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Short communication

Changes in ecosystem service values in Zoige Plateau, China

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ABSTRACT

Climate change and human activities in high-altitude, cold pasture areas with fragile environments can cause land use changes that significantly affect ecosystem services and functions. Our study investigated changes in ecosystem services in response to land use changes caused mainly by climate change and human activities on the Zoige Plateau, a region in the eastern fringe of the Tibetan Plateau with large areas of grassland and wetland. The aim was to provide guidance for sustainable management of high, cold pasture areas. We used remote sensing to evaluate land use changes, and then applied a fast method for evaluating ecological service values in 1975, 1990, and 2005. The value of ecosystem services dropped from 61.46×10^9 yuan in 1975 to 58.61×10^9 yuan in 2005, exhibiting an accelerating rate of decrease, mainly due to the degradation of wetlands and, to a lesser extent, high-cover grassland. Waste treatment and water supply were the two largest service functions, contributing about 42% of the total service value. The results suggest that future land use planning should emphasize the protection of wetlands, high-cover grassland, and woodland, which have the highest ecosystem service values and showed the greatest degradation during the study period.

1. Introduction

The valuation of ecosystem services has become a hot topic in ecological economics research. Ecosystem services can be defined as the conditions and processes through which natural ecosystems and the species they comprise sustain and fulfill human life (Daily, 1997), or as the goods and services provided by ecosystems that contribute to human welfare, both directly and indirectly (Costanza et al., 1997a,b). The growing body of literature on the valuation of ecosystem services ranges from studies on the value that temperate forests contribute toward fresh water supplies (Nuñez et al., 2006), to the spatial scales of ecosystem services (Hein et al., 2006), to changes in the value of ecosystem services in response to land use changes during urbanization (Li et al., 2008b), to the impact of land use change on the provision of ecosystem services in tropical montane cloud forests (Martínez et al., 2009). Other studies have focused on how land use changes are coupled to ecosystem services (Metzger et al., 2006; Collard and Zammit, 2006; Yoshida et al., 2010) or how changes in the value of ecosystem services can be estimated (Chen et al., 2009; Li and Ren, 2008). In each of these studies, researchers have obtained insights that can provide important guidance for land managers.

Our study focused on the Zoige Plateau, an extensive, high-altitude, cold pasture area in the eastern fringe of the Tibetan Plateau. Dramatic changes in land use have occurred here in recent decades as a result of climate warming and human activities such as overgrazing, excessive land reclamation for agriculture, and misuse of water resources (Xiao et al., 2010). The objectives of our study were (1) to assign specific value coefficients for ecosystem services in the Zoige Plateau and determine whether these coefficient could be used to evaluate changes in ecosystem services in the study area; (2) to estimate changes in the value of ecosystem services resulting from land use changes caused by climate change and changing human activities; and (3) to provide information and advice to support regional sustainable development policies.

2. Methods

2.1. Study area

The Zoige Plateau (lat 32°20′N to 34°08′N, long 101°30′E to 103°30′E, elevation 3300–4806 m above mean sea level) lies within the upper reaches of the Yellow River, in the eastern fringe of the Tibetan Plateau (Fig. 1). Covering a total area of 381×10^4 ha. It has the largest peatland in China. The climate is characterized by two distinct seasons: in winter (from November to April), it is cold and dry, with little precipitation and strong sunshine, whereas in summer (from May to October), the climate is wet (Zhang and Lu, 2009).

