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Original Research

Tradeoffs and Time Lag in Ecosystem Services during Degradation and Restoration Processes in a Freshwater Lake Region in Northern China

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Abstract

Understanding the tradeoffs between ecosystem services is important to ensure the success of ecological restoration projects. This study assesses the tradeoffs and time lag between ecosystem services during the degradation and restoration of a freshwater lake. Changes in land cover and ecosystem service value (ESV) were studied from 1984 to 2015 in Mata Lake. Results suggested that land cover change fluctuated frequently in Mata Lake, specifically for water and lakeside wetland. The ESV change was later than land cover change in time scale, indicating a time lag between land cover change and ESV change. Results of Pearson's correlation analyses showed that tradeoffs in ecosystem services mainly occurred in provisioning and regulating services. We noted that the temporary increase of single ecosystem services such as food production in the lake was detrimental to the long-term development of total ecosystem services. On the contrary, improvement of some regulation services at the cost of provisioning services contributed significantly to total ESV. The biodiversity conservation was significantly related to other ecosystem services, while food production and raw materials were not. Hence, biodiversity conservation is holistic and affected by multiple circumstances. Our research in Mata Lake has significant implications on future restoration and management projects for other lakes worldwide.

Keywords: ecosystem restoration, ecosystem service value, land cover change, land use dynamic index, time lag

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Introduction

Ecosystem services have benefited humans since primitive times and have drawn increasing attention as the relationship between humans and ecosystems has intensified [1]. The Millennium Ecosystem Assessment proposed an ecosystem services classification that includes provisioning, regulating, cultural, and supporting services [2]. To improve understanding and assist in the management of different ecosystems, ecosystem service valuation has been widely studied [3]. However, ecosystem service value (ESV) is often ignored when society focuses on the market value. Valuation of ecosystem services, particularly nonmarket ecosystem goods and services, has been in increasing demand over the last few decades [4]. Following the definition of ecosystem services, systematic and accurate theoretical methods for ecosystem services valuation [5-6] have been developed and applied worldwide. Scholars started to evaluate ecosystem services as a method to guide the decision-makers in ecosystem management [7-9].

Tradeoffs between ecosystem services occur when one ecosystem service rises at the cost of other services [10]. Figuring out tradeoffs between ecosystem services can help stakeholders with ecosystem conservation and management, as the potential losers and winners of land cover changes may cause changes in ecosystem services. In the recent past, tradeoffs between ecosystem services was partly proven, especially between only two ecosystem services [11]. Jiang et al. [12] mapped changes in agriculture and forestry, carbon storage, and biodiversity in a landscape in the UK for a time period of 70 years. They figured that there was a significant increase in agricultural provisioning at the cost of biodiversity. Howe et al. [13] used 1324 relevant reports to identify tradeoffs and synergies, where tradeoffs had at least one loser and one winner of ecosystem services and synergies had at least two winners. They found that tradeoffs are more recorded than synergies. A private interest like financial gains accompanies management choices, which mostly change land cover. Many scholars have researched similar relationships between ecosystem services, but have mostly focused on only two ecosystem services at one time [11]. Studies conducted in China also lack a systematic approach to ecosystem service relationships. Holistic research on the relationship between ecosystem services is needed for better understanding and application in ecological management.

Recovering from ecosystem damage caused by humans is defined as ecological restoration [14], and remediation of ecosystems has become a significant concern worldwide [15]. Most measures in lake restoration have dealt with water quality improvement. About 130 million USD was invested for ecological restoration by the Swedish government from 1995 to 2011, in which aquatic environments were prioritized [16]. The Chinese central government have also made substantial investments and strict laws in ecological plans of lakes, which resulted in improved water quality from 2005 to 2017 [17].

Our research has focused on Mata Lake in China, which had undergone significant changes in land use/cover rather than water quality. Land cover changes result in changes in ecosystem services, which has different sides. Land cover changes can increase the vulnerability of ecosystem services; on the other hand, it can be beneficial and make a win-win effect between land cover changes and ecosystem services [18-20]. With land cover changes in spatial patterns caused by management choices, ecosystem services transform from one to another and then tradeoffs and synergies happen between ecosystem services [21-24]. Recent restoration work in Mata Lake has offered us an opportunity to study the changes empirically and understand the relationships and tradeoffs in ecosystem services and land cover changes. Therefore, the two primary aims of our study were: 1) to identify the tendency of land cover changes and ESV changes during degradation and restoration of the Mata Lake; and 2) to demonstrate the tradeoffs and relationship between different ecosystem services.

