Zooplankton Community Structure and Seasonal Variation in the Yangtze River Estuary and Adjacent Waters: Postprint

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Abstract

Based on survey data collected from 150 stations across four seasons during 2006-2007 in the Yangtze River estuary and adjacent waters (29°30' N-32°30' N, 120°00' E-127°30' E), this study investigated the zooplankton community structure, species composition, dominant species, and their seasonal variations. The results demonstrate that the zooplankton community in the Yangtze River estuary and adjacent waters possesses rich species diversity. A total of 460 zooplankton species were identified throughout the four seasons, belonging to 7 phyla and 246 genera; in addition, 54 types of planktonic larvae were recorded. Among these taxa, Copepoda constituted the most dominant group, comprising 193 species (41.96%); Amphipoda ranked as the second dominant group with 51 species (11.09%); and Hydromedusae was the third dominant group with 34 species (7.39%). Species diversity of zooplankton exhibited pronounced seasonal variation, following the pattern: summer (317 species) > autumn (309 species) > spring (230 species) > winter (138 species). Calanus sinicus and Sagitta bedoti served as the dominant species across all four seasons in the Yangtze River estuary and adjacent waters. The zooplankton assemblage could be broadly categorized into five ecological groups: nearshore low-salinity group, eurythermal and euryhaline group, low-temperature high-salinity group, high-temperature euryhaline group, and high-temperature high-salinity group. Correlation analysis between zooplankton community abundance and environmental factors, incorporating synchronous hydrological and hydrochemical data, revealed that salinity represents the primary environmental factor influencing zooplankton community abundance in the Yangtze River estuary and adjacent waters.

Full Text

Preamble

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Seasonal Variation in Zooplankton Community Structure in the Changjiang Estuary and Its Adjacent Waters

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Abstract

Seasonal variation of zooplankton community structure, species composition, and dominant species were determined based on samples collected from 150 stations during four research cruises in the Changjiang Estuary and its adjacent waters (29°30 N—32°30 N, 120°00 E—127°30 E). The study was conducted from July to August 2006 (Summer), December 2006 to February 2007 (Winter), April to May 2007 (Spring), and October to December 2007 (Autumn). The mesoscale study areas were positioned from the Changjiang Estuary to the transition area where freshwater from the Changjiang plume and offshore water masses, such as the Kuroshio and its branches, mix with each other.

In total, 460 species of zooplankton belonging to 246 genera and 18 groups from seven phyla, together with 54 types of pelagic larvae, were identified in the Changjiang Estuary and its adjacent waters during four seasons. The 18 groups of zooplankton included Hydromedusae, Siphonophora, Scyphomedusae, Ctenophora, Polychaeta, Cladocera, Copepoda, Ostracoda, Isopoda, Mysida, Cumacea, Amphipoda, Euphausiacea, Decapoda, Chaetognatha, Appendicularia, Thaliacea, and pelagic Mollusca. The most dominant group of zooplankton was Copepoda, including 193 species and accounting for 41.96% of the total species. Amphipoda ranked second, with 51 species accounting for 11.09% of the total species. Hydromedusae was the third dominant group of zooplankton with 34 species and accounted for 7.39% of the total species.

There was considerable seasonal and spatial variation in the community structure of zooplankton in the Changjiang Estuary and its adjacent waters. More zooplankton species were found in summer (317 species and 43 types of pelagic larvae) and autumn (309 species and 28 types of pelagic larvae) than in spring (230 species and 27 types of pelagic larvae) and winter (138 species and 21 types of pelagic larvae). The number of species increased gradually from the inshore to offshore waters and from north to south during all seasons.

There were seasonal changes in dominant species in the Changjiang Estuary and its adjacent waters: in spring and winter, dominant species was replaced by *Zonosagitta bedoti*; *Calanus sinicus* and *Centropages dorsispinatus* was the most dominant species, but in summer and autumn, the most dominant species were *Calanus sinicus* and *Subeucalanus subcrassus*, respectively. Only were dominant in all four seasons. Based on species composition and ecological distribution, the zooplankton community in the Changjiang Estuary and its adjacent waters could be divided into five ecological groups, including the coastal brackish water, eurythermal euryhaline, hypothermal hypersaline, hyperthermal euryhaline, and hyperthermal hypersaline group. The dominant species were distributed primarily in the coastal brackish water group and eurythermal euryhaline group.