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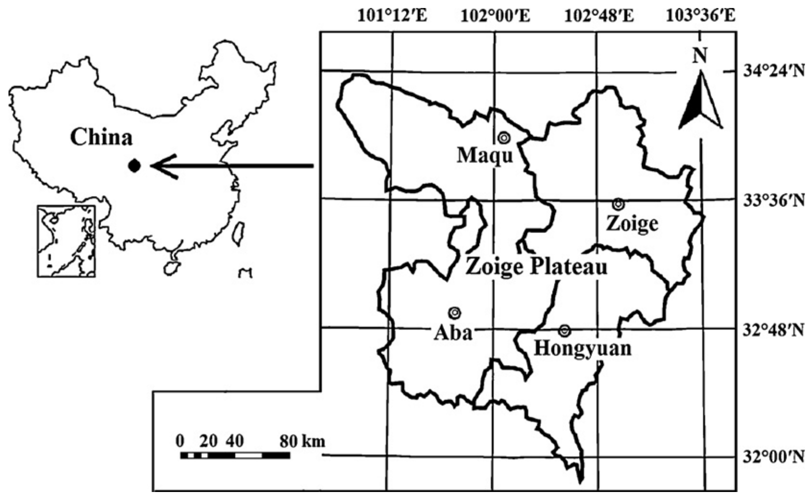

Fig. 1. The location of the study area.

The mean annual temperature in the area averages 1.6 °C, annual rainfall is 400–800 mm, and the dominant land types are grasslands and wetlands.

Climate warming (at a rate of 0.70 °C/10 yr) and increasing intensity of land use have caused rapid degradation of the Zoige Plateau, mainly in the form of grassland and wetland degradation (Li et al., 2008a). From 1975 to 2005, the areas of forest, high-cover grassland, shrubland, and wetlands decreased significantly, while construction land, unused land, moderate- and low-cover grassland, and cropland have increased significantly (Deng et al., 2010; Hu et al., 2009; Wang et al., 2008). According to statistics obtained from local governments, livestock numbers increased from 695.5×10^4 in 1990 to 790.0×10^4 in 2005, while the human population increased from 15.49×10^4 to 21.68×10^4. This combination of human activities and climate change make the Zoige Plateau an attractive study area. Also, the area includes all 6 of the land classification types listed in the resource and environment database established by the Chinese Academy of Sciences (cropland, woodland, grassland, water body, construction land, and unused land), and 23 of the 24 sub-types (see Table A.1, Supplementary information).

2.2. Data collection

The data used to estimate changes in the size of various ecosystems were extracted from one cloud-free multispectral scanner images obtained in 1975, two cloud-free thematic mapper images obtained in 1990 and 2005, and one cloud-free enhanced thematic mapper image obtained in 2000. Although these satellite images were pre-georeferenced, they could not be compared directly because they used inconsistent coordinate reference system and resolution. We used a three-step image preparation procedure (Zhao et al., 2004) to reduce potential position errors among the three data sets: (1) we identified the *X* and *Y* coordinates of pairs of points that represent prominent features on both the 2000 ETM image and the 1:100,000 topographic map of the Zoige Plateau, (2) using the topographic map as the georeferenced standard together with the GEOREFERENCING and RESAMPLING modules of IDRISI® Release 2 software (Clark Labs, 2001), we resample the 2000 ETM data set into a Universal Transverse Mercator (UTM) coordinate system, and (3) using the same procedure as in step 2 and the georectified 2000 data as the master dataset, we resampled and rectified the 1975, 1990, and 2005 raw images. An average root mean square error of less than 0.5 was achieved in steps 2 and 3 for all images and the pixel size was retained at $30 \times 30\,m^2$. We used version 3.3 of the Arcview GIS software (ESRI, Redlands, CA) to consolidate and analyze our land use data.

2.3. Assignment of ecosystem service values

Costanza et al. (1997a,b) classified the global biosphere into 16 ecosystem and 17 service function types, and estimated the ecosystem services value of each type. Using the parameters set by Costanza et al. Xie et al. (2003) extracted the equivalent weighting factor for ecosystem services per hectare for terrestrial ecosystems in China, and used these factors to correct the value coefficient for Chinese ecosystems (Table A.2, Supplementary information). We assigned ecosystem service values per unit area for each land use category in the Zoige Plateau based on the nearest equivalent ecosystems suggested by Xie et al. (e.g, woodland equates to forest) and used the modification method suggested by Su et al. (2006) to modify the Xie et al. coefficients.

