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Lake-wetland ecosystem services modeling and valuation: Progress, gaps and future directions

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ABSTRACT

Lake-wetland ecosystems provide valuable ecosystem services (ES), but lake-wetland ecosystems have suffered great loss from rapid urban expansion and other land use changes. Despite great efforts in increasing our understanding about ES produced by lake-wetlands, significant challenges (e.g., data, information, and implementation) still remain. This paper provides a thorough review of the progress in lake-wetland ES research. It addresses the pressing management needs for reliable biophysical models and economic valuation methods that quantify the trade-offs, across different spatial–temporal scales, and that can assess the effectiveness of alternative wetland management scenarios. The review identified significant gaps, namely, the need to identify data sources for more robust quantitative analyses of the link between ecosystem characteristics and final ES; the lack of information that can be used for generating evidence of trade-offs to compare alternative management actions; and the inadequate attention to incorporating information on potential trade-offs into wetland management. We conclude with lessons for future research including: (i) wetland ES monitoring programs to collect observed data on ES indicators and ecosystem characteristic metrics; (ii) integrated ES assessment models to track ES trends and evaluate ES trade-offs across temporal-spatial scale; and (iii) financial incentives to compensate ES suppliers for conservation to guarantee implementation.

1. Introduction

Ecosystem services (ES) are defined as the contributions of ecosystems to human wellbeing (Costanza et al. 1997; MEA, 2005; TEEB, 2010). The concept of ES has drawn increasing attention amongst researchers due to its significance and relevance to practical management of diverse ecosystems (Müller and Burkhard, 2012; Salata et al., 2017). ES highlight the associated trade-offs between alternative management options (Goldstein et al., 2012). Research into ES has increased substantially in recent decades (Seppelt et al., 2011; Guerry et al., 2015; Costanza et al., 2017). However, studies still cannot meet the increasing demand by policy-decision makers for both data and robust evidence (Martinez-Harms et al., 2015; Förster et al., 2015), and the process of transforming research findings into actual management practice has been slow. Lake-wetland ecosystem is among the most important ecosystems on Earth, defined as the wetlands formed by the swamping process around the shores of lakes or shallow lakes, and include lakes in this study. The area of global wetlands is approximately 7–10 million km^2, accounting for 5–8% of the total land area (William and James, 2015). These systems provide humans with both intermediate ES and final ES, such as provisioning service (e.g., fresh water provision), regulating service (e.g., water purification, flood regulation, climatic regulation), supporting service (e.g., habitat for wildlife), and cultural service (e.g., recreation) (de Groot et al., 2012; MEA, 2005; William and James, 2015). Intermediate ecosystem services are attributes of ecosystems measured as processes and functions, which include supporting services and some regulating services in the MEA (2005). Final ecosystem services are the ultimate biophysical outcomes that are of obvious and clear relevance to human benefits, which include provisioning services, cultural service and some regulating services (Boyd and Banzhaf, 2007; Nahlik et al., 2012).

The value of ES provided by wetland ecosystems in the world was estimated by Costanza et al. (2014) to be 23.2% of the total global ES value of US$125 trillion/yr. Due to the important role of wetland

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ecosystems, a series of wetland conservation plans have been implemented, including Ramsar Convention (Ramsar Convention, 2008), the Wetlands Conservancy (http://wetlandsconservancy.org/about-us/), The Nature Conservancy (https://www.nature.org/), and China's National Wetland Conservation Program (NWCP) (Wang et al., 2012), etc. However, it is still in its early stage for policy-makers and practitioners to recognize ES as a potentially insightful approach to address wetland management challenges. In the past two decades, scientists have made important progress on lake-wetland ecosystem services (LWES) assessments. However, scant data has been a long-lasting issue. This has limited wetland management from achieving desirable outcomes.

This paper aims to increase our understanding about how ES are applied in environmental management to meet the demand for national and international wetland conservation and sustainability by supporting continuing human wellbeing. The paper is structured in three parts. First, we systematically review some key progress on ES research. Second, we outline the management needs for biophysical models and economic valuation methods to quantify trade-offs under alternative management scenarios, identifying three gaps hindering wetland management by comparing the management demands with current status of research in the field. Finally, we conclude lessons and a discussion about future research direction.

2. Methods

We conducted a systematic literature review comprising three steps. First, we used the ISI Web of Science (hereafter WoS) database to collect publications because it provides a practical way to identical studies on the research field. Searches in WoS using the keywords '*ecosystem service∗*' and '*lake*' or '*wetland*' by discipline and date (up to 21 June 2018) yielded 2114 matches. The WoS search introduces many irrelevant articles since this method includes the cited references of the searched articles. Second, from this set of publications, we then used EndNote to refine the articles by searching the same combined keywords in the "title" or "key words" domains, assuming that papers containing these terms in their titles or key words explicitly focus on LWES. The total number of publications was reduced to 1026 (Fig. 1). Many books, book chapters and reports were removed from the search and only 11 key references retained in this study, which may introduce some bias. Third, we imported the refined list of EndNote files into the WoS, and then researched and derived all information of these articles as the input of the CiteSpace software for literature analysis (Chen et al., 2010). We classified the literature into three categories: (1) LWES evaluation; (2) driving factors; and (3) ES trade-offs analysis. The authors were from 85 countries/regions, and the top 10 largest countries included the US, China, England, Australia, Canada, Netherlands, France, Spain, Germany, and Sweden, totaling up to 68.5% of the total number of articles used (Fig. 2).

