Island ecosystem services value, land-use change, and the National New Area Policy in Zhoushan Archipelago, China

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ABSTRACT: Inhabited islands in China now face increasing stress from urbanisation and related development policies. Since the National New Area was established in 2011, dramatic land-use changes in the Zhoushan Archipelago have affected its ecosystem health and biodiversity. The National New Area policy further promoted Zhoushan's economic development but exerted more pressure on its ecosystems. To explore sustainable development, this study attempts to determine how ecosystems in the archipelago have been impacted through the variation in ecosystem services value (ESV) by means of the InVEST model. The outcomes indicate that: (i) the total ESV and carbon storage have declined, with a remarkable increase in built-up land and decrease in farmland and wetland; (ii) the encroachment on farmland and wetland by built-up land is identified as the main reason for the impairment of ecosystem services; (iii) the National New Area policy has affected the island ecosystems by transforming the orientation of development to a national strategic position, encouraging specific kinds of spatial planning with different development patterns and focuses, and introducing preferential policies on administration, land use, etc.

Keywords: China, ecosystem services value, InVEST model, island cities, Zhoushan Archipelago

https://doi.org/10.24043/isj.20

Introduction

Ecosystems provide a range of services of fundamental importance to human well-being, health, livelihoods, and survival (Costanza et al., 1997; Costanza et al., 2014; MEA, 2005; TEEB Foundations, 2010; TEEB Synthesis, 2010). Ecosystem services represent the benefits that living organisms derive from ecosystem functions that maintain the Earth's life-support system, including climate regulation, water supply, and nutrient cycling (Costanza et al., 1997). However, over the long-term process of utilising and transforming nature, we typically emphasise only the direct consumer value or market value of natural resources while neglecting ecosystem services and their value (Chen & Zhang, 2000).

The International Environment Research Group was the first team to be engaged in probing ecosystem service functions for humans (SCEP, 1970). Ehrlich and Ehrlich (1981) proposed the concept of ‘ecosystem services’ and systematically studied whether biodiversity loss would affect ecosystem service functions. Since 1990, numerous studies have been conducted to explore both the concepts and valuation techniques of ecosystem services. Notable examples include the publication of *Nature’s Services: Societal Dependence on Natural Ecosystems* by Daily (1997) and the research conducted by Costanza et al. (1997), who presented the principles and methods for estimating the global value of 17 ecosystem services provided by 16 dominant global biomes. In 2005, the concept of ecosystem services gained broader attention in both research and policy communities when the United Nations published its Millennium Ecosystem Assessment (Braat & de Groot, 2012; Costanza et al., 2014; Costanza & Kubiszewski, 2012). Subsequently, *The Economics of Ecosystems and Biodiversity* (TEEB) report undertaken by the UN Environment Programme was picked up extensively by the mass media, bringing ecosystem services to a broader audience (Costanza et al., 2014). Hundreds of projects and groups are currently working toward improved understanding, modeling, valuation, and management of ecosystem services and natural capital (Costanza et al., 2014).

Islands are an indispensable element of coastal zones, and island ecosystems differ from terrestrial ecosystems. The Millennium Ecosystem Assessment (MEA) (2003) defines islands as “lands isolated by surrounding water and with a high proportion of coast to hinterland.” An island and its surrounding seas comprise an integrated system, and island ecosystems provide both terrestrial and marine ecosystem services (Lin et al., 2013). Islandness likewise strengthens the links between a place’s ecosystem services and the inhabitants of the place itself (Aretano et al., 2013; D. Wang et al., 2014). Islands are among the most vulnerable places to human activities and environmental change (Chen et al., 2013), with the result that they have attracted significant attention from researchers in recent years.

Since the 1990s, studies on island ecosystems have focused mainly on assessing ecosystem services and health (Parsons et al., 2008; D. Wang et al., 2014; Xu et al., 2004; Zhao et al., 2004), ecological degradation and restoration (Samways, 2000; Samways et al., 2010; Shi et al., 2012), management and planning of islands and their surrounding seas (Oost et al., 2012; Saunders, 1990; Sovacool, 2012), and the response of island ecosystems to anthropogenic effects (Angeler & Alvarez-Cobelas, 2005; Lin et al., 2013; Wang et al., 2010). Land-use and land-cover changes are underlying causes of the fragmentation and loss of natural habitat (Alcamo & Bennett, 2003). Human encroachment into surrounding natural and semi-natural ecosystems has impaired regional ecosystem service functions (Wu et al., 2013), particularly on islands. Substantial research has been conducted into techniques for evaluating ecosystem services. Methods of monetary valuation have drawn the most attention from researchers because they make ‘unpriced’ services comparable with services that have market value, enable the aggregation of various ecosystem services, and allow full-cost accounting (Wang et al., 2010). A range of methods for monetary valuation have been developed, including the direct market approach, surrogate market approach, experimental market approach, and benefit transfer method (Curtis, 2004; Farber et al., 2002; Freeman et al., 2014; Wang et al., 2010).

Several inhabited islands in China now face increasing stress from urbanisation (Lin et al., 2013). Urban spatial expansion on Xiamen Island over the past 30 years has occupied large areas of woodland, farmland, water area, and coastal wetland, thereby decreasing the ecosystem services value (ESV) and significantly fragmenting the landscape pattern (Lin et al., 2013). Land reclamation projects were conducted there to ease land shortage but led to ecosystem service losses (Wang et al., 2010). Zhao et al. (2004) also discovered that the total ESV of Dongtan in the East Beach of Chongming Island declined from 1990 to 2000, which was largely attributable to the loss of tidal flats. The intensity of human activities is closely dependent on national or regional development strategies and varies across different periods, causing discontinuous changes in land use or ecosystems. However, few attempts have been made to research the influence of development policies, especially national development policies, on ecosystem services, regardless of the degree, direction, and mechanism of the effects.

Similar challenges have confronted the Zhoushan Archipelago, which is located in the northeastern seas of China's Zhejiang province. Analyses of land-use and land-cover changes from a long-term series of remote sensing data in Zhoushan Archipelago revealed that built-up areas have expanded sharply at the cost of the tidal zone and arable lands from 1970 to 2011: Most of these areas are located around the periphery of the archipelago's islands (Chen et al., 2013; X. Zhang et al., 2013). Such dramatic land-use changes, mainly driven by urbanisation and development policies, have contributed to an overall decrease in ecosystem health (Lu et al., 2010) and a slight decline in the function of biodiversity (Lin, 2015). The Zhoushan Archipelago New Area was set up in 2011 to enhance China's maritime economy, expand its marine development strategy, and promote its ability to integrate global resources (Long et al., 2014). That is, development and further urbanisation in this area will undoubtedly continue. Thus, to explore sustainable management and guide future island development, it is of great importance to understand the state of the islands' natural environment and ecosystems before and after implementation of the National New Area policy.

This study uses the research method developed by Xie et al. (2008) – with some adaptations to the local situation in the Zhoushan Archipelago – to calculate ESV as well as introduces the integrated valuation of environmental services and tradeoffs (InVEST) model, a widely applied tool for ecosystem service mapping and valuation (Kareiva, 2011). This paper presents systematic research into the dynamic patterns of land use and ESV in Zhoushan, using remote sensing images in 2009 and 2014 as well as socioeconomic and ecological data from the scholarly literature and government sources. We aim to determine changes in land use, ESV, and carbon storage over the study period; reveal how the National New Area policy has influenced ecosystem services in the archipelago; and provide preliminary policy recommendations to explore sustainable use of the islands.

