Impacts of land management on ecosystem service delivery in the Baiyangdian river basin

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Abstract As the largest freshwater lake in northern China, Lake Baiyangdian provides a diversity of ecosystem services: it guarantees water flow to a number of beneficiaries and is an important component of sustainable regional development. However, the flows of sustainable ecosystem services from Lake Baiyangdian mainly depend on upstream hydrological and nutrient retention functions. For sustainable land management, it is important to explore the implications of upstream land-use changes by humans on the ecosystem services supplied by Lake Baiyangdian. In this study, ecological assets and hydrological time series were analysed, and the InVEST model was used to investigate the implications of land management on the delivery of ecosystem services. The results showed that significant changes in ecological assets occurred in the Baiyangdian river basin during the period 1980–2007, characterised particularly by an increase in forested area and a decline in

wetland area. A significant decline in the ecological status of the Baiyangdian river basin, expressed as an abrupt change in stream flow time series 1970–2011, was also noted. Water yield and surface run-off functions were mainly influenced by precipitation, but changes in land-cover patterns exacerbate the impacts of these two factors. Nutrient retention was influenced more by altered land cover than by precipitation. Due to data gaps, it was not possible to link upstream ecosystem functions to the ecosystem services contributed by Lake Baiyangdian. It will be necessary to establish a long-term ecological monitoring programme in order to gather the data needed to gain a deeper understanding of the interconnections between ecosystem function and services. The ultimate aim of such a programme must be to incorporate ecosystem services into ecosystem management and policy-making.

Keywords Baiyangdian river basin · Land management · Ecological assets · Ecosystem services

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Introduction

Ecosystems supply essential ecological functions through bio-geochemical cycles and other natural processes (MEA 2005; de Groot et al. 2010). However, increased anthropogenic impacts have affected ecosystem resources and spatial relationships within ecosystems in recent decades (Folke et al. 2004; Foley et al. 2005; Bennett et al. 2009). During the past century, humans have changed landscape structures and processes more rapidly than ever before, resulting in the conversion of natural ecosystems into human-dominated systems (Foley et al. 2005; Mooney et al. 2009). A number of human activities currently threaten ecosystem functions, often leading to water

shortages, eutrophication, flood damage, soil erosion and dwindling fisheries. The ecosystem service concept provides an appropriate conceptual and methodological framework for clarifying the link between ecosystems and human well-being (Carpenter et al. 2009; Seppelt et al. 2011; Lester et al. 2013). As a result, over the past two decades, studies of ecosystem services by scientists, managers and decision-makers have gained prominence in the ecological and economic literature (Vandewalle et al. 2008; Burkhard et al. 2010). The key attraction of the ecosystem service concept to scientists and decision-makers lies in the potential for win–win outcomes (Adams 2014). Nevertheless, attention to ecosystem services does not simultaneously optimise ecosystem services. Despite the burgeoning interest in evaluating ecosystem services (Daily 2000; de Groot et al. 2002), there are currently no widely accepted methods for including spatial and temporal patterns of ecosystem service flows (i.e. the demands of beneficiaries and how these relate to the capacity of ecosystems to supply services) in the assessment of services (Turner and Daily 2008). The paucity of scientific methods and monitoring data for linking ecosystems to human well-being is thus hindering the implementation of management decisions (Kremen 2005; NRC 2005; US EPA 2009; Seppelt et al. 2011).

Despite the current emphasis on ecosystem service research, policy makers still lack spatially explicit tools and data for incorporating ecosystem service assessments into land management and policy decisions. When undertaking ecosystem service assessments, ecologists focus on ecosystem characteristics associated with the delivery of services (Kremen 2005; Díaz et al. 2007), while economists focus on economic evaluation to determine the value of services to humanity (Tong et al. 2007). To conduct such evaluations and for land management planning purposes, resource managers require spatially explicit assessments of the flow of ecosystem services to beneficiaries (Daily and Matson 2007). However, current ecosystem service assessments tend to rely on secondary data, making use of the benefit transfer method rather than primary data or biophysical and socio-economic models (Eigenbrod et al. 2010; Seppelt et al. 2011). Scientists are unable to understand ecosystem service flows to beneficiaries and the underlying processes and functions that deliver such services. The flow of ecosystem services depends on underlying biophysical conditions and features highly distinctive patterns across different temporal and spatial scales, due to changes in land use, land cover, and ecological assets. In this context, the following definitions need to be noted: ‘land cover’ refers to the components of the landscape, both natural and artificial; ‘land use’ refers to the purposes

for which humans use landscape resources; ‘ecological assets’ only refers to natural or semi-natural landscape, such as forest, wetland and farmland; and ‘land management’ refers to the presence of human activities that affect land cover through ecosystem exploitation, land-use management and ecosystem management (Bennett et al. 2009). The ecosystem service approach is not itself a land management measure (Adams 2014). Enabling ecosystem service-based land management requires consideration of the key ecosystem processes and functions capable of guaranteeing delivery of ecosystem services to human communities.

