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Assessment of the Value of Services and Emergy in the Zhoushan Coastal Waters Ecosystem

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Abstract

Based on the four aspects of the marine ecosystem service system, namely supply, regulation, culture and support, the service function system of the marine ecosystem in the Zhoushan coastal area was constructed. The ecosystem valuation by assigning economic value to its services through valuation methods (the market value method, results reference method, shadow engineering method, replacement cost method) and the emergy analysis method were used to estimate the service value of the Zhoushan coastal marine ecosystem. The results revealed that in 2015, the total valuation of the marine ecosystem services of Zhoushan coastal water was 868.47×10^4 CNY, while the total emergy-currency value was 1246.92×10^8 CNY. The per unit valuation of the ecosystem services was 417.57×10^4 CNY/km^2, while the per unit emergy-currency value is 600×10^4 CNY/km^2. In the total valuation of the Zhoushan offshore ecosystem, the proportion of the values of supply services, regulating services, support services and cultural service was 11.80, 19.47, 29.66 and 39.6%, respectively. In the total emergy-currency value, the value of the supply services, regulation services and cultural services accounted for 9.19, 5.52 and 85.37% respectively. The results provide important reference for the maintenance and sustainable use of the marine ecosystem services, scientific management of the marine ecosystem in the Zhoushan coastal waters.

Keywords: Zhoushan coastal waters, Marine ecosystem, Ecosystem services value, Emergy value

1. Introduction

Marine ecosystem services refer to a variety of benefits which the marine ecosystem contributes to human well-being (Chen et al., 2006; Daily et., 1997; Constanza et al., 1997), including four basic types, the supply services, regulatory services, cultural services and support services (Chen et al., 2006; Millennium Ecosystem Assessment, 2005). The assessment of the marine ecosystem services value will estimate the economic value of the service in a currency amount for the particular marine area, which plays a key role in the national economy, compensable use of the marine ecosystem services, ecological compensation, marine or coastal spatial planning, integrated management of the coastal zone and carbon trading (Luisetti et al., 2011).

The specific research on marine ecosystem services has been carried out by the foreign scholars (Constanza et al., 1997; Peterson and Lubchenco, 1997; Holmlund and Hammer, 1999; Duarte Carlos et al., 2000; Souter and Lindén., 2000; Patterson, 2002; Schroter et al., 2005). Marine ecosystem services research in China started relatively late. In 2002, the research on the Jiao Zhou Bay ecosystem services funded by the State Oceanic Administration set a precedent for the study of marine ecosystem services in China. Since then, Chen et al. (2006), Xu et al. (2003) and other scholars tried to establish the framework for the valuation of marine ecosystem services according to the research results of Costanza et al. (1997) and other indicators. In 2005, the State Oceanic Administration launched the research program of the marine ecosystem service function and its value assessment, which mainly focused on the concept of marine ecosystem service, the definition of the content (Chen et al., 2006; Zhang et al., 2007; Shi et al., 2007), the economic attribute (Wang et al., 2006) and service category division (Shi et al., 2007; Zhang et al., 2007; Song et al., 2007). The program achieved a series of empirical research results on natural ecological types, such as sea area (Zhang et al., 2010; Xia et al., 2014; Lai et al., 2013; Qin., 2015), Island (Shi et al., 2009; Wang et al., 2014; Li et al., 2012), Gulf waters (Wang et al., 2010; Xie et al., 2015), mangrove (Han et al., 200) and Coastal Wetlands (Liu et al., 2008; Li et al., 2013). Zhoushan, the key intersection between China's north and south waterway and the Yangtze River golden waterway, is also the main hub of maritime gateway to all over the world and the key foundation for the implementation of the "marine power" stratiogy. In recent years, the Zhoushan marine economy has undergone rapid development and its value to the marine economy increased from 143.8×10^8 CNY in 2004 to 766×10^8 CNY in 2015. Hence, the marine economy has become the main growth sector of the Zhoushan economic development. However, with further ocean exploration, the marine ecosystem in Zhoushan has been facing a series of problems, such as the disorder of the sea development, the serious pollution of the coastal area and the serious decline of the fishery resources. Accordingly, this study will research on the Zhoushan coastal waters, analyze and evaluate the Zhoushan offshore marine ecosystem services and its economic value. The data collected will contribute to the understanding of the marine ecosystem services by humans, the establishment of the scientific ocean values concept and sustainable development idea, the conscious adjustment of the development and utilization of the marine ecosystem, the supply of ecological economic theoretical support for the sustainable utilization and management decision of the

Zhoushan marine ecosystem services and the provision of reference for the amount of exploitation and marine pollution accident compensation.

As the marine ecosystem is open, the ecosystem service value is estimated to quantify the various components of the system of ecological value. Accordingly, when estimating the value of the ecosystem services in use, we only consider the main flow of energy in the marine ecosystem and its relationship to renewable energy systems, which are not included in the study during the estimation process. The method of emergy evaluation and economic valuation in the dynamic process of the marine ecosystem is shown in Figure 1.

