Spatio-temporal distribution pattern of *Calanus sinicus* and its relationship with climate variability in the northern Yellow Sea

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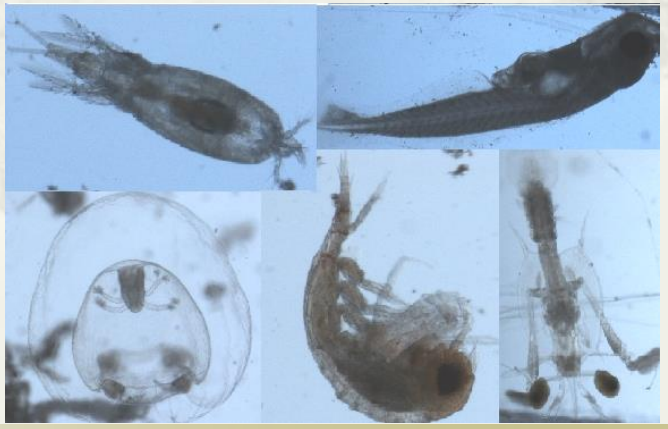
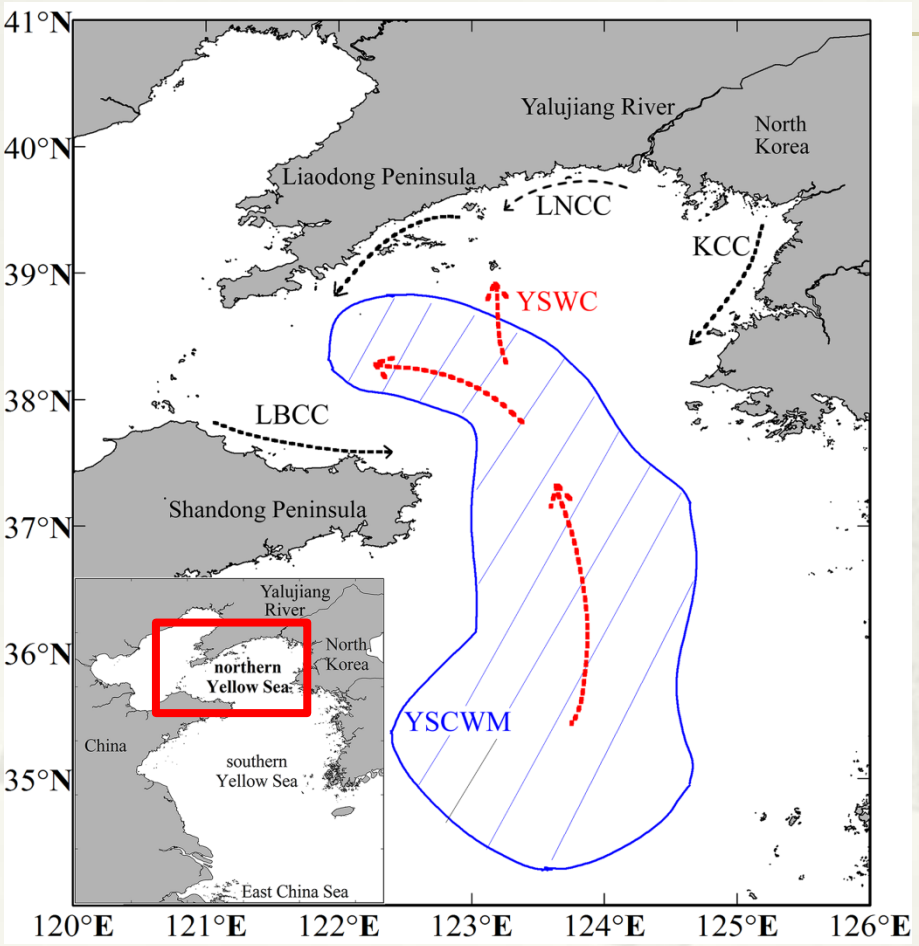
- Zooplankton are **beacons of climate change** because of their physiological sensitivity to temperature, the short life history tightly coupling with climate, the living style of passive floating with ocean currents, seldom commercially being exploited (Richardson 2008).

