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Sensitivity and Uncertainty Analysis of Regional Marine Ecosystem Services Value

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Abstract Marine ecosystem services are the benefits which people obtain from the marine ecosystem, including provisioning services, regulating services, cultural services and supporting services. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services. Marine ecosystem services become increasingly valuable as the terrestrial resources become scarce. The value of marine ecosystem services is the monetary flow of ecosystem services on specific temporal and spatial scales, which often changes due to the variation of the goods prices, yields and the status of marine exploitation. Sensitivity analysis is to study the relationship between the value of marine ecosystem services and the main factors which affect it. Uncertainty analysis based on varying prices, yields and status of marine exploitation was carried out. Through uncertainty analysis, a more credible value range instead of a fixed value of marine ecosystem services was obtained in this study. Moreover, sensitivity analysis of the marine ecosystem services value revealed the relative importance of different factors.

Key words marine ecosystem; ecosystem services value; sensitivity analysis; uncertainty analysis

1 Introduction

Ecosystem services are the benefits which people obtain from ecosystems (MA, 2003). Ecosystem services contribute to human welfare, both directly and indirectly, and therefore represent part of the total economic value of the planet (Costanza *et al.*, 1997; De Groot *et al.*, 2002). In the past few decades many studies have tried to estimate the value of a variety of ecosystem services (Shi *et al.*, 2008). In all the studies, the most notable ones are those of Costantza and Daily (Costantza *et al.*, 1997; Daily, 1997).

As a life-supporting system, marine ecosystem also provides various services for human beings, including food production (*e.g.*, seafood), material production (*e.g.*, biological material for chemical, pharmaceutical use, ornamental resources), oxygen production, provision of genetic resources, climate regulation, waste treatment, biological control, disturbance regulation, recreation value, *etc*. At present, due to the massive expansion of population as well as economic activities, the marine ecosystem of China suffers from a number of environmental problems such as the degradation of water quality, the decline of fish stock, and the loss of biodiversity, which impair marine ecosystem services severely. It is necessary to estimate these services and study their change in order to promote the protection of the marine ecosystem.

In this study, we selected Sanggou Bay, a typical mariculture area, and Miaodao Archipelago, a typical island as our study sites. In this paper, the main factors which affect the marine ecosystem services value are analyzed firstly. Then, a case study is conducted to value the marine ecosystem services in a typical mariculture ecosystem (Sanggou Bay) based on the variation of the prices of ecosystem services. Sensitivity analysis of the marine ecosystem services value has revealed the relative importance of different factors. The variation of ecosystem services flow is also a most important cause of the uncertainty of the ecosystem services value. Through an uncertainty analysis of the non-market ecosystem services value in Miaodao Archipelago, a more credible value range of marine ecosystem services instead of a fixed value is given.

2 Valuation Methods

The valuation methods of the main ecosystem services used in this paper, such as food production, oxygen production, climate regulation and waste treatment, are described in the authors' previous work (Shi *et al.*, 2008).

3 Sensitivity Analysis on the Prices

3.1 Study Site: Sanggou Bay

Sanggou Bay is a typical mariculture area situated in

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the Yellow Sea near Rongcheng City, Shangdong Province, China (37˚01′−37˚09′N, 122˚24′−122˚35′E). Sanggou Bay is a coastal embayment with a surface water area of 143.2 km^2 and an intertidal area of 20 km^2. In this bay, Mariculture is very popular which started in the 1960s (FIO, 1988). Today, the main mariculture species include scallop, oyster, kelp, *etc*. This bay is also a good mariculture site for fish, shrimp, and holothurian mariculture. In 2004, the mariculture area reached 5964.8 ha, and the yield of fishery amounted to 242100 t (Shi *et al*., 2008). The excessive development of mariculture may lead to en- vironmental degradation and impair the marine ecosystem services (Zhu *et al.*, 2000; Zhang *et al*., 2005). Now it is necessary to assess the change of the ecosystem services in Sanggou Bay to promote its sustainable development.

