Session 5 (FIS)

Evaluating the spatiotemporal dynamics of Pacific saury in the Northwestern Pacific Ocean by using *a geostatistical modelling approach*

Jhen Hsu, Yi-Jay Chang, Toshihide Kitakado, Mikihiko Kai, Bai Li, Midori Hashimoto, Chih-hao Hsieh, Vladimir Kulik, Kyum Joon Park

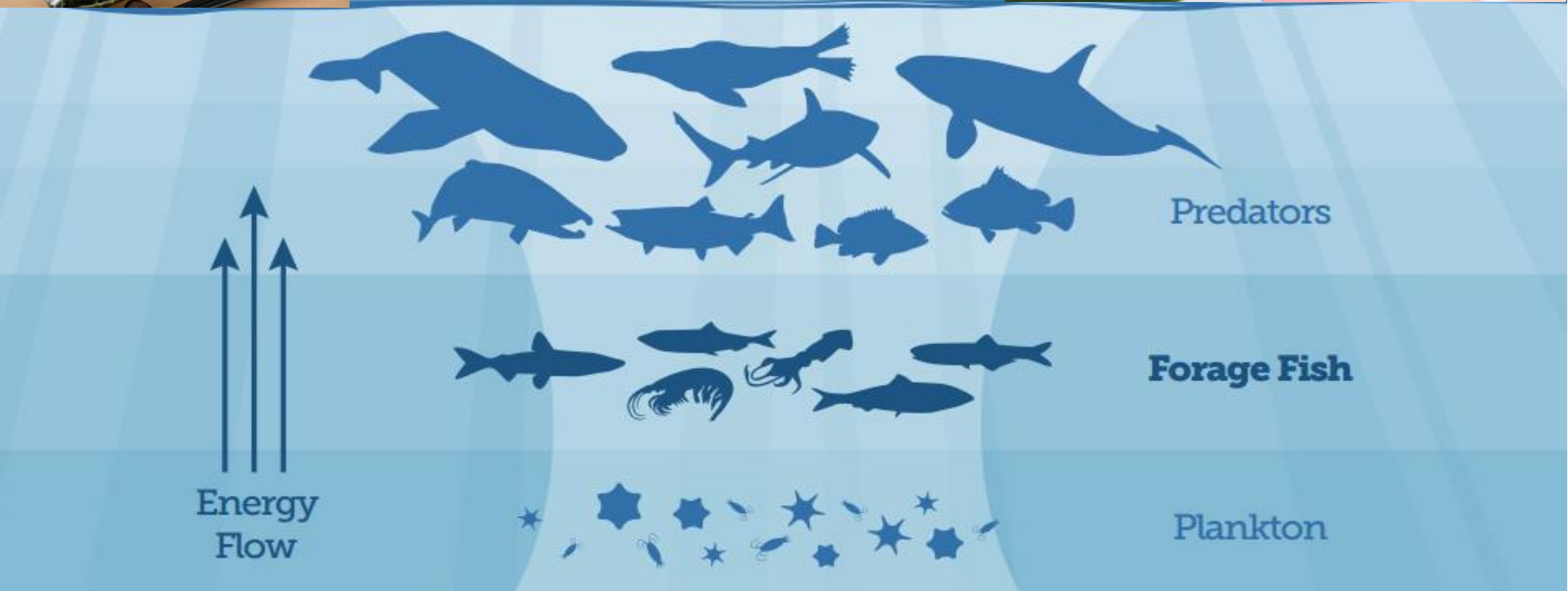
NPFC

Outline

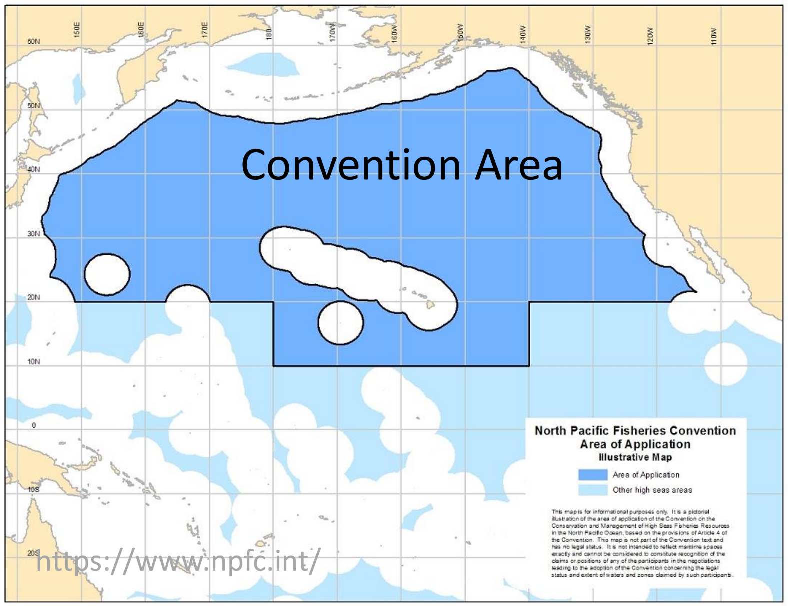
- Introduction of North Pacific Fisheries Commission (NPFC) and Pacific saury;
- Modelling the spatiotemporal dynamics of Pacific saury by using a spatio-temporal modelling framework (VAST);
- Evaluating the influences of various spatial treatments on the estimation of abundance index;
- General conclusions;

How important small pelagic fishes are?

Small pelagic fish species are a key component of marine ecosystems;
In addition, there are substantial commercial fisheries that exploit small pelagic species;



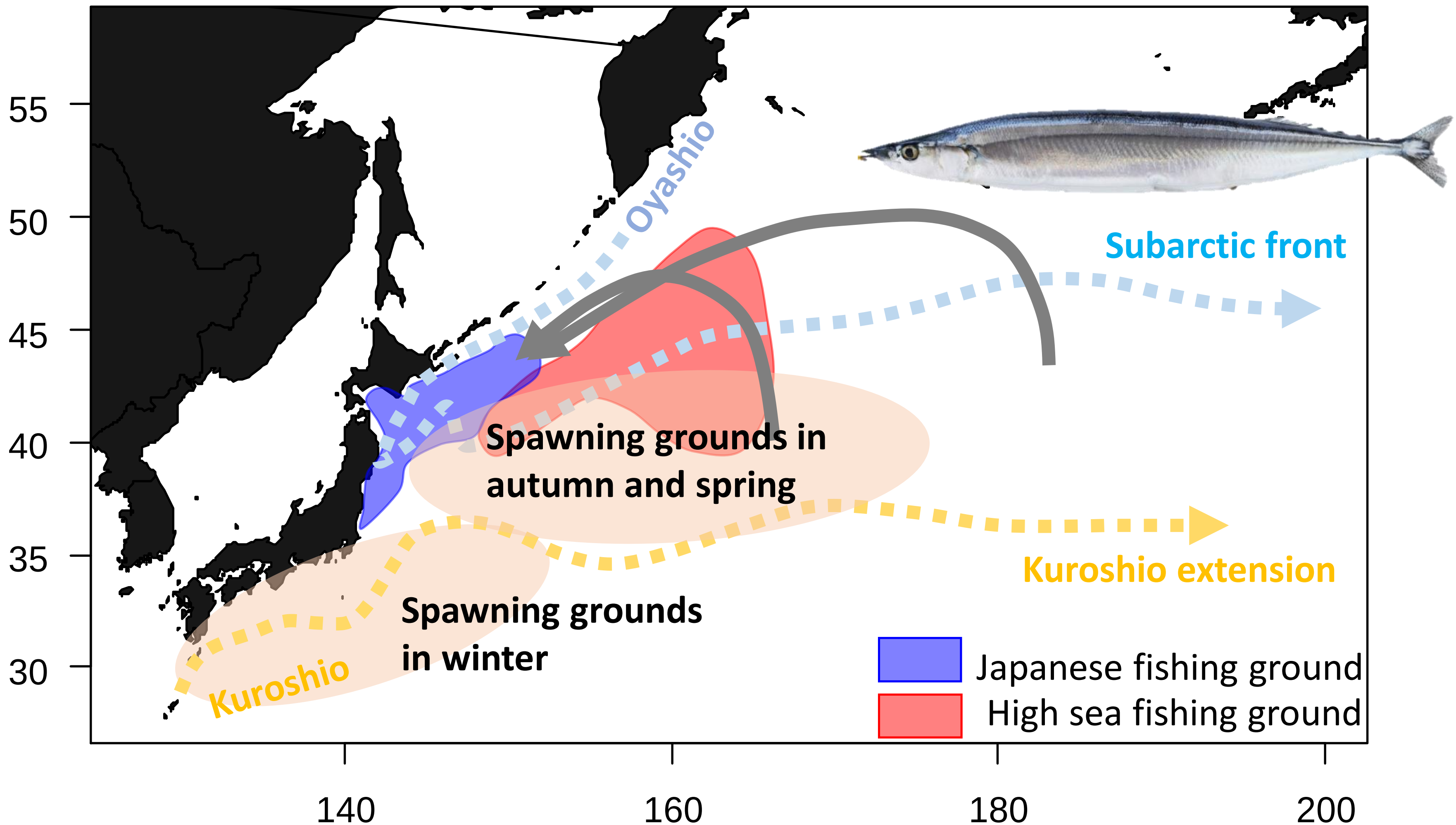
North Pacific Fisheries Commission (NPFC)



