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Original Research Paper

Assessment of Island Land Ecosystem Services Value and Their Spatial Distribution

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ABSTRACT

The ecosystem service value of different land types on Ximen Island in Zhejiang Province is measured using 2012 WorldView-2 satellite remote sensing data and the Chinese terrestrial ecosystem services value table. The spatial distribution of ecosystem services was also studied via geo-statistics and the spatial analysis functions of ArcGIS. The results show that the ecosystem services of Ximen Island are worth 149.557 million Yuan in total. The ecological services displayed obvious spatial heterogeneity. Among the value of individual ecosystem services, mudflat wetlands and woodland occupy a major position with values reaching 136.034 million Yuan and 7.445 million Yuan, respectively. These two services accounted for 90.96% and 4.97% of the total value. The construction land, bare land, and idle land contributed much less to the total. The results indicate that the functional orientation of Ximen Island as a National Marine Specially Protected Area is being fulfilled.

INTRODUCTION

The book "Man and Nature" written in 1864 by George Marsh is often considered the origin of current ecosystem service research. The quantitative study and comprehensive scientific expression of ecosystem service systems began in 1970s. The "ecosystem services" concept was proposed by Ehrlich in 1974. The book "Nature's Services: Societal Dependence on Natural Ecosystems" (Daily et al. 1997) and the paper "The value of the world ecosystem services and natural capital" was published by "Nature" in 1997 (Costanza et al. 1997). The study of ecosystem services has attracted a large number of researchers from different disciplines, especially ecological economists. This research has also been of interest to governments, the public, as well as resource and environment managers.

The journals "Nature" and "Science" have organized related discussions. In addition, there are four other publications that have published special issues or established forums for the valuation of ecosystem services. These include "Ecological Economics" in 1999, "Bioscience" in 2000, "Ecosystem" in 2000, and "Environmental Science and Technology" in 2000. Within this context, the United Nations launched the Millennium Ecosystem Assessment (MA) project. When the project was finished in 2005, it proposed a global assessment framework of ecosystem services.

Island environments have attracted the attention of many researchers in recent years due to their geographic isolation and unique ecosystems. Assessments for the Nanji Archipelago in Zhejiang Province (Pan et al. 2009) and the Miaodao Archipelago in Shangdong Province (Shi et al. 2009) were based on field investigation or public inquiry and used Travel Cost Interval Analysis (TCIA), market price methods, and shadow engineering price methods assessments have been conducted for the ecosystem services of coral reefs (Riopelle 1995, Wang & Zhao 2006). The Costanza calculation method has been used to research the ecosystem services value of Nan'ao Island (Chen & Lin 2011) and Lingshan Island in Shandong Province (Liu 2011).

The ecosystem service value of different land types on Ximen Island in Zhejiang Province is measured using 2012 WorldView-2 satellite remote sensing data and the Chinese terrestrial ecosystem services value table proposed by Xie et al. (2003). The spatial distribution of ecosystem services was also studied via geo-statistics and the spatial analysis functions of ArcGIS.

STUDY AREA

Ximen Island is an uninhabited land mass located in the southern Ocean of Zhejiang Province with a land area of seven square kilometres, mudflat wetlands area of 19.2 square kilometers, and a coastline of 11.81 km. The distance