- Large-scale variations in zooplankton dynamics, including the **poleward movements** (Beaugrand et al. 2002; Lindley & Daykin 2005) and **earlier timing of life cycle events** (Edwards & Richardson 2004), have been widely observed over recent decades.



- In the eastern North Atlantic Ocean and European shelf seas, members of the **warm-water copepod** assemblages were found to have moved more than 1,100 km polewards, and the **colder-water copepod** has decreased in number of species during the period of 1958-2002 (Beaugrand et al. 2002).
- In the North Sea, the cool-water copepod *C. finmarchicus* has **retracted north** and been **replaced by the warm-water copepod** *C. helgolandicus* (Beaugrand et al. 2003).
- In the Central North Sea, some species of copepod **peaks 10 days earlier** in summer from 1958 to 2002 (Edwards & Richardson 2004).

Study area



- The northern YS is an important component of the **Yellow Sea Large Marine Ecosystem (YSLME)** and bordered by three countries - China, North Korea and South Korea.

Why focus on the northern YS?

- **Geographical importance**. The northern YS is a typical warm-temperate sea that is ***presumably sensitive*** to climate variability.
- **Previous findings.** The effects of climate variability on zooplankton have been observed recently in this area. The ***increased species richness of warm-water copepods*** compared to 1959 (Chen et al. 2015), and ***intrusion of warm-water species of zooplankton*** taxa (e.g., thaliacea *Doliolum denticulatum* and chaetognath S*agitta enflata*) into the northern YS (Yang et al. 2012; Franco et al. 2014).

Why choose *C. sinicus* as the target species?

1. **Critical ecological role**

- **Widely distributing** on the continental shelf of the Northwest Pacific Ocean and **dominates** the mesozooplankton in the Yellow Sea, the East China Sea, and the Inland Sea of Japan (Huang et al. 1993; Hulsemann 1994; Anon 1977).
- In the Northwest Pacific Ocean, *C. sinicus* was targeted as one of the "**key species**" in the China-GLOBEC (Global Ocean Ecosystem Dynamics) program (Tang et al. 2005).

2. Observed response of this species to climate change

- In the tropical Yangtze River Estuary, the timing of **abundance peak of *C. sinicus* shifted from June to May**, accompanying the increase of the sea surface water temperature (SST) (Xu et al. 2011).
- In the east part of the Southern Yellow Sea, its **population increased significantly in spring** of 1990s than 1980s, which was probably caused by the increase of SST and the reduction of predator on it (Kang et al. 2007).
- Former study (Yang et al. 2012) in the temperate northern Yellow Sea have showed that the **abundance of *C. sinicus* has significantly increased in autumn**.

Sampling methods

- Zooplankton samples were collected **by the vertical tows** from within 1m above the sea floor to the surface using a plankton net.
- Data were collected in **May, July, and October of 2011** and **January of 2014** at 18 fixed stations (Figure 2).

