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Biogeographic distribution of the cyclopoid copepod genus *Oithona* – from mesoscales to global scales

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ABSTRACT

Abundance and productivity of smaller copepods such as the cyclopoid *Oithona* spp. have been substantially underestimated in most studies, primarily due to large mesh sizes employed during zooplankton tows. Several studies demonstrate that the assemblage structure of *Oithona* spp. shows considerable variation at temporal and spatial scales. We report here the remarkable horizontal variation in distribution as well as abundance patterns of 8 *Oithona* species off northeastern Taiwan in the southeastern East China Sea and compare this distribution pattern with community compositions worldwide. The present study provided the first explanation of a spatial distribution pattern and a relationship between species richness and area, as well as community similarities with increasing distance worldwide for the ecologically important planktonic copepod genus *Oithona*.

1. Introduction

The important role of small planktonic copepods, such as those of the genus *Oithona* Baird, 1843 has been recognized recently in terms of their numerical contribution to the mesozooplankton and particularly due to their high production turnover rates (Gallienne and Robins, 2001), providing a pivotal position in marine food webs, microbial loops, and carbon cycling (Saiz et al., 2003). Cyclopoid copepods of the genus *Oithona* include intermediate to smaller sized (<1 mm) representatives. They comprise neritic and oceanic species. They feed on smaller sized organisms, such as heterotrophic or autotrophic microbes, and copepod nauplii, and are prefered food of fish larvae and other zooplanktivores (Elwers and Dahms, 1999). Different species of *Oithona* show differential levels of adaptability to physical and hydrological parameters, and include cosmopolitan as well as species with a narrower range of distribution. Oithonids, therefore, may play a larger role in the transfer of both bacterial and algal biomass to higher trophic levels than hitherto expected.

Because of larger mesh sizes usually employed in large scale zooplankton research (>200 micrometer mesh size) and variable sampling strategies (Dahms et al., 2012, 2013), up to 92% sampling losses of *Oithona* spp. have been shown in samplings from several oceans (Gallienne and Robins, 2001). Even adult *Oithona* spp., because of their spherical diameter of <200 μm are likely to pass through a net with a mesh diameter >200 μm (Hwang et al., 2006) have thus been undersampled and underestimated (Hwang et al., 2010; Tseng et al., 2011).

To date, reliable information is still lacking regarding the abundance, seasonality, and distribution of the smaller size fraction of mesozooplankter such as *Oithona* spp. in the South China Sea (Hwang et al., 2006). *Oithona* represents the only copepod genus that occurs in all marine geographical regions. The abundance and community structure of *Oithona* exhibits considerable variation, though, at interannual, seasonal, and regional scales (Paffenhöfer, 1993). Temporal variation in copepod communities is related to strong seasonal pulses of the ambient environment. Considering the importance and unresolved distribution patterns of *Oithona* spp. and their adaptability to temperate *versus* tropical waters or oligotrophic *vs.* eutrophic waters (Gallienne and Robins, 2001), we conducted here a spatial distribution study of oithonid species abundance and distribution patterns in the coastal and oceanic water masses of the East China Sea.

It remained unexplored as yet how different *Oithona* species can be separated in their spatial distribution patterns. We investigated the differential distribution patterns of *Oithona* on the basis of a single short-term study at different spatial scales. The main objectives of the present study were to reveal the variation at horizontal meso-spatial horizontal scales (from 1 to 5000 m) in the abundance and distribution patterns of identifiable *Oithona* species around a small volcanic island off northeastern Taiwan in the summer of 2008 and compare this with patterns worldwide.

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2. Materials and Methods

2.1. Study area and sample collection

In order to reveal the distribution and community patterns of *Oithona* copepods in the waters off northeastern Taiwan (Fig. 1), we set up 6 sampling stations in a transect line at 1 kilometer south of Turtle Island of the southeastern East China Sea. The sampling stations were designed in an east to west orientation and had the following distances from each other: 1 m, 10 m, 100 m, 1 km, 2 km and 5 km (Fig. 1). The zooplankton samples of the present study were retrieved from on-board of a research diving boat at noon time on the 27th of May, 2008. Three samples were collected from each sampling station as three replicates. At 6 selected stations copepod samples were collected by surface tows (0-5 m) with a standard North Pacific zooplankton net (mouth diameter 45 cm, 1.8 m long and a mesh size of 100 μm), having a Hydrobios flowmeter (Germany) mounted at the centre of the net mouth. Zooplankton samples were preserved in seawater with 5% buffered formaldehyde immediately on-board (see Dahms et al., 2014).

2.2. Copepod enumeration and identification

In the laboratory, zooplankton samples were split by a Folsom plankton splitter until the subsample contained less than 500 specimens. Adult copepods in subsamples were identified and counted under a stereo-microscope. Species identification was done according to keys and references by Chen and Zhang (1965), Chen et al. (1974), and Chihara and Murano (1997).