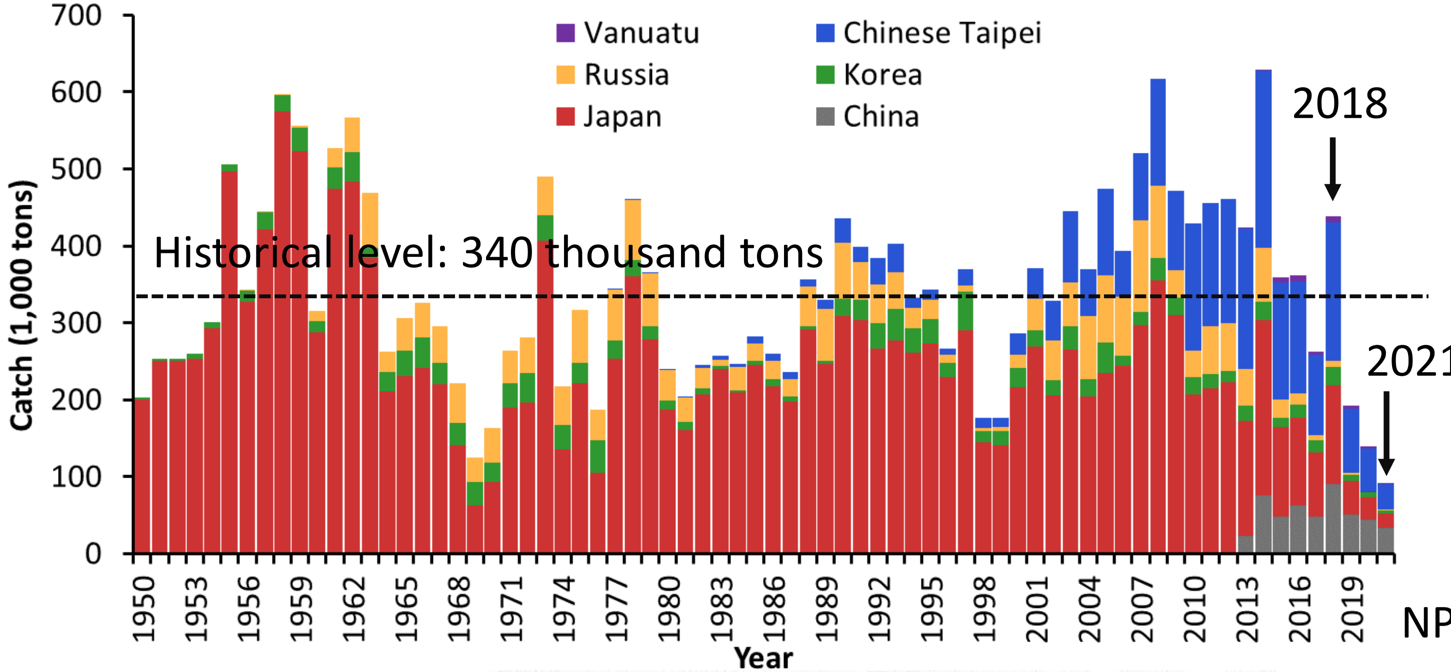
- NPFC
  - Secretariat
  - Scientific Committee
    - Small Scientific Committee on Bottom Fish and Marine Ecosystems
    - Small Scientific Committee on Pacific Saury
    - Technical Working Group on Chub Mackerel Stock Assessment
  - Technical and Compliance Committee
    - Small Working Group on Planning and Development
    - Small Working Group on Operations
  - Finance and Administration Committee

Current Members: Canada, China, EU, Japan, Korea, Russia, Chinese Taipei, USA, Vanuatu

Distribution and migration route of Pacific saury

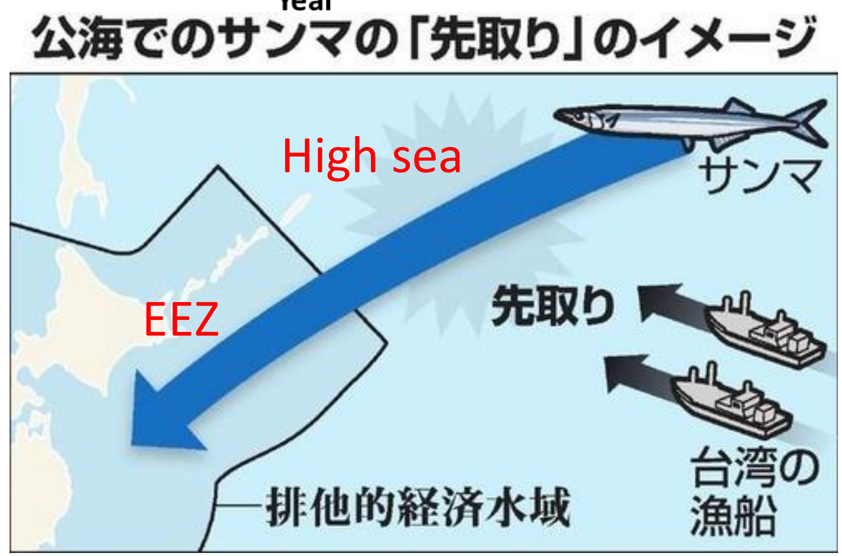


Current issues of the Pacific saury fisheries



NPFC (2022)

Pacific Saury: Overfishing and Environmental Change Puts Future of Japanese Autumn Delicacy in Doubt https://www.nippon.com/en/in-depth/d00505/pacific-saury-overfishing-and-environmental-change-puts-future-of-japanese-autumn-delicacy.html

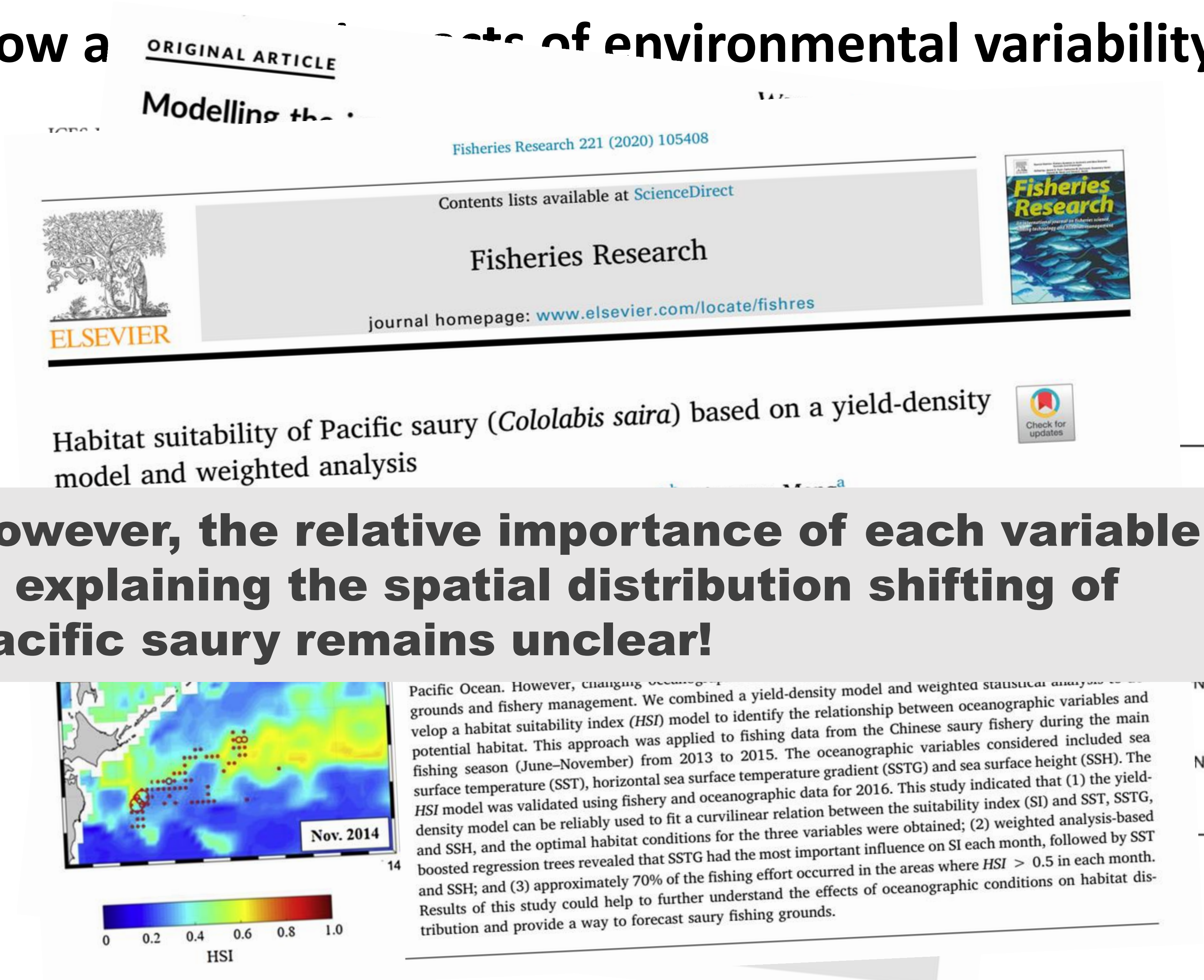


http://blog.livedoor.jp/wkmt/archives/51481410.html

NPFC

First come, first served?

