# Study on the Driving Mechanism of Ecosystem Service Value on Ximen Island Based on STIRPAT Model

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**Abstract.** The ecosystem service value on Ximen Island was calculated using the value table of ecosystem services proposed by Xie et al. according to the land use data from 2006–2017. The STIRPAT model was used to analyze the driving mechanisms of ecosystem services on Ximen Island. The results show that the ecosystem service value of Ximen Island has gradually decreased from 2006 to 2017, and the value of ecosystem services has decreased by 15.842 million Yuan over 10 years. Applying the principal component analysis method can effectively eliminate the collinearity problem in the process of regression analysis. The value of ecosystem services has a high correlation with socio-economic variables. The total population, GDP per capita, the increased rate of forestry output, the proportion of primary industry, and the Engel coefficient are all important driving factors that affect the change of valuable ecosystem services on Ximen Island. Among them, the proportion of primary industry is positive, and the other 4 indicators are negative. The rate of increase in forestry output has the greatest negative impact. A 1% increase in the total population, in the GDP per capita, in the rate of forestry output, in the proportion of primary industry, and in the Engel coefficient results in ecosystem service values varying by 0.199%, 0.165%, 0.289%, -0.144%, and 0.252%, respectively.

## 1 Introduction

Ecosystem services refer to all the benefits that humans receive from ecosystems [1]. Ecosystem service research is an interdisciplinary field linking ecology, economics, and sociology, and it is a hot topic in the field of ecological research [2].

In 1997, the book The Dependence of Human Society on Natural Ecosystems was published, and the paper "Evaluating the Value of Global Ecosystem Services and Natural Capital" was published in Nature [3]. From 2001–2005, the United Nations-funded Millennium Ecosystem Assessment (MA) was completed. The global research project “Ecosystem and Biodiversity Economics (TEEB)” was completed in 2010. This project had been initiated by the Group of Eight (G8) and five major developing economies under the auspices of the United Nations Environment Programme. The study of ecosystem service valuation has gradually evolved from basic assessments to research on spatio-temporal changes and driving mechanisms [4-5].

There is spatial heterogeneity in the value of ecosystem services at different regional scales. Under the influence of different drivers, the composition and worth of ecosystem services will change with time. Human activities are the main external driving factors that affect the value of regional ecosystem services. Land use or land-cover change caused by human activities is one of the most important driving forces. These activities affect the ecology of a region in three primary ways: changing the spatial distribution of the biological resources, changing ecosystem diversity, and altering ecological processes. Land-use change reflects one of the most direct relationships between humans and ecosystem services, the spatial heterogeneity of ecosystem services, and temporal trends in ecosystem services and their spatial distribution [6-9]. For example, the impact of urbanization on land use, landscape patterns, and ecological processes strongly influences the regional ecosystem structure, ecosystem function, and spatial heterogeneity of service value [10-12].

The mechanisms by which human activities act on regional ecosystem services are relatively complex, as the relationship between the two is nonlinear and complex. These mechanisms largely affect the spatial heterogeneity and temporal variation characteristics in the price of ecosystem services. In-depth study of the mechanisms driving the market value of ecosystem services can expand the research field, reveal the ecosystem services changes, and facilitate the implementation of management based on ecosystem services.

Island ecosystems include geographical parts of the island and offshore areas, and they exhibit ecological characteristics of both land and sea. As a kind of marine ecosystem, islands have attracted the attention of many scientific researchers in recent years due to their

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geographical independence and particular features of the ecosystem. The main research areas in the field of island ecosystem services include the evaluation of the ecological services of archipelago islands, such as Nanji Archipelago in Zhejiang Province [13] and Miaodao Archipelago in Shandong Province [14], as well as the evaluation of the ecological services of individual inhabited islands, such as Xiamen Island in Fujian Province [15] and Ximen Island in Zhejiang Province [16]. At present, research on island ecosystem services has mostly been restricted to the evaluation stage of ecosystem services. Studies on spatio-temporal changes and driving mechanisms of the value of island ecosystem services have only been conducted for Jintang Island and Cezi Island in Zhejiang Province [17-18]. Therefore, further research is needed.

