Temporal Evolution of the Yellow Sea Ecosystem Services (1980–2010)

Qixiang Wang a, Jingjing Song a,b,*, Jian Zhou a, Wenxi Zhao a, Hongjun Liu a, Xuei Tang b

a Marine Biology Institute of Shandong Province, 7 Youyun Street, Qingdao, Shandong Province, China
b Ocean University of China, 5 Yushan Street, Qingdao, Shandong Province, China

* Corresponding author.
E-mail addresses: wqxb@163.com (Q. Wang), songjingjing208@mails.ucas.ac.cn (J. Song), zhoujian.park@163.com (J. Zhou), vincychao@163.com (W. Zhao), hongjunl@126.com (H. Liu), tangxx@ouc.edu.cn (X. Tang).

Abstract

Marine ecosystem services refer to benefits that people obtain from marine ecosystem. Understanding temporal evolution of these services is a fundamental challenge of natural resource management in marine ecosystems. Yellow Sea is one of the most intensely exploited shallow seas in the Northwest Pacific Ocean. In this study, we analyzed the value of the four classes services (provisioning services, regulating services, cultural services and supporting services, including 14 individual services) of the Yellow Sea on temporal scales. From 1980 to 2010, the total value of the four classes of services was between 297 and 2,232 billion RMB yuan. Only the proportion of cultural services as a percentage of the total value continued to increase for the entire period, from 0.9% in 1980 to 9.4% in 2010. Provisioning services reached their highest point at 18.4% in 2000, and then fell to 10.1% in 2010. Meanwhile, the percentage of regulating services and supporting services declined, falling from 14.4% and 79.4% in 1980 to 10.1% and 70.4% in 2010, respectively. This study represents the first attempt to analyze the temporal evolution of Yellow Sea ecosystem services. It will provide the theoretical basis for further study of the ecological mechanisms of marine ecosystem services.

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1. Introduction

Marine ecosystem services are the benefits that people obtain from marine ecosystems, including the ocean, shallow seas, and estuaries [29, 16, 23, 9, 38]. The Yellow Sea is one of the most intensely exploited shallow seas in the Northwest Pacific Ocean with 10 percent of the world's population (600 million people) depending the marine resources from the sea for sustenance, economic opportunities, and ecological services. Yet, climate change, over fishing, invasion of non-native species, and other impacts of a rapidly growing human population increasingly threaten the marine resources and the benefits they provide [9].

People commonly think of oceans as relatively featureless expanses that defy the divisions created from drawing lines on maps [34]. However, recent political and scientific advances have highlighted the need for a comprehensive approach to planning for marine and coastal uses and the need for practical tools to make a more comprehensive approach to marine conservation a reality on the ground and in the water [34]. Quantifying the economic value of services provided by marine ecosystems and incorporating these values into socioeconomic analyses is key to conserving these ecosystems and the benefits they generate [14, 20]. However, ecosystem services valuation techniques have a number of intrinsic problems in quantifying the great complexity of social–ecological systems in which ecosystem services are enjoyed or used by humans [24]. For example, the Yellow Sea coastal ecosystem includes two million hectares of marshes, more than ten river estuaries, abundant seagrass beds, and sand beaches, where more than 10 per cent of the global population lives [45, 32, 31]. Beside the challenges inherent in valuation techniques, the lack of empirical information about services flow and how they are changing over time is also a significant problem in quantification of ecosystem services. Only after having a better understanding of how the characteristics of ecosystem services evolve over time, we can protect them effectively.

This paper presents results of an attempt to estimate the economic value of 14 ecosystem services provided by the Yellow Sea on temporal scales. This paper has two major goals: (1) to analyze the characteristics of the Yellow Sea marine ecosystem services, and (2) to discover the temporal evolution of ecosystem services provided by the Yellow Sea. This study will contribute to the protection, development, and management of shallow seas worldwide.
2. Materials and methods

2.1. Study area: Yellow Sea

The Yellow Sea (31°40′–39°50′N, 119°20′–126°50′E) is a marginal sea in the Northwest Pacific Ocean (Fig. 1). It is located between mainland China and the Korean Peninsula. The Yellow Sea extends about 960 km from north to south and about 700 km from east to west, and has an area of about 380,000 km². The extensive coastline of the Yellow Sea and strong connections between the marine ecosystems and coastal societies were the primary reasons for its selection as a case study. It should be noted that the Yellow Sea in this study only covers the coastal areas of China. The coastal cities are Liaoning province, Shandong province and Jiangsu province.

2.2. Ecosystem services classification

The most widely used classification system for ecosystem services was developed through the Millennium Ecosystem Assessment and they identify four classes of ecosystem services based on the types of benefits they provide to society (Table 1) [23]:

![Fig. 1. Maps of the Yellow Sea.](image-url)

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2.3. Valuation methods

Valuation methods were supplied by the standard of the People's Republic of China [12] and the methods in reference.

2.3.1. Provisioning services assessment

2.3.1.1. Food production

Aquatic aquaculture

(1) Quantity assessment: We used the annual production of the main marine culture categories to create an evaluation index, including fish, shrimp and crabs, shellfish, macroalgae, and others.

