Marine Pollution Bulletin xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

The cumulative effects assessment of a coastal ecological restoration project in China: An integrated perspective

Deqiang Ma [a], Liyu Zhang [b], Qinhua Fang [a,c,*], Yuwu Jiang [d], Michael Elliott [e]

[a] Coastal and Ocean Management Institute, Xiamen University, Xiamen 361102, China
[b] Xiamen Oceans and Fisheries Institute, Xiamen 361000, China
[c] Fujian Provincial Key Laboratory for Coastal Ecology and Environmental Studies, Xiamen University, Xiamen 361102, China
[d] State Key Laboratory of Marine Environmental Science, Xiamen University, Xiamen 361102, China
[e] Institute of Estuarine & Coastal Studies, University of Hull, Hull HU6 7RX, UK

ARTICLE INFO

Article history:
Received 22 July 2016
Received in revised form 13 February 2017
Accepted 15 February 2017
Available online xxxx

Keywords:
Ecological restoration
Ecoengineering
Seabed dredging
Dyke opening
Hydrodynamic conditions
Water quality

ABSTRACT

Large scale coastal land-claim and sea-enclosing (CLASE) activities have caused habitat destruction, biodiversity losses and water deterioration, thus the local governments in China have recently undertaken seabed dredging and dyke opening (SDADO) as typical ecological restoration projects. However, some projects focus on a single impact on hydrodynamic conditions, water quality or marine organisms. In a case study in Xiamen, China, an integrated effects assessment framework centres on ecohydrology, using modeling of hydrodynamic conditions and statistical analysis of water quality, was developed to assess the effects of ecological restoration projects. The benefits of SDADO projects include improving hydrodynamic conditions and water quality, as a precursor to further marine biological improvements. This study highlights the need to comprehensively consider ecological effects of SDADO projects in the planning stage, and an integrative assessment method combining cumulative effects of hydrodynamic conditions, water quality and biological factors.

1. Introduction

The rapid growth of population and economic development has placed global ecosystems under increasing pressures (McKee et al., 2004; Millennium Ecosystem Assessment, 2005). Those pressures are especially increasing in wetland and estuarine areas where habitats have been claimed for agriculture and urbanization (McLusky and Elliott, 2004; Lambin and Meyfroidt, 2011; Seto et al., 2012; Wang et al., 2014; Wolanski and Elliott, 2015). In particular, large scale coastal land-claim and sea-enclosing (CLASE) greatly change coastal ecosystems (MacKinnon et al., 2012; Wang et al., 2010; Shen et al., 2016). Land-claim was previously termed reclamation until nature protection bodies emphasized that this is not 'reclaiming' but *per se* 'claiming' land from the sea (McLusky and Elliott, 2004). Confronting the increasing degradation of ecosystems, ecological restoration projects and particularly ecoengineering have aimed at restoring ecosystems, including habitat and biodiversity restoration. This has been widely and increasingly implemented in coastal states (Davis and Slobodkin, 2004; Mitsch and Jørgensen, 2003; Wortley et al., 2013; Elliott et al., 2016).

There are various types of ecological restoration projects in coastal areas each with varying purposes. Elliott et al. (2016) separated such ecoengineering projects into two types: Type A in which the hydrodynamic functioning (ecohydrology) and the habitat structure are created thus allowing the ecology then to develop, and Type B where species may be reintroduced, restocked, replanted etc. to allow recovery as long as the physical conditions are sufficient for sustainable ecology to develop. In China, seabed dredging and dyke-opening (SDADO) activities have been adopted as the main types of ecological restoration projects to improve the marine environment particularly in semi-enclosed bays. Dyke opening is synonymous with the practice of managed realignment, managed retreat, depolderisation or set back in Europe (Elliott et al., 2007, 2016).

