S-08 14:30-14:45

Projecting the poleward habitat expansion of whale sharks (*Rhincodon typus*) in the West Pacific and the East Indian Ocean in response to climate change

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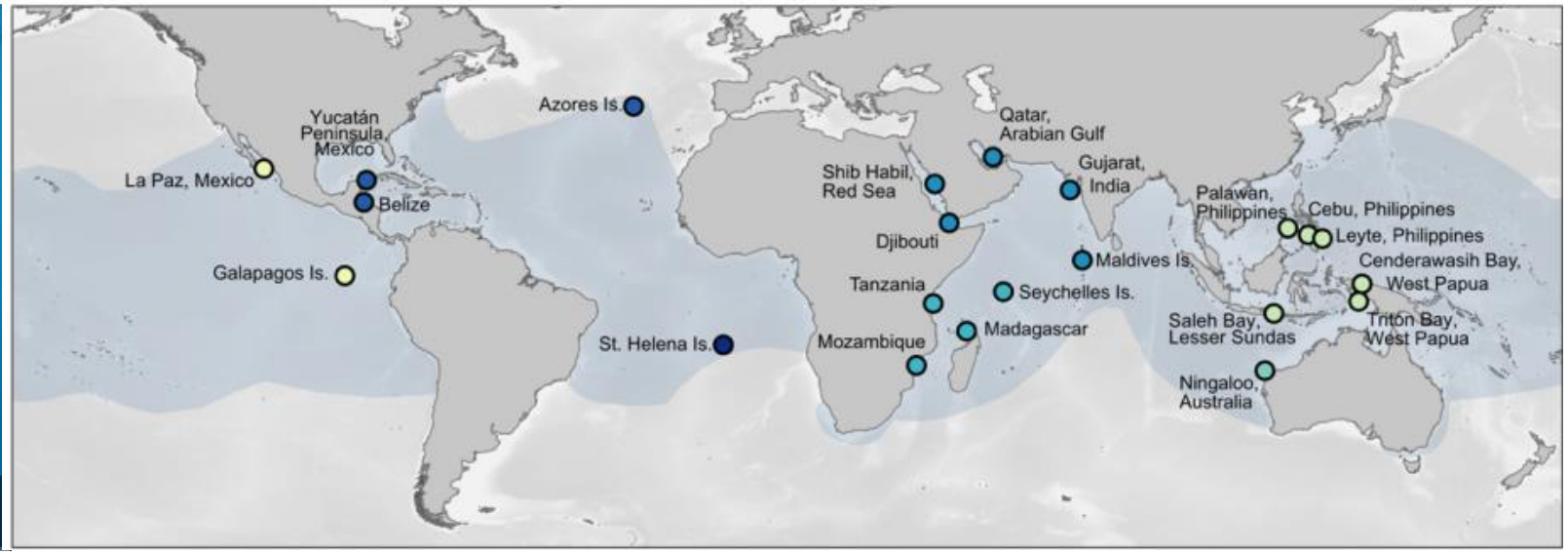
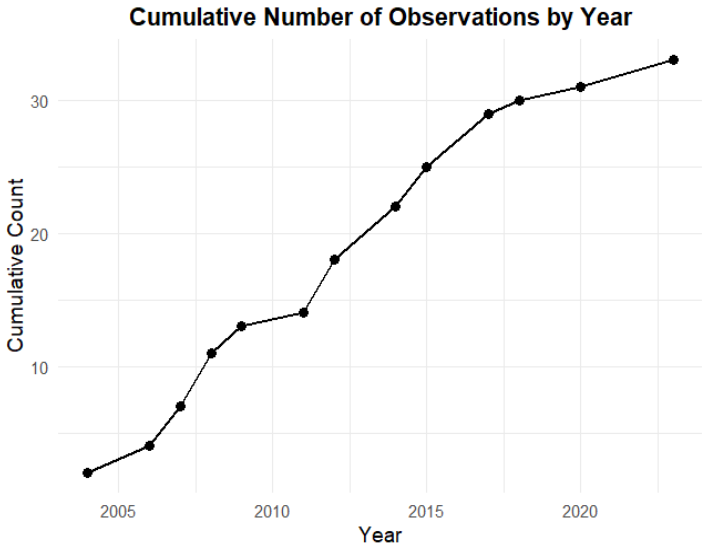
Rhincodon typus

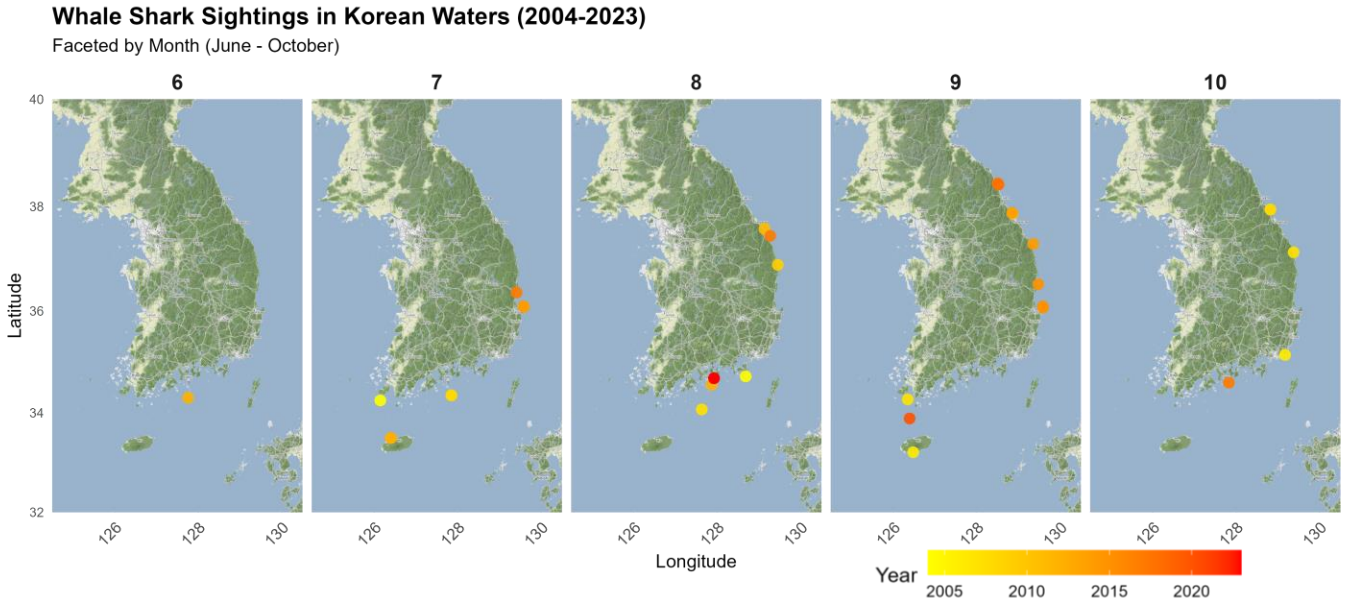
- Conservation status: **IUCN Endangered , CITES Appendix Ⅱ**
- Geographic range: Worldwide, Highly Migratory
- Core distribution: between approximately 30˚N and 30˚S
- The northernmost records : 44˚N in Canada (Turnbull and Randell 2006) and Japan (Tomita et al. 2014)
- Circumtropical distribution: largely constrained by the 21–22°C (Duffy 2002, Afonso et al. 2014, Tomita et al. 2014)



(Womersley et al. 2022)

