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Planktonic copepod compositions and their relationships with water masses in the southern Taiwan Strait during the summer upwelling period

Dong-hui Guo [a,b,*], Jia-qi Huang [b], Shao-jing Li [a,b]

[a] State Key Laboratory of Marine Environmental Science, Xiamen University, Xiamen 361005, Fujian, PR China
[b] Department of Oceanography, Xiamen University, Xiamen 361005, Fujian, PR China

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ABSTRACT

The species composition and distribution of planktonic copepods in relation to hydrographical characteristics in the southern Taiwan Strait were investigated during the summers of 1988, 1994, 2005 and 2006. Two station groups (I and II) and two copepod assemblages (nearshore and offshore) based on sea surface temperature, salinity, chlorophyll *a* and copepod abundance were revealed through cluster and detrended correspondence analysis. Station-group I was found in nearshore regions including the upwelling areas, and primarily consisted of coastal/neritic species; while station-group II was found in offshore regions and primarily consisted of oceanic species. Indicator analysis identified the coastal/neritic species *Temora turbinata* and *Acrocalanus gibber* are good indicators of the nearshore assemblage. The oceanic species *Paraeuchaeta russelli* and 6 additional species are indicators of the offshore assemblage. The results showed that *Acartia pacifica* is an indicator species of coastal waters with freshwater runoff, and *Calanus sinicus* is an indicator species of hypothermic upwelled waters in the southern Taiwan Strait during summer.

1. Introduction

The Taiwan Strait, particularly its southern region, is known for its complex hydrographic patterns driven by interactions among water masses of different origins. The complexity in the southern region reaches its highest level during the summer when the southwest monsoon prevails. Three distinct water sources and associated hydrographic processes have been postulated in previous studies. Runoff from two major mainland rivers, Zhujiang and Hanjiang Rivers, contributes to the warm and fresher coastal waters that dominate along the mainland coast (Huang, 1991; Hu et al., 1999, this issue). At the southern opening of the strait, warm and saline waters are often observed intruding from the adjacent South China Sea under the influence of the southwest monsoon (Huang, 1991; Hu et al., 1999, this issue). However, the most important feature in summer is the frequent occurrences of cold, saline upwelling waters associated with wind events and topography in the southern Taiwan Strait (Hong et al., 1991, 2009; Shang et al., 2004; Tang et al., 2002, 2004; Zhang et al., 2006; Hu et al., this issue). Two upwelling regimes have been well recognized both near the mainland coast and the Taiwan Bank.

The highly diversified and variable hydrographic conditions in the Taiwan Strait, have profound impacts on the structure and function of its ecosystem. For example, a highly productive fishery ground was found around the Taiwan Bank, which is supported by the constant nutrient supplies from its local upwelling flows. It is essential for us to understand coupled hydrographic and biological processes in the southern Taiwan Strait, with an ultimate goal of fully understanding its biological system and the roles of environmental control. To do so, a first step is to recognize the zooplankton compositions and their relationships with water masses of different origins. In this study, we explore the community structure and composition of marine planktonic copepods in the southern Taiwan Strait, aiming to find useful biological indicators of water masses and physical controls on the distribution, advection and mixing of planktonic copepod species.

Planktonic copepod distribution is highly influenced by hydrographic conditions. Community composition and distribution of copepods potentially indicate the existence of different currents and water masses (e.g. Beaugrand et al., 2002; Morgan et al., 2003). Previous survey data suggested that copepods such as *Paraeuchaeta russelli* could be biological indicators of upwelling in the Taiwan Strait (Huang et al., 1991, 1997). However, it has been difficult to find unambiguous associations between single species and particular water masses due to the nebulous natures of copepod behavior and physical processes. In recent years, the development of multivariate methods have allowed us to analyze the relationship between species assemblages and its associated multivariate environment variables, providing powerful tools for us to identify indicators of biological systems and their relationships with water masses (Kingsford and Suthers, 1994; Siokou-Frangou et al., 1998; Grothues and

* Corresponding author at: Department of Oceanography, Xiamen University, Xiamen, Fujian, 361005, PR China. Tel.: +86 592 2188471.
E-mail address: gudh@xmu.edu.cn (D.-h. Guo).

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Cowen, 1999; Zhu et al., 2000; Hsieh et al., 2004; Hwang and Wong, 2005; Hwang et al., 2006, 2007; Dur et al., 2007; Tseng et al., 2008; Lan et al., 2008).

In this study, we used multivariate methods for the first time to study the relationship between copepods and associated water masses in the southern Taiwan Strait. Zooplankton data from four summer season surveys (1988, 1994, 2005 and 2006) were used. Both the variations in summer hydrographic patterns and potential long-term correlations between physical and biological variables provide us opportunities to use spatial and temporal relationships between copepod species compositions, distributions and hydrographic variables to predict physical and biological conditions in the southern Taiwan Strait. Our primary goal is to identify these physical–biological relationships and to infer copepod indicators of major water masses in the southern Taiwan Strait.

2. Materials and methods

2.1. Zooplankton samples and hydrographical data collection

Four cruises were conducted during summer, involving 15 stations from August 31 to September 3, 1988; 10 stations from August 29 to September 8, 1994; 15 stations from July 4 to 15, 2005; and 21 stations from June 20 to July 2, 2006 (Fig. 1).