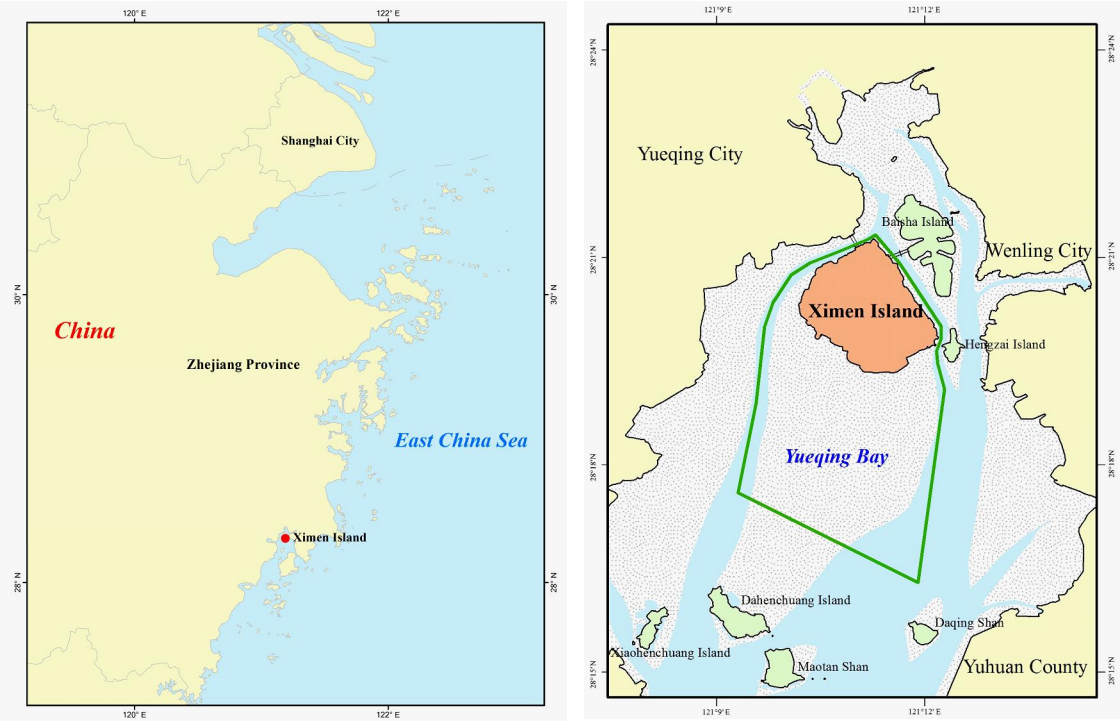


Fig. 1: The location of Ximen Island in Zhejiang Province China.

between Ximen Island and the mainland is only 320 m. Ximen Island is northwest-south trending. The landforms of the island can be divided into hills, plains and coastal wetland.

In 2005, China approved the establishment of the Ximen Island Marine Specially Protected Areas with a total area of 3080.15 ha that includes Ximen Island and the surrounding coastal wetlands. The functional orientation of this conservation area is to protect the country's northern latitude mangrove communities and a variety of wetland birds. There are four administrative villages on the island: Nan'aoshan village, Aoli village, Ximen Island village and Shanhou village. In 2011, the total population of the island was 4,654 and the annual per capita income was 23,833 Yuan.

DATA SOURCES AND METHODS

Data sources and preprocessing: We obtained remote sensing images from the WorldView-2 satellite. These images had a spatial resolution of 0.5 m. The images were panchromatic and multispectral. The imaging date is March 31, 2012 with the tidal 450 cm. This information was combined with observations from a site visit to Ximen Island. On this visit we the measured the island and the surrounding area control point information and photographed large island features. Our interpretation of the remote sensing images mainly utilized visual methods. We established recognition criteria for features and used the powerful data processing and analysis capabilities of ArcGIS to classify the land types of the Ximen Island remote sensing images.

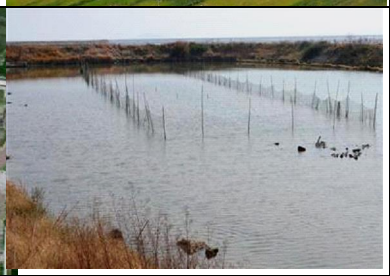
The result of the Ximen Island classification shows that the main types of land use include a total of 12 categories, i.e., woodland, paddy, water aquaculture, dryland, other garden, pond water, rural homestead, highway land, special land, idle land, bare land and mudflat wetlands.

According to our analysis the mudflat wetlands have the highest area proportion of the different land use types, accounting for approximately 77.6% of the total. This is followed by woodland which is mainly located in central Ximen Island, about 12.2%. Dryland and water aquaculture, the area proportion are more than 2%. The area proportion of bare land and other types are lower than 2% with sporadic distribution throughout the island.

Research Methods

The evaluation methods of ecosystem services value: Constanza et al. (1997) used economic principles to quantitatively evaluate global ecosystem services value. Xie et al. (2003) expanded on the evaluation model of Constanza to establish a table of the ecosystem service value per unit area in China (Table 3). This table is based on survey answers

Table 1: Photos used for land classification.

Type	Satellite remote sensing images	Scene photos	Characterization
Paddy			Regular shape Textures simple Clear boundary
Aquaculture Water			Regular shape Textures simple Clear boundary
Woodland			Rough texture Wider distribution area

from 200 ecologists. Using the research of Xie et al. (2003) and the computing model proposed by Constanza, we computed the ecosystem service value of different land types on the island.

$$ESV = A_k * VC_k \quad ...(1)$$

$$ESV_f = A_k * VC_{fk} \quad ...(2)$$

In the Equation 1, ESV is the value of total ecosystem services in the study area, A_k is the area of different types of island land, and VC_k is the value of ecosystem services in the type of the island land. In Equation 2, ESV_f is the value of ecosystem services per unit area and VC_{fk} is the value of ecosystem services per unit area in the type of the island land.