Based on previous research results, this paper selects Ximen Island of Zhejiang Province as the study area. The ecological service value table proposed by Xie Gaodi is used to calculate the ecosystem service value of Ximen Island. The STIRPAT model is then used to study the driving forces of ecosystem service value change on Ximen Island.

# 2 Study area and data

## 2.1. Overview of the study area

Ximen Island is an inhabited island within the sea area of southern Zhejiang Province, with a land area of approximately 7 km2, a beach area of 19.2 km2, and a coastline length of 11.81 km. At the nearest point, the island is only 320 m from the mainland. Ximen Island has a subtropical marine monsoon climate with four distinct seasons. The average annual temperature of Ximen Island is 17.6°C, and the average annual precipitation is 1474 mm. Ximen Island is rich in tidal flat resources which are mainly distributed on the southern, western, and northeast sides of the island. Currently, the mangroves of Ximen Island represent the northernmost mangrove forest in China, and they are distributed along the beach on the southern side of Ximen Island (28º 20′ 54.9″ N-28º 20′ 57″ N, 121º 10′ 41.4″ E-121º 10′ 44.7″ E). According to field surveys, there are also many species of birds in the Ximen Island tidal flat wetland, such as nationally protected egrets and globally endangered Black-billed Gull.

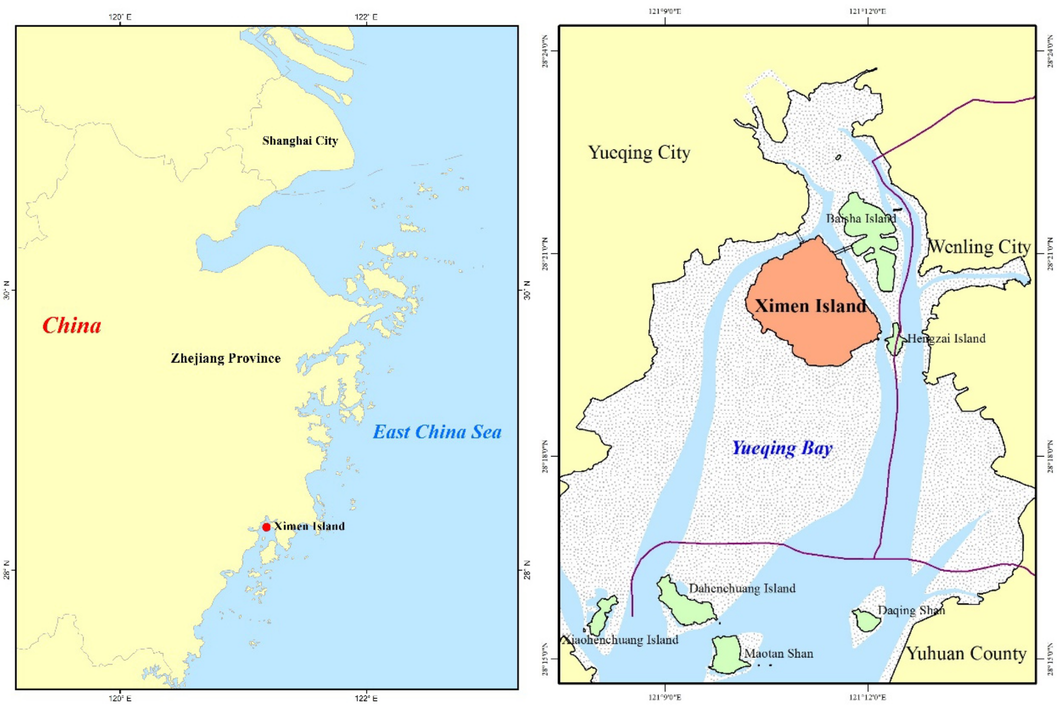


**Fig. 1.** Location of the Ximen Island.

The Ximen Island Marine Special Protection Area was established in 2005 with the approval of the State Oceanic Administration and the Zhejiang Provincial People's Government. It is the first state-level marine special protection zone in Zhejiang Province. According to the approved development plan for the Ximen Island Marine Special Protection Area in Yueqing City, the Ximen Island Marine Special Protection Area includes Ximen Island and its surrounding coastal wetlands. It consists of three major functional areas: the Ximen Island Scenic Area, the Huandao Coastal Ecological Protection Landscape Area, and the Nantuo Ecological Protection and Development Zone. The total protected area spans 3080.15 hectares.