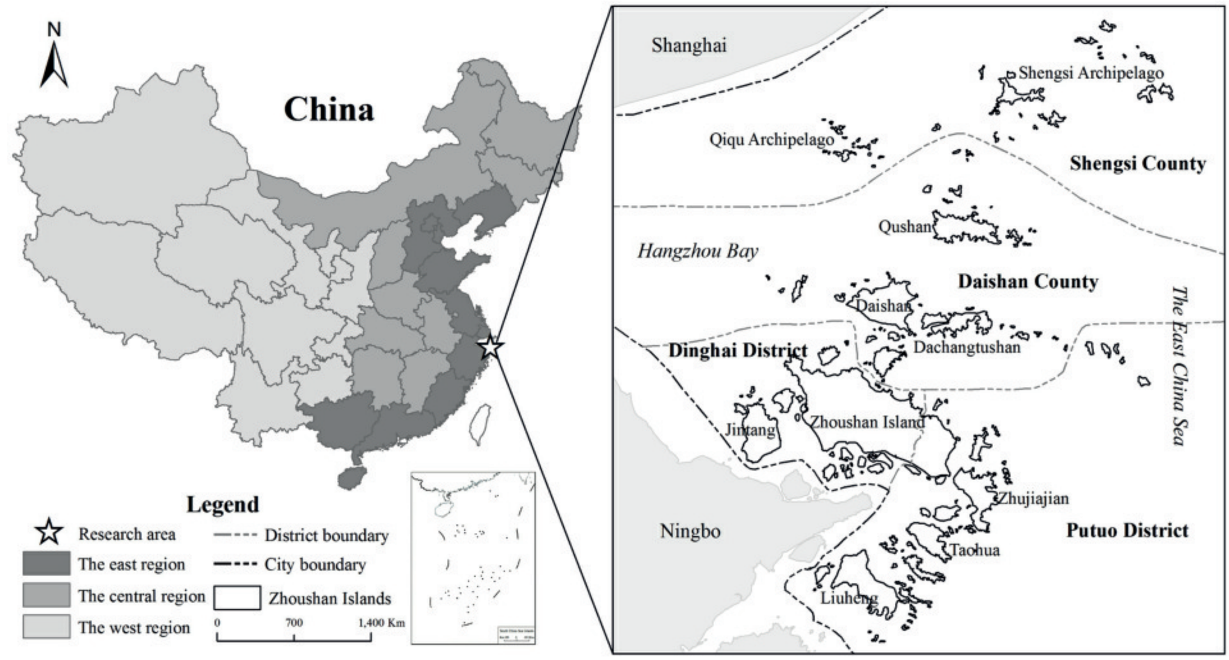

Figure 1: Study area.

Data and methods

Study area

The Zhoushan Archipelago (29°32′–31°04′N, 121°30′–123°25′E) is located on China's eastern coast. The study area is at the intersection of the Yangtze River Estuary and Hangzhou Bay, close to Ningbo.

This area includes 583 islands and has a land area of 1027.4 km2, with over 1200 km of coastline. It comprises two districts of the Zhoushan Archipelago, namely, Dinghai and Putuo (Figure 1). These two districts were identified as the planned urban area by the local development master plan, were more developed, and received more anthropogenic effects than Zhoushan's two other counties, Daishan and Shengsi. The study area is comprised of a hilly landscape, with a monsoon-influenced subtropical marine system climate (X. Zhang et al., 2013). The mean annual temperature is 16.1°C, and the average annual rainfall is around 1200 mm. Coniferous, evergreen broad-leaved, and deciduous broad-leaved forests are widely distributed (X. Zhang et al., 2013).

The National New Area is set up by the State Council and undertakes national strategic developmental and reform activities, aiming to: allow full utilisation of potential comparative and competitive advantages, optimise industrial layout, and improve economic quality and efficiency in each selected region. The general development target and orientation of the New Areas are uniformly planned and approved by the State Council. Open and preferential policies also favor these areas. In 1992, the first National New Area, the Pudong New Area of Shanghai, was established, and since then 18 further New Areas have been set up (as of April 2017), including the Binhai New Area of Tianjin and the Lanzhou New Area of Gansu.

The Zhoushan Archipelago New Area is the fourth National New Area and the first New Area with a marine economy theme. This New Area prioritises the industrial development of ports, logistics, shipbuilding, manufacturing of marine engineering equipment, marine tourism, and pelagic fishery. It is designed as a base for modern marine industry, an ecological island city, and a maritime garden city. Over the past decade, Zhoushan has undergone unprecedented expansion (Chen et al., 2013). In 2013, the archipelago's permanent population was 1,142,000 people, the population density reached 793 people per km2, the Gross Domestic Product (GDP) per capita amounted to 81,582 yuan, and the added value of the marine economy accounted for 69.10% of Zhoushan's GDP. With the initiation of the Peninsula Project in 1997 and the construction of cross-sea bridges, Zhoushan's development has been subjected to continually strengthening mainland-island contact, which has exerted great pressure on the archieplago's limited land resources and ecosystems.

Data collection and processing

This study utilises remote sensing images to interpret land-use changes; utilises equivalent value coefficients (EVC) proposed by Xie et al. (2008) and revisions based on socioeconomic and ecological data from local and national governments to evaluate ESV; and utilises carbon density data from the literature to compute carbon storage and sequestration values. Equivalent value coefficients (EVC) refer to equivalent factors for ecosystem services value.

Land-use and land-cover change data were produced from a Landsat5 TM (Thematic Mapper) image (30 m) and a GF-1 WFV4 image (19 m), which were acquired on 17 July 2009 and 16 March 2014 respectively. Geometrical rectification, coordinate system unification, crop processing, and interpretation were performed using the ERDAS IMAGINE software. Due to the research scope and available data, we could only adopt moderate-resolution remote sensing images, which thereby limited our classification scheme. Given that many relevant studies also adopt such a classification scheme, and bearing in mind Zhoushan's land-use status, five land-use categories were defined and classified in this study: forest (woodland and garden plots), farmland (paddy field and dryland), wetland (aquaculture area and coastal wetland), water area (rivers, lakes, and reservoirs), and built-up land (urban area; rural settlements; bare land; land for industry, mining, and transportation; and industrial salt flats). The various subcategories were roughly determined to improve our understanding of the situation, but they were not determined from interpretation of the remote sensing images. Supervised classification, a technique for developing the rules for assigning reflectance measurements to land-use categories based on sufficient known pixels and a predefined algorithm, was applied to guarantee classification consistency and accuracy, combined with human-machine interactive interpretation. The Kappa coefficients validated by Google Maps were 88.57% in 2009 and 87.62% in 2014, which met the recommended value suggested by Janssen and Vanderwel (1994).

