Albacore	3		3			3	3	3		4	4		1	1		1	1			8			5
Bigeye						4	5	5	5	6	6		6	6	6	6			9			9	
Skipjack						6	6	6		6			6		3	3			5		5 (7)		
Yellowfin						7	5	5	5	6	6 (7)	6		6		6			9			9	
Striped marlin											1						1						
Swordfish																		2				2	

WCPFC

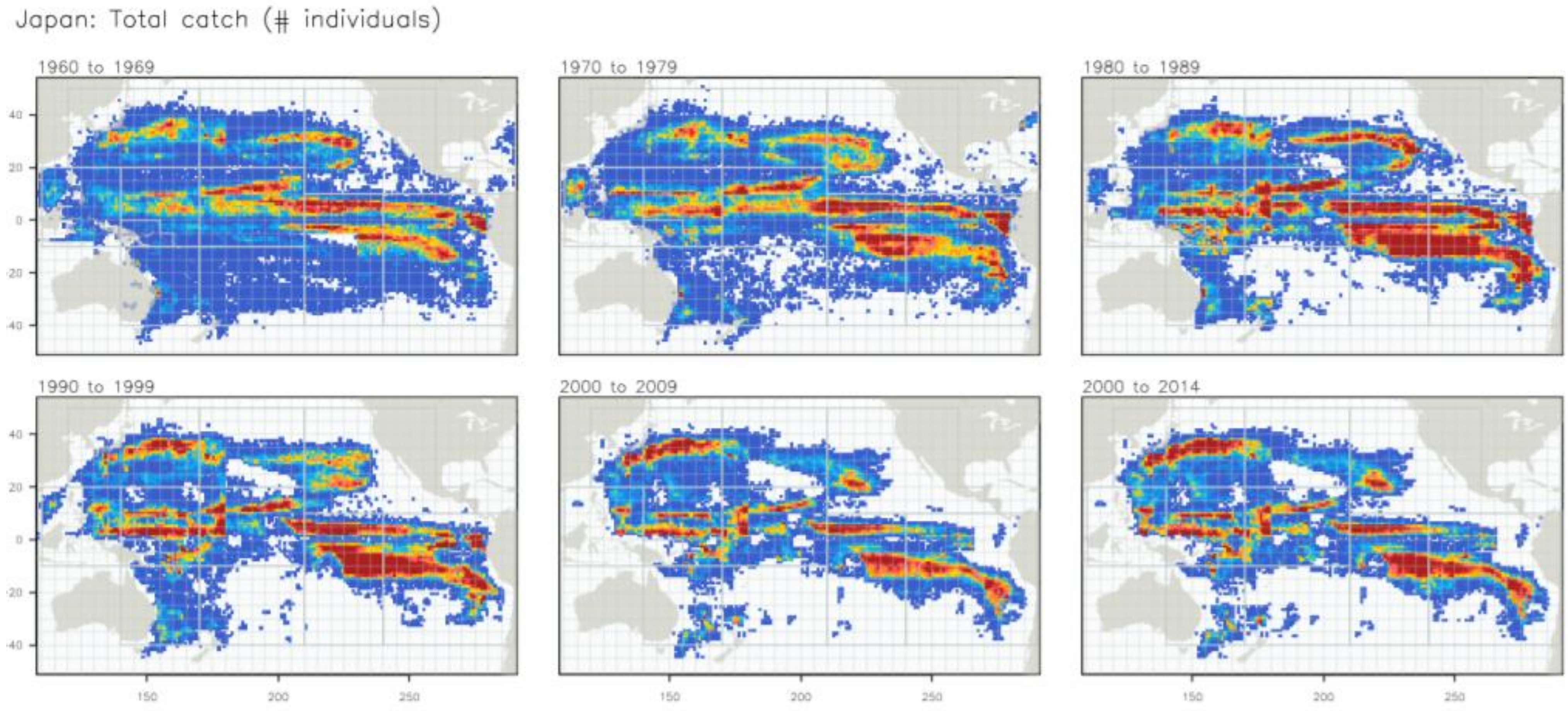
Why Spatial?

- Initially size segregation of SP albacore by latitude
- Also spatial expansion of fisheries over time



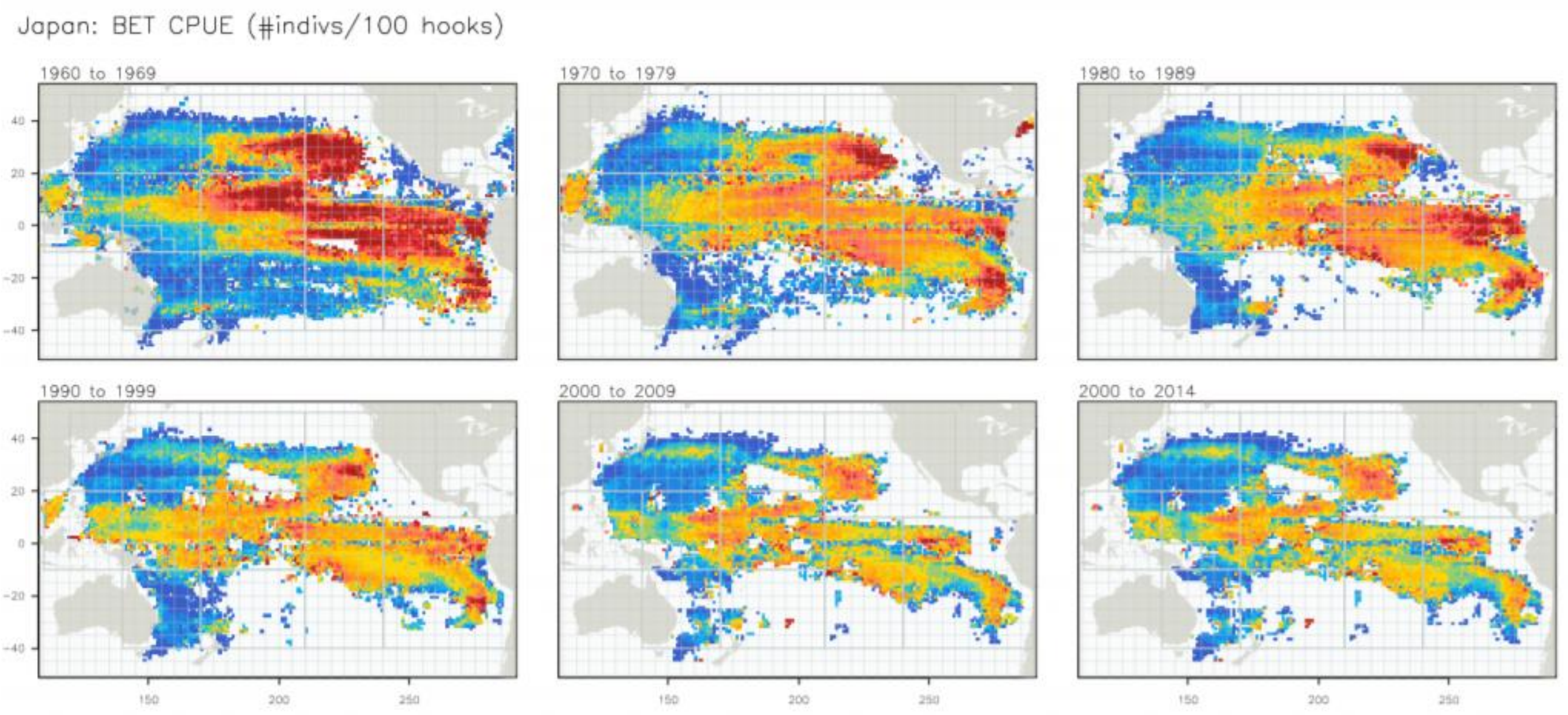
Why Spatial?

- Spatial heterogeneity in fisheries



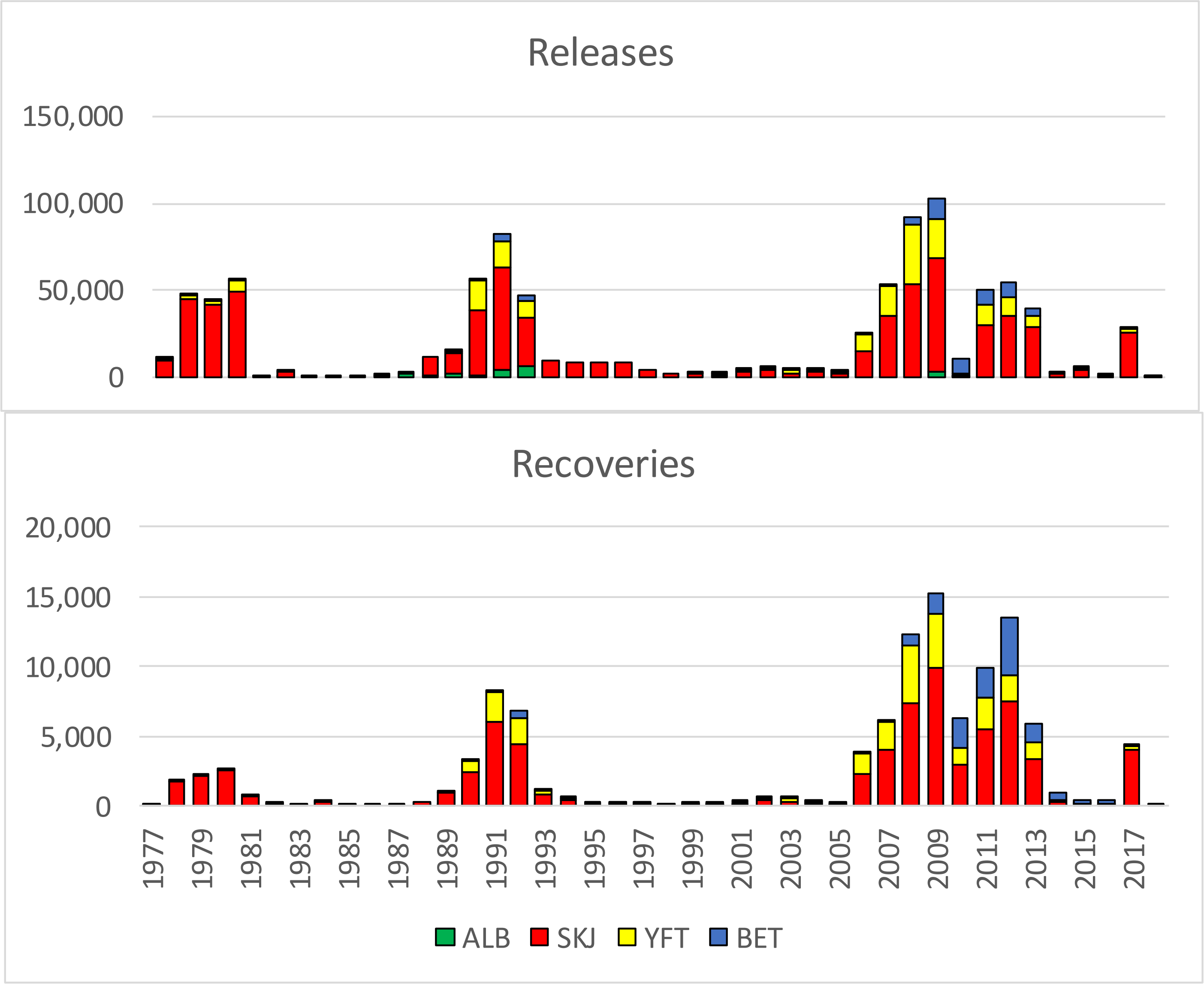
Why Spatial?

