

Postprint: Spatiotemporal Evolution of Ecosystem Patterns and Driving Forces in the Yangtze River Basin

Authors: Kong Lingqiao, Zhang Lu, Zheng Hua, Xu Weihua, Xiao Yi, Ouyang Zhiyun

Date: 2018-02-01T00:00:00+00:00

Abstract

The ecosystem pattern of the Yangtze River Basin is complex, with ecological environment changes resulting from land use changes driven by multiple socio-economic, policy, and natural factors. This study analyzes the ecosystem pattern and evolution characteristics of the Yangtze River Basin from 2000 to 2015, as well as the contributions of major driving forces to ecosystem changes. Over the 15-year period, approximately 64,000 km² of ecosystem types underwent changes, with urban areas increasing by 67.5%, farmland decreasing by 7.5%, and forests increasing by 2.1%. Dramatic ecosystem changes were concentrated in the downstream region, as well as in large cities, urban agglomerations, and Grain for Green Program areas in the middle and upper reaches. The degree of landscape fragmentation and landscape diversity of the ecosystem increased. The ecosystem patterns and compositions differed significantly among the upper, middle, and lower reaches. Over the 15-year period, forests increased significantly in both the upper and lower reaches, urban areas expanded significantly and farmland and wetlands decreased significantly in the lower reaches, while wetlands increased most significantly in the upper reaches. Urbanization was the primary driving force for ecosystem pattern evolution, with a contribution rate of 48.0% to ecosystem changes, reaching as high as 64.5% in the lower Yangtze River. Ecological protection and restoration projects were the second driving force, with a contribution rate of 32.8% to ecosystem changes, reaching as high as 47.8% in the upper reaches. The contribution rates of water resource development and agricultural development were 8.5% and 9.9%, respectively. Additionally, climate change has led to the expansion of plateau lake areas. To protect the sustainable development of the Yangtze River Basin ecosystem, it is necessary to delineate ecological protection red lines, rationally plan land use in the urbanization process, protect high-quality farmland, and prohibit the development of important wetlands.

Full Text

Driving Forces Behind Ecosystem Spatial Changes in the Yangtze River Basin

KONG Lingqiao, ZHANG Lu, ZHENG Hua, XU Weihua, XIAO Yi, OUYANG Zhiyun

State Key Laboratory of Urban and Regional Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

University of Chinese Academy of Sciences, Beijing 100049, China

Abstract

The natural environment varies significantly among the upper, middle, and lower reaches of the Yangtze River Basin, with distinct regional topography and climatic conditions and unbalanced economic development. The impacts of various socioeconomic factors, policies, and natural factors on land use stimulate changes in the ecological environment. Knowledge of ecosystem patterns, characteristics, and driving forces is fundamental for studying ecosystem services, ecological environmental problems, and ecological risk assessments. This study analyzes ecosystem patterns, changing characteristics, and primary driving forces from 2000 to 2015 in the Yangtze River Basin. During this 15-year period, approximately 6.4×10^4 km² of ecosystems changed, including a 67.5% increase in urban land, a 2.1% increase in forest, and a 7.5% reduction in croplands. These dramatic changes were concentrated in the lower reaches, major cities in the upper and middle reaches, urban agglomerations, and reforested cropland areas. Ecosystem patterns and compositions differed among the upper, middle, and lower reaches. Forests and wetlands in the upper reach and urban land in the lower reach increased significantly, whereas croplands and wetlands in the lower reach decreased substantially. Analysis of landscape patterns revealed that the degree of landscape fragmentation and landscape diversity increased. Between 2000 and 2015, ecosystem pattern changes in the Yangtze River Basin were influenced by urbanization, ecological conservation and restoration, water resource development, agricultural development, geological hazards, and climate change. The contributions of primary driving forces to ecosystem changes varied across reaches. Urbanization was the most important driving force, with a contribution rate of 48.0% and up to 64.5% in the lower reach. Ecological conservation projects were the second most important driving force, with a contribution rate of 32.8% and up to 47.8% in the upper reach. Water resource development and agricultural development contributed 8.5% and 9.9%, respectively. Additionally, the area of plateau lakes increased due to climate change. To sustainably protect the ecosystem in the Yangtze River Basin, it is necessary to design ecological conservation redlines, conduct reasonable land use planning in urbanization, conserve high-quality cropland, and prohibit development on important wetlands.