2.3. Data analysis

The copepod community structures were analyzed using the Paleontological Statistics (PAST) computer package (Hammer et al., 2001). Bray–Curtis similarity coefficient and average linkage routine were applied for non-metric multidimensional scaling (NMDS) analyses. NMDS was applied to test the similarities in the copepod community of *Oithona* spp. among different geographical zones obtained from the Marine Plankton Copepod website (Razouls et al., 2005–2012 - http://copepodes.obs-banyuls.fr/en [accessed February 03, 2012]). Information about *Oithona* congeners from different geographical areas worldwide were made available by Razouls's database. To evaluate similar distribution patterns of *Oithona* species, the data of 23 geographical zones comprising 40 *Oithona* species were analyzed using nonmetric multidimensional scaling (NMDS) to elucidate the variations of presence and species richness worldwide. The species richness in each geographical zone was using Bray–Curtis similarities prior to conducting the NMDS analyses. Further, Minimum Spanning Tree (MST) analysis with weights less was applied to find the smallest difference among each geographical zone.

3. Results

3.1. Hydrological structure

Monthly-averaged information derived from Advanced Very High Resolution Radiometer (AVHRR) recordings for sea surface temperature and seawater chlorophyll *a* values for May 2008 are shown in Fig. 2. The image for sea surface temperatures (Fig. 2A) shows the sea around Turtle Island with a temperature of about 24 °C. Sea surface concentration of chlorophyll *a* (Fig. 2B) shows the highest regional distribution along the coast of the mainland of China, with concentration levels higher than 5.0 mg m^{-3}. From satellite images it can be inferred that the surface water towards the area around Turtle Island could be characterized by the interplay of East China Sea waters with the Kuroshio Current (KC) during the sampling period.

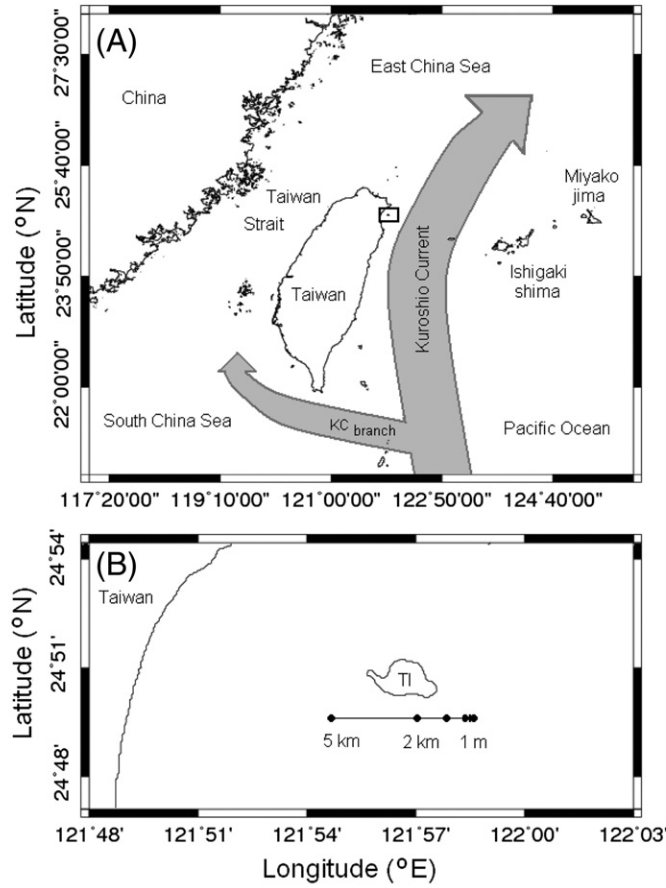

Fig. 1. Map of the study area (A) and sampling stations (B) in Turtle Island. KC is the Kuroshio Current and TI is the location of Turtle Island.

3.2. Copepod community structure

From 18 samples, which were collected in the present study, 8 *Oithona* species were identified in total: *O. attenuata*, *O. brevicornis*, *O. fallax*, *O. longispina*, *O. rigida*, *O. setigera*, *O. similis* and *O. simplex*. The average abundance, relative abundance (RA) and occurrence ratio (OR) of each species are shown in Table 1. Among all the samples, the most abundant species was *O. similis* (56.67 ± 24.24 ind. 10^{-1} m^{-3}, RA: 48.25%), *O. fallax* (25.06 ± 14.45 ind. 10^{-1} m^{-3}, RA: 21.33%) and *O. setigera* (12.39 ± 7.97 ind. 10^{-1} m^{-3}, RA: 10.55%). The three species *O. fallax*, *O. setigera* and *O. similis* have the highest OR value (100%) and were recorded in all 18 samples. These species were followed by *O. attenuata* with 83.3% OR, whereas *O. rigida* showed the lowest values of OR (11.1 %) which were identified from two samples only. The observed patterns showed that total abundance was significantly decreased with distance from east to west ($r = -0.923$, $p = 0.009$, Pearson's correlation), species richness was not significant ($r = -0.670$, $p = 0.146$, Pearson's correlation) (Fig. 3). These results indicated that a higher density of copepods were distributed in the area close to the hydrothermal vent site. We analyzed the relation between species richness and total abundance and found no significant differences ($r = 0.623$, $p = 0.186$, Pearson's correlation).

The variation of species number (Fig. 3A) and copepod abundance (Fig. 3B) at each sampling station are demonstrated in Fig. 3. The average number of *Oithona* species identified at each station ranged between 4.67 (station 2 km) and 5.67 (station 1 m) (Fig. 3A). The lowest average abundance of total *Oithona* copepods in the present study was 52.00 ± 21.70 (ind. 10^{-1} m^{-3}) at station 5 km, whereas the highest record of abundance was 136.67 ± 59.20 (ind. 10^{-1} m^{-3}) at station