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Plastics and small pelagic fishes in surface ocean

Shin-ichi Ito[1], Haodong Xu[1,2], Ziqin Wang[1,3], Shike Gao[1,4], Yoshimasa Matsumura[1,5]
[1](AORI, Univ. of Tokyo) , [2](Texas A&M), [3](GSALS, Univ. of Tokyo),
[4](Shanghai Ocean Univ.), [5](National Institute for Environmental Studies)


Haodong Xu


Ziqin Wang

Today's Contents

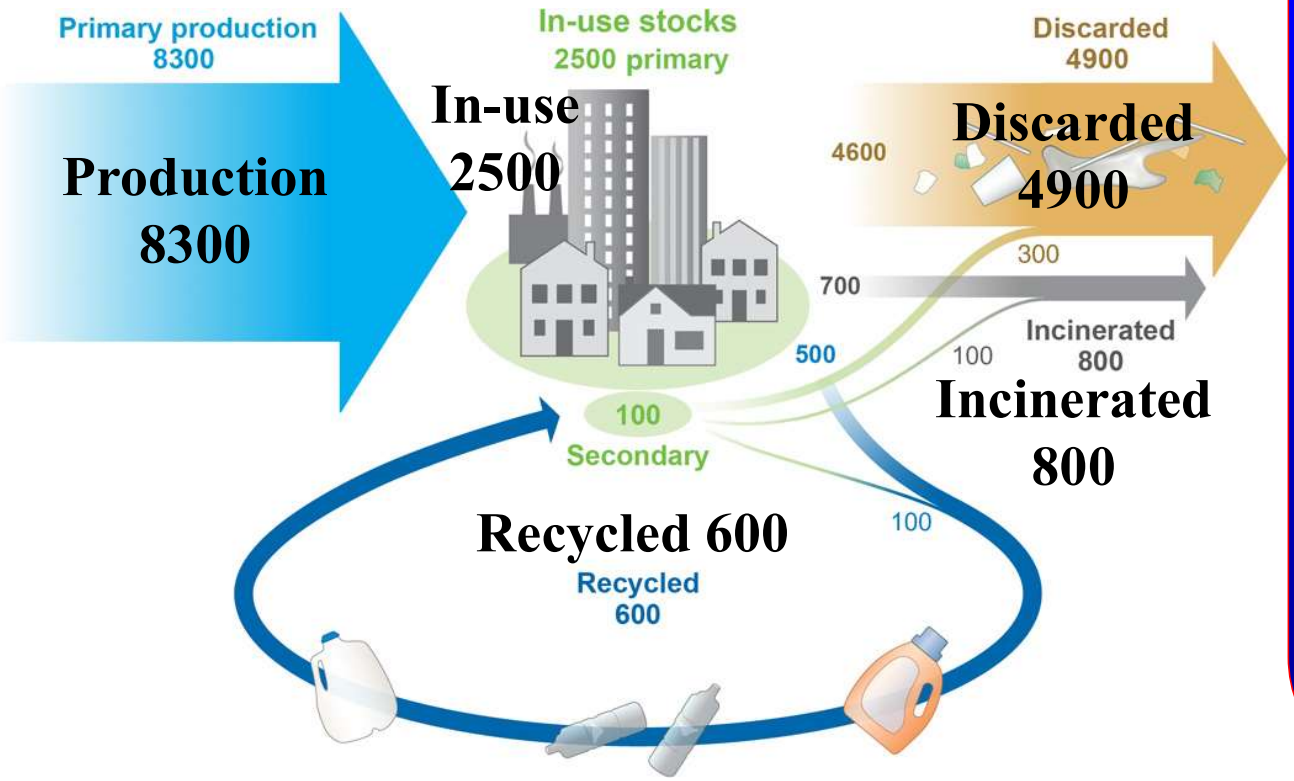
1. Needs for microplastic modelling
2. Model settings for microplastic
3. Historical microplastic distribution in NW Pacific
4. Encounter rate of microplastics by chub mackerel
5. Caveats and future perspectives


Shike Gao


Yoshimasa Matsumura

Production, use, and fate of plastics

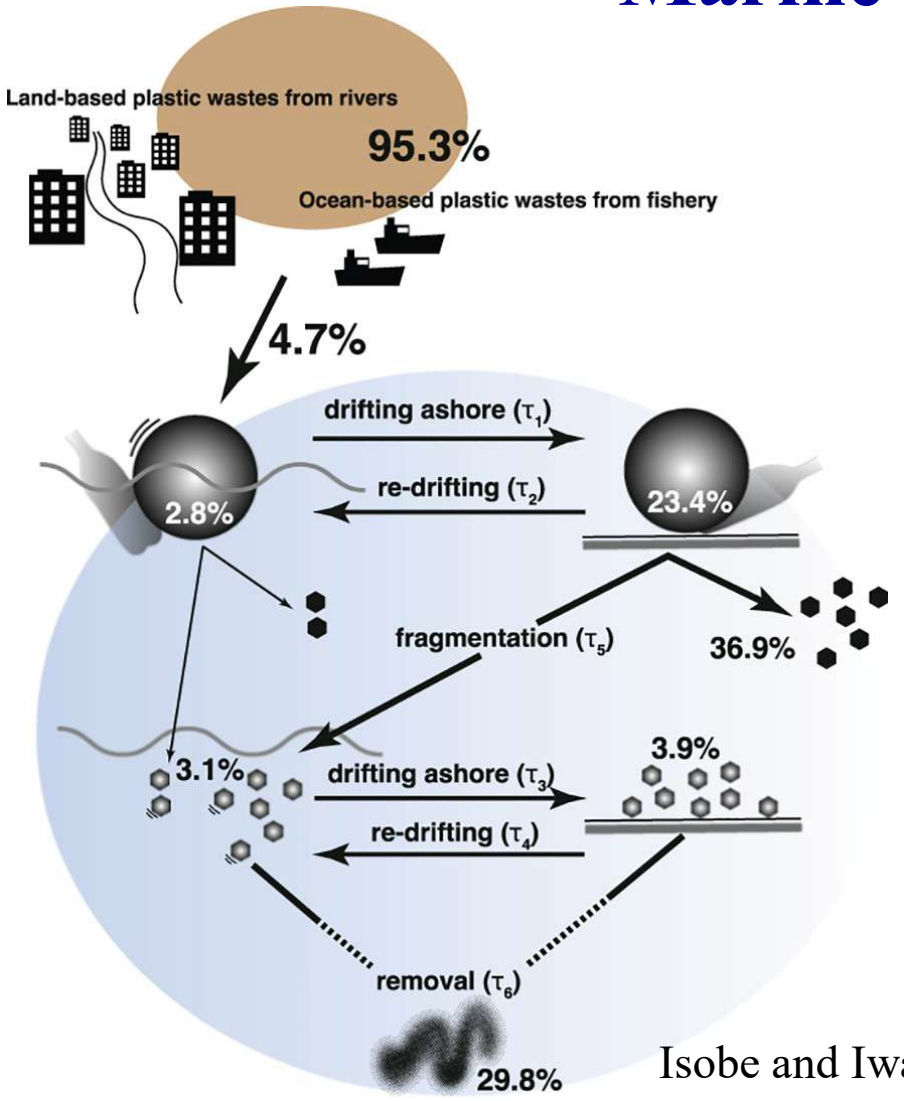
plastic flow in the world (unit: 1 million t)
total during 1950 - 2015



Geyer et al. (2017, Sci. Adv.)

- **4.9 billion metric tonnes plastic was discarded (79% of the wasted plastic) until 2015.**
- **31.9 million metric tonnes of mismanaged plastic waste is released into the natural environment each year (Jambeck et al., 2015).**

Marine microplastics

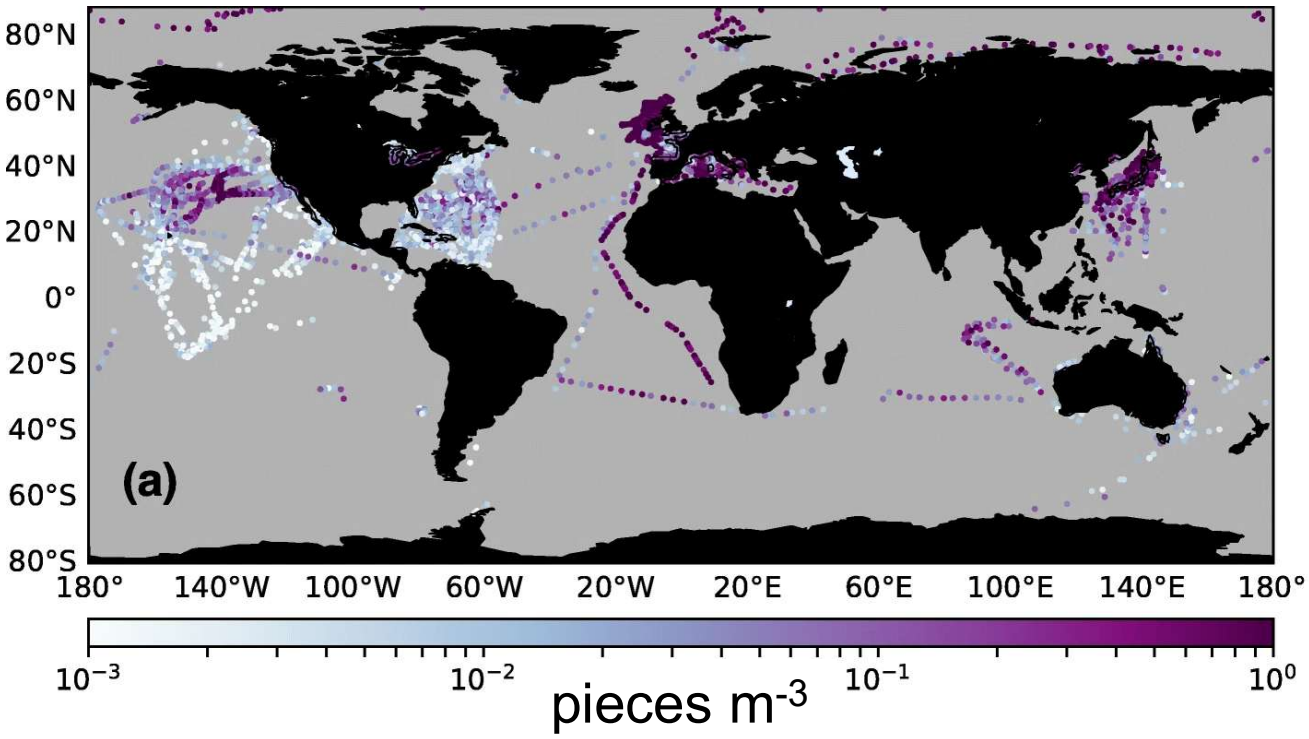


- **4.7% of mismanaged plastic waste (542.2 million metric tonnes) discharged to ocean between the 1960s and today.**
- **Those plastic are fragmentated into microplastics on the beach and in the ocean by waves and ultraviolet exposure.**

Size of microplastics (<5mm) can affect on zooplankton and small pelagics.

