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ScienceDirect
Marine Environmental Research 64 (2007) 38–53
MARINE ENVIRONMENTAL RESEARCH
www.elsevier.com/locate/marenvrev

Comparing the distribution of ciliate plankton in inner and outer areas of a harbor divided by an artificial breakwater

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Received 31 May 2006; received in revised form 22 December 2006; accepted 30 December 2006

Abstract

The distribution of ciliate plankton was compared between inner and outer areas of a harbor divided by an artificial breakwater in Kuryongpo, on the eastern coast of Korea, from February 2001 to October 2003. Less dissolved oxygen and higher concentrations of nitrogenous nutrients and phosphate were observed in the inner area. The abundance of oligotrich ciliates peaked in February 2001, when nanoflagellates bloomed in the inner area. The photosynthetic ciliate *Mesodinium rubrum* showed differing population dynamics annually, with blooming peaks in October 2001 in the inner area and in February 2003 in the outer area. The tintinnid species *Tintinnopsis beroidea* and *Helicostomella subulata* were generally more abundant in the outer area. Total ciliates were significantly related to oligotrich abundance in the inner area, and to tintinnid abundances in the outer area. Ciliate distribution showed quantitative and qualitative differences between the inner and outer areas in connection with the distribution of other plankton communities: oligotrich ciliate abundance increased with nanoflagellate blooms; dominance of *M. rubrum* was consistent with blooming of micro-sized phytoplankton (diatoms and dinoflagellates); large-sized tintinnids concurred with small dinoflagellates; and ciliate abundances decreased with mesozooplankton increases. The results indicate that the breakwater induces eutrophication in the inner area and provides suitable conditions for nanoflagellate blooms, which serially trigger opportunistic increases in oligotrich ciliates.

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doi:10.1016/j.marenvres.2006.12.008

Keywords: Ciliate plankton; Breakwater; Nanoflagellates; Phytoplankton; Zooplankton

1. Introduction

Planktonic ciliates have long been thought to be major consumers of nano- and picoplankton as well as important prey of mesozooplankton, thus acting as a critical link between microbial and macroscopic components of marine food webs. In temperate near-shore environments, ciliates often show strong seasonal cycles (Hargraves, 1981; Verity, 1987). However, fluctuations in ciliate abundance characterized by abrupt appearances of favorable food causing the potential for rapid growth and by patchiness causing short-term variations could obfuscate seasonal signals (Graziano, 1989). Oligotrichs, tintinnids, and *Mesodinium*, which are often the dominant elements in marine ciliate plankton, have different nutritional characteristics; oligotrichs combine some degree of autotrophy with heterotrophy, while tintinnids are obligate heterotrophs, and *Mesodinium rubrum* is the only ciliate that is completely photosynthetic (Lindholm, 1985). The distributions of the former two heterotrophic groups largely correspond to favorable food availability. Factors controlling ciliate distribution appear to be as complex as for other planktonic groups. Food availability may be the most important factor (Verity, 1985, 1986), while predation by zooplankton may heavily reduce ciliate abundance (Gifford and Dagg, 1990; Turner and Granéli, 1991). Therefore, under natural conditions, it is not easy to observe directional patterns of ciliate distribution as related to other planktonic communities.

In general, two types of coastal water environment are recognized: open and enclosed waters. Compared to open water, enclosed environments in many respects provide different living conditions for planktonic organisms. In enclosed environments, water is pulsed with large inputs of nutrients and stratifies easily, inducing phytoplankton outbursts (Cushing, 1989). Artificial structures such as breakwaters and natural embayment barriers reduce water circulation from the oligotrophic ocean, causing eutrophication.

A series of studies has clarified the effect of a breakwater on phyto- and mesozooplankton communities in Toulon Bay on the north coast of the Mediterranean Sea (Jamet and Bogé, 1998; Jamet et al., 2001; Richard and Jamet, 2001; Despiau et al., 2002). The breakwater created two sub-ecosystems: the small inner bay was heavily polluted, while the large outer bay was less polluted. The structure of the zooplankton community in the inner bay was very different from that of the outer bay (Jamet et al., 2001; Richard and Jamet, 2001). The inner bay was characterized by high chlorophyll *a*, abundant zooplankton, and a low diversity index of zooplankton. Phytoplankton production was also much higher in the inner area than in the outer bay (Despiau et al., 2002). The sensitive zone of an artificial breakwater thus forms an interesting experimental *in situ* site that can be used to determine how physicochemical changes in environmental factors affect plankton community structure, and to clarify the interrelationships between the components of these communities.

However, few studies have compared the distributional mode of ciliate plankton between two areas divided by a breakwater, although ciliates play an important role in linking major components of low trophic level communities in coastal ecosystems. To understand the relationships among the abundances of ciliate, phyto-, and zooplankton,