How a... effects of environmental variability?


ORIGINAL ARTICLE

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ELSEVIER

Habitat suitability of Pacific saury (*Cololabis saira*) based on a yield-density model and weighted analysis

Pacific Ocean. However, changing ... grounds and fishery management. We combined a yield-density model and weighted statistical analysis to develop a habitat suitability index (*HSI*) model to identify the relationship between oceanographic variables and potential habitat. This approach was applied to fishing data from the Chinese saury fishery during the main fishing season (June–November) from 2013 to 2015. The oceanographic variables considered included sea surface temperature (SST), horizontal sea surface temperature gradient (SSTG) and sea surface height (SSH). The *HSI* model was validated using fishery and oceanographic data for 2016. This study indicated that (1) the yield-density model can be reliably used to fit a curvilinear relation between the suitability index (SI) and SST, SSTG, and SSH, and the optimal habitat conditions for the three variables were obtained; (2) weighted analysis-based boosted regression trees revealed that SSTG had the most important influence on SI each month, followed by SST and SSH; and (3) approximately 70% of the fishing effort occurred in the areas where *HSI* > 0.5 in each month. Results of this study could help to further understand the effects of oceanographic conditions on habitat distribution and provide a way to forecast saury fishing grounds.

However, the relative importance of each variable in explaining the spatial distribution shifting of Pacific saury remains unclear!

Objectives of this study

- How did the Pacific saury distribution change in the past?
  - To quantify the magnitude of distribution shifting of Pacific saury over time;

- However, projections of future distribution of Pacific saury solely based on the environmental variables may be misleading;
  - To investigate the extent to which the spatial shifting can be attributed to the factors of:

Local/regional environmental variables (e.g., SST, Southern Oscillation Index; SOI);

Unmodelled spatiotemporal variables (e.g., species interaction; fishing harvest; complex oceanographic condition);

Quantify the *"Unmodelled"* effects on saury distribution

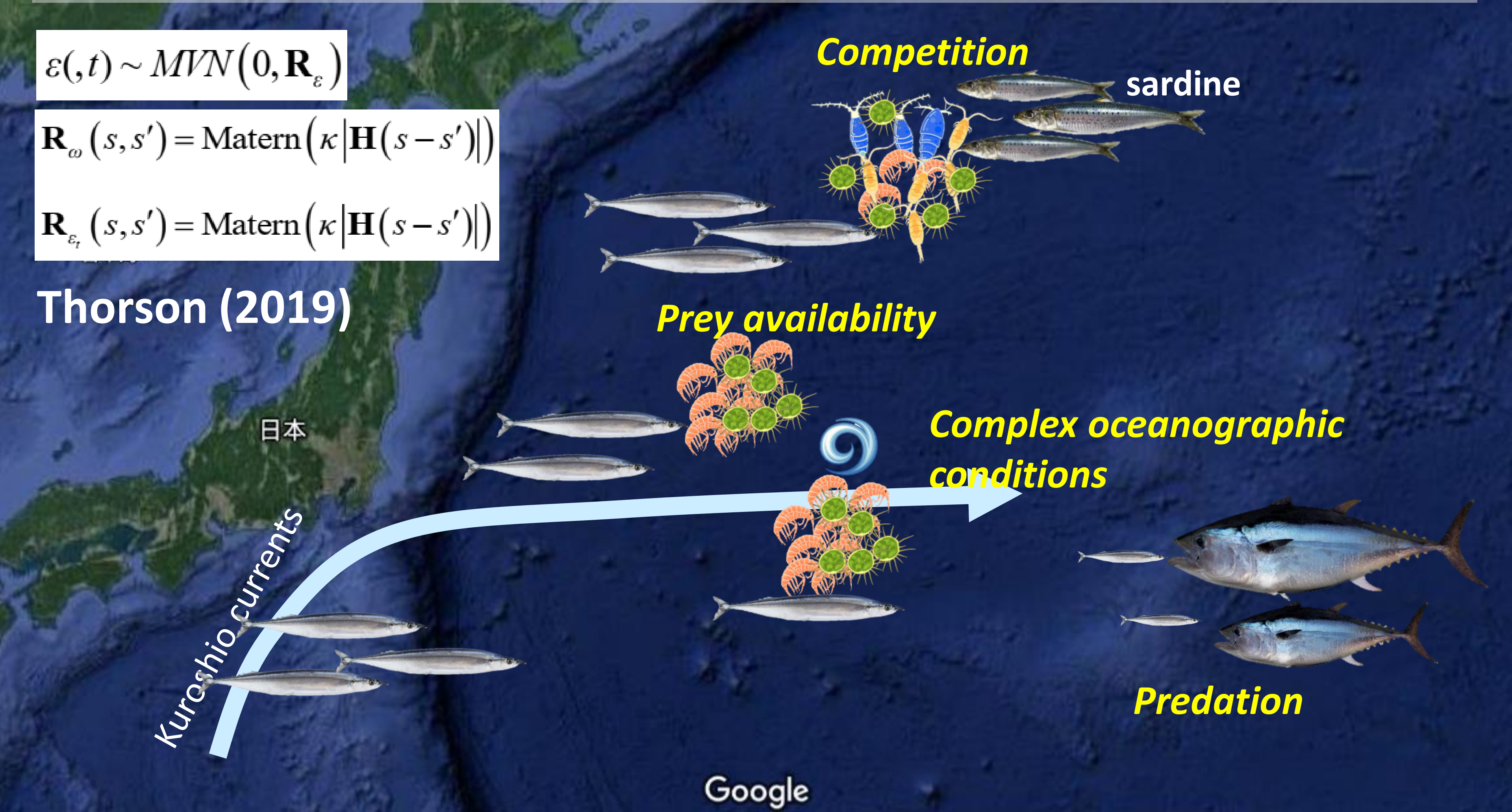
- The *geostatistical approach (VAST)* provides a more complicated treatment over than conventional species distribution models;

$$\varepsilon(,t) \sim MVN\left(0, \mathbf{R}_{\varepsilon}\right)$$

$$\mathbf{R}_{\omega}\left(s, s'\right) = \text{Matern}\left(\kappa \left|\mathbf{H}\left(s - s'\right)\right|\right)$$

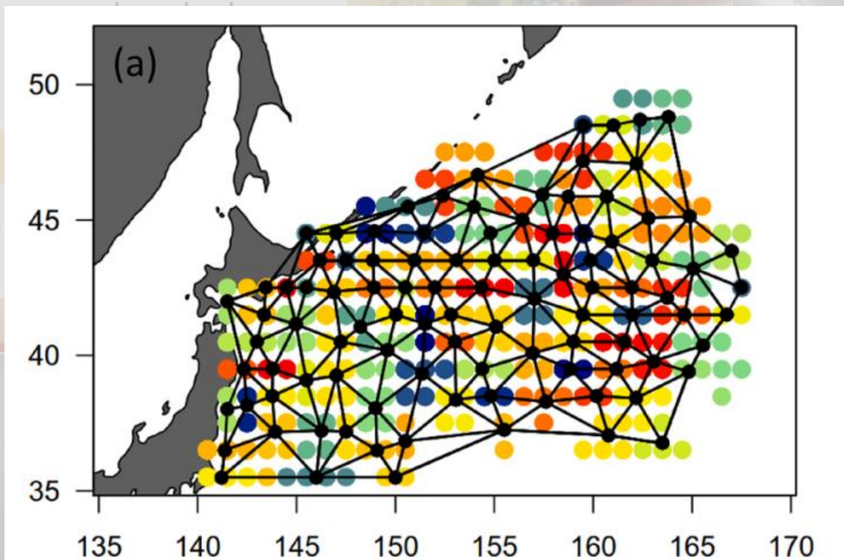
$$\mathbf{R}_{\varepsilon_t}\left(s, s'\right) = \text{Matern}\left(\kappa \left|\mathbf{H}\left(s - s'\right)\right|\right)$$

Thorson (2019)



