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# The Impact of Land Use and Biological Invasions on Ecological Service Values of Coastal Wetland Ecosystems: A Case Study in Jiangsu Province, China

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**Abstract:** Land use/land cover changes (LULCCs) and biological invasions significantly impact coastal wetlands (CWs) and their ecosystem services and functions. The exact impacts, however, are difficult to quantify and are often neglected in policymaking. The evaluation of ecological service value (ESV) is conducive to clarifying the ecological and environmental changes caused by LULCCs and biological invasions. The objective of this study was to investigate their impact on CWs in Jiangsu Province, China, and provide useful information and advice for policymakers concerned with sustainable development. In this paper, basic data were obtained through geographic information system technology, and CW ecosystems' services were calculated via the ESV coefficients per unit area of different wetland types. Accordingly, this study found the current land use methods responsible for significant ecosystem disruption and reductions in the area of natural vegetation. Currently, the area of natural vegetation only accounts for 43% of the total area recorded in 1987. In 2018, the total ESV of wetland vegetation (*Spartina*, *Phragmites*, and *Suaeda*) was estimated to be USD 14.10 million, while that of farmland was USD 8.58 million, and that of forests was USD 2.09 million. Natural vegetation only covered 9% of the total land area but produced 60% of the total ESV. *Spartina alterniflora* exhibited the highest ESV per unit area, with USD 1.35 million. However, the CWs of Jiangsu Province have recently shown a shift in vegetation composition due to the invasion of *Spartina alterniflora*. Currently, the dominant species in these CWs are *Spartina alterniflora* and *Phragmites australis*, while the local population of *Suaeda salsa* has significantly declined. Therefore, it is necessary to strengthen the preservation and restoration of wetland vegetation, control the invasive potential of *Spartina alterniflora*, and consider the implementation of suitable protective measures for native plants.

**Keywords:** land use; biological invasions; ecological service value; coastal wetlands

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## 1. Introduction

Coastal wetlands (CWs) serve as a gateway between the marine and terrestrial ecosystems [1,2]. Their significance lies in their ability to safeguard coasts, relieve coastal erosion and sea level rise, provide food and contribute to the global economy. The CWs exhibit substantial productivity and ecological service values (ESVs) [3–5]. The rapid growth of the economy and society has resulted in significant pressures on both population and land resources. Consequently, numerous CWs have been transformed to yield various land uses, such as farmland, aquaculture ponds, harbors, and construction sites. While these transformations have the potential to generate substantial social and economic advantages, they have also led to the depletion and deterioration of a considerable number of

CWs [6,7]. The land conversions resulted in a significant decline of 53% (from 6463 $km^2$ to 3036 $km^2$) in CWs in the Yellow Sea area of China between 1984 and 2015, among which there was a 67% decrease in salt marshes and a 49% decrease in beach areas. Furthermore, the rate of land reclamation surpassed the rate of growth of CWs during this period [8]. Currently, CWs are affected by both land uses and alien species. Among these, *Spartina alterniflora* has been identified as having the most pronounced impact; this species started to spread into China during the 1970s, and its geographical range underwent a significant expansion in subsequent decades, recently spreading from Liaoning to Guangxi [9]. Nearly 94% of *Spartina alterniflora* are distributed in the CWs of Jiangsu, Shanghai, Zhejiang, and Fujian provinces, causing serious impacts on local soil geomorphology, biological taxa, and ecosystem functions [10].

Ecosystem services refer to the roles of ecosystems and ecological processes, which can provide biological resources, natural environmental conditions and benefits for human survival [11,12]. ESV assessments measure the ecological benefits of ecosystems in the region during a given period, which can help us to quantitatively and intuitively understand the region's ecological management measures, and then propose measures to improve the ecological environment [13]. As a basic human practice, LULCCs change ecosystem services, altering the structure, processes and functions of ecosystems, and thus affect the ecosystem's service values [14]. Currently, the main method of assessing ecosystem service values based on land uses is the equivalent value method, which is based on the value per unit area, and was proposed by Costanza and Xie et al. [15,16]. It is simple, and is intuitive and easy to use, with a small amount of data, which makes it suitable for assessing the value of ecosystem services at a large scale [17]. Evaluations of the value of ecosystem services based on land use data have been widely undertaken, especially in the context of exploring their correlations [17]. Some studies have shown that a reasonable land use layout can effectively improve the value of regional ecosystem services and protect the ecological environment [18]. For example, Cao et al. [19] took the New York Bay Area as their research object, assessed the ecosystem service value of the region from 1996 to 2015, and explored the influence of land use landscape patterns on its changes in each research stage [20], finding that the changes in land use structure caused the degradation of the ecosystem's service function. Han et al. [21] explored the temporal and spatial coupling relationship between land use intensity and ecosystem service value in the northern area of Liaodong Bay. However, there are few studies on the effects of LULCCs and biological invasion on CWs' ecosystems and their ESVs.