Computation of ESV

When detailed valuation data are unavailable for a study region, the benefit transfer method is recognised as a useful way to bridge the data gap (Wang et al., 2010). Based on the pioneering work of Costanza et al. (1997), Xie et al. (2003) developed an enhanced benefit transfer method to evaluate China's terrestrial ecosystem services by surveying 200 Chinese ecologists in 2002. This method was successfully utilised in an ecological assets valuation of the Tibetan Plateau. Xie et al. (2008) subsequently modified the EVC from their previous study through a survey of 500 Chinese ecologists in 2007. The method of Xie et al. (2008) is relatively feasible and has been widely applied in China (Lin et al., 2013; W. Wang et al., 2014; Wu et al., 2013). To compensate for the deficiency of static evaluation, which can only be utilised to evaluate the ESV of a particular year at a national scale, Xie et al. (2015) further proposed more detailed EVC and an integrated method for dynamic evaluation of Chinese terrestrial ESV at monthly and provincial scales by introducing space-time adjustment factors of NPP (Net Primary Productivity), precipitation, and soil conservation.

Given the accessibility of data, this study adopted the EVC proposed by Xie et al. (2008). Each land-use type provided nine service functions (Table 1). The food production function per unit farmland was set as the standard, with an EVC of 1. EVCs of other ecosystem services were estimated by the surveyed Chinese ecologists, who compared them with the standard value. However, ecosystems are idiosyncratic (Daily et al., 2000). Direct application in a particular area of the EVC that is suitable for the entire country may lead to inaccurate results. Therefore, this study rectified the EVC based on the specific circumstances of the study area.

First, area rectification was conducted (Xu et al., 2012). The EVC benchmark in Xie et al. (2008) was the average food production of farmland per hectare per year in China. By assuming that the proportional relationship among the EVCs of different land-use types remained constant, we adjusted the benchmark to the average food production of farmland per hectare per year in the study area to reflect the ESV spatial disparity between the study area and the country as a whole. The formula of area rectification was as follows:

$$E_{ij}' = \frac{q}{Q} \times E_{ij} \tag{1}$$

Where q and Q are the average food production of farmland per hectare per year in the study area and in China respectively; E_{jj} and E_{jj}' are the EVCs of ecosystem service function j of land-use type i before and after rectification. The factor of area rectification of the study area was 1.16 (Appendix A1) (National Bureau of Statistics of China, 2013; Zhoushan Bureau of Statistics, 2013).

Second, the EVC of forest ecosystem were separately rectified because it composed a large proportion of the study area (Ai & Hong, 2015; Xu et al., 2012). Forest biomass usually varies in different regions due to different types of plants and hydrothermal conditions. Generally, a larger biomass implies stronger ecosystem service functions (Xu et al., 2012). We assumed a linear relationship between ecosystem service functions and biomass. Given a lack of biomass data, the forest stock volume, which could largely represent biomass, was utilised to rectify the EVC of forest ecosystem as follows:

$$E_{1j}' = \frac{b}{B} \times E_{1j} \tag{2}$$

where b and B are the average stock volumes of forest ecosystem per hectare per year in the study area and in China respectively; E_{1j} and E_{1j}' correspond to the EVCs of forest ecosystem of ecosystem service function j before and after rectification. The factor of forest rectification of the study area was 0.34 (Appendix A2) (National Bureau of Statistics of China, 2013; Forest Resources Monitoring Center of Zhejiang Province, 2007).

Third, the economic value of the standard EVC of 1 was rectified. This referred to the economic value of the natural food production of farmland with average output in China per hectare per year. However, given the difficulty in assessing this value precisely, we referred to the study by Xie et al. (2015) in which the value was determined as the annual net profit per unit area of major grain produced by farmland ecosystem in the study area, which was calculated as follows:

$$D = S_r \times F_r + S_w \times F_w + S_c \times F_c \qquad (3)$$

where D is the ESV of the standard EVC of 1 per hectare per year; S_r, S_w, and S_c are the percentages of area sown with rice, wheat, and corn of the total sown area in a particular year of the study area respectively; F_r, F_w, and F_c are the average net profits per hectare of rice, wheat, and corn in that year of the study area respectively. In this study, the ESV of the standard EVC of 1 was 4959.38 yuan per hectare (Appendix A3) (Price Department of the National Development and Reform Commission, 2013; Zhoushan Bureau of Statistics, 2013).

Thus, the ESV per unit area (Table 1) in Zhoushan (Appendix A4) could be calculated as follows:

$$VC_{ij} = \begin{cases} E_{1j} \times \frac{q}{Q} \times \frac{b}{B} \times D & i = 1 \\ E_{ij} \times \frac{q}{Q} \times D & i = 2,3,4 \end{cases} \qquad (4)$$

Where VC_{jj} is the ESV per unit area of ecosystem service function j of land-use type i (yuan/ha); i=1 refers to forest ecosystem while i=2,3,4 refer to farmland, wetland, and water area ecosystems.

The total ESV of the study area was calculated as follows:

$$ESV = \sum_{i=1}^{m} \sum_{j=1}^{n} A_i \times VC_{ij} \qquad (5)$$

Where A_i is the interpreted area of land-use type i (ha); ESV refers to the total ESV of the study area. EVC and ESV per unit area were computed with the data in 2012 to make ESVs in 2009 and 2014 comparable. When the ESV per unit area in Table 1 was multiplied by the area of each land-use type in 2009 and 2014 in Table 3, the ESV of these two periods could be acquired (Table 5).

Table 1: ESV per unit area per year (yuan/ha).

Service type	Service subtype	Forest	Farmland	Wetland	Water area
Provisioning services	Food production	643.05	5760.27	2073.70	3052.94
	Raw materials production	5806.95	2246.50	1382.46	2016.09
Regulating services	Gas regulation	8418.13	4147.39	13,882.24	2937.74
	Climate regulation	7930.97	5587.46	78,051.60	11,866.15
	Hydrological regulation	7969.94	4435.40	77,417.97	108,120.18
	Waste treatment	3351.66	8006.77	82,947.82	85,539.94
Supporting services	Soil formation and conservation	7833.53	8467.59	11,462.93	2361.71
	Biodiversity maintenance	8788.37	5875.47	21,255.38	19,757.71
Cultural services	Providing aesthetic value	4053.17	979.25	27,015.64	25,575.58
Total		**54,795.76**	**45,506.10**	**315,489.73**	**261,228.03**

Computation of carbon storage and sequestration value

The method of Xie et al. (2008) for evaluating ESV must be considered a crude approximation and will introduce errors depending on the type of ecosystem service and its spatial heterogeneity (Costanza et al., 1997). Specifically, the method ignores factors such as rarity, spatial configuration, size, and quality of habitat in every hectare of a given land-use type (Tallis & Polasky, 2009). Although a few rectifications have been made, several unrectified factors still exist. This paper thus introduces the InVEST model to compensate for these limitations. InVEST was developed by the Natural Capital Project as a suite of computer-based models that can convert changes in land-use and land-cover patterns into changes in carbon storage, water availability, crop production, etc. (Nelson et al., 2010) to reveal variation in ecosystem services. It is spatially explicit and employs a tiered method to handle data availability and the state of system knowledge (Tallis & Polasky, 2009).

In the present study, given our needs and spatial limitations, we only evaluated the carbon storage and sequestration value with the carbon module to reveal the influence of land-use and land-cover changes on the ecosystem service function of carbon sinks. The ways in which humans manage terrestrial ecosystems are critical to climate regulation (Natural Capital Project, 2015).

Table 2: Carbon pools (Mg/ha).

Code	Land-use type	C_above	C_below	C_soil	C_dead
1	Water area	0.00	0.00	29.58	0
2	Forest	18.49	4.34	107.64	2.08
3	Farmland	3.64	0.36	82.25	0.77
4	Wetland	0.00	0.00	19.78	0.00
5	Built-up land	0.00	0.00	25.22	0.00

Note: C_above, C_below, C_soil and C_dead refer to the amount of carbon stored in aboveground biomass, belowground biomass, soil, and dead organic matter per hectare respectively.

