Advancing Wetland Policies Using Ecosystem Services – China's Way Out

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Abstract China's wetlands provide valuable services to society, which are necessary for sustainable development. The Chinese government considers wetland protection a national priority, and is making progress on the ambitious goal of protecting more than 90 % of its natural wetlands by 2030. Despite the rapid growth in conservation actions, wetlands remain threatened because government, industry, and the public are using wetlands unsustainably, and there exists weak enforcement of wetland protection laws. Chinese policymakers in part are trying to use the ecosystem services approach to incentivize conservation to reduce wetland losses across spatial scales (local, regional, and national). However China currently lacks a systematic, scientific process for monitoring wetland ecosystem services, so scientists and managers can establish and refine ecological compensation schemes. In this paper we present a scientific framework on monitoring wetland ecosystem services aimed at improving national wetland policies in China. First we review the current status of China's wetlands and its wetland policies. In particular we present the growing popularity of ecological compensation in China, which is driving the demand for ways to measure

and value ecosystem services in China. Next we outline the major challenges threatening wetland protection and the science policy needs on wetland ecosystem services. Lastly we present a scientific framework on monitoring wetland ecosystem services aimed at helping meet China's growing policy demands on ecosystem services.

Keywords Wetland conservation · Ecosystem services · China's wetland policies · Monitoring

Introduction

China possesses significant water pollution and water shortage challenges that threaten economic growth and human livelihoods. In China, two-thirds of its cities have insufficient water supplies, more than 20 % of its residents lack access to potable water (CAS 2007), and 60 % of its lakes are eutrophic (MEP 2012). These complex water problems have severely impacted China's wetland ecosystems, which are critical to sustaining local and regional economies. In the 1990s and 2007, the algal blooms in Lake Tai triggered water supply crises that crippled agriculture, cities, industry, fisheries, and tourism resulting in billions of dollars in economic losses (Le et al. 2010). In recent decades the water declines in Baiyangdian Lake affected communities by substantially reducing water regulation, reed production, and biodiversity services (Li et al. 2004). Furthermore the vast water level fluctuations in Bosten Lake, mainly influenced by the runoff of Dashankou station (Qiu et al. 2013), have increased regional vulnerability by impacting agricultural irrigation and fish populations (Ma et al. 2011). Wetland ecosystems are critical for water-related ecosystem services, such as water supply and purification, thus continued wetland degradation and loss will accelerate China's water problems.

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To more effectively address the degradation of wetlands in China, the People's Republic of China (PRC) became a signatory of the Ramsar Convention on Wetlands in 1992. The PRC recognizes the importance of wetlands in solving the nation's water resource dilemmas, and is implementing conservation policies to attempt to reverse wetland declines, such as the: (1) National Wetland Conservation Plan (NWCP), (2) Pilot Functional Zoning Plan (PFZP), and (3) ecological compensation schemes. China possesses more than 20 laws and statutes related to wetland protection (e.g., Statute of Natural Reserves, Protection of Wild Animals of China Law, Statute of Extinction of Protection of Aquatic Wild Animals, etc.), however to date there is no single, comprehensive wetland law (Wen et al. 2005; Wang et al. 2012). The lack of a national law poses significant challenges for ensuring the protection of wetlands and wetland reserves. The primary Chinese policy on wetland conservation is the National Wetland Conservation Action Plan (NWCAP) issued by the State Council to serve as a guideline for the wise use of wetlands. The policy steps and targets of the NWCAP are outlined in the NWCP (2002–2030), which was approved in 2003. The NWCP aims to establish 713 wetland reserves to protect more than 90 % of natural wetlands (including marshes, rivers, lakes, and offshore and coastal wetlands) by 2030 while restoring 14,000 km² of natural wetlands in China (Wang et al. 2012). Complementing the NWCP is the PFZP, which is a major policy initiative on creating a national zoning scheme to ensure the protection of key ecosystems for national security (Fan and Li 2009; Zhang and Bennett 2011; Fan et al. 2012; CCICED 2013; CCICED 2014). The primary mechanism to fund wetland conservation is ecological compensation, which uses ecosystem service values to adjust the relative benefits and costs of environmental protection among stakeholders (ADB 2011). Ecological compensation encompasses payments for ecosystem services and fiscal transfer schemes between provincial governments designed at improving the distribution of funds and the clarification of management responsibilities (Liu et al. 2008a; ADB 2011; Li et al. 2012). In 2012 the Ministry of Finance issued 30 billion CNY (\$US 4.8 billion) in subsidies to over 600 counties and cities to fund ecological compensation projects, mainly for watershed ecosystem services. Municipal and provincial governments are currently working to implement ecological compensation mechanisms to meet the wetland protection targets.