Furthermore, we measured environmental factors and determined the responses of zooplankton community to the factors, including temperature, salinity, concentration of suspended matter, and concentration of chlorophyll. Results of Pearson' s correlation analysis revealed that the most important environmental factor influencing changes in zooplankton community structure in the Changjiang Estuary and its adjacent waters was salinity. Furthermore, the Changjiang diluted water introduced a large number of nutrients, which was beneficial to the growth of plankton, but the estuarine turbidity limited the distribution of zooplankton.

Keywords: Changjiang Estuary; zooplankton; community structure; dominant species; seasonal variation

1. Survey Area, Sampling, and Analysis Methods

Surveys were conducted during four seasonal cruises in the Changjiang Estuary and its adjacent waters (29°30 N–32°30 N, 120°00 E–127°30 E): spring (April-May 2007), summer (July-August 2006), autumn (October-December 2007), and winter (December 2006-February 2007). A total of 150 observation stations were established in the survey area.

For zooplankton field sampling, we used a HYDRO-BIOS plankton net with a mesh size of 0.505 mm. For water depths less than 30 m, vertical tows were performed from bottom to surface using a net with 50 cm mouth diameter and 145 cm length. For water depths greater than 30 m but less than 200 m, vertical tows from bottom to surface were conducted using a net with 80 cm mouth diameter and 280 cm length. For stations deeper than 200 m, double-layer vertical tows were performed: one from 200 m to surface, and another from bottom to 200 m. Each net was equipped with an imported flowmeter (E-Flow) to measure filtered water volume. Collected samples were fixed and preserved in 5% formaldehyde solution. In the laboratory, debris was removed from samples, zooplankton biomass was weighed using an electronic balance (Sartorius CP124S), and species identification and individual counting were performed under a stereomicroscope. All field sampling and laboratory analysis procedures followed the Technical Regulations for Marine Biological and Ecological Investigation [14].

Synchronously observed parameters included water temperature, salinity, suspended matter concentration, and chlorophyll concentration. Sampling and analysis of these parameters were conducted according to the Technical Regulations for Marine Biological and Ecological Investigation [14], Technical Regulations for Marine Chemical Investigation [15], and Technical Regulations for Marine Meteorological Investigation [16].

[Figure 1: see original paper] Sampling stations in Changjiang Estuary and adjacent areas

2. Data Processing

This study used Surfer 11.0 mapping software to plot survey station maps and horizontal distribution maps of zooplankton species numbers. Pearson correlation analysis was performed on zooplankton abundance and environmental factors using SPSS 20.0. Environmental factors included surface temperature, bottom temperature, surface salinity, bottom salinity, surface suspended matter concentration, bottom suspended matter concentration, and chlorophyll a concentration.

Dominant species were determined based on the dominance index (Y) for each species [17]: $Y = (ni/N) \times fi$, where ni is the individual number of species i, N is the total individual number of all species, and fi is the occurrence frequency. Species with $Y > 0.02$ were identified as dominant species.

1. Community Structure and Seasonal Variation of Zooplankton in the Changjiang Estuary and Adjacent Waters

A total of 460 zooplankton species were identified across four seasons in the Changjiang Estuary and its adjacent waters. Copepoda was the most dominant group, accounting for 41.96% of total species, followed by Amphipoda (11.09%) and Hydromedusae (7.39%). Other groups included 54 types of pelagic larvae.

The species composition of zooplankton communities showed significant seasonal variation. Summer was the most species-rich season with 317 zooplankton species (68.91% of annual total) and 43 types of pelagic larvae. High species numbers were found in the estuary mouth area, east of Zhoushan Islands, and the continental shelf of the northeastern East China Sea, while low values occurred in Hangzhou Bay and the inner Changjiang River section. Species numbers increased from inshore to offshore and from north to south.