Four basic types of carbon pools were considered: the amounts of carbon stored in aboveground biomass, belowground biomass, soil, and dead organic matter. The carbon pool data (Table 2) of each land-use type were obtained from relevant literature (An, 2014; Ekoungoulou, 2014; Xi et al., 2013; Ye, 2012; Zhang et al., 2012; J. Zhang et al., 2013; Zhu et al., 2013). Combined with the land-use maps of 2009 and 2014, based on the economic value of carbon of US$66 per ton (Tol, 2009) and the default market discount rate of 7%, the carbon module produced corresponding carbon storage maps and the value of carbon sequestration. The social value of a sequestered ton of carbon is equal to the social damage avoided by sequestering the ton of carbon into the atmosphere (Stern, 2007; Tol, 2005). According to the calculation results, the average carbon density of these two years was 90.58 Mg/ha, which was similar to the result of the study by Lin (2015) concerning Zhoushan of 93.77 Mg/ha in 2010. This slight difference is mainly attributed to the different research scope and period.

Changes in ecosystem services before and after establishment of the National New Area

Land-use dynamics and land-cover changes

As shown in Table 3, forest, farmland, and built-up land were the three largest land-use types in the study area, both in 2009 and 2014. Forest occupied nearly 50% of the total area, but the proportion of wetland and water area was merely 10.29% in 2009 and dropped to 7.79% in 2014.

Over the study period, built-up land, forest, and water area increased, whereas farmland and wetland decreased. Although water area showed the largest increase rate (39.32%), its area increase was only 458.37 ha. Built-up land presented a remarkable increase in both area (2957.85 ha) and change rate (17.40%), with an annual growth area of 591.57 ha. By contrast, farmland and wetland notably decreased by 3681.72 ha (15.39%) and 2950.56 ha (34.46%), with an annual decrease of 736.34 ha and 590.11 ha respectively. Variation in the forest area was relatively moderate.

Table 3: Total area and area changes of land-use types from 2009 to 2014.

Land-use type	Total area (ha)		Change area (ha)	Change rate (%)
	2009	2014		
Water area	1165.86	1624.23	458.37	39.32
Forest	43,848.99	45,421.20	1572.21	3.59
Farmland	23,930.37	20,248.65	-3681.72	-15.39
Wetland	8563.14	5612.58	-2950.56	-34.46
Built-up land	17,001.00	19,958.85	2957.85	17.4

The land-use conversion matrix (Table 4) indicates common and diversified transitions among all land-use types. The conversion replacement rates of the wetland, water area, and farmland were extremely high at 64.09%, 50.66%, and 45.47% respectively. Almost 30% of wetland was transformed into built-up land. Farmland was mainly converted into forest and built-up land, accounting for 22.55% and 16.28% respectively. The conversion between built-up land and other land-use types (excluding wetland) was relatively balanced, whereas the conversion from wetland to built-up land was much larger than the reverse conversion. Therefore, in the study area, the area increase in built-up land was mainly derived from wetland.

Table 4: Land-use conversion matrix from 2009 to 2014 (ha/%).

2009	2014				
	Water area	Forest	Farmland	Wetland	Built-up land
Water area	**575.19 (49.34)**	129.87 (11.14)	222.93 (19.12)	27.72 (2.38)	208.44 (17.88)
Forest	165.42 (0.38)	**38,333.70 (87.42)**	3113.64 (7.10)	253.89 (0.58)	1681.83 (3.84)
Farmland	494.01 (2.06)	5397.30 (22.55)	**13,048.11 (54.53)**	830.52 (3.47)	3896.10 (16.28)
Wetland	107.64 (1.26)	221.67 (2.59)	336.51 (3.93)	**3074.67 (35.91)**	2352.42 (27.47)
Built-up land	265.32 (1.56)	1103.67 (6.49)	3437.10 (20.22)	574.65 (3.38)	**10,821.42 (63.65)**

Note: The study area is surrounded by ocean. Given the variation in tides and reclamation projects, the land area is not a constant; slight conversion between the land and ocean exists, particularly for the wetland. This study highlights the terrestrial region of islands; thus, we did not include the conversion data of oceans in this table.

Notably, from the perspective of spatial distribution of land-use conversion (Figure 2), the occupation of wetland by built-up land concentrated in the northern and southeastern coastal areas of Zhoushan Island and islands in Putuo District, such as Zhujiajian, Xiazhi, and Liuheng. Therefore, coastal mud flat resources were substantially developed and utilised over the study period.