Due to the differences in land type classes, we needed to establish connections between the land classes proposed by Xie et al. (2003) and the land types of Ximen Island. The relationships we established between the two classification systems are summarized in Table 4. The ecosystem services value of construction land was assumed to be zero.

GIS based spatial analysis methods: Conventional ecosystem service assessment results are often expressed as a single numerical value which cannot reflect the spatial relationships and distribution of island ecological services. These methods obscure the inherent spatial heterogeneity of islands. Based on the following steps, we establish a method to spatially express of the value of ecosystem services.

Table 2: The status quo land use information of Ximen Island in 2012.

No.	Land use types	Area (m^2)	Proportion (%)
1	Woodland	3,850,926	12.2
2	Paddy	561,781	1.8
3	Water aquaculture	817,348	2.6
4	Dryland	1,124,233	3.6
5	Other garden	85,719	0.3
6	Pond water	96,076	0.3
7	Rural homestead	501,654	1.6
8	Highway land	23,404	0.1
9	Special land	3,083	0.009
10	Idle land	15,220	0.05
11	Bare land	6,981	0.02
12	Mudflat wetlands	24,515,491	77.6
	Total	31,601,916	100%

***Boundary determination*:** Methodology for determining

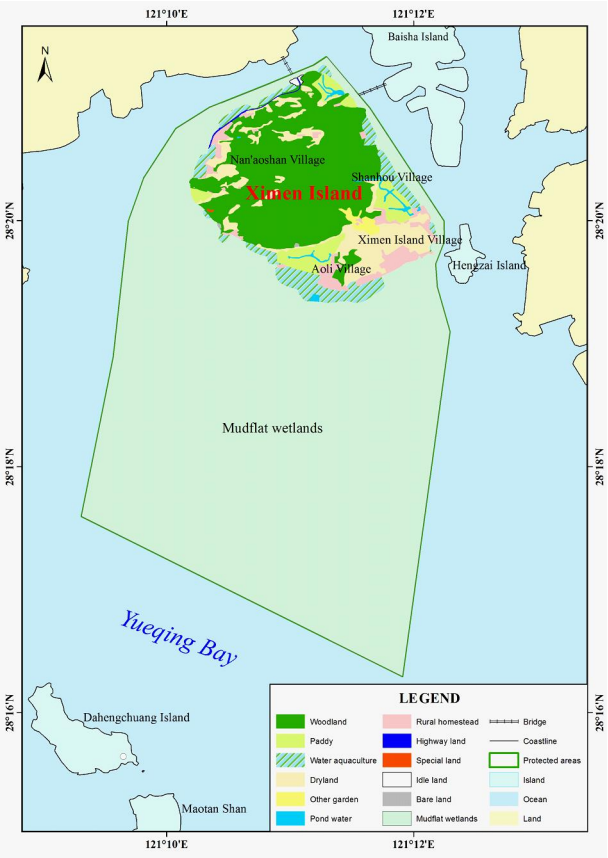


Fig. 2: The land use map of Ximen Island in 2012.

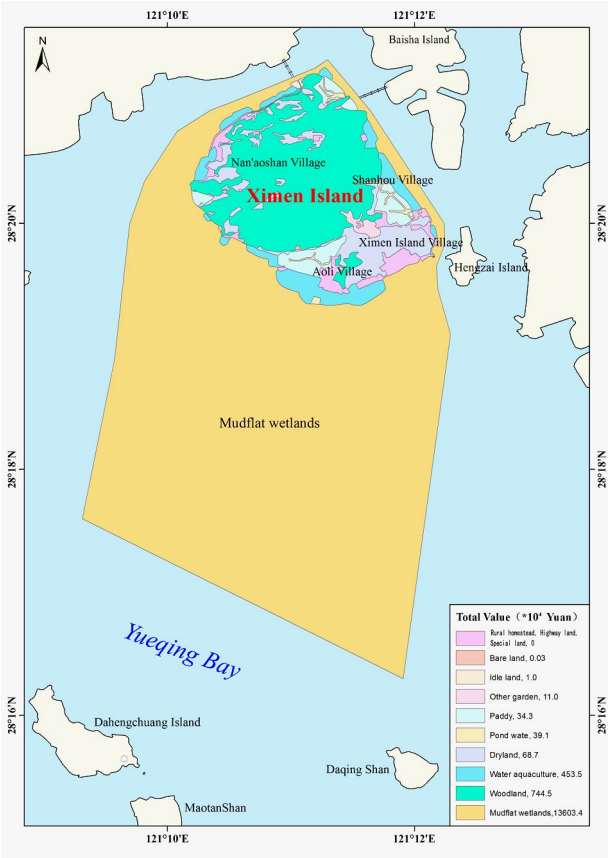


Fig. 3: The spatial distribution of total ecosystem service value on Ximen Island.

boundaries should take full account of local geographical features, ecosystem characteristics, natural disasters, and the range of anthropogenic influence. The study scope of Ximen Island includes the island's coastal land and wetlands which cover the entire range of Ximen Island protected areas.

