Long-term changes in demersal community structure of an urban bay: Transition from bottom-heavy to top-heavy pyramids

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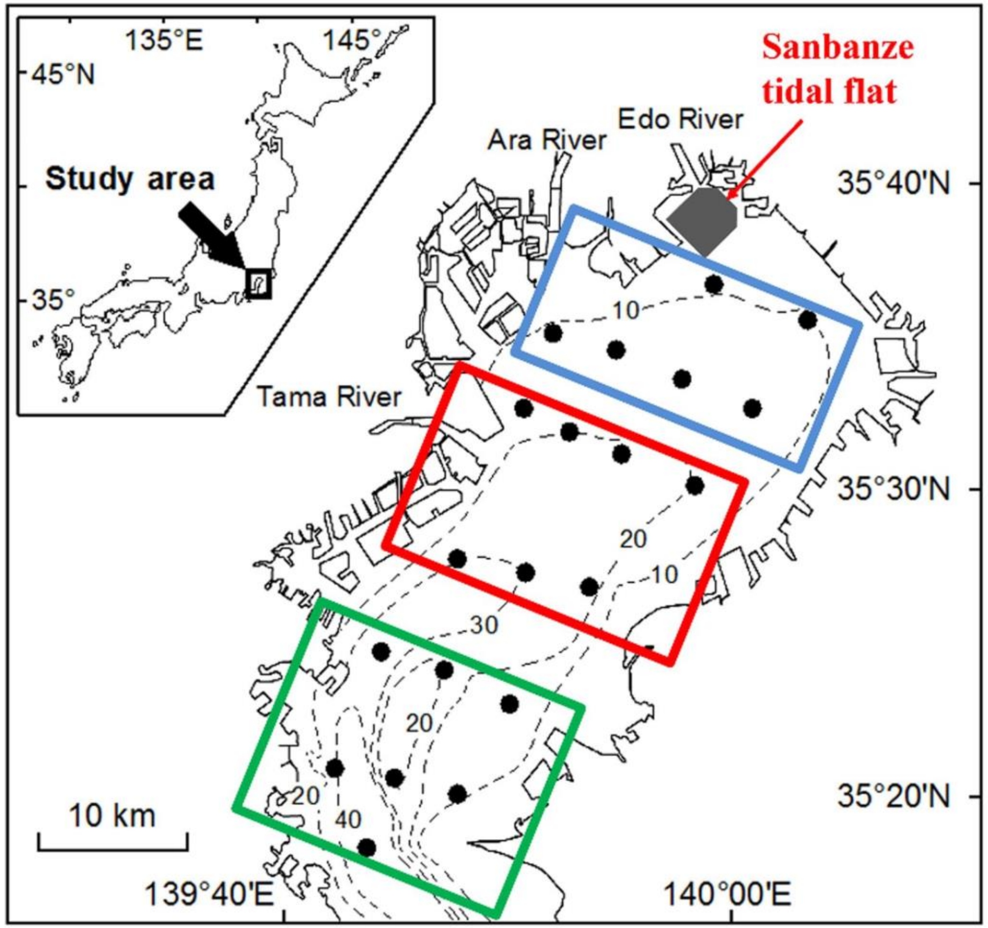
Introduction

- Human activities such as land use changes, pollution, and fishing are changing ecosystem functioning across the oceans of the world.
- The coastal zone is situated at the interface between land and sea, making it one of the most impacted areas of the world's oceans.
- Factors such as nutrient loading can induce eutrophication and bottom water hypoxia, which may cause shifts in fish assemblages and alter the overall health and functioning of ecosystems.
- Studying the response of fish community structure to human activities using reliable indices is essential to understand the dynamics of ecosystem functioning and conserve the integrity of the system.
- Community structure of aquatic ecosystems has been increasingly described using fish community size spectra.