Isobe and Iwasaki (2022, Sci. Total Env.)

Distribution of marine microplastics



Isobe et al. (2021, Microplastics and Nanoplastics)

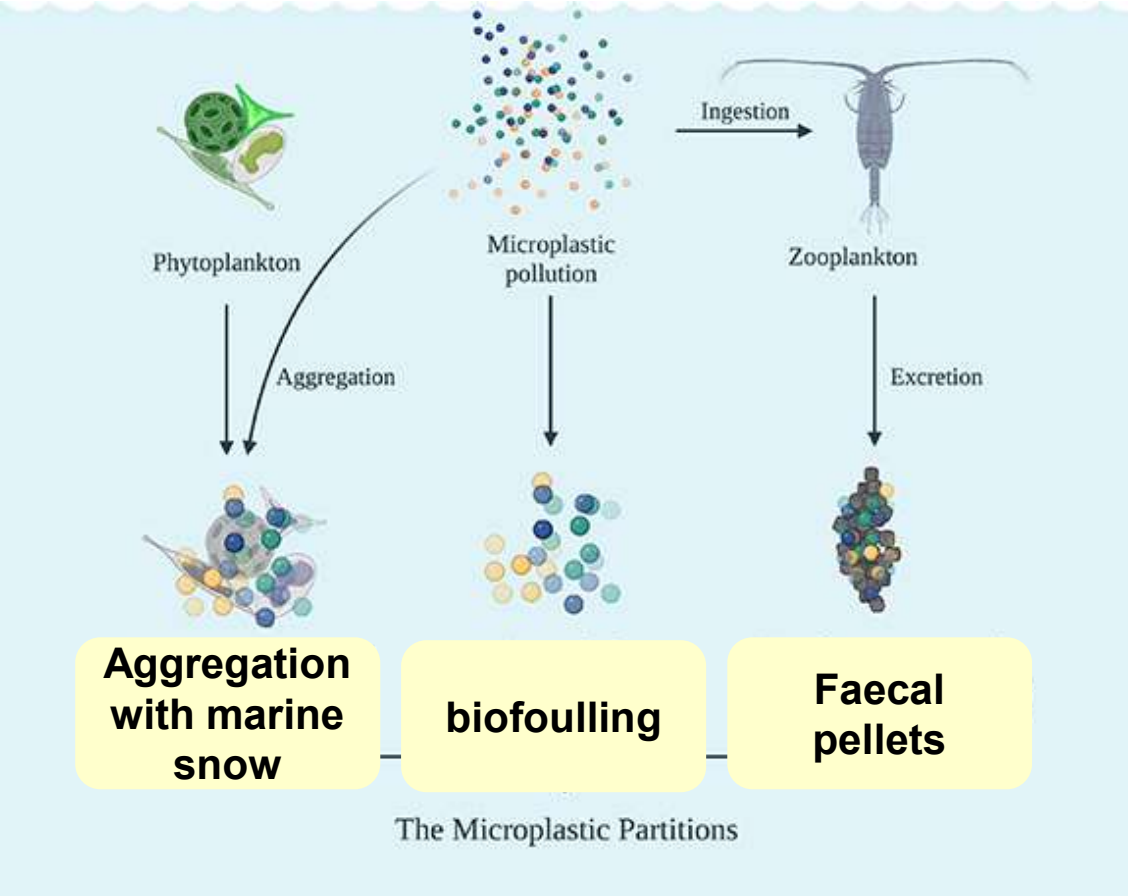
From Arctic to Antarctic, microplastics have been detected in the world's ocean.

However,
Loaded plastics
>> Floating plastics

Missing sink!

Removable process of microplastic from the surface has been undetermined.

Biological removal of microplastics



Andrews et al. (2024, Env. Res. Letters)
Adapted from Coyle et al. (2020, Case Std. Chem. Env. Eng.)

Biological removal is important process for microplastics.

However, the estimated timescale has large uncertainties.

24–26 days
- **biofouling simulations (Kooi et al., 2017)**

4–6 weeks
- **Field incubation (Kaiser et al., 2017; Amaral-Zettler, 2021)**

1–10 years
- **mass balance models (Isobe and Iwasaki, 2022)**

Questions

Q1: What the order of biological removal timescale is?

Q2: Where the biological removal happens?

Q3: Where does risk happen for small pelagics to encounter microplastics?

Objectives

1. **To provide the most realistic and plausible plastic emission scenario required to evaluate the basin-scale distribution of microplastics.**
2. **To characterize the biological removal timescale and removal hotspot.**
3. **To estimate microplastic encounter risk for chub mackerel.**

2. Model settings for microplastics

Basic setting is the same as Xu et al. (2025, Mar. Poll. Bull.)

Particle tracking model

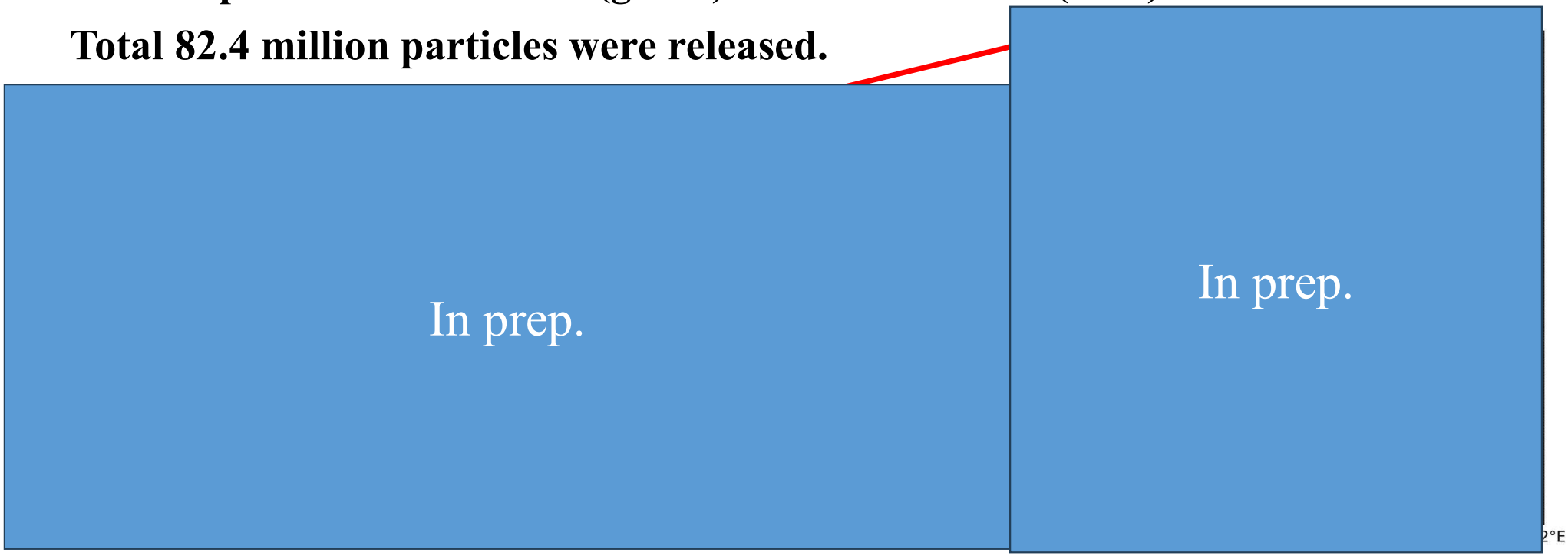
North Pacific (100E – 75W, 13S – 60N), during 1951-2015.

Velocity field: Meteorological Research Institute MRI.com reanalysis (MRI.COM; Tsujino et al., 2017): 1/11 deg., 5 days interval

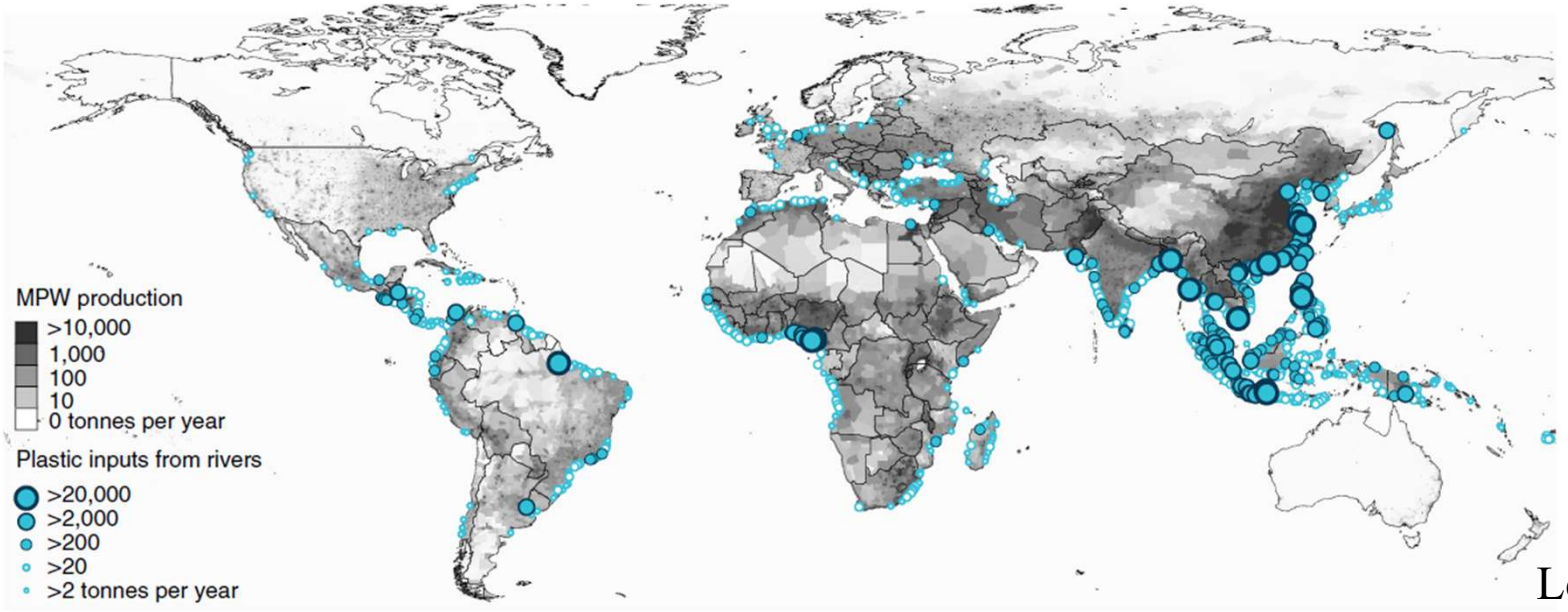
Particle tracking model: kinaco (Matsumura & Ohshima, 2015)

Release point: 17376 coastal (green) and 10565 rivers (blue)

Total 82.4 million particles were released.