Ecological compensation has attracted increased interest amongst decision-makers as a policy instrument to internalize environmental externalities worldwide (Engel et al. 2008; Farley and Costanza 2010; Schomers and Matzdorf 2013). Examples include: (1) national-scale ecosystem services programs in Costa Rica (Pagiola 2008) and Mexico (Muñoz-Piña et al. 2008), (2) payments for watershed services in Pimampiro, Ecuador, (3) payments for carbon sequestration by the PROFAFOR program in Ecuador (Wunder and Albán

2008), and (4) environmental payments as a REDD implementation mechanism in the Brazilian Amazon (Börner et al. 2010). However a significant problem limiting the effectiveness of ecological compensation schemes is the lack of scientific data on ecosystem services. In China ecological compensation is a major policy initiative, but its success will depend in part on credible and legitimate ecosystem service values. Chinese decision-makers are asking scientists to develop monitoring programs to determine the social and environmental outcomes of conservation efforts to help guide compensation payments and management actions. For example, China recently conducted its first national assessment of ecosystem change (2000–2010) led by the Ministry of Environmental Protection (MEP) and Chinese Academy of Sciences (CAS) - a \$24 million effort to estimate China's ecosystem services for decision-making (Ouyang et al. 2014). The Chinese government is trying to improve environmental protection by synchronizing ecological protection with economic development via ecosystem services, but moving ideas into practice will require significant scientific advancements.

In recent years Chinese institutions have focused on advancing scientific research on wetland ecosystem services. Chinese scientists are attempting to assess ecosystem services at various spatial and temporal scales to forecast ecosystem services trends, and improve wetland valuation. The aim is to advise policymakers on wetland conservation in China as well as provide examples to the international community on analyzing wetland ecosystem services at regional to national scales. The objective of this paper is to present a framework on monitoring and valuing ecosystem services for wetlands. First we present the current status of wetlands and the main conservation policies in China. Next we outline the major challenges threatening wetland protection and the science policy needs on wetland ecosystem services. Lastly, we present a scientific framework on monitoring wetland ecosystem services to meet growing policy demands on ecosystem services in China.

Wetland Status in China

According to the World Wildlife Fund for Nature (WWF), China contains 10 % of the world's wetlands (Lu and Jiang 2004; Wang 2015), which supply local (e.g., water supply), regional (e.g., flood protection), and global (e.g., critical habitat for migrating birds) benefits to people. China has all 42 Ramsar wetland types (RCS 2006) of which natural wetlands occupy 4.9 % of the country's terrestrial area with marshes, rivers, and lakes being the dominant types (China News 2014) (Fig. 1). Wetlands are estimated to produce 54.9 % of China's annual ecosystem service values (An et al. 2007) since they supply 96 % of the country's available freshwater resources, making them critical for water security (SFA 2009). They also

Fig. 1 Composition of wetland types in China

provide valuable habitat necessary for commercial fisheries, rice cultivation, and reed production. However provisioning services only provide a fraction of the total value of wetland services since wetlands also produce important regulating services such as water purification, flood regulation and cultural services such as tourism, and spiritual meaning, which are all critical to sustainable development (MEA 2005; Russi et al. 2013). Lastly, wetlands are important sources of biodiversity since they support 2,276 species of higher plants and 1,724 animal species in China, which support the delivery of multiple ecosystem services (SFA 2009).

Despite their importance wetlands are the most threatened ecosystems in China. In 30 years (1978–2008) wetland area has experienced a 33 % decline from 309,296 km² in 1978 to 207,897 km² in 2008 (Niu et al. 2012). Furthermore since the 1950s China has suffered major losses in all wetland types: 23.0 % of freshwater swamps, 16.1 % of lakes, 15.3 % of rivers, and 51.2 % of coastal wetlands (An et al. 2007). Losses in wetland habitat have severely impacted biota in which 13.9 % of wetland species are categorized as extinct or endangered (An et al. 2007). The direct human threats to wetlands are: land reclamation (30.3 %), pollution (26.1 %), overexploitation of biological resources (24.2 %), water and soil loss and siltation (8 %), and unwise use of water resources (6.6 %) (Lei and Zhang 2005). The primary human threat is land reclamation, and agriculture is the main driver where more than 50 % of natural wetlands have been transformed to cropland (Cai et al. 2010). For instance, the Sanjiang Plain, the largest continuous marshland in China, has suffered severe wetland losses due to increased conversion for grain production. Wetlands in the Sanjiang Plain covered 53,400 km² in 1950 and 8,900 km² in 2000, receding by more than 80 % in the past 50 years (ADB 2008). Wetlands are also vulnerable to climate change (Zhang et al. 2011), for example wetland area in the Qinghai-Tibet Plateau has declined by 13,800 km² over the past 50 years, which scientists link to increased air temperatures across the region (An et al. 2013).