- Spatial heterogeneity in populations

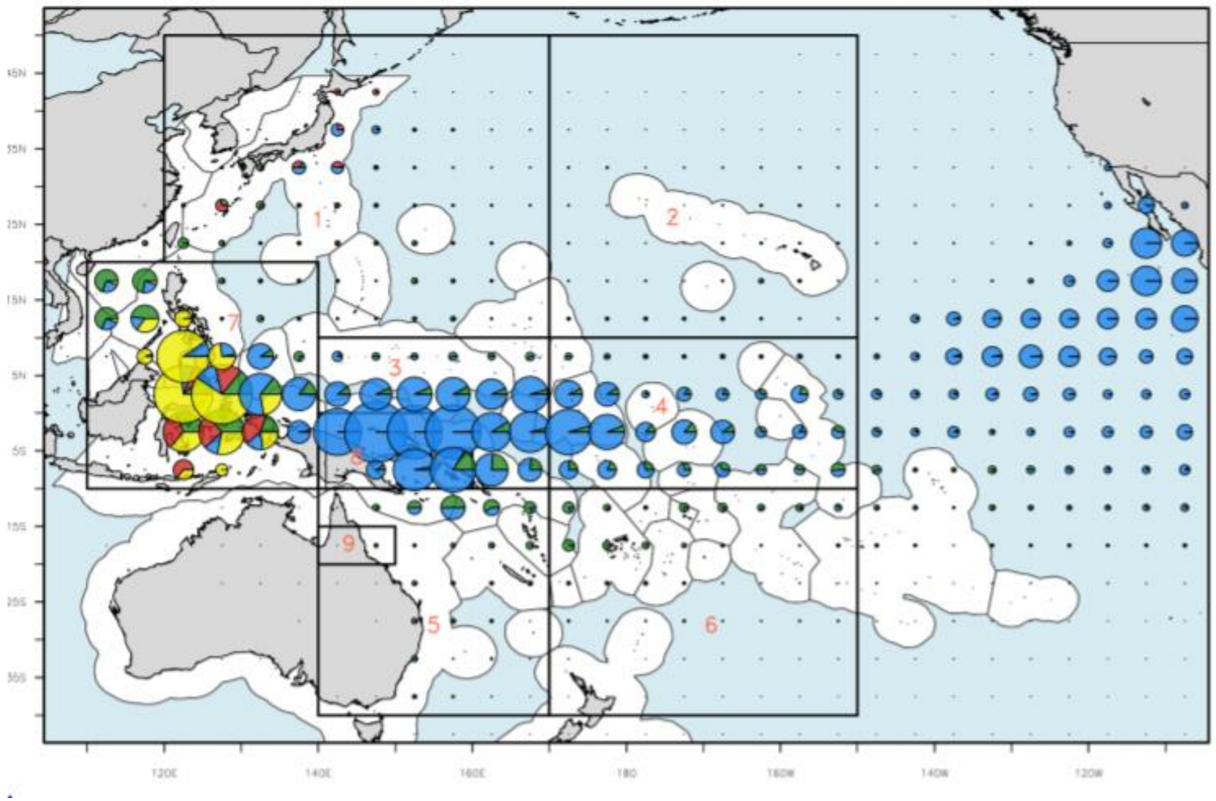


Why Spatial?

- Rich history of tuna tagging data
- SKJ assessment not possible without tagging → spatial approach is essential



Method used in MULTIFAN-CL



- Defined model regions with specific estimates of recruitment, abundance by region
- Most population dynamics (*M*, growth, etc.) shared across regions
- Fisheries defined to be specific to regions, with unique or shared selectivity and catchability
- Region-specific populations linked by movement, may be age-specific, seasonal but no inter-annual variation

Movement

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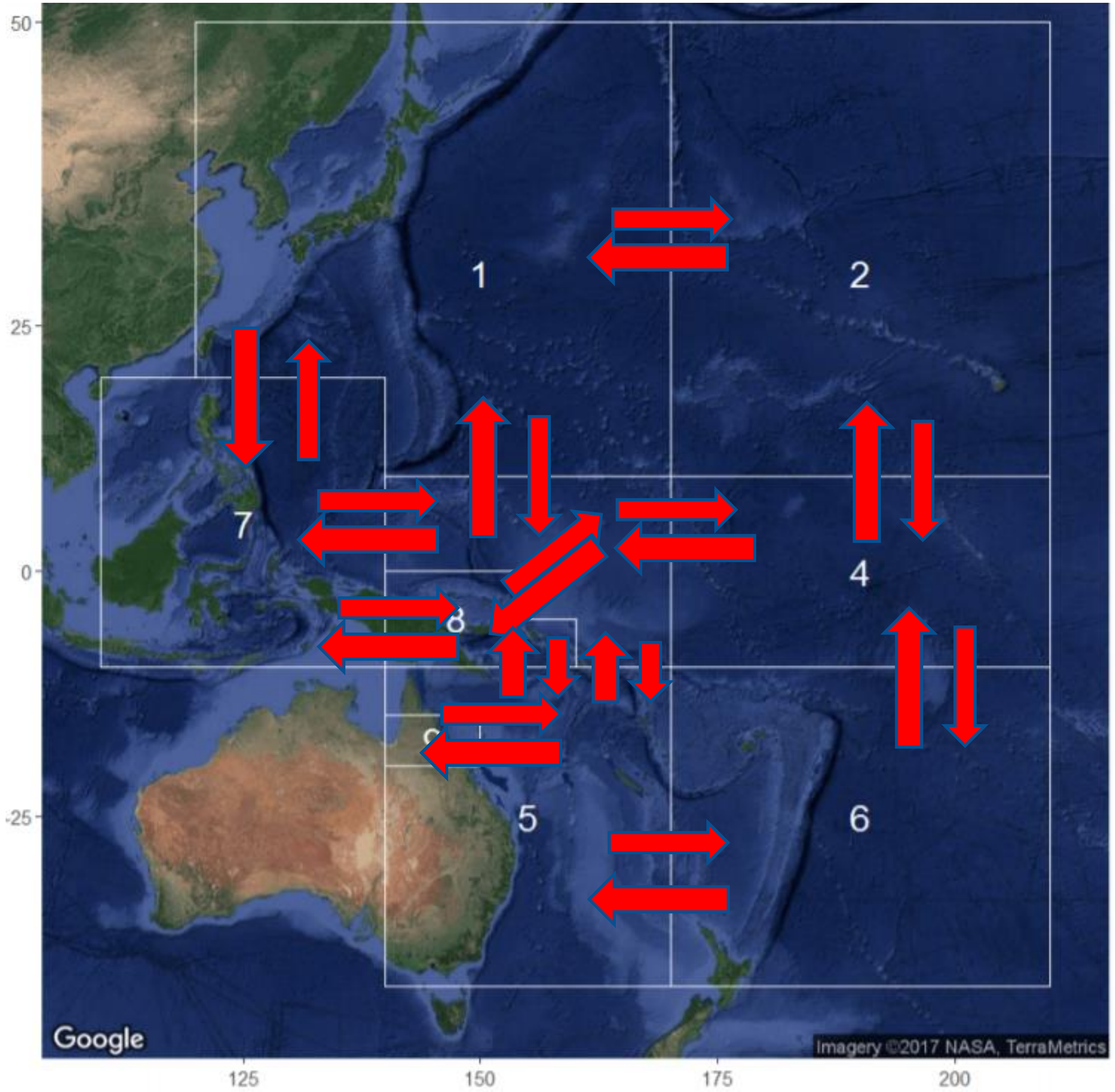


- Movement coefficients only for adjacent regions

	2	3	4	5	6	7	8	9
1	1	1	0	0	0	1	0	0
2		0	1	0	0	0	0	0
3			1	1	0	1	1	0
4				0	1	0	0	0
5					1	0	1	1
6						0	0	0
7							1	0
8								0

