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Analysis

Estimating the ecosystem service losses from proposed land reclamation projects: A case study in Xiamen

Xuan Wang [b], Weiqi Chen [a,b,*], Luoping Zhang [a,b], Di Jin [c], Changyi Lu [a,b]

[a] State Key Laboratory of Marine Environmental Science, Xiamen University, Xiamen 361005, PR China
[b] Environmental Science Research Center, Xiamen University, Xiamen 361005, PR China
[c] Marine Policy Center, Woods Hole Oceanographic Institution, Woods Hole, MA 02543, USA

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ABSTRACT

Economic valuation of ecosystem damages is an important building block in the development of full cost accounting which may lead to improvements in environmental policy making. Based on an analysis of the negative impacts of land reclamation on coastal ecosystem services and a review of different valuation techniques, this study develops a framework for selecting relevant valuation methods for different ecosystem services and for developing total ecosystem loss estimates for land reclamation projects. We illustrate the framework through a case study of Tong'an Bay, Xiamen, China where four reclamation schemes have been proposed. The results show that the costs associated with ecosystem damages are significantly higher than the internal costs of these reclamation projects.

1. Introduction

There is a growing volume of literature on ecosystem services (Costanza et al., 1997; Daily, 1997; de Groot et al., 2002; Beaumont et al., 2007; Fisher et al., 2009). Most notably, Costanza et al. define ecosystem goods and services as the benefits human populations derive, directly or indirectly, from nature (Costanza et al., 1997). The Millennium Ecosystem Assessment (MEA), a monumental work involving over 1300 scientists and the first attempt to fully interpret, understand and assess the interrelation between ecosystems and human well-being at a global scale, mentions that ecosystem services are the benefits which people obtain from ecosystems (MEA, 2003). This paper follows Daily (1997) and MEA (2003) in using the term "services" to encompass both the tangible and intangible benefits humans derive from ecosystems, which are sometimes separated into "goods" and "services".

The techniques for valuating ecosystem services have drawn attention in recent years (Lal, 2003; UN, 2003; Curtis, 2004; Hein et al., 2006; Dale and Polasky, 2007; Li et al., 2008; Yang et al., 2008; de Groot et al., 2010). Curtis (2004) described a new approach to valuing ecosystem services and goods, using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to various attributes. Hein et al. (2006) analyzed the spatial scales of ecosystem services, and examined how stakeholders at different spatial scales attach different values to ecosystem services. de Groot et al. (2010) provided an overview of the challenges involved in applying ecosystem service assessment and valuation to environmental management, and analyzed trade-offs involved in land cover and land use change. The economic valuation of ecosystem services plays an important role in linking human activities and natural systems. Traditional market cannot recognize the economic impact of environmental damages if ecosystem services do not have a price. Existing technologies that reduce the environmental impacts of human activities on ecosystem services cannot be fully implemented if the environmental services they preserve are free (MEA, 2005). Monetary valuation provides a mean to allow "unpriced" services to be compared with services that have market values. Valuation also enables the aggregation of different ecosystem services and allows full cost accounting. Unfortunately, there has been little study on the valuation of ecological losses from land reclamation (Peng et al., 2005; Xiong et al., 2007; Wang et al., 2010).

This paper presents a systematic research on the valuation of coastal ecosystem service losses caused by land reclamation, including the development of a framework for selecting valuation methods and relevant models, and a case study in China. The results of the study provide much-needed information on the ecological losses associated with land reclamation, and help stakeholders and decision-

* Corresponding author. State Key Laboratory of Marine Environmental Science, Xiamen University, Xiamen 361005, PR China. Tel.: +86 592 2181907; fax: +86 592 2186913.
E-mail address: wqchen@xmu.edu.cn (W. Chen).

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makers to make informed choices among various options and to promote sustainable marine resource uses.

2. Methods

2.1. The Negative Impacts of Land Reclamation on Coastal Ecosystem Services

Coastal ecosystems provide a variety of ecological services that directly or indirectly translate to economic values to humans (MEA, 2003; Hanley et al., 2003; Eggert and Olsson, 2009). Coastal waters support fish populations that constitute a significant source of protein, sustain ecosystem stability through conservation of biodiversity, mitigate climate change through carbon sequestration, act as sinks for byproducts of industrial or agricultural production, and provide recreational and aesthetic benefits. This paper adopts the framework of the MEA (2003) as a baseline for the classification of coastal ecosystems (Table 1). Marine and coastal natural resources are, for the most part, renewable. If properly managed, they should provide continuing returns into the future without diminishing their productivity (Remoundou et al., 2009). However, increasing human activities in coastal areas exert growing pressure on the marine and coastal ecosystems. In order to ease the problem of land shortage, reclaiming land from the sea has become a common approach in many parts of the world. In fact, large-scale land reclamation has caused significant damage to coastal ecosystems and the services they provide. Land reclamation occupies coastal space, permanently change the intrinsic natural quality (e.g., topography, physiognomy and shoreline) of a coastal ecosystem, and alter the hydrodynamic effect of sediment transport or inshore current systems, as well as endanger the animals and plants (e.g., benthic organisms and mangroves) in and near the reclamation area (Lu et al., 2002), all of which will directly or indirectly damage the provisioning, regulating, cultural and supporting services generated by the coastal ecosystem. For example, reclamation may change seaside and sandy beaches which provide the aesthetic and recreational service; it would reduce tide-absorbing capacity of a bay, causing damage to waste treatment service; it may destroy coastal plants and phytoplankton which play an important role in gas regulation service through photosynthesis; it may also destroy mangroves and coral reefs which provide erosion control service as natural coastal defense against storm surges and biodiversity maintenance service as important habitats for fish and wildlife.

Ecosystems maintain their functional integrity through a natural balance of materials and energy flowing through, cycling within, and leaving them. This equilibrium is supported by natural, physical, chemical and biological processes. Land reclamation may disturb the equilibrium or destroy coastal ecosystems (Wang and Chen, 2009).

