Using ecosystem service trade-offs to inform water conservation policies and management practices

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Environmental managers and policy makers are increasingly discussing trade-offs between ecosystem services, but few studies have analyzed these trade-offs with a view to informing land-use planning. Using specialized models, we quantify ecosystem services in several land-use scenarios relative to actual land-use change over a 9-year period. These scenarios were developed in an effort to maintain agricultural production while improving water quality and increasing water quantity in the watershed of the Miyun Reservoir, the only source of surface water currently available for domestic use in Beijing, China. Within the watershed, from 2000 to 2009, forest cover and urban area increased by 33% and 280%, while water provision and water purification services declined by 9% and 27%, respectively. Under a hybrid scenario of agricultural expansion with riparian grassland buffers, three services – water provision, water purification, and sediment retention – as well as agricultural production all improved as compared with 2009 levels. Riparian grassland protection zones, seldom used in China, can effectively resolve trade-offs among multiple ecosystem services and are now being considered and implemented in several locations.

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The Chinese Government recognizes ecosystem services as vital to national security and sustainable economic development (Daily *et al.* 2013; Ouyang and Zheng 2014). A prime challenge is to co-develop and communicate ecosystem service science in a way that meets policy makers' needs, helping to resolve difficult trade-offs associated with alternative development pathways. Over the past century, the main focus in China and indeed the world was on maximizing the production of single ecosystem goods, such as crops and timber, often at the expense of regulating services such as soil conservation, flood control, and climate stability (MA 2005; Dosskey *et al.* 2012). Today, an understanding of the trade-offs between biodiversity and multiple ecosystem services is crucial for managing complex landscapes and regions characterized by multiple stakeholders, and for defining sustainable development pathways into the 21st century (Power 2010; Prager *et al.* 2012; White *et al.* 2012).

During the past decade, there have been improvements in our understanding of how land-use change alters ecosystem types, patterns, processes, and services (Foley *et al.* 2005; Ray *et al.* 2010; Euliss *et al.* 2011). First-generation, rudimentary models (eg Integrated Valuation of Ecosystem Services and Trade-offs [InVEST]) of land-use impacts on biodiversity and a range of ecosystem services have been developed specifically for analysis of trade-offs (de Groot *et al.* 2010; Kareiva *et al.* 2011; Polasky *et al.* 2011; Tallis *et al.* 2011). Newer studies, co-developed with decision makers, are beginning to estimate the response of multiple ecosystem services to land-use changes, and to integrate those responses into sustainable land-use policies and management (Ruckelshaus *et al.* 2013). This work involves many challenges, such as engaging with decision makers to generate realistic scenarios, acquiring high-quality data, parameterizing and interpreting models, and working iteratively with decision makers to inform real policy choices.

We address these challenges in the context of the Miyun Reservoir watershed, the only surface-water source for Beijing. Here, the three main management goals are sustainable improvements in (1) water quantity, (2) water quality, and (3) rural livelihoods. Many conservation measures have been put in place in this watershed to increase water quantity and quality, especially after a policy promoting "Sustainable use planning for Beijing water resources in the early 21st century" was implemented in 2001 (Yuan 2003). These measures include targeted policies that aim to convert farmland to forest, protect forests near key surface-water sources, and convert rice paddy fields into dry land agriculture. However, over the past two decades, the water level of Miyun Reservoir has declined while the reservoir's concentrations of non-point-source pollutants have increased (Zheng *et al.* 2013). Decreased river discharge and increased nutrient concentrations are

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of great concern for water resource managers in Beijing (Chen *et al.* 2007; Zuo *et al.* 2011). Competition between upstream and downstream water users and land-use changes within the watershed are putting severe pressure on the Miyun Reservoir's viability as a source of drinking water.

The principal challenges facing Beijing's water managers are determining how land-use changes will affect water quantity and quality, and understanding how to manage land uses in the Miyun Reservoir watershed to secure both sustainable delivery of water to Beijing residents and local livelihoods. To address these challenges, we first characterized the changes in priority ecosystem services during the decade (2000–2009) in which Beijing developed and executed major water resource policies aimed at sustainable management (Wang 2001). We then built four alternative trajectories of land-use change for the 2000–2009 period to determine their potential impacts on water quantity and quality for the Miyun Reservoir.