2.4. Calculation of ecosystem service values

Xie et al. (2003) proposed nine types of service functions and estimated their corresponding ecosystem services value. Based on the modified coefficients (Table A.2, Supplementary information), we adjusted the value coefficients from Xie et al. for the ecosystem service functions of each land use category (Table A.3, Supplementary information). Once the ecosystem service value per unit area was determined for each land use category, the following equations were used to determine service value for each land use category, for each service function, and for the total ecosystem service value:

$$ESV_k = A_k \times VC_k, \tag{1}$$

$$ESV = \sum_k A_k \times VC_k, \tag{2}$$

$$ESV_f = \sum_k A_k \times VC_{kf}, \tag{3}$$

where ESV_k, ESV, and ESV_f refer to the ecosystem service value of land use category *k*, the total ecosystem service value, and the value of ecosystem service function *f* respectively; A_k is the area (ha) for land use category *k*; VC_k is the value coefficient (yuan $ha^{-1}\,yr^{-1}$) for land use category *k*; and VC_{kf} is the value coefficient (yuan $ha^{-1}\,yr^{-1}$) for land use category *k* with ecosystem service function type *f*.

Since the biomes we used as proxies for land use categories are not perfect matches, and since uncertainties exist in the value coef-

Table 1
Zoige Plateau land use patterns in1975, 1990, and 2005.

Land use type	1975		1990		2005		Change in area since 1975 (ha)
	Area (ha)	%	Area (ha)	%	Area (ha)	%	
Cropland	29,116	0.76	27,837	0.73	28,455	0.75	−661
Woodland	568,577	14.90	553,059	14.50	544,298	14.27	−24,279
High-cover grassland	1,230,949	32.27	1,148,815	30.11	1,067,157	27.97	−163,792
Moderate-cover grassland	794,613	20.83	864,389	22.66	907,451	23.79	112,838
Low-cover grassland	462,323	12.12	512,726	13.44	562,119	14.74	99,796
Wetlands	530,835	13.92	519,666	13.62	498,008	13.05	−32,827
Water body	58,488	1.53	57,582	1.51	57,784	1.51	−704
Construction land	3485	0.09	4366	0.11	5221	0.14	1736
Unused land	136,378	3.58	126,321	3.31	144,272	3.78	7894
Total	3,814,764	100	3,814,764	100	3,814,764	100	0

ficients, an additional sensitivity analysis was needed to determine the percentage change in ESV for a given percentage change in the value coefficient. For each analysis, we calculated a coefficient of sensitivity (CS) using the standard economics concept of elasticity, as follows (Kreuter et al., 2001):

$$CS = \frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} - VC_{ik})/VC_{ik}}, \quad (4)$$

where ESV is the estimated ecosystem service value, VC is the value coefficient, *i* and *j* represent the initial and adjusted values, respectively, and *k* represents the land use category. If $CS > 1$, then the estimated ecosystem value is elastic with respect to that coefficient and it is important to accurately define VC, but if $CS < 1$, then the estimated ecosystem value is considered to be inelastic and the results of the ESV calculations will be reliable even if the VC value has relatively low accuracy.

3. Results

3.1. Changes in land use

Table 1 summarizes the land use changes in Zoige Plateau since 1975. Grassland comprises the largest portion of the total (about 66%). During the study period, the decrease in area and percentage of cover was greatest for high-cover grassland, followed by wetlands. The largest increase in area was for moderate-cover grassland, followed by low-cover grassland; the rate of increase (% change) was greatest for construction land, followed by low-cover grassland. Among the nine land use categories, high-cover grasslands, woodlands, and wetlands showed a continuous decrease, but only wetlands showed an accelerating rate of decrease.