In this study, we chose the highly representative CWs of Jiangsu Province as the study area, and used remote sensing (RS) and geographic information system (GIS) technology to determine the areas of the CWs and their multiple land use types. We then combined this with ESV calculation to analyze the changes in ESVs occurring due to ecosystem changes, in order to explore the variations in ecosystems and their values as related to local land uses and alien species, and to provide methods for the utilization and protection of China's CWs.

## 2. Materials and Methods

*The Study Area*

Jiangsu Province has the largest proportion of total beachfront area in China [22]. The CWs of Jiangsu Province are located in the central part of China's coast, mainly in the cities of Lianyungang, Yancheng, and Nantong (Figure 1). The ecosystem structure of Jiangsu's CWs is divided into natural ecosystems (natural coastal wetlands) and artificial ecosystems (artificial coastal wetlands). The natural ecosystem consists of mudflats and vegetated beaches. The artificial area is divided into farmland, forest land, aquaculture ponds, salt fields, and building land. Water conservancy projects, land enclosure, and the introduction of exotic species have changed the structure and function of Jiangsu's coastal wetland ecosystems.

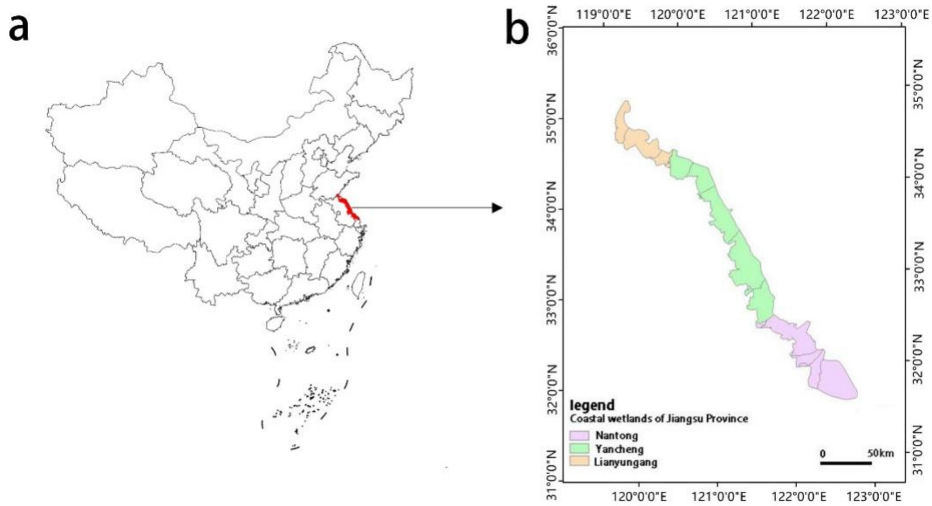


**Figure 1.** Study area. (**a**) The coastal wetlands of Jiangsu Province in China. (**b**) The coastal wetlands in Lianyungang, Yancheng, and Nantong.

The climate is of the typical continental monsoon type. The mean annual temperature is 13.8 °C. The frost-free period is 210–224 days. Mean annual evaporation 1923.8 mm. Mean annual rainfall is 700 mm. Intrazonal tidal soil and salt soil are the main soil types. The dominant plant species are *Phragmites australis*, *Spartina alterniflora*, and *Suaeda salsa* [23].

## 3. Methods

### *3.1. Classification of Coastal Wetlands Ecosystems in Jiangsu Province*

Wetland ecosystems can be classified into artificial wetland, salt marshes, *Phragmites*, *Suaeda*, and *Spartina*, and mudflats [24]. The wetlands and their multiple land use types in the study area were determined using RS and GIS technology, including remote sensing image selection, pre-processing, and interpretation.

### *3.2. Analysis of Landscape Fragmentation in Jiangsu CWs Ecosystem*

The landscape fragmentation index and the average patch area were chosen as the benchmark reference indexes to establish landscape fragmentation and integrity evaluation indexes, respectively. Landscape fragmentation is a phenomenon by which the original continuity of an ecological landscape is divided into multiple isolated and discontinuous patches due to the influence of natural or anthropogenic factors [25,26]. Habitat fragmentation is an essential feature of an existing landscape, and is closely associated with nature conservation [27]. Many endangered species require large areas of natural habitat to ensure their survival [28–30].

The landscape fragmentation index (S) was used to describe the degree of landscape fragmentation [31]; it was calculated using the software Fragstats 4.0, and can be described with Equation (1):

$$S = \left[1 - \sum_{i=1}^{m} \sum_{j=1}^{n} \left(a_{ij}/A\right)^2\right] \quad (1)$$

where $a_{ij}$ is the area of patch ij; A is the total area of the landscape ($m^2$). S is between 0 and 1. The smaller the S is, the lower the fragmentation of the patch is, meaning much greater completeness.