Materials and methods

Study area

Located approximately 100-km north of the city of Beijing, the Miyun Reservoir spans 188 km^2 and has a storage capacity of 43.17×10^8 m^3 (WebFigure 1). Its watershed has a semi-arid, continental monsoon climate with an annual mean temperature of 9°–10°C and annual mean precipitation of 489 mm. The topography is characterized by steep slopes and deep valleys. Approximately 80% of the watershed is located in Hebei Province, with the remaining 20% in the greater municipality of Beijing (WebFigure 1). The current total population in the catchment is approximately 878,000, of which approximately 805,000 (92%) are engaged in agriculture (Tang *et al.* 2010). The average net income of farmers in the Beijing townships (downstream) is about three times that of farmers in Hebei Province (upstream) (Zheng *et al.* 2013). In the upstream sections of the Miyun Reservoir watershed, the conservation of water-related services is directly at odds with further agricultural development and the improvement of household livelihoods, and this remains a major challenge in the region.

Although many conservation measures have been implemented in the Miyun Reservoir watershed, especially since 2001, the mean annual inflow from runoff decreased from 1.3 billion cubic meters (BCM) during the 1960s to less than 0.4 BCM during the 2000s, mainly due to land-use changes and an increase in upstream water utilization (especially for agricultural development) (Zuo *et al.* 2011). The total nitrogen concentration, which averaged 0.76 mg L^{-1} in 1987–1988, increased to 3.28 mg L^{-1} by 2003–2005. Total phosphorus has a much shorter monitoring record but currently ranges from 0.017 to 0.076 mg L^{-1} (Chen *et al.* 2007). At the same time, rapid population growth has increased the demand for water in Beijing. Between 2010 and 2014, the population of Beijing increased from 13.6×10^6 to 21.5×10^6, but per-capita water availability is only around 100 m^3, making Beijing one of the most water-scarce cities in China. The sustainable improvement of local livelihoods and water-related ecosystem services in the Miyun Reservoir watershed is therefore a high priority for the city.

Land-use changes and scenarios

We used Landsat™ images from 2000 and 2009 to generate a baseline land-use change map, with a spatial resolution of 30 m × 30 m. We classified land use and land cover (LULC) into eleven types: dry land, paddy field, orchard, coniferous forest, deciduous forest, mixed forest, shrub land, grassland, construction land, wetland, and bare (rocky/sandy) land (Figure 1). From 2000 to 2009, there were large increases in forest cover and decreases in agricultural land due in large part to afforestation policies (Figure 1 and WebTable 1).

There are trade-offs between the two priority regulating services and the agricultural production that underpins rural livelihoods; the government wants to consider these trade-offs in land-use planning. To illustrate the different trade-offs associated with different land-use policies, we developed alternative scenarios of potential land-use change (relative to 2009 conditions) based on three principles: (1) maintaining or improving agricultural yields, (2) using vegetation restoration approaches shown through scientific assessment to be the most effective, and (3) minimizing trade-offs by identifying and protecting areas of high ecosystem service provision.

We selected three principal management measures likely to be feasible in biophysical, socioeconomic, and political terms: (1) agricultural development, (2) planting trees or grasses with different evapotranspiration rates, and (3) conservation of riparian buffers that play a key role in pollutant retention (Cooper *et al.* 1987; Lowrance *et al.* 1988). From this, the following four realistic alternative scenarios of potential land-use change were developed:

- FTG (forest to grassland): convert the increased forest area observed over 2000–2009 to grassland.
- AD (agricultural development): any area that was farmland in 2000 or 2009 remains farmland, except for areas that underwent urban or waterway development by 2009. Overall this results in an increase in farmland of 58.9% relative to the actual farmland in 2009 (at the expense of mostly forest and grassland).
- RCTAD (riparian conservation with trees and agricultural development): the same conditions as in AD, but with the addition of an 80-m-wide riparian broadleaf tree buffer to improve water

purification. Forests increase by 4.2%, primarily replacing riparian farmland and grassland.

- RCGAD (riparian conservation with grassland and agricultural development): the same conditions as AD, but with the addition of an 80-m-wide riparian grassland buffer. Grasslands increase by 39%, primarily on riparian farmland and forest.