The same sampling procedure was used for all cruises. Zooplankton samples were collected by vertical tows from 3 m off the bottom to the surface with a maximum sampling depth of 200 m using a plankton net (80 cm in diameter, 270 cm in length and a mesh size of 505 μm) at each station. All zooplankton samples were preserved on the vessel in seawater with 5% neutralized formalin added. In the laboratory, aliquots containing 300–500 copepods were obtained using a Folsom splitter for species identification and enumeration, and the remainder of the samples were inspected for rare species that might have been missed. Copepods were classified and counted under a dissecting microscope. The count of each copepod species from a sample was normalized by the water volume filtered to the abundance estimation (ind/m^3).

Vertical temperature and salinity profiles for the sampled water depth at each station were recorded simultaneously with Mark III (Neil Brown Instrument Systems Inc, Massachusetts, USA), SBE 19/SBE 917 (Sea-Bird Electronics Inc., Washington, USA) temperature–conductivity–depth (CTD) sensors during these cruises. Water column temperature and salinity data were processed and provided by the Center for Marine Instruments at Xiamen University (Huang, 1991; Hu et al., 1999; Chen et al., 2005; Zhu et al., 2006). The satellite images of the sea surface temperature (SST) and chlorophyll *a* (Chl *a*) recorded by the NASA MODIS were provided by the Remote Sensing and Numerical Modeling Group at Xiamen University. The surface chlorophyll *a* (Chl *a*) was measured on board and provided by Prof. Huang Bangqin (Xiamen University).

2.2. Data analysis

Dominance (Y) of each copepod species was calculated using the following equation:

$$Y = \frac{n_i}{N} f_i \quad (1)$$

where n_i denotes the abundance of species i, f_i is the frequency of occurrence of species i, and N is the total copepod abundance. A threshold value of $Y \geq 0.02$ (Chen et al., 1994; Xu and Li, 2005) was applied for determination of dominant species.

Cluster analysis (Quinn and Keough, 2002) and detrended correspondence analysis (DCA, Hill and Gauch, 1980; Ter Braak and Prentice, 1988; Jongman et al., 1995; Jan and Petr, 2003) were employed to station groups. Similarity levels of copepod species composition among the station samples were measured using Bray–Curtis similarity coefficients and cluster dendrograms were generated to interpret linkages. Relationships between environmental variables and abundance of copepods were analyzed through DCA using CANOCO 4.5 software. Only frequently observed copepod

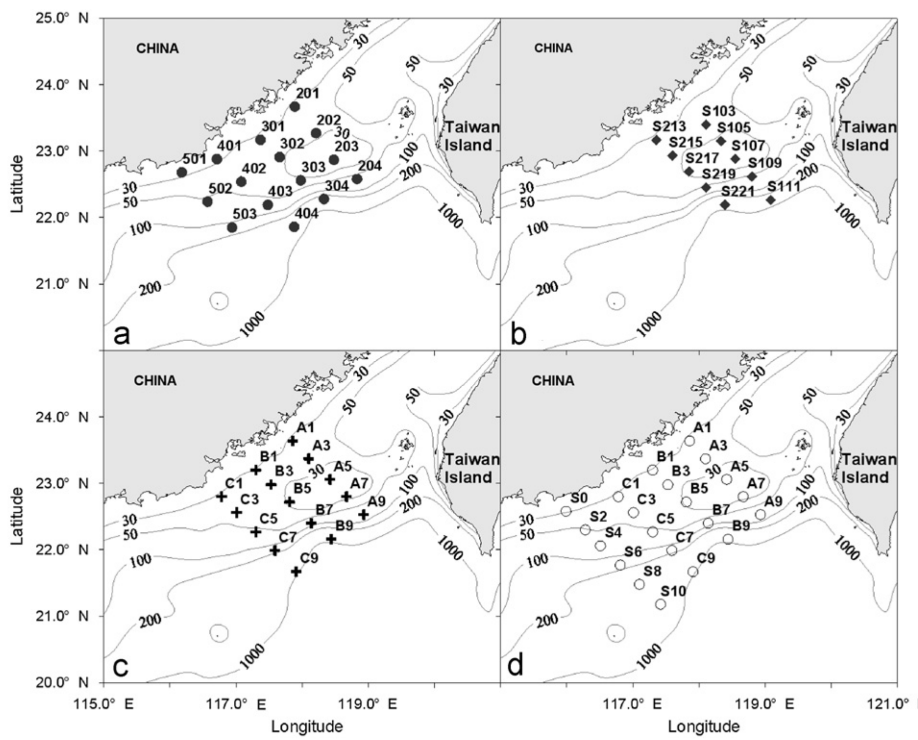

Fig. 1. Map of the study area showing locations of sampling stations in the southern Taiwan Strait during August 31 to September 3, 1988 (a); August 29 to September 8, 1994 (b); July 4 to 15, 2005 (c); and June 20 to July 2, 2006 (d). The lines indicate the 30, 50, 100, 200 and 1000 m depth contours.