Rhincodon typus in South Korea

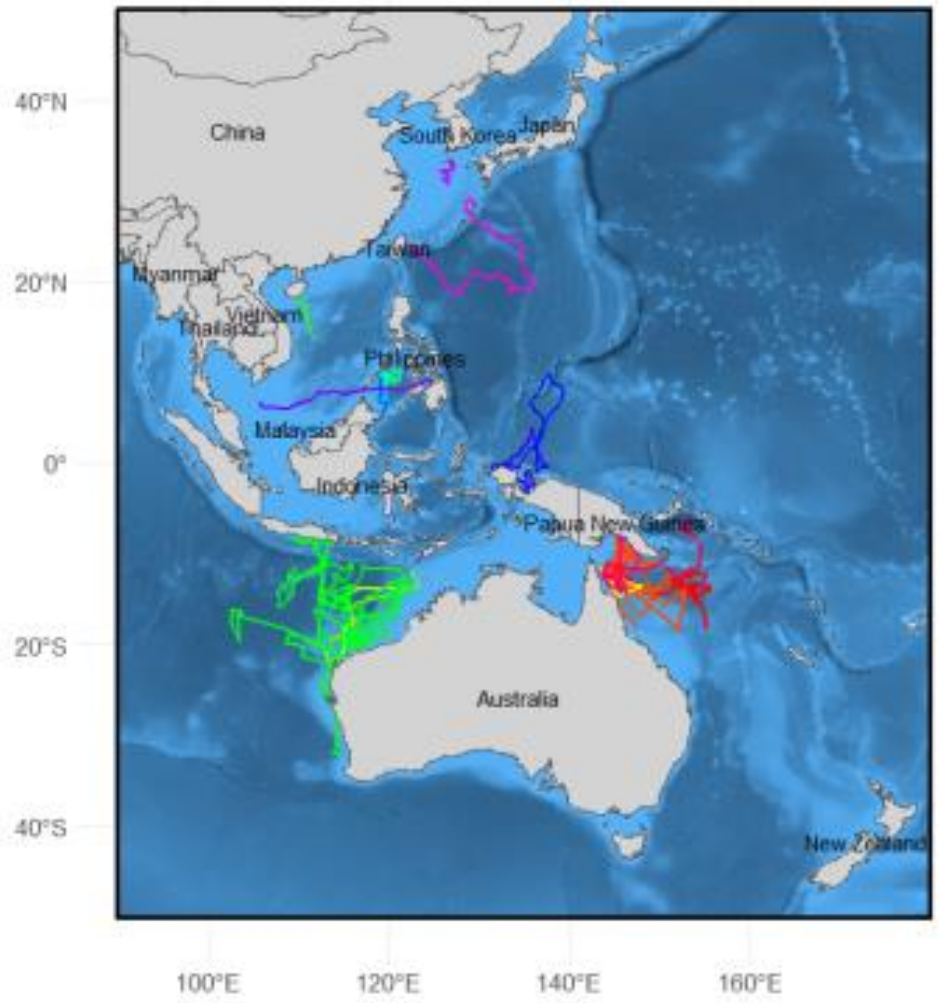




- Total 33 observations over the last 20 years and only appear from **June to October**
- Average length**: 5.2 m** (mostly 4-5m Juveniles)
- Repeat spatial patterns observed (e.g., pairs, consecutive days, weeks, years in same locations)

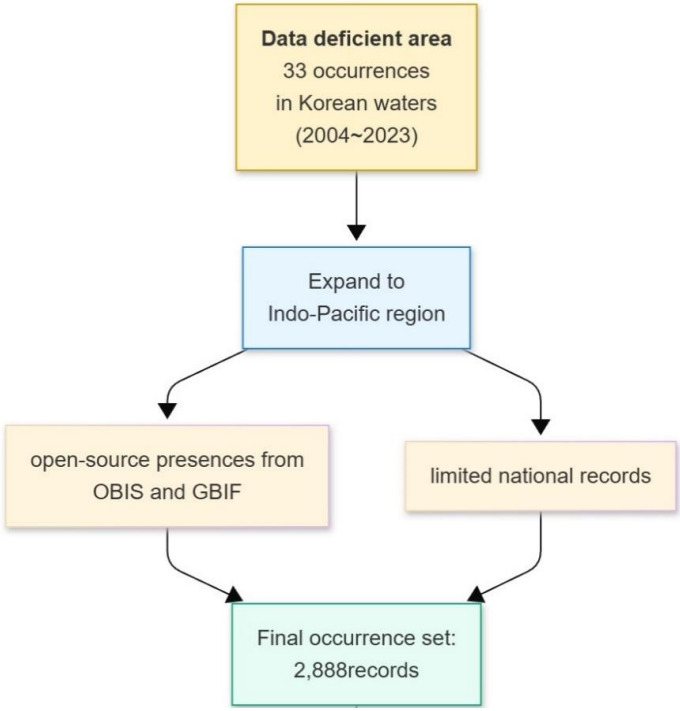
Our primary objective is to **develop a robust SDM framework for a data-deficient 'frontier zone.**

1. *Are recent sightings random vagrancy or seasonal fringe habitat?*
2. *How do environmental drivers differ between this 'range edge' (Korea) and established 'aggregation sites' (Philippines, Ningaloo reef)?*
3. *How will this habitat change in the future under different climate scenarios?*



Study area configuration

- Genetics define one 'Indo-Pacific' unit, but movement studies confirm the 'Asia-West Pacific' as a key functional unit (IUCN, 2025).
- **Enlarge** the **spatial domain** from the Korean waters to the Indo-Pacific in order to add more observation data.