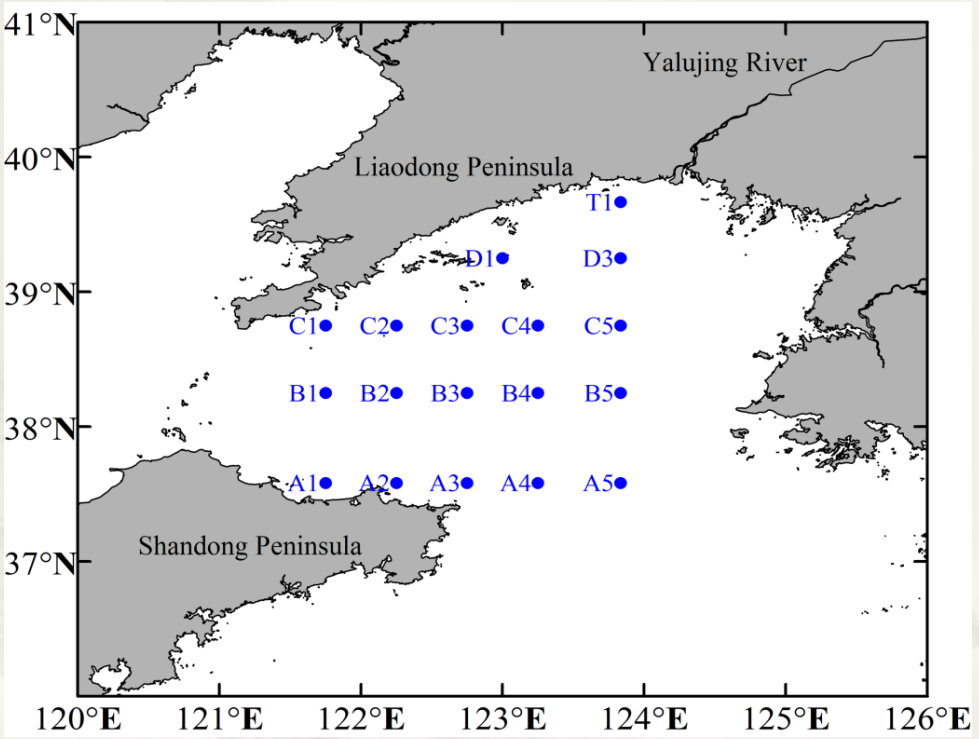


Fig. 2. Sampling stations in the northern Yellow Sea.