## 2.2 Data sources and processing

The land use data in this study derives from remote sensing satellite images from 2006 to 2017. The land use classification of remote sensing images was mainly accomplished via supervised classification method. This method establishes supervised classification and then uses the powerful data processing and analysis capabilities of ArcGIS and ENVI to derive land use data from the Ximen Island remote sensing images.

The interpretation of remote sensing image data was carried out according to China's land use classification system, the requirements for calculation of ecosystem service value, and the characteristics of land use in Ximen Island. The results show that the main types of land use include a total of 12 categories, i.e., Woodland, Paddy, Water Aquaculture, Dry Land, Other garden, Pond Water, Rural Homestead, Highway Land, Special Land, Idle Land, Bare Land, and Mudflat Wetlands. The results of land classification in 2012 and 2017 are shown in Table 1.

**Table 1.** Land use of Ximen Island in 2012 and 2017.

| Land use type | (2006) Area ($m^2$) | (2017) Area ($m^2$) |
|---|---|---|
| Woodland | 3850926 | 4429133 |
| Paddy | 561781 | 549115 |
| Water Aquaculture | 817348 | 781618 |
| Dry Land | 1124233 | 680688 |
| Other Garden | 85719 | 2203 |
| Pond Water | 96076 | 70517 |
| Rural Homestead | 501654 | 1628 |
| Highway Land | 23404 | 23404 |
| Special Land | 3083 | 3083 |
| Idle Land | 15220 | 15220 |
| Bare Land | 6981 | 70517 |
| Mudflat Wetlands | 24515492 | 22713800 |

We obtained the primary industry levels, the GDP per capita, the increase in forestry economic output, the population counts, and the Engel coefficient of urban residents from the statistical reports on the national economy and social development of Yueqing City during 2006-2017, which includes Ximen Island. The above socio-economic data will be used for STIRPAT model analysis.

# 3 Research methods

## 3.1Ecosystem service function value estimation

On the basis of the evaluation model proposed by Constanza et al., Xie Gaodi developed Chinese ecosystem services value paradigm via a survey of 200 ecologists in China. This method has been widely used in China. Therefore, the study employs the research results of Xie and uses the model proposed by Constanza to calculate the ecosystem service value of Ximen Island from 2006 to 2017.

**Table 2.** Chinese ecosystem services value per unit area for different ecosystem types [Units: Yuan/ ($hm^2$•a)].

| 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 materials | 2300.6 | 44.2 | 1172.4 | 88.5 | 61.9 | 8.8 | 0 | 0 |
| Entertainment and 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: Based on the original table regarding increases in shrubs and building land types. The ecosystem service value of shrubs is the average value of the forests and grasslands. The ecosystem service value of building land is 0.

Using the ecological service value table proposed by Xie et al., the value of ecosystem services in Ximen Island during 2006-2017 was calculated (Table 3).

**Table 3.** Ecosystem Service Value of Ximen Island from 2006–2017 (Units: Ten Thousand Yuan).

| Year | Ecosystem service value | Year | Ecosystem service value |
|---|---|---|---|
| 2006 | 15581.8 | 2012 | 14955.7 |
| 2007 | 15477.5 | 2013 | 14764.1 |
| 2008 | 15373.1 | 2014 | 14572.5 |
| 2009 | 15268.8 | 2015 | 14380.8 |
| 2010 | 15164.4 | 2016 | 14189.2 |
| 2011 | 15060.1 | 2017 | 13997.6 |

## 3.2 Construction of ecosystem service value driving model with STIRPAT

### *3.2.1 Principle of STIRPAT model*

Ehrich and Holdren proposed the IPAT model in 1971 [19]. It is widely used in the field of environmental economics because it is simple, systematic, and sound:

$$I=P\times A\times T \tag{1}$$

Where $I$ is the environmental impact, $P$ is the size of the population, $A$ is the level of affluence, and $T$ is the level of technology.