Method

Study area-Tokyo bay

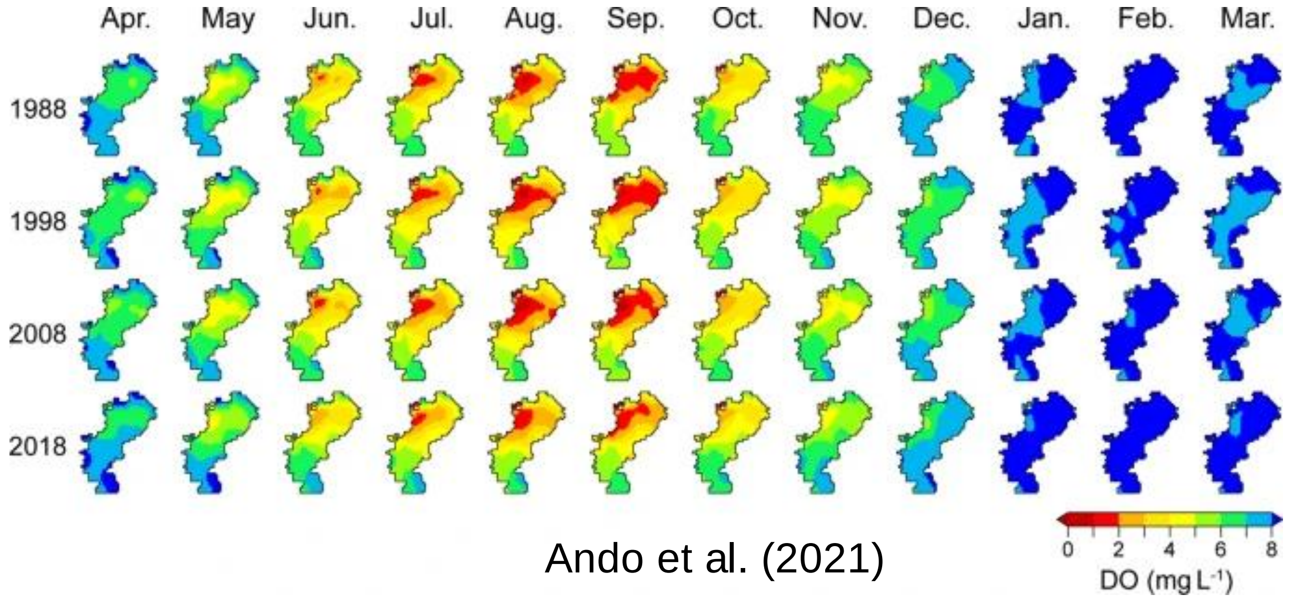


Surface area: 960 km^2
Mean depth: 19 m

Survey period:
1977-1995 and 2003-present (over 40 years)
Sampling method:
two 5-t bottom trawlers, with a 3-cm cod-end mesh net, twice or four times a year in different seasons
Sampling locations: 20 stations; each species was recorded by weight and counted

Environmental condition:

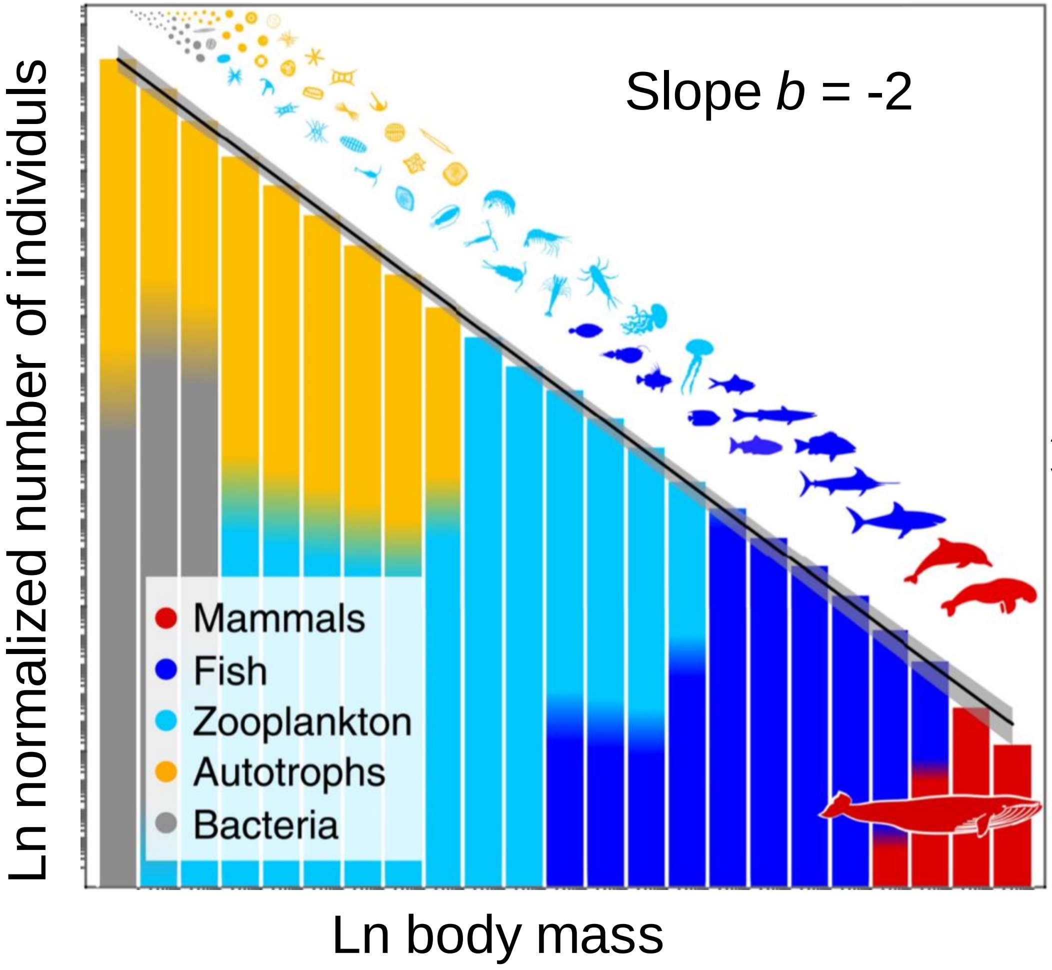
- Water temperature has been increasing over the past decades.
- Bottom water hypoxia occurs in the northern to central part of the bay during every summer.