Lake Baiyangdian is the largest freshwater lake in northern China and provides a vast diversity of ecosystem services important for sustaining regional development. The management watershed of the lake is the Baiyangdian river basin. As in many other places, water protection has become a high-priority environmental target in China (Jiménez-Madrid et al. 2012). To meet the present need to sustain the flow of ecosystem services from Lake Baiyangdian to beneficiaries, immense land-use changes have taken place in the Baiyangdian river basin over the last few decades, and these have seriously reduced natural fluctuations in freshwater quantity and its quality. In the Baiyangdian river basin, the land was originally managed for domestic water supply, irrigation water use, flood control and hydroelectric power generation in a manner that neglected the trade-offs and long-term consequences of choosing these services over those provided by Lake Baiyangdian. The major factors currently threatening Lake Baiyangdian ecosystem services include human alterations to water flow, changes in land use and land cover, and chemical inputs. To reduce the risk of unwanted trade-offs in the ecosystem services supplied by Lake Baiyangdian and to guarantee the future flow of sustainable ecosystem services, managers need to assess the influence of land management on ecosystem processes and functions.

Taking the Baiyangdian river basin as the study area, the objectives of this study were to (1) monitor and analyse changes in ecological assets in the basin as a result of land management; (2) identify hydrological changes; and (3) explore the effects of land-use changes on hydrological and water purification functions. Hydrological and water purification functions were chosen because they are the main features influencing Lake Baiyangdian’s ecosystem status and service delivery. The results obtained in the study are intended to provide guidance to land management agencies on suitable methods for sustaining upstream ecosystem processes and functions, in order to maintain ecosystem services dependent on downstream lake ecosystems.

Study area and methods

Study area

The Baiyangdian river basin, located in the middle of the North China Plain ($113^{\circ}39'–116^{\circ}11'E$, $38^{\circ}4'–40^{\circ}4'N$), covers an area of $31,200\text{ km}^2$ (Fig. 1). This river basin has complex topography, with mountains to the west and plains to the east. The mountainous area is mainly covered with forest and grassland, while the plain area is mainly covered with arable land. Meteorological data collected over the past 50 years at meteorological stations within, or adjacent to, the upstream watershed area indicate the following climate conditions: mean annual temperature range $6.8–12.7^{\circ}\text{C}$, mean annual precipitation 548 mm and mean annual pan evaporation range $1500–2000\text{ mm}$ (Bai et al. 2013). The human population density in the Baiyangdian river basin is higher than the average for the whole of China, with more than $448\text{ individuals km}^{-2}$ (Bai et al. 2011). In recent years, natural variability and a suite of

human development and wastewater discharge activities have increasingly impacted upon the hydrological cycle and water purification processes of watershed ecosystems. The Baiyangdian river basin is currently experiencing extreme water shortages and severe deterioration in water quality, with the result that the system is unable to sustain the stream flow requirements or to ensure ecosystem services in Lake Baiyangdian. These serious environmental threats to which the Baiyangdian river basin is currently being subjected are of great concern as regards human survival and development.

Data collection

Data on monthly stream flow (for the period 1970–2011) and water consumption at nine hydrological stations in the study area (see Fig. 1) were taken from a hydrological database on the Haihe river basin (Daqing River Management Authority and local basin water conservancy department).

Fig. 1 Location of the study area and hydrological stations in Baiyangdian river basin

Analysis of ecological assets

The first step was to conduct a systematic analysis of ecosystems in the Baiyangdian river basin. To achieve this objective, a standard map of the study area was obtained and formed the basis for creation of a spatial database (using ArcGIS). The Landsat MSS, TM and ETM images for the years 1980, 1990, 2000 and 2007 were then rectified and classified, and a combination of supervised and unsupervised methods was used to derive spatial distributions of distinctive land-cover types. The overall accuracy of the classification for 2007 with ground-based survey data was 92 %. Spatial resolution mismatches among those images were avoided because all layers were resampled into a 100 m $\times$ 100 m grid. A transfer matrix of the ecological assets for 1980–2007 was calculated using the intersect command of ArcGIS Tools.