Keywords: Yangtze River Basin; ecosystem; spatial pattern; driving forces

Introduction

The Yangtze River is China's largest river and a strategic water source for national water resource allocation projects including the South-to-North Water Diversion Project. It connects eastern, central, and western China and features diverse ecological environments, making it one of the world's most biodiverse regions and one of 35 priority conservation areas for the World Wide Fund for Nature. The Yangtze River Economic Belt has the world's largest population and most complete urban system of any mega-watershed economic zone, with its population and GDP exceeding 40% and 45% of the national total, respectively. It constitutes an important component of China's ecological security strategy pattern.

The natural environment of the Yangtze River Basin is complex, with obvious natural differentiation among the upper, middle, and lower reaches. Topography, landforms, and climatic conditions vary significantly across regions, and national economic development is unbalanced. The distribution and changes of ecosystems show significant spatial regional differences. Overexploitation and disorderly development of resources and energy have caused severe ecosystem degradation in some areas of the Yangtze River Basin. As China's urbanization accelerates, most provinces and cities in the Yangtze River Basin have land development intensity far exceeding the national average. However, ecological protection and restoration projects such as the Yangtze River Basin shelterbelt system construction project, natural forest protection program, and Grain-for-Green program have promoted vegetation restoration in the basin.

Socioeconomic factors, policy factors, and natural factors affecting land use changes in the Yangtze River Basin are numerous and complex. Revealing the evolution characteristics and driving forces of ecosystem patterns is fundamental for studying ecosystem services, environmental problems, and ecological risk assessment in the basin. International research has primarily focused on using remote sensing to obtain spatial distribution changes of land use, scenario simulation, and relationships with socioeconomic factors, as well as impacts of land use change on ecosystem services. Domestic studies have mainly explored ecosystem pattern changes or single ecosystem evolution at small and medium scales, such as in the Yangtze River source region, Taihu Lake Basin, Chaohu Lake Basin, and Yangtze River Delta region. This study analyzes the spatial distribution, composition, and change characteristics of ecosystems in the entire Yangtze River Basin to reveal ecosystem pattern evolution and driving forces.

Data Sources and Research Methods

Ecosystem classification data were obtained from the National Ecological Environment Ten-Year Change (2000-2010) and Five-Year Change (2010-2015) Remote Sensing Survey and Assessment Projects supported by the Chinese

Academy of Sciences and Ministry of Environmental Protection. The 30-meter resolution land cover datasets were derived from domestic environmental disaster satellites (HJ-1A/B) and American Landsat OLI imagery. Supported by a large sample library from ground survey plots, object-oriented multi-scale segmentation and decision tree classification methods were used to classify ecosystems into eight major categories: forest, shrub, grassland, wetland, cropland, urban land, glacier/permanent snow, and bare land. Based on the ecosystem composition characteristics of the Yangtze River Basin, these were reclassified into 6 secondary subclasses and 19 tertiary subclasses.

ArcGIS 10.3 was used for spatial data cutting, analysis, and statistics. ENVI 4.8 change detection modules calculated ecosystem transfer spatial distribution and area composition. The study area was divided into $10 \text{ km} \times 10 \text{ km}$ grids to calculate the proportion of ecosystem change area within each grid, showing hotspot regions of ecosystem change. Fragstats 4.2 landscape pattern analysis software calculated global and class-level landscape indices, including mean patch size (MPS), number of patches (NP), patch density (PD), edge density (ED), and Shannon diversity index (SHDI) to assess changes in landscape fragmentation and diversity.

The contribution rates of driving forces to ecosystem changes were determined by calculating the area of ecosystem transformation under each driver, including urbanization occupying cropland and natural ecosystems; ecological protection and restoration policies; water resource development; agricultural development; and geological hazards and climate change. The proportion of ecosystem change under each driver to the total change area yielded the contribution rates.

Ecosystem Pattern Characteristics of the Yangtze River Basin

The Yangtze River Basin contains diverse ecosystem types. Forest ecosystem has the largest area, accounting for 34.2% of the total basin area, followed by cropland at 28.7%. Wetland ecosystem accounts for 8.9%, grassland and shrub 7.5%, and urban ecosystem 3.7%. These four ecosystem types occupy 89.6% of the total basin area.

Among forest ecosystems, coniferous forest has the largest area (64.6% of total forest area), followed by broadleaf forest and mixed coniferous-broadleaf forest. Shrub ecosystem is dominated by broadleaf shrub (97.7%). Grassland ecosystem consists mainly of meadow and sparse grassland (65.2%). Wetland ecosystem includes lakes, reservoirs, ponds, and rivers with approximately equal total areas. In cropland ecosystem, paddy fields and dry land account for 97.2%. In urban ecosystem, construction land accounts for 83.8%.