Movement

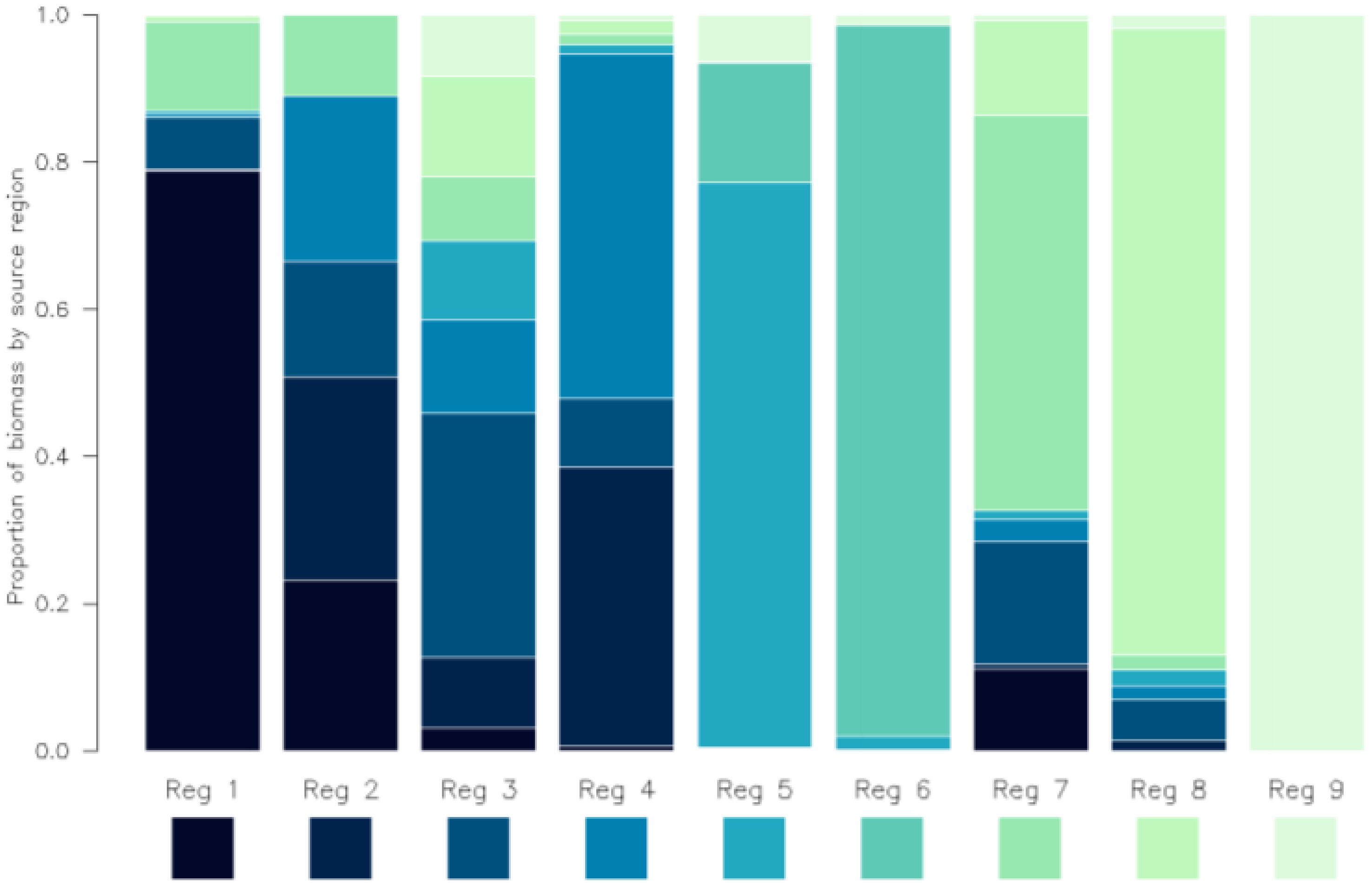
- Fully implicit solution → movement can occur to all regions in a single time step

$$\mathbf{N}_{\mathbf{at}} = \mathbf{B}_{\mathbf{a}}^{-1} \cdot \mathbf{N}'_{\mathbf{at}};$$

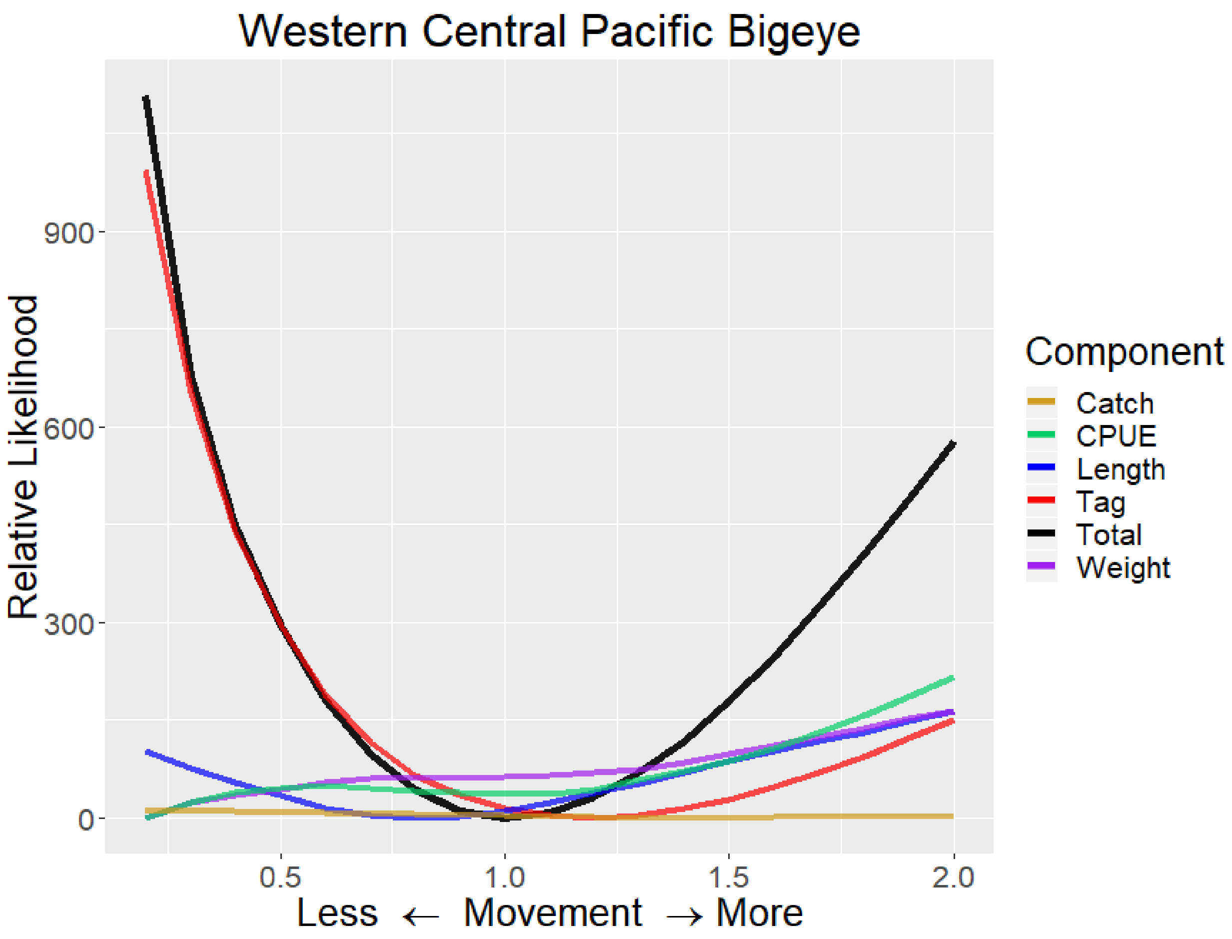
$$\mathbf{B}_{\mathbf{a}} = \begin{bmatrix} 1+\nu_a^{12}+\nu_a^{13}+\nu_a^{14} & -\nu_a^{21} & -\nu_a^{31} & -\nu_a^{41} & 0 & 0 & 0 \\ -\nu_a^{12} & 1+\nu_a^{21}+\nu_a^{25} & 0 & 0 & -\nu_a^{52} & 0 & 0 \\ -\nu_a^{13} & 0 & 1+\nu_a^{31}+\nu_a^{34} & -\nu_a^{43} & 0 & 0 & 0 \\ -\nu_a^{14} & 0 & -\nu_a^{34} & 1+\nu_a^{41}+\nu_a^{43}+\nu_a^{45}+\nu_a^{46} & -\nu_a^{54} & -\nu_a^{64} & 0 \\ 0 & -\nu_a^{25} & 0 & -\nu_a^{45} & 1+\nu_a^{52}+\nu_a^{54}+\nu_a^{57} & 0 & -\nu_a^{75} \\ 0 & 0 & 0 & -\nu_a^{46} & 0 & 1+\nu_a^{64}+\nu_a^{67} & -\nu_a^{76} \\ 0 & 0 & 0 & 0 & -\nu_a^{57} & -\nu_a^{67} & 1+\nu_a^{75}+\nu_a^{76} \end{bmatrix}$$

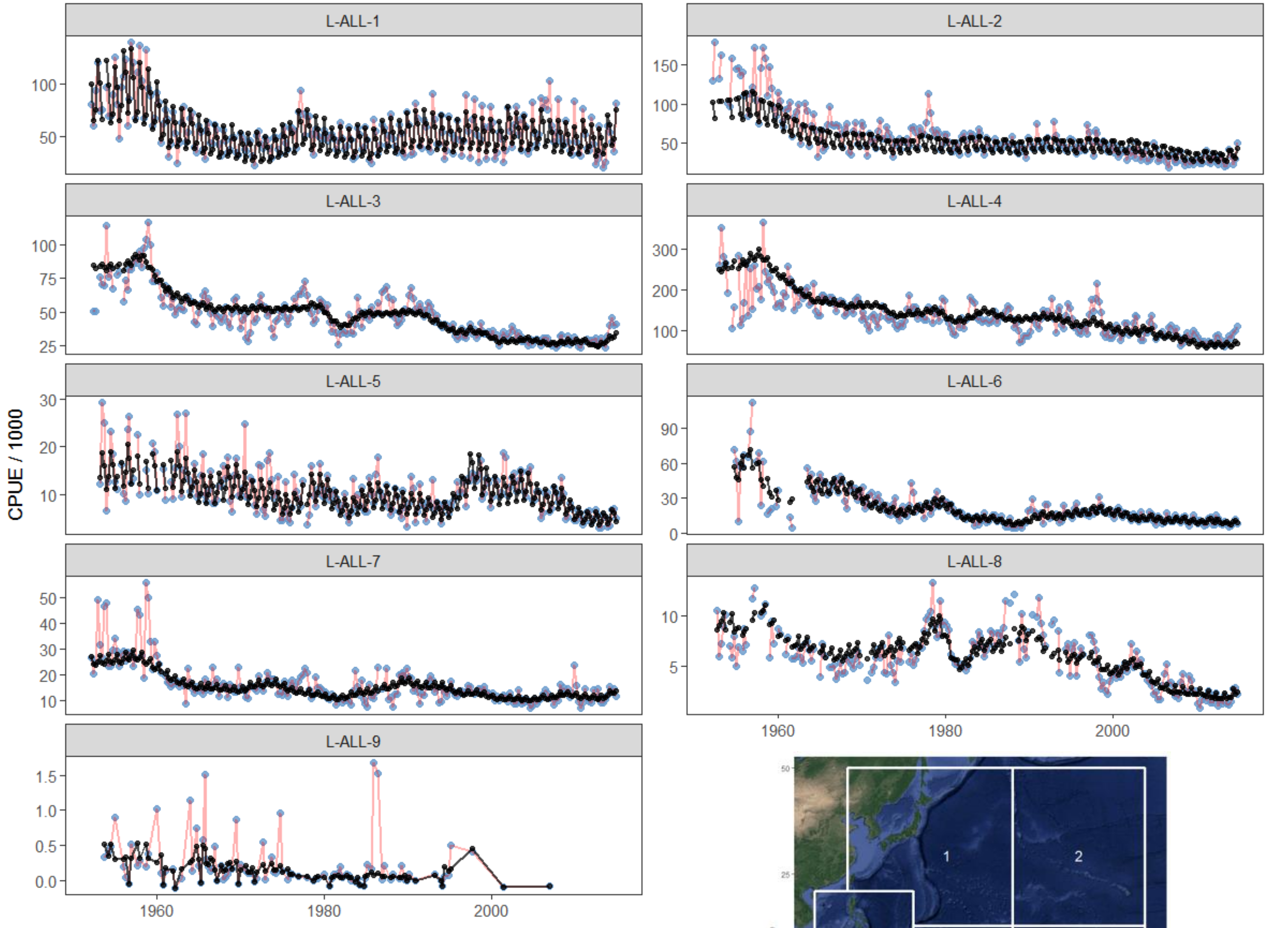
$$\nu_a^{xy} = \phi_0^{xy} \exp\left(\phi_1^{xy} \kappa_a\right)$$