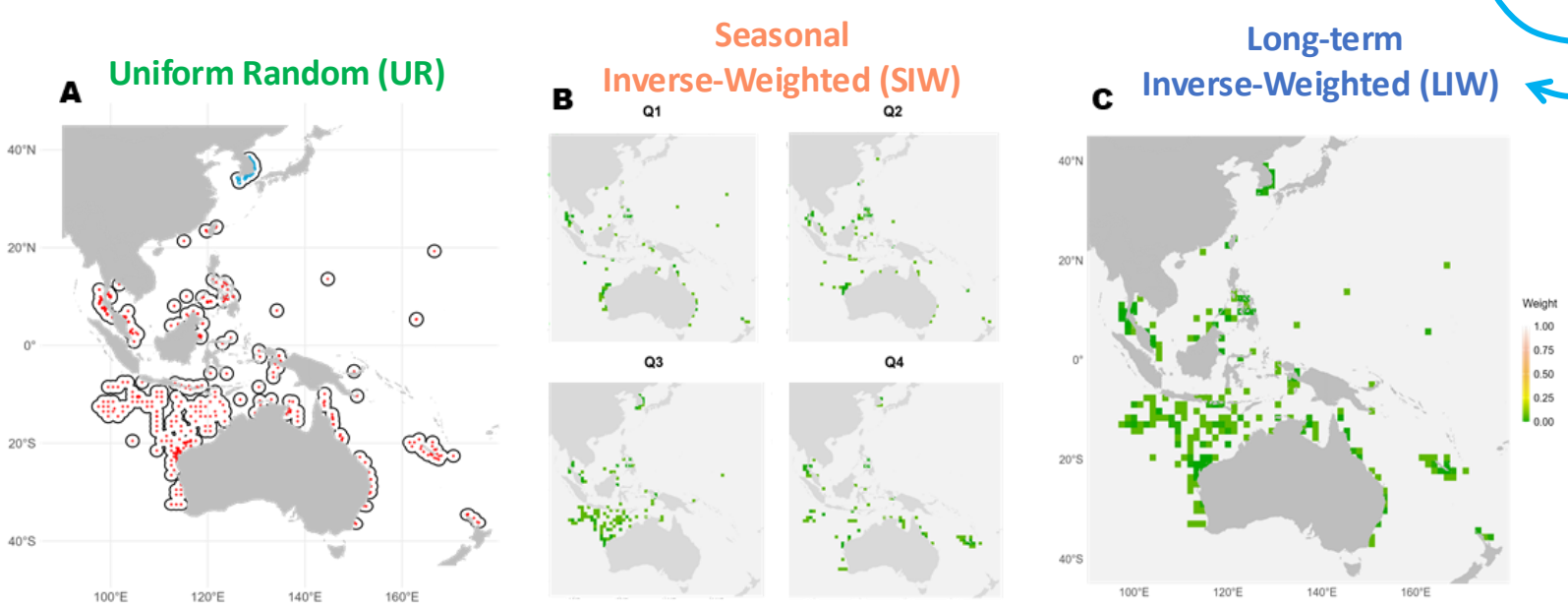
Observation data

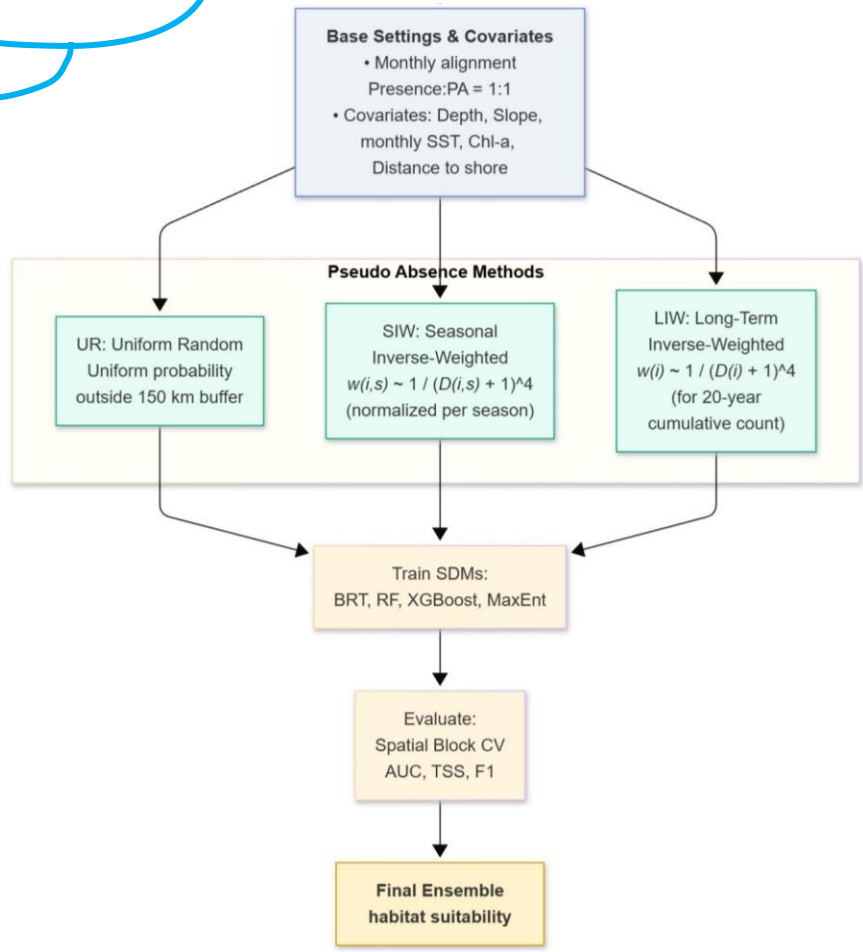
- OBIS / GBIF data(R package)
- Temporal range: **2004-2023**
- Spatial extent: West Pacific and East Indian Ocean
- **2855 observation records**(Delete missing Institution code, duplicate data on the same date/location)

Environmental data

		Contemporary			Future			
Variable	**Units**	**Temporal period**	**Resolution**	**Source**	**Temporal period**	**ESM model**	**Resolution (lon, lat)**	**Country**
Chlorophyll-a (Chl-a)	mg/m^3	2004–2023 (monthly)	4 km	Satellite remote sensing (MODISA)	2050s, 2070s, 2090s	ACCESS-ESM1-5	360, 300	Australia
						CanESM5	360, 291	Canada
						GFDL-ESM4	360, 180	USA
Sea surface temperature (SST)	°C	2004–2023 (monthly)	4 km	Satellite remote sensing (MODISA)		NorESM2-MM	360, 385	Norway
						KIOST-ESM	360, 200	Korea
Water depth	m	-	0.00417°	Bathymetric data (GEBCO)	-	-	-	
Distance from shore	m	-	4 km	Calculated from coastline data	-	-	-	
Slope	%	-	0.05°	Bathymetric data (Bio-oracle)	-	-	-	

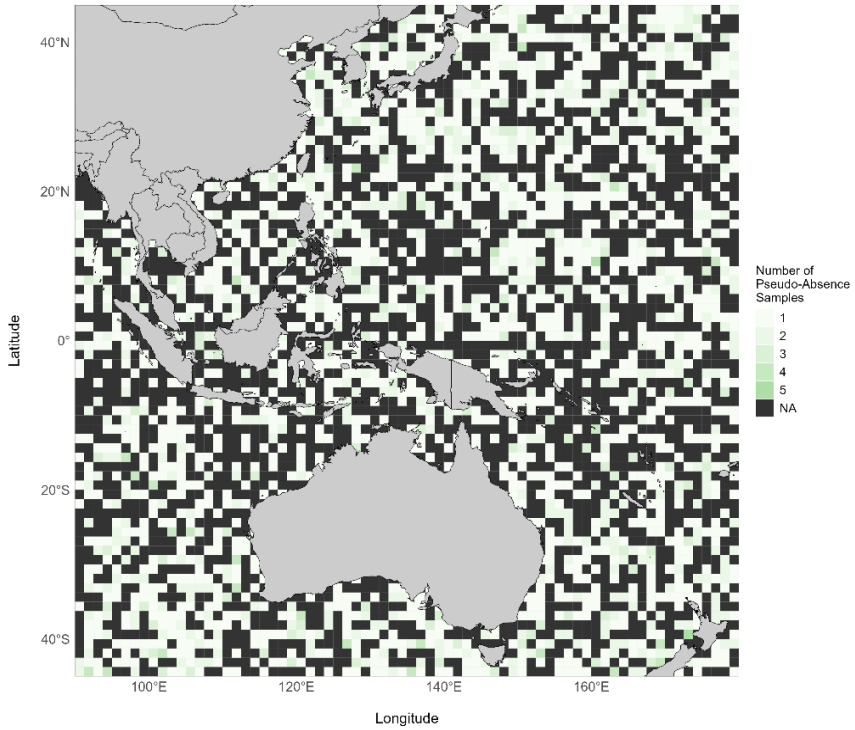
$$w_{i,} = \frac{1}{(D_i + \varepsilon)^{\gamma}}$$





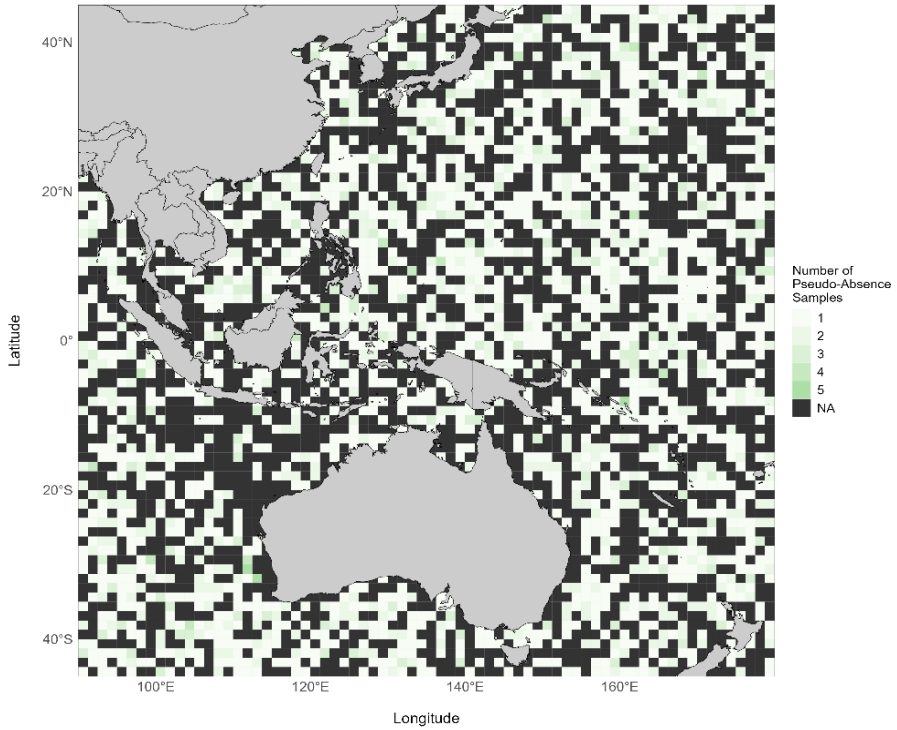
- Tested 3 Pseudo-Absence methods to find the most realistic 'absence' data
- Give **high weight to areas with zero observations** over 20 years
- MaxEnt, XGBoost, BRT, Random Forest and Spatial Block CV

Uniform Random (UR)



vs

Long-term Inverse-Weighted (LIW)