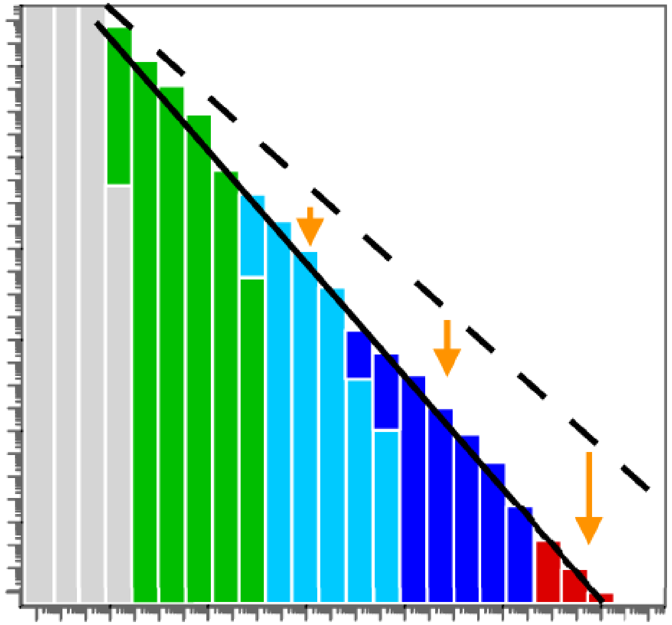
Ando et al. (2021)

Method

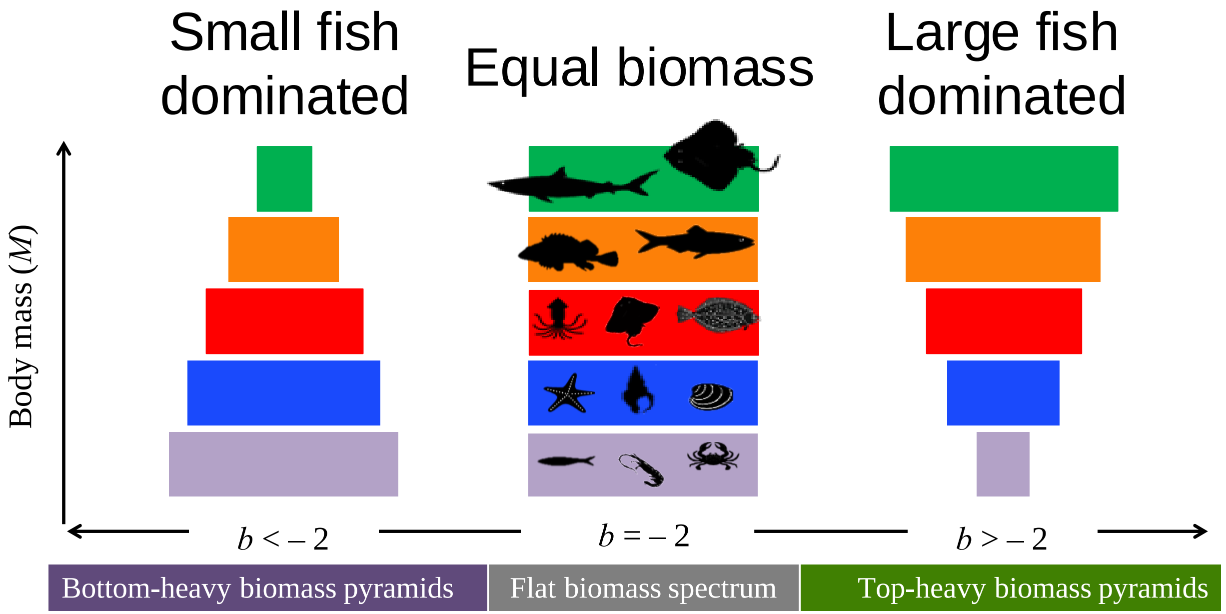
Fish size spectrum



Modified based on Hatton et al. (2021)

