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Review Paper

Wetland ecosystem services research: A critical review

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A B S T R A C T

Systematic knowledge of the development, trends, and limitations of wetland ecosystem services (WES) is extremely meaningful for the direction of WES studies and wetland management. A systematic literature review was conducted by collecting 1711 peer-reviewed articles through the Web of Science and ScienceDirect by searching the "topic" domain using the combined keywords "ecosystem service" OR "ecosystem services" and "wetland". The results indicated that current studies focus on WES evaluation, driving factors, wetland management, and policy design, which accounted for 90.9% of the obtained articles. The driving factors are mainly multiple factors, land use change, policy and management, and climate change. Riverine wetlands, multiple wetland types, and lacustrine wetlands are the main wetland types in existing studies, and the evaluated WES types are mainly supporting and regulating services. The applied evaluation approaches mainly include the biophysical and qualitative methods, which accounted for 76.4% and 14.3% of the total studies, respectively. Two main limitations in WES studies are a lack of unified WES evaluation indicators and comprehensive WES studies. In the future, WES research should focus on generating unified WES evaluation indicators for comparison across different studies and up-scaling. Long-term program should be established to gather data for creating ecological production functions to determine the marginal influence of wetland land characteristics on the final WES to refine the management options. Stakeholders should also be involved in the process of designing payments for ecosystem services programs.

1. Introduction

Wetlands are vital for human survival. They cover a total area of 12.1 million km^2 and account for 40.6% of the total global ecosystem services (ES) value (Costanza et al., 2014; Ramsar Convention on Wetlands, 2018). Wetlands are acknowledged as both critical for ES delivery (Mitsch and Gossilink, 2000; Rebelo et al., 2017; Zhang et al., 2017; Sieben et al., 2018) and highly threatened by a range of human activities (Ramsar Convention Secretariat, 2006; Zhang et al., 2017; Tong et al., 2017; Best, 2019; Sieben et al., 2018). Globally, many wetlands have been exploited or used unsustainably (Mitsch and Gossilink,

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2000; Rebelo et al., 2017), which has resulted in a 35% loss in the global wetland extent since 1970 (Ramsar Convention on Wetlands, 2018). Despite 169 countries having ratified the Ramsar Convention, wetland losses and degradation continue (Ramsar Convention on Wetlands, 2018).

There have been many literature reviews on wetland ecosystem services (WES) since the Millennium Ecosystem Assessment (MEA) in 2005 (MEA, 2005). The review studies have mainly focused on WES research from the local scale (Steinman et al., 2017; Sterner et al., 2017) to the national scale (Kimmel et al., 2010; Bassi et al., 2014), management and regulation (Blignaut et al., 2013; Dam et al., 2014; Blanchard et al., 2015), drivers of wetland change and mechanism analysis (Pejchar and Mooney, 2009; Wondie, 2010; Boulton et al., 2016; Peralta-Maraver et al., 2018), quantitative approaches (Barbier, 2016; Seppelt et al., 2011; Vigerstol and Aukema, 2011; Cools et al., 2013; Janse et al., 2019; Langan et al., 2018), or theories and future directions (Liu et al., 2010; Maltby and Acreman, 2011; Pirard and Lapeyre, 2014; Xu et al., 2018). In addition, from the perspective of wetland types, WES review studies have mainly concentrated on coastal wetlands (Sierszen et al., 2012; Zhao et al., 2016), mangroves (Walters et al., 2008; Friess, 2016; Kelleway et al., 2017), lacustrine (lake) wetlands (Steinman et al., 2017; Sterner et al., 2017), and riverine wetlands (alongside rivers and streams) (Wondie, 2010; Dam et al., 2014; Yang et al., 2016). Existing review studies clearly elaborate the quantification evaluation methods for each WES type and the corresponding advantages and disadvantages of each method, thereby revealing the main drivers of dynamic changes in WES and providing principal guidance for WES management and regulation. On the basis of existing reviews, further understanding of WES research trends on a global scale, including the study themes, drivers of wetland change, wetland types, WES types, and study methods, as well as engaging in an in-depth discussion on how to incorporate WES research into management decision making and policy design, are important scientific issues in WES research. Our study seeks to fill this knowledge gap, at least in part.