Hydrographical conditions

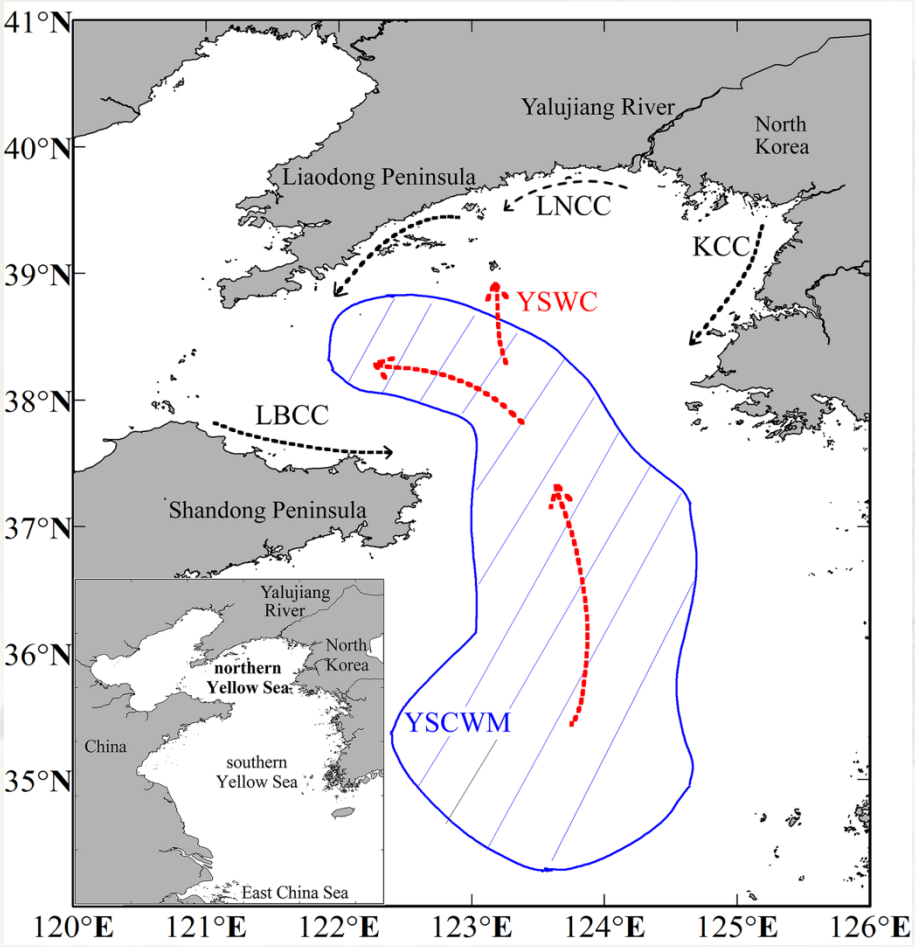


Fig.1. Main currents and water masses in the northern Yellow Sea (Shi et al. 2012).

- **warm season pattern** (mid-April to mid-November)
- **cold season pattern** (mid-November to mid-April)

- During summer, the **Yellow Sea Cold Water Mass (YSCWM)** resides the bottom of the central portion of the northern YS.

- The winter circulation pattern is characterized by the northward **Yellow Sea Warm Current (YSWC).**

Spatial distribution patterns

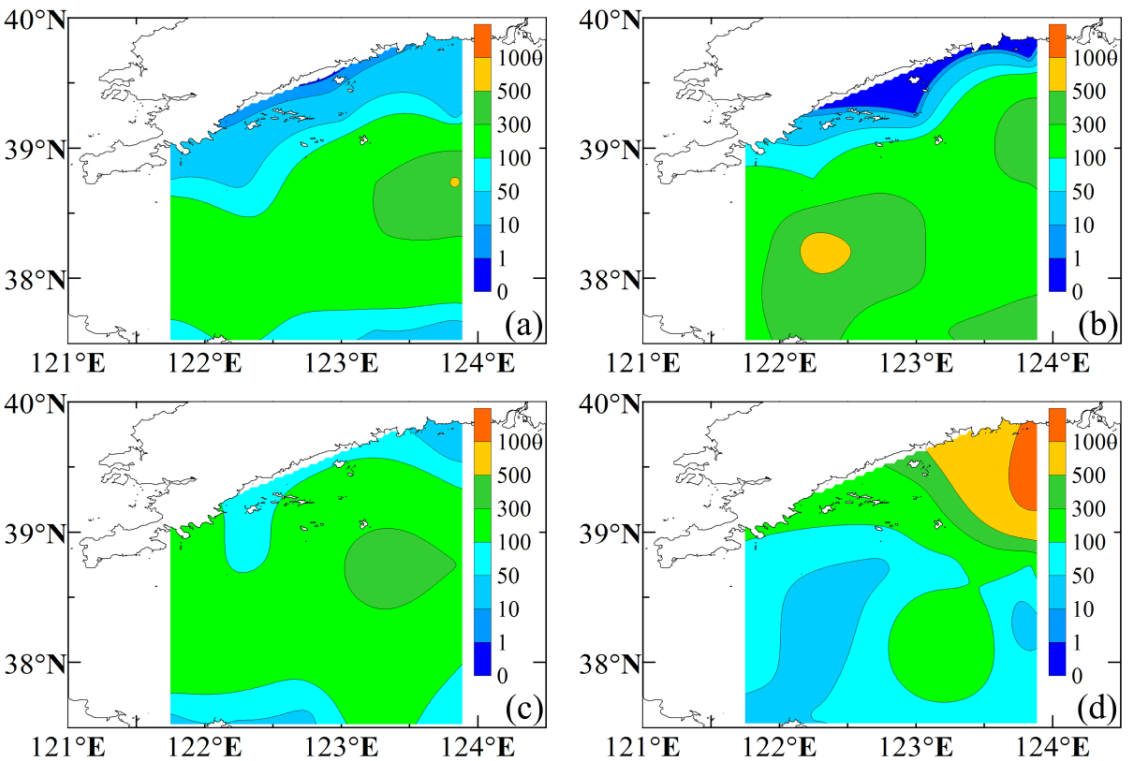


Fig. 3. Spatial distribution of the *C. sinicus* abundance (ind. m^{-3}) in the northern YS.

