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Can mangrove plantation enhance the functional diversity of macrobenthic community in polluted mangroves?

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ABSTRACT

Mangrove plantation is widely applied to re-establish the plant community in degraded mangroves, but its effectiveness to restore the ecological functions of macrobenthic community remains poorly known, especially when pollution may overwhelm its potential positive effect. Here, we tested the effect of mangrove plantation on the ecological functions of macrobenthic community in a polluted mangrove by analyzing biological traits of macrobenthos and calculating functional diversity. Mangrove plantation was shown to enhance the functional diversity and restore the ecological functions of macrobenthic community, depending on seasonality. Given the polluted sediment, however, typical traits of opportunistic species (e.g. small and short-lived) prevailed in all habitats and sampling times. We conclude that mangrove plantation can help diversify the ecological functions of macrobenthic community, but its effectiveness is likely reduced by pollution. From the management perspective, therefore, pollution sources must be stringently regulated and mangrove plantation should be conducted to fully recover degraded mangroves.

1. Introduction

Mangroves are the vital habitat in intertidal regions worldwide, offering various ecological functions and services by mangrove plants and the associated macrobenthos (Ewel et al., 1998; Nagelkerken et al., 2008). Mangroves are, however, very susceptible to anthropogenic disturbance, especially pollution and exploitation. It is estimated that ~30% of the mangrove areas worldwide have been lost over the last 60 years and further loss will likely occur in the next few decades due to anthropogenic activities (Alongi, 2002). As mangroves provide nursery and breeding grounds for a variety of macrobenthos, the loss of mangroves may cause a concomitant change in the macrobenthic community and hence its ecological functions, such as energy flow and nutrient recycling.

Mangrove plantation is a straightforward operation and has been widely applied to restore degraded mangroves, or even expand mangrove areas (Lewis, 2005). Although mangrove plantation can help re-establish the plant community with a high success rate, its effectiveness to recover the macrobenthic community remains dubious because establishment of macrobenthic community is a complicated process, depending on the life history of macrobenthos and environmental conditions. Bosire et al. (2004) demonstrated that mangrove plantation can enhance the taxonomic diversity of macrobenthic community in an over-exploited mangrove. In polluted mangroves, however, the positive effect of mangrove plantation may be overwhelmed by the negative effect of pollutants (e.g. toxicity) on macrobenthos (Rakocinski et al., 2000). More importantly, increase in taxonomic diversity does not necessarily indicate diversified ecological functions since different species can have similar or even same ecological roles (i.e. functional redundancy) (Naeem and Wright, 2003; Cadotte et al., 2011). For the sake of environmental conservation and management, therefore, studying the ecological functions of macrobenthic community is vital to evaluate the recovery of mangrove ecosystems as a whole.

The ecological functions of macrobenthic community can be evaluated by analyzing the biological traits of macrobenthos (e.g. morphology, physiology and life-history), which are associated with various ecosystem processes and services, such as productivity, energy flow and nutrient recycling (Bremner, 2008; Cadotte et al., 2011; Wong and Dowd, 2015). Therefore, biological trait analysis can be applied to elucidate ecosystem functions following environmental changes (Bremner et al., 2006; van der Linden et al., 2012; Veríssimo et al., 2012). In addition, functional diversity can be calculated from biological trait data to provide a quick estimate of ecosystem functions (Petchey and Gaston, 2002; Cadotte et al., 2011). To date, these functional approaches are increasingly applied to evaluate ecosystem functions because they can explain ecosystem functions explicitly, allow

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geographical comparisons, discriminate different types of disturbance, and provide *a priori* prediction of the impact of environmental changes on ecosystem functions (Archaimbault et al., 2005; Mouillot et al., 2006; Dolédec and Statzner, 2008).

In this study, we investigated how mangrove plantation alters the ecological functions of macrobenthic community in a polluted mangrove by analyzing biological traits of macrobenthos and calculating functional diversity. Given the adverse effect of pollutants, we hypothesized that mangrove plantation cannot significantly diversify the ecological functions of macrobenthic community. In this case, mangrove plantation is mainly conducive to the recovery of plant community but not macrobenthic community, and thus more management measures are needed to recover degraded mangroves as a whole. Furthermore, we examined the relationship between taxonomic diversity and functional diversity. As studying the biological traits of macrobenthos is time-consuming, management efforts can be simplified and reduced if taxonomic diversity can act as a proxy for functional diversity in polluted mangroves.