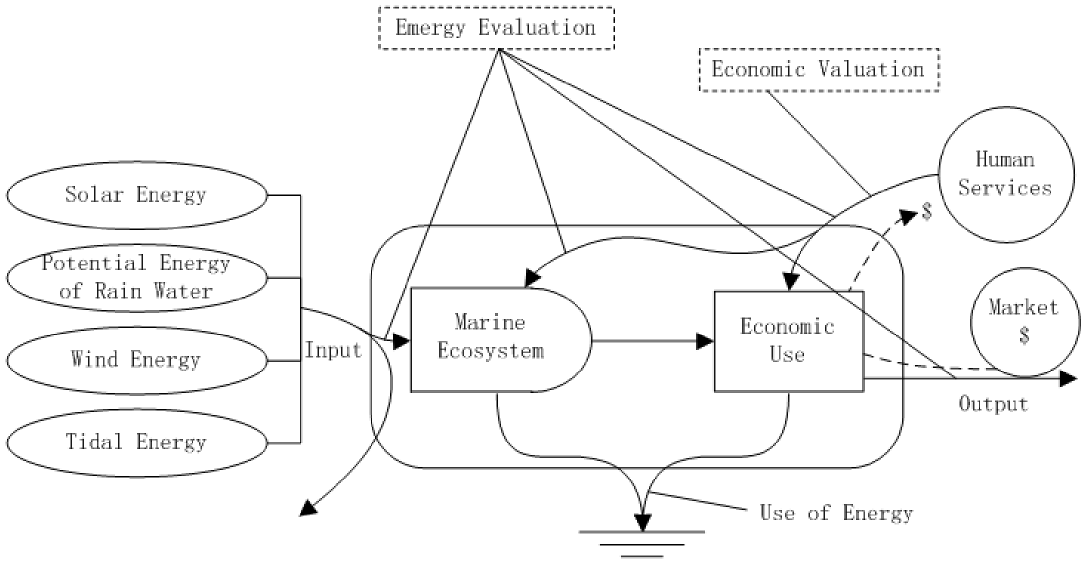

Figure 1. Emergy and economic valuation of the inshore marine ecosystem services in Zhoushan

2. Materials and Methods

2.1 Overview of the Area Where the Research is Conducted and Data Sources

Zhoushan city is located on the southeast coast of China, surrounded by the East China Sea on the east, Hangzhou Bay on the west, Zhejiang Province on the South and close to the Yangtze River Estuary on the north. It has a subtropical monsoon climate. The coastline is extends for 2444 km, accounting for 7.6% of the total sea area of China, and the sea area of Zhoushan is up to 2.08×10^4 km^2, which is 14.4 times of its land area. The sea area of Zhoushan is dotted with numerous islands, equivalent to about 20% of the total number of islands in China. There are more than 58 islands whose size are over 1 km^2, accounting for 96.9% of the total area of the islands. Zhoushan sea water depth is generally from 20 m to 40 m, the main deep water sections are 38 m. The sea line over 15 m deep is up to 200.7 km, while that over 20 m deep is about 103.7 km. In the summer the Zhoushan sea surface average temperature is around 28 to 29℃, while in the winter it is 8℃. The average salinity of the Zhoushan sea is 29 to 34 ‰ monthly. There are 1163 species of marine organisms identified in the Zhoushan coastal zone and coastal waters, including 91 species of phytoplankton, 103 species of zooplankton, 480 species of benthic animals, 131 species of benthic plants and 358 species of swimming animals. The large yellow croaker, small yellow croaker, octopus and cuttlefish (Squid) are the 4 most abundant type of sea animals, the main varieties of fish include more than 36 kinds such as eel, chub mackerel, grouper, horse crab, shrimp, etc. Zhoushan city has the typical characteristics of a city by the sea, such as fishing, island, harbor, sea lines, business and those tourism resources combined with island scenery. Marine culture and Buddhist culture are unique in the Yangtze River Delta cities.