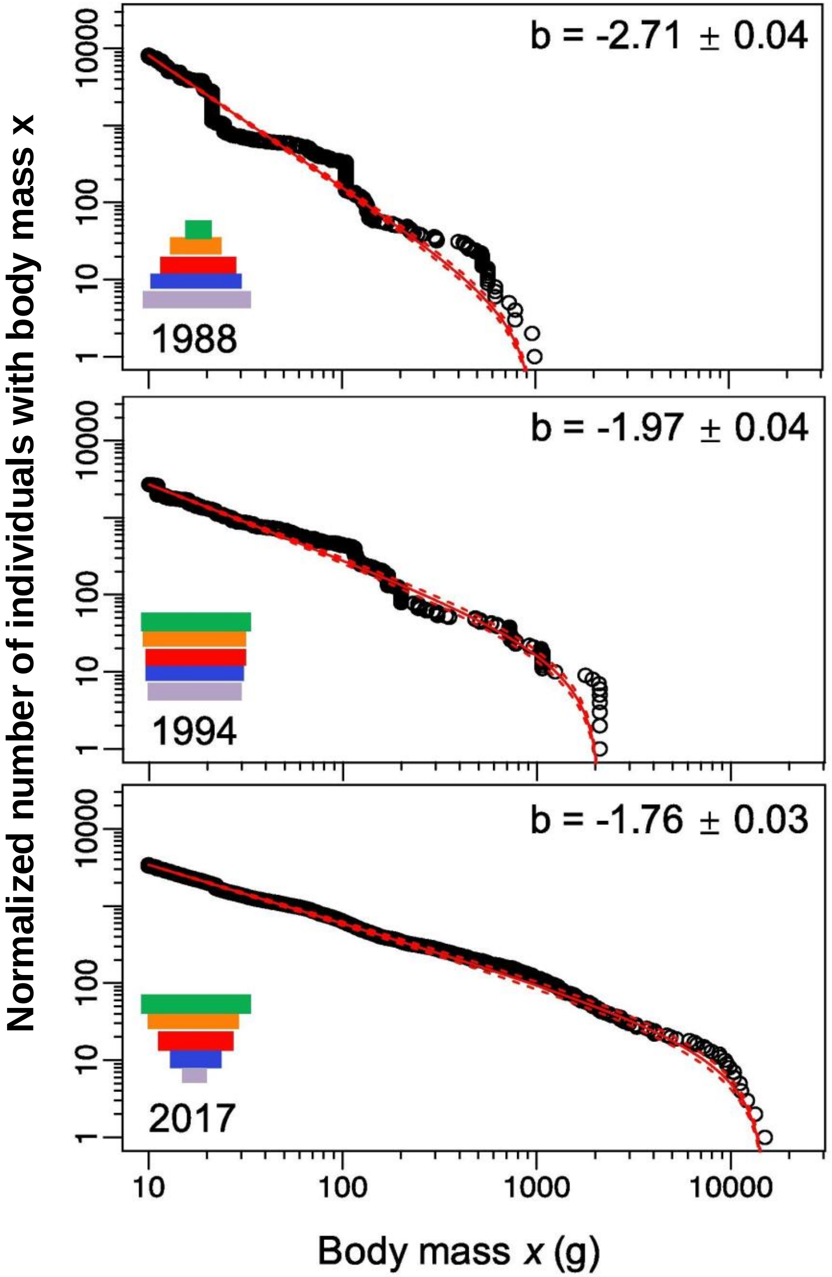


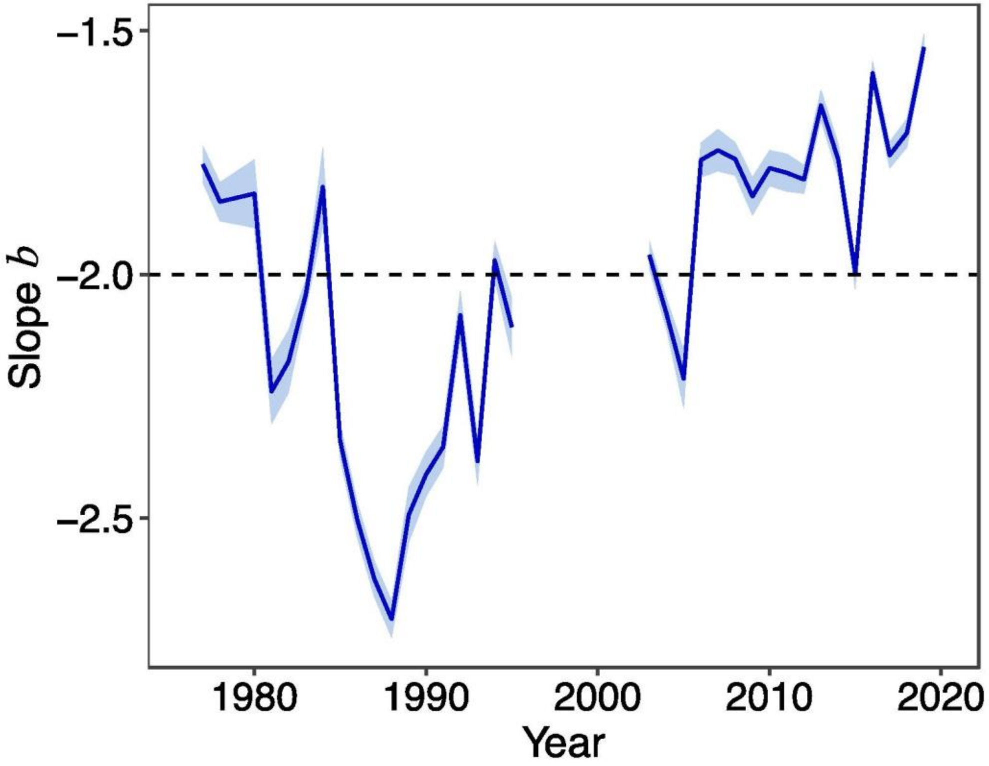
A healthy ecosystem generally have a size spectrum with a slope of -2. Human activities like fishing, which selectively target larger fish, can result in a steeper slope.