Based on the IPAT model, Dietz et al. proposed the 'stochastic impacts by regression on population, affiliation, and technology' (STIRPAT) model in 1994 [20]. The model was established to incorporate randomness into the IPAT model to analyze the impact of human driving forces on environmental pressures. The STIRPAT model can be expressed as the following formula:

$$I=cP^{\alpha}A^{\beta}T^{\gamma}e \tag{2}$$

Where $c$ is a constant coefficient; α, β, and γ are elastic coefficients; and $e$ is a model error. $I$ indicates the percentage of change in environmental pressure caused by a 1% change in $P$, $A$, or $T$ due to the driving force under the assumption that other influencing factors are not changed. This is similar to the elastic analysis method in economics.

The standard STIRPAT model provides a simple causal analysis framework that breaks down the impact of human activity on the environment. This provides a method for analyzing the factors driving environmental impacts. It can also predict the environmental responses to changes in human and social factors, such as population size and affluence, and it can be widely applied in the field of environmental economics.

### *3.2.2 Alternative driving factors and correlation analysis*

In practice, the original STIRPAT model allows for the addition of social or other influencing factors to analyze their impact on the value of ecosystem services. Based on the characteristics of the island ecosystem, this paper adopts an extended STIRPAT model to analyze the driving factors of trends in ecosystem service value.

In this paper, the ecosystem service value function is taken as the environmental pressure, the population is expressed as the total population, and the wealth of the populace is expressed as the per capita GDP. The rate of increase in forestry output and the increase in forestry output reflect the regional natural environment. The change in the level of primary industry can reflect the change in intensive land use. The Engel coefficient of urban residents can be used as an indicator reflecting social and economic development and it can, to a certain extent, also reflect changes in land use patterns.

**Table 4.** Socioeconomic statistics of Yueqing City.

| Year | The proportion of the first industry | GDP per capita(Yuan) | Forestry output increase rate | Value added due to forestry output (Billion Yuan) | Population (Ten Thousand People) | Engel coefficient of urban residents |
|---|---|---|---|---|---|---|
| 2006 | 4.0 | 25637 | -18.2 | 0.18 | 118.21 | 28.4 |
| 2007 | 3.5 | 30355 | -45.7 | 0.10 | 119.59 | 27.9 |
| 2008 | 3.6 | 33615 | 14.1 | 0.12 | 120.91 | 28.9 |
| 2009 | 3.5 | 34396 | 7.5 | 0.14 | 122.49 | 28.9 |
| 2010 | 3.4 | 40224 | -14.3 | 0.12 | 126.99 | 30.1 |
| 2011 | 3.3 | 45705 | -17.9 | 0.11 | 126.03 | 31.5 |
| 2012 | 3.2 | 47323 | 33.8 | 0.16 | 127.16 | 32.9 |
| 2013 | 3.0 | 51612 | -2.8 | 0.15 | 127.79 | 33.8 |
| 2014 | 2.9 | 54950 | -4.7 | 0.14 | 128.73 | 30.5 |
| 2015 | 2.7 | 59728 | 5.2 | 0.15 | 128.04 | 30.8 |
| 2016 | 2.6 | 65086 | -4.6 | 0.13 | 129.59 | 31.1 |
| 2017 | 2.3 | 72905 | 7.1 | 0.14 | 130.32 | 30.8 |

The Pearson correlation test was performed on the above-mentioned driving factors and ecosystem service value time-series data, and the primary drivers were further screened. The test results are shown in Table 5.

**Table 5.** Pearson test results for alternative driving factors and ecosystem service values.

| | **The proportion of primary industry** | **GDP per capita** | **Forestry output increase rate** | **Value added due to forestry output** | **Population** | **Engel coefficient of urban residents** | **Ecosystem service value** |
|---|---|---|---|---|---|---|---|
| The proportion of primary industry | 1 | -0.984** | -0.291 | 0.023 | -0.893** | -0.532 | 0.981** |
| GDP per capita | -0.984** | 1 | 0.345 | 0.068 | 0.922** | 0.592* | -0.993** |
| Forestry output increase rate | -0.291 | 0.345 | 1 | 0.463 | 0.387 | 0.469 | -0.336 |
| Value added due to forestry output Population | 0.023 | 0.068 | 0.463 | 1 | 0.031 | 0.245 | -0.108 |
| Engel coefficient of urban residents | -0.532 | .592* | 0.469 | 0.245 | 0.736** | 1 | -0.532 |
| Ecosystem service value | 0.981** | -0.993** | -0.336 | -0.108 | -0.896** | -0.532 | 1 |

From the above test results, there are significant correlations between the five driving factors and ecosystem service values, with correlation coefficients above 0.3. The correlation between 'value added of forestry output' and ecosystem service value is not high, with a correlation coefficient of only 0.108. Therefore, the 'value added of forestry output' factor was removed to more accurately analyze the driving forces of ecosystem service value.