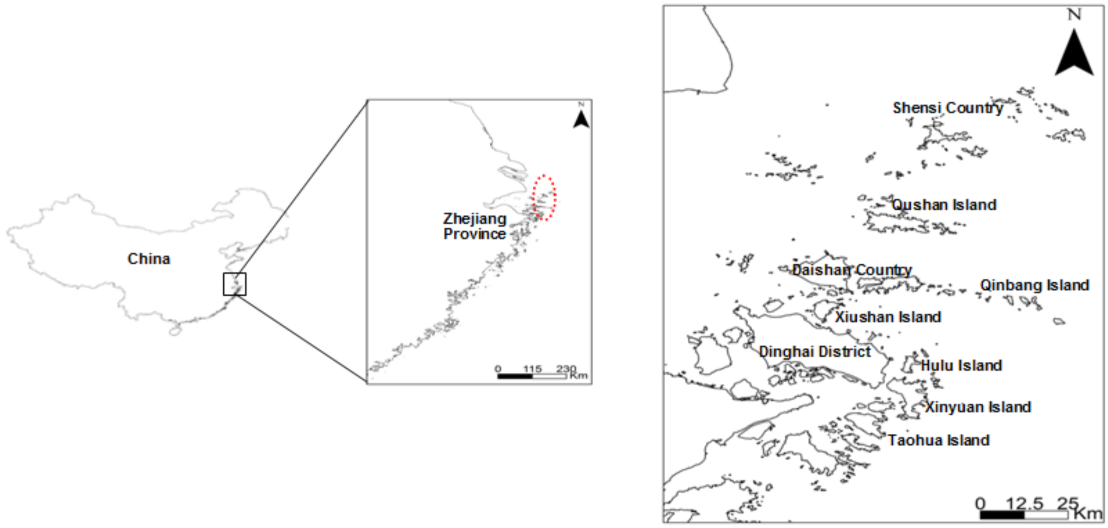

Figure 2. Schematic representation of the study area

2.2 Research methods

Food supply

Food supply refers to the sea food services provided to humans by the marine ecosystem. The food supply service in the Zhoushan Ocean consists of two parts, namely the Zhoushan inshore seafood products and aquaculture production of seafood including fish, shrimps, crabs, shellfish, seaweed and other edible seafood. When using the market value method to calculate the value of the food supply, it is required to deduct the cost of production. The formula used to calculate it are based on the monetary value method (Market Value Method):

$$V_f = \sum_{i=1}^{n} QF_i \times MF_i - \sum_{i=1}^{n} RF_i \qquad (1\text{-}1)$$

and the emergy evaluation method:

$$V_{f_E} = \sum_{i=1}^{n} \frac{QF_i \times T_{S_i}}{E_{mr}} \qquad (2\text{-}1)$$

Where, V_f refers to food supply service value (CNY/a); QF_i denotes the amount of category seafood in Zhoushan inshore fishing (t/a); MF_i indicates the category seafood market price (CNY/t); RF_i refers to the category seafood cost (CNY/t). V_{f_E} is the emergy-currency value of food production service (CNY/a); T_s represents to emergy conversion ratio of the category seafood (seJ/unit); Emr is the emergy dollar ratio (seJ/$).

Gene resource supply

Gene resources refers to the genes and genetic information carried by marine organisms, which are directly related to the number of marine species in the proper region (Zhang et al., 2007). The genetic resources supply service of the marine ecosystem in the Zhoushan coastal waters are mainly derived from the effectiveness of the marine gene resources utilization as well as the potential benefit of the gene resources development. The formula used for its calculation are based on the monetary value method (Results Reference Method):

$$V_n = Q_n \times P \qquad (1\text{-}2)$$

and the emergy evaluation method:

$$V_{n_E} = \frac{Q_d \times T_d}{E_{mr}} \qquad (2\text{-}2)$$

Where, V_n is the Value of the gene resources supply (CNY/a); Q_n refers to the value of the gene resources supply in the unit area of the Zhoushan sea area CNY/(km^2·a); P denotes the Zhoushan sea area (km^2); V_{n_E} represents the emergy-currency value of maintaining the diversity of the Zhoushan sea area (CNY/a); Q_d indicates the number of species in the sea area; T_d denotes the emergy conversion ratio of the species (seJ/unit); Emr is the emergy dollar ratio (seJ/$).

Climate regulating

Climate regulating services is used to explain the absorption of greenhouse gases by marine ecosystems and various ecological processes, such as the role of the marine biological pump which will achieve the regional or global climate regulation (Zhang et al., 2007). Marine ecosystem climate regulating services in the Zhoushan area come from marine organisms (such as algae, shellfish, etc.), which will absorb and fix various greenhouse gas by photosynthesis. A previous study showed that the contribution of CO_2 in the climate regulating services is high to 70% (Melillo et al., 1990). Thus, the regulation of the CO_2 content in the atmosphere needs to be considered when evaluating the climate regulating services of the marine ecosystem. The formula used to calculate it are based on the monetary value method (Market Value Method):

$$V_c = Q_c \times P_c \qquad (1\text{-}3)$$

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and the emergy evaluation method:

$$V_{C_E} = \frac{Q_C \times T_C}{E_{mr}} \qquad (2\text{-}3)$$

Where, V_C is the value of climate regulation services (CNY/a); Q_C denotes the fixed volume of CO_2 (t/a); P_C is the market transaction price of CO_2 (CNY/a); V_{C_E} represents the emergy-currency value of the climate regulation services (CNY/a); T_C is emergy conversion ratio of CO_2 (seJ/unit); Emr is the emergy dollar ratio (seJ/$).