2.2. The Framework for Selecting Valuation Methods

Although there has not been a well-defined approach to estimate the losses of coastal ecosystem services so far, a range of methods for resource valuation and ecosystem services valuation have been developed (Farber et al., 2002; Freeman, 2003; Curtis, 2004). These methods can be divided into three types: (1) Direct Market Approach is used where market prices of outputs (and inputs) are available. This includes productivity losses method, production function method and public pricing method; (2) Surrogate Market Approach is used to establish a surrogate capital market from which the shadow prices can be derived, including substitute cost method, defensive expenditure method, restoration cost method, travel cost method and hedonic price method; and (3) Experimental Market Approach or Pseudo-Market Approach is used to construct a pseudo-market by directly surveying a sample of individuals from relevant population. The most commonly used method is the contingent valuation method (CVM) which involves a questionnaire survey of a representative sample of individuals' "willingness to pay" to ensure or prevent a specific environmental change. Ecosystem valuation is typically a costly and time consuming exercise. When valuation data are unavailable for a study region, the method of benefit transfer is often used to bridge data gap. Benefit transfer involves the application of environmental or ecosystem values estimated at one site through market-based or non-market-based techniques to another site (Ledoux and Turner, 2002).

A framework for selecting appropriate valuation techniques based on the characteristics of different ecosystem services is depicted in Fig. 1. Provisioning services, such as seafood production, may be conveniently valued by market price methods. Regulating services, such as flood regulation and waste treatment, are not traded on markets, but we can identify shadow projects that provide similar functions. Thus, Surrogate Market Approach can be used to value these services. Although cultural services, such as aesthetic and recreational services, cannot be measured through Direct Market Approach, indirect market information may be available. In this case, travel cost method or hedonic price method can be used to develop valuation estimates. Supporting services, such as biodiversity maintenance, typically can neither be valued by direct market methods nor by indirect market methods. In such a case, contingent valuation method is often employed. As described previously, the benefit transfer method may be applicable to different ecosystem services with careful comparison of different sites and necessary adjustments. Although valuation estimates based on benefit transfer are often less accurate, it is a very attractive alternative under tight time and budget constraints.

Table 1
A general classification of coastal ecosystem services.

Types of coastal ecosystem services	Sub-services
Provisioning services	Food, raw materials, genetic resources, natural medicines, ornamental resources, water supply, space
Regulating services	Gas regulation, climate regulation, flood regulation, erosion control, waste treatment, biological control
Cultural services	Aesthetic, recreational, spiritual, science and education
Supporting services	Primary production, soil formation, nutrient cycling, biodiversity maintenance

Source: Drawn from MEA (2003) and adjusted for the marine environment based on Remoundou et al. (2009).

2.3. The Monetary Valuation Models

Within the framework for selecting feasible valuation methods (Fig. 1), we establish the following monetary valuation models for each coastal ecosystem service and relevant sub-service.

2.3.1. Provisioning Services

2.3.1.1. Food Supply. Land reclamation may result in the decrease, even extinction, of marine living resources including fish, shellfish, phytoplankton and rare species, thus damaging the food supply service. While it is difficult to value their contribution to marine food chains and the ecosystem, the value of marine plants such as phytoplankton can be partially captured by the gas regulation service. The value of rare marine species is mainly embodied in the biodiversity maintenance service. In order to avoid double counting, only aquatic resources with commercial values are discussed in this section.

As renewable resources, marine aquatic resources can generate continuous revenue streams under reasonable exploitation. Thus the damage to food supply can be calculated using data from commercial fishing. The valuation model is:

$$D_f = \frac{R_f \cdot \alpha}{S_0} \times S \tag{1}$$

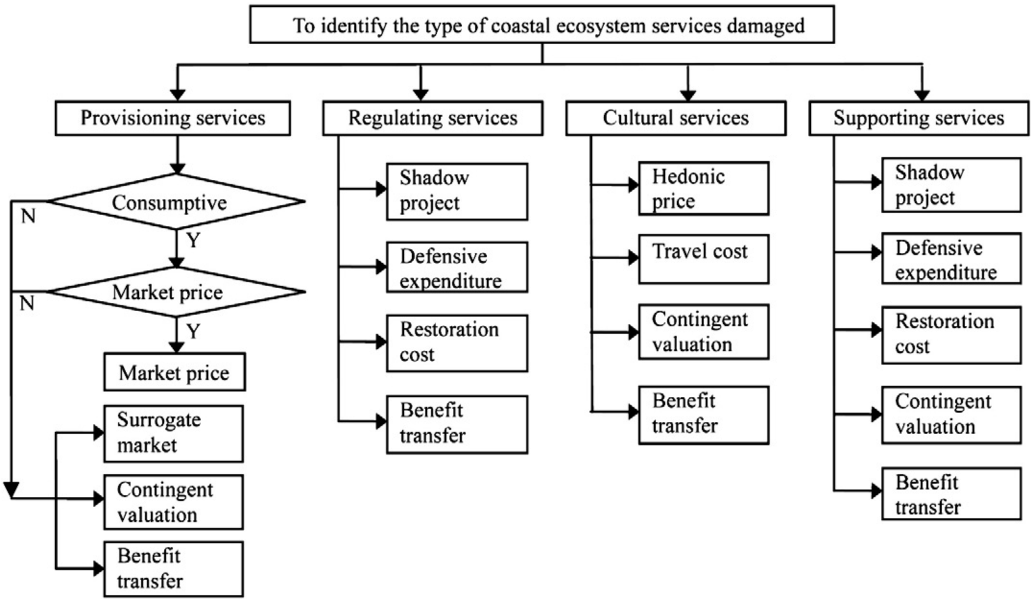

Fig. 1. The framework for selecting valuation methods.

where D_f is the loss of food supply service (US\$ year^{-1}); R_f is the revenue of marine fishing (US\$ year^{-1}); α is the average profit rate of marine fishing (%); S_0 is the area of the study region (m^2); and S is the area of reclamation (m^2).

2.3.1.2. Genetic Resources. The damage to genetic resources may be evaluated using the CVM or benefit transfer method. The valuation model adopting the benefit transfer method is as follows:

$$D_g = V_g \times S \tag{2}$$

where D_g is the loss of genetic resources (US\$ year^{-1}); V_g is the value of genetic resources per unit sea area (US\$ m^{-2} year^{-1}); and S is the area of reclamation (m^2).