### *3.2.3 Alternative driving factors and correlation analysis*

In our application of the STIRPAT model, the ecosystem service value is regarded as the environmental impact (*I*), the population size is measured by the total population (*P*), and the affluence level is quantified by the per capita GDP (*A*):

$$I=ap^bA^cT_1^dT_2^eT_3fk \quad (3)$$

where $I$ is the ecosystem service value and $a$ is a constant term. $B$, $c$, $d$, $e$, and f are the elastic coefficients of $P$, $A$, $T_1$, $T_2$, and $T_3$.

In order to determine the parameters by regression analysis, the two sides of the formula are subjected to logarithmic transformation to obtain the following extended model:

$$lnI=lna+b*lnP+c*lnA+d*lnT_1+e*lnT_2+f*lnT_3+lnk \quad (4)$$

### *3.2.4 Principal component regression analysis*

Although each variable is significant for the dependent variable in the regression equation, some of the independent variables are related to each other. In other words, there is a problem of collinearity, which makes it difficult to evaluate the contribution rate of the independent variables. Therefore, it is necessary to perform collinear diagnosis on the variables in the regression equation and determine their influence on the parameter estimation. Principal component analysis attempts to recombine many of the original indicators into a set of new unrelated comprehensive indicators called principal components or factors. The main components can better reflect the comprehensive information of many original related indicators. Therefore, using the principal component as a new independent variable for regression analysis will make the regression equation and parameter estimation more reliable.

In this study, Pearson correlation analysis was performed on each influencing factor. The results show a significant correlation between the total population, per capita GDP, the rate of increase in forestry output value, the proportion of the primary industry, and the Engel coefficient of urban residents (Table 5). If the regression is performed directly, the equation will be unreasonable due to the presence of collinearity. This makes it difficult to perform an accurate quantitative analysis. Therefore, this paper constructs a STIRPAT model of Ximen Island ecosystem service value based on the principal component analysis of each influencing factor.

When the two principal components were extracted, the cumulative contribution rate reached 90.163% (Table 6). This indicates that it contains 90.163% of the original variable information, and it can therefore basically replace the original variable.

**Table 6.** Total variance explained by each component.

| Component | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | |
|---|---|---|---|---|---|
| | Total | % Variance | Cumulative % | Total | % Variance |
| 1 | 4.457 | 74.291 | 74.291 | 4.457 | 74.291 |
| 2 | 0.952 | 15.872 | 90.163 | 0.952 | 15.872 |
| 3 | 0.492 | 8.204 | 98.366 | | |
| 4 | 0.075 | 1.255 | 99.621 | | |
| 5 | 0.019 | 0.318 | 99.938 | | |
| 6 | 0.004 | 0.062 | 100.000 | | |

The principal component load matrix is shown in Table 7, and the principal component score matrix is shown in Table 8.

**Table 7.** Principal component load matrix.

| | Component | |
|---|---|---|
| | $F_1$ | $F_2$ |
| The proportion of primary industry | -0.950 | 0.259 |
| GDP per capita | 0.975 | -0.190 |
| Forestry output increase rate | 0.477 | 0.796 |
| Population | 0.962 | -0.034 |
| Engel coefficient of urban residents | 0.730 | 0.406 |
| Ecosystem service value | -0.958 | 0.222 |

**Table 8.** Principal component score matrix.

| | Component | |
|---|---|---|
| | $F_1$ | $F_2$ |
| The proportion of primary industry | -0.213 | 0.272 |
| GDP per capita | 0.219 | -0.199 |
| Forestry output increase rate | 0.107 | 0.836 |
| Population | 0.216 | -0.035 |
| Engel coefficient of urban residents | 0.164 | 0.426 |
| Ecosystem service value | -0.215 | 0.234 |

The eigenvectors of the principal component ($F_1$) and the principal component ($F_2$) can be obtained, respectively, by dividing the principal component load vector by the square root of the arithmetic component of the respective principal component eigenvalues. In this way, the two synthetic variables $F_1$ and $F_2$ can be obtained:

$$F_1= -0.450T_2 +0.462A+0.226T_1+0.456P+0.346T_3 \quad (5)$$

$$F_2=0.265T_2-0.195A+0.816T_1-0.035P+0.416T_3 \quad (6)$$

After standardized treatment of ecosystem service value as the dependent variable (*ZI*) and the comprehensive variables $F_1$ and $F_2$ as explanatory variables, (OLS) regression was used. The regression results are shown in Table 9.

