ChinaRxiv

AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-201711.00052

Impacts of Forest Land Resource Changes on Forest Ecosystem Services: A Case Study of Xichuan County, Core Water Source Area of the South-to-North Water Diversion Project (Postprint)

Authors: Yin Gelan, Shao Jing' an, Guo Yue, Dang Yongfeng

Date: 2017-11-01T00:00:00+00:00

Abstract

Forest ecosystems constitute the foundation of human survival and development, and their service functions are irreplaceable. Taking Xichuan County, the headworks location of the Middle Route of the South-to-North Water Transfer Project, as the study area, this study analyzed changes in forestland resources from 2004 to 2014 using data including 2004 TM imagery, 2009 TM imagery, and 2014 GF-1 imagery, with support from software such as PIC and ArcGIS 10.0, and quantitatively assessed forest ecosystem service functions (water conservation, water purification, and soil retention) using the InVEST model. The results indicate: From 2004 to 2014, forested land dominated the county' s forestland resources with rapid area expansion; shrubland and nursery land areas increased slowly; sparse forest land and newly afforested land areas both exhibited a trend of initial increase followed by decrease; Along with changes in forestland resources, forest ecosystem service functions underwent corresponding significant changes: over the 10-year period, the county's water conservation function decreased by 19%, forest water purification function increased by 29%, and soil retention function increased by 6%; For the same forest type, interannual differences in its ecological service functions manifested as average water conservation function declining year by year, average water purification capacity continuously improving, and average soil retention capacity initially increasing then decreasing; Comparing the ecological service functions of five forest types, forested land exhibited the strongest service functions, followed by shrubland and sparse forest land; Over the 10-year period, the levels of water conservation, water purification, and soil retention service functions of the county' s forest ecosystem were positively correlated with the degree of forest cover, displaying a spatial distribution pattern of high in the north and low in the south; The key to scientific management of forest ecosystem services lies

in rationally configuring the distribution patterns of forestland and other land use types, and enhancing the sustainability of composite land use formed by the mosaic of forestland and other land uses. Simultaneously, protection of areas with important service functions should be strengthened while avoiding damage to areas with poorer service functions. Furthermore, future forest management needs to shift from mere forest area expansion to improving forest quality and productivity, thereby enhancing the adaptive capacity of forest ecosystems to climate change impacts.

Full Text

Effects of Forest Resource Changes on Forest Ecosystem Service Functions: A Case Study of Xichuan County, the Core Water Source Area of the South-to-North Water Transfer Project

YIN Gelan[1], SHAO Jing' an[1,2,*], GUO Yue[1], DANG Yongfeng[3]

[1]College of Geography and Tourism, Chongqing Normal University, Chongqing 400047, China
[2]Chongqing Key Laboratory of Surface Process and Environment Remote Sensing in the Three Gorges Reservoir Area, Chongqing 400047, China
[3]Academy of Forestry Inventory and Planning, State Forestry Administration, Beijing 100714, China

---

Abstract

Forest ecosystems constitute the foundation for human survival and development, providing irreplaceable ecosystem services. This study examines Xichuan County, located at the headwaters of the Middle Route of China' s South-to-North Water Transfer Project, as a case study area. Using TM imagery from 2004 and 2009, and GF-1 imagery from 2014, we quantitatively assessed changes in forest resources from 2004 to 2014. Building upon this analysis, we employed the InVEST model to quantitatively evaluate three key forest ecosystem services: water retention, water purification, and soil conservation.

Our results reveal that forestland dominated the landscape matrix throughout the study area, with its area increasing rapidly by 10.85% from 2004 to 2009 and by 7.44% from 2009 to 2014, reaching a forest coverage rate of 45.65% by 2014. While shrubland and nursery woodland areas grew more slowly, sparse forestland and unstocked forestland both exhibited initial increases followed by decreases. These changes in forest resources drove significant corresponding shifts in ecosystem services. At the county scale, water retention capacity declined over the decade, whereas water purification capacity increased by 29% and soil conservation capacity increased by 6%.