- In the **warm season** (e.g. May, July and October of 2011), the high abundance of this species occurred in the **central water masses** of the northern YS (Figure 3a-c).
- While in the **cold season** (e.g. January of 2014) the high copepod abundance appeared in **the nearshore area** of the northern YS (Figure 3d).

Interannual variations

- The abundance of *C. sinicus* was **significantly higher** in 2011-2014 than that in 1959 (p<0.05) and 1982 (p<0.05). The mean abundance was **5.5 times** as many as that in 1959.
- Similarly, the percentage of *C. sinicus* in zooplankton assemblages ranging from 45.6% to 75.8% in different seasons of 2011-2014 was **significantly higher than that in 1982** (p<0.05) with the percentage ranging from 13.6% to 32.4% .

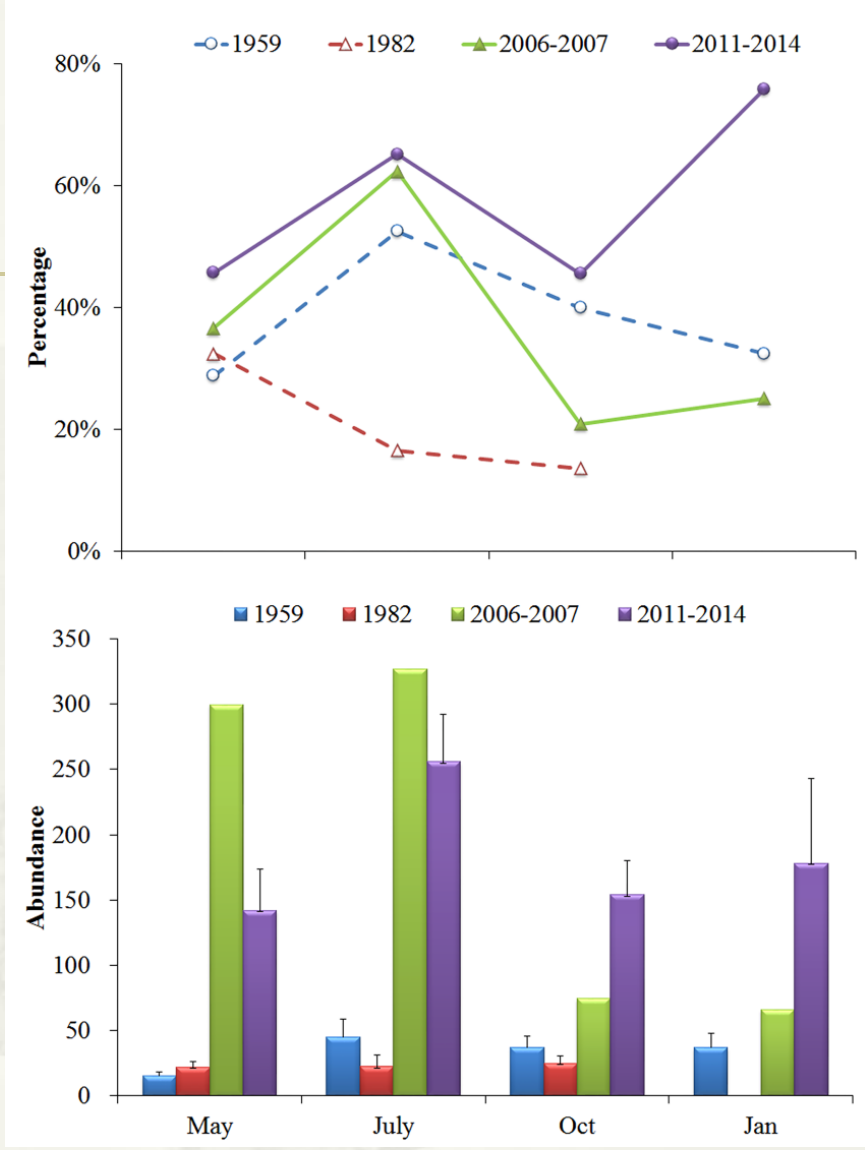


Fig. 4. Comparison on the **s**easonal abundance (ind. m^{-3}) and percentage of *C. sinicus* in the total zooplankton assemblages. *We compiled the historical data in 1959, 1982 and 2006-2007 (Zhu, 2008; Jiang, 2010).