Material and Methods

Study Area

Mata Lake is located in Zibo, Shandong Province, China, and has been named a provincial-level ecological function protection area. The area of Mata Lake Basin is 84,000 ha, extending over 50 villages. The area of open water was once 9,600 ha in the 1930s. Mata Lake Basin at an altitude of 7.59 m belongs to warm temperate continental monsoon climate. The annual average temperature of the lake basin is 12.9ºC and the average annual precipitation is 587 mm. With development in agriculture and economy, the lake has shrunk significantly in land cover. Mata Lake has been chosen as one of the pilot lakes in Shandong Province for restoration work since 2011. The project aims at increasing water storage of the lake, improving water quality of both the lake and the inflow rivers, and creating the Mata Lake Constructed Wetland.

The location of the study area is shown in Fig. 1. The study area was about 7,880 ha around the artificial lake and extended 8.49 km eastward and 5.94 km westward around the lake center, considering the Xiaoqing River as the northern boundary and Qima Road as the southern boundary (within lat 37°2′56″–37°6′55″N, long 117°59′23″–118°9′15″E).

Data Source and Land Cover Classification Based on GIS

The data used for land cover classification in our study were acquired from the Landsat images described

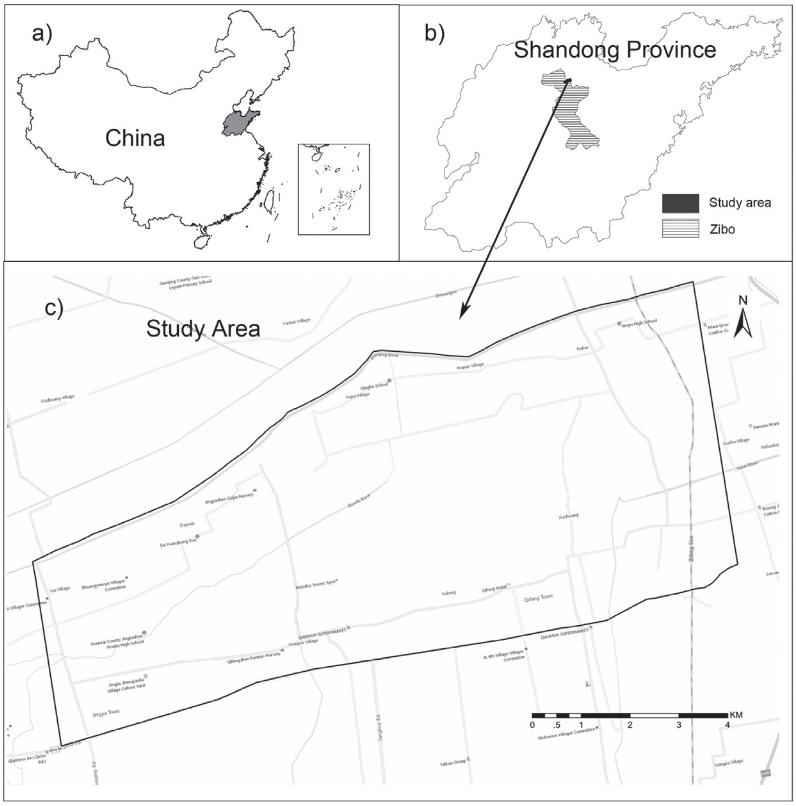

Fig. 1. Location of the study area in Shandong, China.

in Table 1. The images (WRS Path 121 and WRS Row 34) with a spatial resolution of 30 m were obtained from the United States Geological Survey website (http://glovis.usgs.gov/). To reduce potential errors, we chose images with less cloud cover. ArcGIS 10.2 and ENVI 5.1 were used to classify land cover categories and analyze the statistics for each land cover category. After a series of preprocessing, including geometric correction, image cutting and atmospheric correction, supervised classification ("likelihood classification") was used to classify land cover categories. Finally, field survey data and high-resolution images (from the Shandong Provincial Environmental Protection Bureau and Google Earth) were used to rectify and evaluate the classification results. The total accuracies were above 85%, which met the requirements. Land cover was classified into four categories: water, lakeside wetland, settlement, and farmland using a supervised classification technique. Usually, wetlands include both perennially flooded areas and seasonally flooded areas. In our study, lakeside wetlands indicated seasonally flooded areas, which meant that open water was excluded from wetland as a single part.