(2) Value assessment:

\[ V_{SM} = \sum_{i=1}^{5} Q_{Mi} \times P_{Mi} \]  

\( V_{SM} \): the value of aquacultural production (RMB yuan/yr)

\( Q_{Mi} \): the amount of \( i \) marine culture category (t/yr), \( i \) marine culture category represents fish, shrimp and crabs, shellfish, macroalgae and others

\( P_{Mi} \): the average market price of each \( i \) marine culture category (RMB yuan/kg)

| Ecosystem services | Classes |
|--------------------|---------|
| Provisioning services | Food production (aquaculture and fisheries) |
|                     | Raw materials |
|                     | Genetic resources |
| Regulating services | Climate regulation |
|                     | Gas regulation |
|                     | Waste treatment |
|                     | Biological control |
|                     | Disturbance regulation |
| Cultural services   | Recreation and ecotourism |
|                     | Scientific research and education |
| Supporting services | Nutrient cycling |
|                     | Diversity maintenance |
|                     | Primary production |
|                     | Provision of habitat |

Table 1. Ecosystem services classes as described in the Millennium Ecosystem Assessment.
Fisheries capture

The calculation of fisheries capture was the same as aquatic marine culture calculation, except the categories. Fisheries capture categories included fish, shrimp and crabs, shellfish, macroalgae, cephalopoda, and others.

Data collection

The data used in the above calculation formula was quoted from the Chinese Fishery Statistics Yearbook. The average market price was provided by local wholesale market prices.

2.3.1.2. Raw materials

\[ V_{RM} = \sum_{i=1}^{3} Q_i \times P_i \]  

\( V_{RM} \): total value of seafood that humans obtain from marine ecosystems as raw materials

\( Q_i \): the amount of \( i \) seafood (t/yr), \( i \) seafood represents anchovy, seaweed, and laver

\( P_i \): the average market price of \( i \) seafood (RMB yuan/kg)

2.3.1.3. Genetic resources

Ecosystems provide genetic resources at the rate of $600–11200/km²/yr) [7] therefore, we used the median genetic value for our calculations. To calculate the service value of the genetic resources provided by the Yellow Sea marine ecosystems, the genetic value was multiplied by the area of the Yellow Sea and then multiplied by the unit area of the RMB exchange rate.

2.3.2. Regulating services assessment

2.3.2.1. Climate regulation

(1) Quantity assessment:

\[ Q_{RC} = Q_{PP} \times S \times 365 \times 10^{-3} + Q_{LAC} + Q_{SC} \]  

\( Q_{RC} \): quantity of climate regulation (t/yr)

\( Q_{PP} \): microalge primary productivity (mg·m⁻²·d⁻¹)

\( S \): area of assessment sea (km²)

\( Q_{LAC} \): fixed carbons from macroalgae (t/yr)
\( Q_{SC} \): fixed carbons from shellfish (t/yr)

\[
Q_{LAC} = 0.44 \times Q_{LA}
\]  

(4)

\( Q_{LAC} \): fixed carbons from macroalgae (t/yr)

\( Q_{LA} \): production of macroalgae (dry weight, t/yr)

\[
Q_{SC} = (Q_{MS} + Q_{NS} \times S \times 10\%) \times 0.06
\]  

(5)

\( Q_{SC} \): fixed carbons from shellfish (t/yr)

\( Q_{MS} \): production of aquacultural shellfish (t/yr)

\( Q_{NS} \): production of natural sea shellfish (g/m²)

\( S \): area of assessment (km²)

(2) Value assessment:

\[
V_{RC} = Q_{RC} \times P_C
\]  

(6)

\( V_{RC} \): value of climate regulation (RMB yuan/yr)

\( Q_{RC} \): quantity of climate regulation (t/yr)

\( P_C \): the price of the carbon trading market (RMB yuan/t) [27]

2.3.2.2. Gas regulation

(1) Quantity assessment:

\[
Q_{O_2} = Q_{pp} \times S \times 365 \times 10^{-3} \times 32/12 + Q_{LA} \times 0.44 \times 32/12
\]  

(7)

\( Q_{O_2} \): amount of oxygen produced by the marine ecosystem (t/yr)

\( Q_{pp} \): microalgea primary productivity (mg·m⁻²·d⁻¹)

\( S \): area of assessment (km²)

\( Q_{LA} \): production of macroalgae (dry weight, t/yr)

\[
Q_{CO_2} = Q_{pp} \times S \times 365 \times 10^{-3} \times 44/12 + Q_{LA} \times 0.44 \times 44/12
\]  

(8)

\( Q_{CO_2} \): amount of carbon dioxide produced by the marine ecosystem (t/yr)

\( Q_{pp} \): microalgea primary productivity (mg·m⁻²·d⁻¹)

\( S \): area of assessment (km²)