**Table 9.** Regression coefficients of main components and standardized ecosystem Service values.

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Sig. |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | -2.067E-15 | 0.058 | | 0.000 | 1.000 |
| | $F_1$ score | -0.454 | 0.029 | -0.958 | -15.748 | 0.000 |
| | $F_2$ score | 0.228 | 0.062 | 0.222 | 3.657 | 0.005 |

**Table 10.** Test of regression equation with comprehensive variables.

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | 0.983a | 0.967 | 0.959 | 0.20170819 |
| a. Predictors: (Constant), $F_2$ score, $F_1$ score | | | | |

From Table 10, it can be seen that the $R_2$ of the regression equation and the adjusted $R_2$ are both above 0.95, indicating that the regression equation has a very good degree of fit. According to the regression coefficients in Table 9, the regression equation of the dependent variable *ZI* and the comprehensive variables $F_1$ and $F_2$ can be obtained:

$$ZI=0.454F_1+0.228F_2 \tag{7}$$

Formulas (5), (6), and (7) can be used to derive the STIRPAT driving force model for the ecosystem service value of Ximen Island:

$$I=aP^{0.199}A^{0.165}T_1^{0.289}T_2^{-0.144}T_3^{0.252}k \tag{8}$$

According to Formula (8), the levels for elastic coefficients of total population, per capita GDP, forestry output increase rate, proportion of primary industry, and Engel coefficient in the ecosystem service value equation are 0.199, 0.165, 0.289, -0.144, and 0.252, respectively.

## 4 Results and discussion

(1) Xie Gaodi's Chinese unit area of ecosystem service value can effectively calculate the value of ecosystem services and exhibits a level of scientific rigor and rationality. The ecosystem service value of Ximen Island has been declining each year from 2006 to 2017, from 157.818 million Yuan in 2006 to 137.976 million Yuan in 2017. The value of ecosystem services has decreased by 15.8422 million Yuan in 10 years, with an average annual reduction of 15.84 million Yuan. The reduction in the value of ecosystem services is closely related to the rapid development of the industrial economy and the acceleration of urbanization in Yueqing City.

(2) The use of principal component analysis to modify the STIRPAT model can effectively solve the phenomenon of mutual interpretation between various economic and social influencing factors and eliminate the problem of collinearity in the process of regression analysis. In our analysis, the accumulative contribution rate of the main components of the factors driving ecosystem service value change in Ximen Island reached 90.163%, indicating that 90.163% of the information of the original variable has been included. Via the principal component analysis method, a more rational quantitative analysis of the driving mechanisms of ecosystem service value change can be conducted.

(3) The changes in ecosystem service value are highly related to socioeconomic development. The total population, GDP per capita, forestry output increase rate, proportion of primary industry, and Engel coefficient are the main driving factors for changes of ecosystem service value on Ximen Island. When the total population, GDP per capita, forestry output increase rate, the proportion of primary industry, and Engel coefficient increase by 1%, the ecosystem service value will increase by 0.199%, 0.165%, 0.289%, -0.144%, and 0.252%, respectively. The relative importance of driving factors is as follows: forestry output increase rate > Engel coefficient > total population> GDP per capita > the proportion of primary industry. Among these, the proportion of primary industry is positive, and the remaining 4 indicators are negative. The forestry output increase rate has the greatest negative impact. This is directly related to the high level of industrial development in Yueqing City, the slow development of agriculture, and the limited increase in green area. Therefore, Yueqing City should focus on controlling the population growth rate, increasing the green area, and improving the industrial structure in future plans of social and economic development. This will be an effective way to alleviate the pressure of human activities on the fragile ecological environment and achieve sustainable development.

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