3.2 Estimation of Changes in Ecosystem Services

The mariculture data used in this estimation are from Rongcheng Oceanic and Fishery Bureau. For the primary production, we used the data surveyed by the First Institute of Oceanography of SOA from May 1999 to April 2000 which are 230 $mgC\,m^{-2}\cdot d^{-1}$ in the waters and 347 $mgC\,m^{-2}\cdot d^{-1}$ in the intertidal area, and the data surveyed from August 2003 to May 2004 (58 $mgC\,m^{-2}\cdot d^{-1}$). According to the valuation methods proposed by Shi *et al.* (2008), we calculated the values of main ecosystem services in Sanggou Bay in 1999 and 2004 (Table 1).

Table 1 Values of ecosystem services in Sanggou Bay

Item	Value ($\times 10^7$ RMB)	
	1999	2004
Food production	31.96	75.16
Oxygen production	3.97	2.78
Climate regulation	2.79	1.96
Waste treatment	1.04	0.77
Total	39.76	80.67

It is important to point out that, the value of food production is the net value of fishery output from which the cost of fishery has been subtracted. From Table 1 we can see that food production is the dominant ecosystem service in Sanggou Bay which contributed about 80% to the total value of ecosystem services in 1999, and 93% in 2004. And there was a great increase in the value of food production during the five years, but the values of the other services, including oxygen production, climate regulation, and waste treatment, all decreased. The total values of ecosystem services increased by 102.9% from 1999 to 2004. So the massive increase in total value was attributable to the increase in food production value, which neutralized the negative effects (decrease in the value of oxygen production, climate regulation and waste treatment). If we only consider the value of oxygen production, climate regulation and waste treatment, there would be a 29.4% loss in the total value of ecosystem services. Therefore, we should not ignore the decreasing services and analyze why they decreased. We suggest that the main reason is the high intensity mariculture that impairs the ecosystem services.

3.3 Sensitivity Analysis on Ecosystem Services Value

In the estimation, the price coefficient may not be quite accurate in every case. The prices of mariculture species and industrial oxygen may fluctuate, and there are alternatives for the price of CO_2 fixed and the cost of waste water treatment. Due to the uncertainties concerning the veracity of the price coefficient, sensitivity analyses were conducted to determine the dependence of our estimates of changes in ecosystem services value on the price coefficient. In the sensitivity analysis, the coefficient of sensitivity (CS) can be obtained through using the standard economic concept of elasticity, *i.e.*, the percentage change in the output for a given percentage change in an input (Kreuter *et al.,* 2001; Zhao *et al.*, 2004):

$$CS = \frac{(ESV_j - ESV_i)/ESV_i}{(PC_{jk} - PC_{ik})/PC_{ik}},$$

where CS is the ratio of the percentage change in the estimated total ecosystem services value (ESV) and the percentage change in the adjusted price coefficient (PC), i and j represent the initial and adjusted values respectively and k represents the service category. The greater the CS is, the more important the use of an accurate price coefficient is.

To conduct sensitivity analysis in this study, the price of mariculture species, the price of industrial oxygen, and the cost of life waste treatment were each adjusted by 10%. For the price of CO_2 fixed, we can use the Sweden carbon tax rate or forest development cost of China. First we chose the average of the Sweden carbon tax rates and forest development cost of China as an initial proxy. In order to test the robustness, we change the average of the Sweden carbon tax rate and forest development cost of China. The impact of these adjustments on the estimates of the total value of ecosystem services and the associated coefficients of sensitivity are presented in Table 2.

Table 2 Coefficients of sensitivity (CS) resulting from adjustments of price coefficients

Change in price coefficient for	CS (%)	
	1999	2004
Price of mariculture species±10%	80.38	93.17
Price of industrial oxygen±10%	9.98	3.45
Price of CO_2 fixed=China forest development cost	7.02	2.43
Price of CO_2 fixed=the Sweden carbon tax rate	7.02	2.43
Cost of waste water treatment ±10%	2.62	0.95