The upper reach of the Yangtze River is extremely rich in natural resources, with large areas of forest, grassland, and wetland. Coniferous forest is most widely distributed in the upper reach, which also contains 59.9% of broadleaf shrub, 99.5% of coniferous shrub, and 63.5% of the basin's grassland (meadow and sparse grassland). The upper reach has the most marshes, accounting for

86.1% of the basin's total marsh area, and contains 94.7% of the basin's glaciers/permanent snow and bare land. Urban ecosystem in the upper reach accounts for only 19.8% of the basin's total urban area.

The middle reach has the largest areas of forest, cropland, and urban land. It contains 56.6% of the basin's mixed coniferous-broadleaf forest, 57.8% of broadleaf forest, and 53.8% of rivers. Paddy fields in the middle reach account for 52.3% of the basin's total paddy field area, and the middle reach contains the largest construction and transportation land areas.

The lower reach accounts for only 6.9% of the basin's total area but contains 35.5% of the basin's urban land. Construction land accounts for 92.3% of urban area, and lakes and reservoirs/ponds account for 73.6% of wetland area. The lower reach has the largest urban green space (39.1% of basin total) and the most intensive cropland distribution, with paddy fields accounting for 93.8% of cropland area.

Ecosystem Pattern Change Characteristics

From 2000 to 2015, forest and urban areas in the Yangtze River Basin increased significantly while cropland area decreased substantially. Urban area increased by 67.5%, forest by 2.1%, and wetland and bare land increased slightly, while cropland decreased by 7.5% and grassland and glacier/permanent snow decreased. The dominant transformation was cropland to urban land, followed by cropland to forest and cropland to grassland. Approximately 6.4×10^4 km² of ecosystems changed during this period.

In urban ecosystems, construction land increased most (105.1%), followed by transportation land (196.6%) and mining sites (65.0%), while urban green space increased by 61.9%. In cropland ecosystems, dry land and paddy field decreased by 11.4% and 5.1%, respectively. In wetland ecosystems, marshes decreased while lakes and reservoirs/ponds increased.

In the upper reach, forest and wetland increased overall while cropland and glacier/permanent snow decreased. Broadleaf and coniferous forests increased, and wetlands increased mainly in reservoirs/ponds and lakes. Although urbanization level is relatively low in the upper reach, construction and transportation land increased by 28.5% and 62.2%, respectively, and mining sites increased by 12.3%.

In the middle reach, cropland decreased overall by 6.0%, with dry land decreasing most. Urban and wetland areas increased overall, with construction land, transportation land, and urban green space increasing by 71.2%, 97.9%, and 10.9%, respectively.

In the lower reach, urban and forest areas increased significantly while cropland decreased substantially. Urban growth was fastest (104.5% increase), with construction land, transportation land, and urban green space increasing by 47.8%, 18.4%, and 23.8%, respectively. Cropland decreased fastest (15.3% for paddy

fields, 3.4% for dry land). Dramatic ecosystem changes concentrated in the lower reach and large cities like Wuhan and Changsha in the middle and upper reaches.

Landscape pattern analysis shows that at the landscape level, mean patch size decreased, patch density and edge density increased, and Shannon diversity index rose, indicating enhanced overall landscape fragmentation and increased diversity. At the class level, mean patch sizes of cropland and glacier/permanent snow decreased, while patch density and edge density of all ecosystem types increased, indicating enhanced landscape fragmentation.

Drivers of Ecosystem Pattern Changes

Ecosystem pattern changes in the Yangtze River Basin were primarily driven by urbanization, ecological conservation and restoration, water resource development, agricultural development, geological hazards, and climate change.

Urbanization was the most important driving force, contributing 48.0% to ecosystem changes and up to 64.5% in the lower reach. Due to accelerated urbanization, large areas of cropland were converted to urban land, and grassland and wetland were also occupied. The area of ecosystem change caused by urbanization reached 2.86×10^4 km², with the largest transformation being cropland to construction land (590.9 km²).

Ecological conservation and restoration projects were the second most important driving force, contributing 32.8% overall and up to 47.8% in the upper reach. The Yangtze River Basin implemented policies including Grain-for-Green, natural forest protection, and lake restoration, resulting in forest restoration and grassland and wetland recovery. The total change area reached approximately 1.95×10^4 km², with the largest transformation being cropland to forest (501.2 km²).

