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Recruitment from an egg bank into the plankton in Baisha Bay, a mariculture base in Southern China

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ABSTRACT

The potential recruitment of resting eggs of calanoid copepods and rotifers to planktonic populations was investigated in the surface and sub-surface sediments of three mariculture zones: an integrated seaweed *Gracilaria lemaneiformis* and shellfish cultivation area (G), a fish cultivation area (F), and a shellfish cultivation area (S), as well as the sediments of a nearby control sea area (C) in a mariculture base in Southern China. The potential recruitment of copepod and rotifer eggs in the sediments of C and G was significantly higher than in F and S. Potential recruitment in the sub-surface sediments of F and S was not observed, suggesting that fish and shellfish mariculture may be responsible for this decrease. The hatching success of resting eggs of copepods and rotifers was affected by mariculture type, and that large-scale seaweed cultivation may offset the adverse effect of fish and shellfish cultivation on the resting eggs if integrated cultivation is adopted.

1. Introduction

In the past 30 years, mariculture of fish and shellfish has sharply developed. China currently has the world's largest mariculture industry, yielding 29.01 million tons of production in 2013, 55% of production worldwide (FAO, 2015). However, the mariculture of animals causes seawater and sediment quality to deteriorate (Yang et al., 2004). Such deterioration may be mitigated by plants like seaweeds. In 2013, seaweed production in China accounted for 50% of the global seaweed production (FAO, 2015).

The occurrence of a resting egg phase in the life cycle of marine and freshwater planktonic copepods and rotifers has been well documented. The benthic resting eggs of copepods (Marcus, 1996) and rotifers (Pourriot and Snell, 1983) are generally regarded as a mechanism that ensures survival during periods of environmental adversity. Resting eggs in sediments, referred to as egg banks, can survive for a long time and, therefore, are a source of recruitment (Marcus et al., 1994; Santangelo et al., 2014). Egg banks are reservoirs of genetic and ecological information and have been detected in several coastal ecosystems, with egg density values ranging from 10^4 to 10^7 egg$\cdot$m^{-2} (Marcus, 1996; Berasategui et al., 2013; Glippa et al., 2014). Resting eggs are widespread but few studies have been conducted in coastal waters (Jiang et al., 2004).

In marine environments, the disappearance of oxygen is often linked to the formation of toxic hydrogen sulphide (Nielsen et al., 2006). Choi et al. (2016) investigated the effects of hypoxia on *in situ* hatching success of calanoid copepods in Gamak Bay, and found that hypoxia could have adverse effects on recruitment of marine copepods *via* its effects on egg hatching and survival of nauplii. Sediment in fish and shellfish mariculture zones is typically anoxic. Because sulfide is highly toxic to most organisms, egg survival may be adversely affected (Marcus, 1996). Uye et al. (1984) documented a negative correlation between the viability of copepod eggs and the degree of organic pollution (i.e., the presence of anoxia and hydrogen sulfide). Hatching success of copepod resting eggs exposed to anoxia or anoxia-sulphide declined with increasing exposure time or increasing concentrations (Nielsen et al., 2006). Seagrass beds can enhance the accumulation and retention of copepod resting eggs in sediment through various mechanisms

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(Scheef and Marcus, 2011). The role of seaweed is similar to that of seagrass. No studies have examined whether the presence of large-scale seaweed cultivation affects the benthic distribution of copepod resting eggs.

Due to different effects of animal and seaweed mariculture on sediment, we hypothesized that recruitment of resting eggs in different types of mariculture areas could be different. The purpose of the present study was to characterize the potential recruitment of egg banks into the plankton from the surface and sub-surface sediment of a mariculture zone.

2. Materials and methods

2.1. Study area

The investigation was conducted in the bay of Nan'ao Island, one of the largest mariculture bases in Guangdong Province, Southern China (Fig. 1). Nan'ao Island (23°23.5′–23°29.5′ N; 116°56′–17°09′ E) is approximately 8 km off the coast of Shantou City, Guangdong Province. The annual mean rainfall is approximately 1383 mm and annual water temperature ranges from 17.8 °C to 30.8 °C. An irregular semidiurnal tide affects the tidal current, producing an average tidal day of 24.7 h. The mean tidal range is 1.01 m, and the maximum is 1.94 m.

Nan'ao Island is a typical mariculture base. The investigated area, Baisha Bay, is located to the northeast of the island and is a semienclosed bay, stretching 8.34 km along the coastline and spanning an area of 6.84 km^2. Water depth ranges from 1 to 10 m (4.3 m on average), and the eastern part is deeper than the western part. No large rivers or seasonal streams flow into this bay. The mariculture zone is located in a relatively sheltered area. The fish and shellfish mariculture industries in Baisha Bay have been developing since the 1980s, and seaweed culture has been developing since 2000 (Yang et al., 2006). In an area of approximately 1 km^2, more than one thousand 3 × 3-m fish cages have been floating for more than 30 years (Gu et al., 2013). The dominant cultured species are fish (i.e., *Epinephelus akaara* Temminck and Schlegel; *E. awoara* Temminck and Schlegel), shellfish (*Crassostrea gigas* Thunberg; *Perna viridis* Linnaeus) and seaweed (*Gracilaria lemaneiformis* Greville). Mariculture has substantially affected the ecological environment of the bay (NAG, 2013; Yang et al., 2006).