Examining specific forest types, we found that average water retention capacity declined annually, average water purification capacity continuously improved, and average soil conservation capacity initially increased then decreased. Among the five forest types, closed forestland exhibited the strongest service functions, followed by shrubland and sparse forestland. The spatial distribution of all three services showed a clear north-south gradient, with higher values in the north and lower values in the south, consistent with forest cover patterns. The key to scientifically managing forest ecosystem services lies in rationally configuring the spatial distribution of forestland relative to other land uses, enhancing the sustainability of mosaic land-use patterns, strengthening protection of functionally important areas, and avoiding degradation in poorly performing areas. Future forest management must shift from simple area expansion to improving forest quality and productivity, thereby strengthening forest ecosystem resilience to climate change.

Keywords: forest resources; water retention; water purification; soil conservation; InVEST model

---

1. Introduction

Forest ecosystem services refer to the environmental conditions and utilities that forest ecosystems and ecological processes maintain and create for human survival [1-3]. As ecological degradation intensifies, society has increasingly recognized that maintaining and conserving forest ecosystem services constitutes a critical foundation for sustainable socioeconomic development [4-5]. Scholars worldwide have conducted extensive research on forest ecosystem services, yielding substantial achievements [6-13]. Research has primarily focused on evaluating water retention services [14-16], quantifying carbon storage [17], estimating soil conservation values [18-19], and assessing forest vegetation impacts on water quality [20-21]. Studies increasingly emphasize the relationship between ecological processes and forest ecosystem services, particularly the development of ecological models, and are evolving new theories and methods based on existing findings. Research scales have gradually shifted from broad to medium and small scales, with growing attention to dynamic changes in forest ecosystem services and their driving factors [22].

Although existing studies have achieved good results in assessing forest ecosystem services at various scales [23-24], assessment outputs still lack sufficient visibility and operability, hindering management decision-making. Most current assessments lack dynamic spatial representation, and while assessment scales continue to diversify, county-level assessments remain relatively rare compared to larger-scale studies. Counties represent critical administrative units for national and regional forest conservation. Using spatially explicit ecosystem service assessment models to study county-level forest resource dynamics and their impacts on forest ecosystem services can enrich research scales and provide intuitive understanding of forest management histories.

Xichuan County, located in the middle and upper reaches of the Han River, serves as the core water source area for the Middle Route of the South-to-North Water Transfer Project. The maintenance and improvement of its forest ecosystem services directly affect water security for cities along the project route. This study uses TM and GF-1 imagery, supported by PIC and ArcGIS 10.0 software, to quantitatively assess and characterize the spatial patterns of forest ecosystem services, exploring how forest resource changes influence these services. The objective is to provide scientific support for advancing sustainable forest resource management and enhancing forest ecosystem service functions.

---

2. Study Area

Xichuan County (110°58 -111°53 E, 32°55 -33°23 N) is situated in southwestern Henan Province at the junction of Henan, Hubei, and Shaanxi provinces. The Danjiangkou Reservoir, Asia' s largest artificial lake, lies in the southern part of the study area. The terrain forms a horseshoe shape, rising in the northwest and opening toward the southeast, comprising mountainous areas in the northwest, hilly regions in the center, and alluvial plains and mound areas in the southeast. The climate represents a transitional monsoon zone between north subtropical and warm temperate zones. The hydrological system belongs to the Yangtze River basin, with the Dan River running from northwest to southeast through the entire county, covering 93.5% of the total county area. Soils are primarily alluvial and purple soils. The county administers 2 subdistrict offices with a total area of 2,818.12 km^2. In 2014, the county' s GDP reached 80.57 billion yuan, with per capita disposable income for urban residents at 22,639 yuan and per capita net income for farmers at 8,017 yuan. The study area represents a transitional zone between north and south, with abundant plant resources.

---

3. Data Sources

Remote sensing data included TM imagery (30 m spatial resolution) and GF-1 imagery (2 m panchromatic band, 8 m multispectral). TM imagery was obtained from the USGS Earth Explorer website, while GF-1 data was acquired from the China Resources Satellite Application Center. Forest resource survey data for 2009 and 2014, including vector sub-compartment data, afforestation design data, forest harvesting records, and land requisition data, were provided by the State Forestry Administration' s Academy of Inventory and Planning. Meteorological data on solar radiation and precipitation were obtained from the Henan Meteorological Bureau and China Meteorological Data Sharing Service System. Soil data at 1:100,000 scale were sourced from the Nanjing Institute of Soil Science, Chinese Academy of Sciences. DEM data (30 m × 30 m resolution) and basic geographic information data, including water systems, administrative boundaries, and residential areas, were provided by the Xichuan County Forestry Bureau. Socioeconomic data were derived from the China County Statistical Yearbook and Xichuan County statistical records.