Based on an analysis of the current literature on WES studies published on the Web of Science (WOS) and ScienceDirect, we performed a quantitative analysis and systematic review of WES studies by analyzing the number of studies, countries, research institutions, wetland types, ES types, research themes, and study approaches. This study aims to address the following key areas: (1) identify the main development and trends of existing research based on a systematic analysis of current WES studies and (2) reveal the limitations of current WES studies and propose suggestions for the direction of future WES research.

2. Methods

We conducted a systematic literature review in September 2018 with three steps. Because the WOS only contains publications indexed by the Science Citation Index (SCI) and Social Science Citation Index (SSCI), we also searched ScienceDirect to include published papers that are not indexed by the SCI and SSCI. First, we searched the WOS for relevant articles up to August 31, 2018 by searching the “topic” domain using the combined keywords “ecosystem service” OR “ecosystem services” and “wetland”. Second, we searched ScienceDirect with the same “topic” domain up to August 31, 2018. Finally, we read all the works individually to eliminate those irrelevant to WES studies and collected 1711 peer-reviewed articles. We assumed that the existing peer-reviewed articles collected through the WOS and ScienceDirect were representative of the WES studies in the highest cohort with respect to research quality. Thus, we used these peer-reviewed articles to analyze the trends and existing issues in WES research in this study. Following the wetland type classification system of the Ramsar Convention, we identified nine categories and 28 subcategories, namely coastal wetlands (3 subcategories), estuarine wetlands (4 subcategories), lacustrine (lake) wetlands, riverine wetlands (4 subcategories), palustrine wetlands (5 subcategories), peatland, man-made wetlands (8 subcategories), multiple wetlands, and others (Table 1) (Ramsar Convention on Wetlands, 2018). According to the classification system for ES types in the MEA (MEA, 2005), the types of WES were classified into five categories and 30 subcategories, including provisioning services (7 subcategories), regulating services (11 subcategories), supporting services (5 subcategories), cultural services (7 subcategories), and multiple services (indicating the WES research focusing on two or more ES types, e.g., provisioning services and regulating services or regulating services and supporting services) (Table 2).

The research methods were classified into four categories and 18 subcategories, namely qualitative methods (perspective, view, etc.), biophysical methods (models, experiments, field observations, mixed approaches, and biophysical indicators), social sciences methods (statistics and social surveys), economic valuation methods (market price method or market-based estimation, benefit-transfer method, alternative cost method or substitute cost method, hedonic pricing method, opportunity cost method, willingness to pay, travel cost method, and multiple economic valuation methods), and others (energy analysis, visualization, life cycle assessment, etc.).

The drivers of wetland change were classified into nine categories, including climate change, land use change, biological factors (including biodiversity, microorganisms, biological invasion, habitat change, plant type, plant diversity, and vegetation change), policy and management (including conservation policy, resource management, land management, and ecological restoration), other anthropogenic factors (including deforestation, agriculture, grazing, pipeline and road construction, sand mining, water abstraction, urbanization, and economic factors), hydrological change and hydropower development (including freshwater discharges, water physicochemical conditions, hydrological exchange, hyporheic flow, waves, underground water, and dam construction), water quality and pollution control (including water quality, trophic conditions, and pollution control), multiple factors (indicating articles focusing on over two different major factors), and other environmental factors (including salinization, sedimentation, and natural hazards).

Table 1
Statistics of wetland types and applied methods.

