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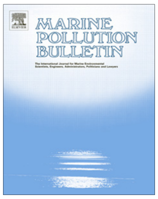

Effects of fish farming on phytoplankton community under the thermal stress caused by a power plant in a eutrophic, semi-enclosed bay: Induce toxic dinoflagellate (*Prorocentrum minimum*) blooms in cold seasons

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ABSTRACT

Six cruises were conducted in a fish farm adjacent to the Ninghai Power Plant in Xiangshan Bay, East China Sea. Fish farming significantly increased NH_4^+, DIP, and TOC concentrations, while it significantly decreased the DO level. These increase/decrease trends were more pronounced in warmer seasons. Although culture practices did not significantly increase phytoplankton density, it drastically enhanced dinoflagellate abundance and domination. Significant differences in species diversity and community composition between the cages and the control area were also observed. Temperature elevation caused by thermal discharge associated with eutrophication resulted in a dominant species shift from diatoms alone to dinoflagellates and diatoms. This is the first report of stress-induced toxic dinoflagellate (*Prorocentrum minimum*) blooms in winter and the winter–spring transition in this bay. Therefore, the effects of aquaculture activity and power plant construction in such a eutrophic, semi-enclosed bay require further attention.

1. Introduction

Mariculture has expanded in scale globally and supplies abundant seafood for human consumption, relieving pressure on food supplies and ocean fisheries (Naylor et al., 2000). Likewise, China's mariculture industry has been growing steadily with the transformation of traditional fishing since the 1980s. Currently, China is the biggest aquaculture country in the world. Such rapid development of mariculture provides enormous nutritional and economic benefits, and decreases the intensity of exploitation on declining wild resources (Yang et al., 2004), thus alleviating China's food pressures caused by population growth. However, the haphazard development and excessive exploitation of aquaculture have potentially negative environmental effects, particularly with fish culture, which requires a lot of nutrient (diet) and energy input (Dong et al., 2008; Yang et al., 2004; Jiang et al., 2012).

The negative effects of fish farming on the environment are highest compared with various other aquaculture systems (e.g. seaweed, mollusks, and crustaceans), although the economic benefit might be the highest (Jiang et al., 2012). Intense fish cages generate considerable particulate organic wastes and soluble inorganic wastes (Alongi et al., 2009; Carroll et al., 2003; Dalsgaard and Krause-Jensen, 2006; Dong et al., 2008; Lauer et al., 2009; Modica et al., 2006; Sara, 2007; Wu, 1995). The huge terrestrial nutrient input combined with the nitrogen (N) and phosphorus (P) discharging from intensive mariculture have led to eutrophication intensification in major Chinese coastal systems (Xiao et al., 2007; Yang et al., 2004), particularly in semi-enclosed waters. The symptoms of eutrophication can cause a succession of serious losses in the ecological, economic, and social benefits of coastal waters (Bricker et al., 2008).

Phytoplankton play a key role in the assimilation of organic matter and excess nutrient inputs in the water column from farming, these primary producers are then grazed by groups higher in the trophic chain (e.g., ciliates, zooplankton, and shellfish) (Azim et al., 2003; Alongi et al., 2009; Olsen et al., 2007; Pitta et al., 2009; Silva et al., 2012). Nevertheless, eutrophic levels and the alteration of nutrient content composition (proportion) induce harmful algal blooms (HABs) (Buschmann et al., 2006; David et al., 2009), which in turn affect the caged fish (San Diego-McGlone et al., 2008). The effects of fish cages on marine phytoplankton (Navarro et al., 2008; San Diego-McGlone et al., 2008; Sidik et al.,

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2008; Skejić et al., 2011; Wang et al., 2006, 2009) and nutrient distribution (Alongi et al., 2003; La Rosa et al., 2002; Neofitou and Klaoudatos, 2008; Pitta et al., 2006, 2009; Wu, 1995; Yucel-Gier et al., 2008) has been well documented. But few of these studies completely focused on phytoplankton community structure and its relationship with environmental parameters under mariculture stress. Furthermore, many coastal power plants have been constructed in China recently (Jiang et al., 2009), and their thermal discharges promote microalgal growth in aquaculture regions adjacent to receiving waters (Jiang et al., 2012). However, almost no research has been done to explore the phytoplankton distribution in fish cages near these power plants. Therefore, it is necessary to investigate the response of phytoplankton assemblages to fish farming under thermal stress.

Fish farming in Xiangshan Bay (XSB, a subtropical, eutrophic, semi-enclosed bay), East China Sea (ECS) has expanded in the last three decades (Ning and Hu, 2002; You and Jiao, 2011; Jiang et al., 2013). In addition, the Ninghai Power Plant, located in the inner bay, began operations on the 17th December 2005. In this context, we hypothesized that fish farming and thermal stress would change the phytoplankton community structure and exacerbate algal blooms in cage areas adjacent to the power plant. To test this hypothesis, we chose a fish farm close to the plant. We then examined the spatio-temporal distribution of phytoplankton abundance, species richness, diversity, evenness, dominant species, and community structure as well as the chemical parameters of the water column in the fish cages (FC) and the control area (CA) from 2009 to 2010. Our objectives were (1) to explore the spatio-temporal distribution of phytoplankton assemblages and water chemistry and to ascertain their relationship in the fish farm and surrounding waters and (2) to evaluate the combined effects of fish farming and thermal discharge on phytoplankton community composition and structure.