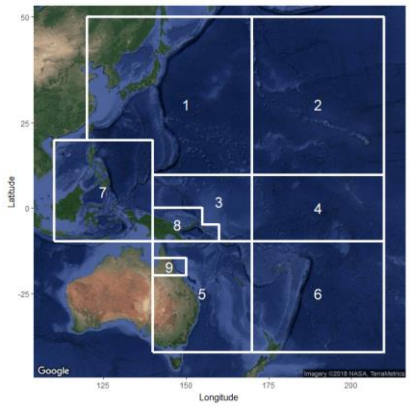
Movement → Stock Composition (BET)



Data informing movement

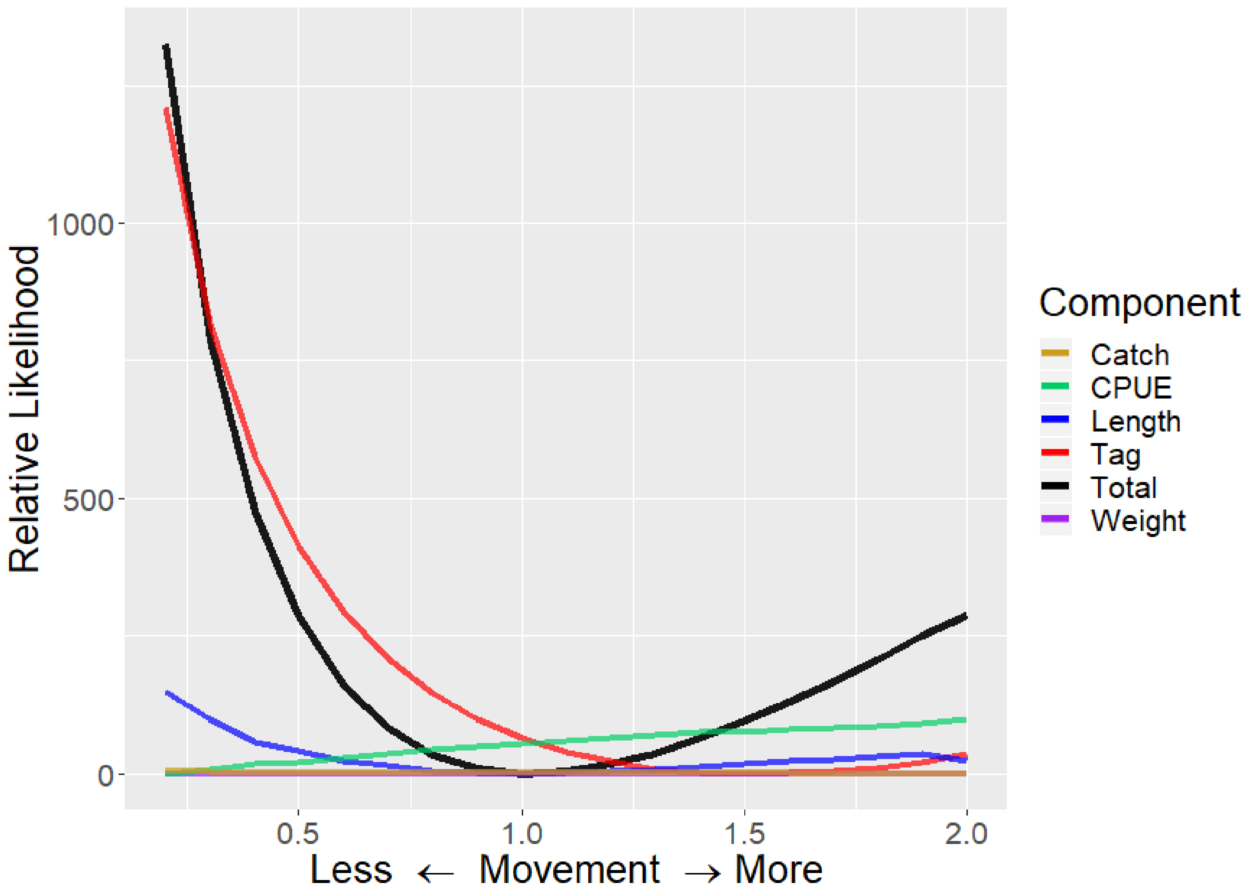




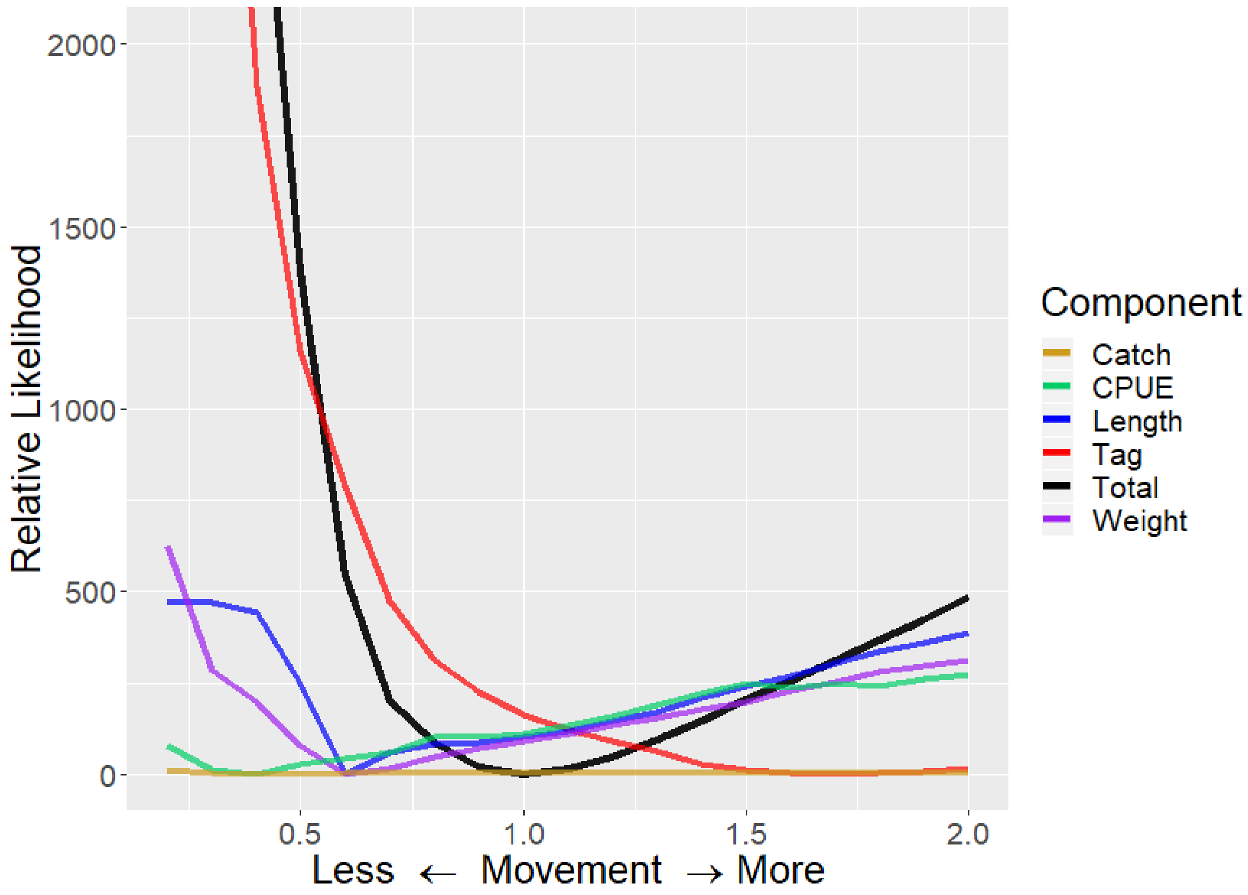