Spatial comparisons

At a larger spatial scale:

- Compared with 1959, *C. sinicus* **in the northern YS became more abundant** in the summer of 2006 and spring of 2007, while its abundance **increased slightly in the southern YS**.
- **A greater increase of its abundance was observed in the northern portion of the YS** of its spatial distribution during the past half century.

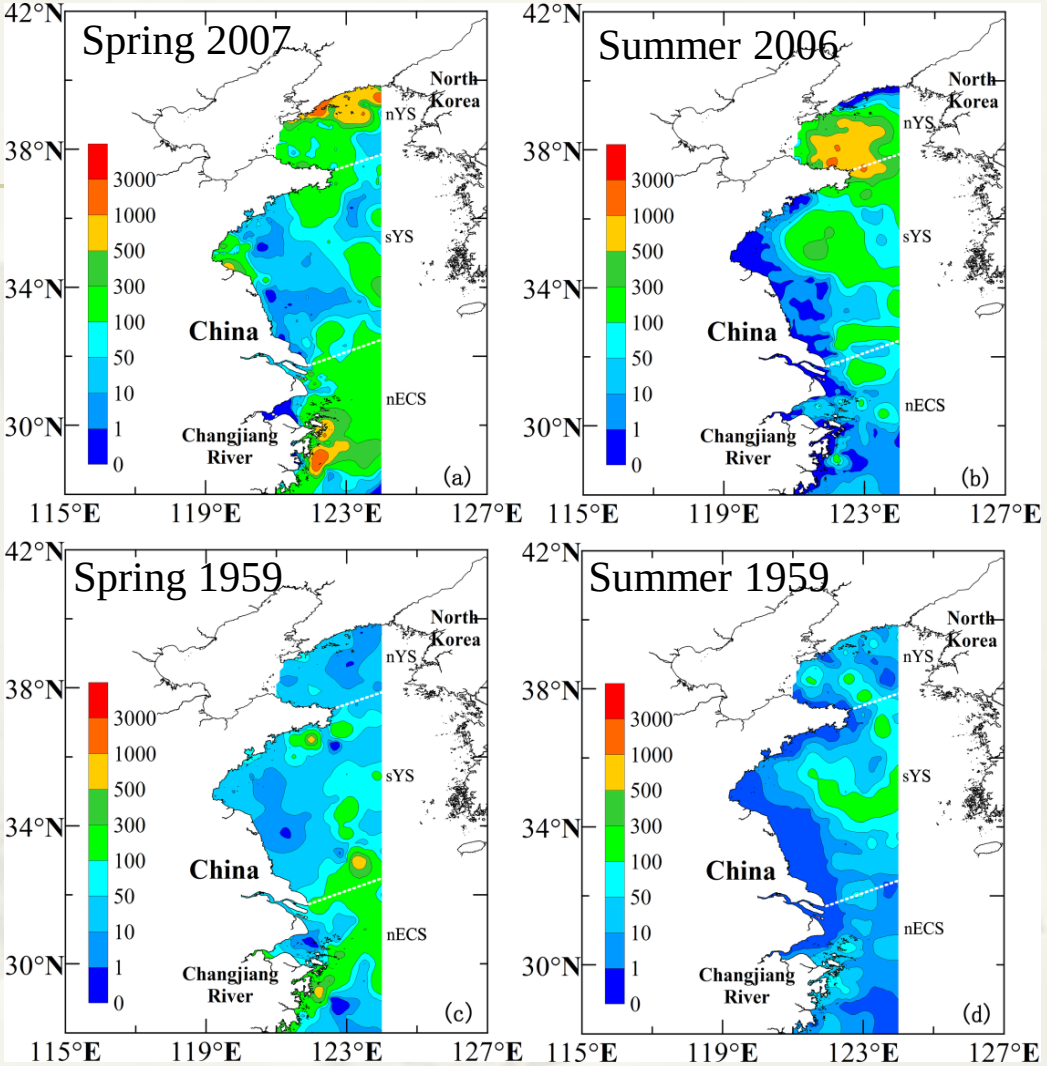


Fig. 5. Spatial distribution of the *C. sinicus* abundance (ind. m^{-3}) in the northern YS, the southern YS and the northern East China Sea. *Additional data sampled in the YS and the northern ECS by SOA of China in 1959, 2006-2007 were collected and analyzed.

Discussions

1. Relationships between the increasing SST and *C. sinicus* population

- Physiologically the lower and upper thermal limits for *C. sinicus* are 5°C and 23°C, respectively (Uye 1988). The **biomass** remains low at lower temperatures but gradually increases to a **maximum around 20°C** (Uye 2000).
- In the northern YS, the SST **was between <0°C and 20°C** throughout the year, **except in July-August** (Zhai et al. 2014).
- ***The increasing SST in the northern YS was likely more suitable for C. sinicus*** since the current SST (Zhai et al. 2014) was still below the optimum temperature for this species (Uye 2000) in most months of the year.

2. The Yellow Sea Cold Water Mass (YSCWM) in the central portion of the northern YS likely provides an important over-summering site for the species.

- **In the southern YS,** in July-August when the surface water temperature in the overall YS reaches the upper thermal tolerance, this species contracts its distribution area, occurs in the **YSCWM (≤10ºC)** (Wang et al. 2003; Pu et al. 2004).