The land-use changes in 2000, 2009, and the four potential scenarios are shown in Figure 1 and WebTable 1.

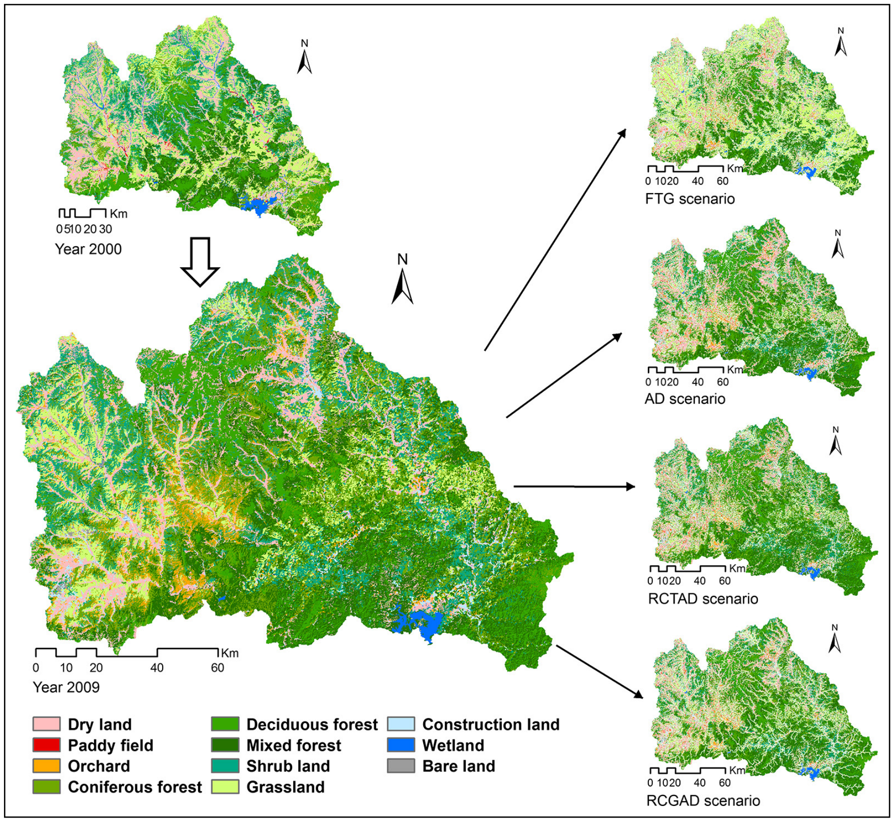

Figure 1. *Land-use patterns for 2000 and 2009, and under four potential land-use scenarios. FTG = forest to grassland; AD = agricultural development; RCTAD = riparian conservation with trees and agricultural development; RCGAD = riparian conservation with grassland and agricultural development.*

Models

We used the InVEST models to quantify the following ecosystem services: (1) water yield (for water resource provision), (2) water purification (for good water quality), and (3) sediment retention (Sharp *et al.* 2015). InVEST quantifies and maps ecosystem services provided by an existing landscape or under potential land conversion scenarios. We used the average climate parameters across 30 years (1980–2009) to generalize the results for the region. We acquired data related to export coefficients, crop and land management, soils, and carbon sequestration rates from locally conducted studies. Input values for each of these models are provided in WebTable 2. We used farmland area as a proxy indicator of agricultural production. We also assessed carbon sequestration services for each LULC type (Li *et al.* 2015) (WebPanel 1). The water yield, water purification, and sediment retention models have been validated with observed data in the Miyun Reservoir watershed, and the relationships between simulated values and observed values were $y = 1.02x$ ($n = 14$; $R^2 = 0.80$), $y = 1.08x$ ($n = 11$; $R^2 = 0.91$) and $y = 0.92x$ ($n = 13$; $R^2 = 0.66$), respectively (Li *et al.* 2013). While these models do not consider land acquisition or policy costs of the scenarios, we assume the costs would be similar to (in the FTG case) or less than (in the AD, RCTAD, and RCGAD cases, since we allow for agricultural expansion that would operate at a net profit) our baseline 2009 conditions.