(2) Value assessment: The value of CO₂ absorption has already been calculated as part of the climate regulation services; therefore, only the value of O₂ release was considered in the gas regulation services.
\[ V_a = Q_{O_2} \times P_{O_2} \]  
(9)

\[ V_a: \text{value of gas regulation (RMB yuan/yr)} \]
\[ Q_{O_2}: \text{O}_2 \text{ release of the marine ecosystem (t/yr)} \]
\[ P_{O_2}: \text{industrial price of O}_2 \text{ (RMB yuan/t)} \]  
[39]

2.3.2.3. Waste treatment

(1) Quantity assessment:

\[ Q_{RWT} = \sum_{i=1}^{2} Q_{Wi} \]  
(10)

\[ Q_{RWT}: \text{quantity of pollution (t/yr)} \]
\[ Q_{Wi}: \text{the amount of i pollution category (t/yr), i present nitrogen and phosphorus (t/yr)} \]

(2) Value assessment:

\[ V_{RWT} = \sum_{i=1}^{2} Q_{Wi} \times P_{Wi} \]  
(11)

\[ V_{RWT}: \text{value of waste treatment (RMB yuan/yr)} \]
\[ Q_{Wi}: \text{the amount of i pollution category (t/a), i present nitrogen and phosphorus (t/yr)} \]
\[ P_{Wi}: \text{the price of i pollution category treatment (RMB yuan/t)} \]  
[44]

2.3.2.4. Biological control

This method was based on the fishery resources assessment [2].

\[ V_{BC} = Q_{PC} \times P_F \times 30\% \]  
(12)

\[ V_{BC}: \text{value of biological control (RMB yuan/yr)} \]
\[ Q_{PC}: \text{potential catch (t)} \]  
[42, 26, 19]
\[ P_F: \text{price of catch (RMB yuan/kg)} \]

2.3.2.5. Disturbance regulation

According to [2], the calculation of disturbance regulation in coastal waters is $88/hm^2/yr. We multiplied this value by the area of the Yellow Sea, then multiplied this by the RMB exchange rate, and then finally calculated the value of disturbance regulation of the Yellow Sea.
2.3.3. Cultural services assessment

2.3.3.1. Recreation and ecotourism

In this evaluation, we used tourism income along the Yellow Sea instead of the recreation and ecotourism services. The data was quoted from the Yellow Sea Coastal Provinces Statistical Yearbook.

2.3.3.2. Scientific research and education

Scientific research

\[ V_{SR} = (Q_{CP} + Q_{EP}) \times \eta_1 / \eta_2 \times P_{EC} \]  

\( Q_{CP} \): pages of research papers in Chinese (page)

\( Q_{EP} \): pages of research papers in English (page)

\( \eta_1 \): solar transformity of the research paper (sej/page) [25]

\( \eta_2 \): ratio of energy to GDP (sej/$) [21]

\( P_{EC} \): exchange rate of dollar-RMB yuan

Education

\[ V_{ED} = \sum_i Q_{PEi} \times \eta_{1i} / \eta_2 \times P_{EC} \]  

\( V_{ED} \): value of education service (RMB yuan/yr)

\( Q_{PEi} \): the number of \( i \) education level, \( i \) present graduate students, college students, secondary vocational education students, and researchers (person)

\( \eta_{1i} \): Energy transformity of \( i \) education level (sej/person/yr) [21]

\( \eta_2 \): ratio of energy to GDP (sej/$) [21]

\( P_{EC} \): exchange rate of dollar-RMB yuan

2.3.4. Supporting services assessment

2.3.4.1. Nutrient cycling

(1) Quantity assessment:

\[ Q_N = Q_{PP} \times S \times 6.43\% \]  

\( Q_P = Q_{PP} \times S \times 0.89\% \)  

\( Q_N \): nitrogen absorption of microalgae (t/yr)
$Q_P$: phosphorus absorption of microalgae (t/yr)

$Q_{PP}$: microalga primary productivity (mg·m$^{-2}$·d$^{-1}$)

$S$: area of assessment (km$^2$)

$Q_{LAN} = Q_{LA} \times 4.818\%$  \hspace{1cm} (17)

$Q_{LAP} = Q_{LA} \times 0.322\%$  \hspace{1cm} (18)

$Q_{LAN}$: nitrogen absorption of macroalgae (t/yr)

$Q_{LAP}$: phosphorus absorption of macroalgae (t/yr)

$Q_{LA}$: production of macroalgae (dry weight, t/yr)

(2) Value assessment: We used the economic method to evaluate the nutrient cycling services. The calculation formula of carbon cycling service refers to formula 6. The calculation formula of nitrogen and phosphorus services refers to formula 11.