The average patch area was used to describe the landscape granularity, and to reveal, to an extent, the degree of landscape fragmentation. With the continuous fragmentation of the landscape, the average patch area decreased rapidly, as is described in Equation (2).

$$C_i = A_i/N_i \quad (2)$$

where $C_i$ is the average patch area of landscape type i, $A_i$ is the total area of landscape type i, and $N_i$ is the number of patches of landscape type i.

### *3.3. Assessment of Ecological Services Value of CWs Ecosystems in Jiangsu Province*

#### 3.3.1. Classification of CWs Ecosystems in the Coastal Zone of Jiangsu Province

In view of the specific characteristics of the ecosystem service functions of Jiangsu's CWs, the ecosystem service function classification system applied here was established with reference to the Global Ecosystem Service Classification proposed by Costanza [15] and the Millennium Ecosystem Assessment (MA). The ecosystem service functions of Jiangsu Province's CWs consisted of provisioning, regulating, supporting, and cultural services. The provisioning services refer to products derived from plants and animals. The regulating services include gas regulation, pollutant purification, and coastal protection. The supporting services refer to the ability of CWs ecosystems to maintain biodiversity. The cultural services are mainly related to recreational, scientific, and educational functions.

#### 3.3.2. Calculation of the Services Value of the CWs Ecosystem in Jiangsu Province

In this study, the ESVs of different CWs types were calculated using Equation (3).

$$V_i = P_i \times A_i \times (1 - S) \quad (3)$$

where $V_i$ is the value of ecological assets (million USD/a); $P_i$ is the coefficient of ESV per unit area of each land use type (million USD/(hm$^2$·a)) (Table 1); $A_i$ is the area of different land use types in the study area (hm$^2$); and S is the landscape fragmentation index.

**Table 1.** ESV coefficients per unit area of different wetland types (USD/km$^2$). Jiangsu Offshore Marine Comprehensive Survey and Evaluation General Report [16].

| Ecosystem Service Functions | *Phragmites* | *Spartina* | *Suaeda* | Farmland | Forest |
|---|---|---|---|---|---|
| Productivity function | 68,194 | 8858 | 18,390 | 21,113 | 77,849 |
| Gas regulation function | 248,474 | 447,092 | 15,550 | 74,971 | 749,272 |
| Pollutant purification function | 491,349 | 539,426 | 57,044 | 0 | 0 |
| Coastal protection function | 0 | 321,748 | 64,349 | 0 | 0 |
| Species diversity conservation function | 37,540 | 18,770 | 18,770 | 0 | 37,540 |
| Tourism, science, and education function | 29,760 | 22,320 | 22,320 | 0 | 29,760 |
| Total | 875,317 | 1,358,214 | 196,423 | 96,084 | 894,421 |

## 4. Results

### *4.1. Proportions of Different Coastal Wetland Ecosystems in Jiangsu Province*

We used RS and GIS technology to determine the types of CWs in the study area via selected remote sensing images (Figure 2a), and the main land types were determined to include salt fields, aquaculture ponds, farmland, and mudflats. The dominant plants in the salt marshes were *Spartina alterniflora*, *Phragmites australi*, and *Suaeda salsa*.

The sizes and percentages of the areas of different land types (Figure 2b,c) in the coastal region of Jiangsu Province were, in order, 42% for farmland, 27% for mudflats, 20% for aquaculture ponds, 6% for *Spartina* salt marshes, 2% for *Phragmites* salt marshes, and 1% for *Suaeda* salt marshes and forests. This indicates that land uses in the coastal areas significantly affected the natural states of the CWs, especially regarding the reduction in the area of *Suaeda* salt marsh due to the degradation of the indigenous plant *Suaeda salsa*.