Results

Forest, grassland, and farmland are the major land-use types in Miyun Reservoir watershed and cover more than 95% of its total area. Between 2000 and 2009, forest and developed land increased by 33% (2564 km^2) and 280% (261 km^2), respectively, whereas farmland and grassland decreased by 17% (526 km^2) and 56% (2171 km^2), respectively (WebTable 1). During the same time period, sediment retention and carbon sequestration services increased by 42% and 31%, respectively, while agricultural production, water provision services, and water purification services decreased by 17%, 9%, and 27%, respectively (Figure 2).

The trade-offs among land-use scenarios are quite stark. Under the FTG scenario, water provisioning increased by 15%, whereas sediment retention, water purification, and carbon sequestration services decreased by 7%, 11%, and 29%, respectively. Thus, the improvement in provisioning services came at the expense of regulating services. The results were similar for the AD scenario, in which agricultural production increased by 42%, while water provision, sediment retention, water purification, and carbon sequestration services decreased by 2%, 56%, 23%, and 7%, respectively. Under the RCTAD scenario, water provisioning decreased by 6% even while all other services increased, including agricultural production (7%), sediment retention (30%), water purification (40%), and carbon sequestration services (6%). The

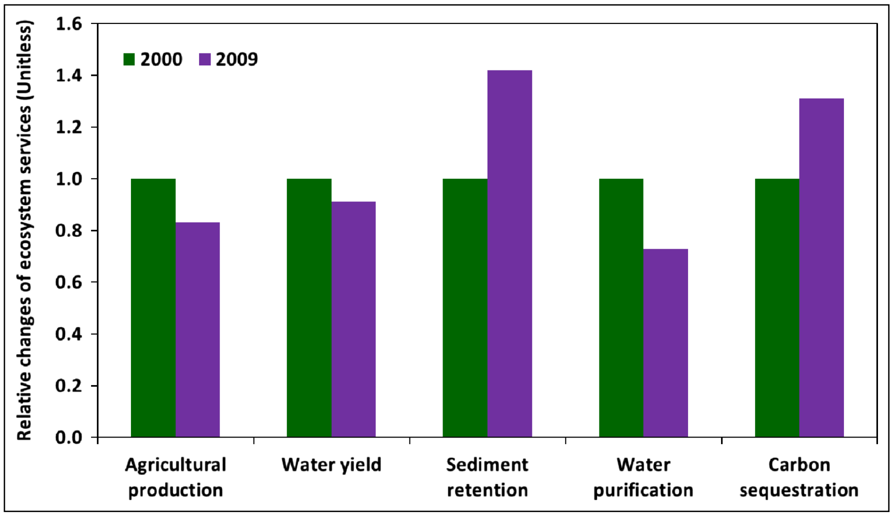

Figure 2. *Relative (normalized) changes of ecosystem services between 2000 and 2009.*

RCGAD scenario, however, featured lower overall increases of water provisioning (7%) with agricultural production (7%), sediment retention (27%), and water purification (24%) services; the only decrease was of 6% in carbon sequestration (Figure 3).

Discussion

Our study reveals the trade-offs of ecosystem services (agricultural production and regulating services, water yield, and carbon sequestration) (Figures 2 and 3), which were found to be similar to those in other contexts (eg Power 2010; Hoyer and Chang 2014). This is a key challenge that decision makers must confront (eg Bagstad *et al.* 2013). Management activities that focus on one service can threaten other services, resulting in unintended degradation and policy failures (Rodríguez *et al.* 2006; Chisholm 2010). Thus, a crucial question facing researchers and decision makers worldwide is how to minimize trade-offs among multiple ecosystem services (Nelson *et al.* 2009; Goldstein *et al.* 2012; Ziv *et al.* 2012).

Through scenario analysis, we found a feasible resolution in the RCGAD scenario, which showed increases in sediment retention, water purification, agricultural production, and water provisioning services, while reducing only carbon sequestration services by 6% (Figure 3). Although increased agricultural development usually leads to reductions in water quality, causing substantial negative externalities (Pretty *et al.* 2006; Gordon *et al.* 2008; Power 2010), the RCGAD minimized trade-offs through riparian conservation, mainly as a result of the following: (1) riparian vegetation (eg grass) is more efficient at retaining sediment and purifying water than other ecosystems in the watershed (Correll 1997; Goldstein *et al.* 2012) and (2) riparian grasslands provide higher water yield because of their lower evapotranspiration in comparison with forests (Chisholm 2010; Ray *et al.* 2010).