Ecological restoration has shown success (Borsje et al., 2011; Zhang et al., 2012; Qi et al., 2013; Mi et al., 2015) although ecological restoration activities are also anthropogenic disturbances in ecosystems. Therefore, these initiatives inevitably generate unintended consequences, which can even harm the original ecosystems and/or not deliver the original aims for the restoration schemes (Elliott et al., 2016). In considering potential negative impacts on ecosystems, it is necessary to comprehensively evaluate the effects of the proposed ecological restoration project to improve the decision-making including planning and design.

Wolanski and Elliott (2015) emphasise that estuarine ecohydrological principles must be followed to create the appropriate basal conditions against which the ecology can develop and conversely if these physical conditions are not successfully created then neither will be the ecology. The links between the geomorphohydrology and marine ecology are

* Corresponding author at: Coastal and Ocean Management Institute, Xiamen University, Xiamen 361102, China.
E-mail address: qhfang@xmu.edu.cn (Q. Fang).

http://dx.doi.org/10.1016/j.marpolbul.2017.02.043
0025-326X/

well known (Gray and Elliott, 2009) and the impacts of SDADO on hydrodynamic conditions have been widely studied (Thieler et al., 2000; Bai et al., 2003; Yang et al., 2010; Yuan and Zhu, 2015) as is the impact on the benthic environment and community (Boyd et al., 2003; Lewis et al., 2001; Smith et al., 2006; Licursi and Gómez, 2009). However, many studies such as the impact assessment of dredging activities in the east coast of the UK (Cooper et al., 2007a) and the Botany Bay in Australia (Fraser et al., 2006) focus on limited aspects of ecosystems, rather than a comprehensive evaluation of all effects on marine ecosystems (Chapman and Underwood, 2011). Furthermore, it is questioned whether from the perspective of ecosystem-based management, SDADO projects currently implemented in China are scientific, defendable and reasonable.

Given the lack of an integrative approach to assess the effects of SDADO projects, this study aims to remedy that omission to assess the integrated effects. In order to achieve this goal, an approach synthesising and considering cumulative changes in hydrodynamic conditions, water quality and marine biodiversity was developed to evaluate the comprehensive effects of SDADO projects on coastal marine ecosystems in Xiamen Bay, China. Hence, here we relate a conceptual framework to this integrated approach where we simulate the changes in hydrodynamic conditions caused by SDADO projects. Then the changing trends in water quality in Xiamen Bay were quantitatively analyzed, and biological impacts were evaluated qualitatively, in order to examine the practical effects of SDADO projects in Xiamen Bay.

2. Study area

Xiamen Bay is a semi-enclosed bay, in southeast China covering 154.2 km^2, and with a water depth of 5–20 m. The population and economy of Xiamen have experienced a rapid growth since social and political reform, reaching 3.7 million and a total GDP of 301.8 billion RMB (US$45 bn) in 2013. The main river flowing into Xiamen Bay is Jiulong River whose catchment is 14,700 km^2 supporting a population of 3.5 million (Chen et al., 2013).

Since the 1950s, Xiamen has implemented large scale land-claim projects (125.7 km^2 in total), leading to negative cumulative impacts on local coastal ecosystems including a significant decline of water quality, habitat and biodiversity deterioration in Xiamen Bay, as well as changes in hydrodynamic conditions (Xue et al., 2004; Zhang et al., 2009; Wang et al., 2013a). To counter this, the Xiamen Government has spent around 10 billion RMB (US$1.5 bn) to implement a series of SDADO projects in the Western Sea Area and the Tongan Bay Area to improve the marine environmental quality around Xiamen Island since 2009 (Fig. 1). The Gaoji dyke, a 2.2 km causeway completed in 1955, cut off the circulating current around Xiamen Island, increasing sediment accretion and water pollution. In order to restore the circulating current around Xiamen Island, the opening of the Gaoji dyke was started in 2010 and ended in 2013 and this produced 33 billion m^3 dredged material from 2009 to 2013.

