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Towards a biodiversity offsetting approach for coastal land reclamation: Coastal management implications

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ABSTRACT

Reclamation of coastal wetlands has a major impact on biodiversity globally. However, important questions remain regarding biodiversity offsets to such anthropogenic modifications. Generally, while formal and accurate quantifications of the residual impacts from development and the gain from offsets are essential, they are usually designated on an arbitrary score. Particularly, a general baseline with uncertainties defined across a dynamic scope has rarely been reported. In this study, a mathematical model was developed to quantify the loss from coastal land reclamation and gain from offsets. It considered the correlation between biodiversity effect size and reclamation, and the risk of failure in restoration based on the offset ratios theory, to determine the optimal amount of offsetting by calculating the biodiversity ratios between damaged and compensated habitat areas. The Yellow River Delta in China was used as a case study. Fuzzy sets or discrete intervals of references were used as the baseline. Minimum offset ratios were calculated for different baselines and values of counterfactual scenarios accounting for time lags for different types of coastal land reclamation. Therefore, no net loss was feasible when biodiversity could be compensated within the offset delay time. In this study, unlike previous methods, designation of an arbitrary score to measure the habitat or biodiversity value was avoided. Instead, this method was based on the change in biodiversity and was grounded in ecological theory. A more science-based approach is proposed, which is supported with a novel formula and existing data sets. These findings will help in the design of biodiversity offsets for coastal land reclamation based on their different impacts on biodiversity. This will inform policy makers about realistic minimal offsetting ratios or offset area requirements accounting for the offsetting delay time, the value of counterfactual scenarios, the correlation between biodiversity effect size and reclamation, the risk of failure in restoration, and the gross quantity of restoration. These results have important implications for the ecological restoration and compensation of coastal wetlands in the face of coastal land reclamation.

1. Introduction

Coastal land reclamation refers to the conversion of coastal wetlands into mariculture, salt pans, urban areas, or other industries (Murray et al., 2014; Yan et al., 2015). Considerable global economic development has been achieved through reclamation of coastal habitats (Ehrenfeld, 2000; Murray et al., 2014). However, coastal land reclamation has led to serious environmental and ecological problems, including the loss and fragmentation of coastal habitats in the intertidal zone, and in estuarine and marine waters (Bulleri and Chapman, 2010). Global coverage of mangroves and coral reefs has declined by more than 35% and 19%, respectively, over the past few decades (Valiela et al., 2001; Wilkinson, 2008); these habitats have been degraded or transformed mainly through the impact of anthropogenic activities, such as land-use change (UNEP, 2006). Mangrove forests have been removed across the tropics for conversion to aquaculture ponds (Alongi, 2002; Giri et al., 2011; Valiela et al., 2001), and saltmarshes have been highly modified by drainage for agriculture for centuries (Bromberg et al., 2009). The use of artificial islands is a popular method for land reclamation, such as for airports or harbors. For example, in Singapore, based on a number of small islands of less than 10 km^2, Jurong Island (reclaimed land area of 32 km^2) was formed to house major petrochemical installations and a power plant (Tsaltas et al., 2010). Coastal waters are seriously degraded, 56% of fisheries in China's exclusive economic zones had collapsed or were overexploited in 2010 (Liu et al., 2016). These changes significantly reduce the abundance and diversity

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of species (Chapman and Blockley, 2009; Vaselli et al., 2008). Many studies have confirmed that coastal land reclamation has a serious impact on macrobenthic communities in coastal wetlands (Blockley, 2007; Dugan et al., 2008). The macrobenthic abundance in natural habitats is significantly higher than that in areas of coastal land reclamation (Bulleri and Chapman, 2010; Chapman and Bulleri, 2003; Chapman and Blockley, 2009; Seitz et al., 2006). Furthermore, coastal land reclamation has major negative impacts on macrobenthic species diversity in coastal seawaters (Yan et al., 2015).

There is an urgent need to explore measures to mitigate the impacts of coastal land reclamation on the biodiversity of coastal habitats. Slowing down or stopping the development can certainly be helpful, but in the face of economic development needs, it is obviously not realistic. An effective strategy is likely to encompass all levels of the mitigation hierarchy (BBOP, 2009; Cuperus et al., 2001; Moilanen et al., 2009; Ten Kate et al., 2004; Perrow and Davy, 2002). That is, policies required are those that: (a) avoid development of important coastal areas, such as careful spatial placement of elements of infrastructure; (b) minimize the duration, intensity, or extent of impacts that cannot be completely avoided, such as increase urban settlement densities rather than distribution; (c) reduce the impacts of development where they occur through effective rehabilitation or restoration on impacted sites; and (d) offset residual impacts where these impacts are unavoidable through activities that protect and/or restore comparable biodiversity elsewhere. There has been a recent focus on the latter strategy because it theoretically provides the greatest flexibility for developers without net loss of biodiversity (Gibbons et al., 2016). The popularity of this strategy lies in the potential to meet the objectives of biodiversity conservation and of economic development simultaneously (Bull et al., 2013); biodiversity offsets could also be an effective measure for pre-existing developments. In the present study, biodiversity offsetting was explored as a potential strategy to mitigate the impacts of coastal land reclamation on biodiversity.

