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Molluscs of an intertidal soft-sediment area in China: Does overfishing explain a high density but low diversity community that benefits staging shorebirds?

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ABSTRACT

The Yellow Sea is a key staging ground for shorebirds that migrate from Australasia to the Arctic each spring. A lot of attention has been paid to the impact of habitat loss due to land reclamation on shorebird survival, but any effects of overfishing of coastal resources are unclear. In this study, the abundance of molluscs in the intertidal mudflats of northern Bohai Bay on the Chinese Yellow Sea was investigated in 2008–2014 from the perspective of their importance as food for northward migrating shorebirds, especially Red Knots *Calidris canutus*. Numerically contributing 96% to the numbers of 17 species found in spring 2008, the bivalve *Potamocorbula laevis* (the staple food of Red Knots and other shorebirds) dominated the intertidal mollusc community. In the spring of 2008–2014, the densities of *P. laevis* were surprisingly high, varying between 3900 and 41,000 individuals/m^2 at distinctly small sizes (average shell lengths of 1.1 to 4.8 mm), and thus reaching some of the highest densities of marine bivalves recorded worldwide and providing good food for shorebirds. The distribution of *P. laevis* was associated with relatively soft sediments in close proximity to the recently built seawalls. A monthly sampling programme showed steep seasonal changes in abundance and size. *P. laevis* were nearly absent in winter, each year settling on the intertidal mudflats anew. Peak densities were reached in spring, when 0-age *P. laevis* were 1–3 mm long. The findings point to a highly unusual demographic structure of the species, suggesting that some interfering factors are at play. We hypothesise that the current dominance of young *P. laevis* in Bohai Bay reflects the combined pressures of a nearly complete active removal of adult populations from mid-summer to autumn for shrimp farming (this clearing of adults may offer space for recruitment during the next spring) and low numbers of epibenthic predators of bivalves, such as shrimps and crabs, due to persistent overfishing in recent decades (allowing freshly settled juveniles to reach high densities). To the best of our knowledge, the idea that overfishing of competing marine mesopredators benefits staging shorebirds, at least in the short term, is novel; it now needs further experimental and comparative scrutiny. The long-term effects of overfishing on benthic communities of the mudflats need further investigation.

1. Introduction

Estuarine intertidal habitats are the most productive areas on Earth (McLusky, 1989; Little, 2000; Castro and Huber, 2005). They combine rich nutrient conditions (resupplied with every high tide) with ample sunlight (during the daytime low water periods), which leads to abundant primary production, often in the form of diatoms. This is fed upon by secondary producers such as bivalves and gastropods (Mollusca) (Peterson et al., 1985; Dame, 2012). Such 'grazing' macrozobenthic animals in turn are eaten by species at higher trophic levels, usually including fish and crabs during high tide, and shorebirds during the times that the sediments are exposed at low tide (Seitz et al., 2001; Gray and Elliott, 2009).

The distribution of molluscs is a function of these predation pressures, along with several external factors including sediment characteristics and wave action (Gosling, 2003; Dame, 2012). Quite recently in evolutionary terms, there has been overexploitation by human population, which has caused major losses of biodiversity in estuarine and coastal ecosystems worldwide (Ellis et al., 2000; Lotze et al., 2006). Human pressures can fundamentally change the structure and function of ecosystems (Jackson et al., 2001; Worm et al., 2006; Defeo et al.,

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2009). For instance, benthic communities of intertidal mudflats worldwide are threatened by bottom-dredging forms of fishery (Jackson et al., 2001; Piersma et al., 2001; Atkinson et al., 2005; van Gils et al., 2006), activities which may have serious downstream effects on the predators of benthic invertebrates (Shepherd and Boates, 1999; Atkinson et al., 2003; Verhulst et al., 2004; van Gils et al., 2006). The loss of coastal ecosystem values is a persistent problem worldwide, especially in rapidly developing countries (Lotze et al., 2006; Worm et al., 2009; MacKinnon et al., 2012; Ma et al., 2014; Murray et al., 2014).

The coasts of the Yellow Sea, at least historically, offered the largest continuous system of intertidal mudflats in the world (Healy et al., 2002). The coastal wetlands contained a rich biodiversity and are key stopover sites each spring for millions of migratory waterbirds in the East Asian–Australian Flyway (Barter, 2002; MacKinnon et al., 2012). These intertidal foreshores are used by high densities of humans as well (CIESIN, 2005). Bottom-dwelling life such as polychaete worms, bivalves, gastropods and crustaceans are harvested all around the Yellow Sea (Melville et al., in press). There is evidence that these fisheries have changed the coastal ecosystem: overfishing has caused major declines of several benthic species, harvests by suction pumps resulted in damage of non-target benthic species, mudflats were poisoned by pesticide used for clearing unwanted organisms before industrially reared spat seeded in the mudflats, and waterbirds were disturbed by massive harvesters in intertidal areas (Lin and Yuan, 2005; Feng and Ma, 2012; MacKinnon et al., 2012; Melville et al., in press). Thus, besides the effects of habitat loss by the remarkably fast land claims (MacKinnon et al., 2012; Murray et al., 2014; Piersma et al., 2015), the effects of fisheries on waterbirds along the Yellow Sea coast are also of concern but little studied.

Bohai Bay, located in northwest of the Yellow Sea, is a staging area supporting half a million migrant shorebirds every year (Barter, 2002; Barter et al., 2003; Yang et al., 2011). On these mudflats molluscs comprise an important food for the waterbirds (Yang et al., 2013). This resource support several important shorebird species, e.g. Red Knots (*Calidris canutus*), Curlew Sandpipers (*C. ferruginea*) and Great Knots (*C. tenuirostris*), in the East Asian–Australian Flyway during their refuelling stage in the Yellow Sea (Yang et al., 2011, 2013). Their presence goes together with heavy fisheries in the mudflats and offshore along Bohai Bay (HPDLR, 2007; Zhao et al., 2008; Jin, 2014).