***Space partition*:** GIS software was used to perform land classification of Ximen Island.

Property assignment and spatial expression: According to the calculated value of individual ecosystem services, a magnitude value was given to each region. We then visualize the value of all ecosystem services included in each region.

RESULTS AND ANALYSIS

The total ecological services value of different types of land: We computed the value of ecosystem services unit area and total value based on the land classification (Xie et al. 2003), and the computing model proposed by Constanza et al. (1997) (Table 5).

The results show that the ecosystem services of Ximen Island are worth 149.557 million Yuan in total. The

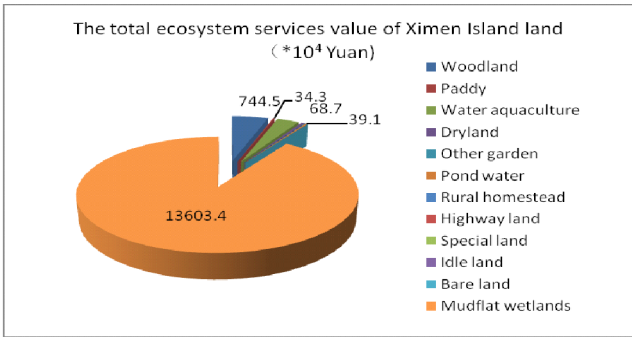


Fig. 4: The ecosystem services value of different land type in Ximen Island.

ecological services displayed obvious spatial heterogeneity. Among the value of individual ecosystem services, mudflat wetlands and woodland occupy a major position with values reaching 136.034 million Yuan and 7.445 million Yuan, respectively. These two services accounted for 90.96% and 4.97% of the total value. The construction land, bare land, and idle land contributed much less to the total. The results indicate that the functional orientation of Ximen Island as a National Marine Specially Protected Area is being fulfilled.

Table 3: Chinese ecosystem services value unit area of different land types [Yuan/ (ha·yr)].

Item	Forest	Grassland	Shrubs	Farm land	Wetland	Water	Desert	Construction land
Gas regulation	3097.0	707.9	1902.5	442.4	1592.7	0	0	0
Climate regulation	2389.1	796.4	1592.8	787.5	15130.9	407.0	0	0
Water Conservation	2831.5	707.9	1769.7	530.9	13715.2	18033.2	26.5	0
Soil formation and protection	3450.9	1725.5	2588.2	1291.9	1513.1	8.8	17.7	0
Waste treatment	1159.2	1159.2	1159.2	1451.2	16086.6	16086.6	8.8	0
Biodiversity Conservation	2884.6	964.5	1924.6	628.2	2212.2	2203.3	300.8	0
Food production	88.5	265.5	177	884.9	265.5	88.5	8.8	0
Raw material	2300.6	44.2	1172.4	88.5	61.9	8.8	0	0
Entertainment Culture	1132.6	35.4	584	8.8	4910.9	3840.2	8.8	0
Total	19334	6406.5	12870.4	6114.3	55489	40676.4	371.4	0

Note: The original table is modified to include the shrub and construction land types. The ecosystem services value of shrubs is the average value of the forests and grasslands. The ecosystem service value of construction land is zero.

Table 4: Relationships between Ximen Island land types and ecosystem services value table proposed by Xie et al. (2003).

Item	Forest	Grass land	Shrubs	Farm land	Wetland	Water	Desert	Construction land	ecosystem services value [Yuan/(ha·yr)]
Woodland	•								19334
Paddy				•					6114.3
Water aquaculture					•				55489
Dryland				•					6114.3
Other garden			•						12870.4
Pond water						•			40676.4
Rural homestead								•	0
Highway land								•	0
Special land								•	0
Idle land		•							6406.5
Bare land							•		371.4
Mudflat wetlands					•				55489

Table 5: The total value of terrestrial ecosystem services on Ximen Island.