Analysis of hydrological monotonic trends and abrupt changes

Maintenance of the stream flow requirements to ensure ecosystem services at Lake Baiyangdian was based on an assumption of stationary hydrology in the Baiyangdian river basin. However, this assumption may not be valid if the hydrological cycle of the upstream watershed is sensitive to human-induced land-use changes. Owing to growing concerns about the implications of land management on the hydrological cycle, trend analysis has been extensively used to identify possible trends in hydrological time series data. The Mann–Kendall statistical test (Mann 1945; Kendall 1995) is a commonly used nonparametric test to detect whether monotonic trends exist in hydrological time series. Unlike other, more powerful, parametric statistical tests, the Mann–Kendall test is independent of distribution and less sensitive to outliers, or to censored or missing data (Yue and Pilon 2002; Hamed 2008). However, changes in a hydrological time series can occur in both a monotonic trend and in a step-change manner. The Mann–Kendall test is limited to the detection of monotonic trends (Kundzewicz and Robson 2004), while the Pettitt test (Pettitt 1979; Yang and Tian 2009; Gao et al. 2011) can be used for detecting step-change in hydrological time series. For these reasons, in this study both the Mann–Kendall and Pettitt tests were used to assess hydrological changes between 1970 and 2011 at the nine hydrological stations in the Baiyangdian river basin (Fig. 1).

InVEST model description

The Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model was used to analyse the capacity of the Baiyangdian river basin to supply

ecosystem services (Tallis et al. 2010). This capacity is defined by Burkhard et al. (2012) as ‘ecosystem functions’. InVEST combines land use and management information with environmental information to produce biophysical and experiment-based sub-models and to create a spatially explicit assessment of ecosystem services. Alternative land management strategies affect the biophysical output of the InVEST model when assessing ecosystem functions under various land-use and land-cover scenarios. Model outputs of the InVEST tool can guide land managers and stakeholders towards policies that will enhance ecosystem service delivery and flow (Nelson et al. 2009). In the present study, the InVEST model was used to analyse and map the influence of land-cover and precipitation changes on water yield, surface run-off and nitrogen retention function, which are of vital importance for sustaining the Lake Baiyangdian ecosystem. Four scenarios were designed: ‘1980’ (land-cover map and precipitation in 1980); ‘1980 plus’ (land-cover map in 1980 and precipitation in 2007); ‘2007’ (land-cover map in 2007 and precipitation in 2007); and ‘2007 plus’ (land-cover map in 2007 and precipitation in 1980).

Water yield

Water yield is an intermediate service of vital importance in terms of providing an ultimate guarantee of ecosystem services. The value difference between precipitation and actual evapotranspiration of each land parcel was used to represent the approximate absolute annual water yield output across the watershed landscape. No distinction was made between surface flow, subsurface flow and base flow in the modelling process. Instead, it was assumed that the water yield output from any pixel would ultimately reach Lake Baiyangdian, thus ensuring that ecosystem services would emerge via each of these three flow types (Tallis et al. 2010). In the InVEST model interface, the input data needed include soil depth, precipitation, plant-available water content (PAWC), average annual potential evapotranspiration (PET), and land cover. In the ‘1980 plus’ scenario, the data inputs were as follows: land-cover map and soil depth in 1980; precipitation, PAWC and PET in 2007. In the ‘2007 plus’ scenario, the data inputs were land-cover map and soil depth in 2007; precipitation, PAWC and PET in 1980.

Surface run-off

The Water Scarcity Module of the InVEST model was used to calculate the capacity to supply a surface water run-off service along the flow path, based on water yield output and water consumption data in the watershed. The total amount of water that actually reaches Lake Baiyangdian

was calculated by subtracting the total consumption in the watershed from the total water yield output of the InVEST model (Tallis et al. 2010).

Nitrogen retention

The Water Purification Nitrogen Retention module of the InVEST model was used to estimate the nitrogen purification function of vegetation and soil provided to Lake Baiyangdian. To estimate the nitrogen retention capacity of watershed ecosystems under alternative land-use and land-cover scenarios, the following parameters were taken into account: model output of the water yield; spatial distribution of land use and land cover; nitrogen loading and filtration rates; and water quality standards (Tallis et al. 2010).