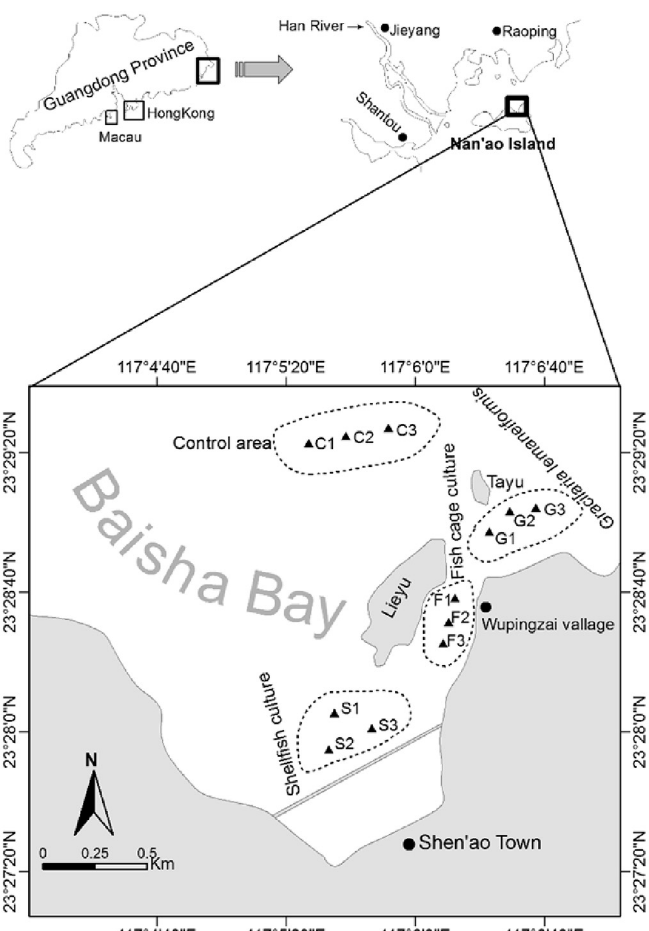

Fig. 1. Map of Baisha Bay, Nan'ao Island, showing the location of the sampling station. The station of G1-G3 was located in seaweed (*Gracilaria lemaneiformis*) and shellfish integrated culture area, F1-F3 located in fish culture area, S1-S3 located in shellfish culture area, and C1-C3 located in the nearby natural sea area (control area).

2.2. Sampling procedures

Three mariculture areas, an integrated *Gracilaria lemaneiformis* and shellfish culture area (G), a fish culture area (F), and a shellfish culture area (S), as well as the nearby natural sea area (Control area, C), were investigated in Baisha Bay in February 2012 and October 2012. Stations G1–G3 were located in G (*Gracilaria lemaneiformis*), Stations F1–F3 were located in F, Station S1–S3 were located in S, and Stations C1-C3 were located in C. Seaweed is cultivated from December to next May every year, therefore, there was seaweed present in February 2012 and no seaweed present in October 2012 during the sampling period. The water temperature was approximately 13.84 ± 0.30 °C and 23.99 ± 0.21 °C, and salinity was approximately 30.42 ± 0.23 and 33.13 ± 0.07 at the sampling time in February and October, respectively. Copepods were identified in previous studies (Chen and Shen, 1974; Chen and Zhang, 1974; Zhang et al., 2010).

Surface sediment was collected using a stainless steel Peterson grab, and samples were acquired from the upper sediment by using a polyethylene spatula and placed in self-sealing polyethylene bags. Three replicate samples were obtained from three sampling stations in each mariculture zone. Three replicate samples were obtained from sediment of the nearby natural sea to evaluate potential recruitment in natural condition. The samples were preserved at 4 °C for about one month. Additional surface water samples were gathered in February 2012 and October 2012 for experimental incubation. The water samples filtered by 0.45 μm membrane were kept cold storage until used. Zooplankton were collected using 0.64 μm plankton nets in February 2012 and October 2012 for species identification.

In addition, in February 2012, each sub-surface sediment sample from the three mariculture areas and the control area was collected for studying the vertical distribution of resting eggs with a Kajak gravity corer. The sub-surface sediments were pushed upward in the sampler by using a piston. The sediment layers were sliced into 2-cm-thick layers with a plastic cutter and placed into self-sealing polyethylene bags, which were stored at 4 °C in darkness for more than 1 month until analysis to ensure that the refractory phase was terminated. The low temperature (4–5 °C) enabled viable diapause eggs to complete their refractory period and, subsequently, hatch (Glippa et al., 2011). The occurrence of H_2S was typically identified by smelling the sediments (Næss, 1996).

2.3. Total organic carbon, nitrogen, phosphorus and heavy metals

Total organic carbon (TOC) and total nitrogen (TN) were analyzed using a CHNS/O analyzer (Perkin-Elmer 2400 Series CHNS/O Analyzer, USA) according to Chinese national standards