Result

The size spectrum and changes in its slope over the past decades





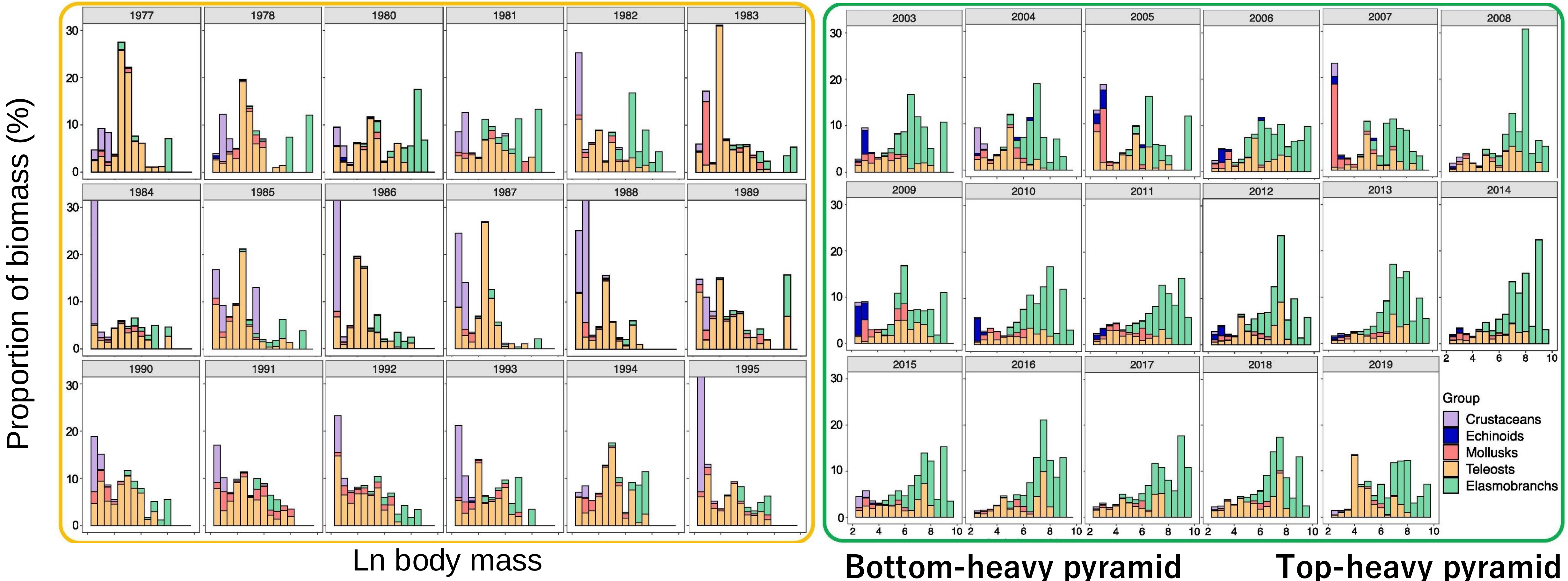
The slopes (denoted by *b*) differed significantly between the two sampling periods, with a steeper mean slope in 1977–1995 (–2.2) than in 2003–2019 (–1.8).