Air quality control

Air quality control services mainly refer to the stable amount of CO_2 absorption by the marine ecosystem and the maintenance of the atmospheric chemical composition by primary oxygen producers through photosynthesis (Zhang et al., 2007). The air quality control service of the Zhoushan marine ecosystem is mainly derived from the release of oxygen by marine organisms. The formula used to calculate it are based on the monetary value method (Shadow Engineering Method):

$$V_O = Q_O \times P_O \qquad (1\text{-}4)$$

and the emergy evaluation method:

$$V_{O_E} = \frac{Q_O \times T_O}{E_{mr}} \qquad (2\text{-}4)$$

Where, V_O is the value of the air quality control (CNY/a); Q_O refers to the quantity of oxygen released from the offshore waters of Zhoushan (t/a); P_O refers to each unit cost of oxygen (CNY/t); V_{O_E} represents the emergy-currency value of the air quality control service(CNY/a); Q_O denotes the amount of oxygen generatiod from the study area; T_O is the oxygen emergy conversion ratio (seJ/unit); Emr denotes the emergy dollar ratio (seJ/$).

Water purification and regulation

Water purification and regulation mainly refers to decomposition reduction, transfer and transformation, absorption and degradation, as well as removal of all kinds of harmful substances in the marine ecosystem due to the involvement of a variety of ecological processes in the marine ecosystem (Zhang et al., 2007). Water purification and regulation services of the Zhoushan marine ecosystem mainly manifests through the biological purification of N (nitrogen) and P (phosphorus) in the coastal waters, as well as the removal of COD (Chemical Oxygen Demand) and petroleum hydrocarbons. The formula used for its calculation are based on the monetary value method (Shadow Engineering Method):

$$V_W = \sum_{i=1}^{n} QW_i \times CW_i \qquad (1\text{-}6)$$

and the emergy evaluation method:

$$V_{W_E} = \sum_{i=1}^{n} \frac{Q_{W_i} \times T_{W_i}}{E_{mr}} \qquad (2\text{-}5)$$

Where, V_W refers to the Service value of the water quality purification and regulation in the Zhoushan sea area (CNY/a); QW_i refers to the pollutants quantity in the category I purified in the Zhoushan sea area (t/a); CW_i is the unit cost for the pollutants of category I purified in the Zhoushan sea area (CNY/t). V_{W_E} is the emergy-currency value of the water quality purification and regulation service in the Zhoushan sea area (CNY/a); T_{W_i} is the emergy conversion ratio of the pollutants of category I (seJ/unit); Emr is the emergy dollar ratio (seJ/$).

Biological control

Biological control mainly refers to the biological regulation and control of the pests and diseases in the marine ecosystem (Zhang et al., 2007). The Zhoushan coastal waters of the biological control services mainly refers to the regulation and suppression of harmful biological activities (such as the incidence of red tide reduction, etc.). The formula used to calculate it are based on the monetary value method (Results Reference Method):

$$V_h = D_h \times P \qquad (1\text{-}5)$$

and the emergy evaluation method:

$$V_{h_E} = \frac{D_{he} \times T_h}{E_{mr}} \qquad (2\text{-}6)$$

Where, V_h refers to the supply service value of the biological control (CNY/a); D_h denotes each unit value of the biological control services in the Zhoushan area CNY/(km^2 a); P is the Zhoushan sea area (km^2). V_{h_E} is the emergy-currency value of the biological control service (CNY/a); D_{he} is the potential seafood resources in a particular sea area; T_h refers to the emergy conversion ratio of the seafood resources (seJ/unit); Emr is the emergy dollar ratio (seJ/$).

Interference regulating

The interference regulating service is defined as the inclusion, attenuation and integratiod function of the marine ecosystem to various environmental fluctuations (such as the reduction of the number of typhoon, storm surge, etc.) (Zhang et al., 2007). The interference regulating service of the Zhoushan ocean ecosystem mainly denotes the attenuation effect that the marine marsh grass community and beach have on natural adversities, such as the ocean storm tide. The formula used to calculate it is based on the monetary value method (Results Reference Method):

$$V_S = D_S \times P \qquad (1\text{-}7)$$

Where, V_S denotes the supply service value of gene resources (CNY/a); D_S is each unit of interference regulating service value provided by the marine organisms in the Zhoushan sea area CNY/(km^2 a); P denotes the Zhoushan sea area domain (km^2).

Support function

Support service refers to the basic services required for the production of other ecosystem services, including the maintenance of its species composition, quantity stability, the supply biological carrier use for material circulation and emergy flow in the system and the support provided to other services (Li and Tan, 2013). The support function of the Zhoushan sea area ecosystem is mainly derived from the nutrient circulation, material cycle, biodiversity, habitat, etc. The formula used for its calculation is based on the monetary value method (Results Reference Method):

$$V_m = (D_m + K_m) \times P \qquad (1\text{-}8)$$

Where, V_m is the value of the support function service (CNY/a); D_m is the unit value of the nutrient recycling service provided by marine organisms CNY/(km^2 a); K_m is the unit value of the habitat provided by marine organisms CNY/(km^2 a); P is the Zhoushan sea area domain (km^2).