2.3.4.2. Biodiversity maintenance

\[ V_{DM} = \sum_{i}^{9} Q_{WTP} \]  \hspace{1cm} (19)

$V_{DM}$: value of biodiversity maintenance (RMB yuan/yr)

$Q_{WTP}$: the average willingness of $i$ city residents to pay for maintenance of rare and endangered species, $i$ represents Dandong, Dalian, Yantai, Weihai, Qingdao, Rizhao, Lianyungang, Yancheng and Nantong

\[ Q_{WTP} = \left( \beta \times Q_{IN} \times Q_{FN} - 278.70 \right) / Q_{FN} \times Q_{PN} \]  \hspace{1cm} (20)

$Q_{WTP}$: the average willingness of residents to pay for maintenance of rare and endangered species (RMB yuan)

$\beta$: the correlation index between average willingness to pay and average household income [37]

$Q_{IN}$: average per capita income (RMB yuan/person)

$Q_{FN}$: average family population (person/family)

$Q_{PN}$: total population of city (person)

2.3.4.3. Primary production

\[ V_{PP} = Q_{PP} \times E \times \sigma \times P_{M} \times \rho \times S / \delta \]  \hspace{1cm} (21)

$V_{PP}$: value of primary production (RMB yuan)
Q_{PP}: microalga primary productivity (mg·m$^{-2}$·d$^{-1}$)

E: transformation efficiency of primary productivity to mollusks [33]

$\sigma$: the ratio of shellfish weight to mollusk weight [22]

$P_M$: average price of shellfish (RMB yuan/kg)

$\rho$: profit ratio of shellfish sales [41]

S: area of assessment (km$^2$)

$\delta$: hybrid carbon content of shellfish [22]

### 2.3.4.4. Provision of habitat

\[ V_{PH} = V'_{PH} \times S \]  

(22)

$V_{PH}$: value of provisioning of habitat (RMB yuan/yr)

$V'_{PH}$: value of provisioning of habitat per unit area (RMB yuan/km$^2$/yr) [2]

S: area of assessment (km$^2$)

### 3. Results

#### 3.1. The value of four classes from 1980 to 2010

The amount and value of 14 ecosystem services of the Yellow Sea were calculated for the period from 1980 to 2010. The results are based on 2010 for the final conversion.

#### 3.1.1. Provisioning services: food production

From 1980 to 2013, marine culture production of fish, shrimp and crab, shellfish, macroalgae in the Yellow Sea showed a continuous increasing tendency (Fig. 2). Shellfish marine culture yield was the highest, followed by macroalgae. Shrimp and crab marine culture production appeared to peak in 1990, and then recovered in 2005. Marine culture production of fish and others was relatively low before 2000, and then began a significant increase in 2000; however, marine culture production of fish, shrimp, and crabs, others was still significantly lower than that of shellfish and macroalgae.

Results (Fig. 3) shows that the fisheries catch production of shrimp and crabs, shellfish and fish present an inverted U type, peaking around 2000, while the production of cephalopoda and others rose slightly after 2000. The yield of fish farming was highest, followed by shrimp and crabs, shellfish, cephalopoda and
others, while macroalgae was the lowest. Fishing production appeared to peak around 2000, and afterwards displayed a declining trend.

From 1980 to 2010, both the production and the value of marine culture of the Yellow Sea ecosystem showed an increasing trend (Figs. 2 and 4). Total production rose from 0.29 million tonnes in 1980 to 7.06 million tonnes in 2010, while the value rose from 2.4 billion RMB yuan to 129.8 billion RMB yuan over the same time period. Beginning about 1990, the value of shellfish marine culture production was greatest, followed by macroalgae, fish, shrimp and crabs, and others. Other types of marine culture production value showed a significant increasing trend after 2000. By 2010, production value of others had increased to 52.8 billion RMB yuan, trailing only shellfish at 53.7 billion RMB yuan (Fig. 4).
Meanwhile, the production and value of fisheries catch of the Yellow Sea ecosystem displayed a downward trend after an initial increase (Figs. 3 and 5). The total catch was only 0.9 million tonnes in 1980, but it soared to 5.3 million tonnes in 2000, and then declined to 3.9 million tonnes in 2010. There was also a peak of catch value in 2000, about 222.5 billion RMB yuan, which then dropped to 174.7 billion RMB yuan in 2010. The value of fisheries catch was the highest, followed by shrimp and crabs, shellfish, others and cephalopoda. Meanwhile, the catch production and value of macroalgae was the lowest.

3.1.2. Provisioning services: raw materials

Since 1995, the fishing yield of anchovy increased significantly, reaching the largest catch of 0.9 million tonnes in 2000, but then showing a decreasing trend after 2000 (Fig. 6). By the end of 2010, the catch of anchovy fell to 0.4 million tonnes. In contrast, the quantity of laver showed a trend of greater volatility,
while seaweed quantity showed little change. The change of total value of raw material supply was closely related to the output of anchovy, which showed a significant downward trend after an initial increase.

3.1.3. Provisioning services: genetic resources

The value of the genetic resources supply in the Yellow Sea ecosystem rose from 9.6 billion RMB yuan in 1980 to 31.4 billion RMB yuan in 1995, and then fell to 14.8 billion RMB yuan in 2010. The trend for genetic resources supply was an inverted U shape.

3.1.4. Regulating services: climate regulation

Table 2 shows the primary productivity of the Yellow Sea. Based on microalgae primary productivity, macroalgae production, production of aquacultural shellfish and natural sea shellfish, we calculated that the regulating service of the Yellow Sea was 5.7, 6.8, 8.5, and 13.9 billion RMB yuan in 1984–1985, 1998–2000, 2006, and 2010 respectively.