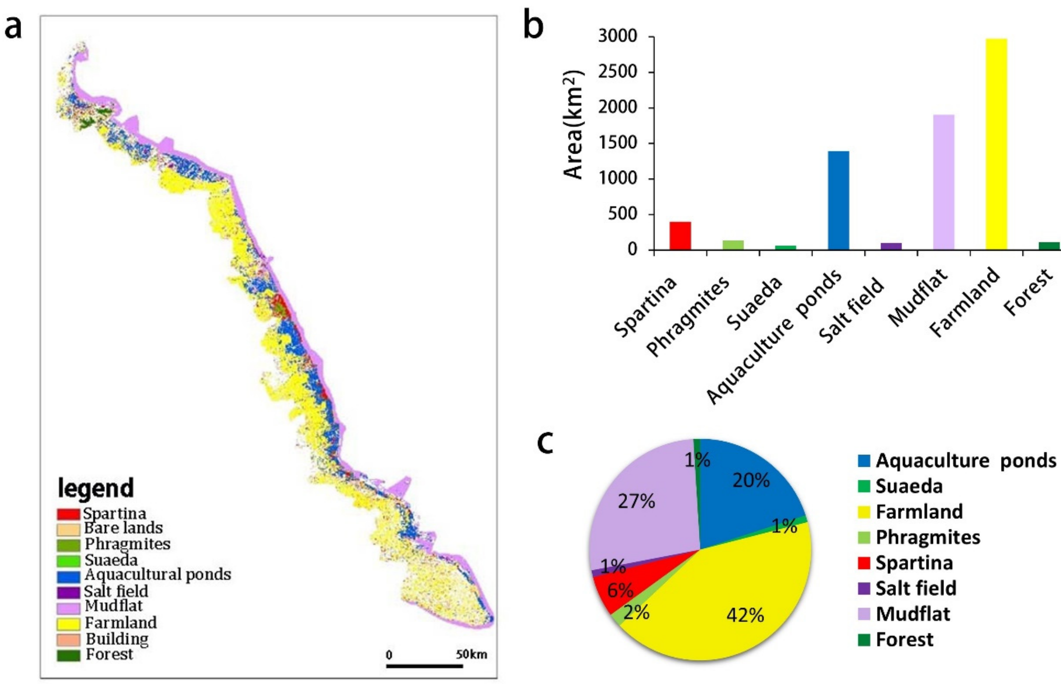


**Figure 2.** Classification of coastal wetlands ecosystems in Jiangsu Province in 2018. (**a**) Distribution of land types in coastal wetlands of Jiangsu Province. (**b**) Areas of different land types in coastal wetlands of Jiangsu Province. (**c**) Area proportions of different land types in coastal wetlands of Jiangsu Province.

### *4.2. Area Variations of Different CWs Ecosystems in Jiangsu Province*

The total area of natural vegetation in the coastal region of Jiangsu Province (Figure 3a) showed a decrease from 1382 km$^2$ in 1987 to 365 km$^2$ in 1997, and then increased from 365 km$^2$ in 1987 to 595 km$^2$ in 2018. Although the area of natural vegetation recovered in 2018, it only occupied 43% of the total area in 1987. This indicates that the human utilization of CWs significantly affected the natural distribution of coastal vegetation in Jiangsu Province in the past. The changes of the area of the three natural salt marshes, of *Spartina*, *Phragmites* and *Suaeda*, show that although the *Spartina* salt marshes decreased significantly in size from 1987 to 1997, it showed a yearly increase from 1997 to 2018; the area of *Phragmites* salt marshes significantly reduced from 1987 to 1997, and then remained stable from 1997 to 2018; and the area of *Suaeda* salt marshes varied from 368 km$^2$ in 1987 to 61 km$^2$ in 2018, showing a yearly decreasing trend. These changes in the area of natural vegetation indicate that the reproductive and expansive capacity of the exotic species of *Spartina alterniflora* was very strong, whereas the adaptive survival capacity of the indigenous plant *Suaeda salsa* was weakened.

To further understand the specific impacts of different types of land development and utilization, as well as invasive plants, on the CWs in Jiangsu Province, the variations in the CWs in three cities were analyzed separately. From Figure 3, it can be seen that the impacts of alien species on the CWs' ecosystems in the three cities were almost the same as those in Jiangsu Province, i.e., a large degree of invasion of *Spartina alterniflora* resulted in the inhibition of *Suaeda salsa*'s growth. While the total area of vegetative wetland decreased in Jiangsu Province after changes in land use, and those in Nantong and Yancheng also decreased, only Lianyungang showed an elevation in the total vegetation wetland area due to the massive invasion of *Spartina alterniflora*.