Table 1. Information of Landsat images used in the study.

Year	Acquisition Date	Cloud Cover	Sensors
1984	24-Dec	5%	TM
1990	25-Dec	76%	TM
1995	23-Dec	0%	MSS
2000	2-May	0%	ETM+
2005	16-Nov	24%	TM
2009	4-Jun	0%	TM
2015	5-Jun	0%	OLI

TM: Thematic Mapper; MSS: Multispectral Scanner; ETM+: Enhanced Thematic Mapper Plus; OLI: Operational Land Imager

Land Use Dynamic Index

Land use dynamic index (LUDI) expresses the quantity of change in a specific land cover category during a certain period of time in the research region [25]. Single LUDI, *K*, is used to represent a specific category of land cover while integrated LUDI, *LC*, expresses the overall land cover change in all land categories. The formula of single LUDI and integrated LUDI is shown in Table 2. *K* and *LC* can describe the rate of land cover change and also forecast land cover change in the future.

Assessments and Calculations of Ecosystem Service Value

Costanza et al. [26] evaluated global ecosystem services using systematic methods that are currently

Table 2. The formulas and parameter descriptions in the method.

Indicator	Formula	Parameter description
Single land use dynamic index (LUDI)	$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\%$	*K* is the single LUDI for a specific land cover category; U_a, U_b are the quantities for the land cover category during the first phase and last phase respectively; and *T* is the duration of the study. When *T* is set as a year, *K* represents the annual rate of change for the specific land cover category in the study region.
Integrated LUDI	$LC = \left[\frac{\sum_{i=1}^{n} \Delta LU_{i-j}}{2\sum_{i=1}^{n} LU_i}\right] \times \frac{1}{T} \times 100\%$	LU_i is the area of land cover category, *i* represents the time of the first phase; $\Delta LU_{i\text{-}j}$ is the difference between the area of the land cover category *i* and area of other land cover categories during the study; and *T* is the duration of study. Similar to the single LUDI, when *T* is set as one year, *LC* represents the annual rate of change for land cover categories in the study region.
Total estimated ecosystem service value	$ESV = \sum (A_k \times VC_k)$	*ESV* is the total estimated ecosystem service value, A_k is the area, and VC_k is the value coefficient of land cover category '*k*' as listed in Table 3 [29].
Single ecosystem service value	$ESV_s = \sum (A_k \times VC_{sk})$	ESV_s is the single ecosystem service value for each ecosystem function '*s*', A_k is the area, and VC_{sk} is the value coefficient for each ecosystem function '*s*', as listed in Table 3 [40].
Coefficient of sensitivity	$CS = \frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} - VC_{ik})/VC_{ik}}$	*ESV* is the total estimated ecosystem service value, *VC* is the value coefficient, *i* and *j* are the initial and adjusted values, respectively, and K is the land cover category. If CS is greater than one, the estimated ecosystem value is elastic with respect to that coefficient. Otherwise, the estimated ecosystem value is considered as inelastic [29]. Higher CS implies that it is critical to use a more accurate ecosystem value coefficient.

used worldwide. However, the application of their methods in China was controversial. For instance, 1) the value of cropland was underestimated; 2) the ecosystem services valuation system proposed could overestimate the ESV in developing countries like China; 3) regulating and supporting services were indirect and difficult to be valued; and 4) certain ecosystem services were ignored due to insufficient information [6].

Xie et al. [6] reclassified the ecosystem services into nine categories. Their valuation method was also based on Costanza's valuation of global ecosystem services and revised by questionnaires for about 700 Chinese ecologists. They valuated the ecosystem services in China in 2010 using equivalent value per unit area [27].