2.3.1.3. Space Resources. Maritime transport resources (e.g., harbors and coastal shipping lanes) are vital to the marine transportation industry and the economy. Land reclamation may lead to siltation of channels and anchorages. This damage can be valuated using the restoration cost method. The valuation model is:

$$D_{dr} = M_{dr} \times C_{dr} \tag{3}$$

where D_{dr} is the loss of maritime transportation industry (US\$ year^{-1}); M_{dr} is an increase of siltation volume (m^3 year^{-1}); and C_{dr} is the dredging cost (US\$ m^{-3}).

Similarly, land reclamation may occupy and destroy intertidal zones and shallow seas, affecting mariculture production. The damage to intertidal zones and shallow seas can be computed using the following model:

$$D_{mc} = \sum V_{mc} \cdot S_{mc} \tag{4}$$

where D_{is} is the loss of mariculture space (US\$ year^{-1}); V_{mc} is the average mariculture profit (US\$ m^{-2} year^{-1}); and S_{mc} is the mariculture area destroyed by land reclamation (m^2).

2.3.2. Regulating Services

2.3.2.1. Gas Regulation. The gas regulation service provided by marine and coastal ecosystems maintains clean, breathable air and helps prevent diseases (e.g., lung cancer) through photosynthesis of coastal plants (such as mangrove) and phytoplankton by absorbing CO_2, releasing O_2 and absorbing other deleterious gases (e.g., SO_2). In addition, gas regulation plays an important role in climate regulation by limiting the greenhouse gases. According to the formula of photosynthesis and respiration, when marine and coastal ecosystems absorb 1 g CO_2, they release 0.73 g O_2. The value of gas regulation services can be estimated by investigating the costs associated with fixing CO_2 and supplying O_2 and the amount of CO_2 absorbed by different ecosystems per unit area and time. The damage to gas regulation service can be calculated using the following model:

$$D_{ga} = \left(C_{CO_2} + 0.73C_{O_2}\right) \sum P_{iCO_2} \cdot S_i \times 10^{-6} \tag{5}$$

where D_{ga} is the loss of gas regulation service (US\$ year^{-1}); C_{CO_2} is the cost of fixing CO_2 (US\$ t^{-1}); C_{O_2} is the cost of supplying O_2 (US\$ t^{-1}); P_{iCO_2} is the amount of CO_2 absorbed by ecosystem type i per unit area and time (g m^{-2} year^{-1}); and S_i is the area of ecosystem type i occupied by land reclamation (m^2).

2.3.2.2. Erosion Control. The presence of coastal ecosystems such as mangroves and coral reefs can prevent and alleviate damages caused by flooding and storm events in coastal zones. The damage to this service caused by reclamation can be estimated using the defensive expenditure method, i.e., the cost of flood protection measures. The valuation model is:

$$D_{ec} = \frac{C \times L(1 + 2\%n)}{n} \tag{6}$$

where D_{ec} is the loss of erosion control service (US\$ year^{-1}); C is the cost of building embankment per unit length (US\$ m^{-1}); L is the length of coastline destroyed by land reclamation (m); maintenance cost per annum taken as 2% of the project cost; and n is the life span, usually 50 years.

2.3.2.3. Waste Treatment. Waste treatment is one of the important services provided by coastal ecosystems. However, land reclamation diminishes the volume of a water body, thereby reducing tide-absorbing capacity. The shadow project method can be adopted to estimate the damage to the waste treatment service, using the treatment costs from sewage disposal plants (Chen et al., 1999). We can establish the following valuation model (Wang et al., 2010):

$$D_{wt} = \sum M_i \cdot \Delta V \cdot C_i \times 365 + \sum \left(\Delta N_i \cdot V - \Delta N_i' \cdot V' \right) \cdot C_i \times \frac{24}{t} \times 365 \quad (7)$$

where D_{wt} is the loss of waste treatment service (US\$ year^{-1}); M_i is the biochemical degradation capacity of pollutant i per unit volume of sea water per day (g m^{-3} d^{-1}); ΔV is the reduction in sea volume due to reclamation (m^3); C_i is the treatment costs of pollutant i (US\$ t^{-1}); ΔN_i is the difference in concentration of pollutant i between high tide and low tide before reclamation (mg L^{-1}); $\Delta N_i'$ is the difference after reclamation (mg L^{-1}); V is the volume of tidal prism before reclamation (m^3); V' is the volume after reclamation (m^3); and t is the period of one tidal cycle (hour).

2.3.2.4. Biological Control. Changes in ecosystems can directly change the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes. These changes can also affect the prevalence of insect pests and diseases affecting marine animals. The damage to biological control service can be valued through the defensive expenditure method, using the expenditure on disease and insect pest extermination, or through the benefit transfer method. The valuation model is:

$$D_{bc} = V_{bc} \times S \quad (8)$$

where D_{bc} is the loss of biological control service (US\$ year^{-1}); V_{bc} is the value of the biological control service per unit sea area (US\$ m^{-2} year^{-1}); and S is the area of reclamation (m^2).

2.3.3. Cultural Services

2.3.3.1. Recreation and Ecotourism. Coastal resources for tourism, such as sandy beaches and coral reefs, could be damaged by land reclamation. Considering that outdoor recreation sites are mostly public, it is inappropriate to estimate the damage utilizing admission fees which are typically subsidized and thus lower than recreationists' willingness to pay. So the adoptable valuation methods could be a surrogate-market approach (e.g., the travel cost method, TCM) (Chen et al., 2004a), or a Pseudo-Market Approach (e.g., the CVM, asking people's willingness to pay or willingness to accept under different environmental qualities). Because the CVM measures a tendency of behavior, not real behavior and payment, the quality of its results are affected by questionnaire design, sample selection and statistical analysis.