- UR (left): Scatters pseudo-absence samples randomly across all areas
- LIW (right): Protects core habitats (dark grey) by sampling only from long-term unobserved locations

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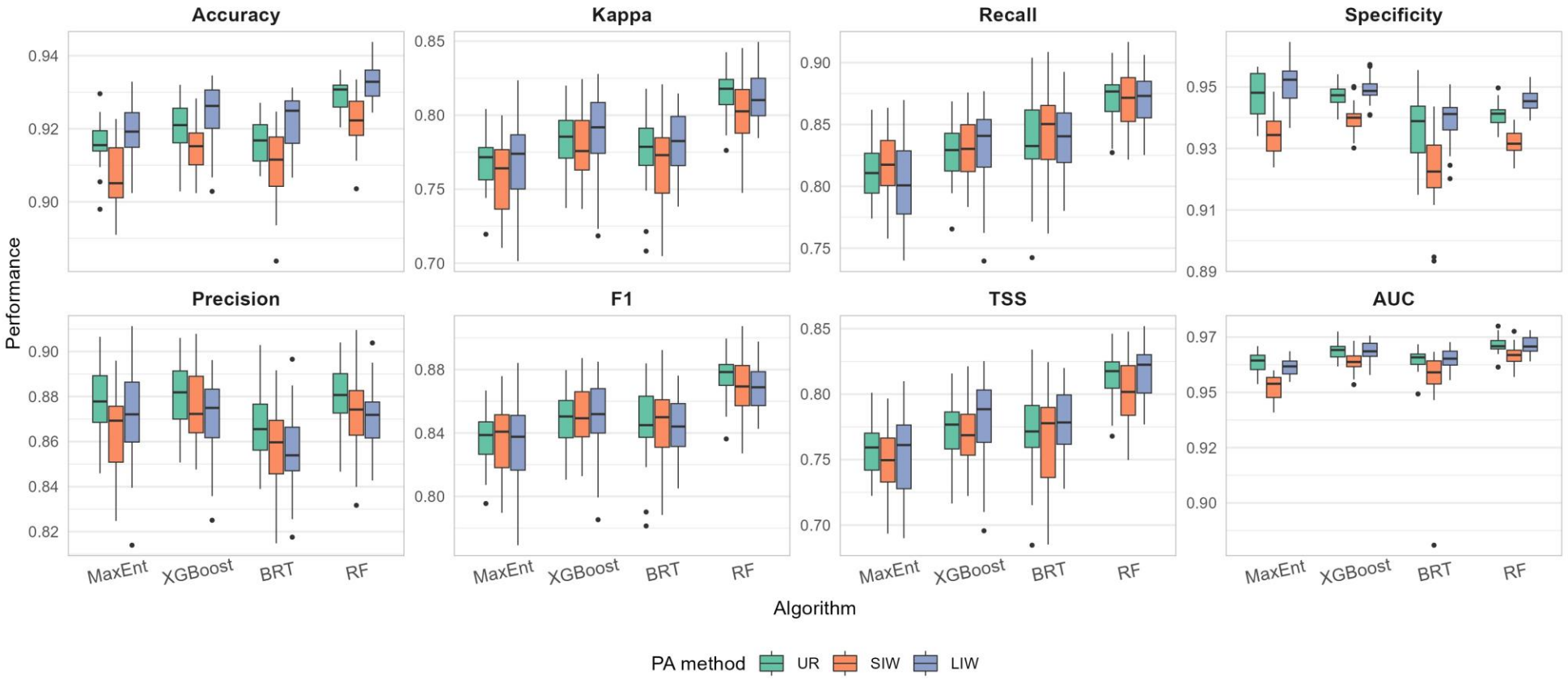
Comparison of model performance metrics



- The **LIW** pseudo-absence method consistently yielded the best model performance across key metrics (TSS, F1, AUC) compared to UR and SIW

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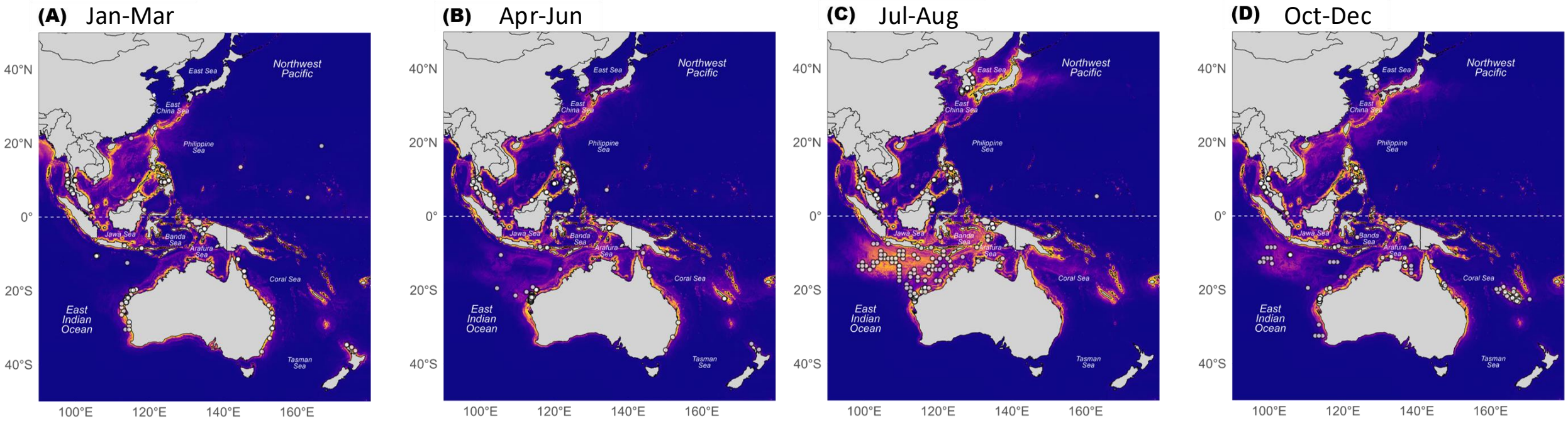
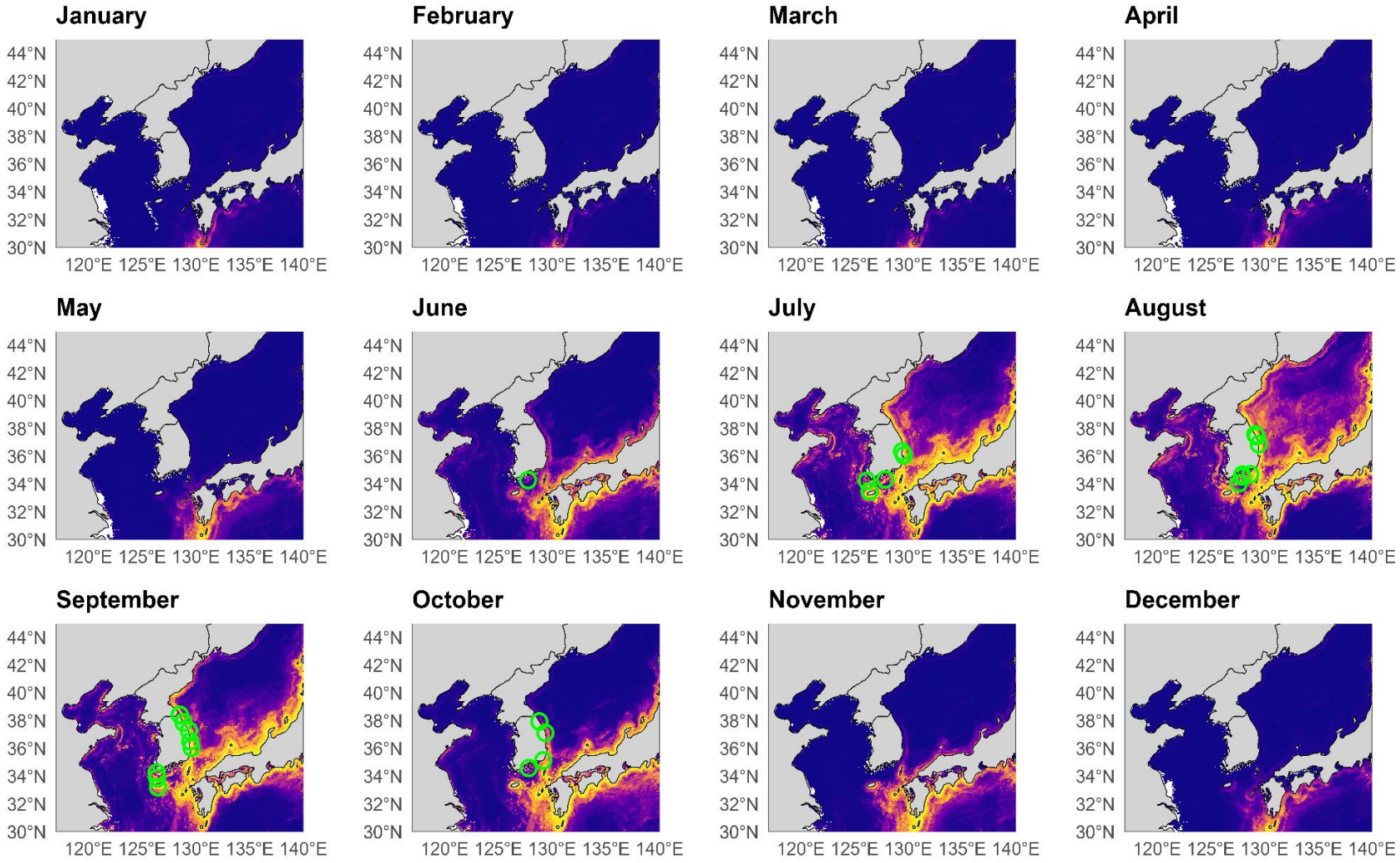
Final Hindcast Prediction based on LIW