Autumn ranked second in species richness with 309 species (67.17% of annual total) and 28 types of pelagic larvae. Species numbers remained high across most areas, particularly in the estuary mouth, east of Zhoushan Islands, and the northeastern continental shelf.

Spring had 230 species (50.00% of annual total) and 27 types of pelagic larvae, while winter had the lowest richness with only 138 species (30.00% of annual total) and 21 types of pelagic larvae. The spatial pattern of increasing species numbers from inshore to offshore and from north to south was consistent across all seasons.

Seasonal variation and composition of zooplankton community in the Changjiang Estuary and its adjacent waters (Jul. 2006 to Dec. 2007)

2. Ecological Groups of Zooplankton Communities

In estuarine and coastal waters, environmental variables and human activities affect zooplankton community distribution and spatiotemporal variation. Riverine runoff carries abundant biogenic materials, causing changes in nearshore nutrient concentrations that alter zooplankton species diversity and dominant species succession [18]. Based on marine planktology literature [19-23] and the adaptability of zooplankton to temperature, salinity, and environment, we classified zooplankton in the Changjiang Estuary and adjacent waters into five ecological groups:

Coastal brackish water group: This diverse group includes *Labidocera euchaeta*, *Paracalanus aculeatus*, and *Acartia pacifica*. It is primarily distributed in nearshore low-salinity waters and the inner Changjiang River section, representing the main ecological group in this sea area. A few species belong to estuarine low-salinity and freshwater species, such as *Pseudodiaptomus poplesia* and *Tortanus vermiculus*.

Eurythermal euryhaline group: This numerically dominant group includes *Calanus sinicus*, *Subeucalanus subcrassus*, and *Zonosagitta bedoti*, widely distributed in the mixing zone of different water masses in the Changjiang Estuary and present across all four seasons.

Hypothermal hypersaline group: This group has few species and low abundance, appearing infrequently mainly in middle and deep layers. Representative species such as *Paraeuchaeta russelli* and *Euphausia pacifica* appear in the East China Sea region with upwelling of deep water and the Yellow Sea Cold Water Mass.

Hyperthermal euryhaline group: This group has low abundance but wide distribution, often appearing in warmer summer and autumn seasons. Representative species include *Calocalanus pavo* and *Labidocera sinilobata*.

Hyperthermal hypersaline group: These temperature- and salinity-tolerant species are widely distributed in waters influenced by the Taiwan Warm Current and Kuroshio, with rich species diversity. Representative species include *Euchaeta concinna*, *Euchaeta plana*, and *Flaccisagitta enflata*.

[Figure 2: see original paper] Seasonal variation and distribution of zooplankton species number in Changjiang Estuary and its adjacent waters

3. Seasonal Variation of Dominant Zooplankton Species

The dominant zooplankton species in the Changjiang Estuary and adjacent waters showed clear seasonal succession. *Calanus sinicus* and *Zonosagitta bedoti* were dominant throughout all four seasons.

In spring, dominant species included *Calanus sinicus* (dominance index $Y = 0.399$, mean abundance 158.6 ± 425.9 ind./m^3), *Paracalanus aculeatus* ($Y = 0.028$), and *Zonosagitta bedoti* ($Y = 0.026$). As water temperature increased and Changjiang River discharge grew, species diversity increased while dominance concentration decreased significantly.

In summer, *Centropages dorsispinatus* became the dominant species ($Y = 0.105$, mean abundance 17.7 ± 45.1 ind./m^3), with *Subeucalanus subcrassus* as the first dominant species ($Y = 0.077$, mean abundance 4.8 ± 17.2 ind./m^3). The dominance concentration reached its lowest seasonal value (0.105) as warm offshore species entered the study area.

