Continental Shelf Research 135 (2017) 14–22

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Spatial variation of the zooplankton community in the western tropical Pacific Ocean during the summer of 2014

Guang Yang[a], Chaolun Li[a,b,c,*], Yanqing Wang[a], Xiaocheng Wang[a,b], Luping Dai[a,b], Zhencheng Tao[a], Peng Ji[a]

[a] Key Laboratory of Marine Ecology and Environmental Sciences, Institute of Oceanology, Chinese Academy of Sciences, 7 Nanhai Road, Qingdao 266071, PR China

[b] University of Chinese Academy of Sciences, 19 Yuquan Road, Beijing 100049, PR China

[c] Laboratory for Marine Ecology and Environmental Science, Qingdao National Laboratory for Marine Science and Technology, Qingdao 266071, PR China

ARTICLE INFO

Keywords:
Zooplankton community
Western tropical Pacific Ocean
Oceanographic survey
Eddies
Water currents
Oligotrophic

ABSTRACT

Knowledge of the zooplankton community in the western tropical Pacific Ocean is poor compared to that of the communities in the central and eastern Pacific Ocean. The zooplankton composition, abundance, biomass and community structure in the western Pacific Ocean were studied based on data collected during a synoptic cruise (August-September 2014). Four zooplankton communities were determined via cluster analysis, and these four clusters were mainly spatially related to four different currents: the Luzon Current (LC), Subtropical Countercurrent (STCC), North Equatorial Current (NEC) and North Equatorial Countercurrent (NECC). The estimated mean abundance and biomass of the zooplankton for the whole surveyed area were 146.7 ± 178.1 ind/m^3 and 36.9 ± 40.3 mg/m^3, respectively. The zooplankton abundance was dominated by small copepods, such as *Clausocalanus furcatus*, *C. pergens*, *Oncaea mediterranea* and *Oithona plumifera*. The zooplankton abundance and biomass values were lowest in the STCC region and highest in the NECC region. BEST analysis based on surface environmental factors showed that chlorophyll *a* (chl *a*), pH, temperature and salinity were the environmental variables that best explained the distribution pattern of the zooplankton community (pw=0.372). The zooplankton abundance was higher south of the salinity front at 16°N, in accordance with the relatively higher nutrient and chl *a* levels. Maximum zooplankton biomass was found in regions on the periphery of the cyclonic Mindanao Eddy (ME) and anticyclonic Halmahera Eddy (HE).

1. Introduction

Zooplankton play an important role in the marine food web, serving as a link between primary production species and higher trophic level species (Calbet and Landry, 2004). Knowledge of the zooplankton community is also fundamental to understanding the biogeochemical cycles and energy flows of marine ecosystems because of the roles of this community in the biological pump (Giering et al., 2014; Mitra et al., 2014).

Due to the considerable influence of the western Pacific Ocean in modulating global and regional climate systems (Hu et al., 2015a), the physical oceanography of this region has received substantial attention (Grenier et al., 2011; Hu et al., 2015a, 2015b; Qiu, 1999; Wang et al., 2015). In the epipelagic zone, the Luzon Current (LC), Kuroshio Current (KC), Subtropical Countercurrent (STCC), North Equatorial Current (NEC), Mindanao Current (MC), North Equatorial Countercurrent (NECC) and New Guinea Coastal Current (NGCC) contribute to the complicated circulation found in the boreal western Pacific Ocean (Hu et al., 2015b). The complex water currents also make this region a hotspot for biodiversity (Tittensor et al., 2010). However, knowledge of the zooplankton in this region is lacking or poor compared to that of the central and eastern Pacific Ocean (Borgne and Rodier, 1997; Fernandez-Alamo and Farber-Lorda, 2006; Ishizaka et al., 1997; Roman et al., 1995; White et al., 1995), as the zooplankton data that do exist for the western Pacific are confined to certain zooplankton groups in coastal waters (Hwang et al., 2007; Nagai et al., 2015; Noblezada and Campos, 2012) and size spectra measurements (Dai et al., 2016). Studying the zooplankton community structure and its relationship with water currents is essential to the characterization of the planktonic food web. Meanwhile, mesoscale processes may play a large role in ecosystem structure and functioning in oceans around the world (Garcon et al., 2001; McGillicuddy et al., 2007; McGillicuddy,

* Corresponding author at: Key Laboratory of Marine Ecology and Environmental Sciences, Institute of Oceanology, Chinese Academy of Sciences, 7 Nanhai Road, Qingdao 266071, PR China.
E-mail address: lcl@qdio.ac.cn (C. Li).

http://dx.doi.org/10.1016/j.csr.2017.01.009
Received 9 August 2016; Received in revised form 10 January 2017; Accepted 18 January 2017
Available online 19 January 2017
0278-4343/

2016). The effect of mesoscale eddies on nutrients could promote phytoplankton and zooplankton production through trophic cascade effects (McNeil et al., 1999), which would greatly impact the biogeochemistry of marine ecosystems, especially in oligotrophic tropical regions. Estimating the impacts of physical processes (currents and mesoscale eddies) on the zooplankton community could help us better understand the biological-physical coupling that controls marine food webs (Smeti et al., 2015).

During a cruise conducted in the summer (25 August to 5 October) of 2014, we collected zooplankton samples from 75 stations in four sections of the western Pacific Ocean. In this paper, we focus on the analysis of the spatial variation in the zooplankton community (composition, abundance and biomass) and its relationship with oceanographic features at different spatial scales (water currents and eddies) and with environmental factors (nutrients, pH and chlorophyll *a*).