Emission scenario (geographical distribution)



Lebreton et al. (2017)

Geographical distribution (Lebreton et al., 2017)

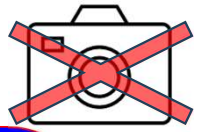
plastic emission of each river was estimated using

- **river discharge**
- **watershed population density**
- **mismanaged plastic waste for one person in each year**

2005-2015 monthly climatology

Temporal change was estimated by each country GDP.

Biological removal

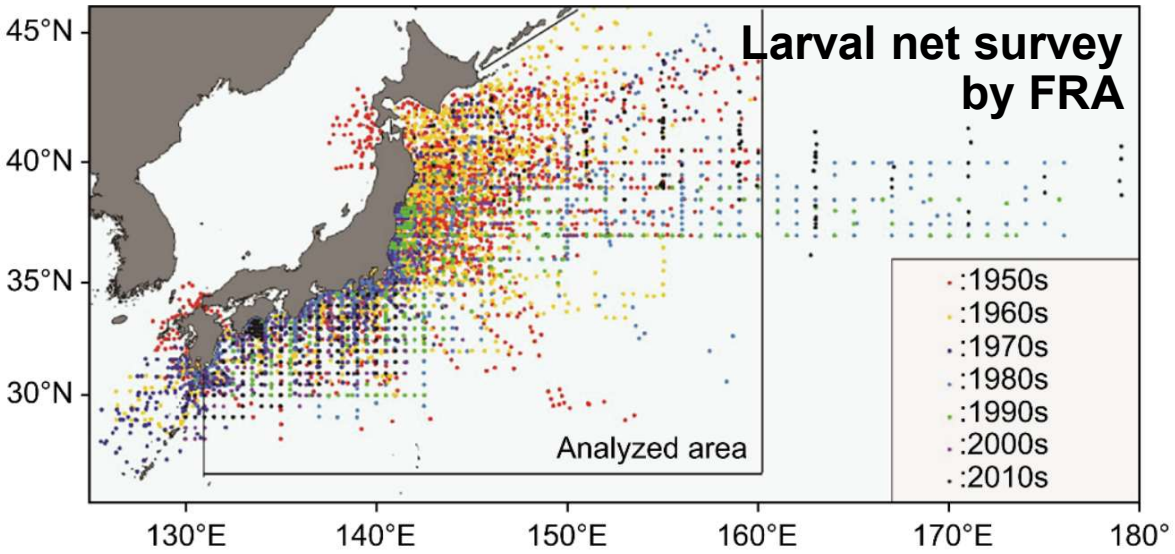


Accumulated chlorophyll-a concentrations ($mg \cdot m^{-3} \cdot day$) were used as threshold to start sinking of microplastic.

A lower threshold indicated a rapid removal speed, particles drifted for shorter period, inducing shortened biological removal timescales, and vice versa.

In prep.

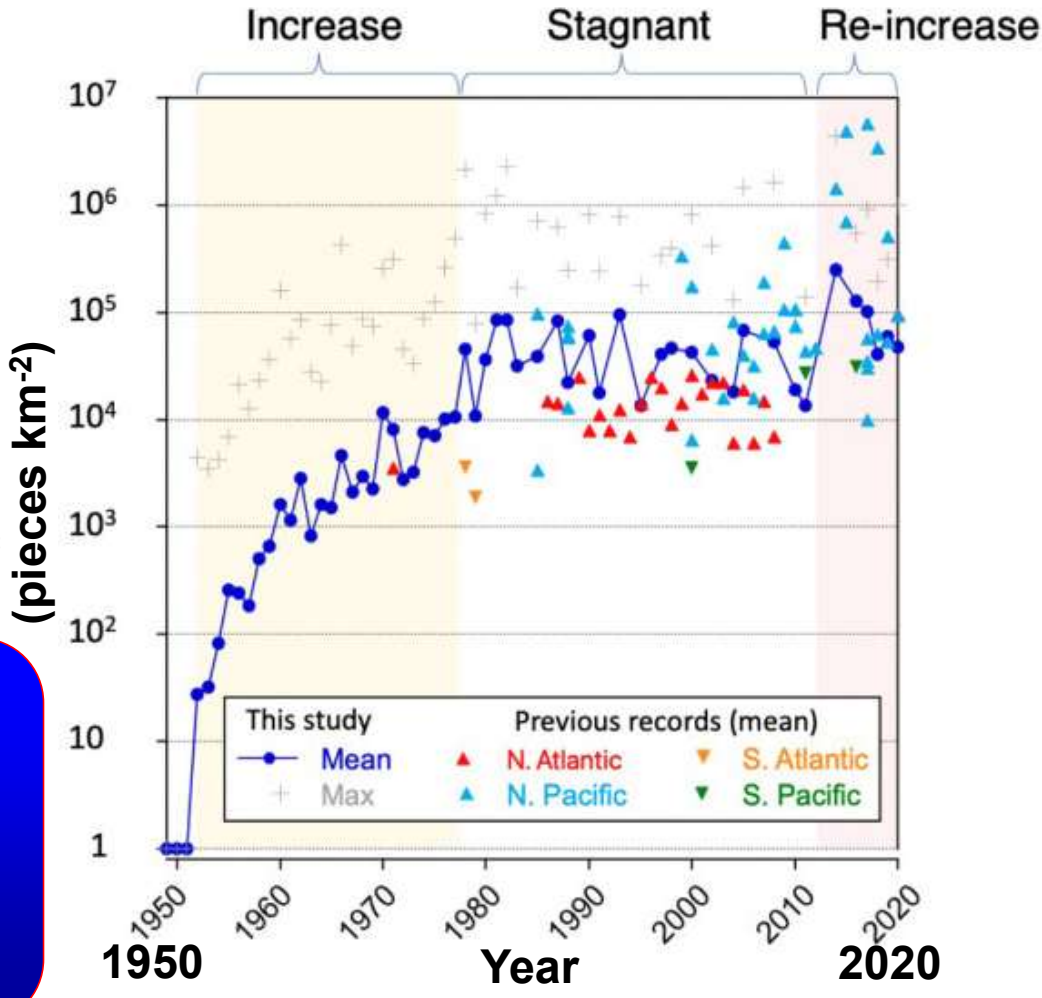
Long-term observations of microplastics



Miyazono et al. (2025, Env. Sci. Tech.)

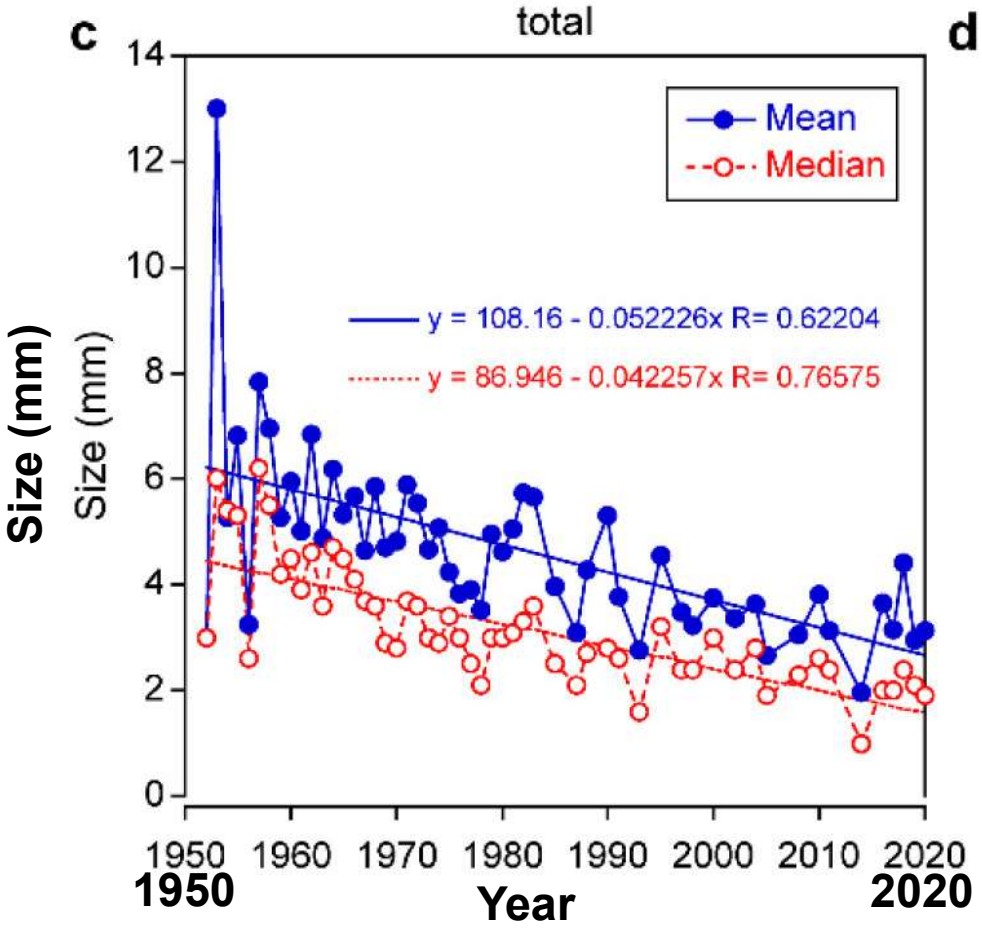
Strategy

- **Threshold (accumulated chl-a): unknown**
- **Find appropriate threshold which reproduces realistic microplastic spatial and temporal changes.**



Miyazono et al. (2025, Env. Sci. Tech.)

Long-term observations of microplastics



Miyazono et al. (2025, Env. Sci. Tech.)