---

4. Data Processing

[Figure 1: see original paper] shows the DEM of the study area. Remote image processing followed the technical specifications for remote sensing image map production (GB 15968-1995) and forestry industry standards (LY/T 1954-2011, LY/T 1955-2011). ArcGIS 10.0 was used for geometric and topographic correction of remote sensing imagery, with registration errors controlled within one pixel. GF-1 imagery was fused using Gram-Schmidt spectral sharpening. Based on forest resource conditions and research needs, land use was classified into six forest types (closed forestland, sparse forestland, shrubland, nursery woodland, unstocked forestland, and non-forestland) and four non-forest categories (construction land, farmland, water bodies, and unused land).

Land use data extraction for 2004, 2009, and 2014 employed a combined approach of remote sensing interpretation and participatory farmer interviews. Using the 2004 interpreted land use map as a base, local farmers were interviewed to trace changes sub-compartment by sub-compartment for 2009 and 2014. These traced changes were then validated using 2009 and 2014 remote sensing imagery, followed by field sampling surveys to verify accuracy. Field verification showed correct interpretation of 1,144.35 hm^2 of unchanged plots (92.13% accuracy) and 365.52 hm^2 of changed plots (92.81% accuracy) in 2004, meeting the study' s precision requirements.

---

5. Model Principles

5.1 InVEST Model Overview The InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) model, developed jointly by Stanford University, WWF, and The Nature Conservancy, quantifies and values ecosystem services. Its primary advantage lies in visualizing assessment results, addressing the limitation of previous abstract textual descriptions [25-28]. The model simulates and predicts ecosystem service changes under different forest landscape scenarios. Based on study area conditions and objectives, this research employed InVEST 2.4.1 with a 30 m × 30 m grid cell as the assessment unit.

5.2 Water Retention Service The water retention module calculates watershed water yield based on water balance principles, then determines water retention capacity. Annual water yield per grid cell (Y) is calculated as precipitation minus actual evapotranspiration, ignoring groundwater influence:

$Y = P - AET$

where P is annual precipitation for grid cell x, and AET is actual evapotranspiration for forest type j in grid cell x. AET is determined by potential evapotranspiration, evapotranspiration coefficients, and root depth. Precipitation data were spatially interpolated from meteorological stations using ArcGIS. Potential evapotranspiration was calculated using the Modified-Hargreaves method [30]. Plant-available water was estimated through nonlinear soil fitting models [31]. Soil depth was derived from forest inventory data, while root depth and velocity coefficients were obtained from literature.

Water retention (WR) is then calculated considering soil thickness, topography, and saturated hydraulic conductivity:

$WR = \min(1, K) \times \min(1, TI) \times Yield$

where K is saturated hydraulic conductivity (cm/d), TI is topographic index, and Yield is the water yield. The average water retention per forest type is obtained by summing retention across all pixels and dividing by forest type area.

5.3 Water Purification Service The water purification module uses total nitrogen (TN) content to characterize water quality, considering only non-point source pollution. The model calculates pollutant interception capacity for each pixel based on its upstream inputs:

$ALV = HSS \times pol$

where ALV is the adjusted pollutant export value for pixel x, HSS is the hydrological sensitivity score, and pol is the export coefficient. Key parameters include water yield data, DEM, TN loads, and forest type data. Average nitrogen output per forest type is calculated by summing outputs across all pixels and dividing by forest type area, with lower values indicating better purification capacity.

5.4 Soil Conservation Service The soil conservation module employs the Universal Soil Loss Equation (USLE) to calculate potential and actual soil erosion:

$USLE = R \times K \times LS \times C \times P$

where R is rainfall erosivity, K is soil erodibility, LS is slope length-gradient factor, C is vegetation cover factor, and P is conservation practice factor. Soil retention equals potential erosion minus actual erosion. Rainfall erosivity was calculated using the Wischmeier monthly formula [33] and spatially interpolated. Soil erodibility was derived from soil type data. The model calculates erosion for each grid cell under both vegetated and non-vegetated conditions to determine retention capacity.