Human threats have dramatically impaired wetland functions that support ecosystem services production. Lake Tai, Baiyangdian Lake, and Poyang Lake have incurred serious losses in ecological functions thereby exemplifying the challenges confronting China's wetland ecosystems. Lake Tai is the third largest freshwater catchment in China stretching across 3 provinces (Jiangsu, Zhejiang, and Anhui) and the Shanghai metropolis. Lake Tai provides many important ecosystem services, such as water supply, flood control, tourism and recreation, and shipping (Qin et al. 2007). The catchment is densely populated and highly developed where in 2000 the mean population density was 1,137 people km⁻² and the GDP per unit area of the catchment was 29.1 million CNY km⁻² (\$US 4.7 million km⁻²) (ADB 2008). Surface waters are heavily polluted because of untreated domestic sewage and non-point pollution from cropland agriculture, aquaculture, animal husbandry, and small enterprises (Qin et al. 2007; Li et al. 2009). In 1990 the trophic state of Lake Tai changed from oligotrophic to eutrophic with the intensification of phytoplankton blooms, which have affected lake vegetation composition, the pollution purification capacity, and fish populations (Guan et al. 2011). Baiyangdian Lake is the largest freshwater lake in northern China supporting people's livelihoods with an array of services, such as fisheries, reed production, water for drinking and irrigation, and local climate regulation. In the past 40 years, lake area in Baiyangdian decreased in half from reduced inflows, increased drought frequency, and increased sedimentation because of climate change, upstream dams, and irrigation (Liu et al. 2006). Reduced inflow and increased discharge of pollutants have reduced lake water quality from Grade III to Grade V (ADB 2008). Hydrological changes in water volume and quality have affected lake structure and functions resulting in a 44 % loss of fish species (Liu et al. 2006). Lastly, Poyang Lake is China's largest freshwater lake, located in the middle of the Yangtze River, and is the most important regional supplier of grain, cotton, oil, pork, and fish commodities (Shi et al. 2009). In

recent years, Poyang Lake has dramatically decreased in area suggesting an ecosystem regime shift to a different functional state where the principal driver is the Three Gorges Dam (Liu et al. 2013). The drying has impacted fishermen and migratory bird species where the mean annual per capita income of fishermen fell to 1,000 CNY (\$US 161) in 2011 from 3,000 to 4,000 CNY (\$US 483–644) because of reduced fish populations (Wang and Jin 2012).

Policies and Challenges

Since China joined the Ramsar Convention in 1992, it has made substantial progress on wetland protection - evident in five notable achievements. First, the Chinese government created the NWCAP and NWCP to coordinate conservation efforts. Second, China increased wetland reserves through an integrated protection network of important wetlands (Ramsar sites or national), nature reserves, and wetland parks. Third, education efforts on wetland conservation increased across government, scientific and educational institutions, media, and non-profit organizations. Fourth, was the employment of science to evaluate China's wetlands via the first (1996–2003) and second (2009–2013) national wetland surveys. Fifth, the central government created a special fund to support ecological compensation schemes to finance wetland conservation.

The State Forestry Administration (SFA) oversees the NWCAP and NWCP (2002–2030), which outline priorities, such as decision support tools, constructed wetlands, and nature reserves. The SFA is the primary organization responsible for coordinating and supervising national wetland conservation efforts in particular the implementation of international conventions. The most ambitious objective is the establishment of 713 wetland reserves to protect more than 90 % of China's natural wetlands by 2030. Overall the SFA with other relevant government departments have made progress in the short-term (2005–2010) goals of the NWCP. During the 11th Five-Year Plan (2006–2010), the Chinese government invested 3.1 billion CNY (\$US 500 million) in wetland conservation, approving 205 projects on wetland protection, restoration, sustainable use, and capacity building (Economic Daily 2012). At the end of 2013, China designated 46 wetlands of international importance (MEP 2014), created over 577 wetland nature reserves, and authorized 468 national wetland parks (Wang 2015). In addition to designations, the NWCP aims to tackle the most difficult aspect of wetland protection, which is awareness among the public and decision-makers at all levels on the importance of wetlands (RCS 2012).

Wetland reserves are increasing across China, yet the majority of reserves are in poor condition due to water withdrawals, development, and water pollution. At the end of May 2011, there were 91 national wetland reserves in

mainland China of which 79 % of the total area was graded as poor condition (Zheng et al. 2012). First, the actual wetland area in Chinese reserves often fluctuates because of water variability and development encroachment. China's total freshwater resources in 2011 was 2.3 trillion m³ representing a 16.1 % decline from the mean long-term value (1956–2000) (MWR 2012). However, total water use continues to increase mainly in the domestic and industrial sectors. Growing water demands amid shrinking supplies is driving water declines in wetlands. For example, Baiyangdian Lake Wetland Nature Reserve has suffered serious declines in water level (Fig. 2) because of increased climatic drought and upstream socioeconomic development in the Baiyangdian River Basin (Zhuang et al. 2011). Furthermore, land reclamation continues to drain wetlands due to insufficient enforcement of reserve regulations. In the Sanjiang National Nature Reserve, 20 illegal reclamation cases were identified in 2004 because increased grain prices made illegal wetland conversion to cropland highly profitable (Wang 2011a). Second, untreated pollution as industrial wastewater, domestic sewage, and agricultural runoff remains a serious hazard to wetland functions (Cheng and Han 2012). In 2011 wastewater discharge totaled over 65.2 billion tons in China (MEP 2012). Degraded reserves show a lack in understanding, cooperation, and accountability on the importance of reducing wetland declines across China.