Data informing movement

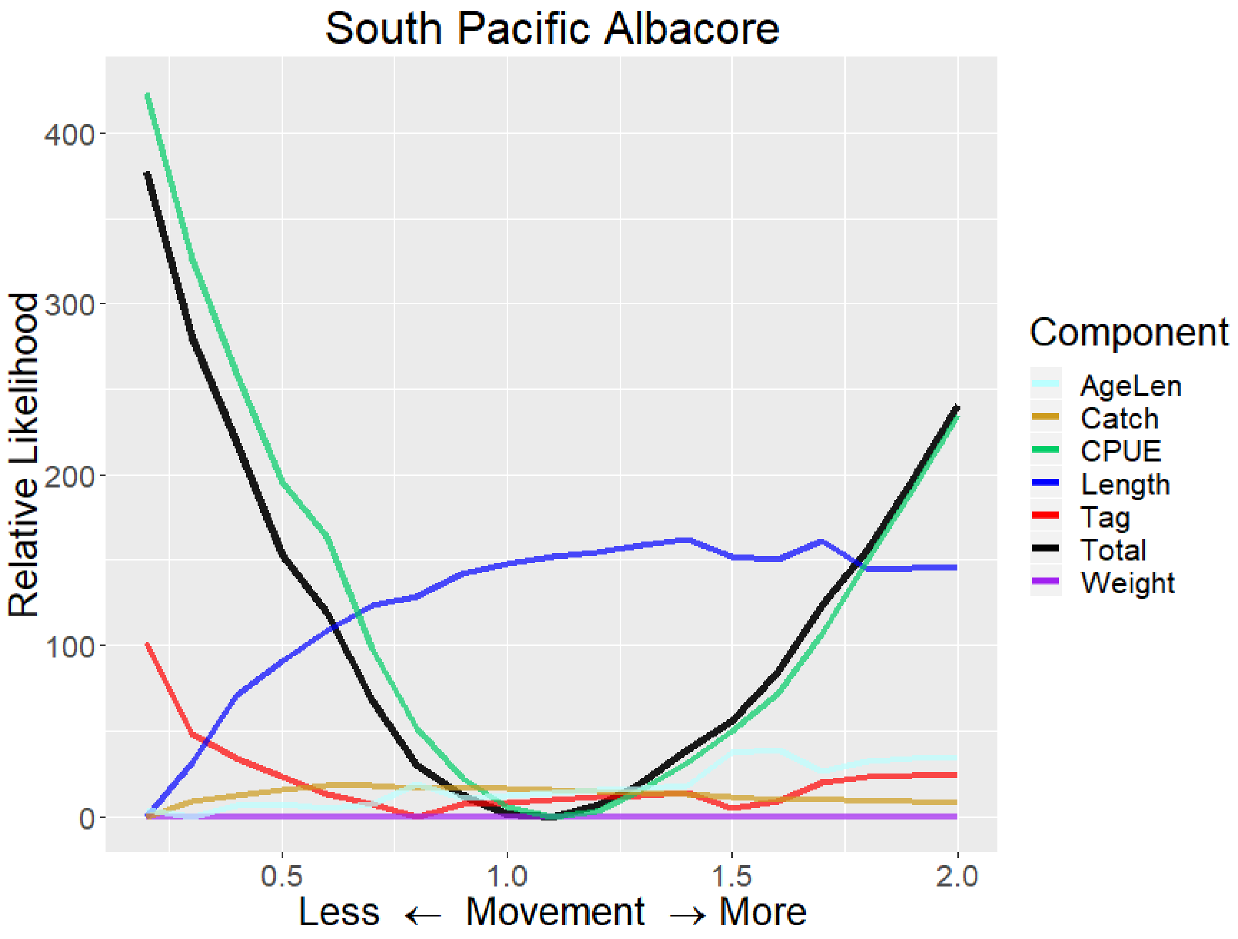
Skipjack

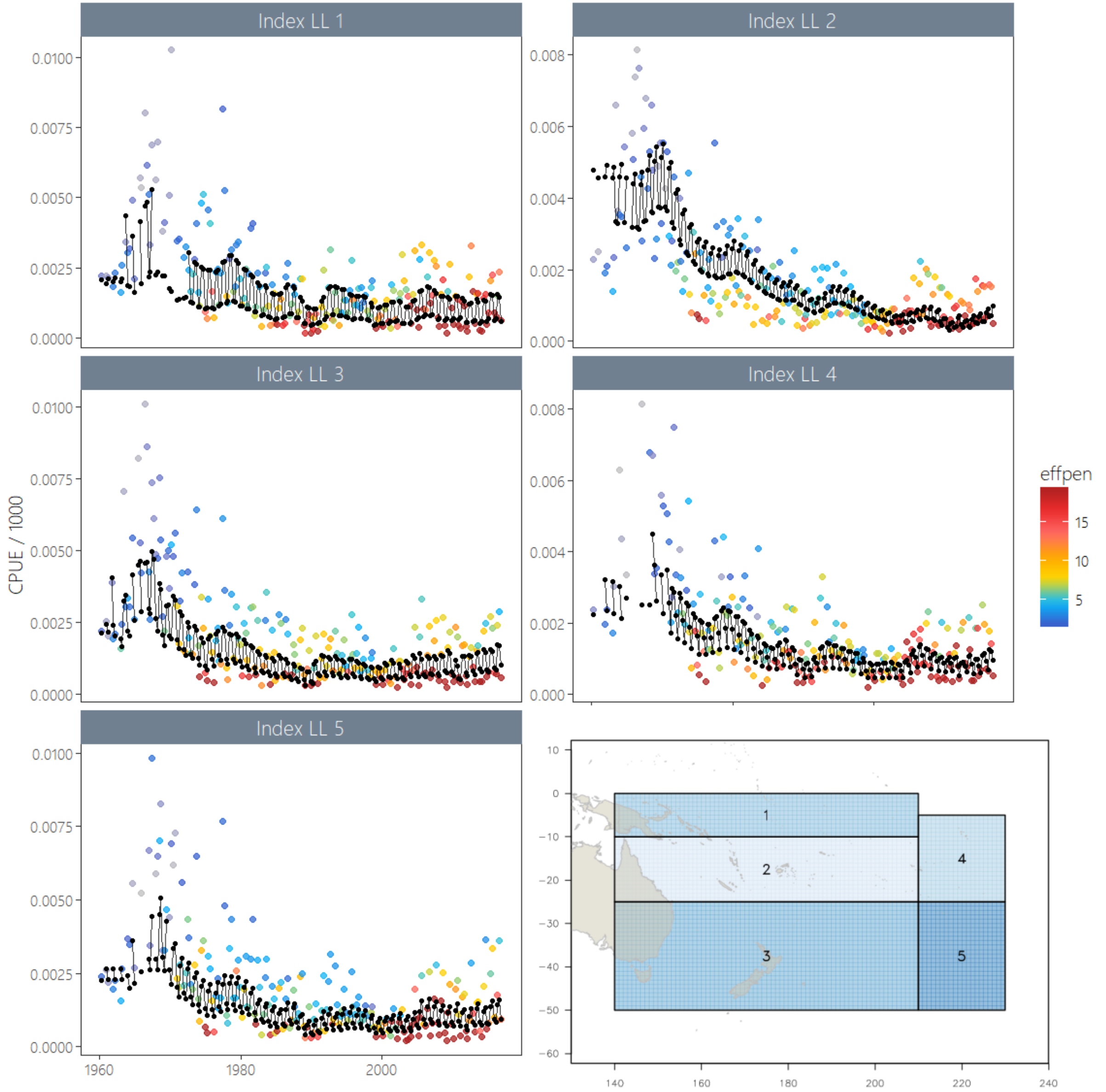


Yellowfin



Data informing movement





Recruitment (BET)