Water resource development contributed 8.5% to ecosystem changes. Water projects caused increases in lake and river surface areas, with large areas of cropland flooded by reservoirs in the South-to-North Water Diversion source region. Agricultural development contributed 9.9%, with cropland expansion occupying wetland, shrub, and grassland. Although total cropland area decreased sharply, local agricultural development still encroached on natural ecosystems, with 465.5 km² of wetland occupied by cropland.

Geological hazards such as the 2008 Wenchuan earthquake and 2013 Ya' an earthquake damaged natural habitats and cropland in seismic areas, causing 185.5 km² of ecosystem degradation. Climate change contributed to ecosystem changes in the upper reach, with global warming causing glacier and permanent snow melt (228.3 km² changed to bare land or lakes).

The contribution of each driving force varied significantly across reaches. In the upper reach, ecological conservation and restoration was the primary driver (42.0% of basin total forest recovery and 43.6% of grassland recovery). In the

middle reach, urban expansion was the primary driver, with urban-occupied wetland and cropland accounting for 45.9% and 29.8% of basin totals, respectively. In the lower reach, urbanization contributed most to ecosystem changes (49.6% of basin total), followed by water resource development and agricultural development, with wetland and cropland occupation accounting for 48.3% and 79.7% of basin totals, respectively.

Conclusions and Discussion

This study reveals the spatial distribution, composition, and changes of ecosystems in the Yangtze River Basin, showing that forest and urban areas increased while cropland decreased. Natural ecosystems increased in the upper reach, while urban and cropland change rates were highest in the lower reach. Dramatic ecosystem changes concentrated in the lower reach and large cities like Wuhan and Changsha in the middle and upper reaches.

Urbanization is the primary driving force of ecosystem change in the Yangtze River Basin, causing severe cropland reduction. Although urbanization promotes rural population transfer to cities, reducing human pressure on fragile ecosystems and facilitating ecological protection and restoration, it also encroaches on natural habitats. The Yangtze River Economic Belt's urbanization will further accelerate according to development plans, requiring reasonable land use planning and implementation of ecological conservation redlines.

China's ecological conservation and restoration projects are also important driving forces, contributing over 30% to ecosystem changes with significant effects. However, human activity interference has enhanced natural habitat fragmentation, requiring improved connectivity maintenance. Wetland area increased overall due to climate change and water project construction, yet wetland loss from urbanization and agricultural development remains severe, particularly marsh and lake loss in the lower reach, which accounts for 71.4% of basin total wetland loss. This leads to biodiversity loss and weakened flood regulation capacity, necessitating ecological redlines for wetland protection.

This study macroscopically reveals the overall distribution pattern, evolution characteristics, and driving forces of ecosystems in the Yangtze River Basin, which is important for studying ecosystem services, environmental problems, and ecological risks. Future research should further analyze ecosystem changes at different spatial scales, investigate the coupling mechanisms among driving factors, and conduct simulations and predictions of future ecosystem changes.

References

- [1] Zhang J X, Liu Z J, Sun X X. Changing landscape in the Three Gorges Reservoir Area of Yangtze River from 1977 to 2005: Land use/land cover, vegetation cover changes estimated using multi-source satellite data. *International Journal of Applied Earth Observation and Geoinformation*, 2009, 11(6): 403-412.

