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Decline in the species richness contribution of Echinodermata to the macrobenthos in the shelf seas of China

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ABSTRACT

Echinoderms play crucial roles in the structure of marine macrobenthic communities. They are sensitive to excess absorption of CO_2 by the ocean, which induces ocean acidification and ocean warming. In the shelf seas of China, the mean sea surface temperature has a faster warming rate compared with the mean rate of the global ocean, and the apparent decrease in pH is due not only to the increased CO_2 absorption in seawater, but also eutrophication. However, little is known about the associated changes in the diversity of echinoderms and their roles in macrobenthic communities in the seas of China. In this study, we conducted a meta-analysis of 77 case studies in 51 papers to examine the changes in the contribution of echinoderm species richness to the macrobenthos in the shelf seas of China since the 1980s. The relative species richness (RSR) was considered as the metric to evaluate these changes. Trends analysis revealed significant declines in RSR in the shelf seas of China, the Yellow Sea, and the East China Sea from 1997 to 2009. Compared with the RSR before 1997, no significant changes in mean RSR were found after 1997, except in the Bohai Sea. In addition, relative change in the RSR of echinoderms and species richness of macrobenthos led to more changes (decrease or increase) in their respective biomasses. Our results imply that changes in species richness may alter the macrobenthic productivity of the marine benthic ecosystem.

1. Introduction

Carbon dioxide (CO_2) emissions from anthropogenic activity have, since the industrial revolution, increased the atmospheric CO_2 concentration from 280 ppm to 391 ppm (Le Quéré et al., 2013; Stocker et al., 2013). Due to the greenhouse effect of CO_2, this increased atmospheric CO_2 has led to sea surface temperature (SST) increasing by 0.74 °C, and sea surface pH decreasing by 0.1 (Orr et al., 2005; Stocker et al., 2013). The increasing SST and decreasing pH have simultaneously resulted in ocean warming and ocean acidification (OA) (Doney et al., 2009; Stocker et al., 2013).

Echinoderms play crucial roles in the structure of marine benthic ecosystems by occupying a large proportion of the total biomass of the macrobenthos (Ambrose et al., 2001; Uthicke et al., 2009), and by occasionally booming (Uthicke et al., 2009). Besides, they also play important roles in the global carbon cycle due to their global distribution and fine calcium carbonate ($CaCO_3$) skeletons (Lebrato et al., 2010). The echinoderms' $CaCO_3$ skeletons are produced through biological calcification processes, which are strongly affected by $CaCO_3$ saturation (Ω). The Ω is calculated by the equation $\Omega = [Ca^{2+}]\,[CO_3^{2-}]/K^*_{sp}$, where $[Ca^{2+}]$ is the calcium ion concentration, $[CO_3^{2-}]$ is the carbonate ion concentration, and K^*_{sp} is the apparent stoichiometric solubility product. Where $\Omega < 1.0$, the seawater will be corrosive for the echinoderm skeleton. Among the three parameters in the equation, $[CO_3^{2-}]$ is the most variable and sensitive to excess anthropogenic CO_2. High CO_2 absorption by seawater, i.e. OA, will consequently lead to lower $[CO_3^{2-}]$ and Ω. The OA will affect all oceanic organisms, but particularly calcifying organisms (Orr et al., 2005; Wood et al., 2008). As one of the calcifying functional communities, echinoderms are a good indicator to explore the responses to OA (Dupont et al., 2010b; Guinotte and Fabry, 2008; Wittmann and Pörtner, 2013). Based on experimental results using Echinodermata individuals, their responses are known to vary among different species and different life stages (Dupont et al., 2010a, 2008, 2010b; Hendriks and Duarte, 2010; Kurihara, 2008; Ries et al., 2009): e.g., size reduction (Brennand et al., 2010; Chan et al.,

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2013); increased calcification at a cost of muscle mass (Wood et al., 2011, 2008); OA resistance (Catarino et al., 2012; Hendriks et al., 2010), and complex responses under ocean warming (Brennand et al., 2010; Gooding et al., 2009; Harvey et al., 2013; Kroeker et al., 2013). In terms of the species composition of Echinodermata, OA could reduce the species richness (Hale et al., 2011; Wootton et al., 2008).

To date, 591 taxa of echinoderms have been recorded in Chinese seawaters (Liao and Xiao, 2011; Liu, 2013), but more new records are continually being reported (Xiao and Liao, 2013). Among the seas of China, the continental shelf areas have been intensively surveyed since the 1980s (Liu, 2013, 2011). However only a small number studies have reported the changes in biomass or species richness of echinoderms in Chinese seas (Li, 2011; Zhang et al., 2012; Zhou et al., 2007). For the Bohai Sea, compared with the community structure in the 1980s, the abundance of echinoderms has decreased, and *Echinocardium cordatum* disappeared in the 1990s (Zhou et al., 2007). For the Yellow Sea, the average biomass of echinoderms in the 1990s was less than that in the 1950s, and no sea urchins were found in the eurythermal community in the 1990s (Zhang et al., 2012). These results reveal detailed changes in two different periods through several independent surveys. However, there are inherent fluctuations in the biomass and species richness of the macrobenthos (Gray, 2002). Thus, it is hard to assess the trends in these changes over a long period by using small-sample comparisons. Simultaneously, the marine environment changes as a result of commercial activities (e.g., infrastructure construction, ocean exploration) (Liu and Diamond, 2005), fishing (especially mariculture) (Cao et al., 2007), and climate changes (e.g. ocean warming, OA) (Belkin, 2009; Cai et al., 2011; Zhai et al., 2014, 2012). All of these factors may affect macrobenthic biodiversity (Paik et al., 2008). Generally, commercial activities and mariculture only impact biodiversity at relatively small and regional scales, but climate changes may have vast effects on a broad scale, for instance covering an entire shelf sea area. The mean SST in the East China Sea and YS increased by 1.22 °C and 0.67 °C between 1982 and 2006, which was 2 and 3.7 times faster than the global mean warming rate, respectively (Belkin, 2009). In addition, in the shelf seas of China, the apparent decrease in pH is not only caused by increased CO_2 absorption in the seawater, but also eutrophication (Cai et al., 2011; Zhai et al., 2014, 2012). Recently, Jin et al. (2015) showed the ratio of echinoderms to the macrobenthos had significantly declined, while no changes in the biomass of echinoderms and macrobenthos in the shelf seas of China over the past five decades. However, little is known about the impacts of these processes over the past several decades on the diversity of the macrobenthos/echinoderms in the shelf seas of China.