International collaborative data collection

Studied area

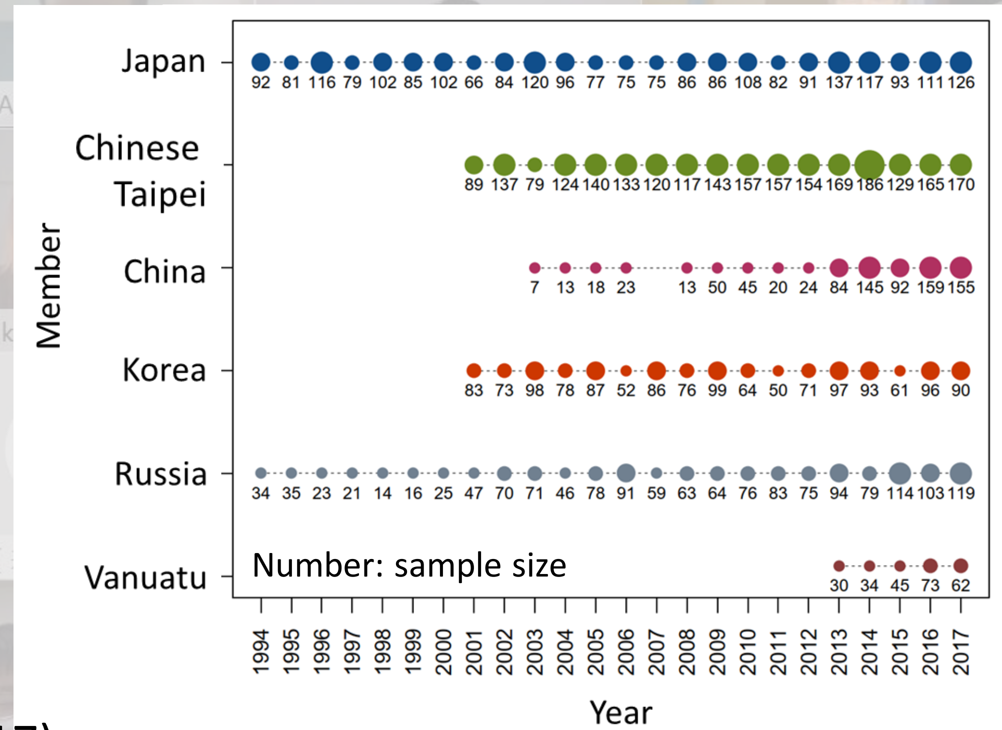


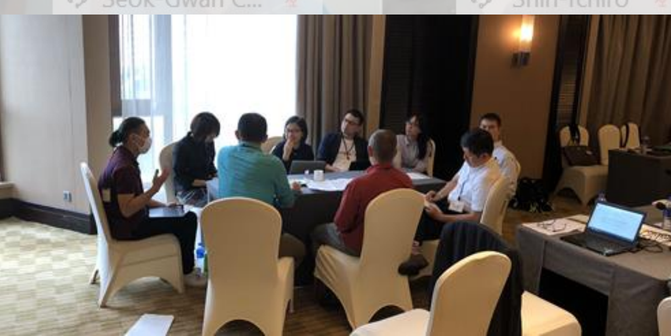
Resolution: 1 × 1 degree

Area: 35–50 ◦N and 140–170 ◦E

Time peiod: May – December (1994-2017)

Fisheries data by NPFC members





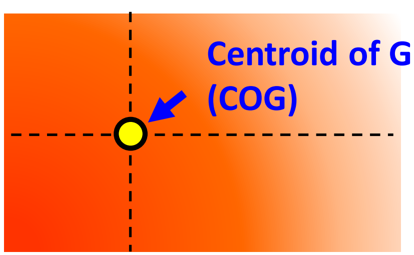
Counterfactual analysis

VAST model (Thorson, 2019)

$$\log(p_i) = \beta(t_i) + \omega(s_i) + \varepsilon(s_i, t_i) + \sum_{j=1}^{n_j} \gamma(j) X(s_i, t_i, j) + \sum_{k=1}^{n_k} \lambda(k) Q(i,k)$$

- $\beta(t_i)$: Temporal effects
- $\omega(s_i)$: Spatial effects
- $\varepsilon(s_i, t_i)$: Spatio-temporal effects (*Unexplained*)
- $X(s_i, t_i, j)$: SST; quadratic SST; chl-a; ~~SSH~~, SOI, ~~PDO~~
- $Q(i,k)$: Catchability covariate (i.e., fleet)

The most plausible (full) model



Reference location from the full model

V.S.

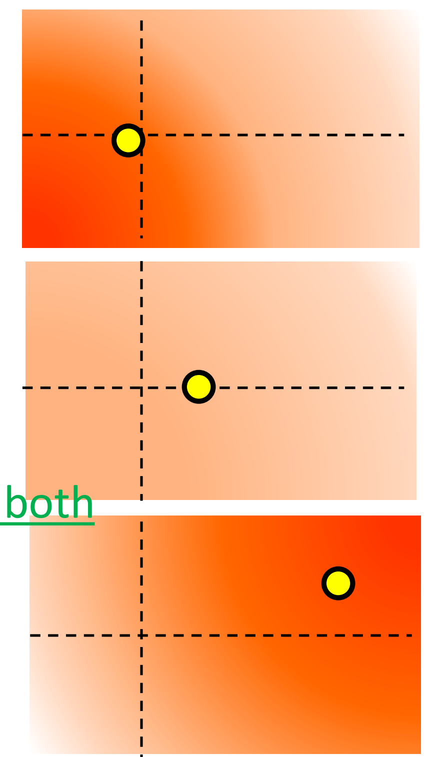
Counterfactual scenarios

Year +
Spatial variation + Unexplained variables

Local environmental variable(s)
(SST, SST^2, *chl-a*)

or both

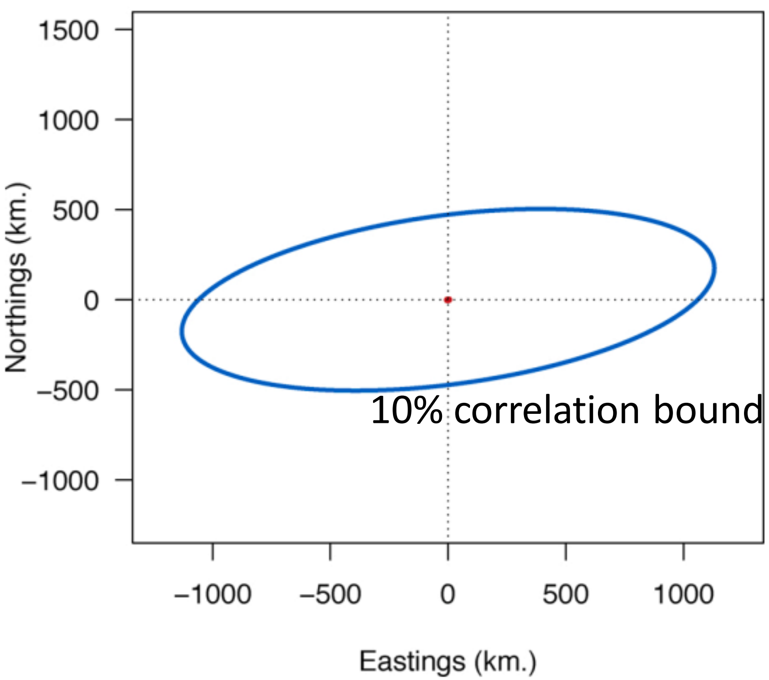
Regional environmental variable(s)
(SOI(*N*,*t*), SOI(*E*,*t*))