Education and scientific research

Education and scientific research service refers to the contribution of the human knowledge system made by the scientific research because of the complexity and diversity of the marine ecosystem, the growth of the national economy and improvement of human welfare (Zhang et al., 2007). The education and scientific research services of the Zhoushan marine ecosystem are mainly derived from the investment in marine scientific research, as well as the number of marine scientific research achievements. The used for its estimation are based on the monetary value method (Cost Substitution Method):

$$V_k = \frac{\sum SI_n}{N} \quad \text{or} \quad V_k = VS \times P \qquad (1\text{-}9)$$

and the emergy evaluation method:

$$V_{k_E} = \frac{SI \times T_i}{E_{mr}} \qquad (2\text{-}7)$$

Where, V_k refers to the value of education and scientific research service (CNY/a); SI_n is the scientific research investment within N years (CNY/ article); N denotes the number of years; VS is the benchmark price of the shallow cultural research CNY/(km^2 a); P denotes the Zhoushan sea area domain (km^2). V_{k_E} is the emergy-currency of the educational research service (CNY/a); SI is the number of essay related to the sea area (each); T_i is the emergy conversion ratio of the essay (seJ/unit); Emr refers to the emergy dollar ratio (seJ/$).

Tourism and entertainment

Tourism and entertainment service refers to the unique landscape and aesthetic features formed by the coastal and marine ecosystems, and the direct commercial value that has been generatiod, such as marine ecological tourism, fishing tours and fishing activities (Zhang et al., 2007). Along the coast of Zhoushan, there are abundant natural resources and landscape, such as natural beach, island and natural coastal wetlands, which are of great value for coastal leisure tourism. The value of tourism and entertainment services of the Zhoushan coastal marine ecosystem is evaluated directly by the value of the coastal tourism industry (monetary value method). The formula for calculating the energy value is based on the energy value method:

$$V_{b_E} = \frac{D_b \times T_b}{E_{mr}} \qquad (2\text{-}8)$$

Where, V_{b_E} refers to the emergy-currency value of the tourism and entertainment service (CNY/a); D_b denotes the income from coastal tourism (CNY); T_b is the emergy conversion ratio of the coastal tourism income (seJ/$); Emr is the emergy dollar ratio (seJ/$).

3. Result and analysis

Food supply

According to the 2015 national economic and social development statistics bulletin of Zhoushan city and the 2015 fishing village income distribution annual analysis of Zhoushan city, in 2015 the Zhoushan marine fishing and aquaculture production was 176.46×10^4 t in total, while the total output value of marine fishery was up to 137.12×10^8 CNY (the average price was 7879 CNY/t). The ocean fishing production was 46.52×10^4 t; the mariculture area was 5779 hm^2, thus the yield was 14.17×10^4 t. Meanwhile, the processing capacity of aquatic products was 73.26×10^4 t, while the output value of aquatic products was 264.39×10^8 CNY (profit ratio of aquatic products processing was 20% estimates, including fishing). Based on the market value method, from the total output value of marine fishery we deducted the deep-sea fishing cost, the cost for the processing of seafood (about 80% of the aquatic product processing output value), the offshore marine fishery production cost, then added the processing cost of seafood products. According to formula (1-1), in 2015 the food supply service price of the marine ecosystem in the coastal waters of Zhoushan was 92.91×10^8 CNY.

The seafood emergy conversion ratio is 3.35×10^6 seJ/J (Campbell et al., 2005). According to formula (2-1), the food supply services emergy of the Zhoushan coastal marine ecosystem is 2.18×10^{21} seJ/a, and the emergy-currency value is 11.73×10^8 CNY.

Gene resource supply

De Groot suggested that each unit gene resources value of an ecosystem is (6-112) $/($hm^2$ a) (Wu et al., 2008). Located in a subtropical marine ecological system, the Zhoushan sea water has a superior natural environment and abundant attractions. Accordingly, the muddy sea water creates favorable conditions for different habitats for migratory fish to migratio, reproduce and grow, which then form the famous fishing ground – the Zhoushan fishing ground with high genetic resources value. Thus, we take 60% of the highest value of De Groot as the unit gene resources service value of the Zhoushan sea ecosystem, namely 436.8 CNY/(hm^2 a) (RMB exchange ratio 1:6.5$, the same below). According to formula (1-2), we calculated that in 2015 the gene resources service value of the Zhoushan coastal marine ecosystem was 9.08×10^8 CNY.

There are 1163 marine species completely identified in the coastal zone of Zhoushan and coastal waters, according to Zhoushan sea marine organism history. The marine emergy conversion ratio is 1.64×10^{19} seJ/each. According to formula (2-2) we calculated the food supply service emergy of the Zhoushan marine ecosystem is 1.91×10^{22} seJ/a, while the emergy-currency value is 1.03×10^{10} CNY (Zhao et al., 2015).