It is shown in Table 2 that the total value of ecosystem services increased or decreased by 8.04% in 1999 and 9.32% in 2004, when the prices coefficient of mariculture species was adjusted by 10%, which indicates that the change of price coefficient of mariculture species had a great effect on the estimates of total ecosystem services value. In addition, the other price coefficients had little effect on the estimation, and there was a 0.345%−0.998% change in total value due to a 10% change in price coefficient of industrial oxygen, a 1.59%–4.58% change while 65.28% change in price coefficient of CO_2 fixed, and 0.10%–0.26% change while 10% change in cost coefficient of waste treatment. The coefficients of sensitivity for oxygen production, climate regulation, and waste treatment services were less than 0.1, and these low CSs indicate that the estimation of total ecosystem services value is rather robust. However, the coefficient of sensitivity for food production was high, ranging from 0.804 to 0.932. The result emphasizes the importance of this dominating service and the importance of obtaining an accurate price coefficient of mariculture species.

4 Uncertainty Analysis on the Value

4.1 Study Site: the Miaodao Archipelago

The Miaodao Archipelago, with a terrestrial area of 56 km^2, is located at the intersection of the Yellow Sea and the Bohai Sea, spanning from 37˚53´30″N to 38˚23´58″N and 120˚35´38″E to 120˚56´36″E, lying to the north of the Shandong Peninsula, China (Wang and Zhang, 2007). Miaodao Archipelago consists of 32 islands from south to north and 10 of which are inhabited. Offshore of the archipelago there is the Miaodao Marine Specially Protected Area which has existed since the 1980s. Being in a special geographic location, the region suffers from a variety of natural disasters, including cold waves, typhoons, squall lines and droughts, which impose potential stresses on the regional ecological environment. In addition, increasing human activities also contribute a great deal to the degradation of the regional habitats.

4.2 Uncertainty Analysis of the Non-Market Value of Ecosystem Services

In this paper, we mainly consider the variation of the non-market values of ecosystem services. In this section, the uncertainty of the values we studied was only resulted from the variation of ecosystem services flow. To explore this issue, we take the most typical non-market ecosystem services as our study objects: climate regulation and oxygen production.

All the data in this case study which covered the period from 1980 to 2006 were collected from the Statistical Bureau and Ocean and Fishery Bureau of Changdao. According to the methods of valuation of climate regulation and oxygen production Presented in Section 2, we calculated their values with different confidence levels.

For the Miaodao Archipelago, the climate regulation is defined as the value of fixing carbon. Fixing carbon is achieved mainly through two approaches: one is phytoplankton primary production and large algae fixing carbon through photosynthesis, and the other is the forest in island fixing carbon through photosynthesis. At the same time, oxygen production takes place along with the fixation of carbon dioxide during photosynthesis.

The calculation procedure in the uncertainty analysis is as follows:

1) Construct the time series of the main ecological factors such as the primary production in the offshore sea, the forest area in island, and the production of large algae according to historical data.

2) Set up climate regulation and oxygen production valuation models which comprise of the above parameters according to the valuation method mentioned in Section 2.

(3) Set up an Integrated Monte Carlo Analysis Model which makes use of the CrystalBall Software, a most popular risk decision tool.

4) Carry out Monte Carlo analysis to determine the values of climate regulation and oxygen production and the total value of non-market ecosystem services respectively.

5) Report the confidence intervals under different confidence levels.

The results of uncertainty analysis are listed in Tables 3, 4 and 5. Fig.1 demonstrates the probability distribution of the total value of non-market ecosystem services. In this case, the ecosystem services value is not expressed as one single value but a series of sets with continuous values under different confidence levels.

Table 3 Climate regulation values of the Miaodao Archipelago

Confidence level (%)	Lower limit (RMB)	Upper limit (RMB)
60	5,158,975,390	7,275,471,854
65	5,083,192,576	7,369,996,808
70	4,974,122,964	7,511,816,015
75	4,847,352,239	7,662,369,070
80	4,711,680,780	7,878,908,681
85	4,399,546,589	8,091,220,220
90	3,963,565,128	8,404,814,534
95	3,171,774,625	9,288,433,453

Table 4 Oxygen production values of the Miaodao Archipelago

Confidence level (%)	Lower limit (RMB)	Upper limit (RMB)
60	3,899,881,519	5,499,828,180
65	3,842,594,176	5,571,283,478
70	3,760,143,973	5,678,490,444
75	3,664,312,773	5,792,299,686
80	3,561,753,141	5,955,990,878
85	3,325,798,078	6,116,485,895
90	2,996,221,774	6,353,544,725
95	2,397,674,791	7,021,508,580