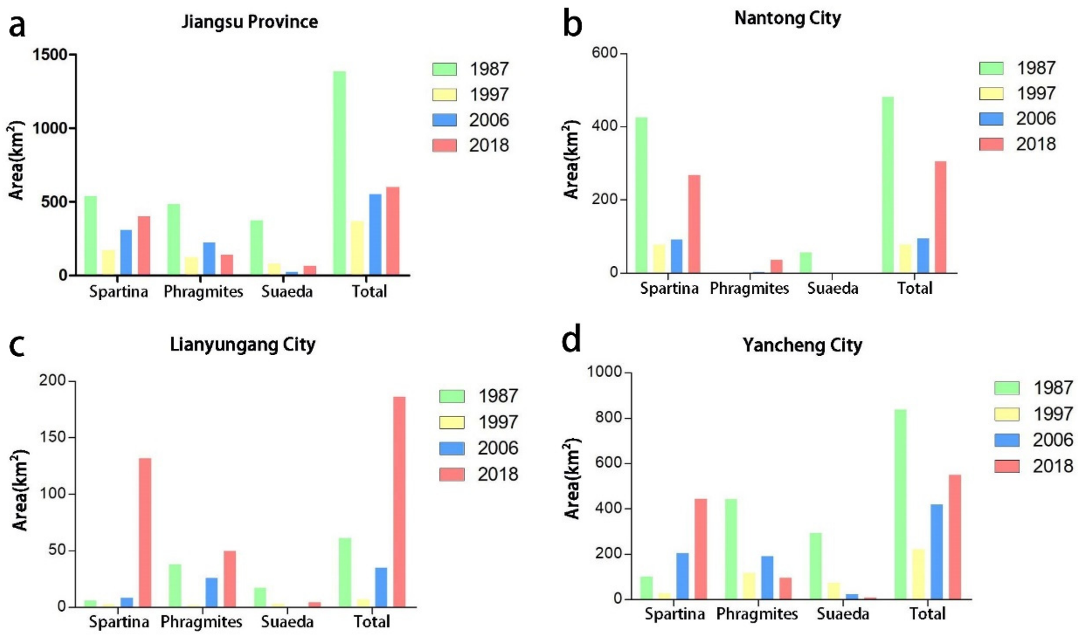


**Figure 3.** Variations in the areas of CWs in different coastal regions of Jiangsu Province over a set number of years: (**a**) in Jiangsu Province, (**b**) in Nantong, (**c**) in Lianyungang, and (**d**) in Yancheng.

### *4.3. Analysis of Landscape Fragmentation in CWs Ecosystems in Jiangsu Province*

Based on the analysis of land use types in 2018 (Figure 4a), the largest average patch area in the coastal region of Jiangsu Province was occupied by mudflats, followed by farmland and aquaculture ponds, while the average patch areas of natural vegetation featuring *Phragmites*, *Suaeda*, and *Spartina* were similar and smaller. This indicates that land use by humans results in smaller natural vegetation patches and larger artificial patches.

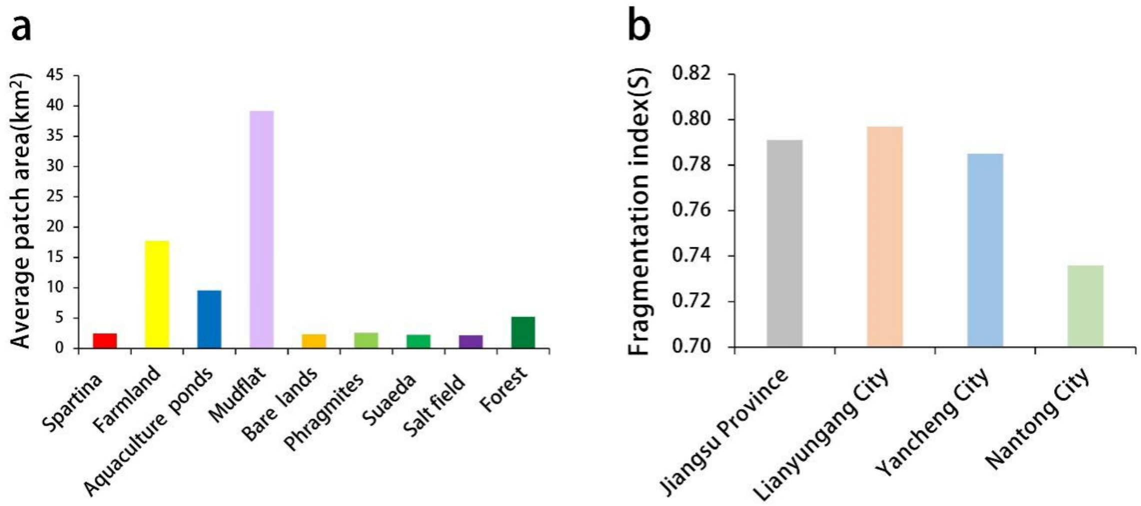


**Figure 4.** Landscape fragmentation in coastal wetlands ecosystems in Jiangsu Province in 2018. (**a**) Landscape analysis of land use types in coastal wetlands of Jiangsu Province. (**b**) Fragmentation index of the coastal region in Jiangsu Province.

By comparing the fragmentation indices of the CWs of Jiangsu Province with those of Lianyungang, Yancheng, and Nantong (Figure 4b), we find that the fragmentation degree of the CWs of Jiangsu Province as a whole was high, with a relatively lower degree of fragmentation in Nantong and the highest degree in Lianyungang, while Yancheng was in the middle. Their much higher degree of landscape fragmentation indicates that the coastal regions of Jiangsu Province were strongly affected by land use types such as reclamation, and the continuity of the original ecological landscape was divided into multiple isolated and discontinuous patches, such as salt fields, farmlands, roads, etc. Therefore, strengthening the connectivity of regional patches represents one of the main ways to manage the coastal landscape in the future.