6. Model Validation

Model outputs were compared with observed data. If deviations were large, parameters were adjusted based on literature and local data, then revalidated. Through iterative calibration, the final model achieved coefficient of determination (R^2) values exceeding 0.76 for all services, meeting validation requirements.

---

7. Results

7.1 Forest Resource Changes Forestland constituted the landscape matrix throughout the study area, showing continuous expansion. Forest coverage increased by 10.85% from 2004 to 2009 and by 7.44% from 2009 to 2014, reaching 45.65% by 2014. Closed forestland increased during both periods, while shrubland and nursery woodland grew more slowly. Sparse forestland and unstocked forestland both showed initial increases followed by decreases. The expansion of closed forestland was concentrated in the north during 2004-2009 and spread to the central and northwest regions during 2009-2014.

presents statistics for each forest type. The changes were driven by strategic policies, particularly the government' s afforestation campaigns. However, the fundamental driver was economic: around 2009, the study area experienced the "Lewis turning point," where rising non-agricultural wages and increasing agricultural opportunity costs caused large-scale rural outmigration. The South-to-North Water Transfer resettlement program relocated populations to other counties, while labor cost increases made marginal farmland cultivation uneconomical, causing agricultural land to lose its competitive advantage against forest expansion [35].

7.2 Water Retention Service Water retention capacity showed marked spatial variation across the county. High-value areas were concentrated in northern mountainous regions, with sub-high values in western low-mountain areas. Multi-year average water retention ranged from 182.08–238.81 mm in the north and 137.20–166.63 mm in the west. Low-function areas were distributed in southeastern mound and alluvial plain regions, with values of 89.44–128.48 mm. This pattern positively correlated with forest cover distribution: the north featured high elevations and concentrated forest patches; the west represented a transition zone with mixed forest and other land uses; the southeast had lower elevations, gentler terrain, and was dominated by farmland and construction land with sparse forest distribution.

From 2004 to 2014, county-level forest water retention declined continuously, with total retention decreasing by 19% despite forest area expansion. Average annual precipitation also declined during this period (841 mm in 2004, 785 mm in 2014), mirroring the water retention trend. Among forest types, closed forestland contributed most to water retention, followed by shrubland and sparse forestland. Average water retention per unit area decreased across all forest types: closed forestland from 347.47 mm to 239.89 mm, shrubland from 295.59 mm to 183.04 mm, and sparse forestland from 178.29 mm to 119.10 mm. This decline reflects both precipitation reduction and forest structural characteristics, as higher canopy density in closed forestland increases interception capacity, while better soil structure and root channels enhance infiltration and storage.

[Figure 3: see original paper] illustrates the spatial distribution of water retention services for 2004, 2009, and 2014.

7.3 Water Purification Service Water purification capacity was strongest in the north and weakest in the southeast, consistent with forest distribution patterns. Total nitrogen output decreased continuously from 254.08 t in 2004 to 207.47 t in 2009 and 180.48 t in 2014, representing a 29% improvement in purification capacity. The reduction in farmland area also contributed to decreased non-point source pollution.

All forest types except unstocked forestland showed decreasing nitrogen output per unit area, indicating improving purification capacity. The ranking of purification capacity was: closed forestland > sparse forestland > shrubland > nursery woodland > unstocked forestland. Canopy density positively correlates with nitrogen removal capacity [36], and closed forestland' s superior soil structure and greater soil thickness provide enhanced adsorption and storage of nitrogen.

and present nitrogen output values by forest type and year, while [Figure 4: see original paper] shows the spatial distribution of nitrogen output.

7.4 Soil Conservation Service Soil conservation capacity showed significant spatial variation, with high values in the north, moderate values in the southwest and center, and low values in the southeast. This pattern aligns with forest distribution and expansion directions. From 2004 to 2014, actual soil erosion and sediment export decreased continuously (65.58 t, 61.57 t, and 54.32 t), while total soil retention increased by 6%, indicating improved soil conservation services.

However, potential soil erosion showed an initial increase then decrease (2,683.08 t, 2,953.73 t, and 2,820.49 t) due to uneven seasonal rainfall distribution and high rainfall erosivity during concentrated precipitation events. Average soil retention per unit area across forest types followed the pattern: closed forestland > shrubland > sparse forestland > nursery woodland > unstocked forestland. Closed forestland' s deep root systems, high canopy density, and location on steep slopes in the north contributed to its superior performance. Root systems physically anchor soil, while decomposition of litter and roots improves soil structure, reduces bulk density, and enhances infiltration and erosion resistance [37-38].

and detail soil erosion and conservation by forest type, and [Figure 5: see original paper] maps the spatial distribution of soil conservation services.