Climate regulation

Based on the primary productivity research, the average annual primary productivity in the Zhoushan sea is greater than 400 g/(m^2 a) (Li et al., 2005). Accordingly, we take 400 g/(m^2 a) as the minimum conservative value of the primary productivity of the Zhoushan sea, which will be calculated by the average value of 617.95 CNY/t of the cost of afforestation (with 260.90 CNY /t) and carbon tax (the Swedish carbon tax is 0.15 $/kg). The solid carbon of the Zhoushan sea area is 832×10^4 t. According to formula (1-3) we calculated that in 2015 the climate regulation service value provided by the Zhoushan marine ecosystem was 51.41×10^8 CNY.

As it is established, the CO_2 emergy conversion ratio is 8.85×10^7 seJ/g(Buenfil, 2001). According to formula (2-3) we calculated the climate regulation service emergy of the Zhoushan marine ecology system is 7.37×10^{20} seJ/a, and the emergy-currency value is 3.96×10^8 CNY.

Air quality control

Based on the Zhoushan ocean primary productivity, the value is calculated by the average value 330.45 CNY/t of the cost of afforestation (valued as 260.9 CNY/t) and the cost of the industrial oxygen production (normally 400 CNY/t). According to formula, the release of O_2 = 2.667×QPP (phytoplankton primary productivity)×P (Zhoushan area), we calculated that the Zhoushan waters annual release of O_2 is 2218.94×10^4 t. In addition, according to formula (1-4), we calculated the air quality control service value of the Zhoushan marine ecosystem as 73.32×10^8 CNY annually.

As we know that the O_2 emergy conversion ratio is 8.65×10^7 seJ/g (Buenfil, 2001), we calculated the air quality control service emergy of the Zhoushan coastal marine ecosystem as 5.26×10^{20} seJ/a according to formula (2-4), while the emergy value is 2.83×10^8 CNY (Zhao et al., 2015).

Interference regulating

The research results of Costanza et al. (2007) showed that each unit interference regulating the service value of the coastal waters is 88 $/(hm² a), or 572 CNY/(hm² a). Thus, according to formula (1-5) we calculated the annual interference regulating service value of the Zhoushan coastal marine ecosystem as 11.90×10^8 CNY.

Water purification and regulating

The ratio of planktonic algae using C (carbon), N and P is 106: 16: 1, which is relatively fixed and called the Redfield value. When phytoplankton fix each 1 mol of C, they will absorb 16 mol of N and 1 mol of P at the same time. According to the primary productivity of the Zhoushan sea area and the quantity of N and P absorbed by phytoplankton, we estimated an annual quantity of N and P fixed by the Zhoushan marine ecosystem as 70.44 g/(m^2 a) and 9.75 g/(m^2 a), respectively. Using the previously reported cost of domestic sewage treatment for N (1500 CNY/t), and P (2500 CNY/t) (Zhao et al., 2003) and the formula (1-6) we calculated the N and P biological purification value of the Zhoushan offshore marine ecosystem as 27.05×10^8.

According to the "management measures for sewage charges" formulated by the State Council, we calculated the value of COD and petroleum hydrocarbons removal with the cost of COD removal at 4300 CNY/t and the cost of oil removal 7000 CNY/t (Zhang et al., 2010). Using the pollution control cost method and the reference of the COD and the petroleum hydrocarbon environmental capacity of the coastal waters in Zhejiang Province (Li et al., 2013), we estimated the value of the COD and petroleum hydrocarbons in the Zhoushan coastal waters (Table 1). According to the "2015 annual Zhoushan Marine Environment Bulletin", in 2015 on March, May, August and October, the average proportion of the first-class, second-class, third-class and fourth-class water area were 1.4, 6.8, 14 and 29%. Thus, we estimated that the annual removal value of the Zhoushan marine ecosystem of petroleum hydrocarbon COD value is 0.72×10^8 CNY. Accordingly, the annual value of the water purification and regulating service provided by the Zhoushan marine ecosystem in Zhoushan is 27.77×10^8 CNY.

Table 1. The value of the COD and petroleum hydrocarbons removal in the Zhoushan coastal sea

Water quality standard	COD environment capacity (10^4/(t a))	COD removal value (10^8/(CNY a))	Petroleum hydrocarbons capacity (10^4/(t a))	The removal value of petroleum hydrocarbons (10^8/(CNY a))
First class	2.48	1.07	0.19	0.13
Second class	3.72	1.80	0.19	0.13
Third class	4.96	2.13	1.14	0.80
Forth class	6.20	2.67	1.91	1.34

As it is established, the N, P emergy conversion ratio are 1.51×10^9 seJ/g and 1.36×10^{10} seJ/g (Odum et al., 2000). According to formula (2-5) we calculated the service emergy of N absorbed by Zhoushan marine ecosystem as 2.22×10^{21} seJ/a, with a emergy-currency value of 11.95×10^8 CNY, and the service emergy of P as 1.81×10^{21} seJ/a, with a emergy-currency value of 9.74×10^8 CNY.

