Continental Shelf Research 72 (2014) 10–20

Contents lists available at ScienceDirect

Continental Shelf Research

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

Research papers

Identification of human-induced perturbations in Daya Bay, China: Evidence from plankton size structure

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ARTICLE INFO

Article history:
Received 26 November 2012
Received in revised form
14 May 2013
Accepted 9 October 2013
Available online 6 November 2013

Keywords:
Size structure
Number size spectra
Phytoplankton
Zooplankton
Daya Bay

ABSTRACT

Plankton size structures were investigated based on estimated individual biovolumes at six typical stations of Daya Bay in the summer (August 2010) and winter (January 2011). The biomass size distribution (BSD) and the number size spectra (NSS) of plankton were established to analyze plankton size structures from taxonomic and ataxonomic perspectives, respectively. In Daya Bay, the phytoplankton individual biovolume was in the range of 64–496,757 μm^3, and the zooplankton individual biovolume was in the range of 1.15×10^6–5.23×10^{11} μm^3. The average biomasses of phytoplankton and zooplankton were 1.60 mg L^{-1} and 1.19 mg L^{-1} in the summer, and .42 mg L^{-1} and .35 mg L^{-1} in the winter, respectively. The ranges of the NSS slope were −1.94 to −.75, −2.60 to −.69, and −2.11 to −1.64 for phytoplankton, zooplankton, and total plankton, respectively. The ranges of the NSS intercepts were 13.17 to 23.97, −3.19 to 38.88, and 20.14 to 27.86 for phytoplankton, zooplankton, and total plankton, respectively. Our results indicate that the thermal water discharge from nuclear power plants, aquaculture and riverine nutrients significantly influenced the BSD and NSS patterns of plankton in Daya Bay. Moreover, the influence of aquaculture was more significant in the summer, and the influence of thermal water discharge was more significant in the winter. In general, a steeper NSS slope usually suggested more human-induced perturbations. The NSS parameters well reflected the horizontal variations of the environmental characteristics between these stations.

1. Introduction

Aquatic food webs are strongly size structured due to the general rule that larger predators eat smaller prey (Dickie et al., 1987; Sheldon et al., 1972). Many observations have indicated that plankton size structures have close correlations with various biotic and abiotic factors. The variation of phytoplankton size structures might be caused by water dynamics (Rodríguez et al., 2001), depth of photic zone (Gaedke, 1992), and nutrient levels (Sprules and Munawar, 1986); the variation of zooplankton size structures might be influenced by nutrient loading, temperature, salinity, and predation (Brucet et al., 2010; Kimmel et al., 2006). The analysis of size structure has been shown to be an effective approach for studying the structure and function of planktonic ecosystems (Sabetta et al., 2008).

Most studies on the size structure of pelagic ecosystems have used a size-abundance spectrum approach (Marquet et al., 2005). This approach can simplify the pelagic food webs, reflect the structure and function of an ecosystem, indicate substance transformation and energy flow, and offer information about production, transfer efficiency, and community variations. The size-abundance spectrum shows in different forms depending on the definitions of particle size (biovolume, wet weight, carbon, etc.) and abundance (density, wet weight, carbon, etc.); therefore, the parameters of these spectra vary in different ranges (Marquet et al., 2005). The biomass size spectrum (BSS) and number size spectrum (NSS) were the two main size-abundance spectrum forms. Quinones et al. (2003) observed that the BSS in biovolume units showed no significant differences on horizontal and temporal scales, while the significant differences in the BSS in carbon units for oligotrophic waters of the Northwest Atlantic were observed. Sabetta et al. (2008) compared BSS in carbon units and NSS in density units in transitional water ecosystems and found that NSS globally showed higher statistical goodness of fit and that NSS parameters could be used as consistent descriptors of phytoplankton size structure of transitional water ecosystems. Although variations exist between different expressions, linear size-abundance spectrum was the conservative property of most pelagic ecosystems. The shape of a size-abundance spectrum is determined by rates of growth, respiration, mortality and trophic dynamics. Productive systems are characterized by a high intercept of the spectrum. As the biomass propagates from small to large sizes, the biomass decreases following the spectrum slope,

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http://dx.doi.org/10.1016/j.csr.2013.10.012

and the slope is determined by the assimilation efficiency and the number of trophic levels. Thus, the slope represents the inherent property of a plankton community (Zhou, 2006). Linear size-abundance spectra have been shown to be an efficient tool to describe, compare, and predict the characteristics of plankton communities (Kamenir et al., 2006; Kimmel et al., 2006; Peters, 1986; Sprules and Munawar, 1986). In recent years, the applications of Laser in situ Scattering Transmissometry, Laser Optical Plankton Counter, and Acoustic Doppler Current Profiler made the study of the vertical and time-sequence size-abundance spectrum in a wide size range feasible. However, size-abundance spectrum is an ataxonomic approach; taxonomic information is an important complement.