Model validation

Yearly monitoring data for water yield and water quality at five monitoring points in the watershed were used to validate each module of the InVEST model. The quality of the InVEST model was validated using the *t* test: if the *t* test accepted the null hypothesis that there was no difference between the monitored data and the predicted output from the InVEST model at the 0.05 significance level, then the model validation passed with good quality [see Bai et al. (2011) for further details of model validation].

Results and analysis

Changes in ecological assets

Spatial distribution

The ecological assets of the Baiyangdian river basin include forest, wetland, grassland and farmland. From 1980 to 2007, farmland was the ecological asset that occupied the largest area, accounting for more than 40 % of the land cover in the basin. However, in following decades, farmland area represented a declining trend (from 13,859.96 km² in 1980 to 12,750.36 km² in 2007), which is equivalent to a loss of about 41.10 km² per year.

Forest and wetlands are the most important ecological assets in the Baiyangdian river basin. They provide ecosystem services for livelihoods and development, and also play significant roles in securing water availability and biodiversity conservation. During 1980–2007, the forest area increased from 6610.64 to 7350.16 km², while the wetland area showed a significant downward trend from 1134.28 km² in 1980 to 413.72 km² in 2007, a decrease of 26.69 km² per year. The spatial distribution of changes in

land use and ecological assets in the Baiyangdian river basin is presented in Fig. 2.

Transfer matrix

An ecological asset transfer matrix was used to derive the detailed transfer characteristics for the period 1980–2007 in the Baiyangdian river basin. During this period, 14.58 % of the farmland area was transferred to built-up area, while 6.28 % was transferred to grassland area and 1.12 % to forest area (Table 1).

Despite increases in the size of the forest area, the retention rate was only 77.68 % during the period 1980–2007. This implies that the growing forest area was mainly comprised of newly planted forest, which would increase the total forest area, but newly planted forest is mainly composed of young trees, the composition of which is too simple to guarantee the supply and delivery of ecosystem services provided by mature forest. Compared with the retention rate of forest area, that of wetland area was relatively low (31.29 %), which illustrates that wetlands are experiencing serious losses that will pose a threat to the services provided by wetlands. Between 1980 and 2007, 57.54 % of the wetland area in the Baiyangdian river basin was converted to farmland.

Hydrological monotonic trends and abrupt changes

Monotonic trends

The monotonic trends in monthly and annual stream flow 1970–2011 at the nine hydrological stations, determined using the Mann–Kendall test (*Z* value), are presented in Fig. 3. Annual stream flow at eight of the nine hydrological stations decreased significantly ($p < 0.05$) in the period, while stream flow at Angezhuang hydrological station showed a non-significant downward trend ($p > 0.05$). The mean annual decrease in annual stream flow varied from 0.01×10^8 m³/year to 0.29×10^8 m³/year. At most of the nine stations, more than half of the monthly stream flow had decreased significantly ($p < 0.01$).

Abrupt changes

The Pettitt test ($U_{t,N}$ value) was used to detect abrupt changes in annual stream flow at the nine hydrological stations during the period 1970–2011. The Pettitt test statistical value represented a non-significant abrupt change at Fuping hydrological station ($p > 0.05$), while it showed a significant abrupt change at Angezhuang hydrological station ($p < 0.05$) and the other hydrological stations ($p < 0.01$). The abrupt change point was detected in about 1997 at all stations (Fig. 4).

Fig. 2 Spatial distribution of Baiyangdian river basin ecological assets from 1980 to 2007

Table 1 Transfer matrix of Baiyangdian river basin ecological assets, 1980–2007

Ecological assets	2007					
	Farmland (%)	Forest (%)	Grass (%)	Wetland (%)	Built-up (%)	Bare (%)
1980						
Farmland	77.61	1.12	6.28	0.26	14.58	0.15
Forest	2.00	77.68	19.93	0.10	0.22	0.07
Grass	11.06	24.44	63.28	0.11	0.87	0.25
Wetland	57.54	1.89	4.80	31.29	4.46	0.02
Built-up	21.98	0.63	0.90	0.50	75.68	0.31
Bare	18.73	0.76	77.21	0.76	1.03	1.50