Although methods of Costanza et al. [26] and Xie et al. [6] are imperfect in estimating ecosystem services, they evaluate approximations of the global ecosystem services comprehensively [28]. As our study focused on the changes in ecosystem services over time, ESV estimations that highlighted tendencies were considered sufficient. The method and parameters of Xie et al. [6] were chosen as they are more suitable for ecosystem services valuation in China. In addition, due to the overlap of some ecosystem services, double counting is a common problem in ecosystem services valuation and can cause inaccuracy and uncertain valuation results [29]. In our study, the method of Xie et al. [6] was modified by removing the supporting services such as nutrient cycling and soil formation in order to avoid double counting. Ecosystem service value coefficients (VCs) used in this study are listed in Table 3. Due to the VC of settlement being zero, the ESV of settlement is only listed in the VCs table. Total estimated ESV and single ESV for each ecosystem service type were calculated by formulas in Table 2.

For each land cover category, the ecosystem type was not perfectly matched in every case. Additionally, the VCs for these ecosystems were not completely

Table 3. Ecosystem service value per unit area of terrestrial ecosystems in China (USD·ha^{-1}·year^{-1}) [6].

Ecosystem services	Gas regulation	Climate regulation	Water conservation	Waste treatment	Biodiversity conservation	Food production	Raw materials	Recreation and cultural	Total
Farmland	42.1	56.72	45.03	81.28	59.65	58.48	22.81	9.94	376.01
Lakeside wetland	140.93	792.36	785.92	842.06	215.78	21.05	14.03	274.26	3086.39
Water	29.82	120.46	1097.61	868.38	200.57	30.99	20.47	259.64	2627.94
Settlement	0	0	0	0	0	0	0	0	0

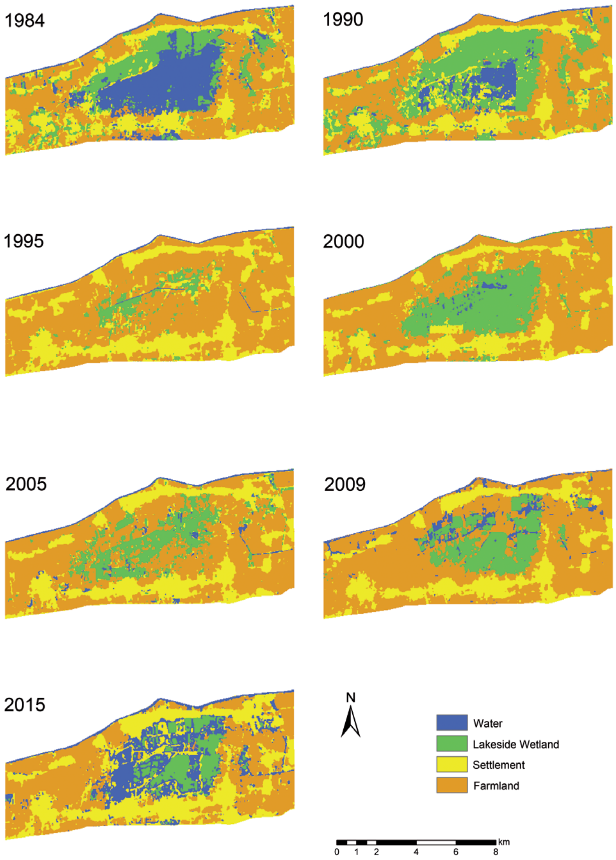

Fig. 2. Land use cover change of the study area between 1984 and 2015.

suitable as a result of climate and geographic variation. Due to these uncertain influencing factors, sensitivity analyses that test the percentage change between ESV and corresponding value coefficient should be applied in ecosystem services valuation [28]. The coefficient of sensitivity (CS), based on the standard economic concept of elasticity, was calculated (Table 2). VCs for land cover categories were each adjusted by 50% in our study.

Pearson correlation analyses of ecosystem services were performed using Statistical Product and Service Solutions (SPSS, version 23.0) software.