Daya Bay is a semi-enclosed shallow embayment with an area of approximately 600 km^2 that is located in the northeast part of the South China Sea. The strong northeast monsoon prevails from October to April; and the southwesterly monsoons occur from May to September. Due to the seasonal changes in monsoons, there are abundant rainfalls in summer and a short in winter in Daya Bay. In addition, the coastal upwelling off of the east of Guangdong Province may bring nutrients from the northern South China Sea in the summer. As an important aquaculture area in southern China, Daya Bay is biologically productive. Because of the increasing nutrient loadings caused by the rapidly expanding aquaculture and industry and the thermal water discharge from nuclear power plants, the ecological environment had profoundly changed in Daya Bay since the 1980s; this change was characterized by a decrease of plankton species and an increase of the small species ratio (Wang et al., 2008). In Daya Bay, previous studies about plankton community structures did not include the plankton size structures (Sun et al., 2011; Wang et al., 2008, 2012).

This study reported the plankton biomass size distribution (BSD) and NSS patterns in typical areas of Daya Bay. We studied the influence of environmental factors on plankton size structure.

2. Materials and methods

2.1. Study area

The Daya Bay is located at 114°29′42″–114°49′42″E and 22°31′12″–22°50′00″N. The water depth ranges from 6 to 16 m, with an average depth of 10 m. The annual mean air temperature is 22 °C. The coldest months are January and February, with a monthly mean air temperature of 15 °C, and the hottest months are July and August, with a monthly mean air temperature of 28 °C. The minimum sea surface temperature occurs in winter (15 °C) and the maxima in summer and fall (30 °C) (Wang et al., 2012; Wu and Wang, 2007). The salinity is usually between 22 and 33 and does not fluctuate substantially. The population, tilth, aquaculture, and industries along the coastal have increased dramatically in the last decades. Fish farming in Daya Bay has increased from an annual production of approximately 100 t (~440 ha cage culture area) in 1988 to approximately 60,000 t (~14,000 ha cage culture area) in 2005, a nearly 600-fold growth over the past 17 years (Wu et al., 2009). In addition, two nuclear power stations, the Daya Bay Nuclear Power Plant (DNPP) and the Ling'ao Nuclear Power Plant (LNPP), have been operated since 1993 and 2003, respectively. The excessive release of waste caused by these human-induced perturbations strongly affected aquatic environment in Daya Bay (Wang et al., 2008, 2012; Wu and Wang, 2007).

2.2. Sampling

Seasonal surveys were carried out in the summer (August 2010) and winter (January 2011). We selected six typical stations in Daya Bay (Fig. 1):

S1 was located at the mouth of the bay, where water exchange occurs between Daya Bay and the South China Sea.

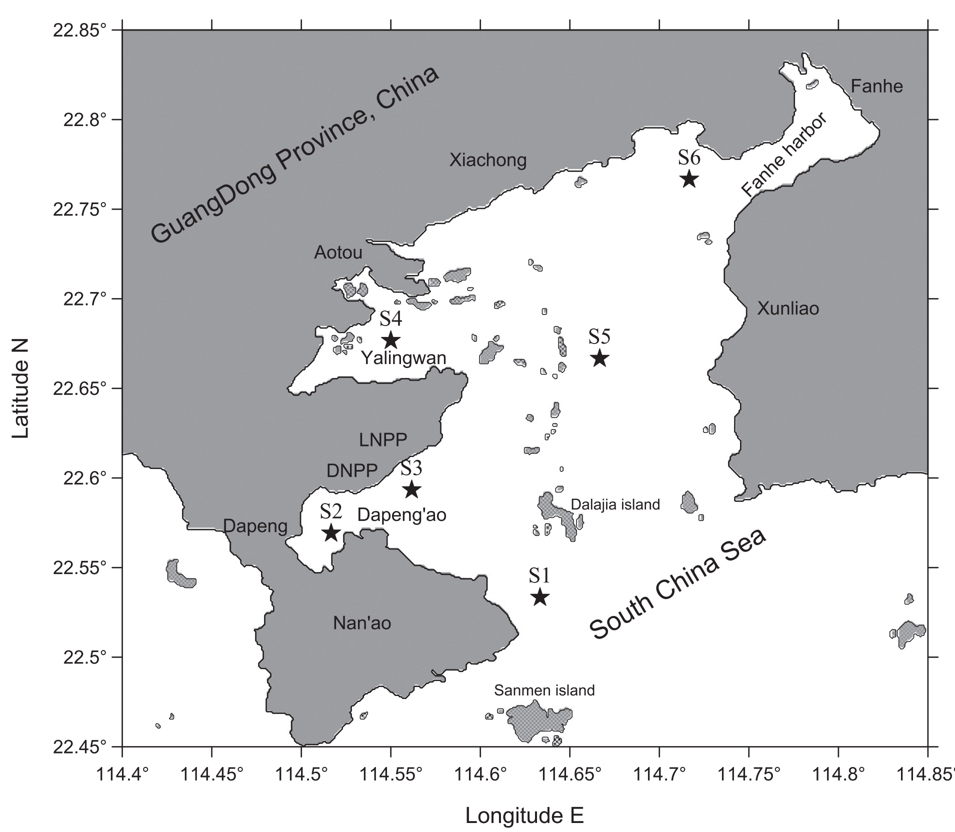

Fig. 1. Location of sample stations in Daya Bay.