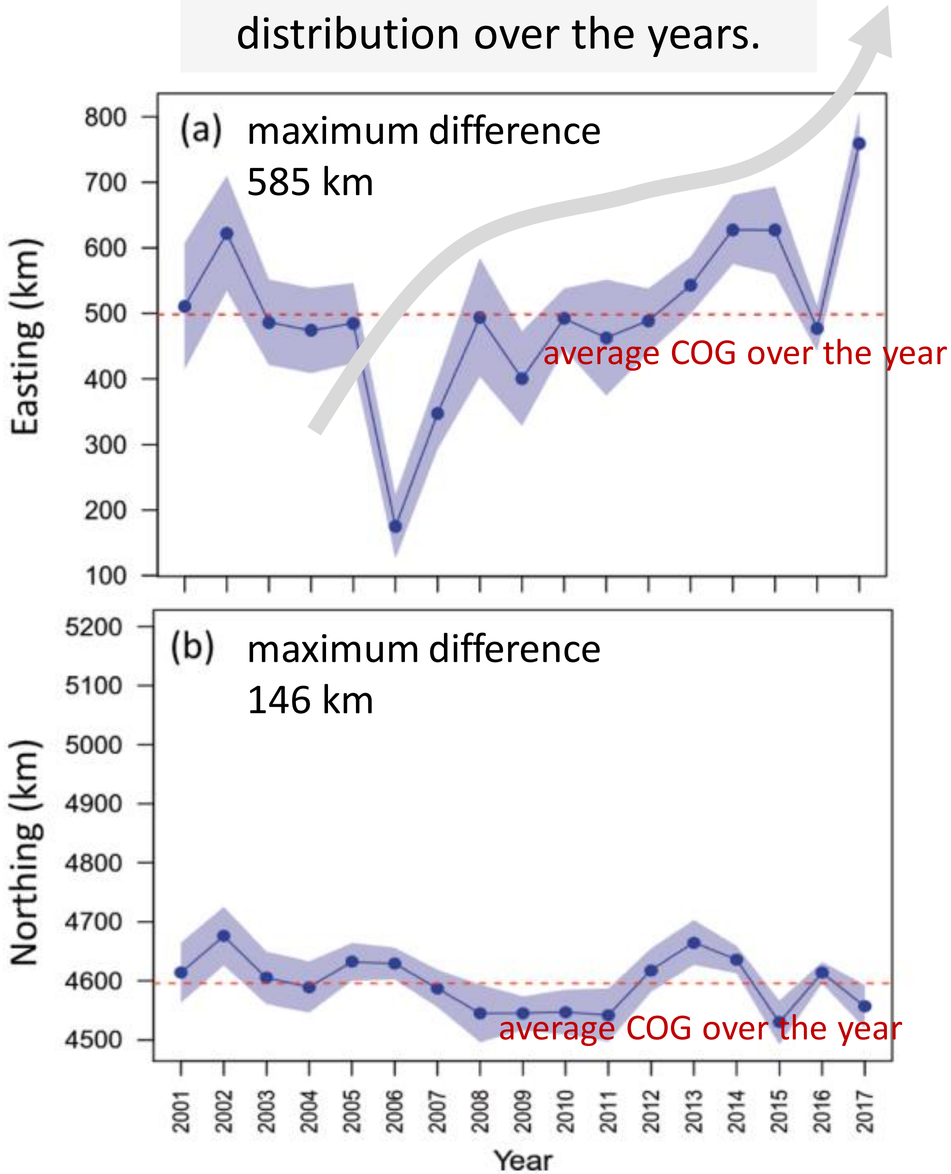
We specifically compare the *spatiotemporal distributions* and *time series of COGs*;

Distribution shifting of Pacific saury

Spatial correlation:
East-West > North-South



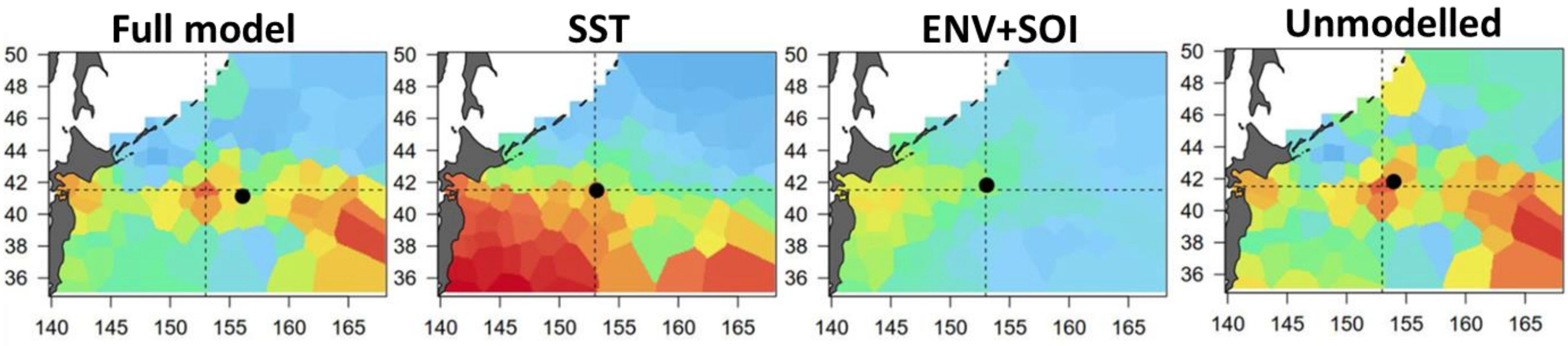
An apparent eastward shift in distribution over the years.



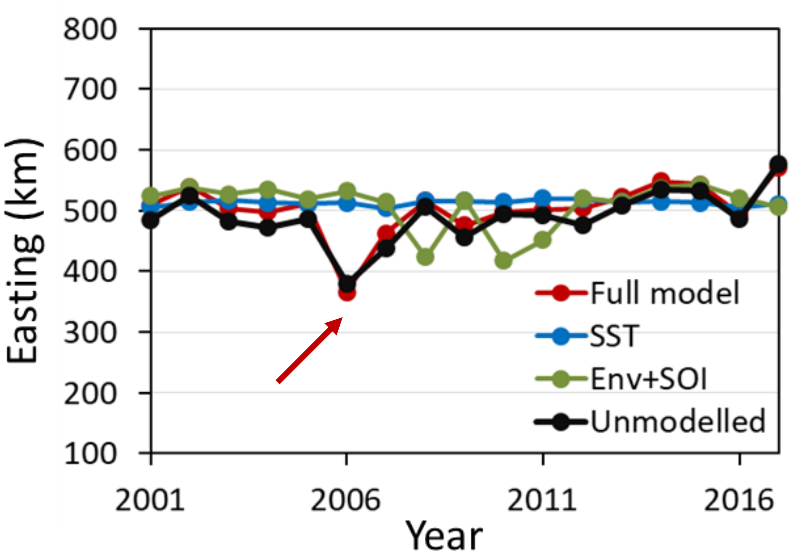
VAST model deviance explained: 69%

Environmental *v.s.* “unmodelled” variables

Example: 2017 **Both are less important** **Most important**



Time-series of COG



- SST, and any combination of local and regional environmental variables could not explain the distributional of saury;
- Instead, the change in spatial distribution is mostly attributed to the “unmodelled” spatiotemporal variables;

Summary

- We found that the centroid of gravity of Pacific saury had an apparent eastward shifting after 2013, and a further shift with a lower relative abundance in 2017;

- We also found that neither a single local or regional environmental variable nor any combination of them could simply explain the distributional shift of Pacific saury;
- Instead, the change in spatial distribution is mostly attributed to the "unmodelled" spatiotemporal variables;

- We emphasize that developing a quantitative understanding of the **underlying mechanisms** is a critical area for future work;

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Evaluating the spatiotemporal dynamics of Pacific saury in the Northwestern Pacific Ocean by using a geostatistical modelling approach

Jhen Hsu [a], Yi-Jay Chang [a,b,*], Toshihide Kitakado [c], Mikihiko Kai [d], Bai Li [e], Midori Hashimoto [f], Chih-hao Hsieh [a,b], Vladimir Kulik [g], Kyum Joon Park [h]

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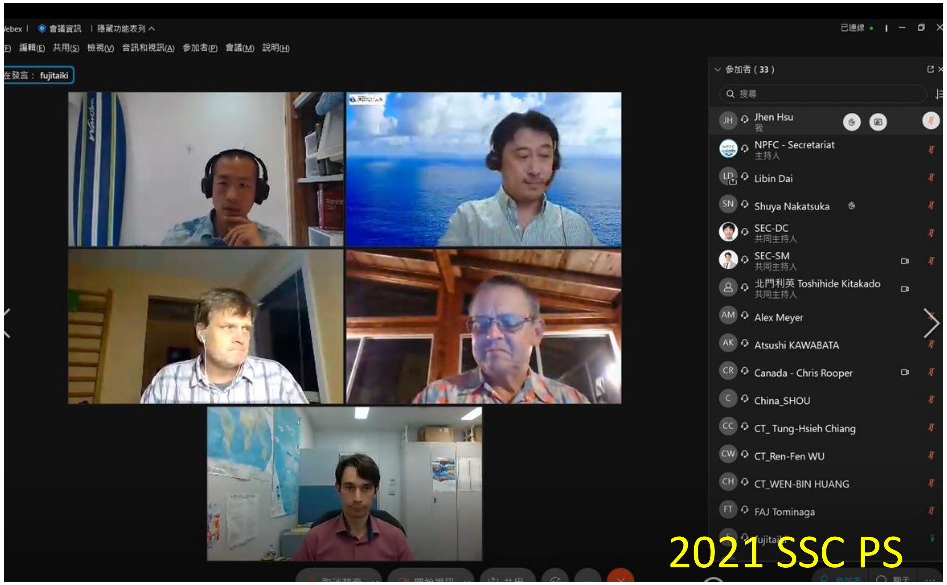
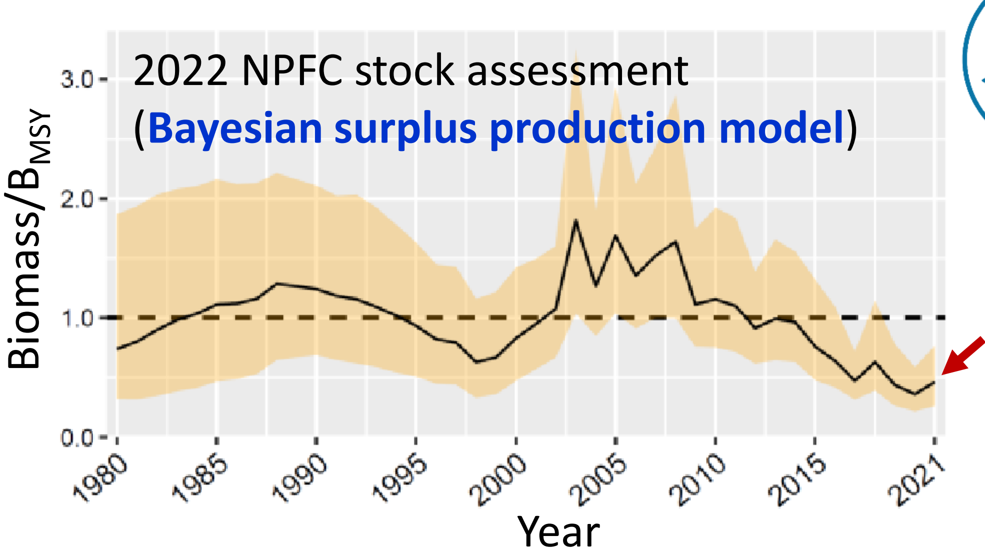
[h] National Institute of Fisheries Science, 216,Gijanghaean-ro, Gijang-eup, Busan, 46083, Republic of Korea