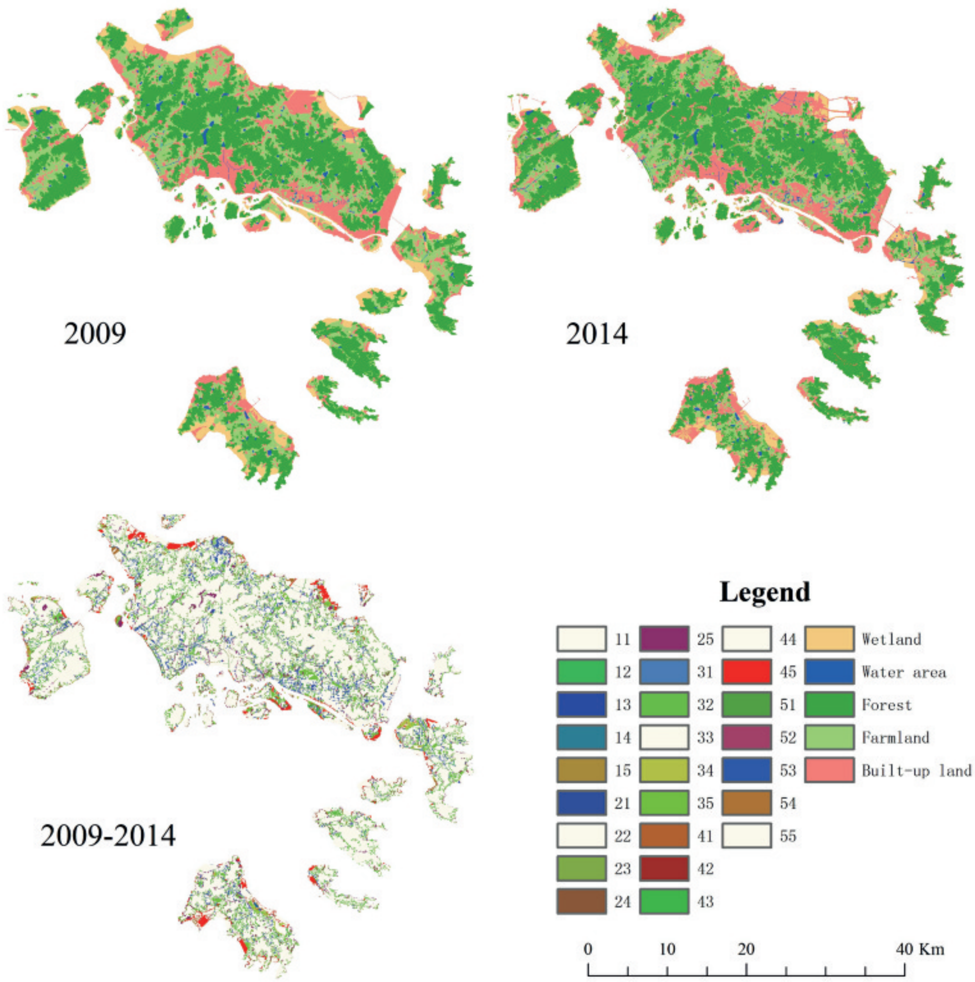

Figure 2: Land-use maps and spatial distribution of land-use conversion from 2009 to 2014: Numbers 1-5 represent water area, forest, farmland, wetland, and built-up land. Except for '11', '22', '33', '44' and '55', the codes in the legend represent land use conversions. '12', '13', '14', '15' indicate the conversions from water area to forest, farmland, wetland, and built-up land. '21', '23', '24', '25' indicate the conversions from forest to water area, farmland, wetland, and built-up land. '31', '32', '34', '35' indicate the conversions from farmland to water area, forest, wetland, and built-up land. '41', '42', '43', '45' indicate the conversions from wetland to water area, forest, farmland, and built-up land. '51', '52', '53', '54' indicate the conversions from built-up land to water area, forest, farmland and wetland.

Spatiotemporal changes in ESV

Table 5 shows the ESV and its variation in each ecosystem service function and land-use type from 2009 to 2014. The total ESV decreased from 6.50 billion yuan in 2009 to 5.61 billion yuan in 2014, with a gross reduction rate of 13.74% and an annual reduction of 0.18 billion yuan. Given the variation in land-use types, the ESV of each ecosystem followed a similar trend: the ESVs of forest and water area ecosystems increased, whereas those of farmland and wetland ecosystems decreased. The change rate of each ecosystem and its service function was the same as that of corresponding land-use type. Forest and wetland ecosystems presented higher ESV, accounting for approximately 40% and 35% respectively of the total ESV. Although wetland occupied less than 10% of the land cover, the highest ESV per unit area contributed to its large ESV.

Table 5: ESV and its variation in each ecosystem service function and land-use type from 2009 to 2014 (a hundred million yuan).

Ecosystem service function	Forest	Farmland	Wetland	Water area	Total	
	2009/2014	2009/2014	2009/2014	2009/2014	2009/2014	Change rate (%)
Food production	0.28/0.29	1.38/1.17	0.18/0.12	0.04/0.05	1.87/1.62	**-13.30**
Raw materials production	2.55/2.64	0.54/0.45	0.12/0.08	0.02/0.03	3.23/3.20	-0.71
Gas regulation	3.69/3.82	0.99/0.84	1.19/0.78	0.03/0.05	5.91/5.49	-7.05
Climate regulation	3.48/3.60	1.34/1.13	6.68/4.38	0.14/0.19	11.64/9.31	**-20.02**
Hydrological regulation	3.49/3.62	1.06/0.90	6.63/4.35	1.26/1.76	12.45/10.62	**-14.68**
Waste treatment	1.47/1.52	1.92/1.62	7.10/4.66	1.00/1.39	11.49/9.19	**-20.00**
Soil formation and conservation	3.43/3.56	2.03/1.71	0.98/0.64	0.03/0.04	6.47/5.95	-7.97
Biodiversity maintenance	3.85/3.99	1.41/1.19	1.82/1.19	0.23/0.32	7.31/6.70	-8.41
Providing aesthetic value	1.78/1.84	0.23/0.20	2.31/1.52	0.30/0.42	4.62/3.97	**-14.11**
Total	24.03/24.89	10.89/9.21	27.02/17.71	3.05/4.24	64.98/56.05	-13.74
Change rate (%)	3.59	-15.39	-34.46	39.32	/	/

Hydrological regulation, climate regulation, and waste treatment were three dominant ecosystem service functions in the study area, accounting for over 50% of the total ESV. Forest ecosystem played a vital role in providing various ecosystem services. The larger decrease in the ESVs of regulating and cultural services accounted for 16.56% and 14.11% respectively, whereas the relatively smaller decrease in the ESVs of the supporting and provisioning services accounted for a corresponding 8.21% and 5.34% (Figure 3).

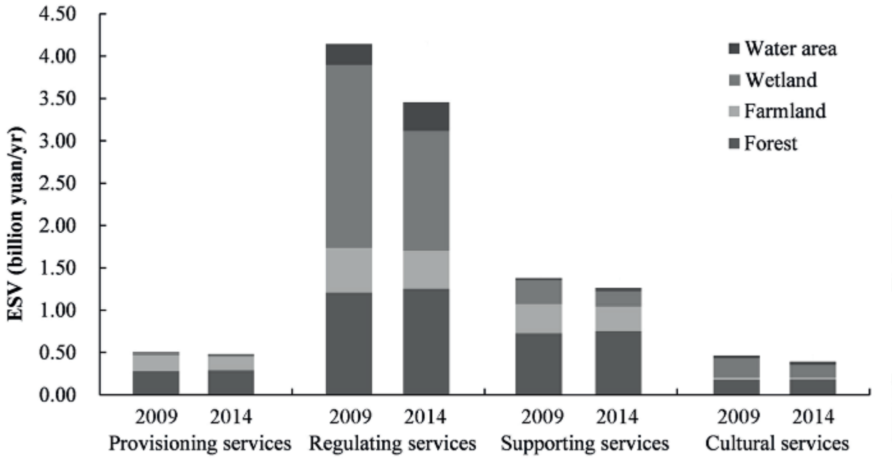

Figure 3: ESV variation in each ecosystem service from 2009 to 2014.

Obviously, the ESV of all the ecosystem service functions consistently decreased, with the regulating service functions of climate regulation, waste treatment, and hydrological regulation having the greatest reduction rates of 20.02%, 20.00%, and 14.68% respectively. The decline in wetland and farmland areas as well as the expansion of built-up land may well explain the ESV reduction in these ecosystem services.

Table 6 shows the spatial difference of ESV from 2009 to 2014. Both districts presented a decreasing trend of the total ESV by 12.14% and 16.30% respectively. The total ESV and ESV per unit area of the central urban area were approximately 50% and 80% of those of the non-central urban area, which were ascribed to their different areas and larger proportions of land-use types with lower ESV per unit area in the central urban area. Over the study period, ecosystem service functions of the non-central urban area were more seriously damaged, with a reduction rate of 15.54% for the total ESV and 14.02% for the ESV per unit area. This effect was probably caused by recent intensive constructions in the non-central urban area.

Table 6: Variation in ESV and ESV per unit area of each island and region from 2009 to 2014.