Wetland type		Number of articles	Subtotal	Percent (%)	Number of articles for each method				
Category	Sub-category				Biophysical methods	Qualitative methods	Social sciences methods	Economic valuation	Others
Coastal	Coastal lagoons	16	89	0.9	11	2	1	2	0
	Coral reefs	3		0.2	2	1	0	0	0
	Others	70		4.1	41	15	5	7	2
Estuarine	Deltas	51	140	3.0	40	2	3	4	2
	Tidal marshes	39		2.3	33	4	1	1	0
	Mangrove swamps	32		1.9	25	2	2	3	0
	Others	18		1.1	12	3	2	1	0
Lacustrine	Lakes	185	185	10.8	132	18	17	15	3
Riverine	Rivers	338	497	19.8	238	36	27	31	6
	Wetlands along rivers and streams	123		7.2	98	7	8	9	1
	Streams	16		0.9	14	0	0	2	0
	Others	20		1.2	12	5	3	0	0
Palustrine	Marshes	48	70	2.8	39	3	6	0	0
	Swamps	14		0.8	7	4	2	1	0
	Fens	3		0.2	2	1	0	0	0
	Bogs	2		0.1	2	0	0	0	0
	Others	3		0.2	2	0	1	0	0
Human-made	Treatment wetlands	16	136	0.9	13	2	1	0	0
	Reservoirs	14		0.8	10	1	3	0	0
	Irrigated agricultural land	7		0.4	21	9	4	3	2
	Multiple	6		0.4	1	1	3	1	0
	Fish and shrimp ponds	4		0.2	2	0	1	0	1
	Canals	2		0.1	2	0	0	0	0
	Farm ponds	2		0.1	2	0	0	0	0
	Others	85		5.0	39	6	3	4	1
Peatland		16	16	0.9	13	1	1	1	0
Multiple		334	334	19.5	197	70	33	30	4
Others		244	244	14.3	137	51	35	19	2
Total		1711	1711	100.0	1147	244	162	134	24

Information on the author, author institute, and author country was only selected based on the first author and the first institute. We read all the literature individually to build a database according to the above criteria for further analysis. The database included the following information: title, publication year, author, author institute, author country, journal, research topic, wetland type (category and subcategory), WES type (category and subcategory), research methods, and drivers of wetland change. However, the lack of unified classification systems of wetland types, WES, methods, and driving factors would have led to some bias in the classifications.

3. Results

3.1. Number of publications (country and research institution)

A total of 1711 papers on WES published between January 1995 and July 2018 were collected. The number of publications increased over time and was the highest in 2017 at 272 (the data for 2018 was excluded because of incompleteness) (Fig. 1). The publications originated from 69 countries; the United States (US) had the largest number of publications (total of 485 papers), followed by China, the United Kingdom (UK), Australia, Germany, Italy, Spain, France, Canada, and the Netherlands. The number of papers published from these 10 countries accounted for 74% of the total publications. The publications stemmed from 868 research institutions, among which the Chinese Academy of Sciences, Beijing Normal University, University of Wisconsin, US Geological Survey, Stockholm University, UK Centre for Ecology and Hydrology, Ohio State University, Wageningen University, University of Maryland, Louisiana State University, and University of Southampton composed the top 10, and accounted for 14.9% of the total publications. The Chinese Academy of Sciences and Beijing Normal University are two major contributors to WES research in China whose publications accounted for 48.1% of the total publications from China.

3.2. Journal distribution

The WES literature originated from 267 journals. Among these, 114 journals had only one publication on WES each, which accounted for 42.7% of all the journals. Overall, 199 journals had less than five publications, which accounted for 74.5% of all the journals and 19.5% of the total number of papers. Additionally, 19 journals had more than 20 publications, which accounted for 7.1% of all the journals; however, the number of papers in these 19 journals accounted for 53.0% of the total

Table 2
Statistics of wetland ecosystem services types and applied methods.