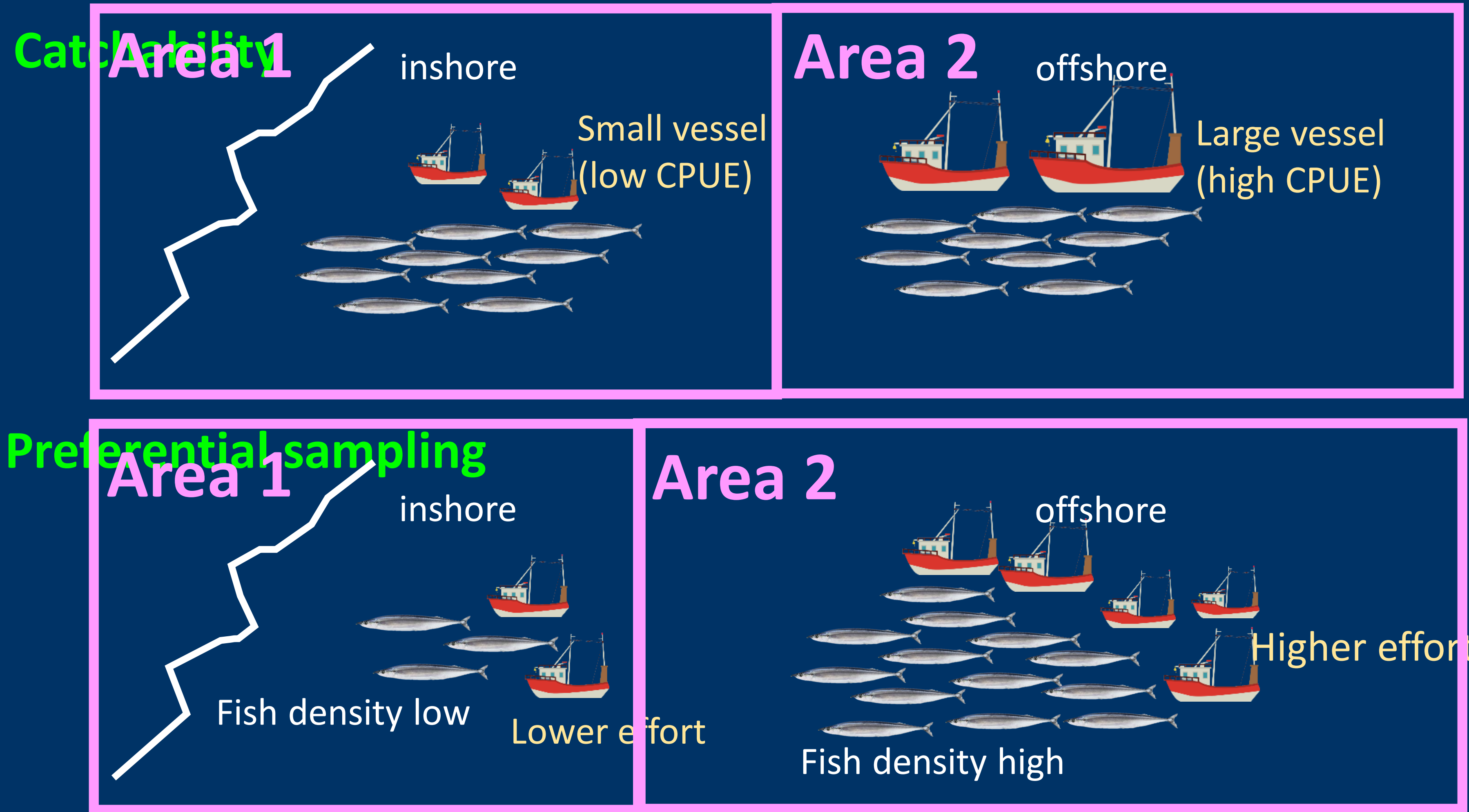
Current stock assessment result of Pacific saury





NPFC-2021-SSC PS08-Final Report

Influences on the fishery CPUE other than fish abundance



- "**Area stratification**" is a common approach to address the effect of spatial heterogeneity in the CPUE standardization;

The most common method for the CPUE standardization

- Statistical linear models have been developed to summarize the combined relationships of many factors;
- Commonly, the **spatial heterogeneity in fish density** is treated as the **area effect**;

$$CPUE = Intercept + Year + Vessel + Area + \ldots$$

???

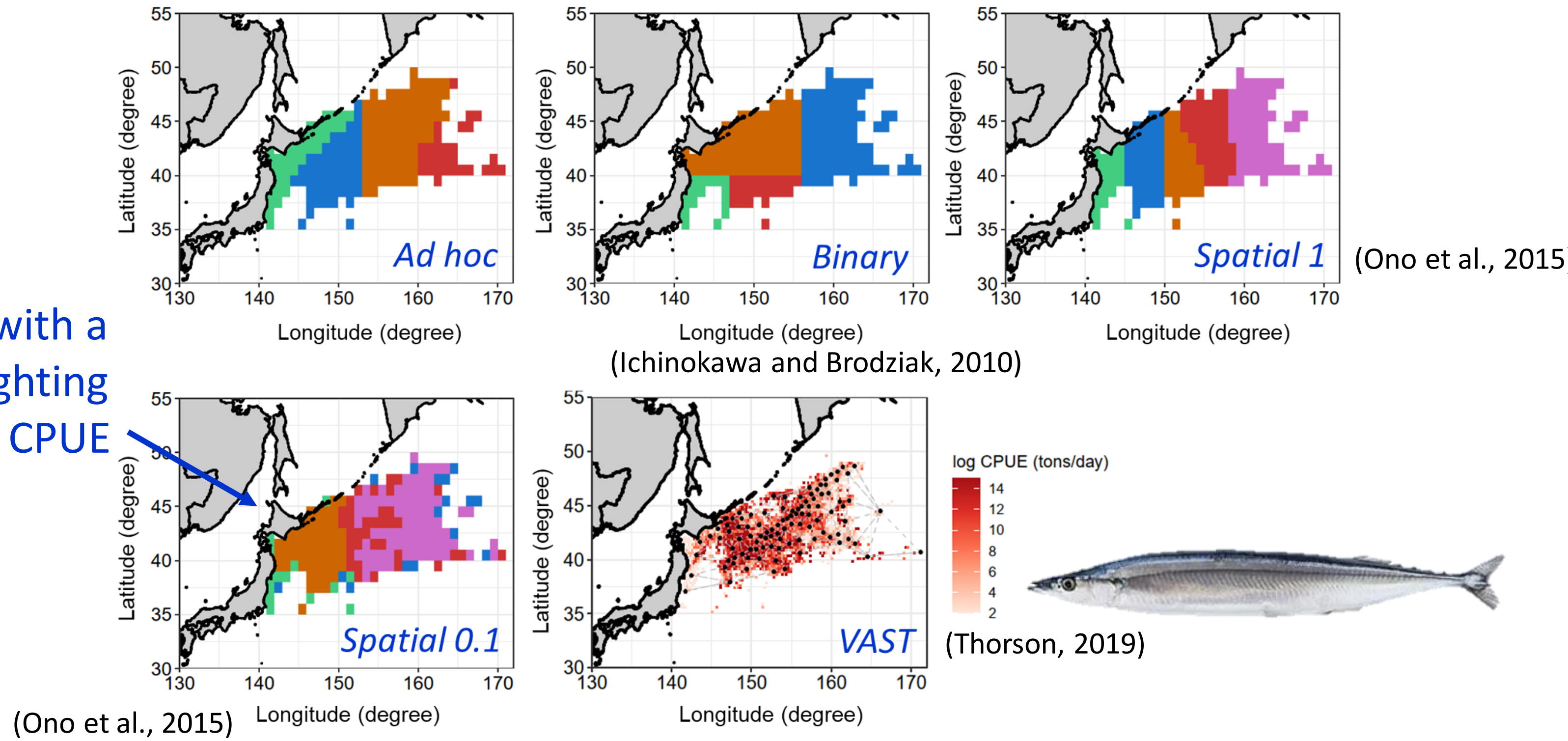
- Annual CPUE was standardized by fixing all covariates other than "year" and "area" to a vector of standardized (or expected) values;

The problem is…how to determine each area strata?