Island/region	Total ESV (billion yuan)		ESV per unit area (yuan/ha)		Change rate (%)	
	2009	2014	2009	2014	Total ESV	ESV per unit area
Central urban area	20.59	18.37	57,883.53	52,707.42	-10.77	-8.94
Non-central urban area	44.25	37.37	75,097.97	64,566.63	-15.54	-14.02
Zhoushan Island	3.36	2.98	59,514.22	53,241.87	-11.24	-10.54
Liuheng	0.99	0.81	93,129.65	78,346.58	-17.70	-15.87
Jintang	0.62	0.54	69,936.46	62,493.69	-13.07	-10.64
Zhujiajian	0.48	0.45	70,959.28	68,539.30	-7.67	-3.41
Taohua	0.32	0.27	75,685.59	67,511.85	-14.20	-10.80
Dengbu	0.20	0.17	133,901.75	117,763.68	-15.23	-12.05
Changbai	0.18	0.10	133,468.57	81,494.57	-45.70	-38.94
Xiazhi	0.11	0.09	64,507.30	49,652.44	-23.25	-23.03
Putuoshan	0.11	0.07	83,560.78	57,104.40	-40.11	-31.66
Cezi	0.10	0.09	66,436.39	61,055.50	-8.35	-8.1

As the largest island in the Zhoushan Archipelago, the total ESV of Zhoushan Island was over three times that of Liuheng Island (the second-ranked island). Over the study period, the total ESV and ESV per unit area of all the islands followed a decreasing trend, among which Changbai, Putuoshan, and Xiazhi presented the greatest reduction rates. On Zhoushan Island, the ESV reduction rate of the Shenjiamen subdistrict even surpassed 50%, and the total ESV of the northern portion of the island decreased by 0.11 billion yuan, which involved a substantial amount of occupation of wetland and farmland in these areas.

Spatiotemporal changes in carbon storage

Although this study has directly rectified the EVC of wetland ecosystem through area rectification, it is still insufficiently thorough given the great variation of area and ESV in the wetland, particularly for its regulating services. Climate regulation was one of the most dominant ecosystem service functions in the study area, accounting for approximately 17% of the total ESV. However, it was seriously damaged, and its ESV declined by more than 20% over the study period. It is known that carbon storage is closely correlated with climate regulation. This study thus introduced the carbon module in the InVEST model to reevaluate in a more precise and spatial manner the value and variation in this important function, as an indirect rectification of wetland ecosystem. As shown by the carbon pools data (Table 2), the carbon density of forest ecosystem was greatest, followed by those of farmland and water area ecosystems. Given that coastal mud flat was the main type of wetland in the study area, the carbon density of wetland ecosystem was relatively smaller, compared with its much larger ESV per unit area.

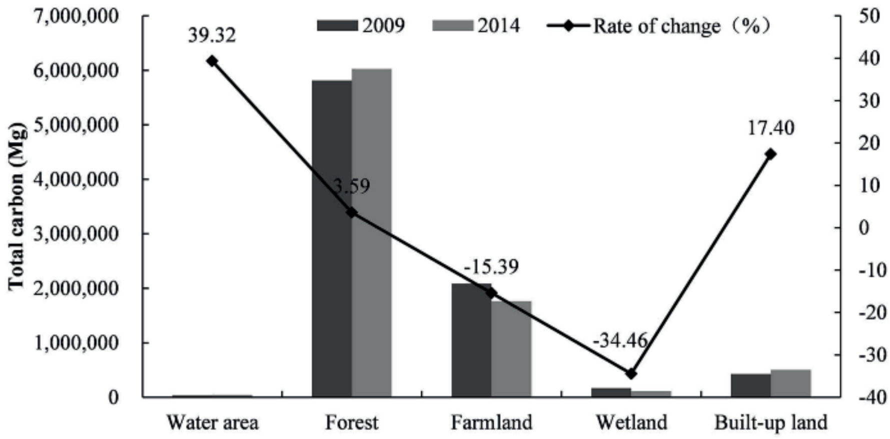

Figure 4: Variation in carbon storage of each ecosystem from 2009 to 2014.

Over the study period, the total carbon storage decreased from 8,536,276.40 Mg to 8,453,993.90 Mg, thereby releasing 82,282.50 Mg carbon, which was equivalent to a total loss of US$4,765,076.88 and an annual loss of US$953,015.38. The release rate was 0.96%. Forest and farmland ecosystems presented greater carbon storage, accounting for approximately 70% and 20% respectively. In terms of the change rate (Figure 4), a significant increase in the carbon storage of water area and built-up land ecosystems existed but was accompanied by a significant decrease in that of wetland and farmland ecosystems. These findings were consistent with the variation in land use. As the farmland ecosystem had the greatest carbon release of 320,724.63 Mg, the encroachment on farmland by built-up land may be the main reason for carbon release, which consequently impaired the ecosystem service function of climate regulation. The slight increase in the forest area helped maintain the release rate at such a low level.

Figure 5 and Table 7 show the spatial pattern of carbon sequestration from 2009 to 2014. Both districts released carbon, but Putuo presented a much higher release rate of 1.81%. Given its large forest area, Zhoushan Island achieved the largest carbon storage, which was nearly six times that of second-ranked Liuheng Island. Most of the islands released carbon. Changbai presented the largest releasing rate of 8.12%, and Liuheng, Jintang, and Zhujiajian released carbon greater than 20,000 Mg. Whether an island or region sequestered or released carbon depended on its land-use conversions, which influenced the climate regulation ecosystem service function.

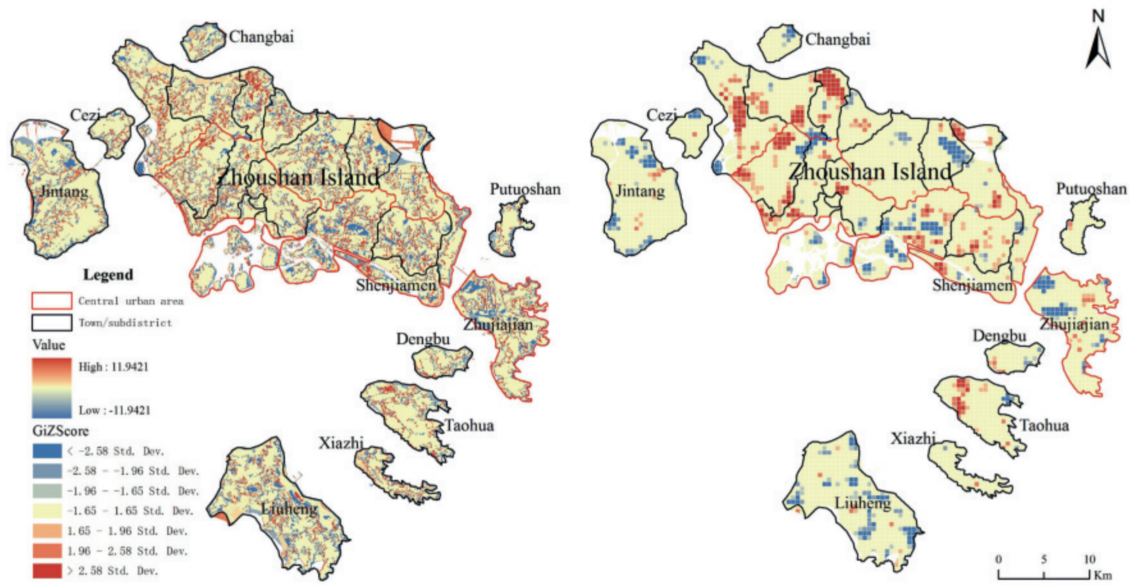

Figure 5: Spatial distribution and hotspot analysis of carbon sequestration from 2009 to 2014.

Table 7: Variation in carbon storage and sequestration value of each island and region from 2009 to 2014.