In this study we hypothesized that, in recent decades, the species richness contribution of echinoderms to the total diversity of the macrobenthos has changed under multiple pressures (ocean warming and OA, among others) in Chinese seas. Meta-analysis was used to test the hypothesis, within which the aim was to address the following three questions: (1) What are the trends in the species richness contribution of echinoderms to the macrobenthos in the shelf seas of China and other sub-seas over a time series of surveys? (2) What are the differences in the contribution between periods? (3) How do the changes in the contribution affect the biomass of echinoderms and the macrobenthos?

2. Materials and methods

2.1. Database development

We searched for studies reporting species numbers of echinoderms via the CNKI (National Knowledge Infrastructure) and ISI Web of Science using the following search criteria: "Title-Abstract-Key" (echinoderm* OR macrobenth*) AND "Title-Abstract-Key" (abundance* OR species* OR biomass* OR weight*) AND "Title-Abstract-Key" ("China sea" OR "Bohai Sea" OR "Yellow Sea" OR "South China Sea" OR "East China Sea") on November 10, 2013. In total, 247 papers (177 Chinese and 70 English) were returned. Then, papers were selected based on their ability to meet the following three criteria. First, the macrobenthos must have been studied using a specific quantitative method: the specimens must have been collected using a 0.1 m^2 box-corer, sieved with a mesh of 0.5 mm aperture, and preserved in 75% ethanol. Second, the survey must have been carried out far away from any intensive human activity regions, e.g. mariculture, ocean infrastructure construction, ocean exploration platforms etc. And third, the study must have reported the species numbers of echinoderms and total macrobenthos. Following the application of these criteria, 51 papers containing 77 datasets on relative species richness (RSR) were obtained (see Supporting Material 1 (SM1), Supporting Material 2 (SM2); SM1 for the datasets and SM2 for the selected paper references).

2.2. Study area

We considered studies conducted over the shelf seas (water depth <200 m) of China, covering the Bohai Sea, Yellow Sea, and East China Sea (Fig. 1a). The South China Sea was not considered due to only three papers met our criteria (SM1). It is hard to obtain acceptable results by three papers.

The Bohai Sea is a shallow inner gulf, located between 37°07′–41°00′N and 117°35′–121°10′E, with a maximum depth of 38 m and covering 78,000 km^2. The sea water temperature features broad ranges: summer SST can reach 24 °C, while winter SST can be 0–2 °C. The mean annual salinity is 30‰. The Yellow Sea is a marginal sea of the Pacific Ocean, located between 31°43′–39°02′N and 119°10′–126°17′E, with a maximum depth of 152 m and covering 380,000 km^2. The range of sea water temperature is from 15 °C to 24 °C, and the mean salinity is 32‰. The East China Sea is also a marginal sea of the Pacific Ocean, located between 23°00′–33°10′N and 117°11′–131°00′E, with a mean depth of 349 m and the continental shelf region covering 550,000 km^2. The mean annual SST is 9.2 °C and the mean salinity is 31–32‰.

Besides these three seas, studies of Jiaozhou Bay and Changjiang river estuary (including the adjacent area) were also analyzed due to their special locations in China. Jiaozhou Bay (35°58′–36°18′N, 120°0′–120°23′E) is an inlet of the Yellow Sea, covering an area of 374.4 km^2. Situated in this bay is the only long-term temperate marine ecological research station, *Jiaozhou Bay Marine Ecosystem Research Station, Chinese Academy of Sciences*, which belongs to the Chinese Ecosystem Research Network (CERN) (Fig. 1b). Meanwhile, Changjiang river estuary is the largest river estuary in China, with an area of 99.6 km^2 (length: about 110 km; width: about 90 km; Fig. 1c). The Yangtze River Delta, developed along the estuary, has become the largest economic zone in China. An SST warming rate between 1982 and 2006 of eight times the global mean SST trend has been reported for this area (Belkin, 2009).

2.3. Relative species richness

Analyzing the species lists from each cruise would be the best way to examine the changes in echinoderms over the long term (Gotelli and Colwell, 2001; Hamilton, 2005); however, in practice, this is virtually impossible to achieve because of the lack of detail in the species composition information in the published studies. More specifically, it is difficult to remove duplicate species records from different cruises if the species lists of each cruise are not presented. Indeed, only a few studies (8 of the 51 papers covered in