8. Conclusion

During the study period, forest area in Xichuan County expanded rapidly (10.85% from 2004-2009, 7.44% from 2009-2014), reaching 45.65% coverage by 2014. While shrubland and nursery woodland increased slowly, unstocked forestland decreased. Spatially, all three ecosystem services exhibited a north-south gradient matching forest distribution patterns. In aggregate, water retention declined, water purification improved by 29%, and soil conservation increased by 6%.

Forest ecosystem services are influenced by both forest quantity/structure (e.g., canopy density, soil thickness, root depth) and meteorological factors. Climate change will inevitably affect forest structure and function. Although regional climate variability impacts services, overall ecosystem service capacity strengthened with forest expansion and quality improvement. Closed forestland emerged as the primary contributor to service provision, followed by shrubland and sparse forestland.

The key to managing forest ecosystem services lies in rational spatial configuration of forestland relative to other land uses, enhancing the sustainability of mosaic landscapes. Spatial output maps enable managers to understand how local forest changes affect service quantity and distribution, facilitating targeted protection of critical service areas. For instance, forest changes on steep slopes in the north pose maximum erosion risks, warranting afforestation to increase canopy density. Nitrogen output maps help identify areas important for water quality protection, particularly forests near the Danjiangkou Reservoir and major rivers, which serve as final barriers against pollutant entry.

While forest expansion improved water purification and soil conservation, declining rainfall degraded water retention. Given climate uncertainty, future forest management must shift from simple area expansion to improving forest quality and productivity through measures like supplementary planting and shelterbelt construction, thereby enhancing resilience to climate change [41].

References

[1] Assessment of ecosystem service functions of shrub and bamboo forests in China. *Acta Ecologica Sinica*, 2011, 31(7): 1936-1945.
[2] Evaluation of forest ecosystem services and their value in China. *Chinese Journal of Applied Ecology*, 2005, 16(8): 1531-1536.
[3] Xiao H, Wu G. Comparative analysis of physical and value-based assessment methods for ecosystem services. *Chinese Journal of Applied Ecology*, 2000, 11(2): 290-292.
[4] Assessment of forest ecological service functions and values in Gansu

Province. *Journal of Arid Land Resources and Environment*, 2007, 21(8): 147-151.
[5] Evaluation of forest ecosystem service value in Chongqing. *Acta Ecologica Sinica*, 2014, 34(1): 216-223.
[6] Li T, Cui YH, Liu AG. Spatiotemporal dynamic analysis of forest ecosystem services using "big data": A case study of Anhui Province, central-eastern China. *Journal of Cleaner Production*, 2017, 142: 589-599.
[7] Preliminary study on forest ecological environment health assessment. *Journal of Soil and Water Conservation*, 2003, 17(5): 16-18.
[8] Global forest resources assessment methods and implications. *Forest Resources Management*, 2005, (4): 24-29.
[9] Relationship between emergy and service function value of forest ecosystems in China. *Acta Geographica Sinica*, 2014, 69(3): 334-342.
[10] Li MS, Huang CQ, Zhu ZL, Shi H, Lu H, Peng SK. Assessing rates of forest change and fragmentation in Alabama, USA, using the vegetation change tracker model. *Forest Ecology and Management*, 2009, 257(6): 1480-1488.
[11] Daily GC, Postel S, Bawa KS, Kaufman L. *Nature' s Services: Societal Dependence on Natural Ecosystems*. Washington D.C.: Island Press, 1997.
[12] Evaluation of urban forest ecosystem service value in Guangzhou. *Chinese Agricultural Science Bulletin*, 2011, 27(31): 27-35.
[13] Preliminary study on forest ecosystem services and their ecological economic value assessment: A case study of Jianfengling tropical forest in Hainan Island. *Applied Ecology*, 2000, 11(4): 481-484.
[14] Assessment of water retention function of forest ecosystems in Taihe County, Jiangxi. *Progress in Geography*, 2012, 31(3): 330-336.
[15] Zhang B, Li WH, Xie GD, Xiao Y. Water conservation of forest ecosystem in Beijing and its value. *Ecological Economics*, 2010, 69(7): 1416-1426.
[16] Guo ZW, Gan YL. Ecosystem function for water retention and forest ecosystem conservation in a watershed of the Yangtze River. *Biodiversity & Conservation*, 2002, 11(4): 599-614.
[17] Dixon RK, Solomon AM, Brown S, Houghton RA, Trexier MC, Wisniewski J. Carbon pools and flux of global forest ecosystems. *Science*, 1994, 263(5144): 185-190.
[18] Annual dynamics of soil conservation value in forest ecosystems. *Acta Ecologica Sinica*, 2010, 30(13): 3482-3490.
[19] Comparative analysis of soil conservation function of InVEST model from different perspectives. *Geographical Research*, 2014, 33(12): 2393-2406.
[20] Lukina NV, Nikonov VV, Gorbacheva TT. Natural water quality formation in forest-covered divide areas in northern Taiga. *Water Resources*, 2001, 28(4): 438-450.
[21] Water quality effects at different levels of Huoditang forest ecosystem in Qinling Mountains. *Acta Ecologica Sinica*, 2007, 25(5): 1838-1844.
[22] Research progress and trends in forest ecosystem service value assessment. *Chinese Journal of Ecology*, 2013, 32(8): 2229-2237.
[23] Forest ecosystem services and their value assessment in China. *Journal of Natural Resources*, 2004, 19(4): 480-491.