### *4.4. Assessing Ecological Service Value of CWs Ecosystems in Jiangsu Province*

Based on the coefficients of ESV per unit area of different land types (Table 1) and the areas of distribution of different land types in Jiangsu Province (Figure 2b), the total ESV of wetland vegetation (including the plants *Spartina*, *Phragmites*, and *Suaeda*) in the coastal region of Jiangsu Province in 2018 was calculated to be USD 14.10 million, the ESV of farmland was USD 8.58 million, and the total forest ESV was USD 2.09 million (Figure 5a), placing it in the top three of all land use types. Although the area of farmland accounted for 42% of the total area of the coastal zone, its ecological value represented only 60% of the ecological value generated by the wetland vegetation that occupied 9% of the total area, indicating that agricultural development in the coastal zone seriously affected the ESV of the CWs. The ESVs can be ranked in descending order as wetland vegetation, farmland, and forest. Hence, the protection and restoration of forest and wetland vegetation should be strengthened in aspiring towards ecological protection in the coastal zone.

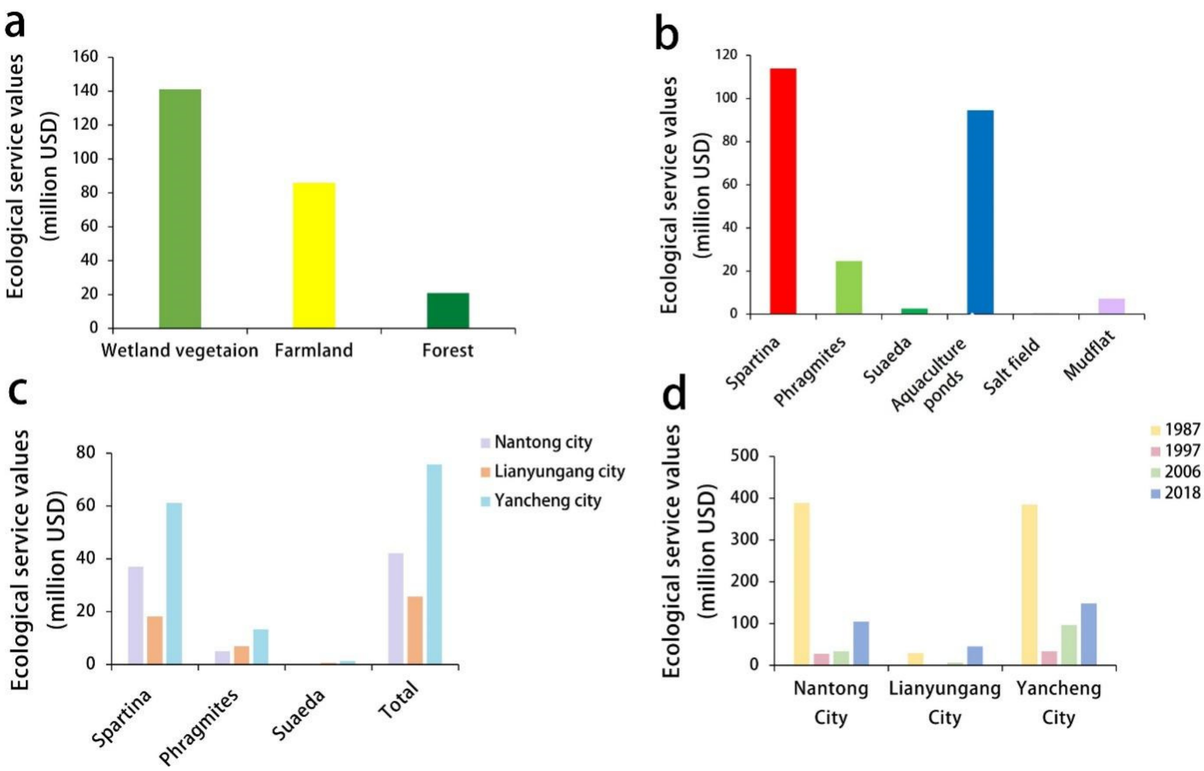


**Figure 5.** ESVs of different types in the coastal region of Jiangsu Province. (**a**) ESV of different land use types in the coastal region of Jiangsu Province in 2018. (**b**) ESV of different wetland types in the coastal region of Jiangsu Province in 2018. (**c**) ESV of land vegetation in the three coastal cities of Jiangsu Province in 2018. (**d**) ESV of natural wetland vegetation in the three coastal cities of Jiangsu Province.

Combining Figure 2b with Table 1, we can calculate the total ESVs of different wetlands in the CWs of Jiangsu Province, and Figure 5b shows that the overall ESVs can be ranked in descending order as *Spartina* wetland, aquaculture ponds, *Phragmites* wetland, mudflats, *Suaeda* wetlands, and salt fields. The ESV generated by mudflats occupying a higher area percentage was relatively lower. In contrast, the ESV generated by the *Suaeda* wetlands occupying a lower percentage of the area was significant. Therefore, the restoration and protection of *Suaeda* should be a priority.