3.1.5. Regulating services: gas regulation

The results of carbon dioxide fixation and oxygen release in the Yellow Sea are shown in Fig. 7. The amount of fixed carbon dioxide rose from

Table 2. Seasonal assessment for primary production (mg C m$^{-2}$ d$^{-1}$) in the Yellow Sea (simulated and observed).

| Time       | Spring | Summer | Autumn | Winter | Annual | Reference |
|------------|--------|--------|--------|--------|--------|-----------|
| 1984-1985  | 623    | 596    | 369    | 111    | 425    | [47]      |
| 1998-2000  | 583    | 604    | 429    | 344    | 502    | [19]      |
| 2006       | 529    | 737    | 586    | 521    | 593    | [11]      |
| 2010       | 973    | 1250   | 909    | 983    | 1029   | [43]      |
0.22 billion tonnes during 1984–1985 to 0.53 billion tonnes in 2010, while the amount of oxygen released rose from 0.16 billion tonnes to 0.38 billion tonnes. Its value also rose from 77.4 billion RMB yuan to 187.6 billion RMB yuan.

3.1.6. Regulating services: waste treatment

Waste treatment results showed that the total removal of nitrogen by the Yellow Sea rose from 10 million tonnes during 1984–1985 to 25 million tonnes in 2010, while the removal of phosphorus rose from 1 million tonnes to 3 million tonnes. The value of nitrogen and phosphorus removal also increased during this period (data not shown).

3.1.7. Regulating services: biological control

The results of [26], who used the primary productivity method, and [19], who used acoustic method, showed that the potential overall catch of the Yellow Sea was 0.83 million tonnes. According to these results, we calculated the biological control value of the Yellow Sea ecosystem at 3.51 billion RMB yuan (base year 2010).

3.1.8. Regulating services: disturbance regulation

[2] demonstrated that the disturbance regulation value of coastal waters was about $8,800/km²/yr). Based on this result, we estimated the disturbance regulation value of the Yellow Sea ecosystem to be about 36.6 billion RMB yuan/yr (base year 2010).

3.1.9. Cultural services: recreation and ecotourism

The tourism income of Liaoning, Shandong, and Jiangsu province along the Yellow Sea coast increased significantly. The income of these three provinces
reached 110.3, 176.4, and 73.9 billion RMB yuan in 2012. The tourism income of Shandong province was the highest (data not shown).

3.1.10. Cultural services: scientific research

The number of papers published in Chinese and English associated with the Yellow Sea showed a rising trend after 2000, which converted into monetary value was also increased significantly (data not shown). The value of articles rose from 4 million RMB yuan in 2000 to 25 million RMB yuan in 2010. The education services value clearly increased from 4.6 billion RMB yuan in 1980 to 45.1 billion RMB yuan in 2010 (data not shown). Scientific researchers provided the highest value, followed by college students, graduate students, and secondary vocational education students.

3.1.11. Supporting services: nutrient cycling

At the end of 2010, the cycle of carbon, nitrogen, and phosphorus nutrition elements of the Yellow Sea ecosystem reached 140 million tonnes, 30 million tonnes, and 3.48 million tonnes (Fig. 8). The total value of nutrient cycling of the Yellow Sea ecosystem amounted to 91.7 billion RMB yuan, which was more than three times the value during 1984–1985.

3.1.12. Supporting services: biodiversity maintenance

The biodiversity maintenance value of the three provinces along the Yellow Sea coast began to rise annually starting in 2001. As of 2010, the biodiversity maintenance value reached 6.7 billion RMB yuan, of which Shandong province was the highest, followed by Jiangsu province and Liaoning province (Fig. 9).

Fig. 8. Amount (left ordinate) and value (right ordinate) of nutrient cycling of the Yellow Sea ecosystem.
3.1.13. Supporting services: primary production

The primary production value of Yellow Sea ecosystem was about 879.7 billion RMB yuan in 1984–1985, and this rose to 2.13 trillion RMB yuan by 2010.

3.1.14. Supporting services: provision of habitat

[2] indicated that the value of marine provisioning of habitat was about $8/hm²/yr). We used this result to gain the provisioning of habitat value of the Yellow Sea at about 3.23 billion RMB yuan (base year 2010).

3.2. Temporal variation in ecosystem services

From 1980 to 2010, the marine ecosystem value of the Yellow Sea showed a rising trend (Fig. 10 and Table 3). The supply of provisioning services, regulating services, cultural services, and supporting services changed over time. Of the four services, only the proportion of cultural services as a percentage of the total value continued to rise, from 0.9% in 1980 to 9.4% in 2010. The
The percentage of provisioning services reached its highest point at 18.4% in 2000; it then fell to 10.1% in 2010. The percentage of supporting services fell from 79.4% in 1980 to 65.5% in 2006 and recovered slightly in 2010. Meanwhile, the percentage of regulating services continued to decline, falling from 14.4% in 1980 to 10.1% in 2010 (Fig. 10).