Results

Land Cover Changes

The changes in individual land cover categories are shown in Figs 2 and 3. Farmland was dominant among land cover categories, extending to 66.11% in 2000. As other land cover categories changed, water registered small percentages of change of 1.20% and 1.34% respectively in 1995 and 2000. While settlement accounted for 23.83%, lakeside wetland varied from 5.62 to 27.53%. Single LUDI for each land cover category and integrated LUDI were assessed (Table 4). The most significant change was for land cover of water, followed by lakeside wetland. Land cover of water decreased most

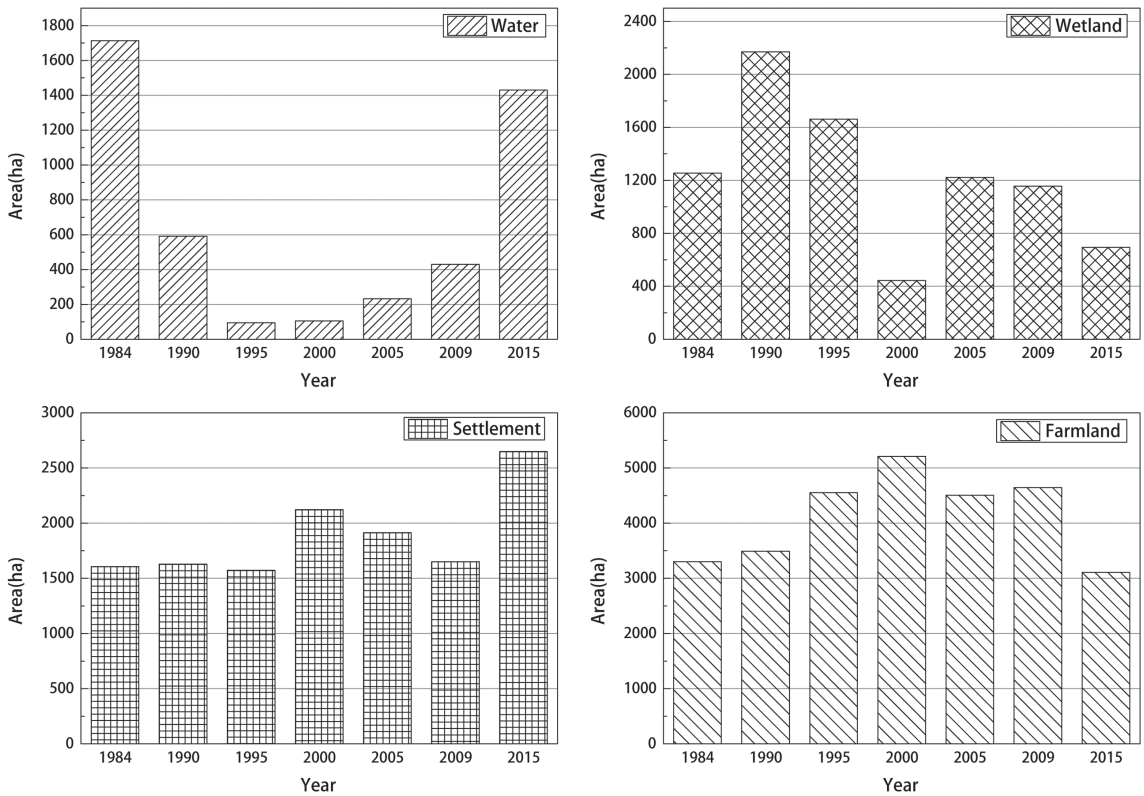

Fig. 3. Areas of land use cover categories in the study area between 1984 and 2015.

Table 4. Single land use dynamic index for each land cover category and integrated land use dynamic index of study area from 1984 to 2015.

	1984–1990	1990–1995	1995–2000	2000–2005	2005–2009	2009–2015
Water	-10.91	-16.79	2.22	23.92	21.41	38.75
Lakeside wetland	12.16	-4.68	-14.67	35.15	-1.35	-6.66
Settlement	0.23	-0.69	6.98	-1.96	-3.44	10.08
Farmland	0.95	6.08	2.89	-2.70	0.76	-5.51
Integrated index	2.38	2.69	3.09	2.30	1.06	4.22

Negative numbers mean the loss of this category of land use/cover.

between 1984 and 1990, while land cover of lakeside wetland increased most. From 1990 to 1995, land cover of settlement registered a slight fluctuation and all land categories except farmland decreased in area. The land cover of water translated to others with a 'high' single LUDI of -16.79, where the negative sign indicates a loss of the land cover category. During the period 1995 to 2000, only land cover of lakeside wetland recorded a sharp decrease. From 2000 to 2005, land cover of settlement and farmland were converted to a lesser extent to water and lakeside wetland with low single LUDI. Land cover of water also increased significantly from 2005 to 2009, while farmland nominally changed in area. Correspondingly, the other two land cover types lost some area. Land cover of water recorded a significant change with the highest single LUDI of 38.75 during the period 2009 to 2015. Thus, the maximal change of land cover occurred between 2009 and 2015, highlighted by the highest integrated LUDI of 4.22.