In autumn, *Subeucalanus subcrassus* remained the first dominant species, while *Calanus sinicus* dominance decreased ($Y = 0.253$) but remained among the dominant species. *Zonosagitta bedoti* ($Y = 0.079$), *Euchaeta plana* ($Y = 0.068$), and *Flaccisagitta enflata* ($Y = 0.055$) were also dominant.

In winter, *Calanus sinicus* regained dominance ($Y = 0.399$) with *Zonosagitta bedoti* ($Y = 0.047$) and *Labidocera euchaeta* ($Y = 0.041$) as co-dominants, and dominance concentration gradually recovered.

Seasonal variation of dominant zooplankton species in the Changjiang Estuary and its adjacent waters (Jul. 2006 to Dec. 2007)

4. Seasonal Variation of Environmental Factors in the Changjiang Estuary and Adjacent Waters

Environmental factors in the Changjiang Estuary and adjacent waters showed significant seasonal variation. Water temperature exhibited distinct seasonal patterns, with surface and bottom temperatures being similar in all seasons except summer when bottom temperature was noticeably lower than surface temperature.

Salinity showed clear seasonal variation, with surface salinity being significantly higher than bottom salinity in spring and summer. The seasonal pattern of suspended matter concentration revealed that average surface concentration was lowest in summer, while average bottom concentrations in spring and autumn were significantly higher than surface values. In other seasons, the difference between surface and bottom suspended matter concentrations was minimal.

Chlorophyll a concentration also varied seasonally, with the highest average values occurring in summer.

Seasonal variation of physical, chemical, and biological characteristics in the Changjiang Estuary and its adjacent waters (Jul. 2006 to Dec. 2007)

5. Relationship Between Zooplankton Abundance and Environmental Factors

Pearson correlation coefficients between zooplankton abundance and environmental factors are presented in Table 4. In spring, zooplankton abundance showed extremely significant positive correlations with temperature and salinity ($P < 0.01$), and a significant negative correlation with suspended matter concentration ($P < 0.05$). In summer, abundance showed extremely significant negative correlations with surface temperature and suspended matter concentration ($P < 0.01$), and significant positive correlations with salinity and chlorophyll a concentration ($P < 0.05$). In autumn, abundance showed extremely significant positive correlations with salinity and chlorophyll a concentration ($P < 0.01$), and extremely significant negative correlations with suspended matter concentration ($P < 0.01$). In winter, abundance showed extremely significant negative correlations with salinity ($P < 0.01$) and significant positive correlations with chlorophyll a concentration ($P < 0.05$).

These results indicate that salinity is the primary environmental factor influencing zooplankton community abundance distribution in the Changjiang Estuary and adjacent waters.

Relationships between zooplankton abundance and environmental variables in the Changjiang Estuary and its adjacent waters (Jul. 2006 to Dec. 2007)

3. Discussion

3.1 Zooplankton Community Structure and Dominant Species

This study identified 460 zooplankton species, with Copepoda, Amphipoda, and Hydromedusae as the dominant groups, accounting for 41.96%, 11.09%, and 7.39% of total species, respectively. These results are consistent with historical reports [5-13]. However, our study area, covering from the inner Changjiang River section to the offshore continental shelf, is substantially larger than previous investigations that focused primarily on nearshore waters west of 124°E. This broader spatial coverage explains why our species richness is significantly higher than previously reported. For example, Wang et al. [9] studied seasonal variation in the Changjiang Estuary and found different patterns, likely because their survey was limited to nearshore areas west of 123°E, which cannot fully represent the zooplankton community structure in the Changjiang diluted water diffusion zone.

The dominant species composition was dominated by copepods, with chaetognaths also being important. Ecological groups were primarily eurythermal euryhaline and coastal low-salinity species. In autumn, high-temperature high-salinity warm-water species such as *Euchaeta plana* and *Flaccisagitta enflata* frequently appeared, consistent with the year-round influence of Kuroshio and Taiwan Warm Current waters in the southeastern and southern parts of the study area.