2. Materials and methods

During the summer of 2014 (25 August to 5 October), a WP2 net (200-μm mesh, 0.2 m^2 mouth size) aboard the R.V. *Kexue* was used to collect zooplankton vertically from 300 m below the surface at 75 stations along four main transects in the western Pacific Ocean: the S10 (123°E) transect, S9 (18°N) transect, S1 (8°N) transect and S2 (130°E) transect (Fig. 1). The WP2 net was equipped with a calibrated flowmeter (Hydrobios) to determine the volume of water filtered.

The temperature and salinity were measured using a Sea-Bird 911 CTD. The seawater used for the chl *a*, nutrient (phosphate, nitrate and silicate) and pH analyses was collected from 6 fixed depths (0 m, 30 m, 75 m, 100 m, 150 m and 300 m) at each station. Generally, 2L of water from each depth was filtered through a Whatman GF/F filter and extracted using 90% aqueous acetone. The chl *a* was measured using a Turner Trilogy instrument, and the nutrients were determined using a Skalar continuous flow analyser. An Orion 4 star pH meter was used to measure the pH.

The surface currents during the sampling period were downloaded from OSCAR at a resolution of 1° (Bonjean and Lagerloef, 2002). Primary production values were determined using MODIS data and a vertically generalized production model (www.science.oregonstate.edu/ocean.productivity/).

The zooplankton samples were preserved in a 5% solution of buffered formalin. In the laboratory, the wet weight of the zooplankton samples was first measured to the nearest 0.0001 g using an analytical balance.

For the microscopy analysis, the large macrozooplankton species (total length > 3 mm) were counted in each entire sample, and all other species were divided using a Folsom plankton splitter and counted in aliquots ranging from 1/2 to 1/256 of the total volume (according to the numerical density of the individuals). Subsamples consisting of approximately 500 specimens were counted using a dissecting microscope (Nikon SMZ 745T).

Multivariate analyses were performed using PRIMER (Plymouth, UK) version 6 (Clarke and Ainsworth, 1993). The analyses used were similar to those outlined by Hunt et al. (2007). The zooplankton abundance data were $\log_{10}(x+1)$ transformed to reduce the weighting of highly abundant species and then subjected to q-type cluster analysis based on the Bray-Curtis similarity and the average linkage group classification (Field et al., 1982). Non-metric multidimensional scaling (NMDS) was also performed to replicate the station groupings produced by the cluster analysis (Hunt et al., 2007). ANOSIM (analysis of similarity) was used to test for differences between the resultant groups. The clustered groups were then subjected to SIMPER (similarity percentages) routines to determine the species contributions to the similarity within groups and the differences between groups.

Indicator value (IndVal) analysis was used to identify the indicator species of each station cluster (Dufrene and Legendre, 1997). The IndVal method combines measures of group specificity (Aij) and group fidelity (Bij):

$$Aij = Nindividualsij/Nindividualsi$$

and

$$Bij = Nsamplesij/Nsamplesj$$

Nindividualsij is the mean number of individuals of species i in the sample of group j, and Nindividualsi is the sum of the mean numbers of individuals of species i among all groups. Nsamplesij is the number of samples in group j in which species i is present, and Nsamplesj is the number of samples in group j. Subsequently, IndVal was calculated as

$$IndVal = Aij \times Bij \times 100$$

The values of A and B are multiplied together because they represent independent information about the species distribution and are multiplied by 100 to produce percentages. A randomization test was used to test the significance of the indicator values of each species (Dufrene and Legendre, 1997). The indicator species analysis was performed using PV-ORD version 6 (McCune and Mefford, 2011).

Species associations were investigated using an inverse (r-type) analysis. To avoid the random association of rare, low-abundance species, 26 species that contributed > 90% of the intra-community similarity based on the SIMPER analysis were chosen. Most of these species satisfied the selection criteria of having more than an arbitrary percentage of dominance at any one station (2% in this study), as proposed by Field et al. (1982). The data were first standardized before the inverse analysis to enable the determination of the similarity between species occurring together at different abundances (Field et al., 1982).

The BEST (Bio-Env+STepwise) procedure was used to estimate which set of environmental variables (temperature, salinity, chl *a*, pH and nutrients) best explained the zooplankton community structure. In this study, the surface and average values (integrated above the 0–300 m water column) of all environmental variables were used separately. BEST analysis is based on determining the Spearman's rank correlation coefficient (ρw) between the biological and environmental similarity matrices. A value of ρw=0 implies no match between the two matrices, whereas a value of ρw=1 denotes a perfect match (Clarke and Ainsworth, 1993).

3. Results

3.1. Oceanography of the region

Four main transects were surveyed in this study (Fig. 1). Transect S10, distributed in the Luzon Strait, was mainly affected by the LC, and the surface temperature at all stations was lower than 28 °C (Figs. 2 and 3). Transect S9 was mainly located in the STCC region (Fig. 1), and warm water with temperatures over 28 °C was present in the upper 50 m, with the thermocline occurring between 100 and 200 m. The temperature at 300 m was typically higher than 15 °C (Fig. 2a). Transect S1 was mainly located in the NEC region, with coastal stations that were influenced by the MC (Fig. 1). Warm water (28 °C) could be found in the upper 75 m, with the thermocline and halocline mainly occurring at depths of 100–150 m (Fig. 2b). Transect S2 spanned a large latitudinal range from the equator to 21.5°N. The surface water at the stations between the equator and 8°N was mainly affected by the NECC (Fig. 1). Upwelling of low-temperature (10 °C) and low-salinity (34.6) water was obvious at the stations from 5°N to 10°N (Fig. 2). The stations from 8°N to 18°N were mainly distributed in the NEC region, and the northern stations were located in the STCC region (Fig. 1). A temperature and salinity front was found at approximately 16°N in transect S2 (Fig. 3).