In the 1980s, water inflow of the study area decreased and agriculture and fisheries developed rapidly. Wetland and water were used as agricultural fields and fish ponds, and were gradually transformed to intersecting segments of farmland. This change from 1984 to 1990 was at the cost of extensive loss of water area (1,121.58 ha, almost one-third compared to 1984). On the contrary, the wetland area was 2,169.72 ha, nearly double compared to 1984. This land use pattern aggravated the decline of open water, which fell to 94.95 ha in 1995 – about one-sixth compared to 1990. The area of farmland rose at a cost of the loss of wetland (507.69 ha) and water (496.26 ha) from 1990 to 1995. Until 2000, the area of farmland continued rising to 5,208.75 ha with the loss of wetland (442.98 ha, decrease to one-fourth compared to 1995). Meanwhile, the settlement area increased to 2,121.66 ha.

During the restoration project in Mata Lake, constructed wetlands were built to improve the water quality and recover ecosystem services. From 2005 to 2015, the water area had recovered to 1,429.74 ha, whereas the wetland area decreased after an initial increase. The loss of farmland was substantial, whereas the other three land cover categories increased. The settlement area increased as a consequence of the project, as other land covers were transitioned into settlement areas before being converted to other land types.

Changes of Ecosystem Service Value

The total ESV estimated for each land cover category in the study area from 1984 to 2015 is shown in Fig. 4. Land cover of lakeside wetland contributed significantly during the study period. There was a peak value with 9.61×10^6 USD in 1984 following by a similar value in 1990. The ESV dropped to 3.60×10^6 USD in 2000. From 2005 to 2015, the value exhibited an upward trend, and recovered to 7.07×10^6 USD in 2015. From 1984 to 2000 the ESV decreased and has been increasing since 2000 (Table 5). The rate of ESV change also implied that land cover of water and wetland had changed more dramatically.

For detailed analysis, single ESVs were calculated and analyzed (Fig. 5). Waste treatment ranked first, followed by water conservation, climate regulation, biodiversity conservation, recreation and culture, gas regulation, food production, and raw materials. Although the waste treatment service dropped from 1984 to 2000 and fell to 0.89×10^6 USD per year, it

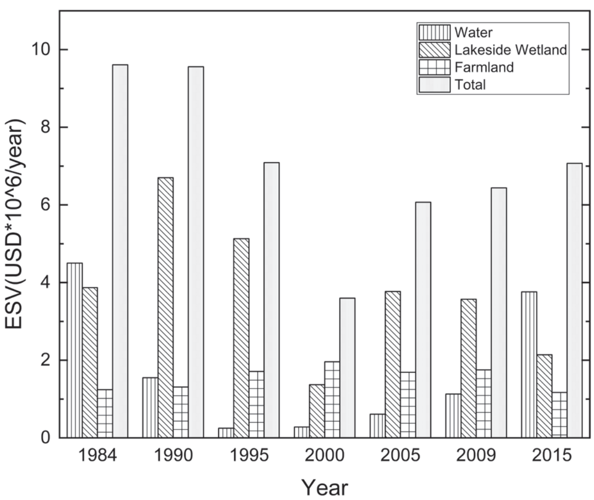

Fig. 4. Total ecosystem service value estimated for each land cover category in study area from 1984 to 2015.

Table 5. Rate of change of ESV for each land cover category in study area from 1984 to 2015.

Land use category	1984–1990	1990–1995	1995–2000	2000–2005	2005–2009	2009–2015
Water	-65.48	-83.94	11.09	119.62	85.63	232.48
Wetland	72.94	-23.40	-73.35	175.74	-5.39	-39.94
Farmland	5.72	30.38	14.46	-13.49	3.05	-33.07
Total	-0.54	-25.85	-49.19	68.56	6.09	9.71

consistently ranked first among the eight ecosystem services. On the contrary, raw materials service ranked last with an average of 0.12×10^6 USD from 1984 to 2015. The rankings of other ecosystem services have shifted over the years.