- In this study, we found a **similar phenomenon** with high abundance occurring in the **YSCWM of the northern YS**, when the SST was above 20°C in July-August (Zhai et al. 2014). The YSCWM likely provides an **over-summering site** for *C. sinicus* populations, with **higher mean abundance in the northern YS** compared to that in the southern YS (see Fig. 5; Wang et al. 2003).

3. Climate-driven shifts in *C. sinicus* abundance and the ecosystem implications

- Large-scale variations of zooplankton assemblages in response to climate change have been widely studied (Beaugrand et al. 2002; Beaugrand 2003; Lindley & Daykin 2005; Beaugrand et al. 2009; Yoshiki et al. 2015).
- In general, **warm-water species** tend **to extend northward** in the latitudinal range of the distribution causing the increase of the species number or/and abundance (e.g. Beaugrand *et al*. 2009; Yoshiki *et al*. 2015), whereas **temperate-water species and cold-water species** exhibit **diverse responses** depending on areas and species (e.g. Batten & Walne 2011; Yoshiki *et al*. 2015).

- In the **subtropical** Changjiang River Estuary of the ECS, the **timing of abundance peak** of the species has advanced from June to May (Xu et al. 2011).
- In comparison, in this study **the seasonal abundance and percentage of *C. sinicus* had increased significantly** in the **warm-temperate** northern YS during the past half century, *highlighting the increasing importance of this key species in the warm-temperate ecosystem*.