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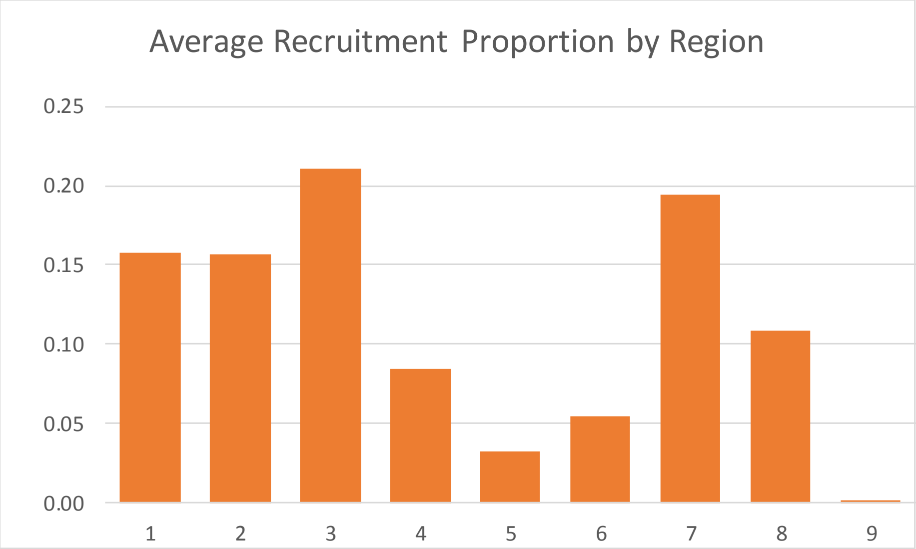
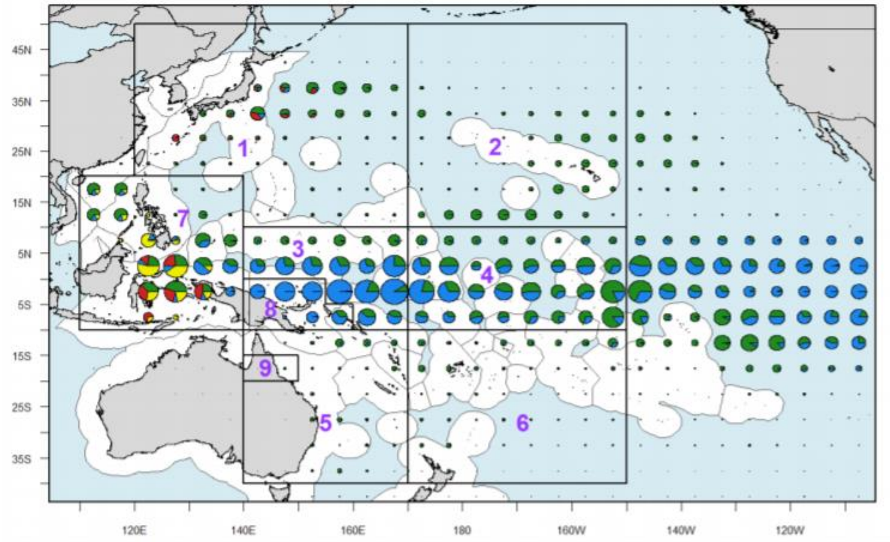
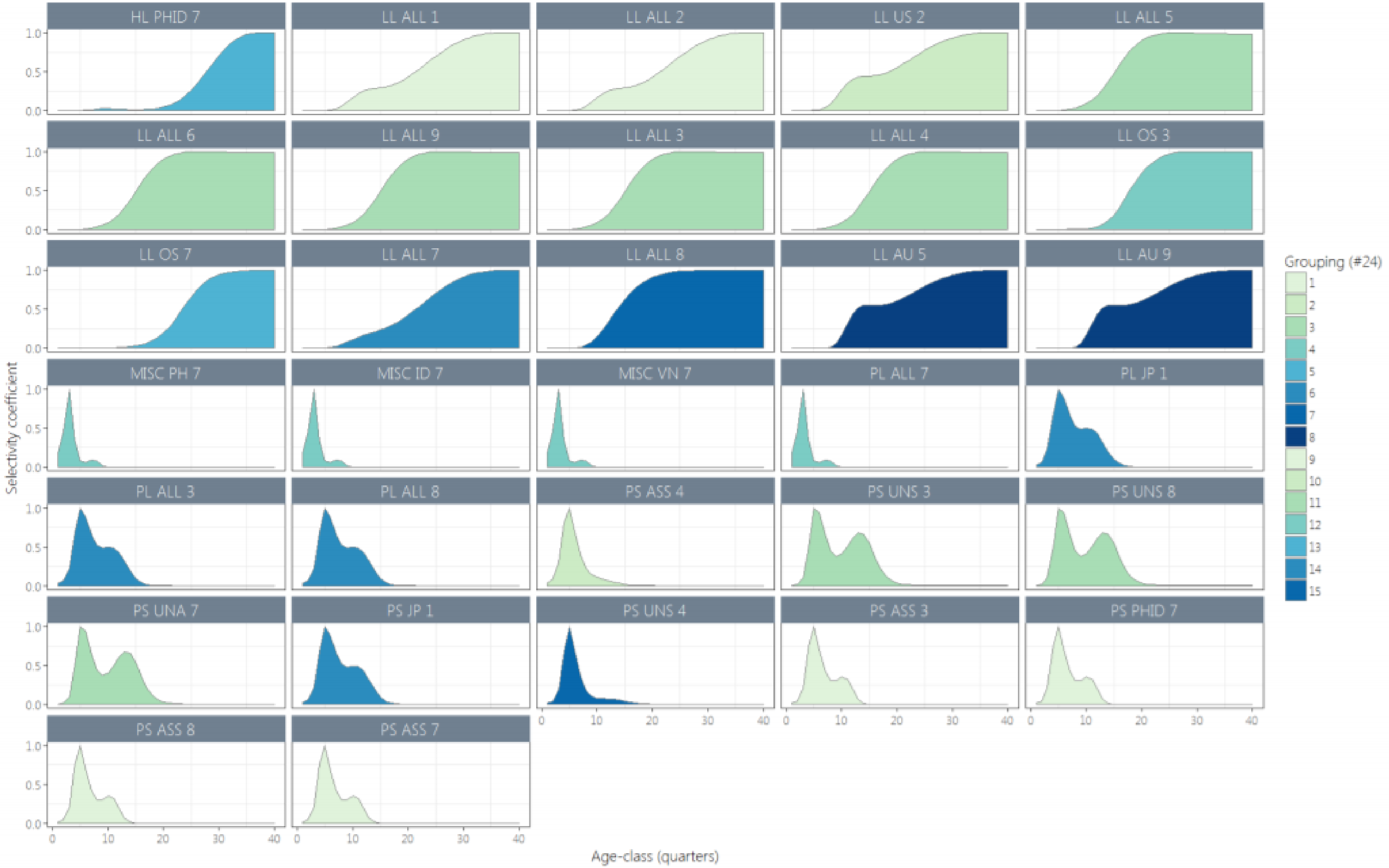
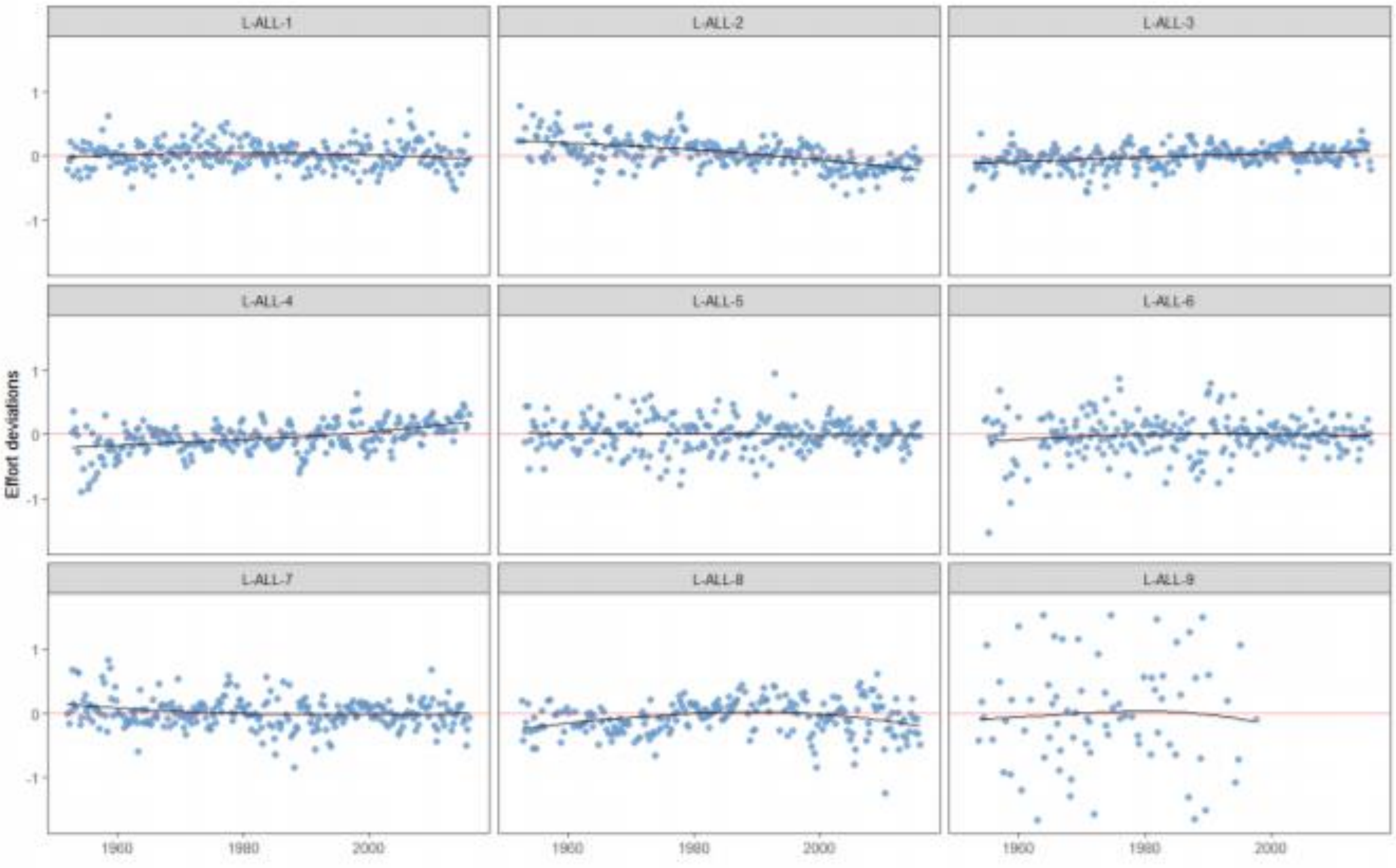




Selectivity



Catchability



Tagging data

- Fully integrated approach (informing F, M, movement, etc)
- Tagging data specified as release groups – by region, time period, length class (allocated to age class dynamically from growth curve)
- Recaptures assigned to fisheries and time periods
- Release numbers adjusted for recaptures excluded from the analysis, to preserve recovery rate of each tag group
- Release numbers also adjusted for initial tag loss (including tagger effects)
- Assume a specified tag mixing period
- Tag reporting rates by tag group and fishery, constrained by priors determined from tag seeding
- Tag recapture observation model is negative binomial, with estimated or specified over-dispersion

