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Latitudinal distribution of zooplankton communities in the Western Pacific along 160°E during summer 2014

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ABSTRACT

A total of 51 mesozooplankton samples collected with a WP2 net from 0 to 200 m depth along 160°E (4°S–46°N) in the Western Pacific from June to July 2014 were analyzed. The latitudinal distribution of mesozooplankton community structure was analyzed. The average biomass and abundance in different provinces generally increased with latitude: the biomass of zooplankton ranged from 1.18 mg DW m^{-3} (11°N) to 97.81 mg DW m^{-3} (45°N), and the abundance of zooplankton ranged from 45.11 ind. m^{-3} (3°S) to 439.84 ind. m^{-3} (41°N). The community structure of zooplankton also showed a significant latitudinal variation. At lower latitudes, calanoid copepods were the most abundant group, while cyclopoid copepods were the most abundant group at higher latitudes. Multidimensional scaling analysis of community structure and other physical/chemical/biological characteristics supported five ecological provinces in the northwestern Pacific: the Western Pacific Warm Pool Province (WARM), the North Pacific Tropical Gyre (NPTG), the North Pacific Subtropical Gyre (NPST), the Kuroshio Current Province (KURO) and the Pacific Subarctic Gyres Province (PSAG). The Kuroshio Current Province can be regarded as a transitional zone between the subarctic and northern subtropical area, and this transitional zone corresponds much more closely to the ecocline concept, rather than the ecotone concept.

1. Introduction

Zooplankton are known to be among the most important primary consumers in pelagic ecosystems, and they always play a central role by linking primary producers and higher trophic levels (Batten et al., 2001; Huskin et al., 2001). In the western Pacific Ocean, most ecological investigations about the mesozooplankton community focused on the marginal seas of China and Japan (e.g. Hirota and Hasegawa, 1999; Sun, 2012). In the open sea, the studies on tropical and subtropical oceans were significantly less than those concerning high latitude oceans (mainly about subarctic region and the transition region of the Oyashio Current and the Kuroshio Current), mainly because of the significance of fish resources at higher latitude (Yamaguchi et al., 2002; Chiba et al., 2006; Chiba et al., 2009). Compared with the Atlantic Ocean and the eastern Pacific Ocean (Woodd-Walker, 2001; Woodd-Walker et al., 2002; Mackas et al., 2007), the knowledge of large-scale patterns of mesozooplankton diversity and community structure in the western Pacific Ocean are still rather limited (Nagai et al., 2015; Yamaguchi et al., 2015).

In the past decades, many efforts have been devoted to understand the biogeographic patterns of plankton community. One classical approach of marine biogeography was the taxonomic classification, which indicated a geographical division based on the relationship and distribution pattern of plankton community, usually controlled by a small number of dominant species (Brinton, 1962; Semina, 1997). Although a large number of global and regional studies often indicated various and more detailed geographical divisions, the traditional "9-belt system" (Arctic, Subarctic, Northern Transitional, Northern Subtropical, Tropical, Southern Subtropical, Southern Transitional, Subantarctic and Antarctic) seems to be the most commonly accepted theory based on a wide variety of organisms for the global ocean (Boltovskoy, 1998). The other method was the non-taxonomic classification. The most influential study was established by Longhurst (1995): based on the physical-chemical processes and seasonal response of phytoplankton dynamics to such processes, he established four primary biomes (Polar, Westerlies, Trades, Coastal biomes) of the upper ocean, and further divided them into a total of 51 secondary compartments, named "Province" (Longhurst, 2007). According to both frameworks of Boltovskoy and Longhurst, the Kuroshio region was regarded as a transtitional zone between the "warm ocean" (the tropical and subtropical Pacific) and the "cold ocean" (the arctic and subarctic Pacific). However, direct evidences for this transtitional zone from large-scale zooplankton community structure were still few.

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In the western Pacific Ocean, the large-scale biogeographic pattern, especially the latitudinal variation of plankton community was studied by several authors. The spatial distribution of phytoplankton pigments along 175°E (from 8°S to 48°N) was studied by Suzuki et al. (1997). They found that the abundance of prokaryotic phytoplankton in the North Pacific Subtropical Gyre was spatially and temporally variable, rather than a homogeneous and stable biological community. Along the same transect, the net-phytoplankton biomass was studied by Han et al. (2004). They found that the latitudinal variation of total chlorophyll *a* concentration, net-phytoplankton chlorophyll *a* concentration and its relative proportion was in accordance with four main water masses of the western Pacific Ocean. Nagai et al. (2015) analyzed the latitudinal distribution of chaetognaths along 137°E (from 3°N to 34°N), and found that the latitudinal gradient of the community was significant from the equatorial Pacific to the Kuroshio Current area. In addition, the latitudinal variations of zooplankton community along 155°E (from 34°N to 44°N) and in the Pacific western boundary currents area (from 3°N to 23°N) were also investigated recently (Yamaguchi et al., 2015; Dai et al., 2016). The above investigations illustrate that the latitudinal gradient of the plankton community is generally significant, but two aspects of our knowledge are still lacking. One is the ecological characteristics of north transitional zone, which is located between the Subarctic and Northern Subtropical area according to the "9-belt system"; another is the ecological difference between the Northern Subtropical area and Tropical area (the Western Pacific Warm Pool).

In this study, based on 51 mesozooplankton samples collected along 160°E in June to July 2014 from 0 to 200 m depth between 4°S and 46°N, we analyzed the latitudinal variations of mesozooplankton abundance, biomass, community structure and environmental variables. In addition, we also assessed the ecotone/ecocline concept in the north transitional zone between the subarctic and northern subtropical area.