According to Figure 5c, the overall ESVs of the beach wetland vegetation in the three coastal cities in Jiangsu Province in 2018 can be ranked as Yancheng, Nantong, and Lianyungang in descending order; however, the main contributor to the ESV of the natural beach wetlands in the three cities was the invasive alien population of *Spartina alterniflora*, whereas the ESV of the indigenous population of *Suaeda salsa* made the smallest contribution, which was negligible. According to the trend of ESV changes over time in the three cities (Figure 5d), the ESVs of the natural beach wetlands in Nantong and Yancheng were similar in the 1980s. In contrast, the ESVs of the two cities in 2018 were lower than those in the 1980s, and Yancheng's ESV was higher than that of Nantong. The ESV of the coastal natural wetlands in Lianyungang increased year by year from 1987 to 2018. Therefore, comparing the ESVs of the three cities, we see that the lowest ecological value emerged in 1997, mainly because the development of CWs in Jiangsu Province had undergone different phases; for example, the "Million Mudflats Development Project" had been implemented, directly causing the ESVs of CWs to reach a historical low point in this year.

Although the ESVs of the three coastal cities increased year by year after 1997, the main factor providing ESV was the presence of the exotic species *Spartina alterniflora*. However, the negative effects of exotic species should also be emphasized.

## 5. Discussions

### *5.1. Variations in Vegetation Area of CWs Ecosystems in Jiangsu Province*

As influenced by the economy and related policies, China's CWs are most often transformed into towns and country land, aquaculture land, farmland, and cofferdam wetlands. In this study, in descending order, the areas of land types in the coastal region of Jiangsu Province were farmland (42%), mudflats (27%), aquaculture ponds (20%), *Spartina* wetland (6%), *Phragmites* wetland (2%) and *Suaeda* wetlands, forest, and salt fields (1%). Natural vegetation represented only 43% of the total area in 1987. This indicates that land use significantly affected the natural state of the CWs in Jiangsu Province. Some studies have shown that the losses of area of CWs around the Liaohe, Yellow, Yangtze, and Pearl River deltas from 1978 to 2014 were linearly and positively correlated with the area of polder [32]. The area of the intertidal zone across the whole nation decreased by 6.7% to 8.9% due to the impact of land use/cover changes and the "squeezing effect" of sea level rise from 1990 to 2015, and overall, the transformed land types in the intertidal zone mainly comprised marine aquaculture (24~48%), weir land under construction/unknown usage (16.5~29%), and agricultural land (9.8~20%) [33,34]. In China, from 1984 to 2016, the total area of coastal land-based aquaculture ponds expanded by 10,463 km$^2$, and more than 50% of the area was converted from CWs to cropland [35]. This shows that land use seriously affected the natural ecosystem of CWs in China.

In addition, this study has analyzed the trends of changes in the areas of three types of natural vegetation, including *Spartina*, *Phragmites*, and *Suaeda*, and the results show that although the presence of *Spartina* decreased significantly in 1997, it showed a yearly increasing trend from 1997 to 2018; the presence of *Phragmites* was significantly reduced from 1987 to 1997, after which its distribution area remained stable from 1997 to 2018; and the area of *Suaeda* decreased from 368 km$^2$ in 1987 to 61 km$^2$ today, with a yearly decreasing rate. The reproductive capacity of the exotic species *Spartina alterniflora* was shown to be very strong, whereas the adaptive and survival capacity of the indigenous plant *Suaeda salsa* was weakened, resulting in the invasion of *Spartina alterniflora* until it represented much of the distribution area of mudflats and *Suaeda salsa*. The invasion of *Spartina alterniflora* mainly promoted the siltation of sediment, which in turn promoted the optimization of the soil's physicochemical properties [36]. This strong siltation-promoting effect of *Spartina alterniflora* led to a rapid expansion of the invaded area on the beach surface year by year, with an average annual increase rate of 9.8% [37]. The area of seaward mudflats invaded by

*Spartina alterniflora* was 85.03 $hm^2$ at this time, accounting for 72.54% of the total invaded area [38]. *Spartina alterniflora* mainly affected the habitat of *Suaeda salsa*, potentially making them unsuitable for the further growth of the latter, leading to the former's invasion and expansion. The ability of the *Spartina alterniflora* population to adapt to external environmental changes was stronger, as a result of which the siltation region was expanded, preventing lots of water from reaching the *Suaeda salsa* population, and ultimately leading to encroachment into the *Suaeda salsa* habitat by *Spartina alterniflora* [39,40]. Therefore, attempts at the restoration and protection of *Suaeda* should be strengthened.