Some benefits of spatial models

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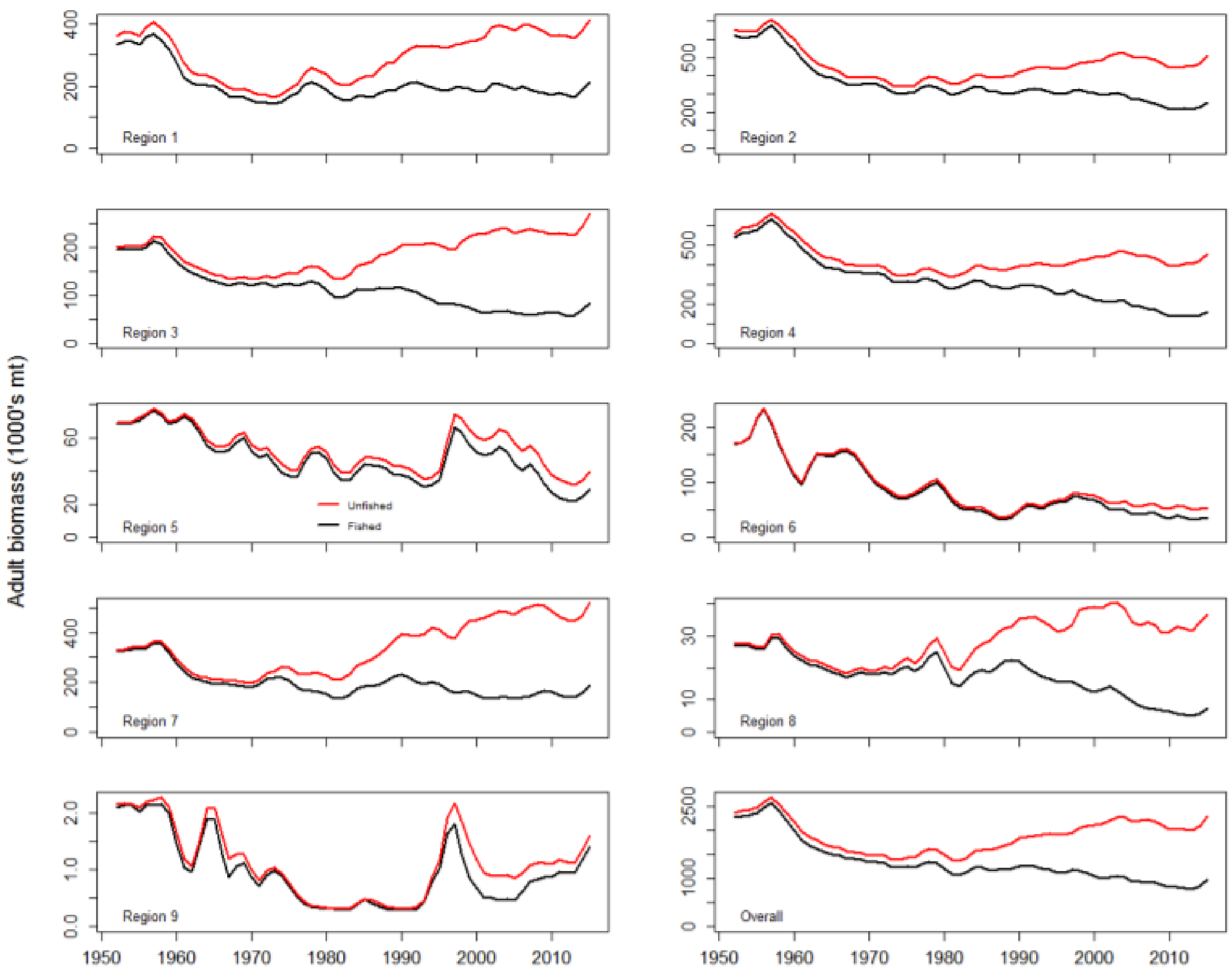
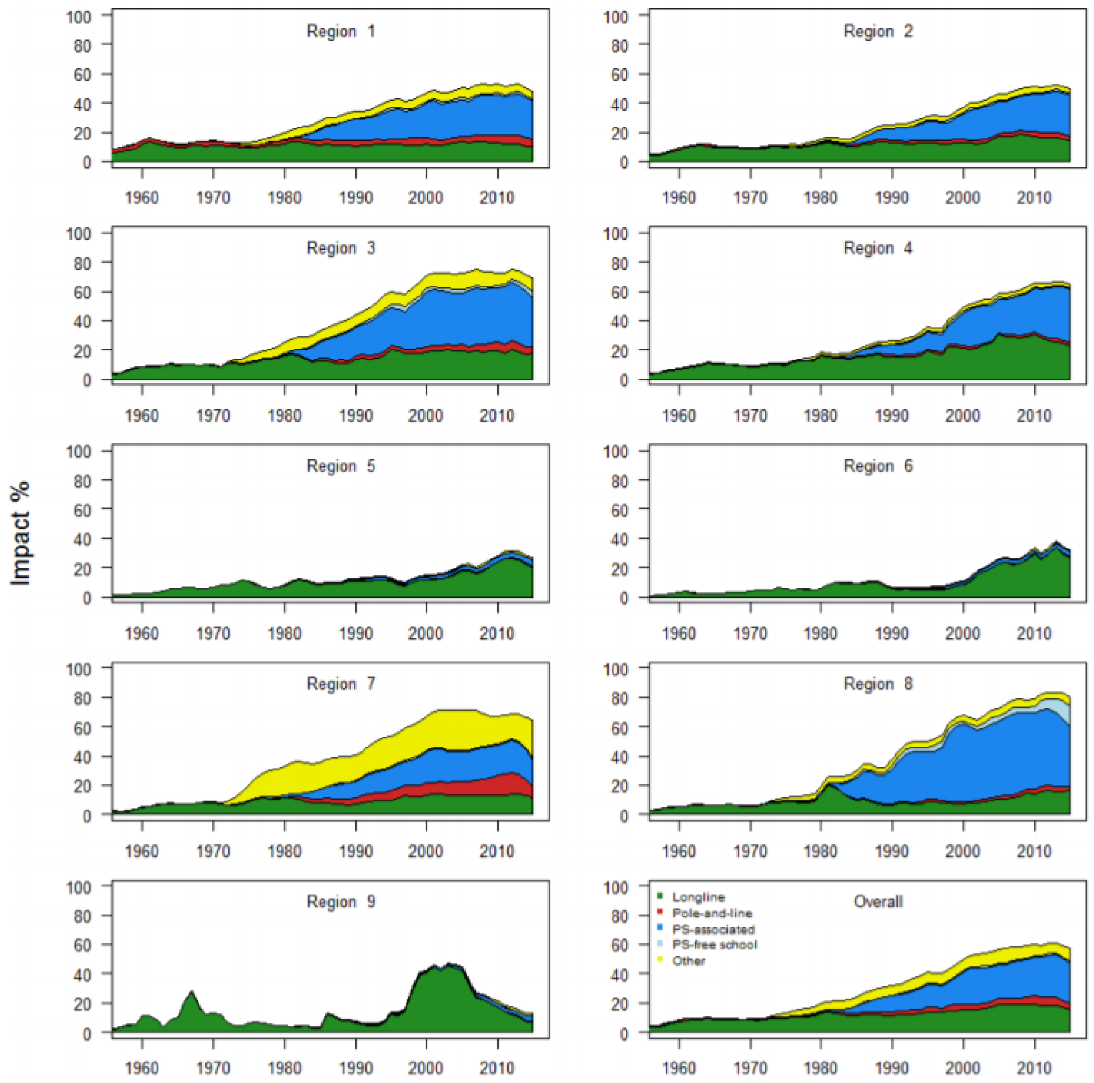
- Biological realism
  - Reflect spatial characteristics of spawning and recruitment
  - Incorporate effects of environmental variation
  - Potential to reflect knowledge of stock structure, spatial variability in growth, *M*, reproductive maturity, etc.
- Management analyses
  - Evaluation of spatial measures, closures
  - Better estimation of interactions of spatially separated fisheries
  - Better estimates of local dynamics to inform local management

Region-specific estimates





Factors to consider in defining spatial structure

- Overall boundaries should reflect stock distribution
  - Although often compromised by political jurisdiction
- Definition of regions
  - Ideally capture ‘less heterogeneous’ population units, similar biological parameters, including movement
  - Reflect the distribution of fisheries, particularly if spatially restricted
  - Consider the spatial distribution of tagging data, if used
  - Consider the spatial resolution of available fisheries data
  - Consider the needs of management analyses, e.g. MSE

Catch and CPUE distributions (bigeye tuna)

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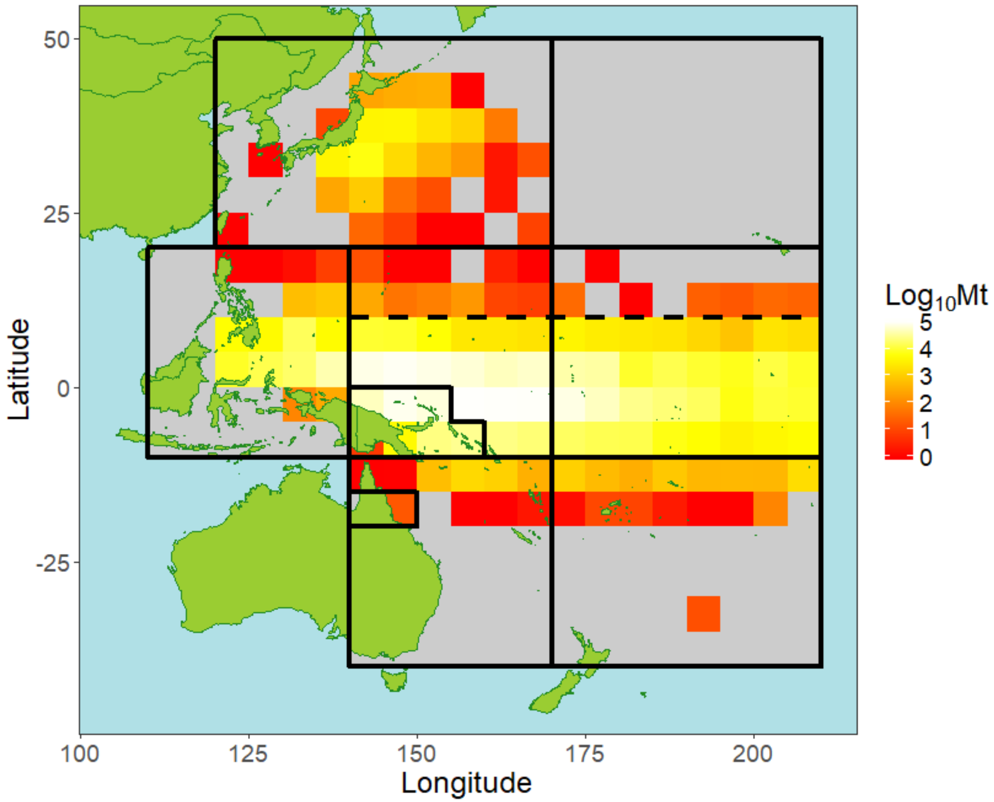
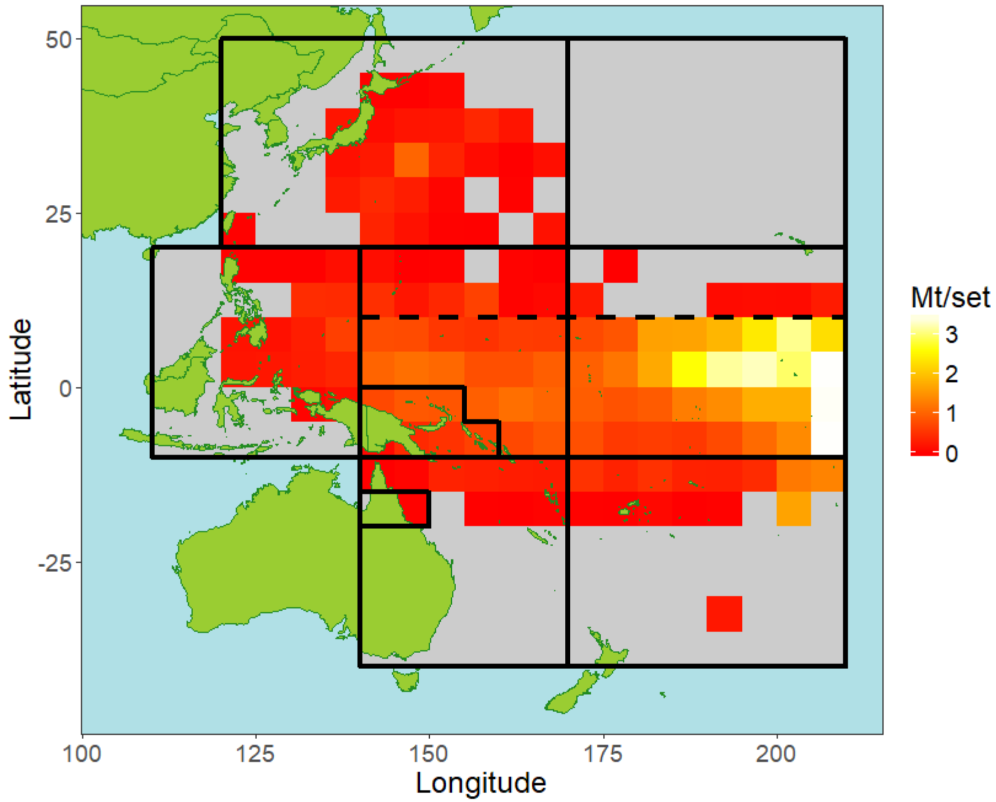
Purse seine catch