Calanus sinicus was the first dominant species in spring and winter with very high dominance, consistent with previous winter and spring surveys [7,9]. However, in summer and autumn, its dominance decreased to 0.253 and 0.399, respectively, and its position as first dominant was replaced by *Centropages dorsispinatus* and *Subeucalanus subcrassus*. This differs from some reports where *Calanus sinicus* remained the first dominant in autumn [8,12], primarily because our study area is much larger, and regional environmental characteristics of the Changjiang Estuary and diluted water area affect statistical results.

The Three Gorges Project began river closure in 2009 and was completed in 2009. Studies on its ecological impacts on the Changjiang Estuary have been reported [8,11,24]. Liu et al. [8] and Chen et al. [11] compared zooplankton community structure before and after the first phase of water storage, finding that species numbers increased rather than decreased, with no significant changes in community structure. Our study, comparing with historical data before the second phase of water storage, similarly indicates that zooplankton species diversity remains high with an increasing trend, and community structure has not changed significantly. However, zooplankton community structure and diversity reflect fluctuations in marine ecosystems, and the changing ecosystem of the Changjiang Estuary and adjacent waters requires continued long-term monitoring.

3.2 Influence of Environmental Factors on Zooplankton Communities

The Changjiang Estuary and adjacent waters form a unique marine physicochemical environment under the combined influence of Changjiang diluted water, Taiwan Warm Current, and Jiangsu-Zhejiang coastal current. Zooplankton community distribution is closely related to water temperature, salinity, and nutrients [25]. Correlation analysis between environmental factors and zooplankton abundance revealed that salinity is the primary factor affecting zooplankton community abundance distribution, consistent with results from Xu et al. [7], Liu et al. [8], and Chen et al. [11] for the Changjiang Estuary and nearby waters.

Our survey covered the area from the Changjiang River mouth to the diluted water diffusion zone, influenced by both river runoff and offshore waters, creating significant spatial environmental differences. Salinity gradients from the estuary to open sea affect community structure in two ways: in areas dominated by Changjiang diluted water with relatively low salinity, the community is dominated by estuarine and low-salinity species; in offshore high-salinity areas east of 123°E influenced by Kuroshio and its branch (Taiwan Warm Current), high-temperature high-salinity species dominate. In summer and autumn when Kuroshio is strong, offshore warm-water species such as *Euchaeta plana* and *Flaccisagitta enflata* expand toward nearshore areas. Studies on the Pearl River

Estuary [26] and the Seine Estuary in the English Channel [27] also demonstrate that salinity is a crucial factor controlling zooplankton communities in estuarine waters.

The Changjiang Estuary is a large muddy delta where the river carries massive amounts of sediment annually. Hydrodynamic processes create a maximum turbidity zone with high suspended matter concentrations [28]. Our results show that in summer, when suspended matter concentration is lowest and chlorophyll a concentration is highest, zooplankton abundance is positively correlated with chlorophyll a. However, in autumn when suspended matter concentration is high and chlorophyll a is low, abundance is negatively correlated with suspended matter and positively correlated with chlorophyll a. While Changjiang diluted water carries abundant nutrients that promote phytoplankton growth, excessively high suspended sediment concentrations reduce water transparency and limit light availability for phytoplankton, thereby inhibiting zooplankton growth and reproduction. This is consistent with findings by He et al. [29] and Du et al. [30]. Deniz Özkundakci et al. [31] also demonstrated that suspended sediment affects feeding by filter-feeding zooplankton.

Temperature is also an important factor affecting zooplankton abundance, particularly in spring and summer. Increased water temperature promotes zooplankton growth and reproduction, as shown by studies in the East China Sea [32] and Changjiang Estuary [12]. However, when surface water temperature becomes too high in summer, it becomes unfavorable for zooplankton metabolic processes. Some species have summer dormancy mechanisms; for example, *Calanus sinicus* lives in the bottom cold water mass for two months during summer with distinct dormancy characteristics [33], which may explain why it was not the first dominant species in summer despite being present. The relatively low bottom water temperature in summer provides a refuge for such species.

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Note: Figure translations are in progress. See original paper for figures.