Ecosystem Services Sensitivity Analyses

Results of sensitivity analyses are shown in Table 6. The CS in all cases were less than one, indicating that the total estimated ESV in the study area was relatively inelastic with respect to the VCs. This also implies that our estimated ESV was robust. A lower value of CS reflects a weaker relationship between land cover area and the VC. However, in our study the values of CS fluctuated due to dramatic land cover changes. Accordingly, all land cover categories made considerable contributions to the ESV in Mata Lake from 1984 to 2015.

The highest percentage of lakeside wetland in the total estimated ESV indicated that its impact was the most influential. Water and farmland had a slight effect on total ESV.

Correlation Analyses

Study results indicated that strong and significant connections between the ecosystem services existed (Table 7). Each pair among waste treatment, water conservation, recreation and cultural, and biodiversity conservation recorded significant positive correlations ($p<0.01$). Climate regulation and gas regulation had significant positive correlation ($p<0.01$). In addition, climate regulation and biodiversity conservation recorded significant positive correlation ($p<0.05$). However, water conservation and food production registered negative significant correlation ($p<0.05$).

Discussion

Changes of Ecosystem Service Value

According to the changes comparing ESV and land cover, the restoration process for ESV was slower than land cover change. Thus, we inferred that a time lag existed between change in land cover and ESV. In

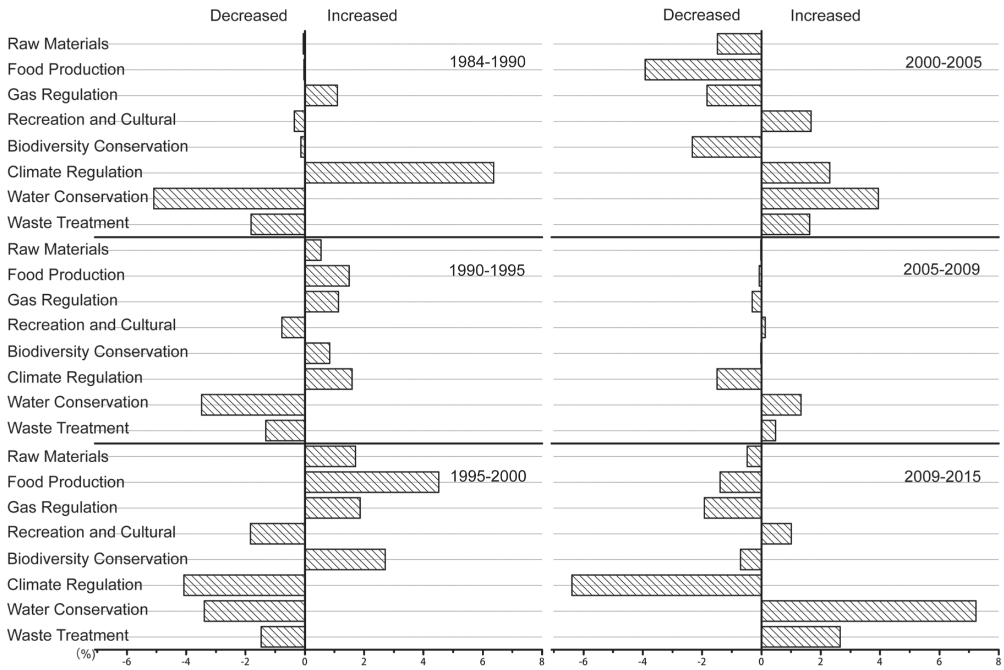

Fig. 5. Changes of single ecosystem service in study area between 1984 and 2015.

Table 6. Percentage change in total estimated ecosystem service value and coefficient of sensitivity (CS) after a 50% adjustment of ecosystem service value coefficients (VC).