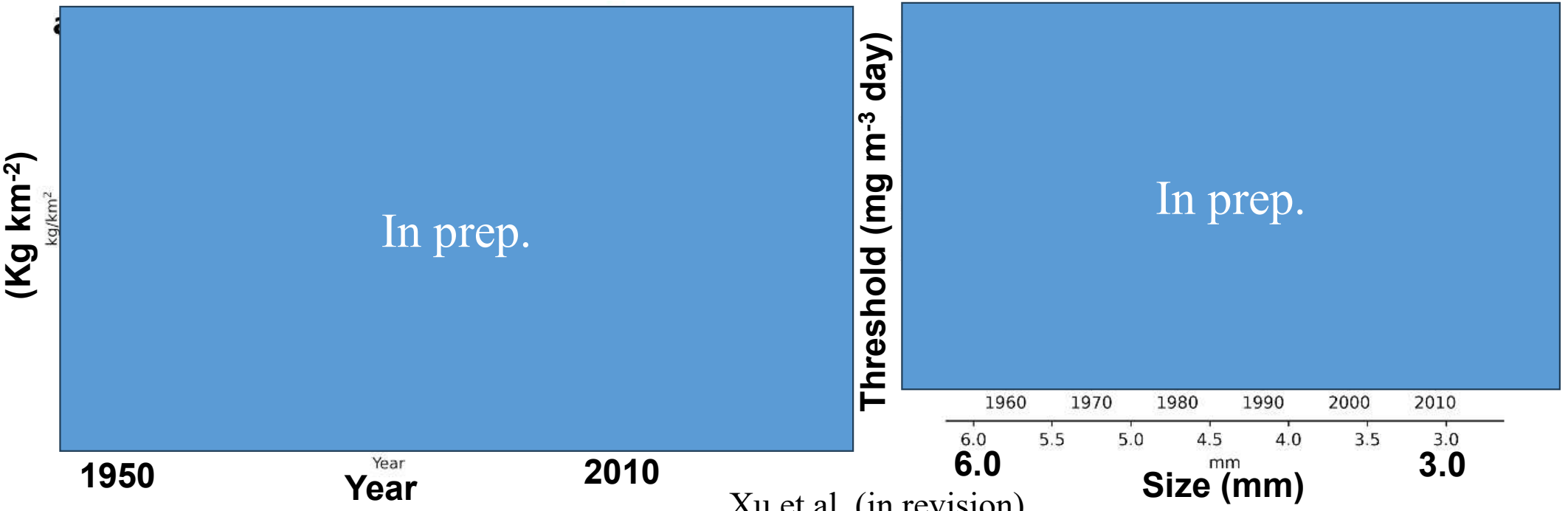
Long-term size reduction

- **Size is decreasing**
- **Smaller microplastics can sink easier**
- **Threshold should be size dependent**

$$Threshold = exp(a \times size + b)$$

3. Results
Historical microplastic distribution in NW Pacific

Historical simulation of microplastics on surface

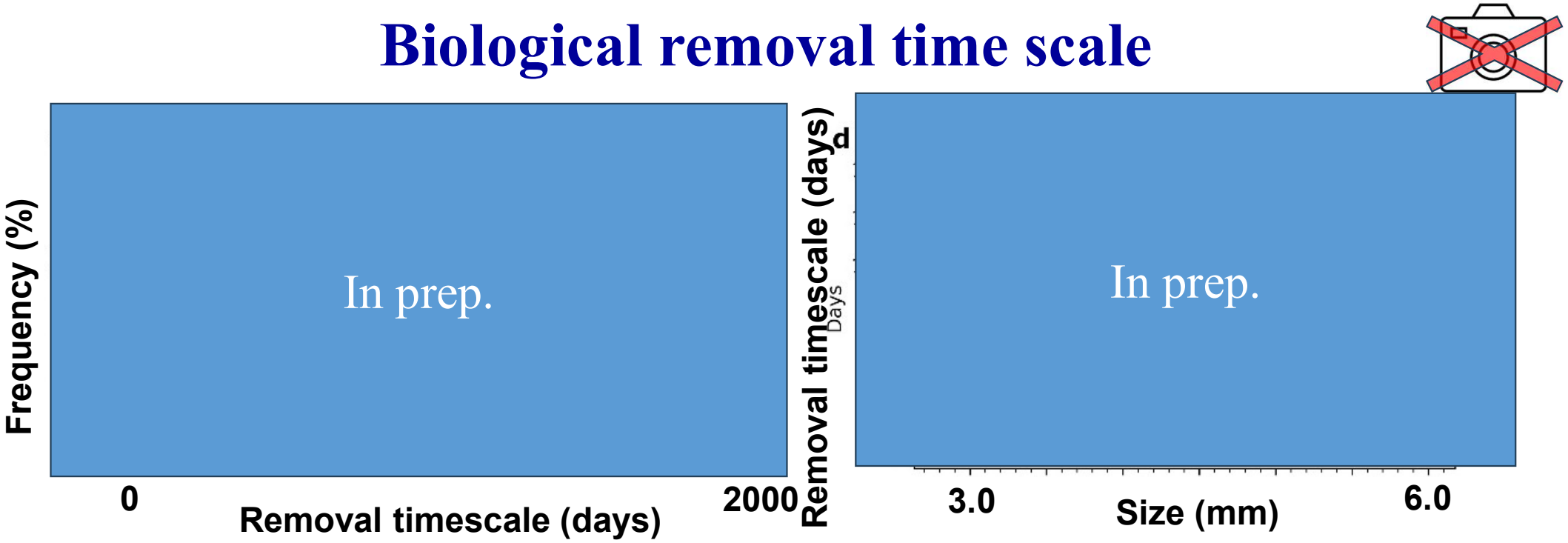


Xu et al. (in revision)

$$Threshold = exp(0.59 \times size + 1.89)$$

- **Optimal**
- **By considering size reduction, model reasonably reproduced the stagnant period during 1980s-2000s.**

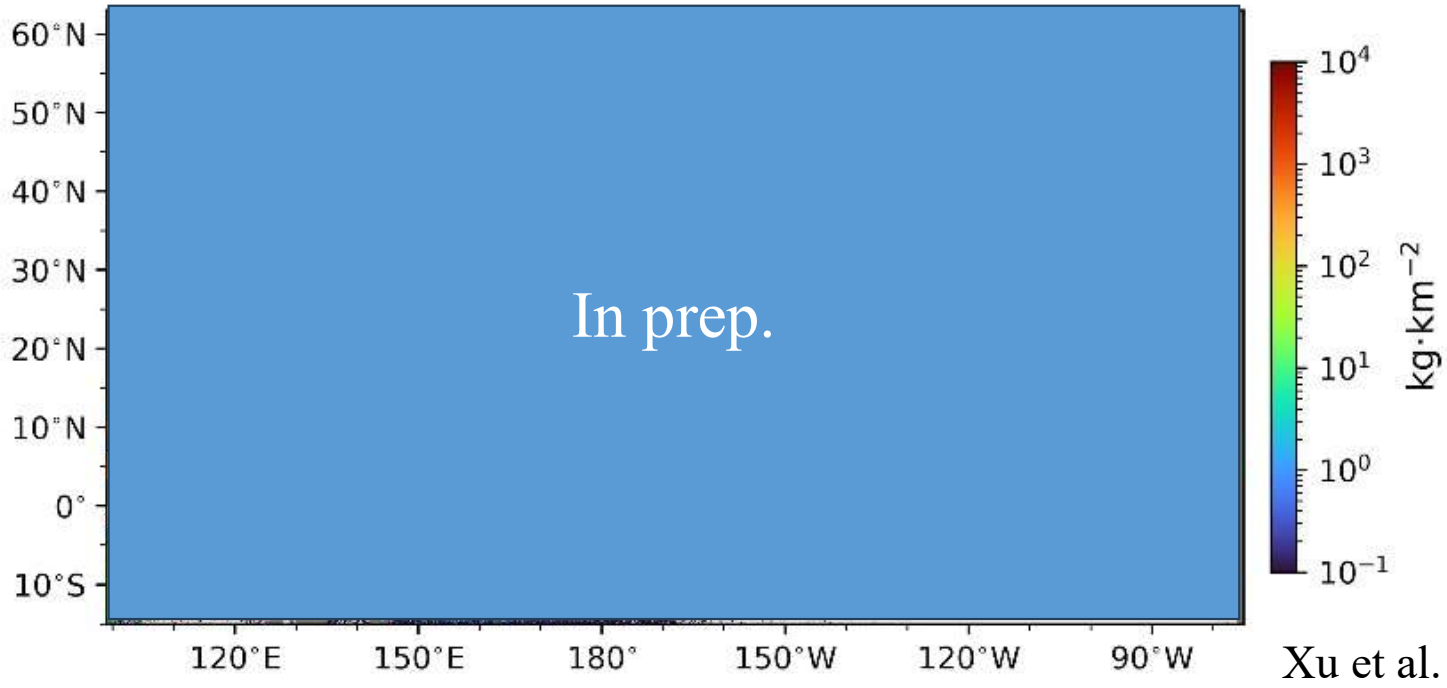
Biological removal time scale



Xu et al. (in revision)

- **Removal timescale is size dependent.**
- **It is shortened from 750 days to 150 days.**

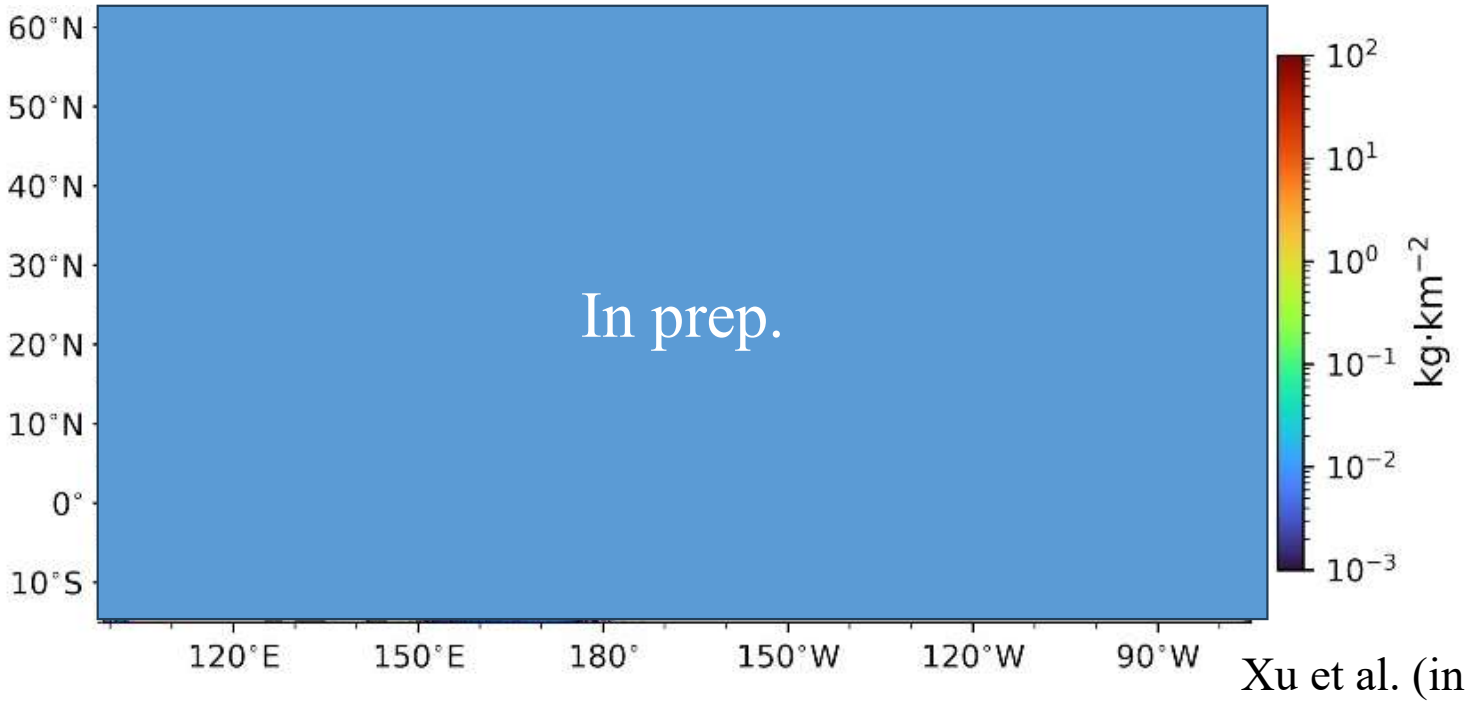
Biological removal from surface



Xu et al. (in revision)