Wetland protection remains a serious problem because of poor coordination among managing agencies, an ineffective legal system, and inadequate financial capital (Wen et al. 2005; Wang et al. 2008). Different agencies have varying responsibilities since the Ministry of Water Resources manages water allocation, the MEP manages water quality, and the SFA is the main overseer of wetland management. The lack of coordination across organizational levels and sectors has resulted in policies and laws not being implemented (Liu and Yang 2012). Also the absence of a comprehensive national wetland law limits coordination and enforcement of wetland protection because responsibility is not explicitly defined (Wang et al. 2008). Nearly a dozen Chinese provinces have created local wetland conservation regulations, but they possess insufficient legal legitimacy (Wang 2011b).

Another major obstacle is the lack of policy tools to finance wetland conservation, a major policy strategy is ecological compensation mechanisms, which has shown promising results in certain cases on protecting ecosystems in China (Liu et al. 2008b; Zhang et al. 2010). The 12th Five-Year Plan (2011–2015) authorized the PFZP to create a national zoning plan to regulate spatial planning in China for economic development, environmental protection, and social welfare (Fan et al. 2010; Fan et al. 2012). The PFZP was compiled by 14 government departments over more than 4 years to: (1) develop restrictions on important ecological or agricultural areas; (2) revise national and provincial fiscal systems to appropriately fund ecosystem management while alleviating poverty;

Fig. 2 Annual water level trend in Baiyangdian lake from 1950 to 2011

(3) improve management where local officials are evaluated on environmental and sustainability targets not only economic development (ADB 2011). The PFZP has identified 386 million hectares (40 % of the country's terrestrial area) as critical ecosystem function zones spanning 436 county-level districts. The central government is trying to address accountability problems on environmental protection by including the PFZP environmental targets in government official evaluations. Ecological compensation mechanisms are the priority policy instruments being used by the central government to implement the PFZP (Zhen and Zhang 2011). In China ecological compensation is an institutional arrangement designed to sustain the use of ecosystem services by minimizing tradeoffs among different stakeholders (CCICED 2006). Ecological compensation funds ecological protections by having beneficiaries (i.e., cities) pay suppliers (i.e., rural villages) for ecosystem services. From 2010 to 2011 the central government established a special fund for wetland compensation projects of 400 million CNY (\$US 64 million) to create a stable funding source for wetland conservation (Wang 2011a; RCS 2012).

However scientists and managers are realizing there needs to be a shift towards performance-based decision-making on the environment for ecological compensation mechanisms to be effective in China (Zhang et al. 2007; Liu et al. 2008b). Zhang et al. (2007) evaluated multiple watershed compensation projects in China, and found that a key step to designing and revising projects is having sound scientific evidence to guide implementation and monitoring to determine their effects. Wetland protection requires the participation of multiple sectors of society, and determining the appropriate amount of economic compensation to incentivize wetland conservation over alternative uses like urbanization or agricultural production is a major scientific and governance challenge (Beijing Review 2015). Internationally experts have found that integrating scientific knowledge and methods into payments for

ecosystem services is critical to policy effectiveness through the establishment of metrics and monitoring (Naeem et al. 2015). However current scientific research and technological development on ecosystem services are insufficient to meet the needs of decision-makers in China (CCICED 2010; Wong et al. 2015). Advancing the measurement and valuation of wetland ecosystem services is a scientific priority in China (Zhang et al. 2010).

Decision Support on Wetland Ecosystem Services

Policymakers are implementing policies aimed at enhancing ecosystem services, but few policies are based on sound science because we currently lack metrics and monitoring protocols on ecosystem services. For instance Naeem et al. (2015) evaluated 118 projects on payments for ecosystem services, and they found that 60 % of the projects lacked: (1) baseline data, (2) monitoring of key environmental factors and services, (3) recognition of ecosystem dynamics, and (4) the inclusion of metrics. The grandest challenge for ecosystem services valuation is integrating ecological production functions with economic valuation functions to connect biophysical processes to human benefits (NRC 2005; Wong et al. 2015). Ecological production functions (i.e., regression models) are important because they can help reduce double counting by making the relationship between intermediate and final ecosystem services explicit by linking ecosystem characteristic indicators (i.e., intermediate services) to final service indicators (NRC 2005; US EPA 2009; Polasky and Segerson 2009; Kareiva et al. 2011; Wong et al. 2015).

