Xiao Wang*, Xin-Ming Pu and Ping Liu

Seasonal Variability of *Calanus Sinicus* Brodsky in the Western South Yellow Sea

**Abstract:** Inter-disciplinary investigations were conducted in the WSYS in 2006–2007 to study the spatial and temporal variations of *Calanus sinicus* and its influencing factors. The distribution of *C. sinicus* in summer varied from that in spring in accordance with the change of the temperature. The species aggregated in the YSCWM to elude the high abundance in the surface and coastal waters. In autumn, the bottom-up effect played a crucial role in the population size. The abundance at the stations in and adjacent the oceanic front was also relatively high. In winter, the highest abundance presented in Haizhou Bay which was related to the entrainment of the YSWC. The abundance was low south of 35 °N thanks to the transportation of the YSWC and the YSCC and relatively high abundance north of 35 °N was related to the jacking effect of the YSWC.

**Keywords:** Distribution pattern; Seasonal variability; *Calanus sinicus*; South Yellow Sea

1 Introduction

*Calanus sinicus* Brodsky is comprehensively studied in the northwest Pacific Ocean thanks to its extensive distribution[1] and common dominance in zooplankton community [2–3]. Meanwhile, it is the main part of diets of predators with different sizes. Since it was chosen as the target species of China GLOBEC, its distribution in summer [4], life history strategy [5], feeding [6] and reproduction [7] were studied in details in the western South Yellow Sea (WSYS).

The Yellow Sea (YS) is a main population centre of this copepod. The complicated hydrographical conditions affected the ecosystem in different seasons in the WSYS, i.e., the coastal currents, including Yellow Sea Coastal Current (YSCC), the Lubei Coastal Current (LCC) and Subei Coastal Current (SCC), Yellow Sea Cold Water Mass (YSCWM), Changjiang River Diluted Water (CDW) and Yellow Sea Warm Cur-
rent (YSWC) [8]. Researches have shown that the presence of the YSCWM plays an important role in maintaining the population in the WSYS [4,9], while little has known about the effects of hydrographical conditions in other seasons. In this study, we investigate the distribution and the influence of environmental factors, especially the hydrographical conditions, on the spatial and temporal variations of *C. sinicus* based on the yearly inter-disciplinary surveys in 2006–2007 which has been the most detailed in the WSYS until now to our knowledge.

## 2 Materials and Methods

We conducted an annual multidisciplinary comprehensive investigation from July, 2006 to November, 2007 in the western SYS (Fig. 1). Sampling methods of zooplankton and environmental factors refered to Wang et al. 2012 [10].

To better understand the regional distribution and the effects of different environmental conditions on *C. sinicus*, we further divide the sampling area into four subregions, that is the coastal area of Shandong Peninsula (region I), Jiangsu coastal area (region III), mixing area in the south of the surveyed area (region IV) and offshore area (region II)(Fig. 1). The offshore area was determined by the sea bottom temperature (SBT) in summer 2006 where the SBT was < 12 °C.

![Fig. 1: Surveyed area (subarea) and sampling stations in the western SYS in 2006–2007](image-url)
3 Results

3.1 The Abundance of *C. sinicus* in Different Seasons

The average of was 99.59±13.15 ind.m$^{-3}$, accounting for 38.95 % of total zooplankton abundance. In summer, the mean abundance was 89.70±8.26 ind. m$^{-3}$ lower than that in spring, but the proportion of the total abundance was 54.17 %, higher than that in spring. Its average abundance and the proportion in total abundance were even lower in autumn, 44.30±5.89 ind. m$^{-3}$ and 28.33 %, respectively. The abundance was lowest in the wintertime, with the an average merely 21.16±2.88 ind. m$^{-3}$, but due to the low total abundance, the proportion in total abundance was higher, up to 37.17 % (Table 1).

Tab. 1: The abundance of *C. sinicus* in different seasons

<table>
<thead>
<tr>
<th>Seasons</th>
<th>Abundance (mean±SE) (ind. m$^{-3}$)</th>
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<tbody>
<tr>
<td>Spring</td>
<td>99.59±13.15</td>
</tr>
<tr>
<td>Summer</td>
<td>89.70±8.26</td>
</tr>
<tr>
<td>Autumn</td>
<td>44.30±5.89</td>
</tr>
<tr>
<td>Winter</td>
<td>21.16±2.88</td>
</tr>
</tbody>
</table>

3.2 Distribution and Seasonal Variations of *C. Sinicus*

The distribution pattern of the species showed apparent distinction in different seasons and sea area. Higher abundance occurred in the coastal area of Shandong Peninsula, the south and southeast part and the abundance was lower than 50, and even 10 ind. m$^{-3}$ in other areas in spring (Fig. 2a). In summer, the abundance was generally >100 ind. m$^{-3}$where the YSCWM existed except that in the northeastern part. The isoline of 50 ind. m$^{-3}$ was just about in accordance with the isotherm 12 °C (Fig. 2b). The distribution pattern in autumn was more or less the same as that in summer. In the coast of Shandong and Jiangsu Province, the abundance was generally lower than 10 ind. m$^{-3}$. Higher abundance occurred in the central, southern and southeastern part of the study area (Fig. 2c). During the wintertime, highest abundance was found in the Haizhou Bay. In the south of 35 °N, the abundance was < 30 ind. m$^{-3}$ and even lower than 10 ind. m$^{-3}$ in most sea area. Conversely, it was generally higher north of 35 °N except the sea area off Shidao (Fig. 2d).