Issue for area stratification on standardized CPUE

- Although several approaches have been developed to create the area stratification in standardizing CPUE data;

Clustering with a **higher** weighting on average CPUE

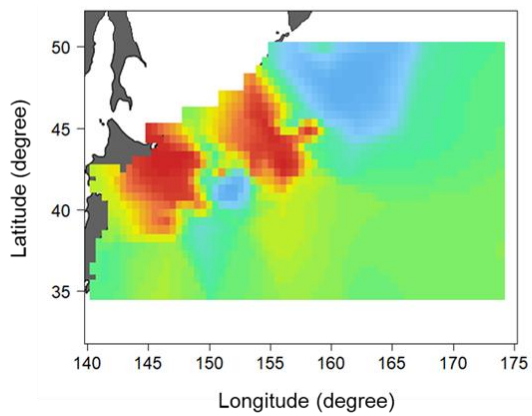


- However, there is no guarantee that the selected area stratification leads to the least biased index of abundance in the preferential sampling;

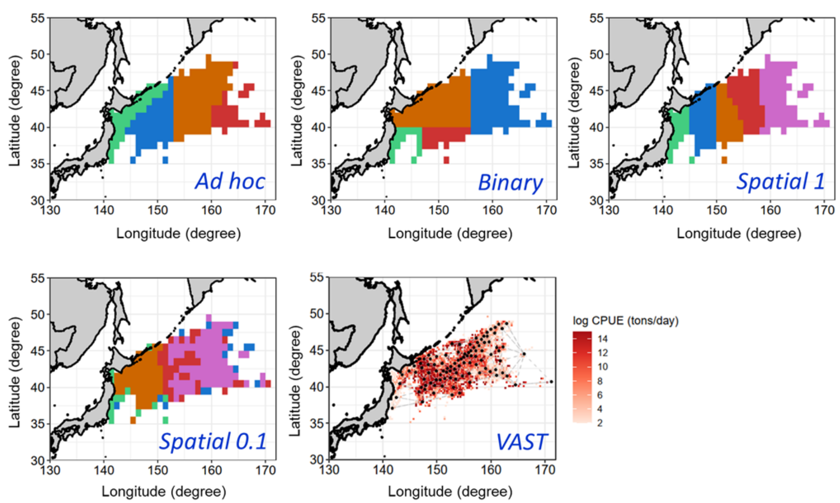
Simulation testing in CPUE standardization

- Simulation testing is a powerful tool because the "true" index is known, so that the standardization method can be tested in terms of how well it predicts the abundance trends;

Underlying "true" density distribution



Spatial treatments in GLMMs



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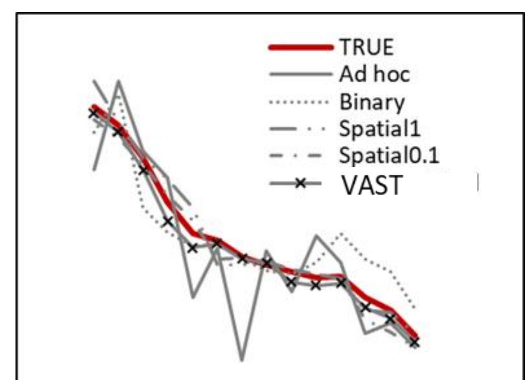
Performance evaluation



Objectives of this study

Using the real-world and simulated data of the Chinese Taipei stick-held dip net fishery in the Northwestern Pacific:

- What is the best spatial treatment in the CPUE standardization?
  - Ad hoc, Binary, Spatial 1, Spatial0.1, and VAST
- To evaluate the impacts of two spatial sampling patterns in CPUE standardization;
  - random v.s. preferential sampling of fishery data;

CPUE standardization model structures

Using GLMMs to evaluate several spatial treatments to standardize CPUE data:

- **Spatially stratified approaches:**

quadratic SST effect

random effect

$$\log(CPUE_i) = Year_i + Area_i + Year_i \times Area_i + SST_i + SST_i^2 + Vessel_i$$

random effect

Ad hoc, Binary, Spatial1, and Spatial0.1

- **Spatio-temporal approach (VAST):**

Year effects

random effect

vessel effects (random effect)

$$\log(CPUE_i) = \beta(t_i) + \omega(s_i) + \varepsilon(s_i, t_i) + \delta(v_i) + \sum_{j=1}^{n_j} \gamma(j) X(s_i, t_i, j)$$

quadratic SST effect

Spatial effects

Spatio-temporal effects

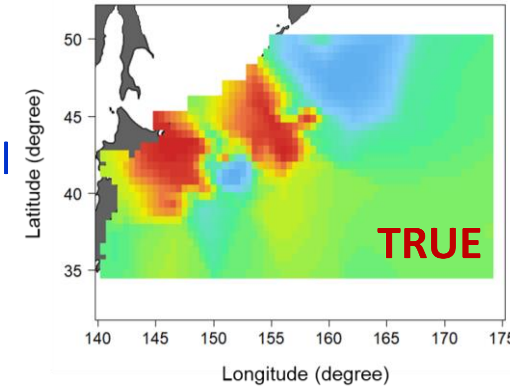
Simulation testing in CPUE standardizations

Simulated "TRUE" base biomass for each grid (*s*) and year (*t*)

$$B(s,t) = \beta(t) + \omega(s) + \varepsilon(s,t)$$

Year effects ↙ Spatial effects ↓ Spatio-temporal effects ↘

$$\hat{d}(s,t) = B(s,t) \times e^{\eta} \qquad \eta \sim Normal(0, 0.2)$$



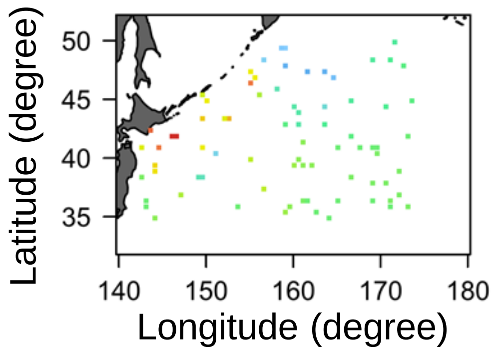
Simulated sampling scenarios

the magnitude of preferential sampling

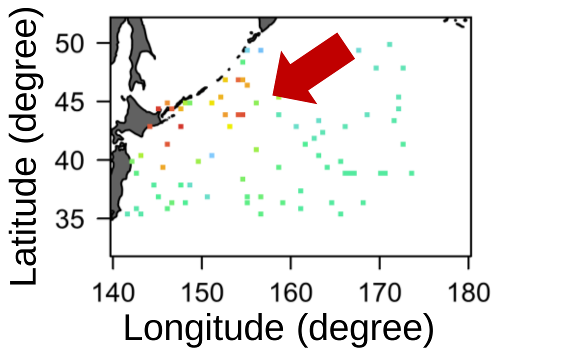
$$P_{pref,s} = \frac{(B_s)^{\varphi}}{\sum_{n_s=1}^{n_s} (B_s)^{\varphi}}$$

Ducharme-Barth et al. (2022)

Random sampling (φ = 0)



Preferential sampling (φ = 8)