Change in value coefficients	1984		1990		1995		2000		2005		2009		2015	
	%	CS	%	CS	%	CS	%	CS	%	CS	%	CS	%	CS
Water	0.23	0.47	0.08	0.16	0.02	0.04	0.04	0.08	0.05	0.10	0.09	0.18	0.27	0.53
Lakeside wetland	0.20	0.40	0.35	0.70	0.36	0.72	0.19	0.38	0.31	0.62	0.28	0.55	0.15	0.30
Farmland	0.06	0.13	0.07	0.14	0.12	0.24	0.27	0.54	0.14	0.28	0.14	0.27	0.08	0.17

general, ecosystem services respond with a time lag in response to varying pressures [30], as confirmed in our study. Firstly, large areas of open water in Mata Lake were swamped and its ESV changed little from 1984 to 1990. After several years, the ESV changed with lakeside wetland decrease. When the lake degraded in the long-term, land cover of lakeside wetland increased [31]. Wetland maintained the underlying water and provided comparable ecosystem services, which can explain the time lag in Mata Lake. This also signifies that wetland could sustain the ESV, and were good ‘containers’ for ESV [32-33]. This also explains the rise in ESV with wetland recovery during the restoration process. Land cover of water and lakeside wetland contributed notably to ESV in the study area, which was also implied in research on ESV of lake and wetland in China [34]. Ecosystem services in the study area mostly consisted of waste treatment, water conservation, and climate regulation, which accounted for nearly 70%. Additionally, the three ecosystem services were based on water and lakeside wetland, which further highlighted the importance of land cover of water and lakeside wetland. According to the average single ESVs, water and lakeside wetland-related ecosystem services ranked highest even in 2000, when the water and lakeside wetland fell and the other two categories increased.

Relationships between Ecosystem Services

Long-term land changes provide a chance to study the relationships between ecosystem services. Results of Pearson correlation analyses indicated that biodiversity conservation was strongly related to most other ecosystem services, which highlights its holistic dependence on multiple circumstances. Regulation services such as waste treatment, water conservation, climate regulation, and gas regulation were also closely interrelated. Gas regulation is climate dependent and mainly reflected by NPP (net primary production) [35-36], and our study illustrates the correlation between gas regulation and climate regulation. Specifically, food production and water conservation presented negative correlation, which was also suggested by the land cover change. Land cover of water and lakeside wetland supported water conservation, while farmland corresponded to food production. During degradation and restoration, these land cover categories experienced notable transformations, highlighting the negative correlation between water conservation and food production. Liu et al. [37] also indicated that the total ESV increased with food production decline in study of wetland rehabilitation of Nansi Lake. This proved the negative effect of food production on total ESV. This relationship informs us that during lake management, the increase in food production eventually harms other

Table 7. Pearson correlation analyses between ecosystem services.

Ecosystem services	Waste treatment	Water conservation	Climate regulation	Biodiversity conservation	Recreation and cultural	Gas regulation	Food production	Raw materials
Waste treatment								
Water conservation	0.984**							
Climate regulation								
Biodiversity conservation	0.982**	0.937**	0.794*					
Recreation and cultural	0.999**	0.977**		0.985**				
Gas regulation			0.966**					
Food production		-0.786*						
Raw materials								

*$p<0.05$; **$p<0.01$

services and decreases the total ESV in the long run. In addition, food production and raw materials were relatively independent of others, which implied that these two were comparatively easily obtainable during the land change period. For lake restoration, food production and raw materials are priority selections, as converting these two to others and the total ESV can improve this way with less harm to the surroundings. It was also found that tradeoffs in ecosystem services showed a preference in the following order: provisioning, regulating, or cultural services [38].

Conclusions

The study based on Mata Lake confirmed that land cover changes affected ecosystem services considerably during both degradation and restoration processes. Land cover of water and lakeside wetland changed significantly in Mata Lake, and the restoration process for ESV was slower than land cover change. We proposed that there was a time lag between land cover change and ESV change. Lakeside wetland land cover would have expanded further if the lake had degraded in the long-term, accompanied by low water levels. The regulating services have significantly increased at the cost of the provisioning services during the restoration process in Mata Lake. The changes indicated the tradeoffs between ecosystem services, which mainly occurred in provisioning and regulating services. Biodiversity conservation was influenced by multiple factors and needs a holistic approach, while food production and raw materials were relatively independent. In particular, food production and water conservation exhibited negative correlation, which highlights the implications for lake management to the decision makers. Therefore, the transformation of land cover and the ESV change on the growth path in Mata Lake proved the feasibility of the lake restoration project and can serve as a significant instructive aid to subsequent restorations in other lakes. Our study highlights the tradeoff of multiple ecosystem services and their consequences in the long-term, which is significant to policy makers for managing lakes worldwide.

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Conflict of Interest

The authors declare no conflict of interest.

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