- Our model successfully captures the large-scale seasonal habitat shift
- Our model's predictions (the yellow areas) match the real sightings (the white dots) extremely well
- The model also accurately predicts the seasonal expansion outside the core range (Korean waters)



Monthly average predicted habitat suitability for whale sharks around the Korean Peninsula from 2004 to 2023.

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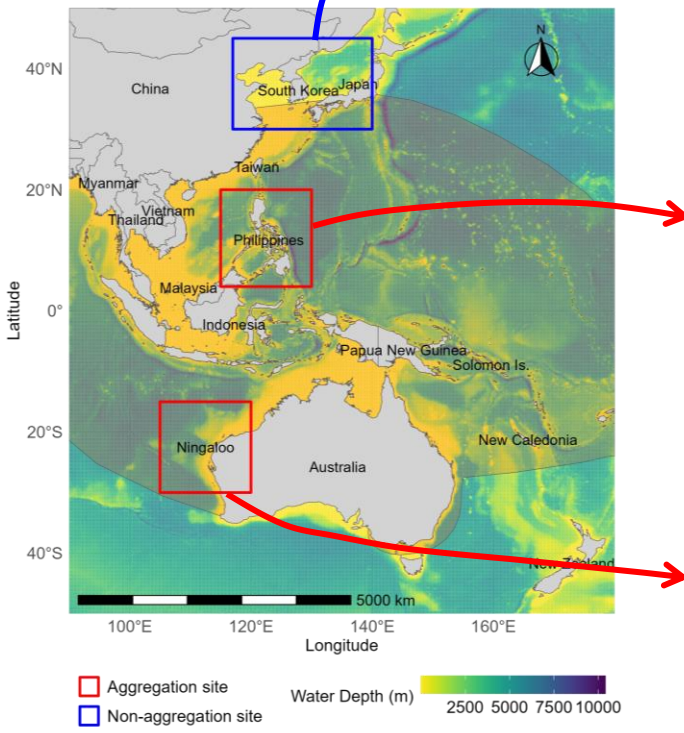
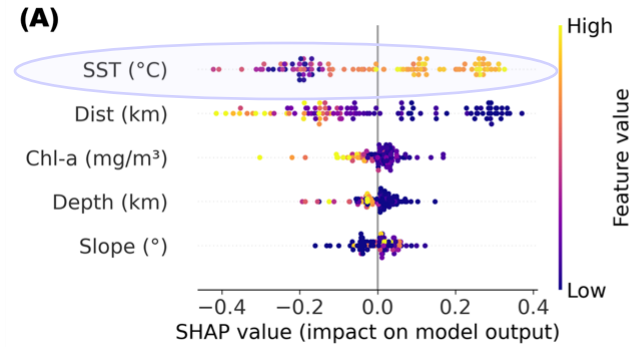
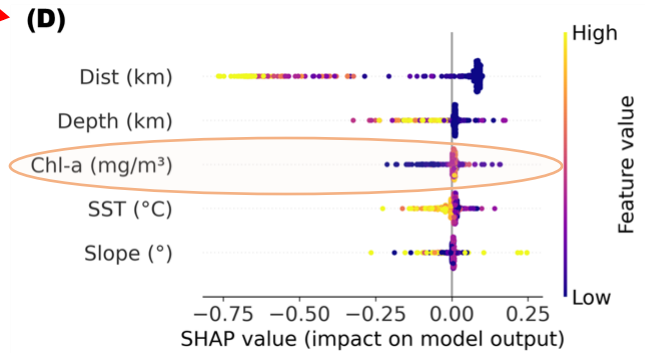
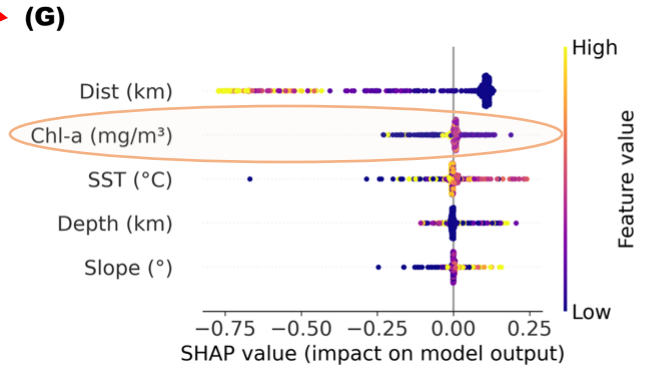
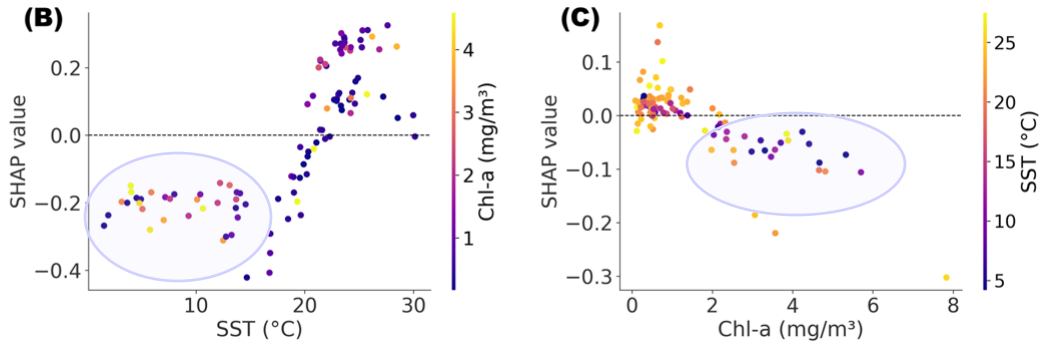
SHAP regional driver analysis