- **Coastal and strong current regions are hotspot of biological removal.**

Horizontal distribution in 2015



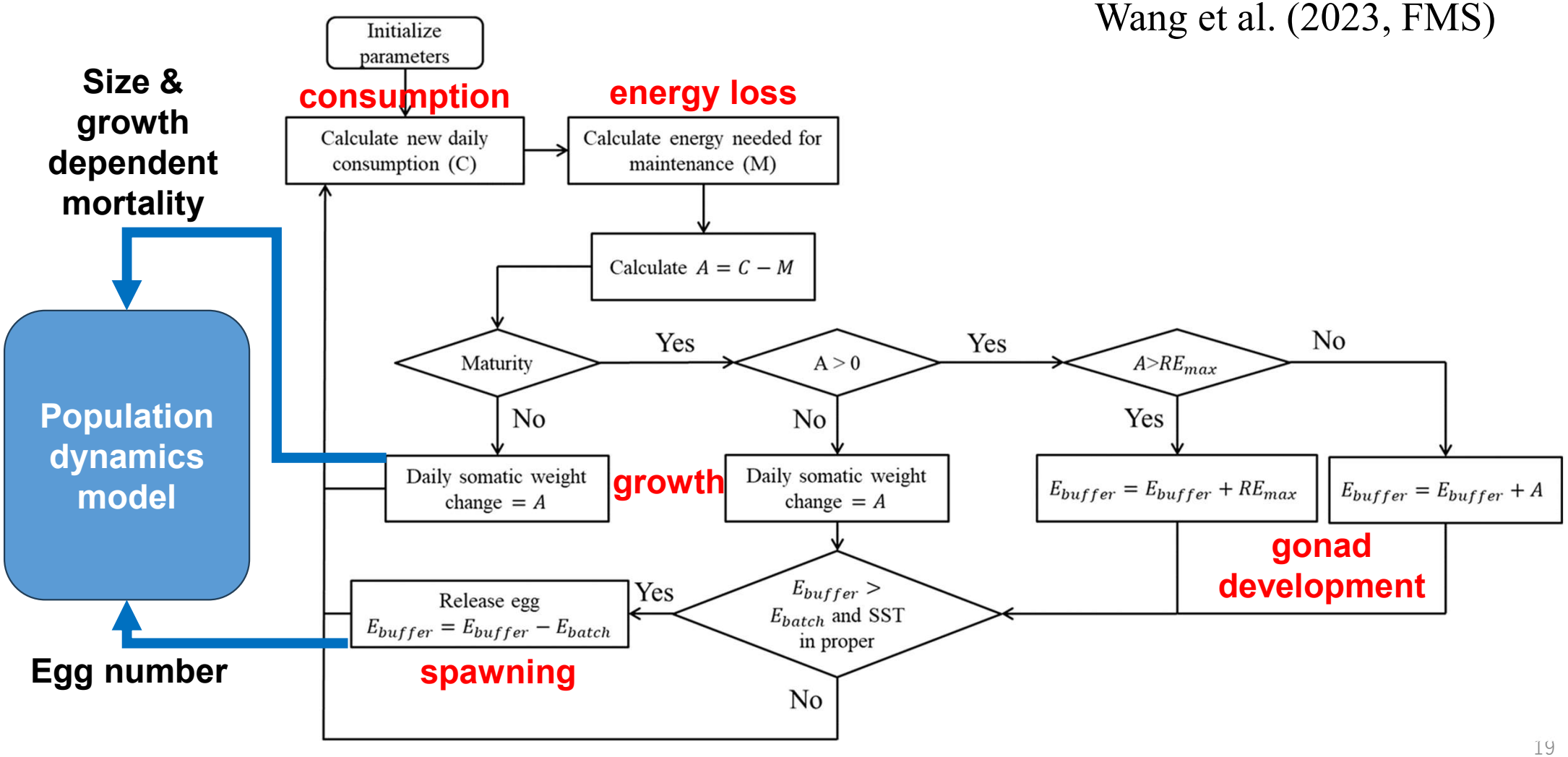
Xu et al. (in revision)

- **Southeast Asia is hotspot**
- **Equatorial counter currents and Kuroshio transport offshore**

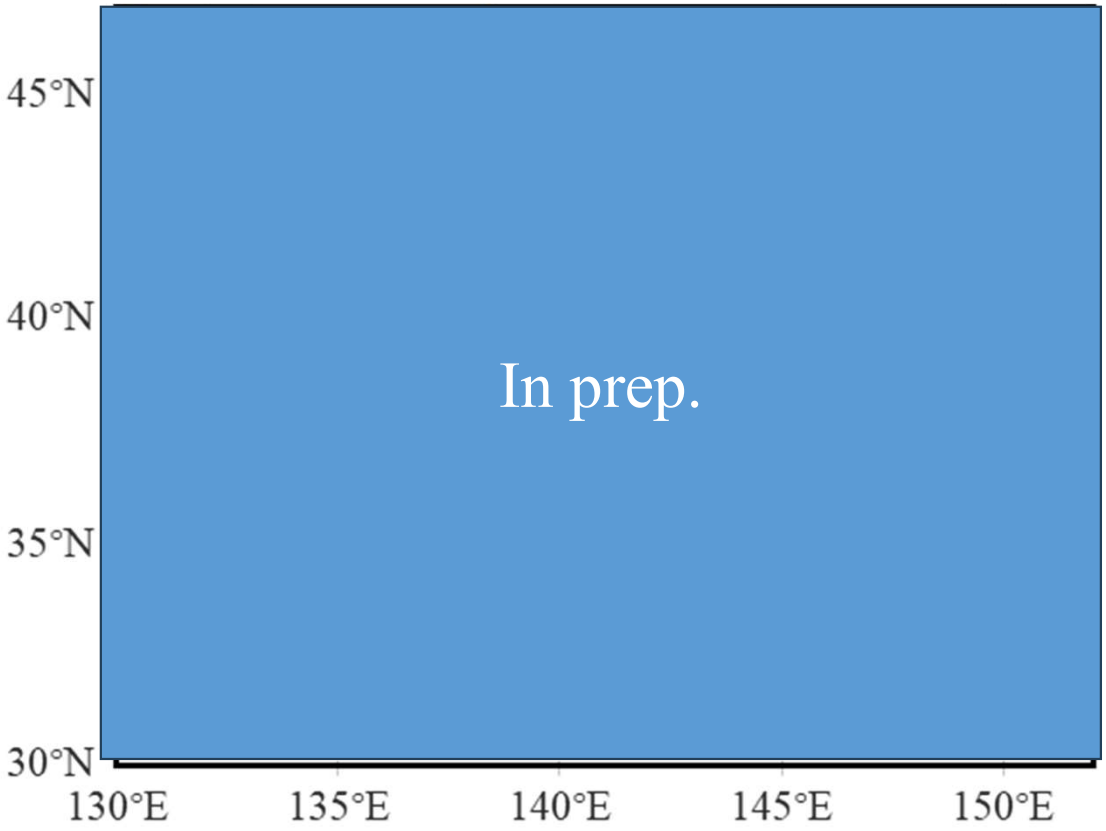
Now we have microplastic distribution
Coupled to a fish growth - population dynamics model
To estimate
4. Encounter rate of microplastics by chub mackerel

Growth-population dynamics model

Wang et al. (2023, FMS)



Microplastic encounter modeling



Gao, Wang et al. (in prep.)

$$\frac{dC_F}{dt} = \underbrace{k_w \cdot C_w}_{\text{intake}} - \underbrace{K_E \cdot C_F}_{\text{egestion}}$$