Xia et al. (2022) *Progress in Oceanography*

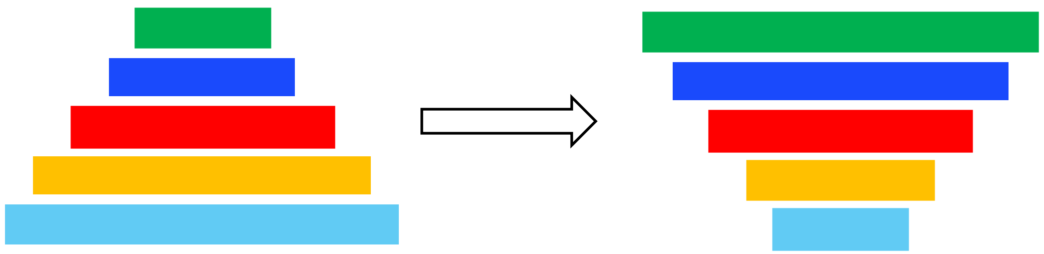
Result

Annual biomass distribution across size groups

Crustacean-dominated　　　　Elasmobranch-dominated



Bottom-heavy pyramid　　　　**Top-heavy pyramid**



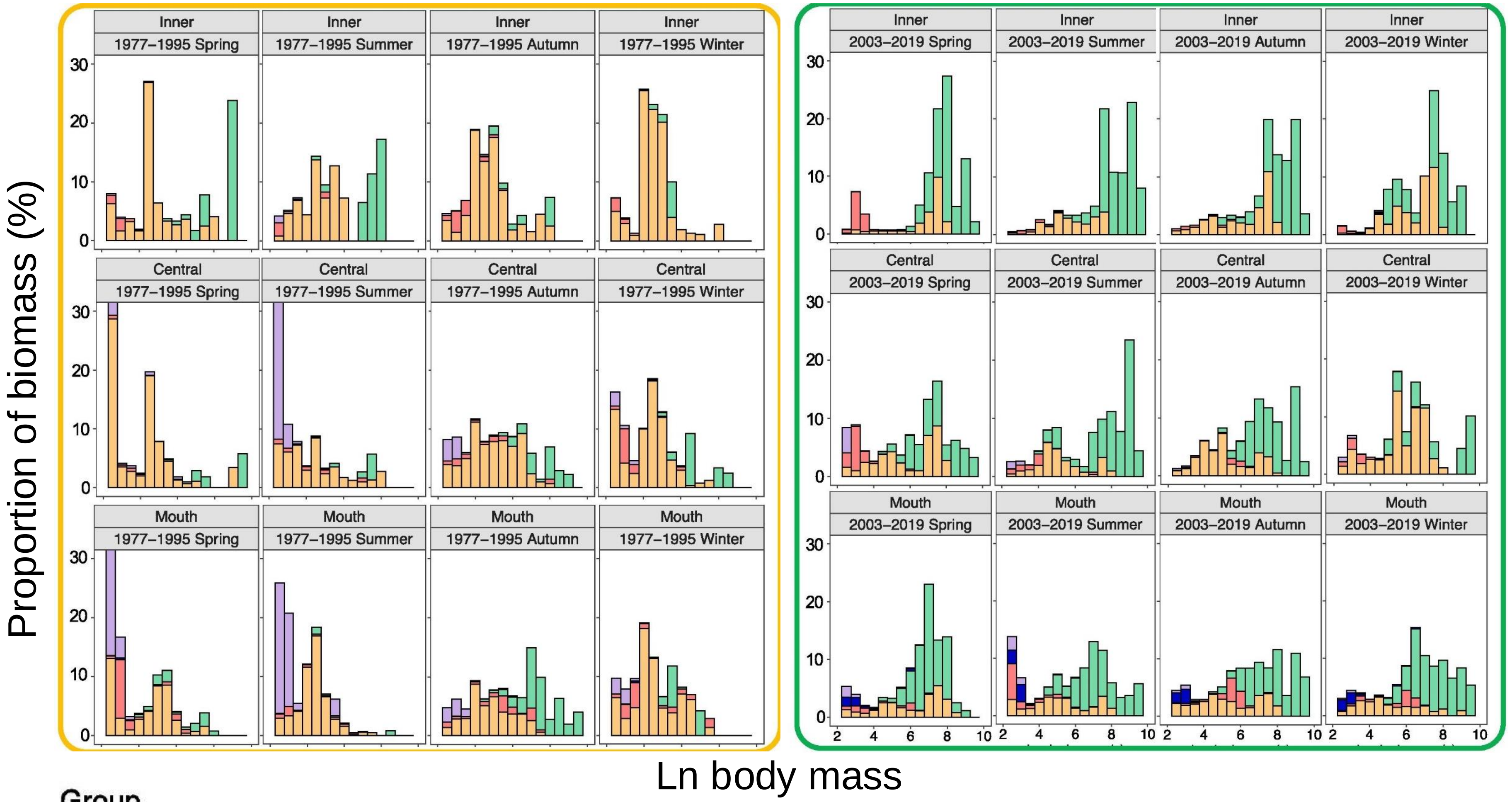
1977-1995　　　　**2003-2019**

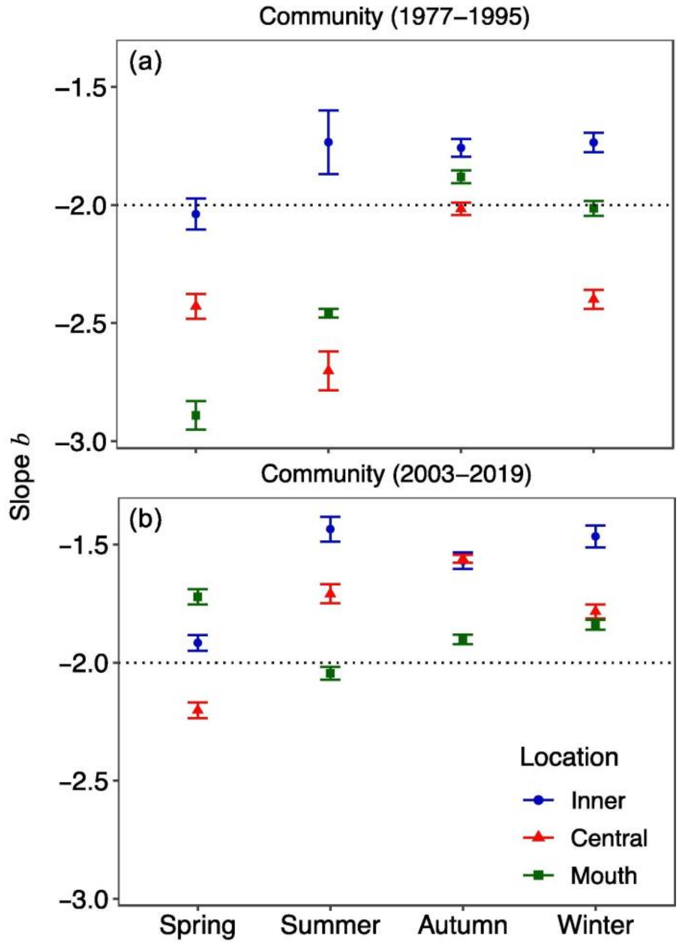
Demersal community has shifted from a bottom-heavy to a top-heavy structure, with a substantial **decline in small-sized crustaceans** and a significant **increase in large-sized elasmobranch fish**

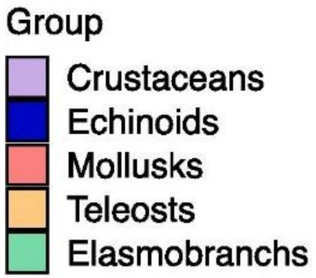
Xia et al. (2022) *Progress in Oceanography*

Result

Time-averaged biomass distribution across size groups by seasons







In 1977-1995, small fish and crustaceans were common in the central and mouth parts of the bay, while large fish were fewer and mostly found in the inner part, forming a bottom-heavy pyramid. In 2003-2019, large fish dominated, particularly in the inner part, creating a top-heavy pyramid.

Xia et al. (2022) *Progress in Oceanography*

Discussion

Question: Why is predator biomass increasing when prey biomass is decreasing?