Biological control

The research results obtained by Costanza et al. (2007) showed that each unit biological control service value of the coastal waters is 38 $/(hm^2 a). Additionally, De Groot reported that each unit biological control service value of the ecosystem is (2-78) $/ (hm^2 a) (Wu et al., 2008). Taking the average of each, 39$/(hm^2 a), namely 253.5 CNY/(hm^2 ·a), as each unit of biological control service value of the Zhoushan ecosystem, we calculated the annual biological control service value provided by the Zhoushan ecosystem as 5.27×10^8 CNY, using the formula (1-7).

According to the research results, the maximum sustainable fishery resource in the Zhoushan sea area was 48.6678×10^4 t/a(Ni and Lu, 2002), and the conversion ratio of the marine products was 3.35×10^6 seJ/J(Campbell et al., 2005). According to formula (2-6), the emergy of the biological control service provided by the marine ecosystem in the Zhoushan coastal area is 7.51×10^{21} seJ/a, with a emergy-currency value of 4.04×10^9 CNY (Zhao et al., 2015).

Habitat

In view of the availability of data, this study only estimated the value of the services provided by the habitat. According to the research results, the marine habitat value is 8 $/(hm^2 a), namely 52 CNY/ (hm^2 a) (Constanza et al., 1997). According to formula (1-8), the annual value of the nutrient circulation service provided by the Zhoushan marine ecosystem is 1.08×10^8 CNY.

Nutrient circulation

Costanza et al. (2007) suggested that the public sea area of nutrient circulation is 118 $/(hm^2 a), coastal nutrient circulation is 3677 $/(hm^2 a). Taking the average of both, 1897.50 $/(hm^2 a), or 12333.75 CNY/(hm^2 a). According to formula (1-8), the annual value of the nutrient circulation service provided by the Zhoushan marine ecosystem is 256.54 $\times 10^8$ CNY.

Education and scientific research

The research results reported by Costanza et al. (1997) showed that each unit area of cultural service value of coastal waters is 62 $/(hm^2 a), or 403 CNY/(hm^2 a). Chen and Zhang (2000) estimated that each unit of scientific research and cultural service value of various ecosystems in China is 3.55 $\times 10^4$ CNY/(km^2 a). Taking the average of both, 3.79 $\times 10^4$ CNY/(km^2 a) as each unit of scientific research and cultural service value of the Zhoushan sea area, using formula (1-9) we calculated the annual education and scientific research value of the Zhoushan marine ecosystem as 7.88 $\times 10^8$ CNY.

Based on Melillo et al. (1990), we conducted a network query, from 2006 to 2015, of databases, such as CNKI, Wanfang database, VIP database and Web Science, Science Direct, and found that there are a total of 5257 articles with the topic of the Zhoushan sea, which represents an annual average of 525.7 articles. Using the emergy-currency value of these scientific articles to assess the service emergy value of education and scientific research, the emergy conversion ratio of the articles is 1.17 $\times 10^{18}$ seJ/article. Thus, according to formula (2-7), we calculated the emergy of the education and scientific research service in the Zhoushan marine ecosystem as 6.15 $\times 10^{20}$ seJ/a, while the emergy-currency value is 3.31 $\times 10^8$ CNY.

Travelling and entertainment

In 2015, Zhoushan received a total of 3876.22 $\times 10^4$ visitors, including 32.24 $\times 10^4$ international tourists, 3843.98 $\times 10^4$ domestic tourists, and the total tourism revenue was 552.18 $\times 10^8$ CNY. Considering that the tourism and entertainment services of the marine ecosystem mainly took place in coastal and offshore waters, if we assume that 60% of Zhoushan tourism revenue was the value resulting from leisure and entertainment service function, the tourism entertainment service value produced by the Zhoushan marine ecosystem in 2015 was 331.31 $\times 10^8$ CNY.

Based on the results of the present study, considering that the tourism income emergy conversion ratio is 4.94 $\times 10^{12}$ seJ/$ (Zhao, 2005). According to formula (2-8), we calculated the emergy of the Zhoushan marine ecological tourism and entertainment services as 1.64 $\times 10^{23}$ seJ/a, while the emergy-currency value is of 10.60 $\times 10^{10}$ CNY.

4. Statistical analysis of marine ecosystem service value in Zhoushan coastal waters

The results presented in Table 2 and Table 3 reveal that the total value of the coastal marine ecosystem in Zhoushan city in 2015 was 868.47 $\times 10^8$ CNY, the gross domestic product (GDP) was 1095 $\times 10^8$ CNY, the marine ecosystem service value accounted for 79.31% of the GDP, 113.38% of the total output value of the marine economy, while the value of the marine ecosystem in the unit areawas 417.57×10^4 CNY/km^2. The supply services, regulating service, support service and cultural services accounted for 11.80, 19.47, 29.66 and 39.06% of the total value of the marine ecosystem, which indicates that the cultural service function has the largest valuation in the Zhoushan marine ecosystem, followed by the support function, regulating services and supply service. In the classification of sub function, the service function value of the Zhoushan coastal marine ecosystem in descending order are: tourism and entertainment, nutrient circulation, food supply, air quality regulation, climate regulation, water purification regulation, disturbance regulation, gene resource supply, educational research services and biological control.