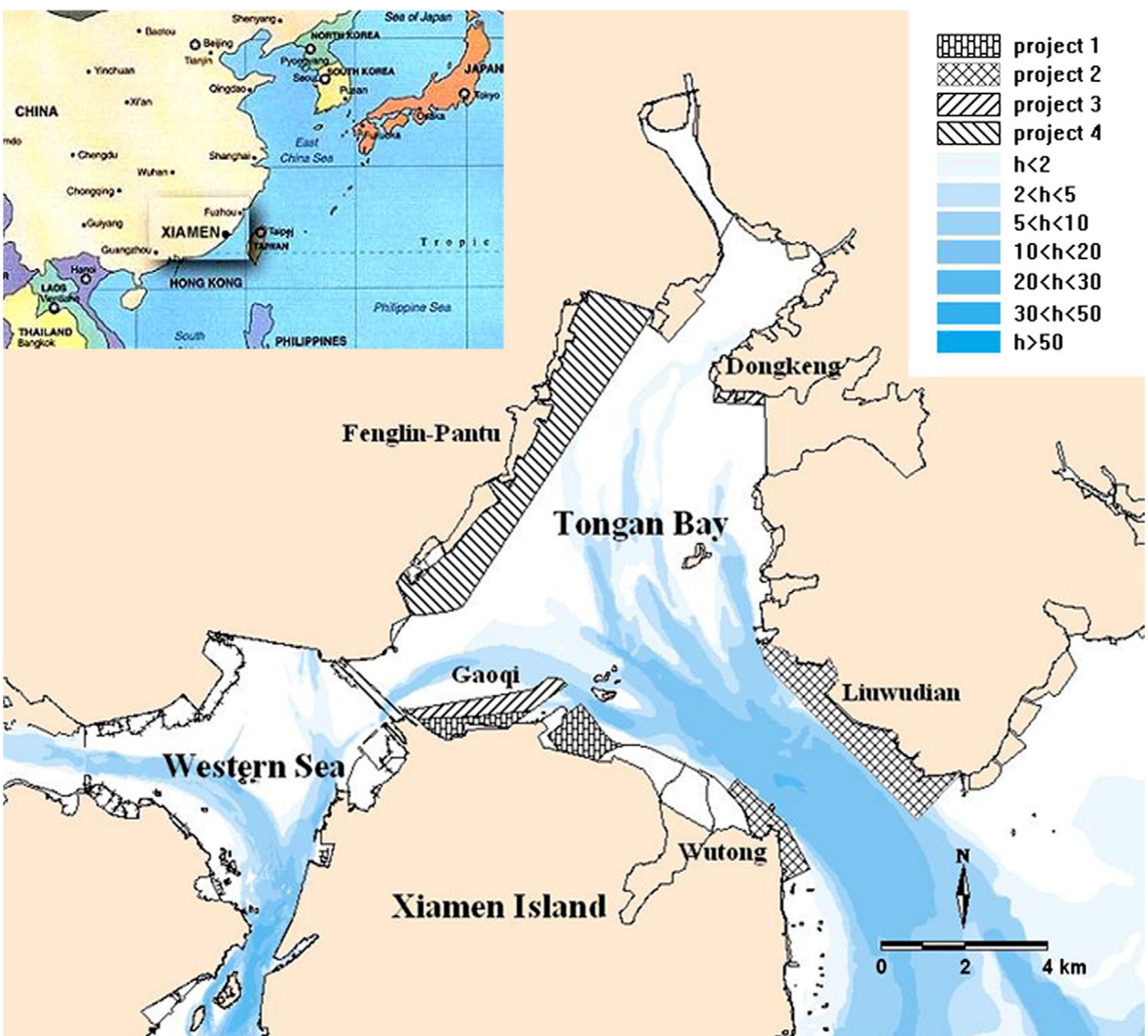

Fig. 2. Location of land reclamation projects in Tong'an Bay.

Table 2
Location and areas of land reclamation schemes in Tong'an Bay.

Schemes	Locations and areas (km^2)					
	Gaoqi	Wutong	Liuwudian	Dongkeng	Fenglin–Pantu	Total
1	1.98					1.98
2	1.98	1.32	4.43			7.73
3	3.37	1.32	4.43	0.26		9.38
4	3.37	1.32	4.43	0.26	9.86	19.24

2.3.3.2. Science and Education. The damage to science and education can be estimated using the CVM or through the benefit transfer method. The valuation model is:

$$D_{se} = V_{se} \times S \tag{9}$$

where D_{se} is the loss of science and education service (US$ year^{-1}); V_{se} is the value of science and education per unit sea area (US$ m^{-2} year^{-1}); and S is the area of reclamation (m^2).

2.3.4. Supporting Services

2.3.4.1. Primary Production. For a given locality, the yields of secondary production ($P_{(n+1)}$) at any particular trophic level ($n+1$) can be predicted from the estimate of primary productivity coupled with the number of trophic levels (Lalli and Parsons, 1997):

$$P_{n+1} = P_1 \cdot E^n \tag{10}$$

where P_1 is annual primary production (g m^{-2} year^{-1}); E is the ecological efficiency (%); n is the number of trophic transfers (which equals the number of tropic levels minus 1).

If the filled areas are mainly the habitat of shellfish, we can then establish a valuation model based on Eq. (10). The model is:

$$D_{pp} = \frac{P_0}{\alpha} \cdot E^n \cdot \beta \cdot P_s \cdot \rho_s \cdot S \tag{11}$$

where D_{pp} is the loss of primary production (US$ year^{-1}); P_0 is the primary productivity (carbon) per m^2 of the filled areas (g m^{-2} year^{-1}); α is the content of organic carbon in phytoplankton (%); E is the ecological efficiency (%); n is the number of trophic transfers from phytoplankton to shellfish; β is the weight ratio of shellfish (including tissue and shell) to its soft tissue; P_s is the average market price of shellfish (US$ g^{-1}); ρ_s is the profit ratio (%); and S is the area of reclamation (m^2).

2.3.4.2. Biodiversity Maintenance. Because diverse marine organisms live in coastal waters, coastal ecosystems are crucial to the maintenance of the earth's biodiversity. However, land reclamation destroys the habitats of coastal species, reducing biodiversity. The CVM is so far the most commonly used method to evaluate the value of biodiversity (Nunes and Van den Bergh, 2001). The maintenance of species diversity is a core of biodiversity. In the study, the damage to biodiversity is valued through surveying people's willingness to pay (WTP) to protect important rare species, or willingness to accept (WTA) when losing the important rare species (Peng et al., 2004). The valuation model is:

$$D_{bm} = S \cdot \sum \alpha_i \cdot \frac{WTP_i(WTA_i) \times U}{S_i} \tag{12}$$

where D_{bm} is the loss of biodiversity maintenance (US$ year^{-1}); WTP_i is the willingness to pay to protect important rare species i (US$ year^{-1} per capita); WTA_i is the willingness to accept the loss of important rare species i (US$ year^{-1} per capita); U is the number of people in the study area; S_i is the habitat area of the rare species i, e.g., the area of nature reserves (m^2); S is the area of reclamation (m^2); and α_i is the weight representing the influence of reclamation on species i, which equals to 0, 0.2, 0.5 or 1 when the influence is insignificant, slight, medium or significant, respectively.