C_F: microplastic concentration in fish

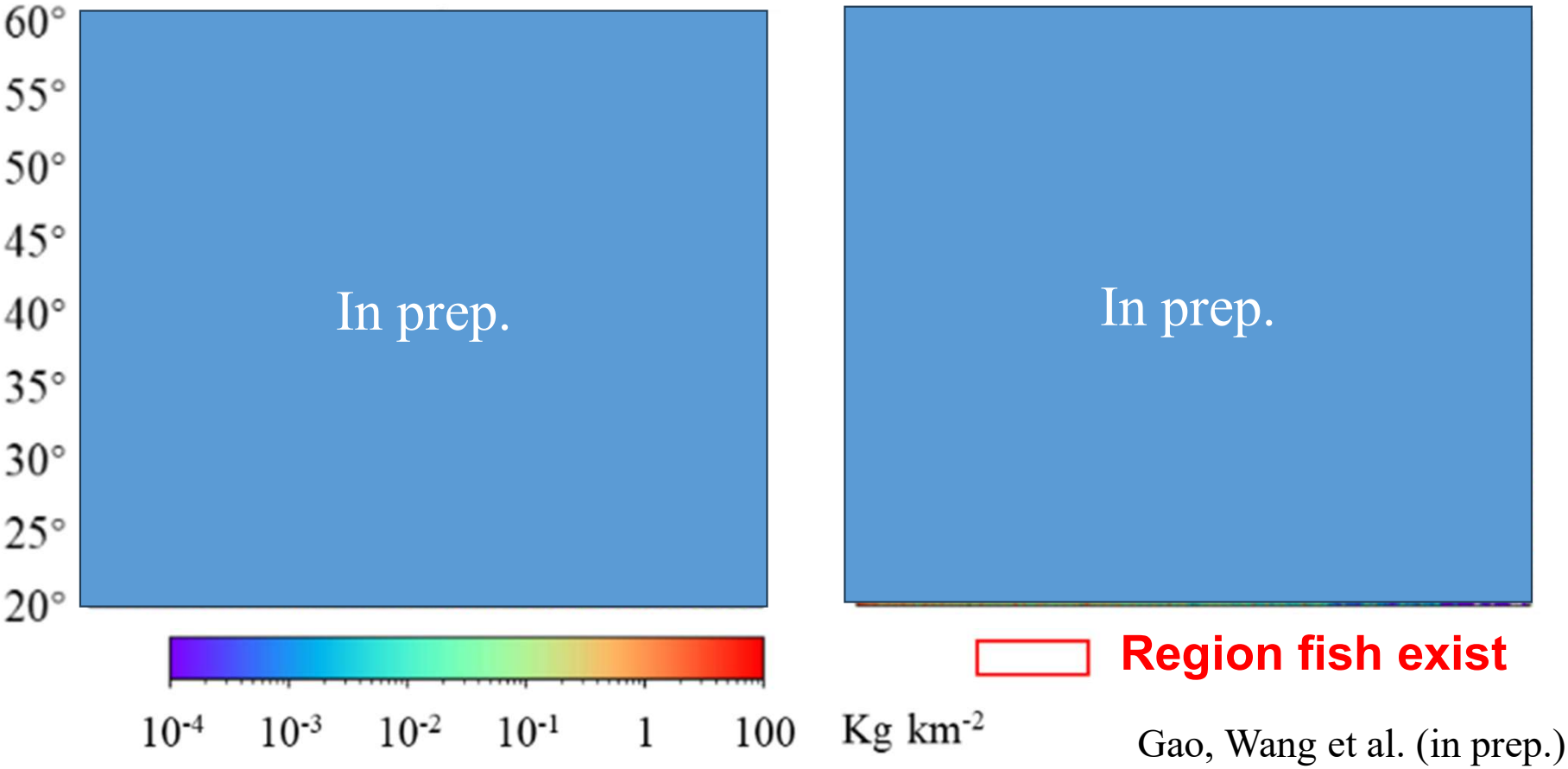
C_W: microplastic concentration in water

K_W: absorption rate from water

K_E: elimination rate from fish

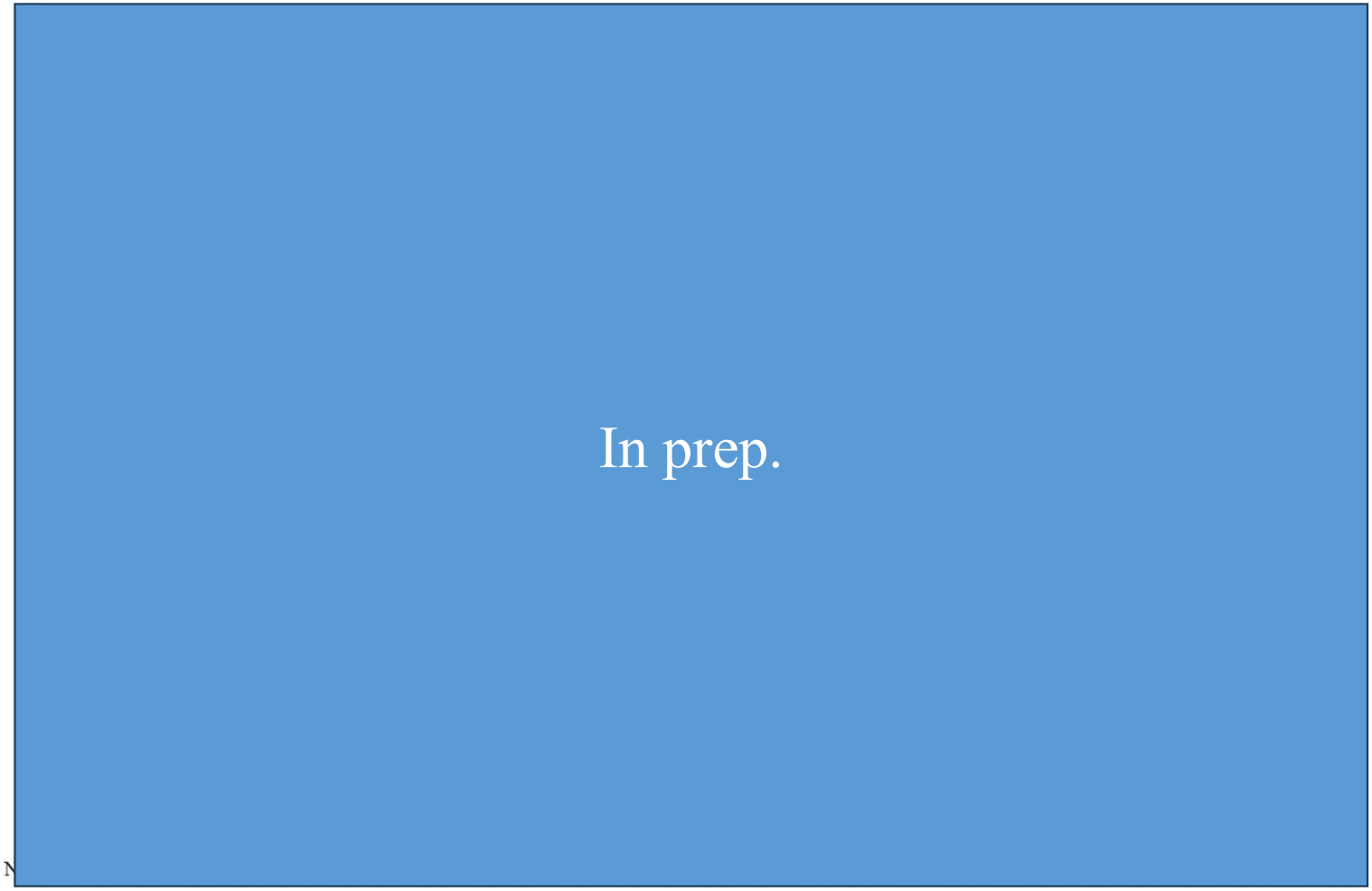
- Seasonal migration was fixed
- Simulate for age-0
- Hatching from Jan. to June

How to look figures



Gao, Wang et al. (in prep.)

Microplastic distribution and fish

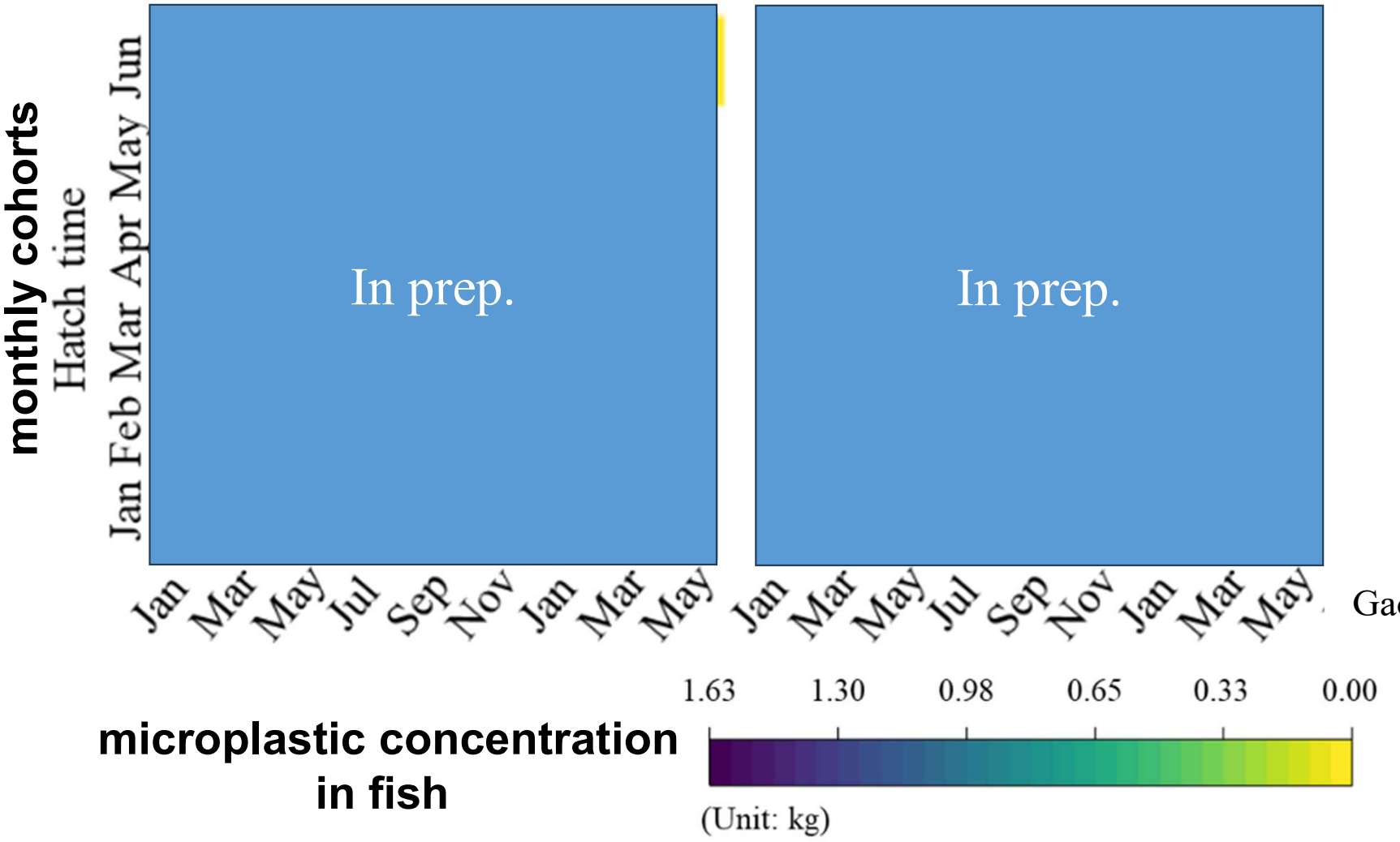


Microplastic concentration shows peak in summer and autumn.

Fish migrate northward during summer and autumn.

Gao, Wang et al. (in prep.)

How to look figures

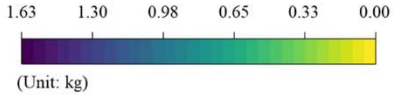


Gao, Wang et al. (in prep.)

Microplastic concentration in Fish

In prep.

In prep.