### 4. Discussion

Using a large collection of data, this study attempted to describe the temporal changes in the coastal ecosystem services of the Yellow Sea ecosystem. The value of the four service classes (supporting services, provisioning services, cultural services and regulating services), including the 14 individual services, was analyzed on temporal scales, from 1980 to 2010.

Although assessments of ecosystem services are currently the focus of intense policy interest [35, 10], there is often a lack of empirical information about marine ecosystem services and how they change over time. In consideration of the importance of the temporal changes, researchers have increasingly focused on the changes of ecosystem services over time. [24] examined the effects of spatial and temporal scales on cultural services valuation in Spain, and attempted to demonstrate that the value of cultural services should be analyzed on multiple spatial and temporal scales [13] also analyzed ecosystem service changes for the periods 1990–2000, 2000–2006, and 2000–2030, and tried to map marginal changes and trade-offs at European scales.

Some have argued that the supporting services, including primary production, nutrient cycling, biodiversity maintenance, as well as habitat provisioning, should really be considered the basis of the other three services and deserved special conservation consideration [23]. In this study, we found that supporting services...
accounted for 80% of the total value in 1980, but that percentage fell to 65% in 2006, and then rebounded slightly in 2010 (Table 3). [3] found that supporting services account for about 72% of the total value at the global scale. Among these services, biodiversity service is a very important part, and it can be highly susceptible to human activities [15]. [40] found positive relationships between biodiversity and ecosystem functions. Their findings further suggested that the elimination of locally-adapted populations and species not only impairs the ability of marine ecosystems to feed a growing human population but also disrupts their stability and recovery potential in a rapidly changing marine environment. [30] attempted to investigate the relationship between biodiversity and the stability properties of estuarine systems. They found that temporal stability increased with species abundance, and temporal stability of maximum values was achieved at an intermediate biodiversity range. Although the value has been rising from 2001, the proportion of biodiversity maintenance as a percentage of the total value was very low (Fig. 9). Moreover, research increasingly suggests that the biodiversity maintenance value of the Yellow Sea is now impacted by habitat, species and human activities [46, 17]. Pollution could result in the reduction or lost of some key habitat (spawning ground or feeding grounds) ecological function. Sea reclamation causing by over-fishing and over-exploited tourism is another important factor which affects the biodiversity maintenance. For example, Jiaozhou Bay of the Yellow Sea has 141.8 km coastline, but the natural coastline was only 12 percent in 2006. More than 90 percent of coastline of Haizhou Bay has been beused for sea farming [36].

Provisioning services are closely related with the needs of human society. Reduced marine fisheries catch is placing increased pressure on food resources in much of the world, especially with more demand for seafood as populations increase. [8] suggested that declines in the provisioning of services will initially be slow but will then accelerate as species from higher trophic levels are lost at faster rates. Ecologists predicted that decreases in biodiversity will lead to reductions in ecosystem functioning and hence in the provisioning of services [5, 6, 1]. So, provisioning services are closely related to human survival, which is also associated with supporting services at a deeper level. In this study, we found that the provisioning services value has been rising steadily from 1980 to 2010, however, the structure of food production was changed, and the raw materials from the Yellow Sea have been diminishing (Figs. 3 and 6). Fisheries catch markets had been showing weakness, and the production declined significantly from 2000. Now, the increases in food production come mostly from aquaculture production. However, large-scale aquaculture activities will bring great pressure on the Yellow Sea ecosystem inevitably [18, 4]. Now, how to restore the provisioning services of the Yellow Sea is a problem that must be solved imminently. In the last few years, people in China tried to use artificial
fishing reef and structure marine pasture to solve this problem, and achieved some results.

Cultural services are another service of the Yellow Sea ecosystem that is highly susceptible to impacts from human activities. The value of this service had increased about 40 times from 1980 to 2010 (Table 3). [24] demonstrated the important role of heterogeneity among stakeholders in relation to ecosystem services valuation, and the crucial function played by cultural services as a tool for nature conservation [28]. demonstrated that recreational amenities are likely to decrease as primary production and nutrient loads increase and nuisance microalgal and macroalgal blooms increase. However, recreational amenities should maintain stability until the point where nutrients reach the threshold. Therefore, even though the cultural services of the Yellow Sea ecosystem are on the rise, vigilance is still required. Meanwhile, we still need to pay attention to the stress caused by over-exploited tourism on the coastline.

According to these analyses, some measures were proposed in this study. Marine culture layout of the Yellow Sea should be planned, and the culture environment and organisms monitoring should also be established. Meanwhile, administrative departments should reduce the amount of inshore fishing boats, accelerate the construction of artificial fishing reef and marine pasture, encourage the behavior of enhancement and releasing. In addition, government departments should be responsible for supervising the enterprises to reduce exhaust pollution, and strengthen the sea reclamation management.

The provisioning of goods and services from marine ecosystems is a strong economic justification for the conservation of marine ecosystems. Understanding the relationship between these goods and services and temporal evolutionary characteristics is a fundamental challenge of natural resource management.