Double-counting is a frequent problem that occurs in ecosystem services valuation, due to the confusion between intermediate services and final services (Fu et al. 2010). Intermediate services are the intermediate biophysical outputs of an ecosystem analogous to ecosystem processes and functions, which are the inputs to the final ecosystem services. In contrast, final ecosystem services are biophysical metrics that have an explicit social value, thus they are the critical component to linking ecological and economic methods (Ringold et al. 2013). If the connections between intermediate and final services are not distinguished, the value of the intermediate services could be double counted when valued with their respective final services (Boyd and Banzhaf 2007; Polasky and Segerson 2009). Therefore the identification of final ecosystem services is essential to minimizing double-counting in order to generate accurate economic values of ecosystems (Boyd and Banzhaf 2007). Methodologically scientists need to identify final ecosystem service indicators, which are measurable, biophysical attributes directly connected to human well-being (see Wong et al. 2015 for details). The optimal approach to avoid double-counting is creating ecological production functions (NRC 2005; US EPA 2009; Polasky and

Segerson 2009; Kareiva et al. 2011; Wong et al. 2015). However few ecological production functions exist, thus scientists are working to generate the necessary empirical data to create the regression models that link the ecosystem functions to the final ecosystem services (Wong et al. 2015).

When ecological production and economic valuation functions from primary studies are unavailable then scientists use the benefit transfer method (TEEB 2010). Benefit transfer is the use of reference values to estimate ecosystem services as per unit area of an ecosystem in a relatively inexpensive and timely manner. The analyst must be cautious when applying benefit transfer because there can be large transfer errors when the primary studies do not match the policy sites (i.e., locations of transferred values) (Brouwer et al. 1999; Woodward and Wui 2001; Brander et al. 2006). Benefit transfer proxies are likely sufficient to understand general ecosystem services trends, but are unsuitable when trying to identify hotspots, priority areas for multiple ecosystem services, and appropriate management actions for specific problems at local and regional scales (Eigenbrod et al. 2010).

Research on Ecosystem Services in China

In China ecosystem services valuation is primarily qualitative and static relying on benefit transfer values from Costanza et al. (1997) and Xie et al. (2003) with few examples linking ecosystem functions to ecosystem services. Despite great efforts to quantify wetland ecosystem services (Wang et al. 2005; Tong et al. 2007; Song et al. 2009; Feng et al. 2013; Lu et al. 2014; Yuan et al. 2014), the dominant valuation methods are benefit transfer and general ecological and social indicators. In China more than 90 % of research on ecosystem services is on economic valuation with minimal studies investigating the connections between ecosystem structure and functions and ecosystem services (Zhang et al. 2010). Economic valuation of ecosystem services will likely have minimal utility in improving conservation and human livelihoods when not based on ecosystem structure and functions (Kremen 2005; Kremen and Ostfeld 2005; Polasky and Segerson 2009). In the case of wetlands, environmental markets in the United States have been used to fund restoration projects for mitigation purposes, but the value of these projects are largely determined in terms of acreage not considering the full suite of desired ecosystem services (i.e., the multiple human benefits of concern to stakeholders). The cost-benefit analysis of land reclamation and/or restoration of wetlands can be inaccurate without direct measurements of processes because: (1) the value of the wetlands can be undervalued and (2) the return on investment to society is difficult to determine (Palmer and Filoso 2009). For instance, the Great Lakes ecosystem – the largest freshwater system in the world – has been plagued with ongoing toxic algae outbreaks, which has spurred over \$US 336 million of recent

investments. However policymakers and scientists remain uncertain if the funding is sufficient because the main challenge is knowing how to direct funds to generate improvements in water clarity and drinkability, which requires understanding the nutrient pollution sources and nutrient cycling dynamics of the lakes (Circle of Blue 2015).

Ultimately confidence on ecosystem services values depends on clear explanations of how management actions influence ecological mechanisms that support ecosystem services outcomes. In China we currently can only make basic interpretations and are unable to quantify tradeoffs, thus we need studies that connect ecological and social indicators via ecological production functions (Wong et al. 2015). Furthermore, many ecosystem services are difficult to value because they are public goods for which no market values exist, thus non-market valuation methods must be employed. In China, current economic valuation techniques are elementary for ecosystem services, and credible application of non-market methods remains a significant challenge in meeting policy needs (Zhang et al. 2010). In summary, the research priorities on advancing the science on ecosystem services are: (1) identify final ecosystem service and ecosystem characteristic indicators, (2) create ecological production functions, and (3) apply non-market valuation methods.