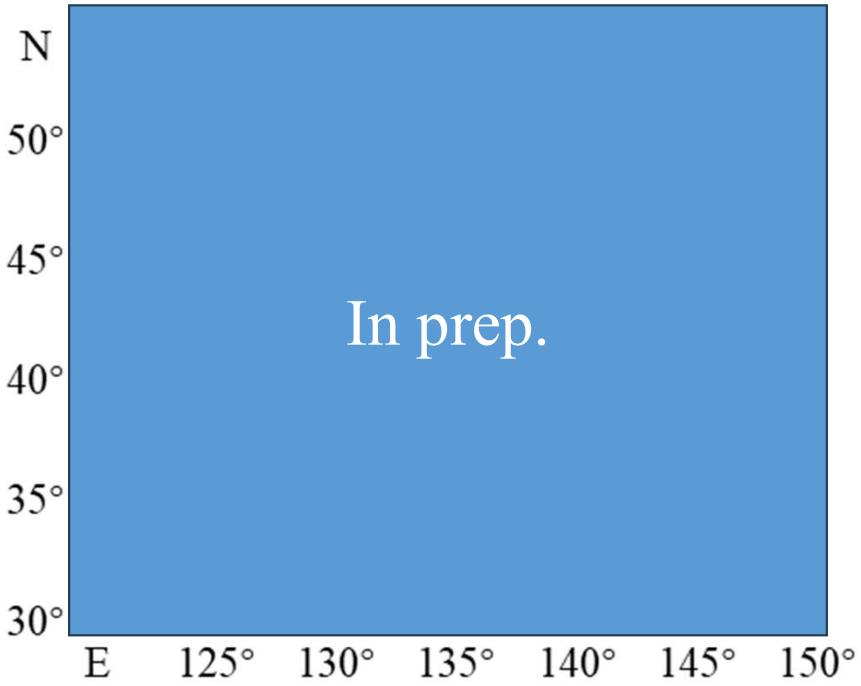


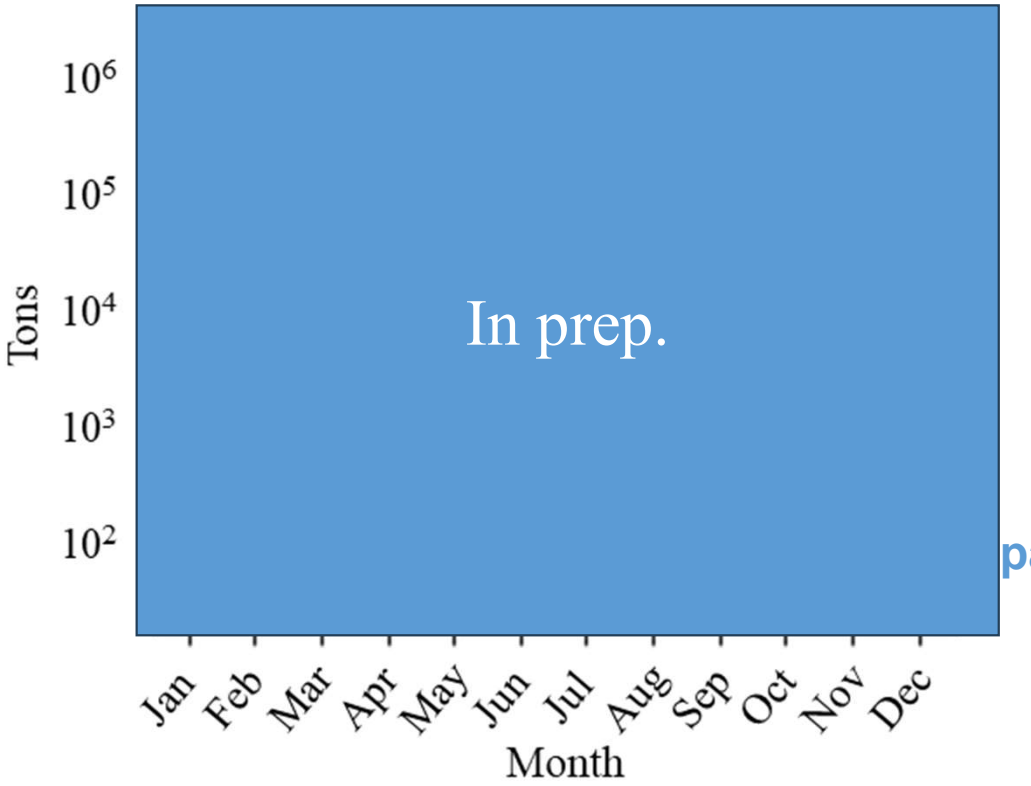
Nov. and Dec. are high exposure season because fish migrate back to south.

Chub mackerel avoid encounter of microplastics by migrating northward during summer and autumn.

Gao, Wang et al. (in prep.)

Emission source



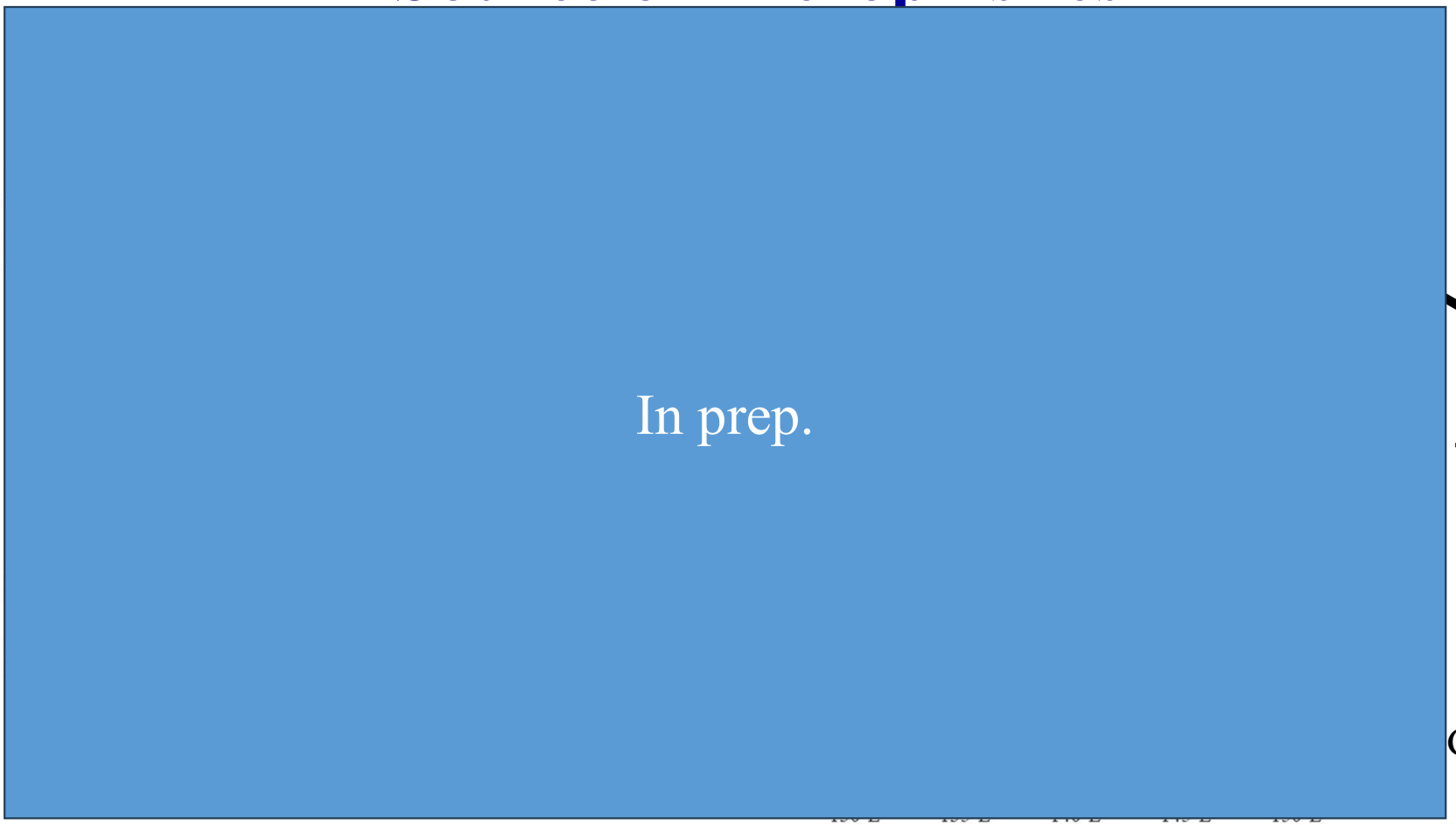


pan

- **Asia is the main source of microplastics.**
- **Peak in summer.**

Gao, Wang et al. (in prep.)