Table 5 Total values of non-market ecosystem services of the Miaodao Archipelago

Confidence level (%)	Lower limit (RMB)	Upper limit (RMB)
60	9,058,856,909	12,775,300,033
65	8,925,786,751	12,941,280,286
70	8,734,266,937	13,190,306,459
75	8,511,665,012	13,454,668,756
80	8,273,433,922	13,834,899,559
85	7,725,344,667	14,207,706,115
90	6,959,786,902	14,758,359,259
95	5,569,449,416	16,309,942,033

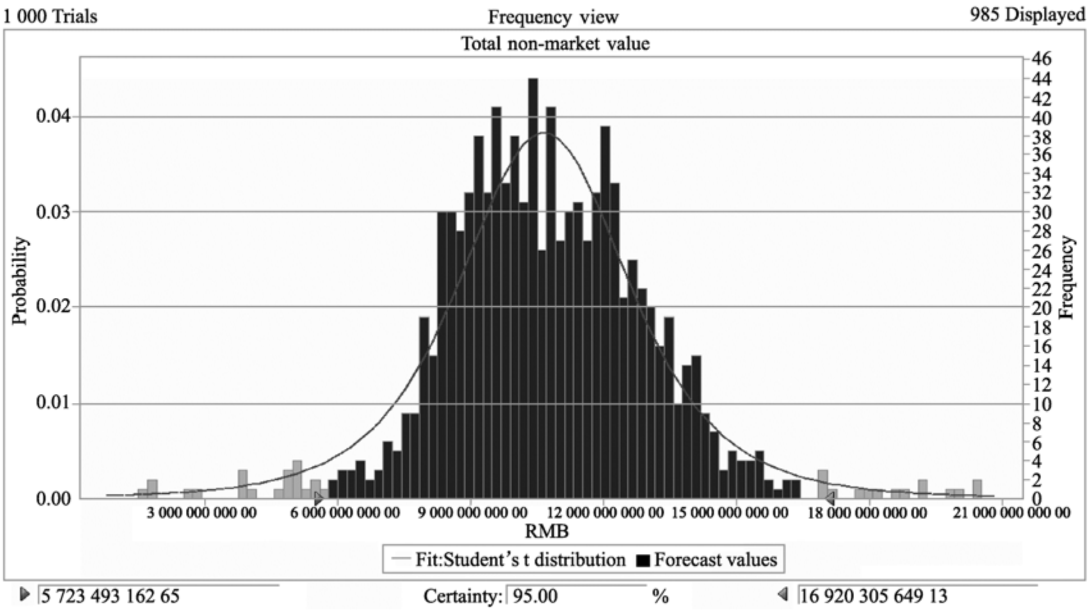

Fig.1 Probability distribution of total non-market value of the Miaodao Archipelago.

5 Discussion

The human being, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services (Costanza, 2000). Marine ecosystem services are increasingly beneficial and scarce as the terrestrial resources become scantly (Costanza, 1999). Marine ecosystem services value is the monetary flow of ecosystem services on specific temporal and spatial scales, which often varies with the goods prices, yields and the status of marine exploitation (Zhang *et al.*, 2006; Zheng *et al.*, 2007). Uncertainty analysis is based on the relationships between the main factors and the marine ecosystem services value.

We estimated the value of main ecosystem services in Sanggou Bay, including food production, oxygen production, climate regulation, and waste treatment. The study showed that the total value of the above services increased from 39.76×10^7 to 80.67×10^7 CNY from 1999 to 2004. The great increase was largely attributed to the increase in the value of food production, which offset the decrease in the value of other services. In the sensitivity analysis, we adjusted the price coefficients of mariculture species, industrial oxygen, CO_2 fixed, and the cost of waste water treatment. We found that the coefficents of sensitivity (CS) of the analysis were less than unity in all cases, which indicates that the estimated ecosystem value is robust with respect to those price coefficients. It is very important to note that the concept of elasticity in traditional economics also exits in the ecological and economic system. As we know, the interaction among the different ecosystem services is very crucial in sensitivity analysis. However, our knowledge of the marine ecosystem being relatively limited, we cannot predict the effect caused by the variation of certain factors at present.