5. Conclusion

This study represents the first attempt to analyze the temporal evolution of the Yellow Sea ecosystem services, which is one of the most intensely exploited shallow seas in the Northwest Pacific Ocean. The total value and the percentage composition structure of the Yellow Sea ecosystem services changed dramatically in last 30 years. Although the total value had been rising, key ecosystem services (including provisioning services, regulating services and supporting service) percentage had continued to drop, except cultural services. This result is enough to arouse our attention. We expect this study will provide the theoretical basis for further study of the ecological mechanisms of marine ecosystem services.
Declarations

Author contribution statement

Qixiang Wang, Jian Zhou, Wenxi Zhao, Hongjun Liu, Xuexi Tang: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Jingjing Song: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

Data used in this study is available at the National Bureau of Statistics of the People’s Republic of China.

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References

[1] F.S. Chapin, E.S. Zavaletta, V.T. Eviner, R.L. Naylor, P.M. Vitousek, H.L. Reynolds, D.U. Hooper, S. Lavorel, O.E. Sala, S.E. Hobbie, et al., Consequences of changing biodiversity, Nature 405 (2000) 234–242.

[2] R. Costanza, R. d’Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O’Neill, J. Paruelo, et al., The value of the world’s ecosystem services and natural capital, Ecol. Econ. 25 (1997) 3–15.

[3] R. Costanza, R. dArge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O’Neill, J. Paruelo, et al., The value of ecosystem services: putting the issues in perspective, Ecol. Econ. 25 (1998) 67–72.
[4] Y. Cui, B.J. Chen, J.F. Chen, Evaluation on self-pollution of marine culture in the Yellow Sea and Bohai Sea, Chinese J. Appl. Ecol. 16 (2005) 180–185.

[5] G.C. Daily, Nature's services: Societal dependence on natural ecosystems, Island Press, Washington DC, 1997.

[6] G.C. Daily, T. Söderqvist, S. Aniyar, K. Arrow, P. Dasgupta, P.R. Ehrlich, C. Folke, A.M. Jansson, B.O. Jansson, N. Kautsky, et al., The value of nature and the nature of value, Science 289 (2000) 395–396.

[7] R.S. de Groot, M.A. Wilson, R.M.J. Boumans, A typology for the classification, description and valuation of ecosystem functions, goods and services, Ecol. Econ. 41 (2002) 393–408.

[8] A. Dobson, D. Lodge, J. Alder, G.S. Cumming, J. Keymer, J. Mcglade, H. Mooney, J.A. Rusak, O. Sala, V. Wolters, et al., Habitat loss trophic collapse, and the decline of ecosystem services, Ecology 87 (2006) 1915–1924.

[9] J. Duffy, Marine ecosystem services, (2006) Retrieved from http://www.eoearth.org/view/article/154472.

[10] European Commission, Our life insurance, our natural capital: an EU biodiversity strategy to 2020, Communication from the Commission to the European Parliament, the Council, the Economic and Social Committee and the Committee of the Regions. Document COM (2011) 244 final, (2011), pp. 16 issued May 3, 2011.

[11] M.Z. Fu, Z.L. Wang, P. Sun, Y. Li, R.X. Li, Size structure and potential export of phytoplankton primary production in the southern Huanghai (Yellow) Sea, Acta Oceanologica Sinica 31 (2009) 100–109.

[12] GB/T 28058-2011, Technical directives for marine ecological capital assessment, General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China, 2011.

[13] R. Haines-Young, M. Potschin, F. Kienast, Indicators of ecosystem service potential at European scales: Mapping marginal changes and trade-offs, Ecol. Indic. 21 (2012) 39.

[14] L. Hein, K. van Koppen, R.S. de Groot, E.C. van Ierland, Spatial scales, stakeholders and the valuation of ecosystem services, Ecol. Econ. 57 (2006) 209–228.

[15] I.E. Hendriks, C.M. Duarte, C.H.R. Heip, Biodiversity research still grounded, Science 312 (2006) 1715.

[16] C.M. Holmlund, M. Hammer, Ecosystem services generated by fish populations, Ecol. Econ. 29 (1999) 253–268.
[17] Z.G. Huang, Species and distribution of marine organisms in China, China Ocean Press, 2008.

[18] X.L. Ji, X.T. Lin, Z.N. Xu, Y.T. Lin, Mechanism of mariculture self-pollution and its effects on environment, Mar. Environ. Sci. 19 (2000) 66–71.

[19] X.S. Jin, X.Y. Zhao, T.X. Meng, The Yellow Sea and Bohai Sea Biological Resources and Habitats, Science Press, Beijing, 2005.

[20] E.W. Koch, E.B. Barbier, B.R. Silliman, D.J. Reed, G.M. Perillo, S.D. Hacker, E.F. Granek, J.H. Primavera, N. Muthiga, S. Polasky, et al., Non-linearity in ecosystem services temporal and spatial variability in coastal protection, Ecosyst. Serv. 7 (2009) 29–37.

[21] S.F. Lan, P. Qin, Emergy analysis of ecosystems, Chinese J. Appl. Ecol. 12 (2001) 129–131.