3. Current status: gaps between progress and management

3.1. Current research progress

3.1.1. LWES evaluation

Evaluating LWES is an important part of global ES evaluation (Costanza et al. 1997, 2014; MEA, 2005; Notte et al., 2015; Angradi et al., 2016). In the past two decades, great progress has been made in this field, covering large and diversified lake-wetland areas (Schallenberg et al., 2013), different spatial scales (Bartsch et al., 2009), and various geographic locations (Reynaud and Lanzanova, 2017; Sun et al., 2017). Schallenberg et al. (2013) assessed the status and trends in 12 ES types across eight lakes with an area above 100 km^2 each in New Zealand, finding that the majority of 12 ES types exhibited degradation trends. Some perceived social priority ES of the Great Lakes of North America (e.g., water purification, water resource supply, biodiversity protection, and landscape aesthetics) were evaluated and showed an overall increase due to substantial land use and engineering initiatives (Lakes, 2016; Isely et al., 2018).

A more recent study by Steinman et al. (2017) further assessed the current state and future trend of ES change in the Great Lakes of North America. Sun et al. (2017) compared the differences in the ES provided by Lake Poyang wetland in China and the Tanguar Haor wetland in Bangladesh, indicating decreasing trends in food security and biodiversity services. Reynaud and Lanzanova (2017) used meta-analysis to estimate the average ES value provided by lakes from a worldwide data set of 699 observations drawn from 133 studies in the world, showing US$106-140 (in 2010 values) per respondent per year for non-hedonic price studies and US$169-403 (in 2010 values) per property per year for hedonic price studies. On a national scale, many countries, including Canada (Simon et al., 2016), China (Dearing et al., 2012; Li et al., 2014, 2015; Xu et al., 2017), Nepal (Bikash et al., 2015) and Ethiopia (Wondie, 2018), have estimated the value of LWES.

Sophisticated methods for quantifying and evaluating LWES found in the literature can be summarized as the following five categories (Fig. 3):

(1) benefit transfer to determine LWES by studying habitat types from the literature or a specific location and transferring functions and/or values via habitat type to new locations (deGroot et al. 2012. Li

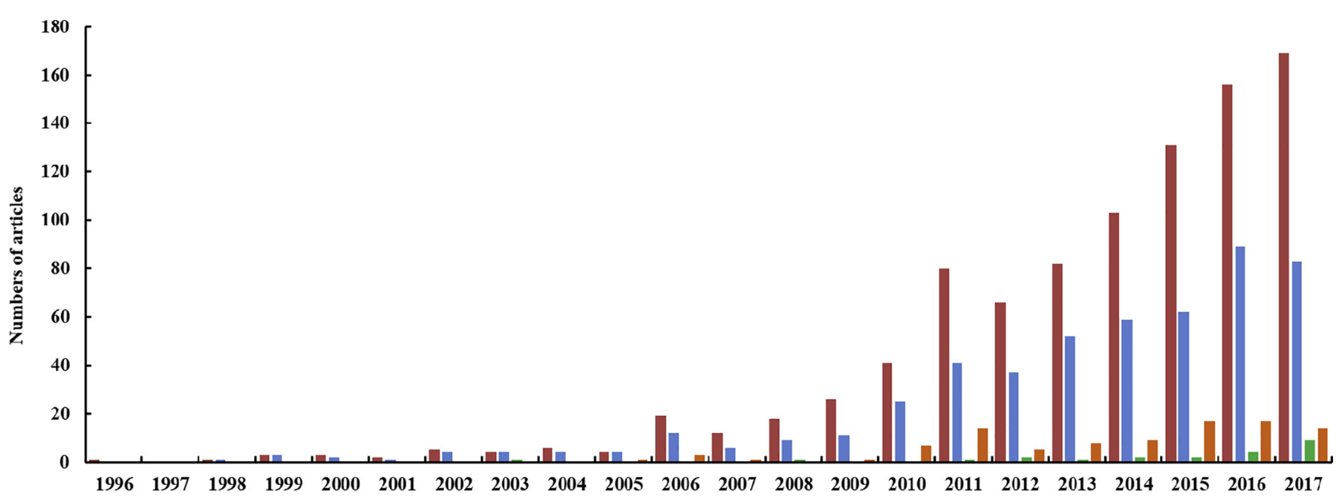

Fig. 1. Numbers of articles on LWES study published between 1996 and 2017.