The Miaodao Archipelago is a typical island ecosystem. In this case, we mainly considered the variation of the non-market ecosystem services value and the uncertainty of that value we studied only resulted from the uncertainty of ecosystem services flow. To study this issue, we chose the most typical non-market ecosystem services as our study objects: climate regulation and oxygen production. Through uncertainty analysis, a more credible value range of marine ecosystem services instead of a fixed value was given. In the study, a new valuation method of ecosystem services was given according to the idea of uncertainty analysis, and the authors made an attempt to apply it to non-market ecosystem services valuation.

To study the general status and variation trend of the marine ecosystem services by combining all the uncertainty factors is an important aim in the quantification of the function of the regional marine ecosystem and we will explore it further in the future.

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References

Costanza, R., 1999. The ecological, economic, and social importance of the oceans. *Ecol. Econ.*, **3l** (2): 199-213.

Costanza, R., 2000. Social goals and the valuation of ecosystem services. *Ecosystems*, **3** (1): 4-10.

Costanza, R., d'Arge, R., de Groot, R., Farberk, S., Grasso, M., Hannon, B., *et al*., 1997. The value of the world's ecosystem services and natural capital. *Nature*, **387**: 253-260.

Daily, G. C., 1997. *Nature's Services*: *Societal Dependence on Natural Ecosystems*. Island Press, Washington D. C., 1-10.

De Groot, R. S., Wilson, M. A., and Boumans, R. M., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecol. Econ.*, **41** (3): 393-408.

FIO (First Institute of Oceanography), State Oceanic Administration of China, 1988. *Integrated Investigation and Study of the Environment for Propagation and Aquaculture in the Sanggou Bay*. Qingdao Press, Qingdao, 1-30.

Kreuter, U. P., Harris, H. G., Matlock, M. D., and Lacey, R. E., 2001. Change in ecosystem service values in the San Antonio area, Texas. *Ecol. Econ.*, **39** (3): 333-346.

MA (Millennium Ecosystem Assessment), 2003. *Ecosystems and Human Well-being*: *A Framework for Assessment*. Island Press, Washington D. C., 26-48.

Shi, H. H., Zheng, W., Ding, D. W., Lu, J. B., and Zhang, X. L., 2008. Valuation of the typical marine ecosystem services–A case study in Sanggou Bay. *Mar. Environ. Sci.*, **27** (2): 100-104.

Wang, X. L., and Zhang, J., 2007. A nonlinear model for assessing multiple probabilistic risks: A case study in South five-island of Changdao National Nature Reserve in China. *J. Environ. Manage.*, **85** (4): 1101-1108.

Zhang ,Z. H., Shi, H. H., Jiang, Z. B., Chen, S., and Ding, D. W., 2006. Sources and implementation of marine ecosystem services. *Chin. J. Ecol.,* **25** (12): 1574-1579.

Zhang, L. H., Zhang, X. L., Li, R. X., Wang, Z. L., Li, Y., Wang, L. C., *et al.*, 2005. Impact of scallop culture on dinoflagellate in Sanggou bay. *Adv. Mar. Sci.*, **23** (3): 342-346.

Zhao, B., Kreuter, U., Li, B., Ma, Z. J., Chen, J. K., and Nakagoshi, N., 2004. An ecosystem service value assessment of land-use change on Chongming Island, China. *Land Use Policy*, **21**: 139-148.

Zheng, W., Shi, H. H., Chen, S., Zhang, Z. H., Wang, Z. L., and Ding, D. W., 2007. Perception of the characters of marine ecological asset and its value. *Mar. Environ. Sci.*, **26** (4): 393-396.

Zhu, M. Y., Zhang, X. L., Li, R. X., and Chen, S., 2000. Impact of shellfish culture on the coastal ecosystem. *J. Ocean Univ. Qingdao*, **30** (2): 53-57.

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