Ecosystem services classification	Ecosystem services type (MEA classification)	Number	Subtotal	Percent (%)	Number of articles for each method				
					Biophysical methods	Qualitative methods	Social sciences methods	Economic valuation	Others
Provisioning	Food and fiber	41	83	2.4	30	2	6	2	1
	Fresh water	28		1.6	24	3	1	0	0
	Multiple	6		0.4	3	1	1	1	0
	Fuel	4		0.2	2	2	0	0	0
	Genetic resources	1		0.1	1	0	0	0	0
	Ornamental resources	1		0.1	1	0	0	0	0
	Others	2		0.1	2	0	0	0	0
Regulating	Water purification and waste treatment	177	298	10.3	144	11	13	8	1
	Water regulation	46		2.7	39	2	2	3	0
	Climate regulation	23		1.3	19	2	0	2	0
	Multiple	14		0.8	11	2	0	0	1
	Storm protection	12		0.7	8	1	1	1	1
	Biological control	7		0.4	4	1	2	0	0
	Erosion control	7		0.4	4	2	1	0	0
	Pollination	6		0.4	6	0	0	0	0
	Air quality maintenance	3		0.2	3	0	0	0	0
	Disaster risk reduction	1		0.1	0	1	0	0	0
	Others	2		0.1	1	1	0	0	0
Supporting	Provisioning of habitat	202	327	11.8	140	26	28	6	2
	Nutrient cycling	107		6.3	95	4	3	3	2
	Water cycling	9		0.5	8	1	0	0	0
	Soil formation and retention	8		0.5	7	1	0	0	0
	Primary production	1		0.1	1	0	0	0	0
Cultural	Recreation and ecotourism	33	50	1.9	19	2	5	6	1
	Multiple	7		0.4	3	0	2	2	0
	Aesthetic values	4		0.2	2	1	1	0	0
	Educational values	2		0.1	1	0	0	1	0
	Inspiration	1		0.1	0	0	0	1	0
	Sense of place	1		0.1	1	0	0	0	0
	Others	2		0.1	1	0	1	0	0
Multiple		953	953	55.7	566	178	95	98	16
Total		1711	1711	100.0	1147	244	162	134	24

number of papers. The five journals with the most publications were *Science of the Total Environment*, *Ecological Engineering*, *Ecosystem Services*, *Ecological Indicators*, and *Ecological Economics*, which accounted for 29.6% of the total number of papers (Fig. 2(a)).

3.3. Wetland types and ecosystem service types

The wetland studies predominantly addressed riverine wetlands (29.0%), multiple wetland types (19.5%), others (14.3%), and lacustrine wetlands (10.8%), which accounted for 73.6% of the total number of studies. Peatland had the least number of publications, accounting for 0.9% of the total number of publications (Fig. 2(d); Table 1). Among the 28 secondary wetland classifications, research on coastal wetlands predominantly addressed other coastal wetland types and coastal lagoons, accounting for 70.8% and 18.0% of the total publications on coastal wetlands, respectively. Research on estuarine wetlands predominantly addressed deltas, tidal marshes, and mangrove swamps, accounting for 36.4%, 27.9%, and 22.9% of the total publications on estuarine wetlands, respectively. The studies of wetland types classified as lacustrine all addressed lakes. Riverine wetland research predominantly addressed rivers and wetlands along rivers and streams, accounting for 68.0% and 24.7% of the total publications on riverine wetlands, respectively. Secondary palustrine wetland research predominantly addressed marshes and swamps, accounting for 68.6% and 20.0% of the total publications on palustrine wetlands, respectively. In addition to other research, research on man-made wetlands predominantly addressed treatment wetlands and reservoirs, accounting for 11.8% and 10.3% of the total publications on man-made wetlands, respectively. The five secondary wetlands with the most publications were rivers, lakes, wetlands along rivers and streams, deltas, and marshes, which accounted for 43.5% of the total publications.

The research on WES types was focused on synchronizing multiple ES types, which accounted for 55.7% of the total publications; this type was followed by supporting services and regulating services, which accounted for 19.1% and 17.4% of the total publications, respectively. There were fewer studies on provisioning services and cultural services, accounting for 4.9% and 2.9% of the total publications, respectively (Fig. 2(e); Table 2). Concerning research on a single ES type, research on food and fiber and on freshwater dominated the provisioning services, accounting for 83.1% of the total publications on provisioning services. Water purification and waste treatment and water regulation dominated the research on regulating