Research Strategy to Monitor Wetland Ecosystem Services

In recent years, Chinese institutions have implemented research programs to advance the science of ecosystem services to improve wetland management in China. Most notably are: (1) the “National Ecosystem Function Zones” to establish wetland ecosystem function zones throughout China (Ouyang 2007); (2) the first national assessment of ecosystem change (2000–2010) led by the MEP and CAS to evaluate the full diversity of China’s ecosystems and their services including wetlands (Ouyang et al. 2014); (3) two scientific programs on measuring and valuing wetland ecosystem services for management at national scales titled “Assessment of Typical Lake and Marsh Wetland Ecosystem Services in China” (2012–2014) and “Coastal Wetland Ecosystem Services and Valuation Technologies in China” (2014–2016). Driving these efforts are the needs of municipal and provincial governments for methods and protocols to monitor and evaluate wetland ecosystem services to improve management. To fill this gap, we present a new scientific framework aimed at helping clarify the measurement and valuation process of wetland ecosystem services. Our objective is not to provide a step-by-step recipe on how to monitor ecosystem services because a universal framework would be impractical since ecosystem services by definition are context specific. The value of ecosystem services is determined by both the location of ecological processes that provide the service, and the location of people

who demand the service (Tallis and Polasky 2011). Hence we designed our framework to provide clarity on how to conceptualize the intermediate and final ecosystem service indicators, measure the contributions of the ecosystem characteristic indicators to the final service indicators via ecological production functions, and how the measurements can improve economic valuation.

Our framework (Fig. 3) consists of three stages: (I) ecosystem service indicators system, (II) evaluation of ecosystem services, and (III) decision support information. Stage I combines natural and social science methods to connect ecosystem functions to ecosystem services via three main steps. First is estimating the relevant ecosystem characteristics supporting the selected ecosystem services (for more details on stage I refer to Wong et al. 2015). In consultation with stakeholders, final ecosystem services are selected and beneficiaries are identified to determine the temporal and spatial scales of the study. Social surveys, socioeconomic datasets, and policy targets are used to locate final services and preferences for non-market valuation. Ecosystem characteristics (i.e., ecosystem structure, processes, and functions) are quantified using direct collection methods (i.e., fieldwork and lab analysis), existing datasets, and biophysical models. The second step is identifying the main human drivers influencing ecosystem characteristics that support

ecosystem services in the study area. The third step is defining the ecosystem service indicator system to create ecological production functions, consisting of three indicator types: (1) ecosystem characteristics, (2) human drivers, and (3) final ecosystem services (the specific indicators require expert and stakeholder judgement to ensure the indicators are based on management targets and the demands of beneficiaries, and are pertinent to the given spatial and temporal context). Stage II consists of two tiers where ecosystem services are evaluated as ecological changes in biophysical units (i.e., final ecosystem service indicators) and economic changes in monetary units. Stage III is the creation of a dynamic monitoring platform and national database of wetland ecosystem services by applying stages I and II at target wetland sites chosen in consultation with stakeholders. Monitoring findings are presented to decision-makers and the public as ecosystem services trends, tradeoffs, and management choices.

Currently, the SFA is in the early phase of developing and testing the framework via a science task force at 14 lake and marsh study sites across China. The study sites cover a diversity of lake and marsh ecosystems spanning a wide geographic range (Fig. 4). The study sites represent critical Wetlands of International Importance, also called ‘Ramsar Sites’ (e.g., Dongting Lake and Poyang Lake) and those facing the most severe water problems (e.g.,

Fig. 3 Research framework on wetland ecosystem services for management. The framework consists of three methodological stages to connect science to policy. Stage I contains three main steps: (1) estimation of ecosystem functions (i.e., ecosystem characteristics); (2) identification of human drivers on ecosystem functions; (3) creation of ecosystem service indicators system based on ecosystem characteristics, human drivers, and final ecosystem services to generate ecological production functions. Stage II ecosystem services are evaluated as ecological changes in biophysical units (i.e., final ecosystem services) and economic changes in monetary units. Stage III is the creation of a dynamic monitoring platform and national database of wetland ecosystem services to assist management on tradeoffs

Fig. 4 Map of China's lake and marsh wetlands and the 14 study sites. The 14 sites represent China's typical lake and marsh wetlands in terms of size, geographic location, and government designation level (i.e., national and provincial). The data sources are from the Institute of Remote

Sensing Applications, Chinese Academy of Sciences. Note the current application of the framework is focused on lake and marsh wetlands not all wetland ecosystem types in China

Taihu Lake and Baiyangdian Lake) (Table 1). The task force aims to improve the science on ecosystem services by testing the indicator selection criteria outlined in Wong et al. (2015) focused on choosing wetland ecosystem characteristic and final ecosystem service indicators (site specific indicators and across site indicators for comparing trends among sites), and advancing ecological production functions and non-market valuation methods. First we are identifying drivers of wetland change, and are evaluating their impact on wetland structure (e. g., wetland area, wetland species, and water pollutant concentration) and hydrological functions (e.g., streamflow magnitude, flood regime, and water level fluctuation) (Palmer and Febria 2012) using process-based models or empirical equations. Next we are mapping the wetland structure to relevant ecosystem characteristics supporting the selected ecosystem services using ArcGIS technology and computer networking, and valuing the services using various economic valuation methods such as market price methods for provisioning services, contingent valuation methods for biodiversity conservation, and travel cost methods for recreational and tourism services.