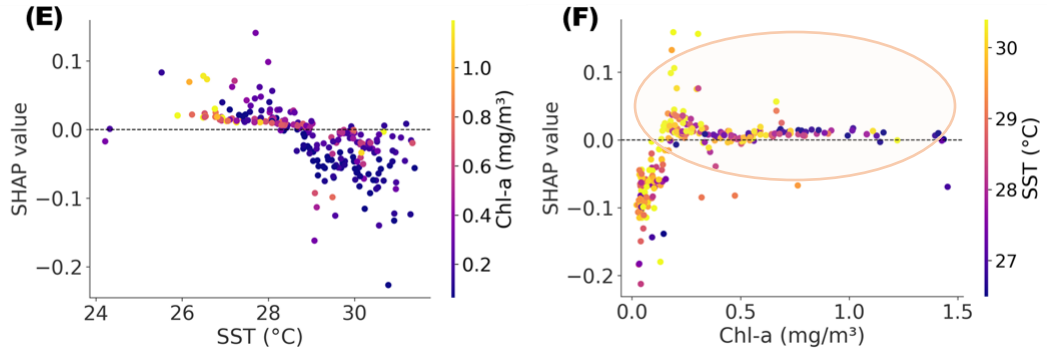


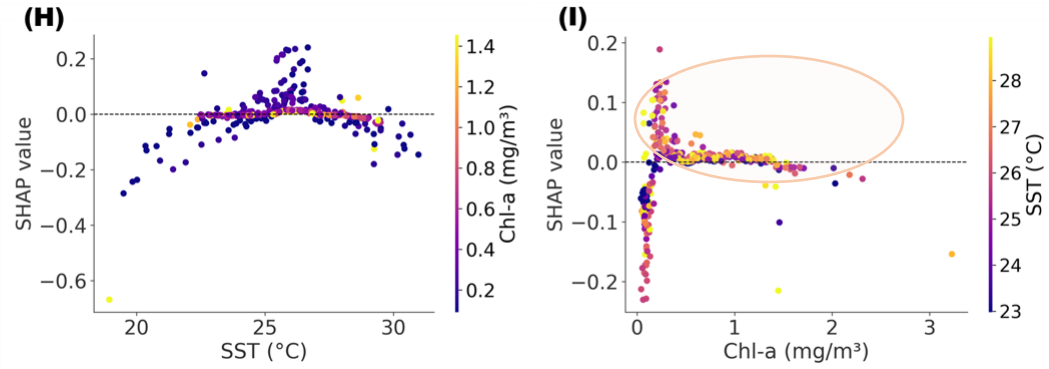












Positive SHAP (+): Predicts 'Suitable'

Negative SHAP (-): Predicts 'Unsuitable

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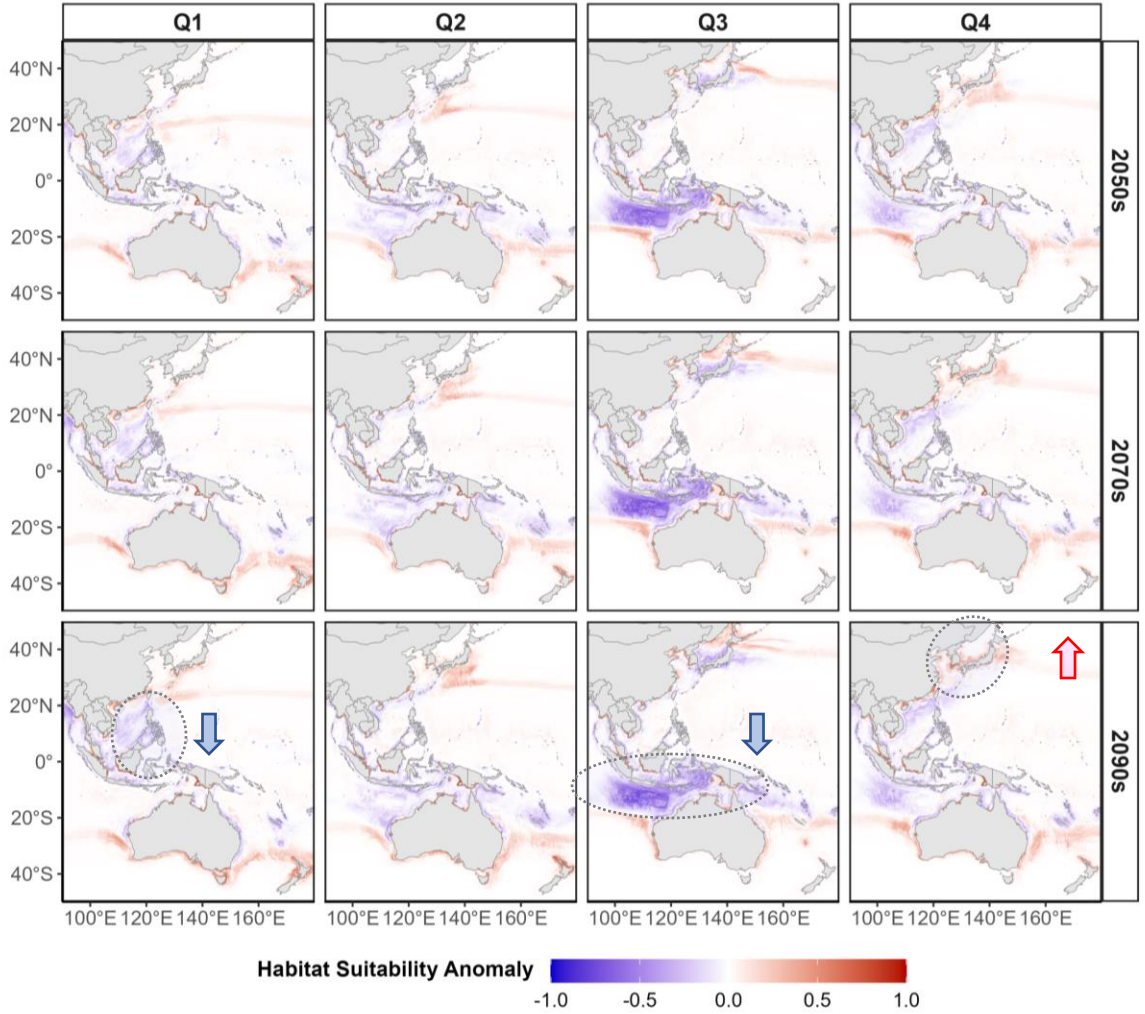
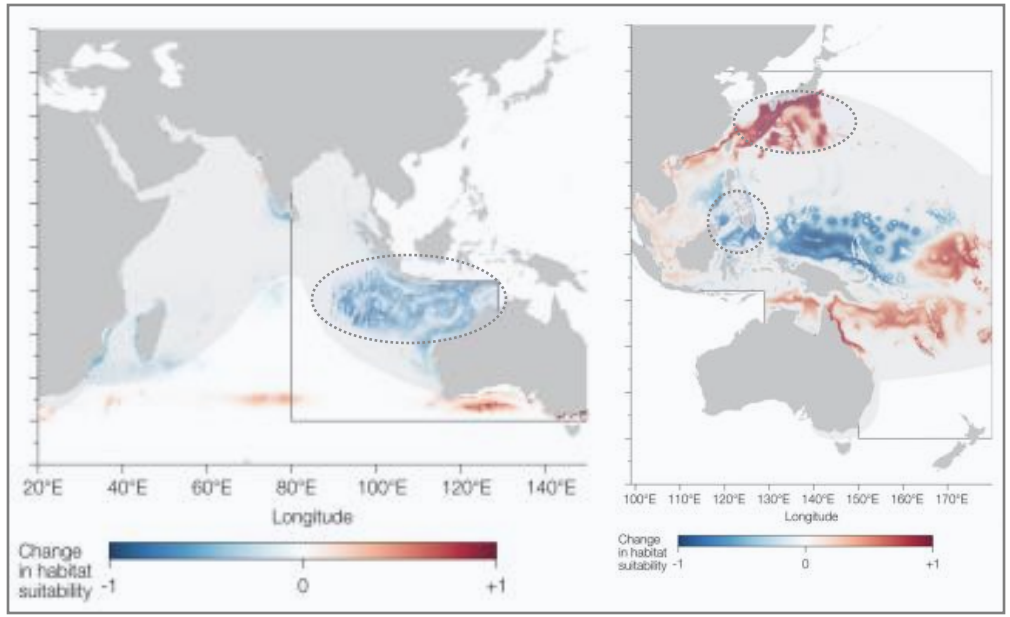
Future Projections Align : Poleward Habitat Edge Expansion



Our Model: SSP585 Anomaly



Womersley et al. (2024)

- **Similarities**: Ningaloo reef, Philippines ↓, NW pacific ↑
- **Difference**: The habitat expansion is Happening *Now*