Fig. 3 Monotonic trends of the nine hydrological stations in Baiyangdian river basin. The solid line and the short dash line represent the Z value at 0.05 and 0.01 significant levels, respectively

Changes in ecological function

Water yield

According to the modelling results, in terms of annual water yield functions, the four scenarios were ranked, from the highest to the lowest, as '2007', '1980 plus', '2007 plus' and '1980'. The highest total annual water yield function ($3.28 \times 10^9 \text{ m}^3$) was produced under the '2007' scenario, followed by the '1980 plus' scenario ($2.81 \times 10^9 \text{ m}^3$). The lowest annual mean water yield function ($2.42 \times 10^9 \text{ m}^3$) was produced under the '1980' scenario (Table 2). The spatial distribution of water yield function under each of the four scenarios is shown in Fig. 5. Under

all four scenarios, the higher values were mainly distributed in eastern and southern areas of the Baiyangdian river basin.

Surface run-off

As the long-term trend in forest area showed an increase, while wetland and farmland area decreased, in terms of annual surface run-off, the four scenarios were ranked, from the highest to the lowest, as '2007', '1980 plus', '1980' and '2007 plus'. The highest total annual surface run-off ($1.56 \times 10^9 \text{ m}^3$) was produced under the '2007' scenario, followed by the '1980 plus' scenario ($1.27 \times 10^9 \text{ m}^3$), while the lowest annual mean water yield

Fig. 4 Abrupt changes in the nine hydrological stations in the Baiyangdian river basin. The short dashed line and the solid line represent the statistical $U_{t,n}$ values at 0.05 and 0.01 significance

levels, respectively. Note that the most probable change point occurs in the series at which the $U_{t,n}$ attains the maximum value: $K_t = \max_{1 \leq t \leq n} |U_{t,n}|$

Table 2 Summary of changes in ecological functions in the Baiyangdian river basin under four alternative scenarios

Scenario	Water yield ($\times 10^8 \text{ m}^3$)	Run-off ($\times 10^9 \text{ m}^3$)	N retention ($\times 10^4 \text{ t}$)
1980	2.42	1.17	2.530
1980 plus	2.81	1.27	2.526
2007	3.28	1.56	3.064
2007 plus	2.56	1.18	3.074

function ($1.17 \times 10^9 \text{ m}^3$) was produced under the ‘2007 plus’ scenario (Table 2). The spatial distribution of surface run-off under each of the four scenarios is illustrated in Fig. 6. Under all four scenarios, the higher values were mainly distributed in western and northern areas of the Baiyangdian river basin.

Nitrogen retention

In terms of annual nitrogen retention function, the four scenarios were ranked, from the highest to the lowest, as ‘2007 plus’, ‘2007’, ‘1980 plus’ and ‘1980’. The highest total annual nitrogen retention function ($3.07 \times 10^4 \text{ t}$) was

Fig. 5 Spatial characteristics of water yield under different scenarios

produced under the '2007 plus' scenario, followed by the '2007' scenario (3.06×10^4 t), while the lowest annual nitrogen retention function (2.53×10^4 t) was produced under the '1980 plus' and '1980' scenarios (Table 2). The spatial distribution of the nitrogen retention function under each of the four scenarios is shown in Fig. 7. Under all four scenarios, the higher values were mainly distributed in eastern and southern areas of the Baiyangdian river basin.

Discussion and conclusions

Discussion

Lake Baiyangdian provides a diversity of ecosystem services that are important for sustaining human livelihoods and socio-economic development (Bai et al. 2011, 2013).

However, the human-induced alterations to land cover in the Baiyangdian river basin that have taken place over the past few decades, without considering the trade-offs between ecosystem services and socio-economic outputs, have resulted in a serious deterioration in ecological functions (Xia et al. 2012). The contradictory demands of resource development, which guarantees socio-economic outputs, and the ecological capacity to sustain ecosystem service flows combine to create a management and policy problem that is of great concern.