Take Bosten Lake as an example, we could first determine the impact of drivers on water level fluctuations and salinity, such as irrigation in the Kaidu River watershed and lake evaporation influenced by climate change. Next we could calculate the contributions of water level and salinity changes on final ecosystem services (e.g., reed production, aquaculture production, and climate regulation) (Fig. 5), and value those final services using market valuation, contingent valuation, and travel cost methods. For stage III, we plan to generate a map of China's lake and marsh wetland values using meta-analytic function transfer from the primary values derived at the 14 study sites. The growing demand for valuation at the national or regional level necessitates "scaling up" methods like meta-analytic function transfer where economic value functions, derived from multiple primary studies, are used to estimate ecosystem services values at policy sites (Brander et al. 2012; Wong et al. 2015). Data limitations impact the credibility of benefit transfer, which the task force is trying to address by creating a database of primary ecological and socioeconomic data on wetland ecosystem services to improve regional and national ecosystem services estimates.

Table 1 Description of the 14 lake and marsh study sites

#	Field site	Area (km ²)	Wetland status	Main threats	Main ecosystem services	Ramsar wetland	National importance	Nature reserve
1	Baiyangdian Lake	342.91	D	Water shortage, Water pollution, Sedimentation	Biodiversity conservation, Recreation and tourism, Reed and aquaculture production		Y	P
2	Bosten Lake	1448.45	D	Water level fluctuation, Salinity, Reclamation	Biodiversity conservation, Flood control, Water regulation		Y	
3	Caohai Lake	120	D	Sedimentation, Water pollution, Biodiversity loss	Water regulation, Climate regulation, Biodiversity conservation		Y	N
4	Chagan Lake	506.84	D	Water pollution, Salinity	Biodiversity conservation		Y	N
5	Dongting Lake	2690	D	Sedimentation, Reclamation, Water pollution	Flood control, Biodiversity conservation, Recreation and tourism	Y	Y	N/P
6	Hengshuihu Lake	187.87	D	Water shortage, Water pollution	Water regulation, Biodiversity conservation, Recreation and tourism		Y	N
7	Honghe	218.35	D	Water shortage, Water pollution, Biodiversity loss	Biodiversity conservation, Climate regulation, Carbon sequestration	Y		N
8	Poyang Lake	2797	D	Sedimentation, Water pollution, Biodiversity loss	Flood control, Water purification, Biodiversity conservation	Y	Y	N/P
9	Qinghai Lake	4952	I	Water pollution, Water level decline	Water storage, Biodiversity conservation, Recreation and tourism	Y	Y	N
10	Ruergai	2980	D	Water level decline, Desertification, Habitat fragmentation	Climate regulation, Water storage, Biodiversity conservation	Y	Y	N
11	Taihu Lake	2427.8	D	Swamp encroachment, Water pollution, Flood water storage	Water provision, Biodiversity conservation, Flood control		Y	
12	Wuliangsu Lake	293.33	D	Water pollution, Artificial reed production	Biodiversity conservation, Gas regulation		Y	P
13	Yeya Lake	87	D	Water shortage, Reclamation, Water pollution	Water storage, Flood control			P
14	Zhalong	2100	D	Water shortage, Water pollution, Reclamation	Biodiversity conservation, Carbon sequestration	Y		N

We categorized the study sites in terms of: (1) wetland area, (2) wetland status as increase (I) or decrease (D) in wetland area, (3) main threats to ecosystem services, (4) main ecosystem services, (5) Ramsar wetland designation, (6) national importance designation by the National Wetland Conservation Action Plan, and (7) nature reserve designation as national (N) and/or provincial (P)

Currently the task force has evaluated the 14 sites using the framework for stages I and II, but an ongoing challenge has been identifying appropriate final ecosystem service indicators for the given management context. The long-term objective is to develop a national wetland decision support system to provide useful scientific tools on ecosystem services for wetland management. Currently the aim of the indicator system is to provide ecosystem services measurements for scientists and decision-makers at the 14 sites to begin building datasets for these priority

locations. The database and information platform will provide a domestic reference for benefit transfer to improve the valuation of lake and marsh wetland ecosystem services. However it is important to note that the current analysis is focused on lake and marshland ecosystems, and does not represent the full diversity of wetland ecosystem types in China. Lastly, the aim is to create technical products that will ultimately underpin a dynamic monitoring scheme that will be used to guide the design of wetland ecological compensation programs.