Abundance in different investigated area varied as the season. That in region Ⅲ was minimum in spring, summer and autumn, but was second only to region Ⅱ in winter. It was always the second of the region Ⅳ in spring, summer and autumn;
however, it was the lowest in winter. The abundance in region I was maximum in spring, but invariably lower than the other two region in summer, autumn and winter. The abundance in region II was maximum in summer, autumn and winter, however, it was evidently lower than region I and region IV in spring (Fig. 3).

Fig. 2: Horizontal distribution of C. sinicus in the western SYS in 2006–2007 (a-spring; b-summer; c-autumn; d-winter)
4 Discussion

The water temperature was 10–18 °C when the species was in its flourishing period of propagation [11]. The average temperature in surveyed area in spring was about 10 °C (Fig. 4a) which was suitable for the proliferation of the species except region I where the water temperature was < 10 °C. Together with the comparatively higher Chl a concentration produced by the phytoplankton spring bloom (Fig. 4a), the environmental factors in most sea area were appropriate for the reproduction of *C. Sinicus*. The distribution of *C. sinicus* was quite uneven in spring: The average abundance was highest in region I, especially in nearshore area and the northeastern part with the abundance > 100 ind. m\(^{-3}\) (Fig. 2a). Oceanic fronts usually have boundary effects and other influences on the the pelagic biogeography [12]. The existence of the oceanic front during the springtime might well play a boundary effect on the expansion of *C. sinicus* population from northeast of region I to region II (Fig. 2a). Besides the local recruitment, the entrainment by the LCC from northern seas contributed to the high abundance in the northeast of region I.

The abundance in region IV was also high where was affected by the northerly SCC, YSCC and the southerly CDW, TWC. The abundance was high (> 100 ind. m\(^{-3}\) in
the transitional area of SCC and CDW, lower (50-100 ind. m$^{-3}$) in the place influenced by YSCC and lowest (< 50 ind. m$^{-3}$) where was affected by SCC or TWC (Fig. 2a).

Zhang and Jin [13] suggested that in spring, *Engraulis japonicus* had a prominent predation on *C. sinicus*. Consequently, the low abundance (< 10 ind. m$^{-3}$) in the southwest of Shandong Peninsula covering southwestern part of region I and northwestern part of region II, might be probably related to the stronger feeding pressure of *E. japonicus*. Due to the influence of the river runoff of Jiangsu Province, like Sheyang River et al., the low salinity and relatively higher temperature SCC extended east- or southeastward and confluence with the northerly cold water (Fig. 2a-b) which constituted the main body of the YSCC. Therefore, the lower abundance of *C. sinicus* in region III might be related to the entrainment of the SCC and YSCC.

In summer, the temperature exceeded the upper thermal limit of *C. sinicus* (Fig. 4b) except where was affected by the YSCWM. The species aggregated inside the YSCWM to avoid the detrimental temperature [4], therefore, the abundance in region II was undoubtedly the highest (Fig. 3b). The region II was a place with highest abundance and lowest Chla concentration. The whole sea areas in summer was not suitable for the population recruitment of *C. Sinicus* thanks to either the deleterious temperature outside the YSCWM or the low food provided inside the YSCWM. The existence of YSCWM is merely provide an over-summering place for the population maintenance, not for recruitment, which could also be speculated by the decreased abundance in summer than that in spring (Fig. 2b).
Autumn is a transitional period between warm and cold season when the YSCWM shrinks, the stable vertical temperature structure begins to vanish and the embryonic form of the YSWC shapes [14]. The abundance in autumn decreased definitely comparing that in spring and summer (Fig. 2a-c). The abundance in region I and region IV varied little, and the distinction was primarily from that in region II affected by the YSCWM. The Chl a concentration remained low (< 0.5 mg. m⁻³) in region II in autumn (Fig. 4c), which was adverse to *C. sinicus* that exposed to the environment with low food availability since summer. Otherwise, external food supply was related to the gonad mature and reproduction of *C. sinicus* [7], therefore, the population could not be recruited immediately with the rising temperature in autumn under the circumstance of low food availability, but might have been threatened by low food concentration since summer which was the leading cause for the decline of the abundance.
The abundance in winter was lowest which was merely about 20% of that in spring. During winter investigation, the temperature was $< 10^\circ C$ except region II, which was not appropriate for the proliferation of *C. sinicus* [11]. Otherwise, the species could be brought into the South China Sea by China Costal Current (CCC) in winter when the northeast monsoon prevails [3,15]. Therefore, the lowest abundance in winter was also related to the hydrographical conditions.

### 5 Conclusion

The distribution pattern of *C. sinicus* varied spatially and seasonally which was determined by both biological and physical conditions. In spring, thanks to the adequate food availability and favorable water temperature, the proliferation of *C. sinicus* began and high abundance occurred in region I, region IV and southeast of region II and lowest in region III. The low abundance in spring was attributed to top-down effect (predation by *E. japonicus*) and physical conditions (barrier by oceanic front; entrainment by SCC and YSCC). The abundance decreased in region I thanks to the relatively high temperature in the surface and coastal area. The presence of the YSCWM in region III provided an ideal refuge for *C. sinicus* to avoid the high temperature in surface and coastal area. The southerly CDW and TWC was closely correlated to the high abundance area in region IV. In autumn, the population in region II shrank evidently which was probably related to the long-term low level of Chl a. Otherwise, the abundance at the stations in the oceanic front was usually high in autumn. As the prevail of the north wind, the YSWC was prosperous which was relevant to the higher abundance in region III, especially in Haizhou Bay. The entrainment of the YSWC and YSCC was related to the low abundance south of 35 °N and the relatively high abundance north of 35 °N was probably the jacking effect of the YSWC.

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**References**