Land reclamation projects may also damage mangroves, and the benefit transfer method can be used to calculate the damage to biodiversity maintenance of mangroves. The valuation model is:

$$D_m = V_m \times S_m \tag{13}$$

where D_m is the loss of biodiversity maintenance of mangroves (US$ year^{-1}); V_m is the value of the biodiversity maintenance of mangroves per unit area (US$ m^{-2} year^{-1}); and S is the area of mangroves destroyed by reclamation (m^2).

2.4. Total Ecosystem Losses

Once we have the damage estimates for individual ecosystem services, we can calculate the total losses as:

$$D_{total} = \sum D_j \tag{14}$$

where D_{total} is the total annual losses associated with land reclamation (US$ year^{-1}); and index j denote individual service loss estimate in Eqs. (1) through (12). Note that in an environmental economics analysis, D_{total} is the external cost, and the social cost (i.e., total cost) of land reclamation equals the sum of internal cost (private project cost) and the external cost. A reclamation project is economically justifiable only if the expected benefits associated with the project are greater than (or equal to) the total costs.

Since the losses resulting from reclamation projects are permanent, the discounted total (lump sum) loss over an infinite horizon is:

$$D = \frac{D_{total}}{r} \tag{15}$$

where r is the discount rate.

3. Case Study

Utilizing the methods described in the previous section, we develop estimates of ecosystem service losses associated with proposed land reclamation projects in Xiamen's Tong'an Bay.

3.1. Study Area

Tong'an Bay, located to the north of Xiamen Island, has a sea area of 89.9 km^2, and features a semi-enclosed bay with a narrow entrance (Fig. 2). The southern half of the bay connects with the Taiwan Strait via the Big and Small Jinmen Channels.

The semi-enclosed nature of the bay makes it susceptible to excessive degradation resulting from anthropogenic pressures, especially land reclamation. Since 1950, some 24 reclamation projects have been implemented, turning 33.65 km^2 of Tong'an Bay into land. With the development of West Side Economic Zone of the Taiwan Strait and the urbanization of surrounding areas, the reclamation demand will continue to grow. As part of regional planning to meet future demand

Table 3
Difference in pollutant concentration between high tide and low tide (mg L^{-1}).

Schemes	COD	TN	TP
Present	0.22	0.21	0.03
1	0.22	0.21	0.03
2	0.22	0.20	0.02
3	0.22	0.20	0.02
4	0.22	0.19	0.02

Table 4
Effects of different land reclamation schemes on protected species.

Species	Scheme 1	Scheme 2	Scheme 3	Scheme 4	Remarks
Chinese white dolphin	Medium (0.5)	Significant (1)	Significant (1)	Significant (1)	Schemes 2, 3 and 4 affect the core protected area of Chinese white dolphin, and scheme 1 is near the protected area.
Lancelet	Slight (0.2)	Significant (1)	Significant (1)	Significant (1)	Lancelet habitat is near the bay entrance, which will be influenced slightly by scheme1, and significantly by schemes 2, 3 and 4.
Egret	Slight (0.2)	Slight (0.2)	Slight (0.2)	Slight (0.2)	There is no egret protected area in Tong'an Bay, but all schemes will influence the egret feeding grounds.

Note: Weights used in value estimation are in brackets.

for land, four reclamation schemes in Tong'an Bay have been proposed. These schemes differ in scale and comprise several reclamation projects surrounding Tong'an Bay (Fig. 2). The location and areas of the four reclamation schemes are shown in Table 2. From small scale to large, scheme 1 includes only project 1 at Gaoqi; scheme 2 consists of projects 1 and 2; and scheme 4 covers all the projects at five locations. The new land resulting from these proposed projects is planned for city construction and commercial real estate.

3.2. Data and Estimation

To develop damage estimates for the entire set of ecosystem services affected by the proposed reclamation projects, we assemble relevant data from different sources. Specific data used for estimating each of the service losses are described as follows.

3.2.1. Food Supply

The loss of food supply service is calculated using direct market method and Eq. (1). The data on profit from marine fishing are from the fishery report of Xiamen Marine and Fishery Bureau (Xiamen Marine and Fishery Bureau, 2004). The average profit of marine fishing in Tong'an Bay is US\$4,045,500 $year^{-1}$. The area of the bay is 89.9 km^2, and the areas of four reclamation schemes are listed in the last column of Table 2.

3.2.2. Genetic Resources

The benefit transfer method and Eq. (2) are used to calculate the loss of genetic resources. De Groot et al. (2002) proposed a direct market method for the valuation of the genetic resources, and the values are between US\$6 ha^{-1} $year^{-1}$ and US\$112 ha^{-1} $year^{-1}$. We choose the mid-value, US\$59 ha^{-1} $year^{-1}$, as the value of genetic resources per unit sea area.

3.2.3. Space Resources

The loss to marine transportation is estimated through restoration cost method and Eq. (3), and the loss of mariculture space is computed by direct market method and Eq. (4). We use hydrodynamic and sediment transport models to simulate and estimate the siltation volume associated with each reclamation scheme. The results show that the siltation volume will increase by 10,000 m^3 $year^{-1}$ for scheme 4. The dredging cost in Xiamen is US\$2.14 m^{-3} (Zhang et al., 2009). The four reclamation schemes will lead to reductions of mariculture areas by 1.98 km^2, 7.73 km^2, 9.38 km^2 and 19.24 km^2, respectively. The average mariculture profit in Tong'an Bay is US \$4540.5 ha^{-1} $year^{-1}$ (Fujian Province Fisheries Research Institute, 2004).

3.2.4. Gas Regulation

We adopt shadow project method and Eq. (5) to calculate the loss of gas regulation service. The amount of CO_2 absorbed by marine ecosystems is 204.3 g m^{-2} $year^{-1}$ (Zhang et al., 2009). The cost of fixing CO_2 is US\$ 150 t^{-1} and the cost of supplying O_2 is US\$53 t^{-1} (Peng et al., 2005).