3.2. Changes in ecosystem service values

The ecosystem service values for each land use category and the total value for each study year (1975, 1990, and 2005) were calculated using modified value coefficients and the area covered by each land use category (Table 2). The total ESV for Zoige Plateau decreased over the study period and the rate of decrease appears to have accelerated during the last 15 years of the period. Overall, the net decline in ESV was about 5% from 1975 to 2005, mainly due to decreases in wetlands and high-cover grassland. Although the ESV of some land uses increased, these increases were too small to offset the decreases.

Because wetlands had the highest value coefficient (Table A.2, Supplementary information) and covered a large area (Table 1), the ESV of wetlands was the highest of the nine land use categories, accounting for about 48% of the total value. High- and moderate-cover grassland cover the largest total area, and thus accounted for a proportionally large proportion of total ESV (about 18% and 9% of the total value, respectively), even though the coefficients for these two land use types were much lower than that for wetlands. Woodlands also generated high ESV (about 18% of the total value) due to its high value coefficient. The combined ESV for wetlands, high-cover grassland, woodland, and moderate-cover grassland accounted for about 93% of the total ESV, indicating that these categories, and especially wetlands, high-cover grassland, and woodland, provide the most important ecosystem services in the Zoige Plateau.

The ecosystem service values (ESV_f) of individual ecosystem functions are shown in Table 3. In general, the changes in the contribution of each ecosystem function to the total ESV were small. The contribution of each ecosystem function to the overall ESV was greatest for waste treatment, followed by water supply; this likely resulted from the high ability of wetlands, high-cover grassland,

Table 2
Total ecosystem service values (ESV) for each land use types in Zoige Plateau in 1975, 1990, and 2005.

Land use type	ESV ($\times 10^9$ yuan yr^{-1})			Change (1975–2005)[a]		
	1975	1990	2005	$\times 10^9$ yuan	%	%/yr
Cropland	0.1780	0.1702	0.1740	−0.0040	−2.2702	−0.0757
Woodland	10.9929	10.6928	10.5235	−0.4694	−4.2701	−0.1423
High-cover grassland	11.8292	11.0399	10.2552	−1.5740	−13.3062	−0.4435
Moderate-cover grassland	5.0907	5.5377	5.8136	0.7229	14.2004	0.4733
Low-cover grassland	1.4809	1.6424	1.8006	0.3197	21.5858	0.7195
Wetlands	29.4555	28.8358	27.6340	−1.8215	−6.1840	−0.2061
Water body	2.3791	2.3422	2.3504	−0.0286	−1.2037	−0.0401
Construction land	0.0013	0.0016	0.0019	0.0006	49.8135	1.6605
Unused land	0.0507	0.0469	0.0536	0.0029	5.7883	0.1929
Total	61.4582	60.3095	58.6067	−2.8515	−4.6397	−0.1547

[a] Positive and negative values represent increases and decreases, respectively.

Table 3
Values of ecosystem service functions (ESV_f) for Zoige Plateau in 1975, 1990, and 2005.

Ecosystem service function	1975		1990		2005	
	ESV_f ($\times 10^9$ yuan yr^{-1})	%	ESV_f ($\times 10^9$ yuan yr^{-1})	%	ESV_f ($\times 10^9$ yuan yr^{-1})	%
Gas regulation	4.6525	7.57	4.5661	7.57	4.4660	7.62
Climate regulation	11.7246	19.08	11.4946	19.06	11.1030	18.94
Water supply	11.9976	19.52	11.7633	19.50	11.4072	19.46
Soil formation and retention	7.7620	12.63	7.6410	12.67	7.4847	12.77
Waste treatment	13.5122	21.99	13.2654	22.00	12.8477	21.92
Biodiversity protection	5.7740	9.39	5.6717	9.40	5.5522	9.47
Food	0.9861	1.60	0.9730	1.61	0.9526	1.63
Raw materials	1.4715	2.39	1.4338	2.38	1.4099	2.41
Recreation and culture	3.5786	5.82	3.5016	5.81	3.3843	5.77
Total	61.4582	100	60.3095	100	58.6067	100

and woodland to treat wastes and supply water. All nine types of service functions decreased, and all but raw materials showed an accelerating rate of decrease from 1975 to 2005.