More broadly, our approach illustrates how information can help guide local land-use decisions to minimize the trade-offs between local and regional interests and address sustainability challenges: (1) understanding the shared driver(s) (vegetation restoration, agricultural development) causing the trade-off between services (eg carbon sequestration versus water yield, or agricultural production versus water purification/sediment retention); (2) making ecosystem service trade-offs explicit in decision making; and (3) prioritizing areas that provide high ecosystem service levels, and protecting these areas to achieve a high return on investment.

Today in China, there is a broad shift underway, driven by a powerful vision of securing natural capital as a foundation for improving human well-being. Although scientific findings do not always translate directly into policy changes, there is currently a complex and fruitful interplay between science and policy. For example, the Beijing Government is implementing a program called the "Ecologically-Clean Small Watershed Plan" through integrated landscape planning, including mountain, water, cropland, forest, and infrastructure land uses at the watershed scale, restoration of riparian vegetation, adaptive restoration of forest and grassland vegetation, and other measures (Ministry of Water Resource of China 2013). By 2015, of the 576 small watersheds present in the mountainous areas around Beijing, 291 "ecological-clean small watersheds" had been constructed.

The analyses presented here are informing policy discussions and supporting decisions in areas beyond but with similar biophysical and social conditions to those

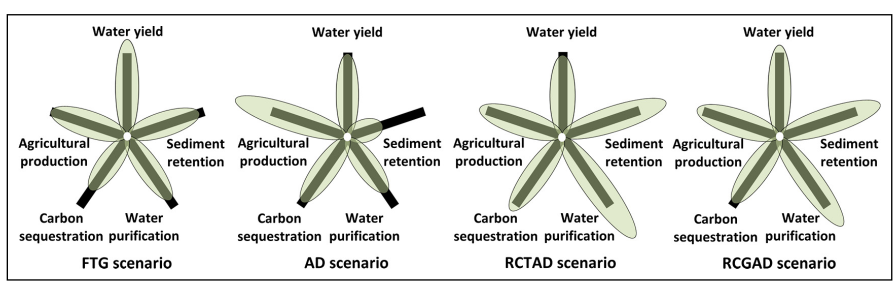

Figure 3. *Trade-offs between different ecosystem services under alternative land-use scenarios. The lengths of the dark green bars represent ecosystem service provision in 2009 and the lengths of the light green petals represent the services under different scenarios.*

of the Miyun Reservoir watershed. We provide three examples:

(1) In the water-scarce Loess Plateau, planting grasses might be more water-efficient than tree-based restoration and can be equally efficient with respect to enhancing other services, given the increase in evapotranspiration from afforestation (Chisholm 2010; Ray *et al.* 2010; Cao *et al.* 2011). This approach is now being considered by decision makers in this region.

(2) In many locations, it has been demonstrated that riparian zones can effectively reduce trade-offs among multiple ecosystem services, yet the option to conserve or restore riparian areas has often been neglected in China. Riparian zones are also important ecological corridors with many ecological functions (Brinson and Eckles 2011), and certain regions are known for protecting them (eg Washington State Shoreline Management Act [Morrison 1988], the "Protection Policy for Lakeshore, Riverbanks, Littoral Zones and Floodplains" in Quebec, Canada [Sunohara *et al.* 2012]). The Beijing Government is currently investing 17 billion yuan ($2.7 billion) in the Yongdinghe River Ecological Corridor project to restore riparian zones and riverine areas in the Yongdinghe River Basin (Figure 4a) (Wong *et al.* 2015).

(3) Previously in China, problems of water scarcity and pollution were seriously aggravated by having three separate governmental departments in charge of land use, water resources, and water pollution control. Now, with emerging ecosystem service analyses showing the value of integrated management, "multiple planning integration" from the National Development and Reform Commission, Ministry of Land and Resources, Ministry of Environmental Protection, and Ministry of Housing and Urban–Rural Development is being pilot-tested in some regions (Shen 2015) to minimize ecosystem service trade-offs.