- [2] Liu J Y, Zhang Z X, Xu X L, Kuang W H, Zhou W C, Zhang S W, Li R D, Yan C Z, Yu D S, Wu S X, Jiang N. Spatial patterns and driving forces of land use change in China during the early 21st century. *Journal of Geographical Sciences*, 2010, 20(4): 483-494.
- [3] Long H L, Heilig G K, Li X B, Zhang M. Socio-economic development and land-use change: Analysis of rural housing land transition in the Transact of the Yangtze River, China. *Land Use Policy*, 2007, 24(1): 141-153.
- [4] Long H L, Tang G P, Li X B, Heilig G K. Socio-economic driving forces of land-use change in Kunshan, the Yangtze River Delta economic area of China. *Journal of Environmental Management*, 2007, 83(3): 351-364.
- [5] Lambin E F, Meyfroidt P. Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences of the United States of America*, 2011, 108(9): 3465-3472.
- [6] Long H L, Heilig G K, Wang J, Li X B, Luo M, Wu X Q, Zhang M. Land use and soil erosion in the upper reaches of the Yangtze River: Some socio-economic considerations on China' s Grain-for-Green Programme. *Land Degradation & Development*, 2006, 17(6): 589-603.
- [7] Carreño L, Frank F C, Viglizzo E F. Tradeoffs between economic and ecosystem services in Argentina during 50 years of land-use change. *Agriculture, Ecosystems & Environment*, 2012, 154: 68-77.
- [8] Polasky S, Nelson E, Pennington D, Johnson K A. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the State of Minnesota. *Environmental and Resource Economics*, 2011, 48(2): 219-242.
- [9] Lawler J J, Lewis D J, Nelson E, Plantinga A J, Polasky S, Withey J C, Helmers D P, Martinuzzi S, Pennington D, Radeloff V C. Projected land-use change impacts on ecosystem services in the United States. *Proceedings of the National Academy of Sciences of the United States of America*, 2014, 111(20): 7492-7497.
- [10] Goldstein J H, Caldarone G, Duarte T K, Ennaanay D, Hannahs N, Mendoza G, Polasky S, Wolny S, Daily G C. Integrating ecosystem-service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences of the United States of America*, 2012, 109(19): 7565-7570.
- [11] Bryan B A, Crossman N D. Impact of multiple interacting financial incentives on land use change and the supply of ecosystem services. *Ecosystem Services*, 2013, 4: 60-72.
- [12] Long H L, Tang G P, Li X B, Heilig G K. Socio-economic driving forces of land-use change in Kunshan, the Yangtze River Delta economic area of China. *Journal of Environmental Management*, 2007, 83(3): 351-364.
- [13] Lambin E F, Meyfroidt P. Global land use change, economic globalization,

and the looming land scarcity. *Proceedings of the National Academy of Sciences of the United States of America*, 2011, 108(9): 3465-3472.

[14] Long H L, Heilig G K, Wang J, Li X B, Luo M, Wu X Q, Zhang M. Land use and soil erosion in the upper reaches of the Yangtze River: Some socio-economic considerations on China' s Grain-for-Green Programme. *Land Degradation & Development*, 2006, 17(6): 589-603.

[15] Carrreño L, Frank F C, Viglizzo E F. Tradeoffs between economic and ecosystem services in Argentina during 50 years of land-use change. *Agriculture, Ecosystems & Environment*, 2012, 154: 68-77.

[16] Polasky S, Nelson E, Pennington D, Johnson K A. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the State of Minnesota. *Environmental and Resource Economics*, 2011, 48(2): 219-242.

[17] Lawler J J, Lewis D J, Nelson E, Plantinga A J, Polasky S, Withey J C, Helmers D P, Martinuzzi S, Pennington D, Radeloff V C. Projected land-use change impacts on ecosystem services in the United States. *Proceedings of the National Academy of Sciences of the United States of America*, 2014, 111(20): 7492-7497.

[18] Goldstein J H, Caldarone G, Duarte T K, Ennaanay D, Hannahs N, Mendoza G, Polasky S, Wolný S, Daily G C. Integrating ecosystem-service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences of the United States of America*, 2012, 109(19): 7565-7570.

[19] Bryan B A, Crossman N D. Impact of multiple interacting financial incentives on land use change and the supply of ecosystem services. *Ecosystem Services*, 2013, 4: 60-72.

[20] Liu J Y, Zhang Z X, Xu X L, Kuang W H, Zhou W C, Zhang S W, Li R D, Yan C Z, Yu D S, Wu S X, Jiang N. Spatial patterns and driving forces of land use change in China during the early 21st century. *Journal of Geographical Sciences*, 2010, 20(4): 483-494.

[21] Zhang J X, Liu Z J, Sun X X. Changing landscape in the Three Gorges Reservoir Area of Yangtze River from 1977 to 2005: Land use/land cover, vegetation cover changes estimated using multi-source satellite data. *International Journal of Applied Earth Observation and Geoinformation*, 2009, 11(6): 403-412.

[22] Long H L, Heilig G K, Li X B, Zhang M. Socio-economic development and land-use change: Analysis of rural housing land transition in the Transact of the Yangtze River, China. *Land Use Policy*, 2007, 24(1): 141-153.

[23] Xu X B, Yang G S, Tan Y, Zhuang Q L, Li H P, Wang R R, Su W Z, Zhang J. Ecological risk assessment of ecosystem services in the Taihu Lake Basin of China from 1985 to 2020. *Science of the Total Environment*, 2016, 554-555: 7-16.