In 2015, the emergy of the Zhoushan coastal marine ecosystem was 19.8×10^{22} seJ, the total emergy-currency value was 1246.92×10^8 CNY, the ecosystem service emergy-currency value of per unit area was 600×10^4 CNY/km^2. The supply of services, regulating services, cultural services value accounted for 9.19, 5.52 and 85.37%. In the valuation of the Zhoushan coastal marine ecosystem, tourism and entertainment services accounted for the largest proportion, which means that in the development of a marine industry economy, the marine tourism industry is still an important part of the development of the marine ecosystem in Zhoushan, and is a key part to promote the development of marine economy in Zhoushan city.

Table 2. Service value of the Zhoushan marine ecosystem in 2015

Service type	Sub-function	Service value (CNY/a)	Value per unit area CNY/(km^2 a)	Ratio of value (%)
Supply service	Food supply	92.91×10^8	44.67×10^4	10.75
	Gene resource supply	9.08×10^8	4.37×10^4	1.05
Regulating service	Climate regulating	51.41×10^8	24.72×10^4	5.92
	Air quality control	73.32×10^8	35.25×10^4	8.44
	Disturbance regulating	11.90×10^8	5.72×10^4	1.37
	Water purification regulating	27.77×10^8	13.38×10^4	3.20
	Biological control	5.27×10^8	2.53×10^4	0.54
Supporting service	Habitat	1.08×10^8	0.52×10^4	0.12
	Nutrient circulation	256.54×10^8	123.34×10^4	29.54
Cultural service	Educational research	7.88×10^8	3.79×10^4	0.91
	Tourism and entertainment	331.31×10^8	159.28×10^4	38.15
Totally		868.47×10^8	417.57×10^4	100

Table 3. Value of inshore marine ecosystem service emergy value in Zhoushan

Service type	Sub-function	Raw data	Emergy tansformity (seJ/unit)	Emergy (seJ/a)	Emergy-currency value (CNY/a)	Emergy-currency value per unit area CNY/(km^2 a)	Ratio of value (%)
Supply service	Food supply	6.52×10^{14}J	3.35×10^6	2.18×10^{21}	11.73×10^8	5.64×10^4	0.94
	Gene resource supply	1163 pieces	1.64×10^{19}	1.91×10^{22}	1.03×10^{10}	49.5×10^4	8.25
Regulating service	Climate regulating	8.32×10^{12}g	8.85×10^7	7.37×10^{20}	3.96×10^8	1.90×10^4	0.32
	Air quality control	6.07×10^{12}g	8.65×10^7	5.26×10^{20}	2.83×10^8	1.36×10^4	0.23
	nitrogen uptake	1.47×10^{12}g	1.51×10^9	2.22×10^{21}	11.95×10^8	5.74×10^4	0.96
	Phosphorus uptake	2.03×10^{11}g	1.36×10^{10}	1.81×10^{21}	9.74×10^8	4.69×10^4	0.78
	Biological control	2.24$10^{15}$J	3.35×10^6	7.51×10^{21}	4.04×10^9	19.4×10^4	3.23

Cultural services	Educational research services	525.7 articles	1.17×10^{18}	6.15×10^{20}	3.31×10^{8}	1.59×10^{4}	0.27
	Tourism and entertainment	3.31×10^{10} CNY	2.96×10^{12}	1.64×10^{23}	10.60×10^{10}	5.10×10^{6}	85.10
Totally				19.8×10^{22}	1246.92×10^{8}	600×10^{4}	100

Note: The emergy dollar ratio is 2080×10^{13} seJ/$.

5. Conclusion and prospect

The huge service function value of the Zhoushan offshore marine ecosystem provides great value to the economic development of Zhoushan city. Accordingly, the health and stability of the Zhoushan ocean economy play a significant role in the development of the national economy. The evaluation results show that the function of marine education and scientific research service in Zhoushan is worth to be implemented. Moreover, the investment in the field of marine research needs to be increased in order to improve the research ability, which is combined with basic research, applied research, data research. Due to the limitations of the human understanding and research on the sea, the research on the service type of the marine ecosystem still needs to be further developed. The service functions proposed and evaluated in our study is much less than the actual marine functions, and in the evaluation process, because of certain obstacles, such as the evaluation method, average value of evaluation data errors, we assumed the research value to be lower than the value provided by the actual marine ecosystem value. Therefore, the value of the marine ecosystem in Zhoushan coastal waters reported here is only a conservative estimation.

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