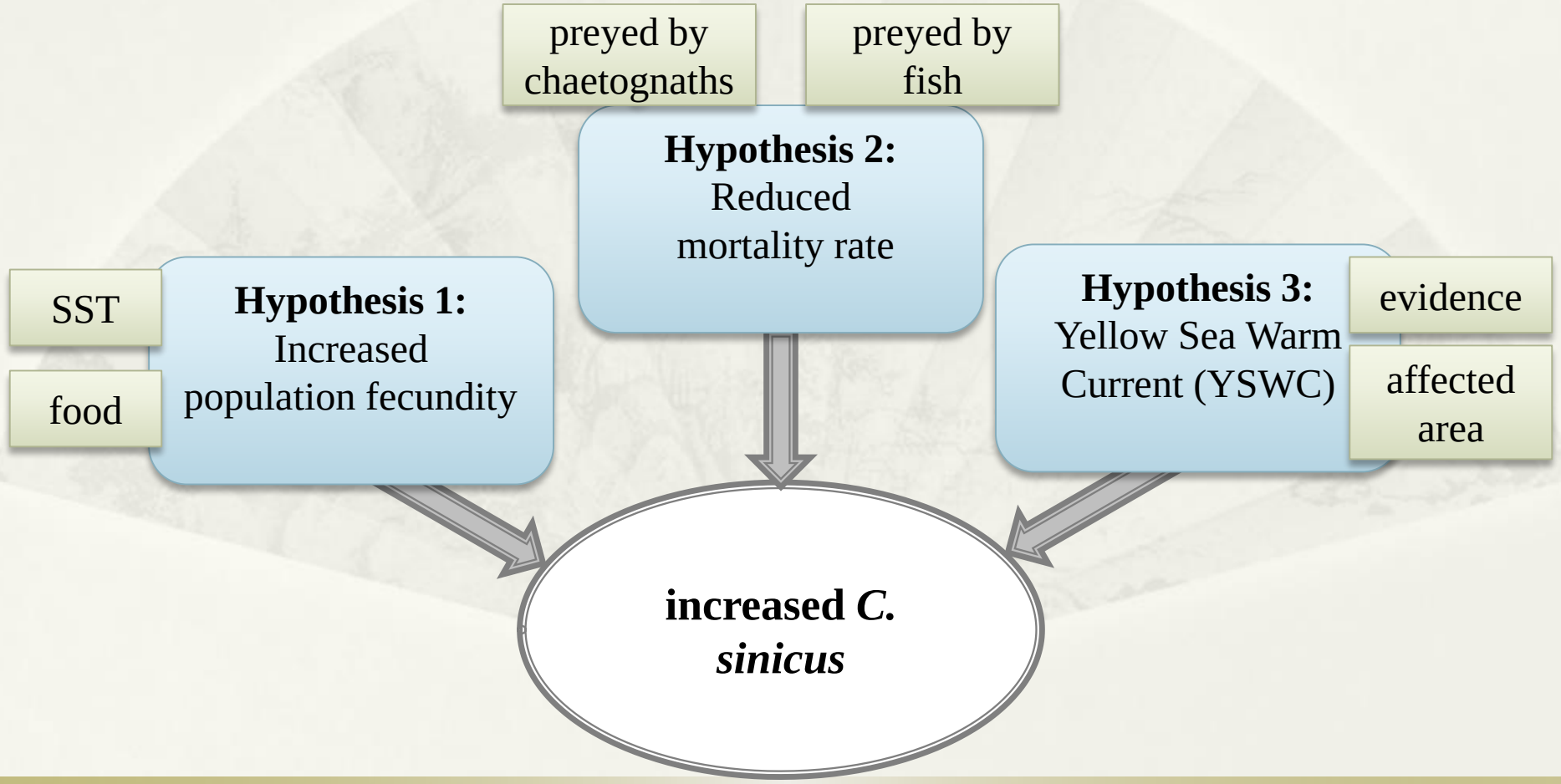
Different response models to climate change between subtropical and temperate seas

Still many unknown questions……

- Due to limited data available in the study we were unable to identify :
  1. whether there is a shrinking spatial habitat of the species at the southern edge?
  2. the relationship between the increased *C. sinicus* abundance and fish.
  3. the relationship between the increased *C. sinicus* abundance and large-scale hydrological process.
  4. ……

What to do in the future?

- What caused the population of *C. sinicus* to increase greatly in the northern YS in the past half century?



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Original Article

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Thank you for your attention!

Questions?***cindyyang81@hotmail.com***