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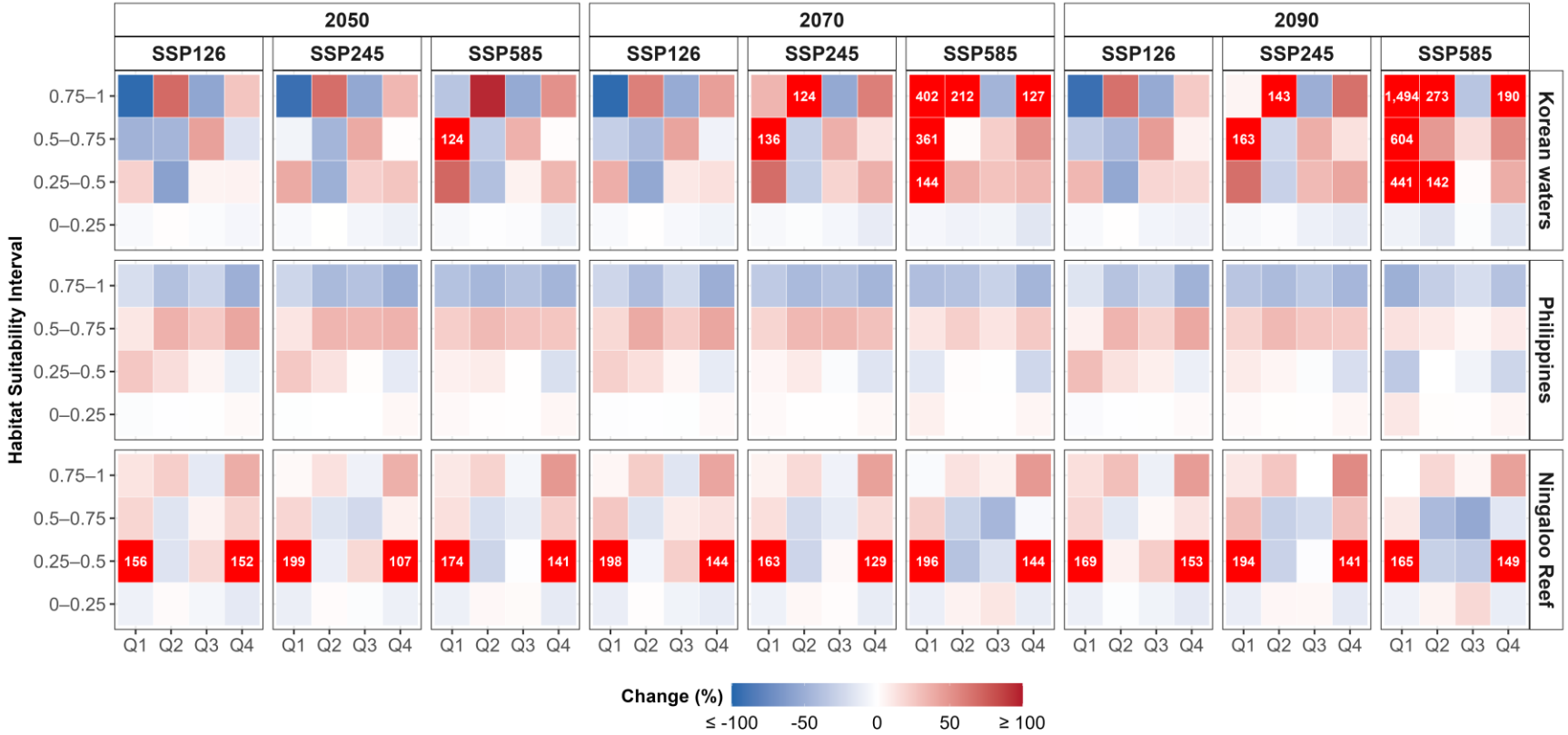
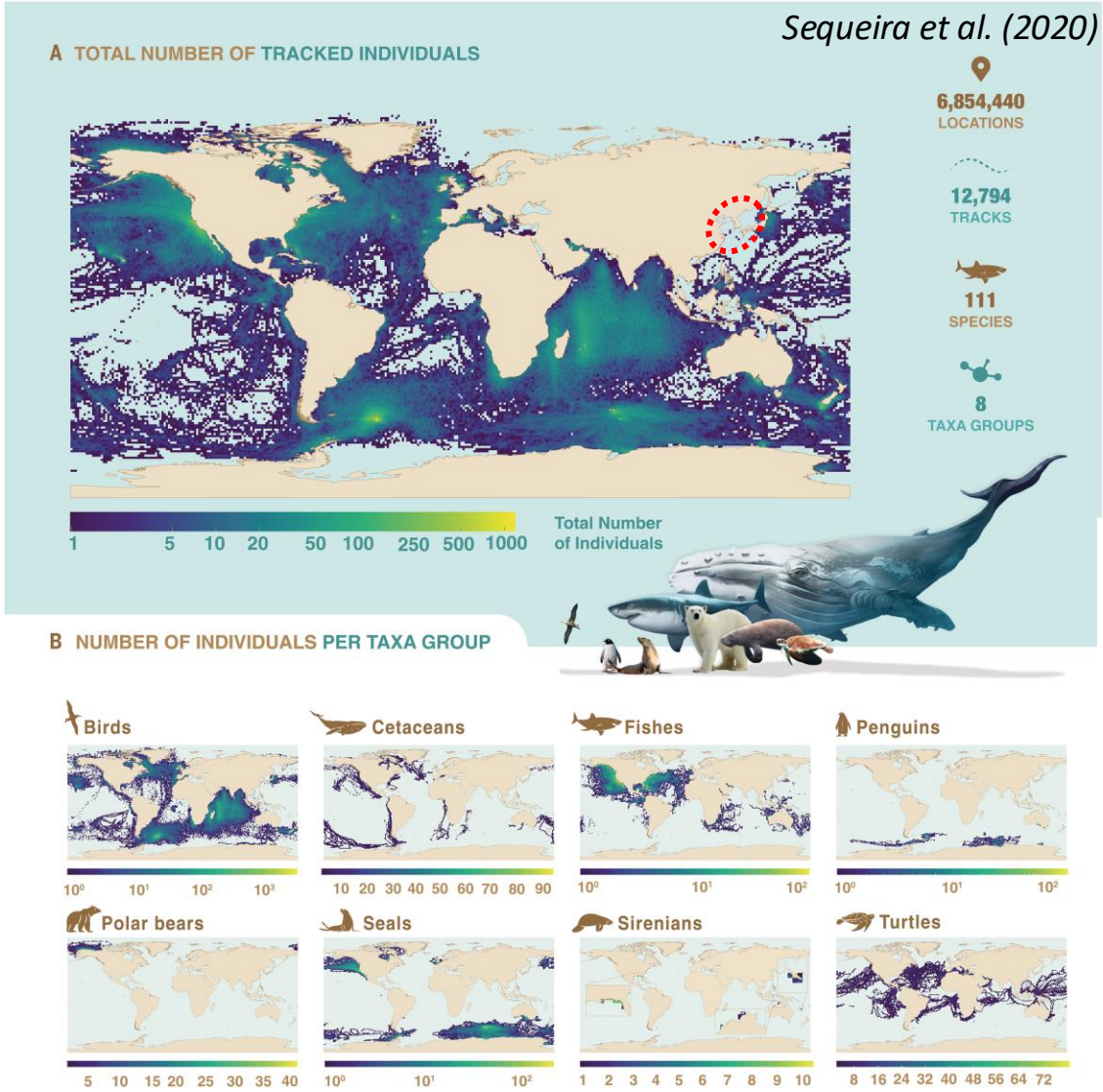
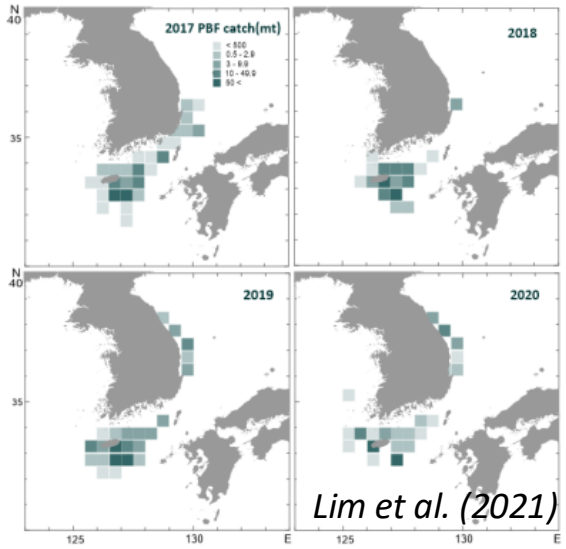
Projected percentage change in habitat under SSP585