The overall objective of this study was to employ an ecological assets analysis system (the hydrological time series analysis) and the InVEST model to investigate the implications of land management, with the aim of sustaining watershed ecosystem processes and functions for enabling downstream flows of lake ecosystem services. The ecological assets transfer matrix obtained showed that

Fig. 6 Spatial characteristics of surface run-off under different scenarios

the ecological assets had experienced dramatic changes during the period 1980–2007, as evidenced by the increase in forest assets and the decrease in wetland assets. The increasing growth rate of forested area was mainly the result of the extensive ‘Grain to Green Programme’ and the ‘Three Norths Shelter Forest System Project (TNSF)’ in the region, while the decreasing rate of wetland area was mainly due to hydraulic engineering construction, increased anthropogenic water use and climate change (Yu and Guo 2009; Wang et al. 2014). Wetlands are one of the most important ecological assets in the Baiyangdian river basin for sustaining the capacity of watersheds to supply ecosystem functions. Degradation of the wetland area due to human activities has seriously exacerbated the impact of climate change on hydrological drying in the Baiyangdian river basin, as indicated by the significant declining trend

in the Mann–Kendall test and the abrupt changes indicated by the Pettitt test. Furthermore, the InVEST model results relating to water yield, surface run-off and N retention under four alternative scenarios reflected changes in land use and land cover, which will exacerbate the impacts of future climate change in terms of sustaining ecological functions. Water yield and surface run-off mainly depend on precipitation, but human alterations to land cover can result in changes to the evapotranspiration rate of the landscape, thereby influencing the spatial pattern of both functions. In the past few decades, a period of serious climate drying has occurred in the Baiyangdian river basin, which has led to a significant downward trend and abrupt changes in stream flow in the watershed. Human alterations to land cover, as well as an increase in human water-use competence, have exacerbated the existing problem (Liu

Fig. 7 Spatial characteristics of nitrogen retention under different scenarios

et al. 2011). Evidence of this can be found by comparing water yield and surface run-off function changes under the four alternative scenarios (see Figs. 5, 6).

In contrast to the water yield and surface run-off functions, the nitrogen retention function was more influenced by land-cover changes than by precipitation, as shown by the model results for the four alternative scenarios. The higher nitrogen retention function in '2007' and '2007 plus' compared with '1980' and '1980 plus' (Fig. 7) was mainly a result of the increasing extent of forested area. Among all the land-cover scenarios tested here, forest has the greatest potential to retain nitrogen, but the spatial distribution of ecological assets can also influence the total nitrogen retention function on watershed scale.

Guaranteeing ecosystem service flows from Lake Baiyangdian to beneficiaries requires consideration of trade-offs between ecosystem services at both local and

watershed scales (Burkhard et al. 2012). Spatially explicit trade-off results, which can highlight the relationships between ecosystem providers (supply) and beneficiaries (demand), can also be used as a guide for improving watershed management and policy design, with the objective of enhancing sustainable development (Burkhard et al. 2014). In this study, the InVEST model was used to assess the general influence of land-cover and precipitation changes on water yield, surface run-off and nitrogen retention functions. However, due to gaps in the data, it was only possible to model three function changes between 1980 and 2007. It was noted that the higher precipitation in 2007, compared with 1980, was not representative of the general declining trend in precipitation, and thus could not be used to reflect the general trend in water yield and the declining trend in surface run-off. While the InVEST model can be a practical tool for mapping ecosystem

services on a spatial scale, it should be noted that this aspect is still at the initial stage of development (Burkhard et al. 2014). Due to gaps in the data, the model is currently unable to map the ecosystem service beneficiaries that relate to ecosystem functions, which would be valuable for guiding management and policy design. Therefore, a long-term ecological monitoring programme needs to be established to gather the necessary data for creating the model interconnections between ecosystem functions and services. In addition, an increasing level of cooperation among different stakeholders is needed to ensure sustainable land-use management, so as to maintain the delivery of sustainable ecosystem services.

Conclusions

The main conclusions of this study were that:

1. During 1980–2007, the Baiyangdian river basin experienced far-reaching changes to ecological assets, in particular an increase in forested area and a decline in wetland area.
2. In the past four decades, stream flow time series in the Baiyangdian river basin have undergone significant downward trends and abrupt changes.
3. Water yield and surface run-off functions are mainly influenced by precipitation, but changes to land cover can exacerbate the impacts of these two factors. In contrast, nutrient retention function is influenced more by changes to land cover than by precipitation.
4. In order to guarantee flows of ecosystem services from Lake Baiyangdian to beneficiaries, the trade-offs between ecosystem services at both local and watershed scale need to be considered. To achieve this, it is necessary to obtain more data, which will enhance understanding of the vital interconnections between ecosystem functions and services, and to promote stakeholder involvement when striving to achieve sustainable land management.

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