Island/region	Carbon storage (Mg)		Sequestration carbon (Mg)	Sequestration rate (%)	Sequestration value ($)
	2009	2014			
Central urban area	3,112,440	3,077,500	-34,940	-1.12	-2,893,200
Non-central urban area	5,423,280	5,373,320	-49,960	-0.92	-2,023,820
Changbai	94,058	86,424	-7634	-8.12	-442,108
Liuheng	875,746	829,428	-46,318	-5.29	-2,682,310
Zhujiajian	593,580	568,881	-24,699	-4.16	-1,430,380
Jintang	874,613	845,902	-28,711	-3.28	-1,662,700
Cezi	144,678	142,141	-2537	-1.75	-146,893
Putuoshan	130,319	128,049	-2270	-1.74	-131,458
Dengbu	128,674	127,144	-1530	-1.19	-88,652
Xiazhi	175,510	173,577	-1933	-1.10	-111,941
Zhoushan	5,072,540	5,095,520	22,980	0.45	1,330,950
Taohua	446,003	453,747	7744	1.74	448,475

Potential effects of the National New Area development policy on island ecosystem services

The implementation of the National New Area policy caused a huge demand for construction land. However, given the scarce land resources in the archipelago, people preferred to occupy farmland, wetland, and unused land, thereby altering the ecosystem patterns and affecting the ecosystem services. The transformation of the developmental orientation caused rapid economic development and urbanisation in Zhoushan but also had an overall influence on ecosystem services. Simultaneously, specific kinds of spatial planning practices led to spatial differences in the declines in ESV and carbon storage. Preferential policies guaranteed Zhoushan's development but further influenced island ecosystem services, particularly for the differentiated land-use policy.

Impacts of transforming developmental orientation

The National New Area policy specified and enhanced Zhoushan's developmental orientation. Before Zhoushan was established as a National New Area, its urban development planning for 2000 to 2020 only positioned this region as an ocean and marine cultural city with a developed economy. However, after the establishment of the New Area, its development became part of national strategy. Thus, the orientation was transformed into three aspects: a pilot area for marine economic development in Zhejiang; an important economic growth pole of the Yangtze River Delta; and an experimental zone for comprehensive marine development, which involves many aspects, such as transforming and upgrading the marine industrial structure, optimising the layout of the port industry, education and introducing skills, and protecting the marine environment on a scientific basis. These three strategic orientations raised Zhoushan's development goals and construction intensity. The number of provincial key construction projects in Zhoushan increased from 19 in 2011 to 44 in 2015. Since 2013, 100 major projects have been implemented annually, mainly in Dinghai and Putuo, with an annual investment of up to approximately 50 billion yuan. Leading industries were also transformed from agriculture and fishery to non-agricultural industries, such as ports, logistics, shipbuilding, manufacturing of marine engineering equipment, marine tourism, and pelagic fishery.

Table 8: Variation in ESV in response to socioeconomic drivers and land-use changes.

Index	2009	2014	Change rate (%)
ESV (billion yuan)	6.50	5.61	-13.69
Carbon storage (Mg)	8,536,276.40	8,453,993.90	-0.96%
GDP (billion yuan)	41.85	68.33	63.29
ESV/GDP (%)	15.53	8.21	-47.14
Total population (person)	1,063,000	1,146,000	7.81
Area of built-up land (ha)	17,001.00	19,958.85	17.40

Note: Given that ESVs in 2009 and 2014 were both computed based on the price level in 2012, the corresponding GDPs in 2009 and 2014 were also adjusted, with the GDP in 2012 set as the baseline, using data from the National Bureau of Statistics of China and the Zhoushan Bureau of Statistics. Area of built-up land was derived by interpreting remote sensing images.

Such transformation of developmental orientation caused rapid economic development and urbanisation in Zhoushan. Cargo throughput of the Ningbo-Zhoushan port surpassed Shanghai for the first time in 2012, and the gap widened to 34 million tons in 2013. In addition, Zhoushan's per capita GDP exceeded the average level of Zhejiang Province in 2005, and since 2011 this gap has gradually widened: The per capita GDP of Zhejiang Province was only 81.89% that of Zhoushan in 2014. However, with the growth of GDP, total population, and built-up land area, the ESV and carbon storage of Zhoushan declined, and the ratio of ESV to GDP decreased by nearly 50%, as shown in Table 8. These results indicate that substantial economic growth, population growth, and expansion of built-up land exerted negative effects on Zhoushan's ecosystem services.

Specific kinds of spatial planning producing spatially distinct damage to island ecosystem services

The National New Area policy specified Zhoushan's developmental pattern. Zhoushan Island is set as the city center. Changbai, Cezi, and Jintang are located in the western development belt, which is the main region for industrial development and urbanisation. Liuheng, Xiazhi, Taohua, Dengbu, Zhujiajian, and Putuoshan are located in the eastern development belt, with the themes of marine recreational industry and maritime garden city. Over the study period, the total population and population engaged in the secondary sector on Zhoushan Island increased by 6.04% and 5.25% respectively and the number of industrial enterprises in the western development belt increased from 625 in 2009 to 788 in 2014. In the western development belt, farmland and wetland decreased by 16.25% and 41.23%, with a large increase of 41.23% in built-up land, while in the eastern development belt, farmland and wetland decreased by 26.91% and 29.11%, with a large increase of 36.01% in built-up land. Under such influence, the total ESV and ESV per unit area of the western development belt declined by 19.04% and 16.22% respectively, which were higher than those of the eastern development belt (16.20% and 13.17% respectively). The situation was identical for the carbon release rate: 3.49% in the west and 2.94% in the east. Furthermore, the ESVs of regulating and cultural services of the western development belt declined by 22.27% and 19.95% respectively, which were higher decreases than those of the eastern development belt (18.17% and 15.46% respectively). It is clear that the impairment in ecosystem services was more serious in the western development belt.

Moreover, the new developmental pattern of 'south for life, center for ecology, and north for production' was implemented on Zhoushan Island. With people mainly migrating to the southern part of the island, urban areas expanded. The northern marine industrial belt, located within the range of Xiaosha and Zhanmao, is a pilot area for industrial transformation and an upgrading and agglomeration area for the development of new marine industries. Over the study period, the population engaged in the secondary sector of this region increased remarkably by 47.37%. Farmland and wetland decreased by 12.14% and 27.58% while built-up land increased by 14.86%. However, given the exploitation of ports, piers, and industrial land along the northern shoreline, the ESV in this area decreased by 0.11 billion yuan, and the ecosystem service functions of climate regulation and waste treatment were seriously impaired, with decrease rates of 12.01% and 12.68% respectively.

Besides Zhoushan Island, the islands of Liuheng, Jintang, and Changbai presented the largest declines in total ESV, which were 0.18, 0.08, and 0.08 billion yuan respectively. The carbon release rates of these three islands were also greater than those of the other islands. Liuheng and Jintang are the two islands closest to the mainland in the study area. Liuheng is the central town in the eastern development belt, and Jintang is a key town in the west, where the container port coastlines are mainly distributed. Given the principle of coordinated and integrated development for land and sea, these two islands suffered greater anthropogenic interference. Over the study period, the population engaged in the secondary and tertiary sectors on Liuheng and Jintang increased by 17.43% and 19.01% respectively. On Liuheng, farmland and wetland decreased by 24.41% and 27.10% respectively, built-up land increased by 14.86%, and four ecosystem services suffered severe impairment with decrease rates over 12%. On Jintang, farmland and wetland decreased by 19.19% and 33.74%, built-up land increased by 41.71%, and the regulating and cultural services suffered more serious impairment with decrease rates of 15.22% and 12.48% respectively. Changbai and Liuheng are planned to prioritize the development of vital marine industries, such as shipbuilding and manufacturing of marine engineering equipment. Despite its extremely small land area, the advantageous location and abundant resources of Changbai led to its rapid development and serious impairment in terms of ecosystem services, wherein the total ESV and ESV per unit area declined by 45.70% and 38.94% respectively, and the carbon release rate reached a maximum of 8.12%. Furthermore, given the slight variation in forest on other islands, forest in Changbai declined by 16.03%, and wetland also reached the greatest decrease rate of 58.76%, with built-up land having the largest increase rate of 72.74%. As a result, seven of nine ecosystem service functions' decrease rates of ESV were over 30%, with the function of climate change having the greatest reduction rate of 51.91%.