3.2.5. Erosion Control

Defensive expenditure method and Eq. (6) are used to estimate the loss of erosion control service. Using GIS software, we measure the lengths of existing natural coastline which may be destroyed by the four reclamation schemes as 5.73 km, 15.87 km, 17.13 km and 30.86 km, respectively. The cost of building embankment is US \$$2.86*10^5$ km^{-1} in Xiamen (Zhang et al., 2009).

3.2.6. Waste Treatment

The loss of waste treatment service is estimated based on shadow project method and Eq. (7). The results of a GIS-based analysis suggest that the four reclamation schemes will reduce the water body by $3.96*10^6$ m^3, $18.28*10^6$ m^3, $21.44*10^6$ m^3 and $33.97*10^6$ m^3, respectively. Through simulations using a hydrodynamic model, we find that the current tidal prism is $333.8*10^6$ m^3. Under the four reclamation schemes, it will reduce to $328.4*10^6$ m^3, $313.65*10^6$ m^3, $308.15*10^6$ m^3 and $278.8*10^6$ m^3, respectively. As a result, the difference in pollutant concentration between high tide and low tide might change. We develop simulations of the concentration differences for COD, TN and TP separately for the four schemes using a hydrodynamic-pollutant dispersion coupling model. The results are summarized in Table 3. Although there are small reductions in TN and TP, the model results do not indicate substantial deviations from the baseline at the unit level as the scale of land reclamation project increases from scheme 1 to scheme 4. Nevertheless, given the significant reduction in tidal prism, the annual damages to waste treatment service are measureable at the regional level. The biochemical degradation

Table 5
Losses of coastal ecosystem services associated with different land reclamation schemes (1000 US\$ $year^{-1}$).

Coastal ecosystem services	Scheme 1	Scheme 2	Scheme 3	Scheme 4
Provisioning services				
Food	89.1	347.9	422.1	865.8
Genetic resources	11.7	45.6	55.3	113.5
Space	899	3509.8	4259	8757.3
Regulating services				
Gas regulation	76.3	298	361.6	741.7
Erosion control	65.6	181.6	196	353
Waste treatment	17,161	104,367	120,763	223,456
Biological control	7.7	30.1	36.6	75
Cultural services				
Recreation and ecotourism	220.8	861.9	1045.9	2145.3
Science and education	12.3	47.9	58.2	119.3
Supporting services				
Primary production	529.1	2065.8	2506.8	5141.8
Biodiversity maintenance	195.8	1997.7	2423.9	5026.2
Total losses	19,268	113,753	132,128	246,795
Losses per m^2 (US\$ m^{-2} $year^{-1}$)	9.73	14.72	14.09	12.83

capacity of COD in Tong'an Bay is 0.15 g m^{-3} day^{-1} (Lin et al., 2002). The average treatment cost at sewage treatment plants in Xiamen is US\$0.008 g^{-1} (Wang et al., 2010). Tong'an Bay is a bay with regular semidiurnal tides, so the period of one tidal cycle is 12 h.

3.2.7. Biological Control

We adopt the benefit transfer method and Eq. (8) to calculate the loss of biological control service. Both Costanza et al. (1997) and de Groot et al. (2002) estimated the value of biological control service. We take the average, US\$39 ha^{-1} $year^{-1}$, as the value of biological control service per unit sea area.

3.2.8. Recreation and Tourism

Xiamen University has conducted several studies on the recreation value of Xiamen Island in recent years. According to a TCM study by Chen et al. (2004a), the economic value of recreation on Xiamen Island is US\$0.27 m^{-2} $year^{-1}$. The results of CVM studies by Peng et al. (2004) and Zhang et al. (2009) conclude that the values of recreation and tourism in Xiamen are US\$0.097 m^{-2} $year^{-1}$ and US\$0.1 m^{-2} $year^{-1}$, respectively. The average of these estimates is used in the present study.

3.2.9. Science and Education

The loss of science and education is estimated based on benefit transfer method and Eq. (9). The value proposed by Costanza et al. (1997), US\$62 ha^{-1} $year^{-1}$, is used as the value of science and education services per unit sea area.

3.2.10. Primary Production

The loss of primary production is valued through market price method and Eq. (11). The study by Zhang et al. (2009) shows the primary productivity (carbon) in Tong'an Bay as 55.717 g m^{-2} $year^{-1}$. Lu et al. (2005) calculated the annual average ecological efficiency as 16.1%, the content of organic carbon in phytoplankton (fresh weight) as 7.8% and the ratio of shellfish weight (including tissue and shell) to soft tissue weight (fresh weight) as 6.5:1 in Xiamen sea area. Shellfish are benthic herbivores, so the number of trophic transfers is 1. The average market price of shellfish is US\$1.43 kg^{-1} and the average profit ratio is 25%.

3.2.11. Biodiversity Maintenance

We calculate the loss of biodiversity maintenance using Eqs. (12) and (13). There are three protected species in Xiamen: Chinese white dolphin, lancelet and egret. Their habitat areas are 246 km^2, 152 km^2 and 164 km^2, respectively. Different reclamation projects have different effects on these protected species, and the weights are shown in Table 4. WTPs to protect these three important species are US\$12.0, US\$10.55 and US\$9.0 per capita per year, respectively (Environmental Science Research Center of Xiamen University, 2006). As these protected species are well known in the study area, we use the population in Xiamen (2,000,000) to calculate the regional value.

Mangroves are present in Tong'an Bay, especially in Gaoqi and Fenglin–Pantu. The results of a remote sensing and GIS analysis indicate that the four schemes will destroy mangrove areas by 0.2 ha, 0.2 ha, 0.2 ha and 14.0 ha, respectively. The ecological value of biodiversity maintenance of mangrove ecosystem in China is US\$0.4 m^{-2} $year^{-1}$ (Han et al., 2000).

4. Results

Using the valuation models presented in Section 2 and the previously described data, we estimate the potential losses of coastal ecosystem services caused by the four proposed land reclamation schemes. The results are shown in Table 5.