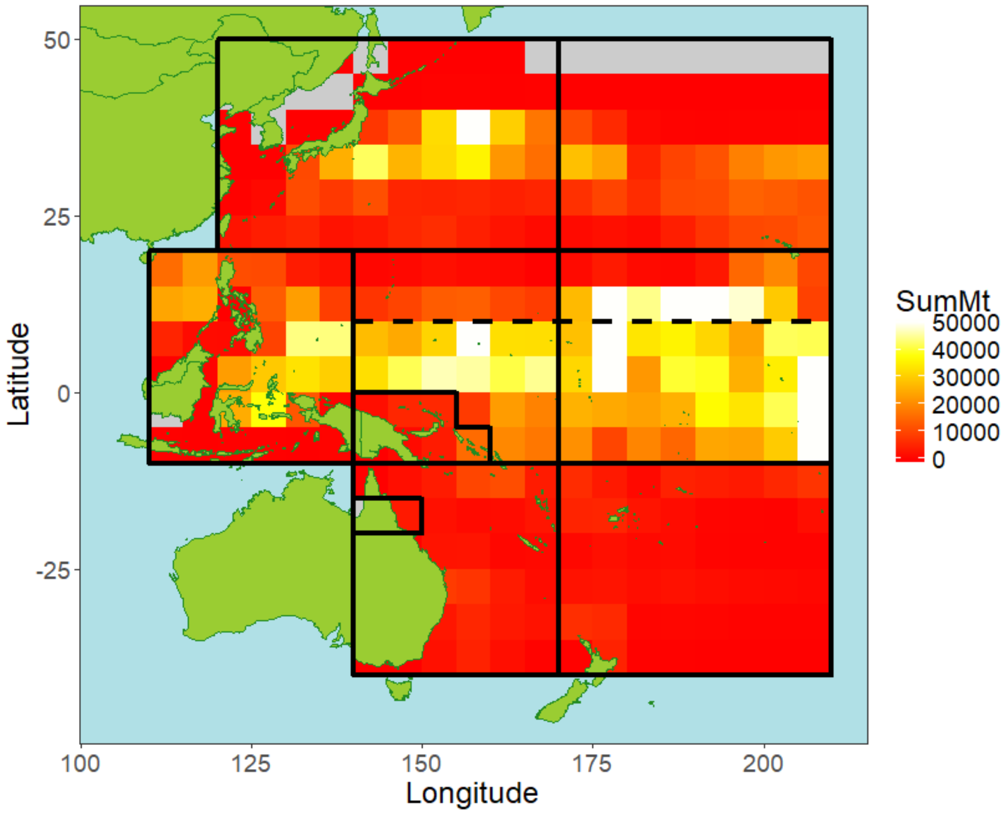


Purse seine CPUE

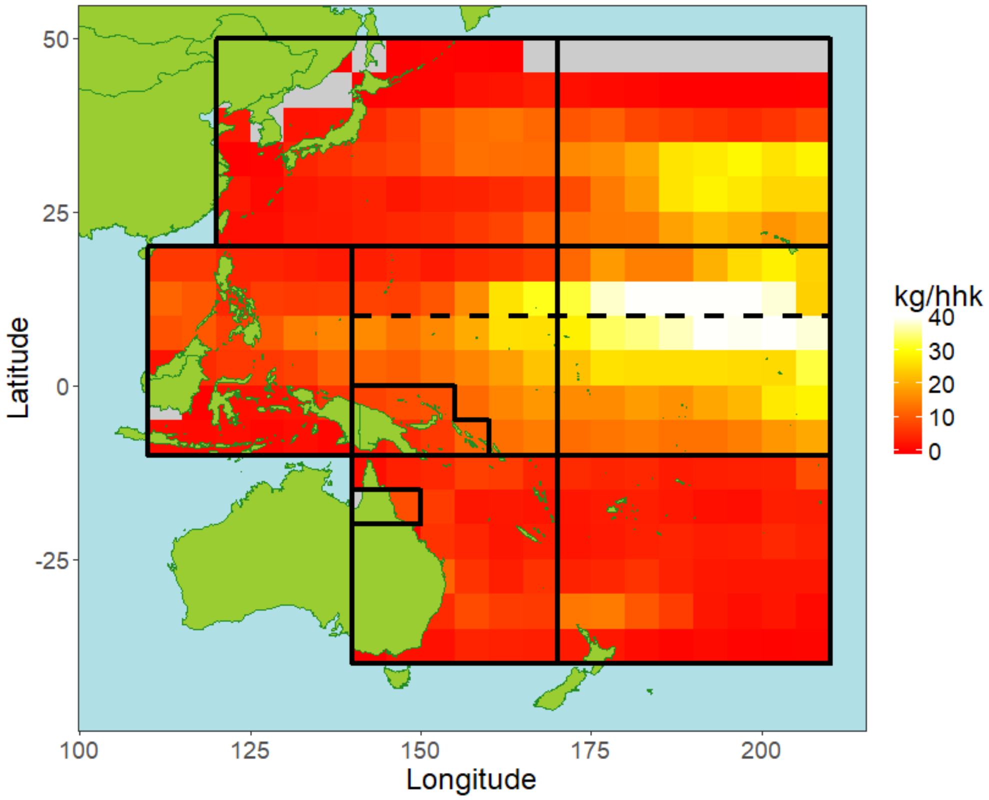


Catch and CPUE distributions (bigeye tuna)

Longline catch



Longline CPUE



Spatial variation in growth (bigeye tuna)

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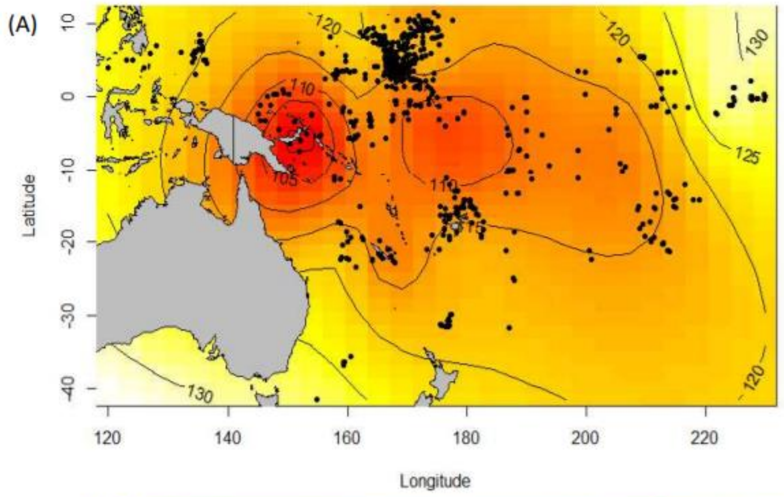
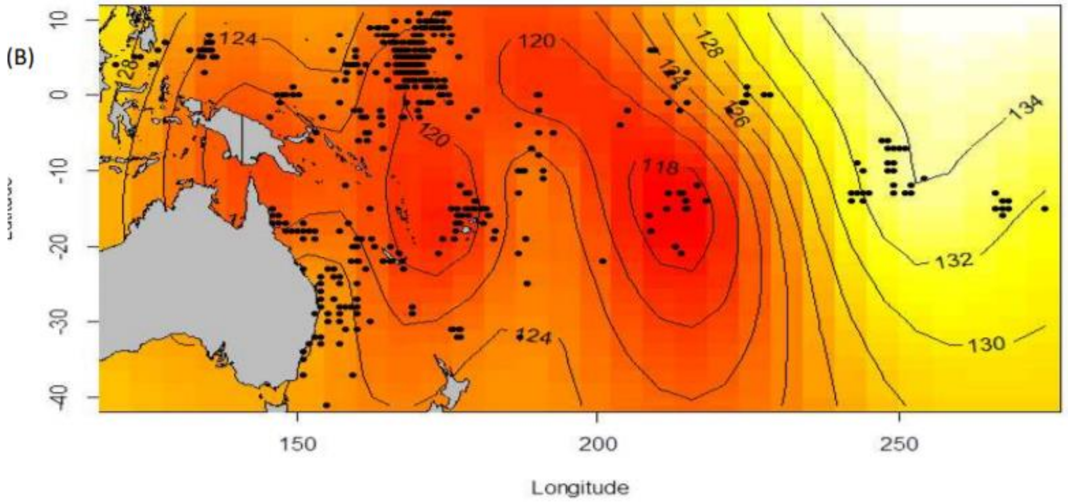
Jess Farley and Paige Eveson, CSIRO



GAM predictions of bigeye mean length at age 3.3 yr



GAM predictions of bigeye mean length at mean otolith weight of 0.06 g

Key current issues and plans for future development

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Issue/Limitation	Planned Development
Spatial variability in growth	1. Multi-stock with different growth – assumes differences are genetic (region of origin) 2. Variability due to environment – requires and length-structured model, growth transition matrix approach
Temporal stability of movement	Time blocks, random walk and/or environmental correlate
Stock-wide SRR, with recruitment allocation according to regional average, plus time devs	Region-specific SRRs

Acknowledgements & Further Information

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- Dave Fournier, Nick Davies

- Current spatially structured tuna assessments (WCPFC):

McKechnie, S., J. Hampton, G. Pilling and N. Davies. 2016. Stock assessment of skipjack in the western and central Pacific Ocean. WCPFC-SC-12-SA-WP-04. https://www.wcpfc.int/file/76209/download?token=Doe4ZmSv

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S. McKechnie, G. Pilling and J. Hampton. 2017. Stock assessment of bigeye tuna in the western and central Pacific Ocean. WCPFC-SC-13-SA-WP-05. https://www.wcpfc.int/file/147351/download?token=b075-R_1

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