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Hypotheses:

① Hypoxia promotes the formation of community top-heavy structures

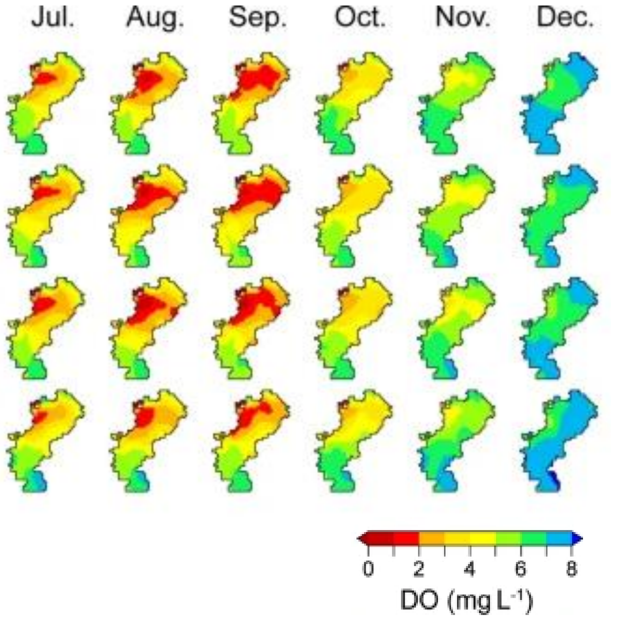
② Energy subsidies from the areas not covered by the bottom trawl survey and the pelagic community enhance the persistence of top-heavy structures

③ Top predators of feeding on relatively low tropic level organisms and/or exhibiting prey switching behavior on the basis of prey abundance

Discussion

Hypothesis ①: Hypoxia promotes the formation of community top-heavy structures

- Due to hypoxia, small-sized individuals in macrobenthic fauna are decimated or move southwards such as mantis shrimps.
- Similarly, the biomass of small-sized teleosts has decreased because their larvae and juveniles eat copepods, which have been declining since the 2000s.
- Large-sized individuals such as stingrays can endure hypoxia and survive.
- After the summer, the macrobenthic fauna started to recover from defaunation in the inner area of the bay as hypoxia began to abate, contributing to explaining seasonal variations in the slope.