Table 9: The change rate of area/ESV of each land-use type/ecosystem service function in each region/island from 2009 to 2014 (%).

Land-use type/ ecosystem service function	Western development belt	Eastern development belt	Northern marine industrial belt	Liuheng	Jintang	Chang bai
Forest	-0.31	4.54	5.99	-0.80	1.04	-16.03
Farmland	-16.25	-26.91	-12.14	-24.41	-19.19	11.63
Wetland	-41.23	-29.11	-27.58	-27.10	-33.74	-58.75
Water area	62.00	73.64	38.13	52.71	48.42	94.78
Built-up land	41.23	36.01	14.86	52.20	41.70	72.74
Food production	-15.27	-21.54	-9.72	-20.54	-15.95	-13.21
Raw materials production	-4.13	-2.29	2.02	-6.64	-2.99	-17.85
Gas regulation	-11.60	-9.76	-2.09	-13.53	-7.93	-37.03
Climate regulation	-26.22	-20.89	-12.01	-21.81	-18.92	-51.91
Hydrological regulation	-20.24	-16.14	-7.42	-16.86	-12.71	-48.14
Waste treatment	-25.70	-21.11	-12.68	-20.33	-18.36	-49.81
Soil formation and conservation	-11.74	-11.95	-3.72	-14.80	-9.51	-30.11
Biodiversity maintenance	-12.88	-11.35	-3.19	-14.19	-8.82	-38.27
Providing aesthetic value	-19.95	-15.46	-6.62	-17.16	-12.48	-49.03
Total ESV	-18.99	-16.16	-7.06	-17.67	-13.03	-45.68

Preferential policies further influencing island ecosystem services

Since the establishment of the National New Area, Zhoushan has enjoyed various resources and preferential policies, which have guaranteed its development but further influenced island ecosystem services. To improve the administrative system and coordination among its administrative divisions, the State Council set up the Zhoushan Archipelago New Area Administrative Committee and even endowed the committee with provincial management rights to enlarge its autonomy with regard to development. In addition, more convenient approval procedures were established for national and provincial key projects utilizing marine areas. Priorities in financial and tax policies comprehensively ensured rapid development and construction.

Among the preferential policies, the differentiated land-use policy demonstrated a direct influence on island ecosystem services. This policy prioritized land use for marine projects. Farmland occupied by national and provincial projects, which could not be supplemented in other cities in Zhejiang Province after evaluation, could be supplemented in provinces elsewhere in China. This facilitated encroachment upon the archipelago's farmland, thereby affecting its ecosystem services. This increased the importance of sound planing and development policy in Zhoushan to offset the negative impacts of provincial-level policies. Moreover, to satisfy the great demand for land, land reclamation projects were heavily promoted, particularly on Zhoushan Island, Jintang, Liuheng, and Zhujiajian. The alongshore method of coastal reclamation mainly used in the construction of urban and industrial areas is today prevalent in Zhoushan Archipelago, due to its low difficulty and construction costs. However, this method has led to a rapid shrinkage of coastal wetland, thereby damaging its regulating services.

Discussion and conclusion

This study revealed the spatiotemporal changes in land use, ESV, and carbon storage of Dinghai and Putuo in the Zhoushan Archipelago before and after the establishment of the National New Area, and it comprehensively analyzed the potential effects of this national policy on island ecosystem services.

The results showed that the total ESV and carbon storage declined by 13.69% and 0.96% respectively, with a remarkable increase in built-up land (17.40%) and decrease in farmland (15.39%) and wetland (34.46%). The ESV of all the ecosystem service functions consistently decreased, with the regulating service functions of climate regulation, waste treatment, and hydrological regulation having the greatest reduction rates. The encroachments upon farmland and wetland by built-up land in the northern and southeastern coastal areas of Zhoushan Island and on the islands in Putuo District were the main causes for the impairment in ecosystem services and carbon release. Forest ecosystem played a vital role in providing various ecosystem services and carbon sequestration because of its large area, high ESV per unit area, and carbon density.

Islands are relatively closed, fragile, and sensitive to external interference. Under the influence of the National New Area policy, the land-use structure in Zhoushan was altered, thereby changing its ecosystem patterns and further impairing ecosystem services. Although the central and local governments have begun taking measures to protect sensitive areas in Zhoushan, we still recommend some preliminary suggestions based on the results obtained here in order to pursue sustainable use of the archipelago. First, given its large forest area and strong ecosystem service functions, the government should pay more attention to forest protection on both small and large islands, in terms of both quality and structure. Second, other land reclamation methods, such as the offshore method of artificial island reclamation, which is suitable for relatively independent industrial bases for logistics, petrochemical, and other industries, can be adopted to partly replace the alongshore method. The balance between conservation and exploitation of coastal wetland should be carefully considered in the future. Finally, although the ecosystem service valuation is advantageous, and a growing number of case study-based publications have proved its usefulness, this approach is seldom used in practice (Wu et al., 2013). ESV should be given adequate weight in land-use decision-making processes for islands. The ESV/GDP relationship could be a good tool for assessing the tradeoff between island development and ecological conservation. If GDP goes up, a net positive variation of the ESV/GDP value means a real improvement in ecosystem services along with the development, which achieves a win-win result.

Several limitations remain. First, our estimate of ESV is limited by data and methods; it thus represents a crude measure and is likely an underestimation. The land-use classification was too rough to acquire more precise results. The maritime ESV was somewhat neglected, given that the boundary between the coast and shallow seas can be difficult to determine using Google Maps, and the derivation of the coastal wetland may result in an underestimated ESV. We also ignored the ESV of built-up land, which might exert a positive or negative effect on the environment. Given the EVC we adopted, just nine ecosystem services were included, with services such as pollination and gene resources being ignored. We conducted EVC rectifications for area and forest ecosystem but did not rectify other ecosystems more precisely. Second, given a lack of thorough carbon density data, we may be underestimating carbon storage. Third, we only comprehensively discussed the potential effects of the national development policy on island ecosystem services; we did not include other factors and carry out a thorough quantitative analysis. Although the absolute ESV and carbon storage may be insufficiently accurate, we are primarily interested in the dynamics of ecosystem services over the study period.

In the future, focus should be placed on more precise measurements of island ESV, including the marine zone and a thorough quantitative analysis of the effects of development policies. The cost-benefit analysis of increased economic development and loss of ecosystem services in islands is also well worth exploring.

Acknowledgements

This work was supported by the Key Program of the National Social Science Foundation of China (No. 14AZD124), National Natural Science Foundation of China (No.41671533; 51508498), and the Fundamental Research Funds for the Central Universities (2016XZZX004-02).

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