Source of microplastics

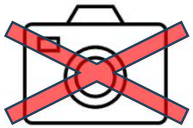


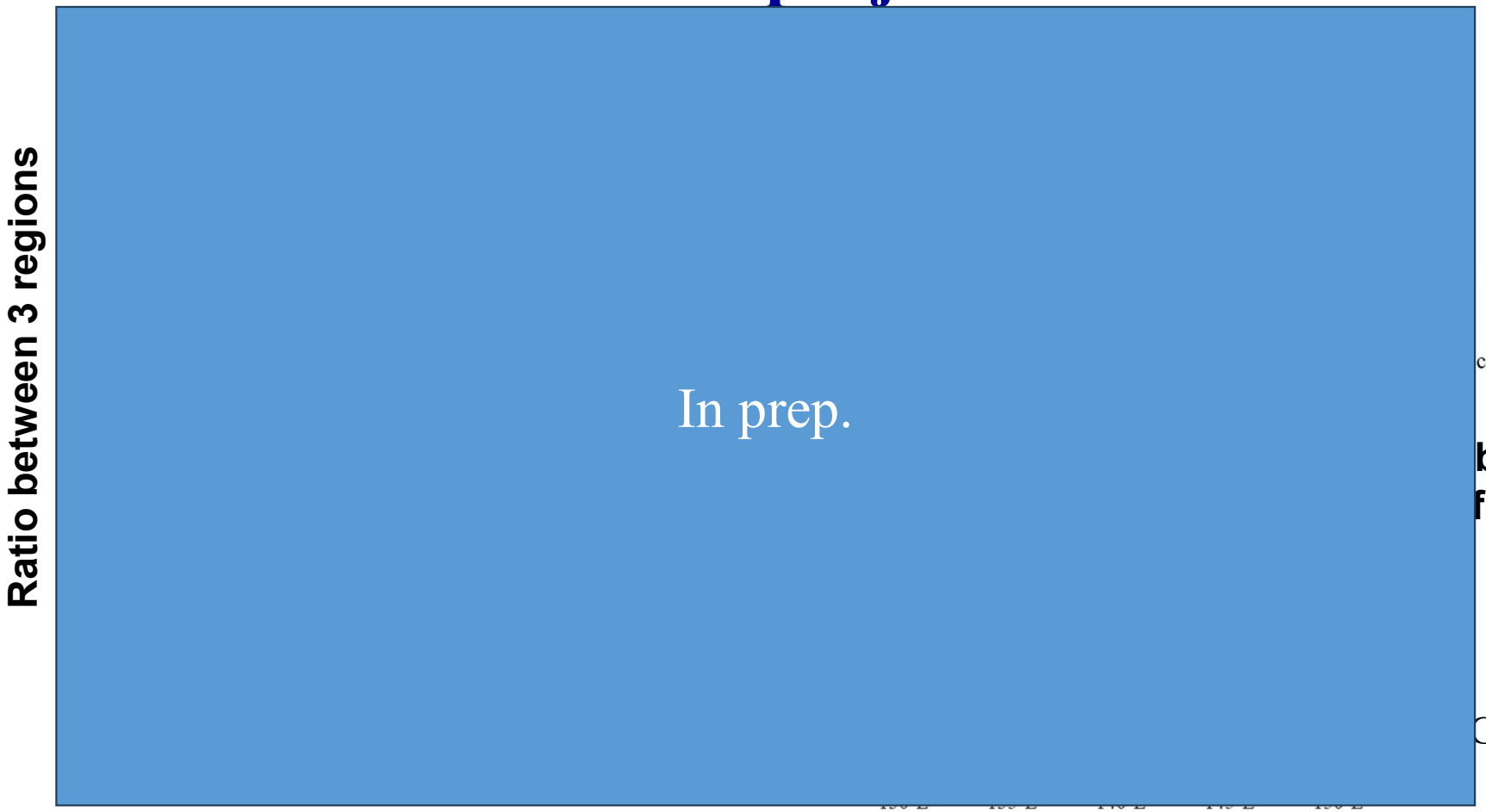
broken line: fish existing box

Gao, Wang et al. (in prep.)

Asia dominates southern boxes in summer. But chub mackerel avoid it. Japan Pacific coast is the main source.

Future projection





broken line: fish existing box

Gao, Wang et al. (in prep.)

Only consider the northward shift of chub mackerel.
Chub mackerel avoid the encounter of microplastics.

Conclusion

1. **Biological removal timescale is 150-750 days.**
2. **Coastal and strong current regions are hotspot of biological removal of microplastics.**
3. **Chub mackerel avoid the exposure of microplastics by ontogenetic migration, especially the microplastics from Asia.**

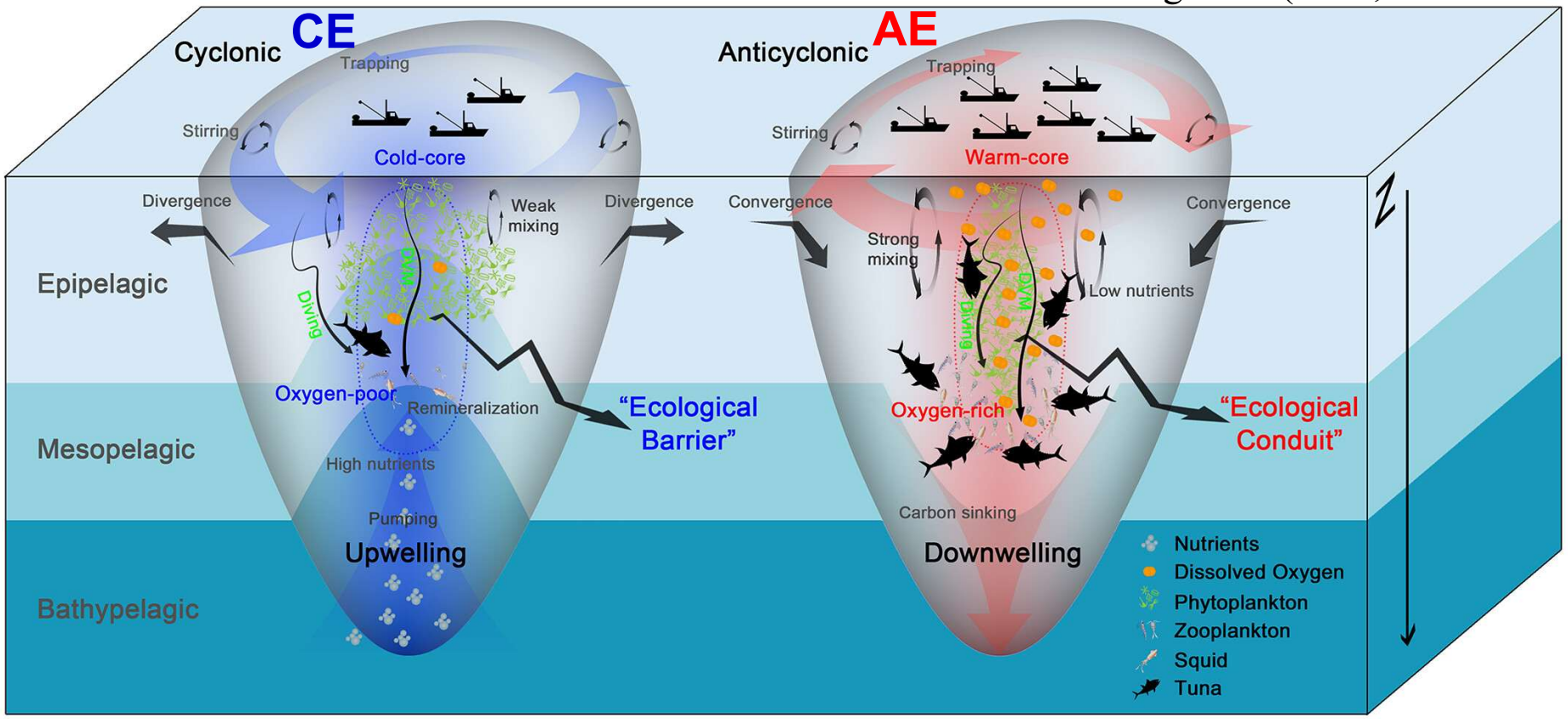
Future

Include self migration (Wang et al., submitted): S3 12:45-13:00.
Include microplastics through prey food.
Include trophic accumulation.
Include eddy and front effects.

Ziqin Wang

Eddy effects

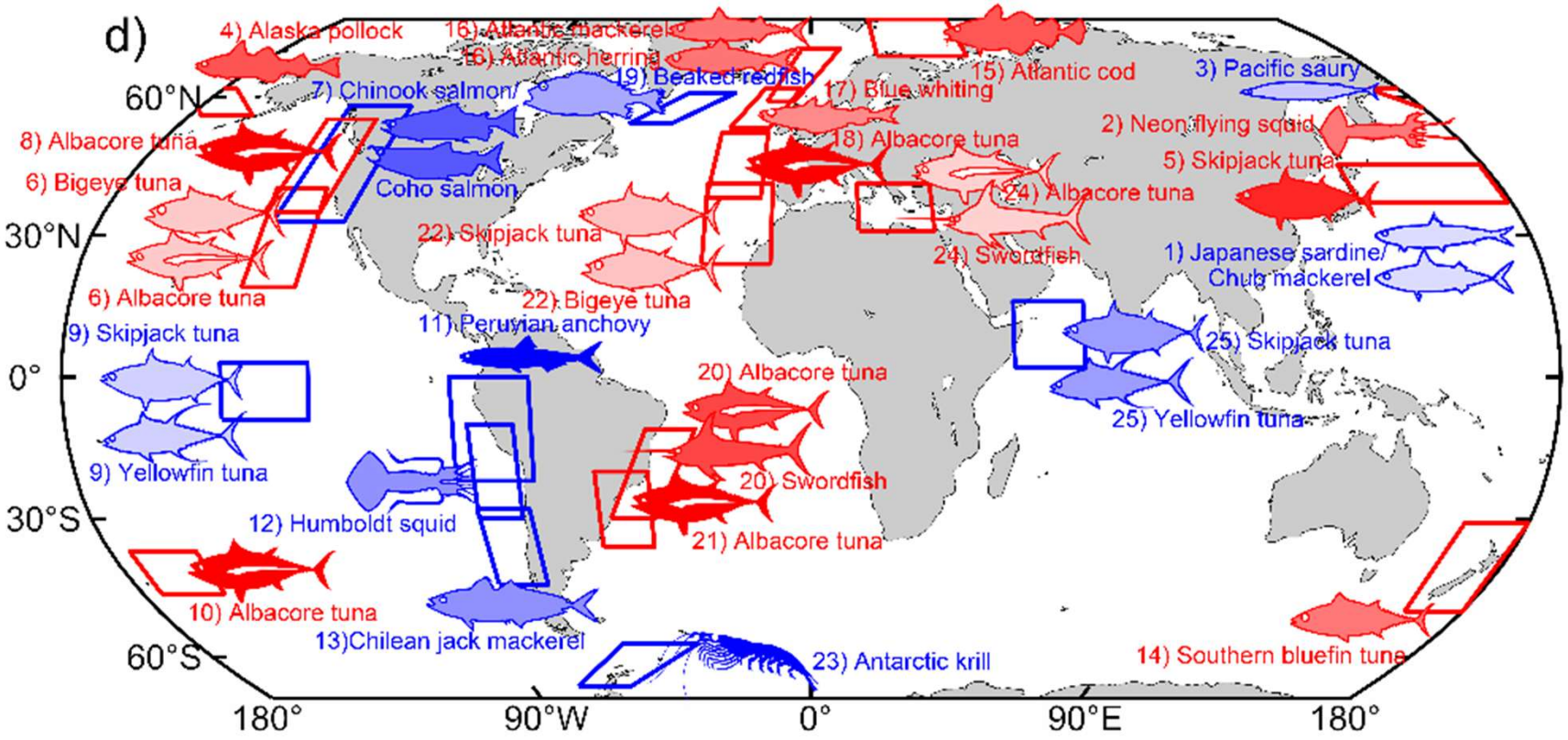
Xing et al. (2023, Fish & Fishery)
Xing et al. (2024, Sci. Tot. Env.)



Anticyclonic eddy traps microplastics
High exposure for higher trophic level fish (lower for small pelagics)

Front effects (barrier effects)

Xing, Gao et al. (2026, Nature Comm.)



Color intensity: effect amplitude

Red: warmer side aggregation

Blue: colder side aggregation

Warmer side of front traps microplastics

High exposure for higher trophic level fish (lower for small pelagics)??

Acknowledgements

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Dr. Kazutaka Takahashi
Dr. Hiroyuki Nakano

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