In conclusion, the grand challenge is how to maintain agricultural production while improving water quality and increasing inflow into downstream reservoirs in northern Chinese watersheds, including the Miyun Reservoir watershed. In our study, the RCGAD scenario improved both regulating and provisioning services, and only decreased carbon sequestration by 6%. We emphasize the importance of riparian conservation in minimizing trade-offs between ecosystem services, reveal that planting grasses instead of trees will help not only to conserve water but also to restore vegetation in the watershed, and demonstrate how to integrate ecosystem service trade-offs into management practices to better inform water conservation policies. This has the potential to be scaled up to improve water management and water conservation policy throughout China.

Figure 4. *Improved (a) and degraded (b) ecosystem services of riparian areas in Haihe Basin, China.*

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References

Bagstad KJ, Semmens DJ, and Winthrop R. 2013. Comparing approaches to spatially explicit ecosystem service modeling: a case study from the San Pedro River, Arizona. *Ecosyst Serv* **5**: 40–50.

Brinson MM and Eckles SD. 2011. US Department of Agriculture conservation program and practice effects on wetland ecosystem services: a synthesis. *Ecol Appl* **21**: S116–27.

Cao SX, Chen L, Shankman D, *et al.* 2011. Excessive reliance on afforestation in China's arid and semi-arid regions: lessons in ecological restoration. *Earth-Sci Rev* **104**: 240–45.

Chen Y, Ma QY, Wang YT, *et al.* 2007. Water chemical properties of Miyun Reservoir, Beijing and the main rivers flowing into the reservoir. *Beijing Linye Daxue Xuebao (J Beijing Forestry Univ)* **29**: 105–11.

Chisholm RA. 2010. Trade-offs between ecosystem services: water and carbon in a biodiversity hotspot. *Ecol Econ* **69**: 1973–87.

Cooper JR, Gilliam JW, Daniels RB, *et al.* 1987. Riparian areas as filters for agricultural sediment. *Soil Sci Soc Am J* **51**: 416–20.

Correll D. 1997. Buffer zones and water quality protection: general principles. In: Haycock N, Burt T, Goulding K, and Pinay G (Eds). Buffer zones: their processes and potential in water protection. Proceedings of the International Conference on Buffer Zones. Harpenden, UK: Quest Environmental.

Daily GC, Ouyang ZY, Zheng H, *et al.* 2013. Securing natural capital and human well-being: innovation and impact in China. *Acta Ecol Sin* **33**: 677–92.

de Groot RS, Alkemade R, Braat L, *et al.* 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. *Ecol Complex* **7**: 260–72.

Dosskey M, Wells G, Bentrup G, and Wallace D. 2012. Enhancing ecosystem services: designing for multifunctionality. *J Soil Water Conserv* **67**: 37A–41A.

Euliss NH, Smith LM, Liu SG, *et al.* 2011. Integrating estimates of ecosystem services from conservation programs and practices into models for decision makers. *Ecol Appl* **21**: S128–34.

Foley JA, DeFries R, Asner GP, *et al.* 2005. Global consequences of land use. *Science* **309**: 570–74.

Goldstein JH, Caldarone G, Duarte TK, *et al.* 2012. Integrating ecosystem-service tradeoffs into land-use decisions. *P Natl Acad Sci USA* **109**: 7565–70.

Gordon LJ, Peterson GD, and Bennett EM. 2008. Agricultural modifications of hydrological flows create ecological surprises. *Trends Ecol Evol* **23**: 211–19.

Hoyer W and Chang H. 2014. Assessment of freshwater ecosystem services in the Tualatin and Yamhill basins under climate change and urbanization. *Appl Geogr* **53**: 402–16.

Kareiva P, Tallis H, Ricketts TH, *et al.* 2011. Natural capital: theory and practice of mapping ecosystem services. New York, NY: Oxford University Press.

Li C, Zheng H, Li SZ, *et al.* 2015. Impacts of conservation and human development policy across stakeholders and scales. *P Natl Acad Sci USA* **112**: 7396–401.

Li YF, Luo YC, Liu G, *et al.* 2013. Effects of land use change on ecosystem services – a case study in Miyun Reservoir watershed. *Acta Ecol Sin* **33**: 726–36.