Biodiversity offsetting can involve the restoration of degraded habitat elsewhere (restoration offsets), or the protection of areas where there is imminent or projected loss of biodiversity (avoid-loss offsets) (BBOP, 2009; Gibbons et al., 2016). This present study mainly focuses on restoration offsets because there are few high-quality wetlands available for protection/averted loss in the selected study area. Most offsetting policies include a requirement for in-kind offsets that conserve similar attributes of biodiversity to those affected by development (McKenney and Kiesecker, 2010). Limitations on the availability of offset sites that can provide in-kind offset can lead to the allowance of a different approach, called out-of-kind offset, where impacts on one biodiversity target can be replaced by improvements in a different biodiversity target (Bull et al., 2013). The scale of offset projects needed to provide equal gains in species diversity in future discounted terms could be determined, thereby fully compensating the losses, which include a compensation with the same species diversity as was lost and a fixed proportion of habitat areas.

This is implemented using an offset ratio (Moilanen et al., 2009) to determine how much biodiversity, relative to the quantity and quality affected, needs to be restored elsewhere to achieve no net loss. The offset ratio needs to encapsulate the ecological equivalence of losses and gains (Quétier and Lavorel, 2011), time lags (Bull et al., 2013), and risk of failure (Moilanen et al., 2009; Gibbons et al., 2016). However, while accurate quantification of the residual impacts from development and gain from offsets is essential, they are usually designated on an arbitrary score. There is a difficulty in assigning loss to a particular activity for the cumulative effects (climate change and other sources might lead to a decline in species diversity), and the risk of failure in restoration is often overlooked in the offset literature, which can arise when restoration technology is not feasible. In addition, restoration offsets of marine coastal ecosystems are feasible, although expensive, and the overall project feasibility involves success criteria that are linked to the recovery of species diversity (Bayraktarov et al., 2016; Ruiz-Jaen and Aide, 2005). Assumed counterfactual scenarios or baselines (Angelsen, 2008; Ferraro, 2009) can be extremely influential in the calculation of the losses and gains, choice of reference frame determining offset feasibility, and effort required to attain objectives when designing and evaluating biodiversity offset schemes (Bull et al., 2014). However, baselines usually have uncertainties, they are rarely described in terms of their plausibility (Ferraro, 2009; Miteva et al., 2012), and are often ignored in offset ratio calculations.

Research into biodiversity offsets has mainly focused on terrestrial ecosystems, but recently there has been a growing interest in applying it to the marine environment. In the present study, a viable policy option for mitigating impacts of coastal land reclamation is explored using the macrobenthos (Balcombe et al., 2005; Mitsch et al., 1998), a typical group of coastal wetland indicator species, as a measure of biodiversity. Macrobenthos are sensitive to changes in environmental factors and are a key link in the food chain for a range of other species (e.g., birds) (Kristensen et al., 2014). These species are functionally important for circulating nutrients and energy within coastal systems (Herman et al., 1999), which have a relatively fixed scope of activity (Li et al., 2016a). In addition, they are extremely valuable components of functioning wetland ecosystems, which have been used as surrogates for wetland function in West Virginia (Balcombe et al., 2005), and are sensitive to decreases in hydro-morphological or physical-chemical functions (Everaert et al., 2013). Therefore, it is important to protect macrobenthic biodiversity in coastal wetlands. To maintain the sustainable use of resources and achieve no net loss of macrobenthic biodiversity, it is necessary to offset the residual impact of coastal land reclamation, and restore habitat elsewhere by planting new coastal vegetation and restoring tidal flows (Suding, 2011; Zedler and Kercher, 2005).

In this study, the Yellow River Delta in China, for which biodiversity offsets are not currently employed in the mitigation of coastal wetland development, was used as a case study. First, a mathematical model was developed to understand the loss from coastal land reclamation and gain from offsets. Second, the loss from coastal land reclamation was quantified by initially investigating the species diversity of different types of coastal land reclamation, and comparing the relative differences in biodiversity associated with a reclamation activity and a close-to-natural or (semi-) natural reference situation. For the currently available empirical data, an absolute impact assessment (changes relative to the original state, which has not been reclaimed) was not possible. Therefore, the relative impact (comparing the relative differences in the biodiversity associated with a reclamation activity and a close-to-natural or [semi-] natural reference situation) was calculated instead. Both methods are deemed appropriate and their use is a matter of value choice for biodiversity assessments (Koellner et al., 2013). Third, fuzzy sets or discrete intervals for references were obtained to handle uncertainties at baseline. Finally, to compensate for the loss of biodiversity caused by coastal land reclamation, additional habitats of equivalent macrobenthic biodiversity must be created elsewhere. The minimum offset ratios under different restoration quantities accounting for time lags were simulated.

2. Materials and methods

2.1. Study sites

The study area (37°35′N to 38°12′N, 118°24′E to 119°22′E) of 1614 km^2, with warm temperate continental monsoon climate and comprised the following sites: (a) along the entire coastline of the Yellow River Delta, located at the mouth of the Yellow River in Dongying City of Shandong Province, China; and (b) the south coast of Bohai Bay and the west coast of Laizhou Bay, also in Shandong Province (Fig. 1).

2.1.1. Coastal land reclamation data collection

Data from the Landsat Multi-spectral Scanner and Thematic Mapper