Looking at the damage estimates for scheme 1, we see that land reclamation in Tong'an Bay will cause significant damages to the waste treatment service (US\$17.2 million $year^{-1}$), the marine space provisioning service (US\$0.9 million $year^{-1}$), the supporting service (US \$0.7 million $year^{-1}$), and the coastal recreational service (US \$0.2 million $year^{-1}$). The total loss of coastal ecosystem services associated with scheme 1 is US\$19.3 million per year, or US \$429 million lump sum (with 4.5% discounting). The losses increase with the scale of land reclamation. For scheme 4, the total loss is US \$247 million per year, or US\$5.5 billion lump sum. The annual loss per unit area rises substantially from US\$9.73 per square meter for scheme 1 to US\$14.72 for scheme 2, and then declines slightly for schemes 3 and 4.

5. Discussions

The project cost of land reclamation in Xiamen is typically US \$88.24 m^{-2} (Peng et al., 2005), and the annual maintenance cost is estimated as 2% of the project cost. In terms of annuity over 70 years at 4.5% discounting, the internal cost of reclamation is US\$5.75 m^{-2} $year^{-1}$. Thus, the external cost of reclamation (i.e., ecological losses) associated with schemes 1 to 4 are considerably higher than the internal cost (i.e., project cost). Adding the internal and external costs, we estimate the total unit costs for the four reclamation schemes as US\$15.48 m^{-2} $year^{-1}$, US\$20.47 m^{-2} $year^{-1}$, US\$19.84 m^{-2} $year^{-1}$ and US\$18.58 m^{-2} $year^{-1}$.

According to the relevant regulation in Xiamen, the user fee for land reclamation in Tong'an Bay is between US\$1.1 m^{-2} and US\$3.3 m^{-2}. Obviously, the fee is too low to reflect the ecosystem losses and unable curb excessive reclamation. Therefore, the user fee standards for land reclamation should be adjusted so that the government can regulate the level of land reclamation and safeguard sustainable development of the coastal zone.

As described previously, the ecosystem services can be grouped into four categories, and within each category there are several sub-services (Table 1). Because one service may overlap another, the problem of double counting needs be avoided. For example, marine ecosystems can accept certain pollutants and render them benign or less harmful through physical, chemical and biological processes, which are embodied in both waste treatment service and nutrient cycling service. We only consider the former in the study. Similar issues exist among ornamental resources, aesthetic service and recreational service, and we only examine the last one.

There are several limitations associated with the approach presented here. The monetary values calculated using defensive expenditure method, shadow project method and contingent valuation methods are all subject to the well-known imperfections, including the questionable assumption of perfect substitutability between ecosystem services and manmade alternatives (Beaumont et al., 2008). In addition, extrapolation of monetary values using benefit transfer, as applied in genetic resources, biological control, science and education calculation, can also lead to inaccuracies. Indeed, some value estimates used in the study are from different parts of the world and more than 10 years old (e.g., the Costanza et al. 1997 study). These estimates are subject to further adjustments for the conditions in the study area and for inflation. Finally, a complete benefit–cost analysis of a land reclamation project must include information on the benefit side, so that the total cost, the sum of both internal and external costs, may be compared with benefit estimates. The benefits associated with reclaimed land are functions of specific land uses (e.g., real estate and marine transportation facilities) and net revenues they generate. Unfortunately, specific land uses are still uncertain for the proposed reclamation schemes.

6. Conclusions

Coastal ecosystems are under tremendous pressure from human activities in many parts of the world. In China, with rapid economic development and growing urbanization in many coastal areas, reclaiming land from the sea has become increasingly intense since the 1980s, and the total area reclaimed reached 540 km^2 by the end of 2007 (Pan, 2008). The prospect for sustainable development in these coastal communities is bleak if current trend of exploitation continues. Unfortunately, decisions by land developers and some local managers are typically driven by short-term direct economic benefits, ignoring the ecological damages and environmental degradation resulting from land reclamation. An important reason is that coastal ecosystem services are usually not captured by the relevant markets for natural resources or ecosystem services (Costanza et al., 1999; Chen et al., 2004b). To bridge the gap between market price and the total cost (i.e., the sum of internal and external costs) for a specific ecosystem service, it is necessary to develop monetary valuation for the service.

This study estimated the total ecosystem service losses from proposed land reclamation projects in Xiamen, China. These costs are significantly higher than the internal costs (project costs) of land reclamation in the study region. Undoubtedly, the integration of ecosystem losses into the total cost accounting will help decision makers to realize the full cost for land reclamation. The four proposed reclamation schemes are economically justifiable only if their expected unit benefits are at least as large as the previously mentioned total unit cost.

The current user fee for land reclamation in Tong'an Bay is too low to reflect the ecological losses and cannot regulate excessive reclamation and environment degradation. Therefore, the user fee standards for land reclamation should be adjusted so that the government can regulate the level of land reclamation and safeguard sustainable development of the coastal zone.

It is our hope that the practical valuation framework and models presented in the paper can provide a useful reference for future studies on land reclamation.

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References

Beaumont, N.J., Austen, M.C., Atkins, J.P., Burdon, D., Degraer, S., Dentinho, T.P., Derous, S., Holm, P., Horton, T., van Ireland, E., Marboe, A.H., Starkey, D.J., Townsend, M., Zarzycki, T., 2007. Identification, definition and quantification of goods and services provided by marine biodiversity: implications for the ecosystem approach. Marine Pollution Bulletin 54, 253–265.

Beaumont, N.J., Austen, M.C., Mangi, S.C., Townsend, M., 2008. Economic valuation for the conservation of marine biodiversity. Marine Pollution Bulletin 56, 386–396.

Chen, W.Q., Zhang, L.P., Hong, H.S., 1999. A preliminary study on evaluation of coastal sea water environmental capacity. Journal of Xiamen University (Natural Science) 38 (6), 897–900.

Chen, W.Q., Hong, H.S., Liu, Y., 2004a. Recreation demand and economic value: an application of travel cost method for Xiamen Island. China Economic Review 15 (4), 398–406.

Chen, Z.F., Chen, W.Q., Zhang, L.P., 2004b. A preliminary study on evaluation of coastal environment and resources. Marine Sciences 28 (12), 79–81.

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., Sutton, P., van den Velt, M., 1997. The value of the world's ecosystem services and natural capital. Nature 387 (15), 253–260.