Lowrance R, McIntyre S, and Lance C. 1988. Erosion and deposition in a field forest system estimated cesium-137 activity. *J Soil Water Conserv* **43**: 195–99.

MA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being. Washington, DC: Island Press.

Ministry of Water Resource of China. 2013. Technical guidelines for construction of the ecological-clean small watersheds. Beijing, China: China Water & Power Press.

Morrison SW. 1988. The Percival Creek corridor plant. *J Soil Water Conserv* **43**: 465–67.

Nelson E, Mendoza G, Regetz J, *et al.* 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Front Ecol Environ* **7**: 4–11.

Ouyang ZY and Zheng H. 2014. Ecological security strategies. Beijing, China: Xuexi Press & Hainan Press (in Chinese).

Polasky S, Nelson E, Pennington D, and Johnson KA. 2011. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the state of Minnesota. *Environ Resour Econ* **48**: 219–42.

Power AG. 2010. Ecosystem services and agriculture: tradeoffs and synergies. *Philos T R Soc B* **365**: 2959–71.

Prager K, Reed M, and Scott A. 2012. Encouraging collaboration for the provision of ecosystem services at a landscape scale – rethinking agri-environmental payments. *Land Use Policy* **29**: 244–49.

Pretty JN, Noble AD, Bossio D, *et al.* 2006. Resource-conserving agriculture increases yields in developing countries. *Environ Sci Technol* **40**: 1114–19.

Ray DK, Duckles JM, and Pijanowski BC. 2010. The impact of future land use scenarios on runoff volumes in the Muskegon River watershed. *Environ Manage* **46**: 351–66.

Rodríguez JP, Beard TD, Bennett EM, *et al.* 2006. Trade-offs across space, time, and ecosystem services. *Ecol Soc* **11**: 28.

Ruckelshaus M, McKenzie E, Guerry A, *et al.* 2013. Notes from the field: lessons learned from using ecosystem service approaches to inform real-world decisions. *Ecol Econ* **115**: 11–21.

Sharp R, Tallis HT, Ricketts T, *et al.* 2015. InVEST 3.2.0 User's Guide. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy, and World Wildlife Fund.

Shen C. 2015. Discussion on difficulties and solutions of multiple planning integration. *Environ Protection* **43**: 17–19.

Sunohara MD, Topp E, Wilkes G, *et al.* 2012. Impact of riparian zone protection from cattle on nutrient, bacteria, F-coliphage, and loading of an intermittent stream. *J Environ Qual* **41**: 1301–14.

Tallis HT, Ricketts T, Guerry AD, *et al.* 2011. InVEST 2.2.2 user's guide. Stanford, CA: The Natural Capital Project.

Tang Y, Zhang Z, Wu J, *et al.* 2010. Two methods to estimate the non-point source pollution load of the typical small watershed in Miyun Area. *J Irrig Drain E-ASCE* **29**: 115–19.

Wang JR. 2001. Recognition on water resource sustainable use planning of Beijing in the early 21st century. *Water Res Plan Design* **2**: 21–23.

White C, Halpern BS, and Kappel CV. 2012. Ecosystem service tradeoff analysis reveals the value of marine spatial planning for multiple ocean uses. *P Natl Acad Sci USA* **109**: 4696–701.

Wong CP, Jiang B, Kinzig AP, *et al.* 2015. Linking ecosystem characteristics to final ecosystem services for public policy. *Ecol Lett* **18**: 108–18.

Yuan J. 2003. Discussion on the implementation of "Sustainable use planning for Beijing water resources in the early 21st century". *Design Water Resour Hydroelectric Eng* **22**: 19–20.

Zheng H, Robinson BE, Liang YC, *et al.* 2013. Benefit, costs, and livelihood implications of a regional payment for ecosystem service program. *P Natl Acad Sci USA* **110**: 16681–86.

Ziv G, Baran E, Nam S, *et al.* 2012. Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin. *P Natl Acad Sci USA* **109**: 5609–14.

Zuo FS, Qi ZY, and Jiang MH. 2011. Evolution characteristics of the Miyun Reservoir inflow and its cause factors analysis. *Beijing Water* **2**: 34–37.

Supporting Information

Additional, web-only material may be found in the online version of this article at http://onlinelibrary.wiley.com/doi/10.1002/fee.1432/suppinfo