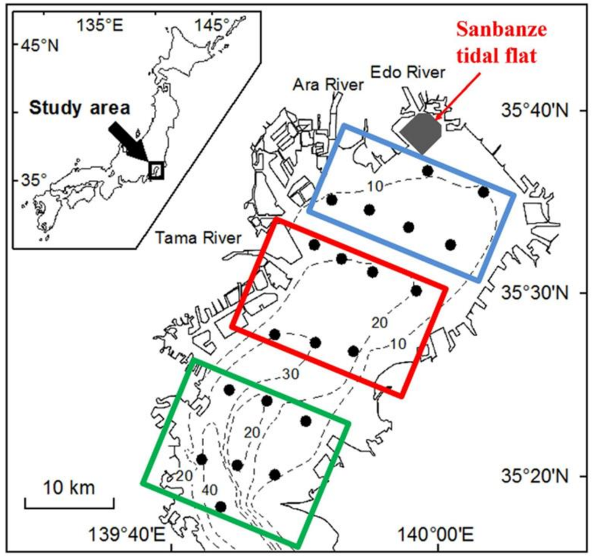


Ando et al. (2021)

Discussion

Hypothesis ②: Energy subsidies from the areas not covered by the bottom trawl survey and the pelagic community enhance the persistence of top-heavy structures

- Shallow waters with depths < 3 m and tidal flats are not hypoxic and are inhabited by short-neck clams; Alien hard clams was introduced into the bay during 1990s and distributed at high densities in the inner bay at depths < 3 m. These bivalves may provide energy subsidies for stingrays.



- Polychaete worms are widely distributed in the bay and have likely been supporting the stingray community in recent years.

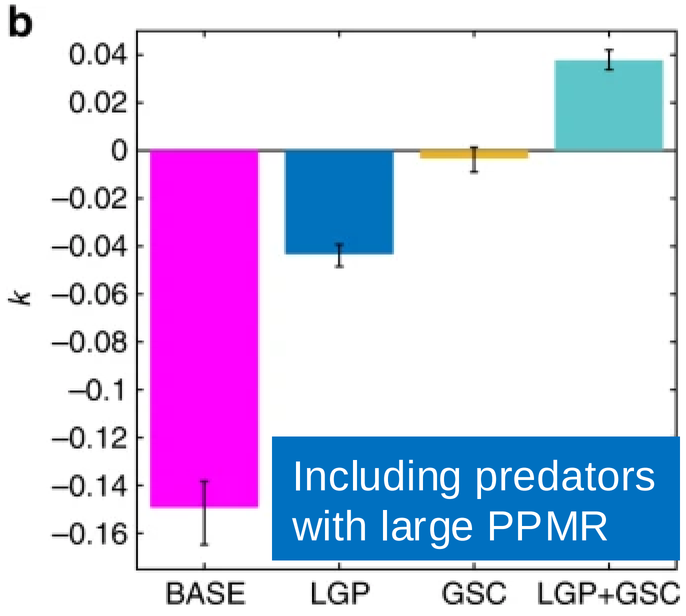
- Stingrays are likely to move southward into the outer bay area in search of food to compensate for the lack of prey in the inner area of the bay; small teleost fishes such as Japanese sardine were found in stingray stomach contents.

Discussion

Hypothesis ③: Top predators of feeding on relatively low tropic level organisms and/or exhibiting prey switching behavior on the basis of prey abundance

- Top predators such as stingrays and Japanese sea bass change the selection of prey species during seasons in response to prey abundance. For example, Japanese sea bass feeds on prey species such as anchovies and sardines but also invades shallow waters where small-sized prey such as shrimps and polychaete worms are abundant.

- Recent theoretical studies have shown that top-heavy pyramids are possible in aquatic communities where large predators feed on smaller prey, such as those with a predator-prey mass ratio (PPMR) of 10^6–10^8.



Woodson et al. (2018)

Summary

- We provide the first evidence that top-heavy pyramids can persist for decades as a regular pattern in marine communities when top predators are not fished.

- Human-induced hypoxia could promote the formation of top-heavy pyramids.

- Energy subsidies may contribute to the persistence of top-heavy pyramids.

- Stomach content analyses should be integrated to quantify those large predatory species' diet in pelagic or benthic systems; the movements of stingrays could be tracked with bio-loggers to help detect their feeding area.

- The implications will enable environmental administrators to formulate sound policies for the remediation of the urban bay ecosystem.