No.	Land use types	Area (m^2)	The value of ecosystem services per unit area (Yuan/ha)	Total value ($\times 10^4$ Yuan)	Proportion (%)
1	Woodland	3850926	19334	744.5	4.97
2	Paddy	561781	6114.3	34.3	0.23
3	Water aquaculture	817348	55489	453.5	3.03
4	Dryland	1124233	6114.3	68.7	0.46
5	Other garden	85719	12870.4	11.0	0.07
6	Pond water	96076	40676.4	39.1	0.26
7	Rural homestead	501654	0	0.0	0.00
8	Highway land	23404	0	0.0	0.00
9	Special land	3083	0	0.0	0.00
10	Idle land	15220	6406.5	1.0	0.007
11	Bare land	6981	371.4	0.03	0.0002
12	Mudflat wetlands	24515491	55489	13603.4	90.96
	The total value of terrestrial ecosystem services on Ximen Island			14955.7	100

The spatial analysis of ecosystem service value of different land types: We also analysed the spatial heterogeneity of ecosystem service value on Ximen Island. We used GIS based spatial analysis methods to obtain a spatial expression of the ecosystem service value per unit area in different regions of Ximen Island. Fig. 5 shows that the ecosystem services with value lower than 10,000 Yuan/(ha·yr) are mainly distributed in the areas of paddy, bare land, dry

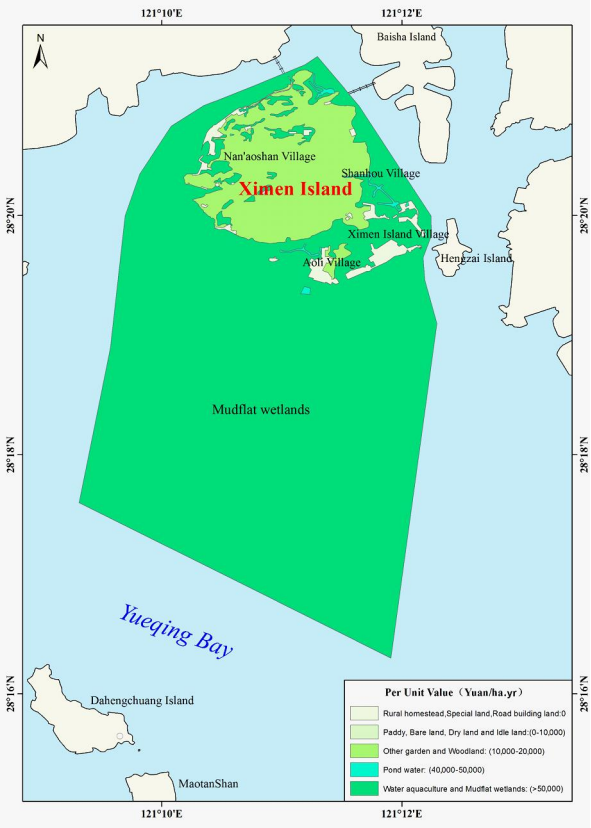


Fig. 5: The spatial distribution of ecosystem service value on Ximen Island Land.

land, and idle land. The value of ecosystems services in built up areas such as rural homesteads, special lands, and roads is zero. The areas with ecosystem service value between 10,000-20,000 Yuan/(ha·yr) are mainly distributed in lands classified as other garden and woodland. The areas with ecosystem service values between 40,000-50,000 Yuan/(ha·yr) and above 50,000 Yuan/(ha·yr) are mainly distributed in the areas classified as pond water, water aquaculture, and mudflat wetlands. The spatial heterogeneity of ecosystem service value is very obvious.

DISCUSSION

The applicability of island ecosystem services value assessment methods: The theory of ecosystem services value is used by many scholars to study ecosystems services value in different regions. Because the method was based at the global scale, there are large errors when it is used to estimate ecosystem service value of medium to small areas. Based on the method of Costanza et al. (1997), Xie et al. (2003) worked out Chinese ecosystem service value per unit area for different ecosystem types which are in line with the national conditions. To a certain extent, the theory of Xie et al. (2003) has more precise values for China's terrestrial ecosystems.

This study assesses the terrestrial ecosystem service value of Ximen Island, analyses the heterogeneity of its spatial distribution, and deepens the research on island ecosystems. However, due to the complex, dynamic and non-linear nature of the ecosystem the estimation still contains a certain bias and uncertainty. In order to accommodate the ecological status of the island, we should further subdivide the land classes of the island and improve the estimation of the Chinese ecosystem service value per unit area.

The applications of island ecosystem services valuation: The purpose of island ecosystem service valuation is to provide decision support to achieve efficient, equitable and sustainable marine ecosystem management. It can clarify the protected items and quantify the protected value in different regions of the island. Via ecological damage survey and assessment, valuation can strengthen the compensation estimation after island development. It can indicate areas needing ecological restoration measures. Thus, evaluating ecosystem services aids in regulating the use of ecological compensation and achieving the purpose of sustainable island use.

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