In this study, we set out a seven-year investigation on molluscs and factors in northern Bohai Bay to test if there is any effect of fisheries on molluscs in the intertidal mudflats. As there is a knowledge gap on intertidal molluscs in the western Yellow Sea in terms of shorebird food conditions (Zhang and Hu, 2005; HPDLR, 2007; Wang et al., 2011; Cai et al., 2014), the aim of this study is to investigate the changes in density and distribution of molluscs. We examined the distribution of bivalves and gastropods in northern Bohai Bay in 2008–2014, monitored from the perspective of their role as a food resource for shorebirds.

2. Methods

2.1. Study area

The study area is located in the coast of Luannan County, Hebei Province, China (Fig. 1) and borders three fishing villages which are now separated from the sea because of previous land reclamations: Beipu, Nanpu and Zuidong (39°1–8′ N, 118°9–21′E). It also includes an actively exploited oilfield (Jidong Nanpu Oilfield) with three artificial islands in the intertidal and subtidal area (two of them presented in Fig. 1, one of which connects with land by a dike). The tidal area is limited by a seawall which was constructed at mid tide in the 1950s to enable the development of what are now among the largest salt works in the world.

Bohai Bay has a semi-diurnal tide and average tidal amplitude is 2.5 m (HPDLR, 2007). The remaining tidal mudflats of study area are 1–4 km wide at low tide and are completely submerged 2 h before high tide. The area has a typical temperate continental climate with cold, dry winters and hot, humid summers. The average temperature is −4 °C in January and 26 °C in July (HPDLR, 2007). The tidal area remains frozen normally between December and February. The local sea surface salinity is 33 ‰ in May and 31 ‰ in August (HPDLR, 2007). For more details of study area, see Rogers et al. (2010) and Yang et al. (2011).

There are two types of shellfish harvests on the intertidal mudflats in the study area. (1) The fishing of the bulk food for White Shrimp (*Litopenaeus vannamei*) raised in the adjacent saltpans. Local fishermen remove all bivalves over 2–3 mm long that occur in the top 2 cm layer of the sediment with suction devices from small fishing vessels (ca. 10 m length). The device consists of engine, pump, pipes and sieve. At high tide, pumping the water from the surface of the mudflats removes the upper layer of mud into the sieve on the boat to collect bivalves. The mud is disturbed to a depth of less than 4 cm. The harvest of White Shrimp-feed is carried out every summer and autumn, after northward migrants leave Bohai Bay, on the mudflats north of the offshore road to the oil island of Jidong Nanpu Oilfield (Fig. 1), and this activity has been ongoing for decades (J.C. Yang pers. Comm.). A similar harvest was carried out in the westernmost part of the mudflats between Nanpu and Zuidong until 2009 (Fig. 1). (2) The fishing of edible clams. For the collection of the edible clams, mainly *Mactra quadrangularis* over 2–3 cm long, fishermen pump the mudflats by suckers powered by engines on floating platforms (2–3 m diameter air-filled tyres). These are operated during outgoing and incoming tides by fishermen standing in seawater. Siphoning edible clams was adopted in 2009, and replaced the traditional digging by hand. It occurs on the mudflats between Zuidong and the sampling transects of this study in southern Beipu (Fig. 1). On the mudflats south to the offshore road to the oil island of Jidong Nanpu Oilfield, 15–20 engines have been active year-round except for midwinter, while 6–10 engines were active between March and May (i.e. during the staging of northward migrants) on the mudflats north to the offshore road. Leaving 5–10 cm-depth tracks after harvest, the disturbance of edible clam harvest appear more destructive for the surface sediments than that of White Shrimp's feed harvest. As we were not interested in quantifying the immediate effects of this fishery, we sampled areas where White Shrimp-feed were harvested, but did not sample areas where large edible clams were harvested. Although transects in Zuidong and Nanpu were in the edible-clam-harvest area in 2009 and one of transects in Nanpu was partly in the edible-clam-harvest area in 2013 and 2014 (Fig. 1), we sampled these transects in spring when fishing did not affect them.

2.2. Invertebrate sampling

2.2.1. Annual/spring sampling

In early and late spring 2008 benthic samples were collected at northern Beipu and Zuidong to investigate mollusc densities and sizes during the northward migration of shorebird migrants. Each site consisted of 4 transects 250 m apart on a grid running from the seawall to the low water line (Fig. 1). At each station, one sediment core of 1/56 m^2 to a depth of 20 cm was taken and sieved over a 1 mm mesh. To distinguish surface-living molluscs (i.e. prey accessible to probing shorebird predators) from deeper-living ones, the top 4 cm was sieved separately (see van Gils et al., 2009). Because gastropods were expected to occur in higher densities, they were sampled by a smaller core (1/267 m^2) to a depth of 4 cm and over a finer mesh (0.5 mm).

In early and late spring 2009 sampling sites were extended to S. Beipu and Nanpu, with 4 transects respectively (Fig. 1). The sampling method was changed to only take the top layer of the 1/56 m^2 core for bivalves with the small core from 2009, as in 2008 we established that all individuals of the numerically dominant bivalve species *Potamocorbula laevis* occurred in the top layer that is accessible to Red Knots (see Zwarts and Blomert, 1992).

Unfortunately, we had to reduce the number of sampling stations in 2010–2014 because of the reclamations of mudflats at Zuidong and