2. Materials and methods

2.1. Study area and sample sites

The XSB (121°25′–122°30′E, 29°25′–29°47′N, Fig. 1) is located in Northern Zhejiang Province, China with a tidal flat area of 198 km^2 and water area of 365 km^2. It is also a long (ca. 60 km in length), narrow embayment connected to the ECS, with long residence times in the inner and middle sections (about 80 and 60 days for 90% water exchanges, respectively) (Ning and Hu, 2002). Six cruises were conducted in the FC and CA during winter (31/01/2010), winter–spring transition (WST, 29/02/2009), spring (23/04/2010), early summer (14/07/2010), midsummer (04/08/2009), and autumn (16/11/2010). This farm mainly consisted of Japanese seaperch (*Lateolabrax japonicus*) and black seabream (*Sparus macrocephalus*) with acreage of about 18.7 ha. Two stations were set in the center of the fish farm and 1000 m south of the farm (control station, Fig. 1). The sampling areas were surrounded by water with 0.5–1 °C temperature elevation caused by the large (82.5 m^3 s^{-1}) thermal discharges (Jiang et al., 2013). According to our unpublished measured data, the surface temperature at the station 100 m away from the outlet was much (about 10 °C in winter and 8 °C in summer) higher than that at the inlet.

2.2. Environmental parameters

Surface (0.5 m depth) and bottom (0.5 m from the bottom) water were collected at each station in 10-L plastic buckets. Water depth, pH, temperature, and salinity were monitored *in situ*. Water temperature and salinity were measured with a YSI model 30 salinity meter (YSI Inc., Yellow Springs, OH, USA), turbidity with a Secchi disc, dissolved oxygen (DO) by Winkler titrations, and pH with an Orion 868 acidity meter (Thermo Electron Co., Waltham, MA, USA). For detecting other parameters, including dissolved silicate (DSi), dissolved inorganic nitrogen (DIN: $NO_3^- + NO_2^- + NH_4^+$), phosphorus (DIP), total organic carbon (TOC), and suspended solids (SS), water samples in 5-L buckets were stored in the dark at 0 °C prior to analysis following the methods of Jiang et al. (2012).

2.3. Phytoplankton community

Surface and bottom water (400–500 mL, each 3 samples) were collected in 500-mL bottles at each station. All samples collected were stored with 2% formalin. After sedimentation (at least 48 h), identification and counting of phytoplankton taxa were carried out on a scaled slide (0.1 mL) under 200× or 400× using a light microscope (Leica DM2500, Leica Microsystems GmbH, Wetzlar, Germany) and at least 300 units (individual cells or colonies) were counted for each sample, according to the morphological classification (Yamaji, 1966; Jin et al., 1982, 1991; Tomas, 1997; Guo and

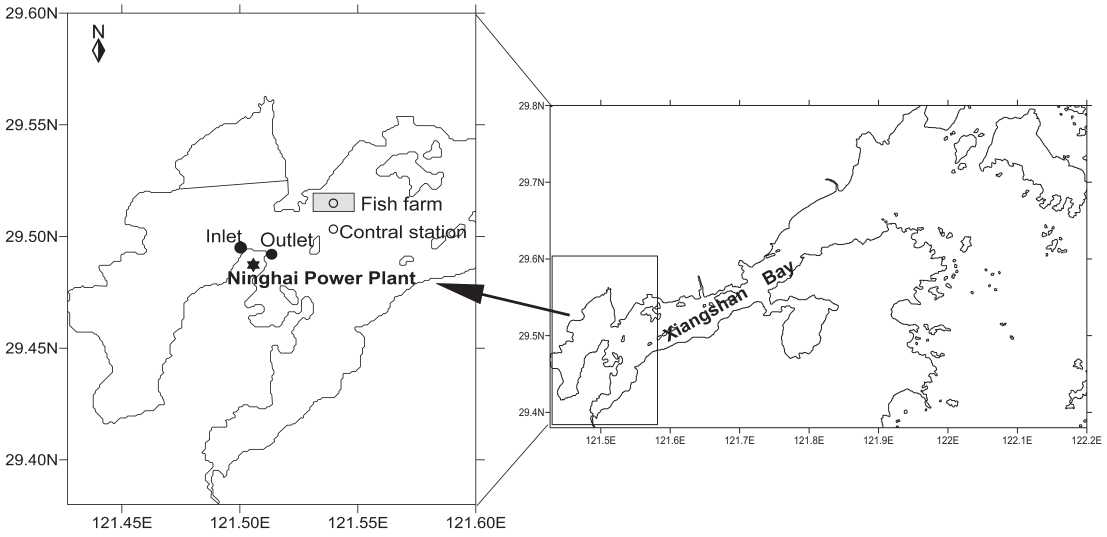

Fig. 1. Study area in the inner section of Xiangshan Bay. Solid circles indicate the inlet and outlet of Ninghai Power Plant; hollow circles indicate the sampling stations.