[24] Nature reserve system planning in Hainan Island based on ecosystem services. *Acta Ecologica Sinica*, 2011, 31(24): 7357-7369.
[25] Nelson E, Mendoza G, Regetz J, Polasky S, Tallis H, Cameron D, Chan KM, Daily GC, Goldstein J, Kareiva PM, Lonsdorf E, Naidoo R, Ricketts TH, Shaw M. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment*, 2009, 7(1): 4-11.
[26] Soil erosion simulation in Beijing mountainous areas using InVEST model. *Research of Soil and Water Conservation*, 2010, 17(6): 9-13.
[27] Study on ecosystem soil conservation function of InVEST model: A case study of Ningde, Fujian. *Research of Soil and Water Conservation*, 2014, 21(4): 185-189.
[28] Spatial pattern and earthquake damage assessment of ecosystem carbon storage function in Wenchuan earthquake-stricken areas. *Acta Ecologica Sinica*, 2013, 33(3): 798-808.
[29] Tallis HT, Ricketts T, Nelson E. *InVEST 2.1 beta User' s Guide*. Stanford: The Natural Capital Project, 2010.
[30] Preliminary study on relationship between soil macropores and infiltration capacity in evergreen broad-leaved forest in Jinyun Mountain. *Journal of Southwest China Normal University (Natural Science)*, 2005, 30(3): 350-353.
[31] Empirical estimation of soil available water content: A case study of northeast black soil. *Journal of Arid Land Resources and Environment*, 2003, 17(4): 88-95.
[32] Spatial pattern of water retention function in Dujiangyan City. *Acta Ecologica Sinica*, 2013, 33(3): 789-797.
[33] Rainfall erosivity index in southeast Fujian. *Journal of Soil and Water Conservation*, 1992, 6(4): 1-5.
[34] [D] China University of Geosciences, 2014.
[35] Farmland marginalization and ecological restoration. *Resources and Environment*, 2011, 21(10): 91-95.
[36] Water quality changes during precipitation processes in natural spruce forest ecosystem in central Tianshan Mountains. *Acta Ecologica Sinica*, 2010, 30(18): 4828-4838.
[37] Comprehensive evaluation of soil conservation capacity of forest ecosystems in Beijing. *Journal of Soil and Water Conservation*, 2009, 16(1): 240-244.
[38] Study on soil and water conservation benefits and mechanisms of forests in loess hilly region. *Journal of Soil and Water Conservation*, 1996, 3(2): 98-103.
[39] Impact of land use change on ecosystem services: A case study of Miyun Reservoir watershed. *Acta Ecologica Sinica*, 2013, 33(3): 726-736.
[40] Several scientific issues on ecosystem service functions. *Biodiversity Science*, 2003, 11(1): 63-69.
[41] Forest ecosystem management oriented toward ecosystem services: Challenges and prospects. *Acta Ecologica Sinica*, 2015, 35(1): 1-9.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.