Costanza, R., Andrade, F., Antunes, P., van den Belt, M., Boesch, D., Boersma, D., Catarino, F., Hanna, S., Limburg, K., Low, B., Molitor, M., Pereira, J.G., Rayner, S., Santos, R., Wilson, J., Young, M., 1999. Ecological economics and sustainable governance of the oceans. Ecological Economics 31 (2), 171–187.

Curtis, I.A., 2004. Valuing ecosystem goods and services: a new approach using a surrogate market and the combination of a multiple criteria analysis and a Delphi panel to assign weights to the attributes. Ecological Economics 50 (4), 163–194.

Daily, G.C., 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, D C.

Dale, V.H., Polasky, S., 2007. Measures of the effects of agricultural practices on ecosystem services. Ecological Economics 64 (2), 286–296.

de Groot, R.S., Wilson, M.A., Boumans, R.M.J., 2002. A typology for the classification, description, and valuation of ecosystem functions, goods, and services. Ecological Economics 41 (3), 393–408.

de Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7 (3), 260–272.

Eggert, H., Olsson, B., 2009. Valuing multi-attribute marine water quality. Marine Policy 33 (2), 201–206.

Environmental Science Research Center of Xiamen University, 2006. Social–Economic Benefits Analysis Report of Comprehensive Improvement in Western Sea, Xiamen.

Farber, S.C., Costanza, R., Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. Ecological Economics 41 (2), 375–392.

Fisher, B., Turner, R.K., Morling, P., 2009. Defining and classifying ecosystem services for decision making. Ecological Economics 68 (3), 643–653.

Freeman, A.M., 2003. The Measurement of Environmental and Resource Values: Theory and Methods, Second edition. Resources for the Future, Washington, DC.

Fujian Province Fisheries Research Institute, 2004. Research Report of Aquaculture Facilities Removal Compensation Standards in Xiamen.

Han, W.D., Gao, X.M., Lu, C.Y., Lin, P., 2000. The ecological values of mangrove ecosystems in China. Ecologic Science 19 (1), 40–46.

Hanley, N., Bell, D., Alvarez-Farizo, B., 2003. Valuing the benefits of coastal water quality improvements using contingent and real behaviour. Environmental & Resource Economics 24, 273–285.

Hein, L., van Koppen, K., de Groot, R.S., van Ierland, E.C., 2006. Spatial scales, stakeholders and the valuation of ecosystem services. Ecological Economics 57, 209–228.

Lal, P., 2003. Economic valuation of mangroves and decision-making in the Pacific. Ocean and Coastal Management 46 (9), 823–844.

Lalli, C.M., Parsons, T.R., 1997. Biological Oceanography: an Introduction2nd ed. Butterworth-Heinemann, Oxford.

Ledoux, L., Turner, R.K., 2002. Valuing ocean and coastal resources: a review of practical examples and issues for future action. Ocean and Coastal Management 45 (9), 583–616.

Li, T.H., Li, W.K., Qian, Z.H., 2008. Variations in ecosystem service value in response to land use changes in Shenzhen. Ecological Economics 69 (7), 1427–1435.

Lin, Y.S., Zheng, X.Y., Zheng, A.R., 2002. The estimation of removed and released cod fluxes in Tong'an bay, Xiamen. Journal of Xiamen University (Natural Science) 41 (3), 340–345.

Lu, L., Goh, B.P.L., Chou, L.M., 2002. Effects of coastal reclamation on riverine macrobenthic infauna (Sungei Punggol) in Singapore. Journal of Aquatic Ecosystem Stress and Recovery 9 (2), 127–135.

Lu, Z.B., Du, Q., Fang, M.J., Qian, X.M., Cai, Q.H., Xu, C.Y., 2005. Carrying capacity of shellfish culture in Dadeng Island sea area of Xiamen. Chinese Journal of Applied Ecology 16 (5), 961–966.

Millennium Ecosystem Assessment (MEA), 2003. Ecosystems and Human Well-being: a Framework for Assessment. Island Press, Washington, D C.

Millennium Ecosystem Assessment (MEA), 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, D C.

Nunes, P.A.L.D., Van den Bergh, J.C.J.M., 2001. Economic valuation of biodiversity: sense or nonsense? Ecological Economics 39 (2), 203–222.

Pan, J.G., 2008. Situation of sea reclamation in China and abroad and its implication on Hainan. The New Orient 13 (10), 32–36.

Peng, B.R., Hong, H.S., Chen, W.Q., Xue, X.Z., 2004. Evaluation of coastal environment and resources: theory, methods and application. Journal of Xiamen University (Natural Science) 43, 184–189.

Peng, B.R., Hong, H.S., Chen, W.Q., Xue, X.Z., Cao, X.L., Peng, J.P., 2005. Ecological damage appraisal of sea reclamation: theory, method and application. Journal of Natural Resources 20 (5), 714–728.

Remoundou, K., Koundouri, P., Kontogianni, A., Nunes, A.L.D.P., Skourtos, M., 2009. Valuation of natural marine ecosystems: an economic perspective. Environmental Science & Policy 12 (7), 1040–1051.

United Nations, European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, World Bank, 2003. Integrated Environmental and Economic Accounting 2003.

Wang, X., Chen, W.Q., 2009. Negative ecological impacts caused by sea reclamation and selection of economic evaluation approaches. Ecological Economy 5, 48–51.

Wang, X., Chen, W.Q., Jiang, Y.W., Zhang, L.P., 2010. Evaluation of losses in bay environmental capacity based on numerical simulation—a case study of sea reclamation in Tong'an Bay, Xiamen. China Environmental Science 30 (3), 1202–1208.

Xiamen Marine and Fishery Bureau, 2004. Fishing Research Report in Western and Eastern Sea Area of Xiamen.

Xiong, P., Chen, W.Q., Wang, X., Meng, H.T., 2007. Cost–benefit analysis of sea reclamation planning projects in Fuqing Bay. Journal of Xiamen University (Natural Science) 46 (s), 122–128.

Yang, W., Chang, J., Xu, B., Peng, C.H., Ge, Y., 2008. Ecosystem service value assessment for constructed wetlands: A case study in Hangzhou, China. Ecological Economics 68 (1), 116–125.

Zhang, L.P., Jiang, Y.W., Chen, W.Q., Wan, Z.W., Hu, J.Y., 2009. Research Report of Mathematical Models and Environment Research in Xiamen Bay. China Ocean Press, Beijing.