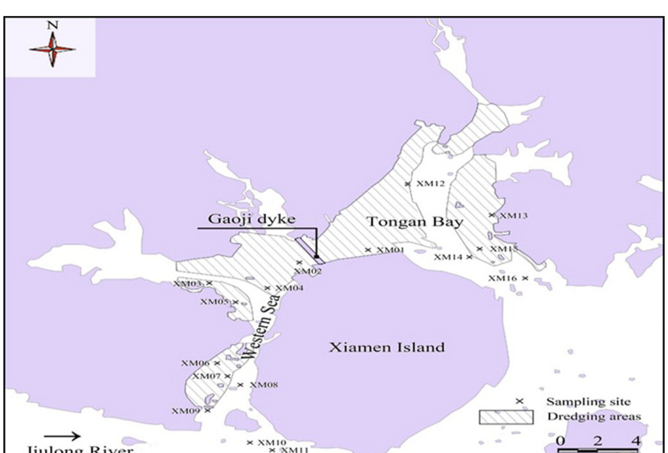

Fig. 1. Dyke opening and seabed dredging projects in Xiamen Bay.

3. Data and methods

3.1. Methods

3.1.1. Conceptual framework

As the purpose of this case study was to use three indicators of hydrodynamic conditions, water quality and marine biodiversity to evaluate the cumulative effects of SDADO projects on the coastal marine environment, a conceptual framework (Fig. 2) was developed to help to understand and assess such cumulative effects. This conceptual framework shows the processes of cumulative effects of the SDADO projects on water quality and marine biodiversity. The SDADO direct impacts are to change the physical environment including hydrodynamic, habitat and biodiversity characteristics (Thieler et al., 2000; Smith et al., 2006). Such physical changes further affect water quality and sediment environments by altering its environmental carrying capacity (Gray and Elliott, 2009; Jing et al., 2013) and water quality is affected by the re-liberation of sediment-bound materials during dredging (Lohrer and Wetz, 2003; McLusky and Elliott, 2004; Hossain et al., 2004; Urban et al., 2010; Cardoso-Mohedano et al., 2016). In addition, water quality is also affected by contaminant inputs and resultant effects on marine biological structure and functioning. The combined impacts affect marine biodiversity although given the complexity of coastal marine ecosystems there is the ability to absorb change, what has been termed environmental homeostasis (Elliott and Quintino, 2007). Here, we evaluated changes in hydrodynamic conditions and water quality to reflect the cumulative effects of SDADO projects on the coastal marine environment; we used quantitative data where possible although qualitative analysis was used in cases of poor data availability.

3.1.2. Model for hydrodynamic changes

Marine engineering projects such as SDADO have changed the hydrodynamics, the bathymetry below the low water (LW) and topography above LW and its coastline in Xiamen Bay (Xue et al., 2004; Li et al., 2011; Wang et al., 2013a). In order to evaluate the impacts of SDADO on the hydrodynamic condition in Xiamen Bay, we used the modified three-dimensional numerical model based on the ROMS model (Shchepetkin and McWilliams, 2003, 2005) developed by Wang et al. (2013b) to simulate and compare changes in current velocity, half-life time and tidal prism before and after SDADO. These three hydrodynamic indicators were selected as they influence the water turnover, flushing rate and residence time and thus the self-purification capacity of coastal bays (Prandle, 2009). The model includes an orthogonal curvilinear coordinate in the horizontal direction and a sigma coordinate in the vertical direction, which is driven by climatological factors including temperature and salinity. A two-way nested-grid method (Oey and Chen, 1992) was used in this model.

3.2. Statistical analysis and data sources

As the implementation of the SDADO project in Xiamen Bay started in 2009, the assessment period is from 2004 to 2013. The assessment area consists of the Western Sea Area and the Tongan Bay Area. Data for sea areas in the years of 2009 and 2014 were used to simulate hydrodynamic changes; temperature and salinity data were derived from a Pacific Regional Ocean Model System (Wang and Chao, 2004; Liu and Chai, 2009). Two high-resolution satellite images in 2009 and January 2014 were used to obtain coastline changes and the changes of sea areas using remote sensing technology (Table 1).