Fig. 5 Influence of threats on ecosystem functions and ecosystem services. Bosten lake has experienced serious water level fluctuations due to regional water consumption for agricultural irrigation and climate change. The changes in hydrological functions have influenced provisioning services like reed production and aquaculture services, and regulating services like climate regulation related to lake evaporation

Discussion

The core objective of an ecosystem services assessment is to make tradeoffs explicit among ecosystem services and alternative decisions (NRC 2005; TEEB 2010). Managing landscapes to maximize one ecosystem service often results in declines in other ecosystem services (Rodriguez et al. 2006; Egoh et al. 2008; Bennett et al. 2009). For example, global food and timber production have negatively impacted regulating services like flood control, biodiversity, and erosion control (MEA 2005). Economic valuation of multiple ecosystem services is useful for assessing ways to balance different uses of wetlands by multiple stakeholders and comparing the costs or benefits of wetland conservation (De Groot et al. 2006). In China a limited number of ecosystem services often drive decisions, which has led to unfavorable ecosystem regime shifts because ecosystem processes that support multiple ecosystem services were not considered (Liu and Yang 2012). Chinese leaders are often unaware of the multiple values that wetlands provide society therefore they opt for conversion over protection in part because they lack information on the true costs and benefits of development (Wang et al. 2008). Tradeoff analyses can help clarify the range of possible outcomes to assist managers in prioritizing services to limit unwanted tradeoffs.

However Chinese policymakers need tools to quantify tradeoffs for ecological compensation schemes to justify wetland protection. In China decision-makers often designate wetland nature reserves without consulting local communities, which has led to conflicts and ineffective protection because local residents are not properly compensated for their economic losses. Wetland reserves are also often designated

for their biodiversity value, thus their management is directed at conserving biodiversity not the maintenance of a range of ecosystem services, which can reduce management effectiveness and public understanding of the full importance of wetland reserves. Ecological compensation programs attempt to reduce tradeoffs by paying residents, farmers, and herders fairly for ecosystem services to make wetland protection feasible. The Chinese government is experimenting with various ecological compensation schemes to balance the costs and benefits of environmental protection.

A major barrier facing ecological compensation is accurate measurement and valuation of ecosystem services to determine conservation outcomes and proper payments (Liu et al. 2008a; Naeem et al. 2015). Two current valuation challenges limiting ecological compensation mechanisms are: (1) low compensation standards in which the annual payments are lower than the economic value of non-conservation practices; (2) a single compensation standard that ignores different ecosystem service production capacities of wetlands in various regions (Deng et al. 2011). Monitoring of ecosystem services is critical to addressing these challenges to establish ecological compensation schemes in China. An ecological compensation program requires ecosystem service values that are credible and legitimate among technical experts, producers, and buyers on the biophysical linkages between landscapes and ecosystem service benefits. Currently the main focus of China's wetland programs is the number of reserves, however there needs to be greater attention on conservation outcomes. Long-term monitoring is essential to create transparency on environmental outcomes to adjust payments to incentivize improvements and ensure wetland services are being delivered. Ecological compensation programs must be grounded in sound science

that clearly illustrates how management actions link to ecosystem changes influencing the supply of the desired services (Palmer and Filoso 2009).

Conclusion

Wetlands have suffered the largest losses from China's rapid expansion, however senior leaders in the Chinese government are trying to address the problems threatening the nation's wetlands. China is actively pursuing conservation policies focused on ecosystem services that require sound science, new finance mechanisms (i.e., ecological compensation), and effective governance. Decision-makers want information on conservation outcomes and guidance on tradeoffs, and Chinese scientists are working to meet these policy needs. Monitoring wetland changes as changes in ecosystem services is an innovative approach to link environmental conditions to human welfare outcomes.

We present a scientific framework that represents this new approach to create a monitoring process aimed at helping managers track trends and forecast wetland impacts. Currently we have completed stages I and II at the 14 study sites, and based on our preliminary work, we are beginning to help the SFA design indicator standards and technical guidelines on how to evaluate lake and marsh wetland ecosystem services in China. Our framework requires scientists to shift their thinking on how wetland monitoring is conducted since it requires developing practical knowledge on how to integrate ecological and economic concepts and methods. Thus from our preliminary work we have identified several challenges, which is currently limiting full implementation of the framework. The challenges are: (1) selecting appropriate final ecosystem service indicators since this requires training natural scientists on social science criteria, (2) acquiring the necessary data to establish the ecological production functions for the desired ecosystem services at each site, (3) implementing dynamic monitoring of the ecosystem services for stages II and III to fill data gaps in a timely manner for management, and (4) translating the evaluation results into policy guidelines for ecological compensation programs. The SFA needs scientific understanding and technical products to design wetland compensation programs in China. Thus the most significant challenge we foresee is devising policy mechanisms capable of effectively incorporating the ecosystem service values (ecosystem quality and economic values) into ecological compensation schemes. As in China the policy demands for credible and legitimate ecosystem service values is growing rapidly worldwide, thus scientists need to create evidence-based approaches for measuring and valuing ecosystem services to begin helping policymakers manage wetlands for multiple human benefits.

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