- [24] Long H L, Tang G P, Li X B, Heilig G K. Socio-economic driving forces of land-use change in Kunshan, the Yangtze River Delta economic area of China. *Journal of Environmental Management*, 2007, 83(3): 351-364.
- [25] Lambin E F, Meyfroidt P. Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences of the United States of America*, 2011, 108(9): 3465-3472.
- [26] Goldstein J H, Caldarone G, Duarte T K, Ennaanay D, Hannahs N, Mendoza G, Polasky S, Wolny S, Daily G C. Integrating ecosystem-service tradeoffs into land-use decisions. *Proceedings of the National Academy of Sciences of the United States of America*, 2012, 109(19): 7565-7570.
- [27] Bryan B A, Crossman N D. Impact of multiple interacting financial incentives on land use change and the supply of ecosystem services. *Ecosystem Services*, 2013, 4: 60-72.
- [28] Lawler J J, Lewis D J, Nelson E, Plantinga A J, Polasky S, Withey J C, Helmers D P, Martinuzzi S, Pennington D, Radeloff V C. Projected land-use change impacts on ecosystem services in the United States. *Proceedings of the National Academy of Sciences of the United States of America*, 2014, 111(20): 7492-7497.
- [29] Ouyang Z Y, Zheng H, Xiao Y, Polasky S, Liu J G, Xu W H, Wang Q, Zhang L, Xiao Y, Rao E M, Jiang L, Lu F, Wang X K, Yang G B, Gong S H, Wu B F, Zeng Y, Yang W, Daily G C. Improvements in ecosystem services from investments in natural capital. *Science*, 2016, 352(6292): 1455-1459.
- [30] Liu J G, Li S X, Ouyang Z Y, Tam C, Chen X D. Ecological and socio-economic effects of China's policies for ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America*, 2008, 105(28): 9477-9482.
- [31] Long H L, Heilig G K, Wang J, Li X B, Luo M, Wu X Q, Zhang M. Land use and soil erosion in the upper reaches of the Yangtze River: Some socio-economic considerations on China's Grain-for-Green Programme. *Land Degradation & Development*, 2006, 17(6): 589-603.
- [32] Carrreño L, Frank F C, Viglizzo E F. Tradeoffs between economic and ecosystem services in Argentina during 50 years of land-use change. *Agriculture, Ecosystems & Environment*, 2012, 154: 68-77.
- [33] Polasky S, Nelson E, Pennington D, Johnson K A. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: A case study in the State of Minnesota. *Environmental and Resource Economics*, 2011, 48(2): 219-242.
- [34] Lawler J J, Lewis D J, Nelson E, Plantinga A J, Polasky S, Withey J C, Helmers D P, Martinuzzi S, Pennington D, Radeloff V C. Projected land-use change impacts on ecosystem services in the United States. *Proceedings of the*

National Academy of Sciences of the United States of America, 2014, 111(20): 7492-7497.

[35] Goldstein J H, Caldarone G, Duarte T K, Ennaanay D, Hannahs N, Mendoza G, Polasky S, Wolny S, Daily G C. Integrating ecosystem-service tradeoffs into land-use decisions. Proceedings of the National Academy of Sciences of the United States of America, 2012, 109(19): 7565-7570.

[36] Bryan B A, Crossman N D. Impact of multiple interacting financial incentives on land use change and the supply of ecosystem services. Ecosystem Services, 2013, 4: 60-72.

[37] Ouyang Z Y, Zheng H, Xiao Y, Polasky S, Liu J G, Xu W H, Wang Q, Zhang L, Xiao Y, Rao E M, Jiang L, Lu F, Wang X K, Yang G B, Gong S H, Wu B F, Zeng Y, Yang W, Daily G C. Improvements in ecosystem services from investments in natural capital. Science, 2016, 352(6292): 1455-1459.

[38] Liu J G, Li S X, Ouyang Z Y, Tam C, Chen X D. Ecological and socio-economic effects of China's policies for ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 2008, 105(28): 9477-9482.

[39] Long H L, Heilig G K, Wang J, Li X B, Luo M, Wu X Q, Zhang M. Land use and soil erosion in the upper reaches of the Yangtze River: Some socio-economic considerations on China's Grain-for-Green Programme. Land Degradation & Development, 2006, 17(6): 589-603.

[40] Xu X B, Yang G S, Tan Y, Zhuang Q L, Li H P, Wang R R, Su W Z, Zhang J. Ecological risk assessment of ecosystem services in the Taihu Lake Basin of China from 1985 to 2020. Science of the Total Environment, 2016, 554-555: 7-16.

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

Source: ChinaXiv – Machine translation. Verify with original.