[22] Z.B. Lu, Q. Du, Y.M. Yan, An estimate of optimal culture areas and output of shellfish in Xiamen coastal waters, J. Oceanogr. in Taiwan Strait 18 (1999) 199–204.

[23] MA (Millennium Ecosystem Assessment), Ecosystems and human well-being: the assessment series (four volumes and summary), Island Press, Washington DC, 2005.

[24] B. Martín-López, E. Gómez-Baggethun, P.L. Lomas, C. Montes, Effects of spatial and temporal scales on cultural services valuation, J. Environ. Manage. 90 (2009) 1050–1059.

[25] F. Meillaud, J.B. Gay, M.T. Brown, Evaluation of a building using the emergy method, Sol. Energy 79 (2005) 204–212.

[26] X.R. Ning, Z.L. Liu, J.X. Shi, Evaluation of primary productivity and potential fishery production of Bohai Sea: Yellow sea and East China Sea, Acta Oceanol. Sinica 17 (1995) 72–84.

[27] W.D. Nordhaus, J.G. Boyer, Warming the world: economic models of global warming, MIT Press, Cambridge, Mass, 2000.

[28] T.G. O’Higgins, A.J. Gilbert, Embedding ecosystem services into the Marine Strategy Framework Directive: Illustrated by eutrophication in the North Sea, Estuar. Coast. Shelf Sci. 140 (2014) 146–152.

[29] C.H. Peterson, J. Lubchenco, On the value of marine ecosystem services to society. Nature’s Services: Societal Dependence on Natural Ecosystems (eds G Daily), Island Press, Washington DC, 1997, pp. 177–194.
[30] R. Pinto, V.N. de Jonge, J.C. Marques, P. Chainho, J.P. Medeiros, J. Patrício, Temporal stability in estuarine systems: Implications for ecosystem services provision, Ecol. Indic. 24 (2013) 246–253.

[31] Q. Sui, The value assessment of wetland ecosystem service in Shandong Province, Master dissertation of Shandong Normal University, 2014.

[32] X.B. Sun, H.Y. Liu, Research progress of coastal wetland in Jiangsu province, Mar. Environ. Sci. 30 (2011) 599–602.

[33] R.V. Tait, Elements of marine ecology: an introductory course, 3rd edn, Butterworths, London, 1981.

[34] H. Tallis, A. Guerry, G.C. Daily, Chapter 6 - Ecosystem Services, Encyclopedia of Sustainability Science and Technology (eds Robert A Meyers), Springer, New York, 2012, pp. 81–100.

[35] P. ten Brink, A. Berghöfer, C. Schröter-Schlaack, P. Sukhdev, A. Vakrou, S. White, H. Wittmer, TEEB-The Economics of Ecosystems and Biodiversity for National and International Policy Makers-Summary, (2009).

[36] UNDP/GEF, The Yellow Sea: analysis of environmental status and trends, Volume 2, Part 1: National Report – China, UNDP/GEF Yellow Sea Project, Ansan, Republic of Korea, 2007.

[37] D. Wang, Study on economic value of marine biodiversity preservation, Doctoral dissertation of Ocean University of China, 2012.

[38] Q.X. Wang, X.X. Tang, Connotation and classification of marine ecosystem services, Mar. Environ. Sci. 29 (2010) 131–138.

[39] R.S. Wang, S.K. Lin, Z.Y. Ou Yang, The theory and practice of ecological province construction in Hainan, Chemical Industry Press, Beijing, 2004.

[40] B. Worm, E.B. Barbier, N. Beaumont, J.E. Duffy, C. Folke, B.S. Halpern, J.B.C. Jackson, H.K. Lotze, F. Micheli, S.R. Palumbi, et al., Impacts of Biodiversity Loss on Ocean Ecosystem Services, Science 314 (2006) 787–790.

[41] S.S. Wu, R.Z. Liu, L.M. Qi, X.B. Liang, Value assessment of marine ecosystem service in Bohai Sea, China population, Resour. Environ. 18 (2008) 65–69.

[42] J.M. Yang, Marine fishery resources and development potential, Ocean Dev. Manage. 4 (1985) 40–46.

[43] X.G. Yang, Chlorophyll and primary productivity estimation based on remote sensing in Yellow Sea, Doctoral dissertation of institute of oceanology Chinese academy of sciences, 2013.
[44] Y.M. Zhao, Z.S. Song, The scientific research of Yellow River delta nature reserve set, China Forestry Press, Beijing, 1995.

[45] Y. Zheng, D. Feng, Y.L. Wen, Wetland conservation status: analysis of problems and counterm easures in Liaoning Province, Wetland Sci. 8 (2010) 204–208.

[46] Q.L. Zhou, S.Y. Yang, B.H. Chen, Studies on marine biodiversity in China, Sci. Technol. Rev. 23 (2005) 12–16.

[47] M.Y. Zhu, X.H. Mao, R.H. Lv, M.H. Sun, Chlorophyll a and primary productivity in the Yellow Sea, J. Oceanogr. of Huanghai and Bohai Seas 11 (1993) 38–51.