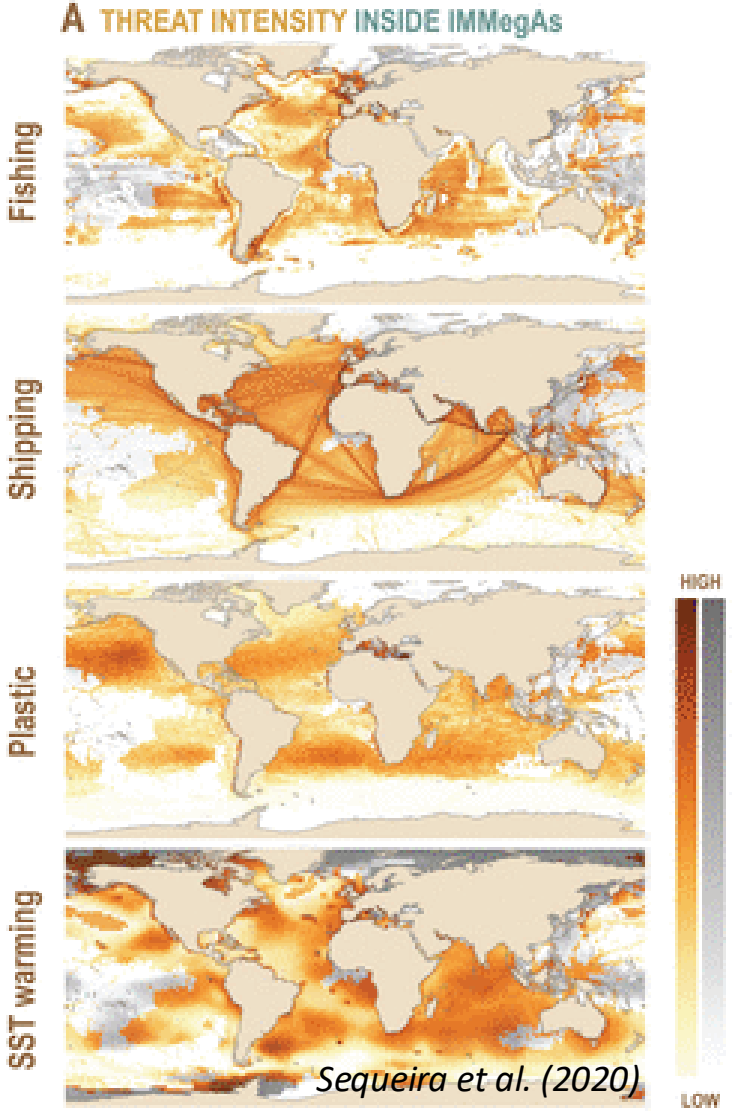


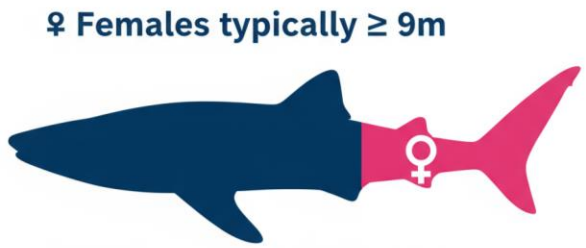
- Korean Waters (Range-edge habitat): **Dramatic GAIN (red)** in high-quality habitat (0.75-1.0)
- Philippines (Core habitat): **Significant LOSS (blue)** of high-quality habitat
- Ningaloo Reef (Core habitat): **Mixed gains/losses** by quarter, suggesting a **seasonal aggregation timing shift**


Sequeira et al. (2020)
A TOTAL NUMBER OF TRACKED INDIVIDUALS
6,854,440
LOCATIONS
12,794
TRACKS
111
SPECIES
8
TAXA GROUPS
1 5 10 20 50 100 250 500 1000
Total Number of Individuals
B NUMBER OF INDIVIDUALS PER TAXA GROUP
Birds
Cetaceans
Fishes
Penguins
Polar bears
Seals
Sirenians
Turtles


청새리상어(2.7/울진 후포/1.3m, 7kg)
악상어(3.21/울진 후포/2m, 96.6kg)
악상어(3.25/고성/169~183cm, 43.7~62.5kg)
청상아리(5.07/울진 후포/253cm, 113.6kg)


2017 PBF catch(mt)
2018
2019
2020
Lim et al. (2021)


A THREAT INTENSITY INSIDE IMMegAs
Fishing
Shipping
Plastic
SST warming
HIGH
LOW
Sequeira et al. (2020)

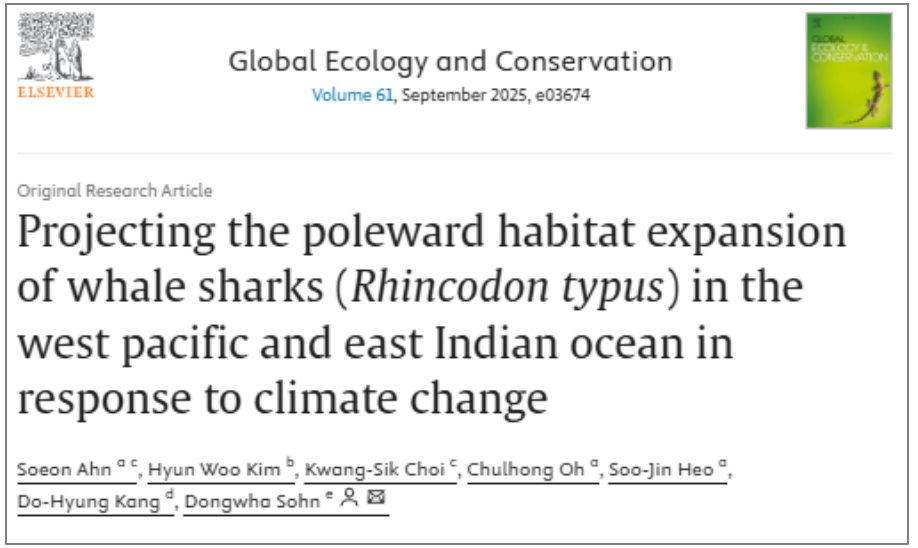


Meekan et al. (2020)

- Protected species since 2016, but 78% of records are from **bycatch**
- Compounded by **illegal fishing and trade** in neighboring regions
- The discovery of a 13m **female** is unusual
- Korean waters may not just be a random fringe habitat, but a habitat with greater **ecological significance**
- Need for **stronger protection and research** in this critical area.

감사합니다

T H A N K Y O U



References

1. Ana M. M. Sequeira et al. ,Global tracking of marine megafauna space use reveals how to achieve conservation targets.Science388,1086-1097(2025).DOI:10.1126/science.adl0239

2. Lim J., M. K. Lee, S. I. Lee, Y. Kwon and D. N. Kim. 2021. Update of Korean fisheries information for Pacific bluefin tuna, Thunnus orientalis. ISC21/PBFWG-2/06

3. Womersley, F.C., Sousa, L.L., Humphries, N.E. *et al.* Climate-driven global redistribution of an ocean giant predicts increased threat from shipping. *Nat. Clim. Chang.* **14**, 1282–1291 (2024). https://doi.org/10.1038/s41558-024-02129-5

4. Meekan MG, Taylor BM, Lester E, Ferreira LC, Sequeira AMM, Dove ADM, Birt MJ, Aspinall A, Brooks K and Thums M (2020) Asymptotic Growth of Whale Sharks Suggests Sex-Specific Life-History Strategies. *Front. Mar. Sci.* 7:575683. doi: 10.3389/fmars.2020.575683

5. Araujo G. et al., (2022) Improving sighting sderived residency estimation for whale shark aggregations: A novel metric applied to a global data set. Front. Mar. Sci. 9:775691. doi: 10.3389/fmars.2022.775691