### *5.2. Land Uses Resulting in Smaller Natural Vegetation Patches and Larger Artificial Patches*

Landscape fragmentation is a key external manifestation of land use change in terms of landscape pattern [41]. It could be used to characterize the degree of landscape disturbance following the long-term interaction of factors, such as natural changes and human activities [26]. In this study, the largest average patch area in the coastal region of Jiangsu Province was represented by mudflats, followed by farmland and aquaculture ponds, and the average patch areas of *Phragmites*, *Suaeda*, and *Spartina* were similar and much smaller. This indicates that land use resulted in smaller natural vegetation patches and larger artificial patches. Studies have shown that the negative effect of habitat fragmentation on plants is a common phenomenon, and can act as a major force in the extinction of native species [42]. Some scholars have pointed out that landscape fragmentation could threaten the security of urban ecosystems [43,44]. Others found that the fragmentation of the vegetation landscape may interfere with biological survival and habitats, and threaten local biodiversity [43,45]. Some studies have reported that fragmentation has the greatest impact on plant species diversity on medium and small islands [46,47], with a proportion of highly area-sensitive species in fragmented forest habitats gradually disappearing, while endangered species richness was found to decrease by 75% in fragmented forests compared to continuous forests [48]. Therefore, habitat fragmentation is closely related to nature conservation. Many endangered species require larger natural habitats so as to ensure their survival. The degradation and large-scale disappearance of *Suaeda* in the coastal region of Jiangsu Province may be related to habitat fragmentation. If the habitat of *Suaeda* needs to be restored, it might be necessary to consider the establishment of much larger habitats that are suitable for *Suaeda salsa* growth. In addition, the largest wetland patches in the CWs of Jiangsu Province were represented by mudflats, which should be protected to avoid their fragmentation and thus to ensure the persistence of wintering habitats for coastal migratory birds.

### *5.3. Ecological Services Value of CWs Ecosystems in Jiangsu Province*

Changes in land use/cover changes would lead to changes in the type and strength of service functions, which in turn causes changes in ecosystem services [49]. This study found that the highest ESV per unit area was offered by *Spartina* salt marsh, at USD 1.36 million, and the lowest ESV was offered by salt fields and mudflats at USD 0.018 million and USD 0.018 million, respectively. This is to say, natural vegetation plays an essential role in ecosystem services. Land use patterns influence the structure and function of regional ecosystems [50], and due to changes in land uses, the total ecosystem service value of China has decreased by 1.52%, mainly affecting the northeastern, northwestern, and northern regions [51]. Minnesota showed a decline in ESV due to a decline in water quality, biodiversity, and C reserves between 1992 and 2001, caused by the large-scale agricultural expansion seen in the region [52]. In contrast, returning farmland to forest land brought about an increase in the ecosystem service value of the Three Gorges Reservoir area [53–56]. Therefore, coastal wetlands should rationally be allocated land use resources, socio-economic factors should be moderately developed to ensure regional ecological security, and the protection and restoration of woodland and wetland vegetation should be strengthened to ensure ecological protection in coastal zones.

This study found that the main provider of ESV was the exotic species *Spartina alterniflora*. Some studies found that the invasion of *Spartina alterniflora* not only affected the carbon cycle of CWs, but also had an important impact on the nitrogen cycle, which led to an increase in the abundance and number of nitrogen-fixing bacteria in the soil [52,57]. Although the exotic species *Spartina alterniflora* can enhance vegetation recovery in CWs and increase their ESVs, its negative impacts on the environment should not be ignored. It was found that developed root systems of *Spartina alterniflora* restrict the growth of macrobenthos such as crabs, causing the numbers of macrobenthos species in the invaded area to be reduced compared with non-invaded areas. The invasion of *Spartina alterniflora* led to moderate and even serious disturbances in the macrobenthos community. In addition, the invasion of *Spartina alterniflora* increased the complexity of the macrobenthos food web in the initial stages of the invasion, and with the prolongation of the invasion, the complexity of the food web decreased [58]. In conclusion, the invasive ability of *Spartina alterniflora* should be scientifically assessed in relation to the growth conditions in the local area, and appropriate conservation measures should be taken. How to balance the ESVs of *Spartina alterniflora*, *Suaeda salsa*, and *Phragmites australis* salt marshes should be the focus of future CW development projects in China.

## 6. Conclusions

Land use and biological invasions are important factors affecting coastal wetland (CW) ecosystems and ecological services. This study found that land uses lead to the serious fragmentation of the ecosystem, and different natural vegetation patches thus emerge. Natural vegetation covered 9% of the total land area but produced 60% of the total value of its ecological services. The highest ecosystem service value per unit area was derived from *Spartina alterniflora* salt marshes, and due to the invasion of this species, the dominant vegetation types in the CWs of Jiangsu Province were mainly *Spartina alterniflora* and *Phragmites australis*, while most of the *Suaeda salsa* population had disappeared. Therefore, it will be necessary to focus on the creation of large habitats suitable for *Suaeda salsa* growth. In addition, the largest wetland patches in the CWs of Jiangsu Province comprised mudflats, which should be protected so as to avoid their fragmentation and ensure the survival of wintering habitats for coastal migratory birds.

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