3.3. Ecosystem sensitivity analysis

For the results of our analysis to be reliable, the sensitivity of ESV to changes in the value coefficients must be relatively low (CS < 1). Using Eq. (4), the percentage change in the estimated total ESV and the corresponding coefficient of sensitivity (CS) resulting from a 50% adjustment in the value of the service value coefficient, indicated that the total ESV estimated in this study was relatively inelastic with respect to change in the value coefficients (Table A.4, Supplementary information). CS was highest for wetlands (0.48) because of the large area and high value coefficient for this land use type. Overall, the sensitivity analysis indicated that our estimates for the study area were robust despite uncertainties in the value coefficients.

4. Discussion

The method we used to estimate ESV derives ESV by multiplying the area of a given land use category by the corresponding value coefficient. As discussed in the previous literature, estimates produced using this method have low resolution, high variation, and high uncertainly due to the complex, dynamic, and nonlinear properties of ecosystems (Limburg et al., 2002; Turner et al., 2003). In addition, there are limitations on the economic valuation of land use types (Costanza et al., 1997b), and problems of double-counting and scales (Konarska et al., 2002; Turner et al., 2003; Hein et al., 2006). Land use can be used as a proxy for ecosystem services, but the biomes used as proxies are not always perfect matches (Kreuter et al., 2001). In addition, the accuracy of the modified value coefficients is questionable because of ecosystem complexity. However, the results of our sensitivity analysis suggest that despite these limitations, the approach we used can produce useful results.

Our estimated total ESV for Zoige Plateau in 2005 was 58.61×10^9 yuan, far less than Zhang and Lu's (2009) estimate of 800×10^9 yuan. However, Zhang and Lu used the method of indirect market evaluation (e.g., avoid cost, replacement cost) to calculate value coefficients corresponding to different service functions and land categories. Other methods (such as indirect market evaluation methods) have also been used to calculate value coefficients. Different valuation methods may lead to different estimation values, leading to criticism of the ecosystem service valuation approach. However, accurately calculating coefficients is less critical for time-series analyses than for cross-sectional analyses because changes in the value of these coefficients tend to affect estimates of directional change to a lesser extent than they affect estimates of the magnitude of ecosystem values at specific points in time (Li et al., 2008b). By calculating the ESV in 1975, 1990, and 2005 and analyzing changes across this time period, uncertainties and errors tended to be reduced or offset in our analyses and the results are credible, particularly in qualitative terms. In addition, our sensitivity analysis indicated that the total ESV estimated for the study area were relatively inelastic with respect to the value coefficients and that our estimates were robust despite uncertainties in the value coefficients.

From 1975 to 2005, Zoige Plateau underwent rapid economic development. Although the decline in ESV has been relatively low compared to the economic increase, the decrease in total ESV was nonetheless large. Expressed as a multiple of GDP, Zoige Plateau's ESV has decreased by about 84% since 1990, a signal that regional planners must immediately focus on sustainable development and ecological protection. To accomplish this, the regional land use plan must emphasize the protection of wetlands, high-cover grassland, and woodland, all of which have high ESV to maintain a balance between economic development and ecosystem health in the future.

Our results suggest that land use type can be used as a proxy for ecosystem services by matching the land use categories to equivalent biomes, thereby facilitating the valuation of ecosystem services for large areas using remote-sensing data. The reliability of the resulting estimates depend on the accuracy of the value coefficients, so future research must focus on ways to more accurately calculate these coefficients. However, for time-series analysis such as this study, our sensitivity analysis suggests that useful results can be obtained using relatively imprecise coefficients.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.agee.2010.10.019.

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