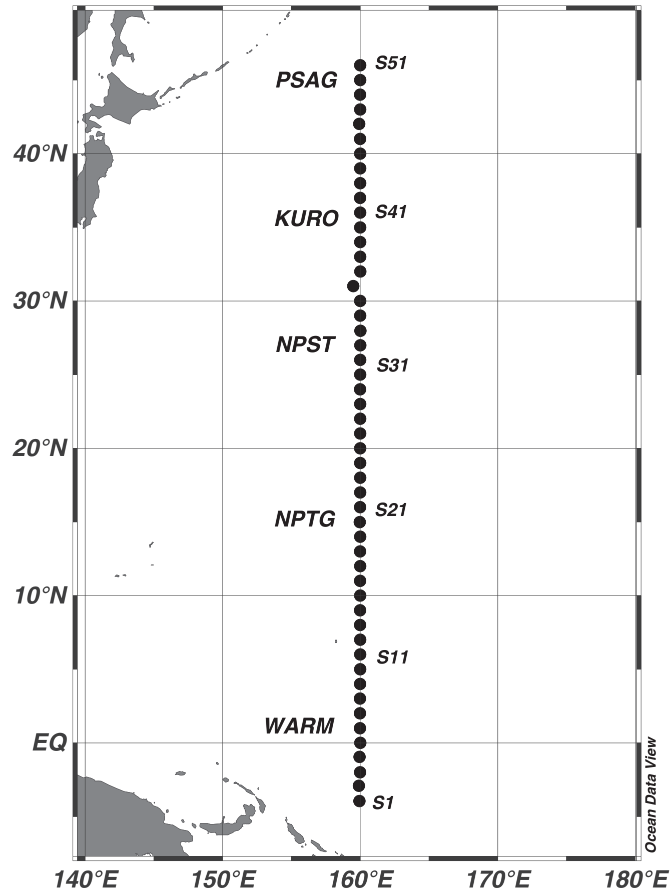

Fig. 1. Map showing sampling stations along the 160°E (4°S–46°N). Five ecological provinces along the line according to Longhurst (2007) were marked as follows: WARM (Western Pacific Warm Pool Province), NPTG (North Pacific Tropical Gyre Province), NPST (North Pacific Subtropical Province), KURO (Kuroshio Current Province) and PSAG (Pacific Subarctic Gyres Province). In Figs. 2, 3, 5 and Table 1, NPTG and NPST were combined into an integral province (North Pacific Subtropical Gyre Province, NPSG), to follow the customary of most oceanographers.

2. Materials and methods

2.1. Field sampling

Fifty-one stations were sampled by the R/V *Xiangyanghong 10* in the western Pacific Ocean along 160°E (between 4°S and 46°N) from June 11 to July 7, 2014 (Fig. 1). Five ecological provinces along the line according to Longhurst (2007) were as follows: WARM (Western Pacific Warm Pool Province, 12°S–10°N, approximately), NPTG (North Pacific Tropical Gyre Province, 10°N–32°N, approximately), NPST (North Pacific Subtropical Province, 32°N–35°N, approximately), KURO (Kuroshio Current Province, great variation in range seasonally, 35°N–45°N, approximately) and PSAG (Pacific Subarctic Gyres Province, north of 45°N, approximately). As argued by Longhurst (2007), the NPST, the north part of the central gyre, is characterized by a strong winter mixture, whereas in summer, both the NPST and NPTG water masses are weakly mixed. Considering that our investigation was conducted in summer, we combined NPTG and NPST into an integral province, named North Pacific Subtropical Gyre Province (NPSG), following the customary of most oceanographers.

Zooplankton samples were collected by the vertical tow of a two-paralleled WP2 net (mesh size of 200 μm, mouth area of 0.25 m^2) from 200 m depth to the sea surface. The two-paralleled WP2 net was equipped with two flowmeters (Hydro-Bios Co. Ltd.) in the mouth to record the volume of water filtered. Zooplankton samples were preserved immediately in 5% (v/v) buffered formalin-seawater solution.

Temperature and salinity were recorded using a CTD system (SBE 911 plus, Seabird Co. Ltd.) at each station. Seawater used for the analysis of chlorophyll *a* (Chl *a*) and total inorganic nitrogen (TIN) concentration was collected from 2 m, 30 m, 75 m, 100 m, 150 m depths. These samples were filtered through Whatman GF/F filter (nominal pore size, 0.7 μm). Chlorophyll *a* on each filter was measured using a Trilogy Laboratory Fluorometer (Model 7200, Turner Designs Co. Ltd.) after overnight extraction with 90% aqueous acetone at −20 °C in the dark. Seawater samples for the measurement of nitrate, nitrite and ammonium concentrations were measured using a Continuous Flow Analyzer (San++, SKALAR Co. Ltd.) (Grasshoff et al., 1999).

2.2. Zooplankton abundance, biomass and diversity

Large particles, water plants and small nekton (body length > 20 mm) were removed before analysis and measurement. A half of each sample was filtered using a mesh (mesh size of 200 μm) and redundant water was removed using dry absorbent papers. These samples were dried under 60 °C for 12 h. The dry weight was measured using an electronic microbalance (CP124S, Sartorius Co. Ltd.) with precision of 0.001 g. In laboratory, 2.5% to 10% of the total mesozooplankton samples were identified to species level when possible and counted according to the individual number using a stereomicroscope (M205c, Leica Co. Ltd.). All the specimens from large-size zooplankton groups, such as chaetognaths and euphausiids, were identified and counted. The biomass and abundance of mesozooplankton were expressed as mg m^{-3} (dry biomass) and ind. m^{-3}, repestively.

Shannon-Wiener diversity index (H') was calculated as following: $H' = -\sum p_i \ln p_i$.

Where H' is the Shannon—Wiener diversity index, p_i is the proportion of the i^{th} taxa in the abundance matrix.