2. Materials and methods

2.1. Sampling design

Futian Mangrove National Nature Reserve (22°31′35″N, 114°00′23″E) in South China was chosen as a study site due to two reasons: a mangrove plant, *Sonneratia caseolaris*, was extensively planted for shoreline protection; the sediment in this mangrove has suffered from organic and heavy metal pollution owing to the discharge of domestic and industrial sewage. Since the plantation of *S. caseolaris* in 1993 (Ren et al., 2011), all individuals of *S. caseolaris* are mature and have reached their maximum height (ca. 12 m) with a density of 48 individuals per 100 m^2. To investigate the effect of mangrove plantation on the ecological functions of macrobenthic community, four habitats were selected for the collection of macrobenthos: three vegetated areas respectively dominated by mangrove plants, *Kandelia obovata* (Ko), *Avicennia marina* (Am) and *Sonneratia caseolaris* (Sc), as well as an open mudflat (Mud) which acts as a reference site. *K. obovata* and *A. marina* are native mangrove plants, whereas *S. caseolaris* is an introduced mangrove plant which indicates the effect of mangrove plantation in this study. The sampling design was described in Leung and Tam (2013). Briefly, macrobenthos were collected using a PVC core sampler (20 cm long; 8 cm in diameter) at each sampling point in August 2008, February 2009, June 2009 and September 2009 (denoted hereafter as Aug 08, Feb 09, Jun 09 and Sep 09, respectively) to examine the temporal variation (Fig. 1). At each sampling point, two samples were collected in the vegetated areas and one in the mudflat due to higher habitat heterogeneity in the former (i.e. $n = 10$ for each vegetated site per sampling month, $n = 5$ for mudflat per sampling month). In the laboratory, the sediment samples were washed through a sieve (mesh size: 0.5 mm) to collect the macrobenthos, followed by identification and enumeration. Sediment properties, including pH, redox potential, particle size, total organic matter, total Kjeldahl nitrogen, total phosphorus, cadmium, copper, zinc and total polycyclic aromatic hydrocarbons (PAHs), were measured and reported in Leung and Tam (2013). In general, the sediment in this mangrove was anoxic (redox potential < -200 mV), silty (silt + clay fractions > 90%, except Ko) and rich in organic matter (>5% dry weight) throughout the sampling period. The concentrations of cadmium and total PAHs were higher in Aug 08 than those in other sampling months.

2.2. Biological trait analysis

A total of eight biological traits, subdivided into 39 trait categories, were chosen for biological trait analysis to represent the ecological functions (e.g. nutrient recycling and energy flow) of macrobenthic community (Table S1 for the details) (Bremner, 2008; Oug et al., 2012; Leung, 2015a). The biological trait data of each species were gathered from various published sources, including theses, books, scientific papers and online databases (e.g. MarLIN BIOTIC: www.marlin.ac.uk/biotic, Marine Species Identification Portal: www.species-identification.org and MarLIN Marine Macrofauna Genus Trait Handbook: http://www.genustraithandbook.org.uk). Fuzzy coding approach was used to score each trait category, ranging from '0' to '3', according to the affinity of the species to it ('0' indicates no affinity, while '3' indicates high affinity). Since species can display multiple behaviors or characteristics, they can score in more than one category in a particular trait, depending on the affinity. For example, a species can score '2' in two categories of feeding mode if it can show these feeding modes with equal affinity. At each sampling point, the score in each trait category of a species (taxa by traits) was multiplied by its abundance (taxa by habitats) and then summed over all species to represent the ecological functions (traits by habitats) (van der Linden et al., 2012).

2.3. Data treatment and statistical analyses

Rao's quadratic entropy index was calculated for each biological trait using a purpose-made Excel macro (Lepš et al., 2006). Functional diversity (FD) was calculated by averaging all these indices of biological traits (van der Linden et al., 2012). Two-way permutational analysis of variance (PERMANOVA) with 'habitat' and 'sampling month' as fixed factors was applied to test their effects on FD. Spearman correlation analysis was used to correlate the sediment properties with FD. Margalef's

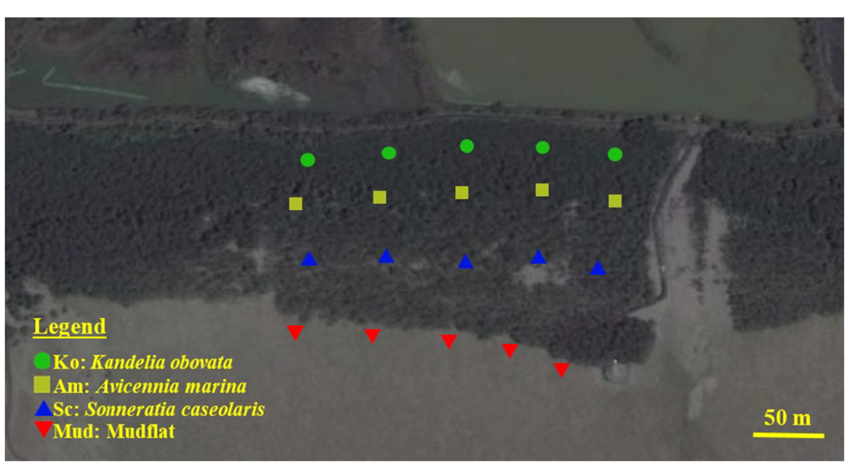

Fig. 1. A sampling map showing the sampling points in different habitats at Futian Mangrove National Nature Reserve. (Retrieved from Google Earth © DigitalGlobe.)

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