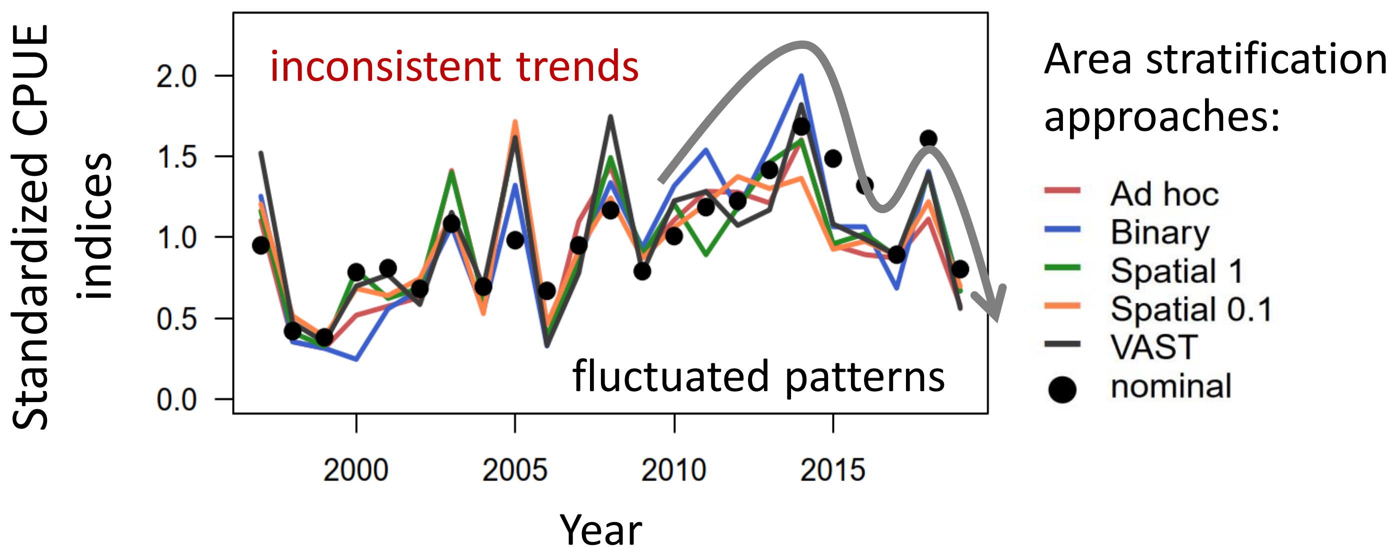
CPUE standardizations

Applying Ad hoc, Binary, Spatial1, Spatial0.1 GLMMs, and VAST

Model performances

Comparing with the "true" index by measuring root mean square error (RMSE) and bias metrics (near one is the best);

Estimated abundance indices from the real-world data



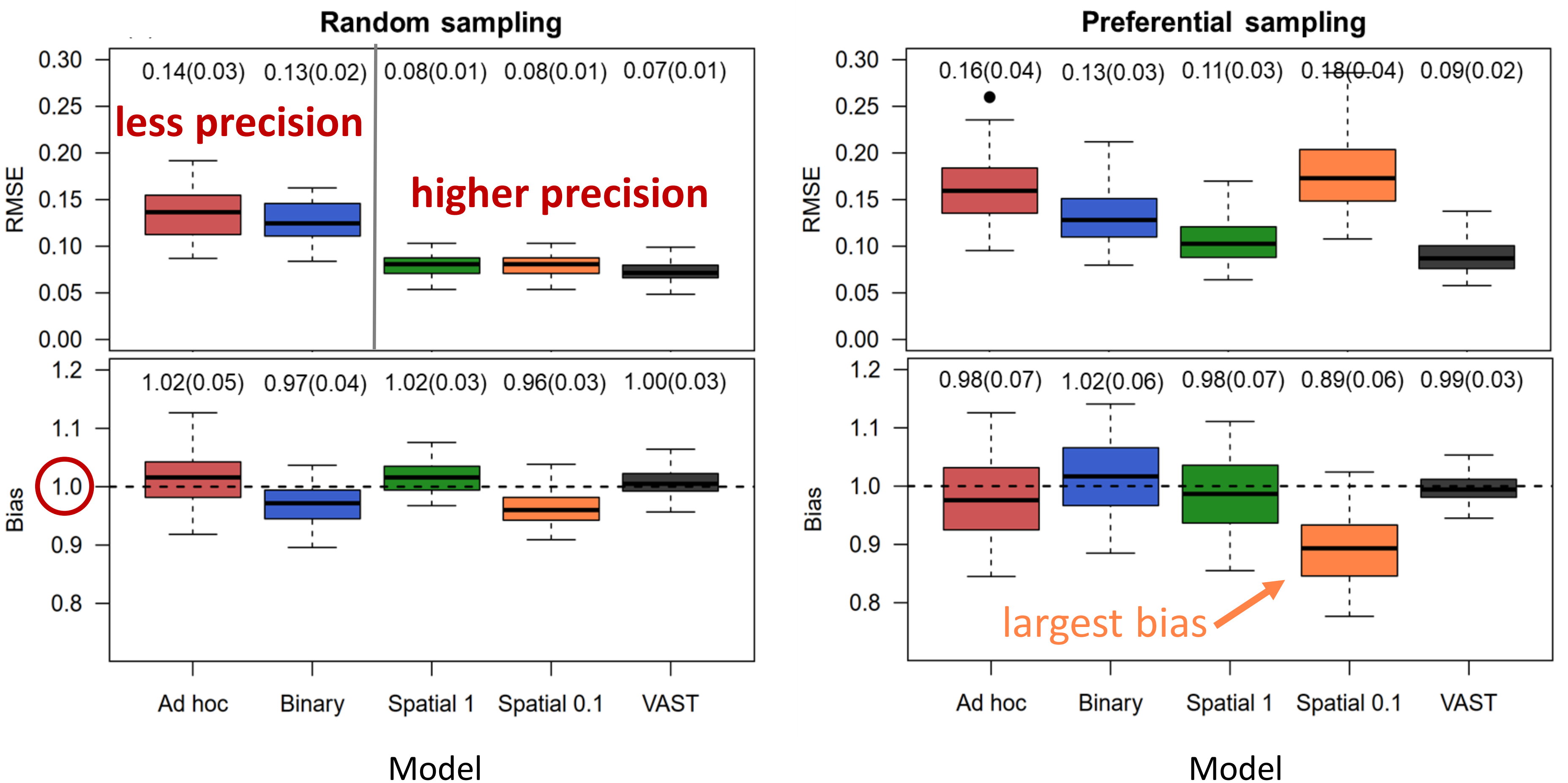
Statistical performance (e.g., cross validation)

Area stratification approaches

	Ad hoc	Binary	Spatial1	Spatial0.1	VAST
R^2	0.25	0.32	0.36	0.39	0.65
Cor	0.43	0.48	0.52	0.53	0.54

More green is better

Results of model performances among spatial treatments under two sampling scenarios



Summary & fishery implications

- Ad hoc manner or constrained to rectangular grids may misinterpret the fish density distribution;
- VAST could better explain the fish density than other GLMMs;
  - Fish density varies continuously across space;
  - The patterns in density distribution over time are described by unmodelled spatiotemporal variable;
- Spatial 0.1 may cause a substantial bias in index estimation if the spatiotemporal distribution of fisher is non-random;
- Spatial 1 is an alternative for defining spatial strata if VAST is not possible;
- Although this study was focused on Pacific saury, the methodology should be broadly applicable to other fisheries for which similar data are available;

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Evaluation of the influence of spatial treatments on catch-per-unit-effort standardization: A fishery application and simulation study of Pacific saury in the Northwestern Pacific Ocean

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Area stratification
Pacific saury

ABSTRACT

Fishery-dependent catch-per-unit-effort (CPUE) data often exhibit spatial heterogeneity over space and time, which means that the spatial treatment in statistical models used to standardize CPUE is critically important. We evaluated several spatial treatments to standardize CPUE data using Generalized Linear Mixed Models (GLMMs). Results include a real-world application and a simulation based on the Taiwanese stick-held dip net fishery for Pacific saury in the Northwestern Pacific Ocean. We compared the performance of three spatially stratified approaches in GLMMs, (i) Ad hoc; (ii) Binary (binary recursive area partitioning based on model selection criteria); and (iii) Spatial clustering (partitioning of grids into discrete strata based on the spatial proximity and average CPUE in each grid), to a spatio-temporal GLMM (VAST). An influence analysis was constructed to quantify discrepancies between unstandardized and standardized indices that assisted in identifying the annual influence of explanatory variables in GLMMs. We developed a simulation to corroborate the results from the case

Available code:
https://github.com/jhenhsuNTU/spatial.treatment.influ.analysis.manuscript

Conclusions

- The change in the spatial distribution of Pacific saury is mostly attributed to the "**unmodelled**" spatiotemporal variables;
- We caution that before projecting fish distribution resulting from climate change/environmental phenomena, analysts should first determine whether the hypothesized driving variables account for a meaningful proportion of variability in the historical distribution data;
- Simulation results indicate that "**unmodelled**" spatiotemporal variables could provide a more precise treatment to address the fish density;
  - For example: nonstationary SST effect (monthly varying) on fish density; biological interaction; complicated oceanographic conditions; preferential sampling;

Acknowledgements

PICES meeting
NPFC Scientific Committee
NPFC Small Scientific Committee on Pacific Saury
Dr. Janelle Curtis (NPFC SC Chair)
Dr. Chris Rooper
Dr. Alex Zavolokin
Dr. Yong Chen

Thank you!
Questions?

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