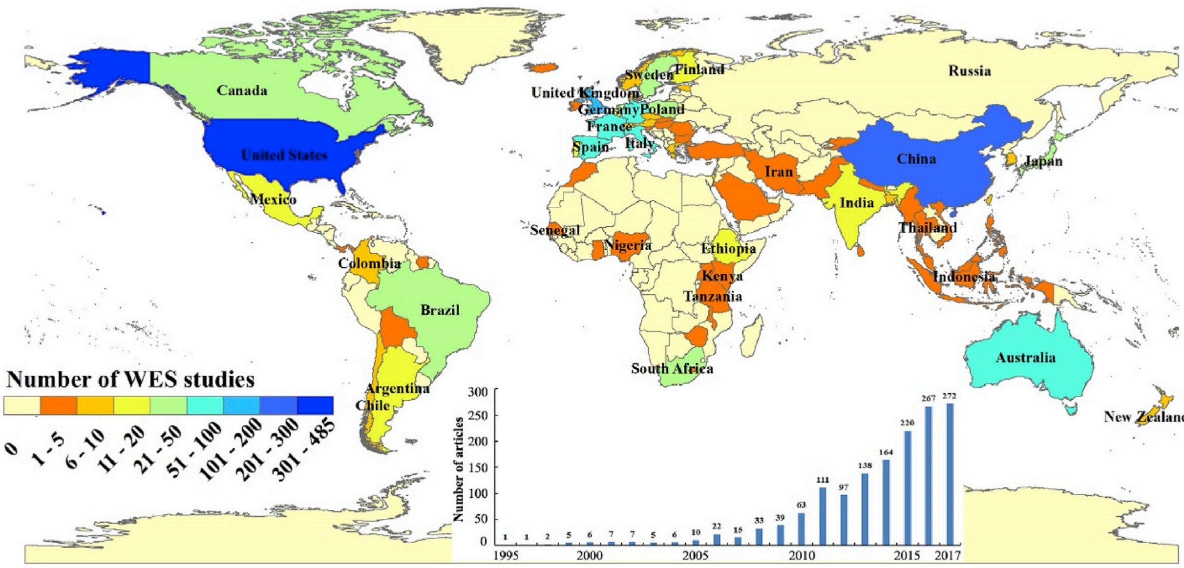

Fig. 1. Distribution and trend of published articles on wetland ecosystem services.

services, accounting for 74.8% of the total publications on regulating services. Habitat provisioning and nutrient cycling dominated the research on supporting services, accounting for 94.5% of the total publications on supporting services. Recreation and ecotourism dominated the research on cultural services, accounting for 66% of the total publications on cultural services. Overall, the research on a single ES type was focused on supporting services and regulating services. In particular, habitat provisioning, water purification and waste treatment, and nutrient cycling were predominantly addressed, accounting for 28.4% of all the publications.

3.4. Research themes

The research themes of WES are very broad and can be divided into seven major categories, including ES evaluation, analysis of driving force, policy and management, review and opinion, trade-off analysis, modeling methods, and others (Fig. 2(b)). The current research was focused on WES evaluation (49.6%), analysis of driving mechanisms (24.0%), and policy and management (17.2%), which accounted for 90.9% of all the research. There were fewer studies on review and opinion, trade-off analysis, modeling methods, and other types of research, which accounted for 5.4%, 3.7%, 2.3%, 1.0%, and 0.5% of all the studies, respectively. Among these, the management and policy studies were concentrated in the US, China, the UK, and Australia, accounting for 52.2% of the total number of studies with this theme.

Driving force types can be categorized into nine categories. The order of these categories from most to least prevalent was multiple factors (above two factors), land use change, policy and management, climate change, biological factors, other anthropogenic factors, hydrological change and hydropower development, water quality and pollution control, and other environmental factors. Studies on the first four categories accounted for 63.3% of the total number of studies on drivers of wetland change (Fig. 2(c)). Among these studies, studies from the US predominately addressed climate change, multiple factors, biological factors, and policy and management, those from China predominately addressed climate change and multiple factors, and those from the UK predominately addressed multiple factors, biological factors, and policy and management, accounting for 58.7%, 64.0%, and 58.3% of the total number of studies on drivers of wetland change in each country, respectively.

3.5. Applied approaches

Biophysical, qualitative, social sciences, and economic valuation methods were the main research methods, which accounted for 67.0%, 14.3%, 9.5%, and 7.8% of the total number of publications, respectively. Biophysical methods were dominated by mixed approaches (indicating multiple models, ecological models, economic valuation methods, and multiple economic valuation methods) and models, and accounted for 50.6% and 44.2% of the total publications with biophysical methods, respectively. There were very few studies on experiments and field observations or biophysical indicators. Economic valuation methods mainly included willingness to pay (choice experiments and the contingent valuation method), benefit-transfer methods, and multiple economic valuation methods (different economic valuation methods are used for different ES types), which accounted for 40.3%, 18.7%, and 17.9% of the total number of studies using valuation methods, respectively.

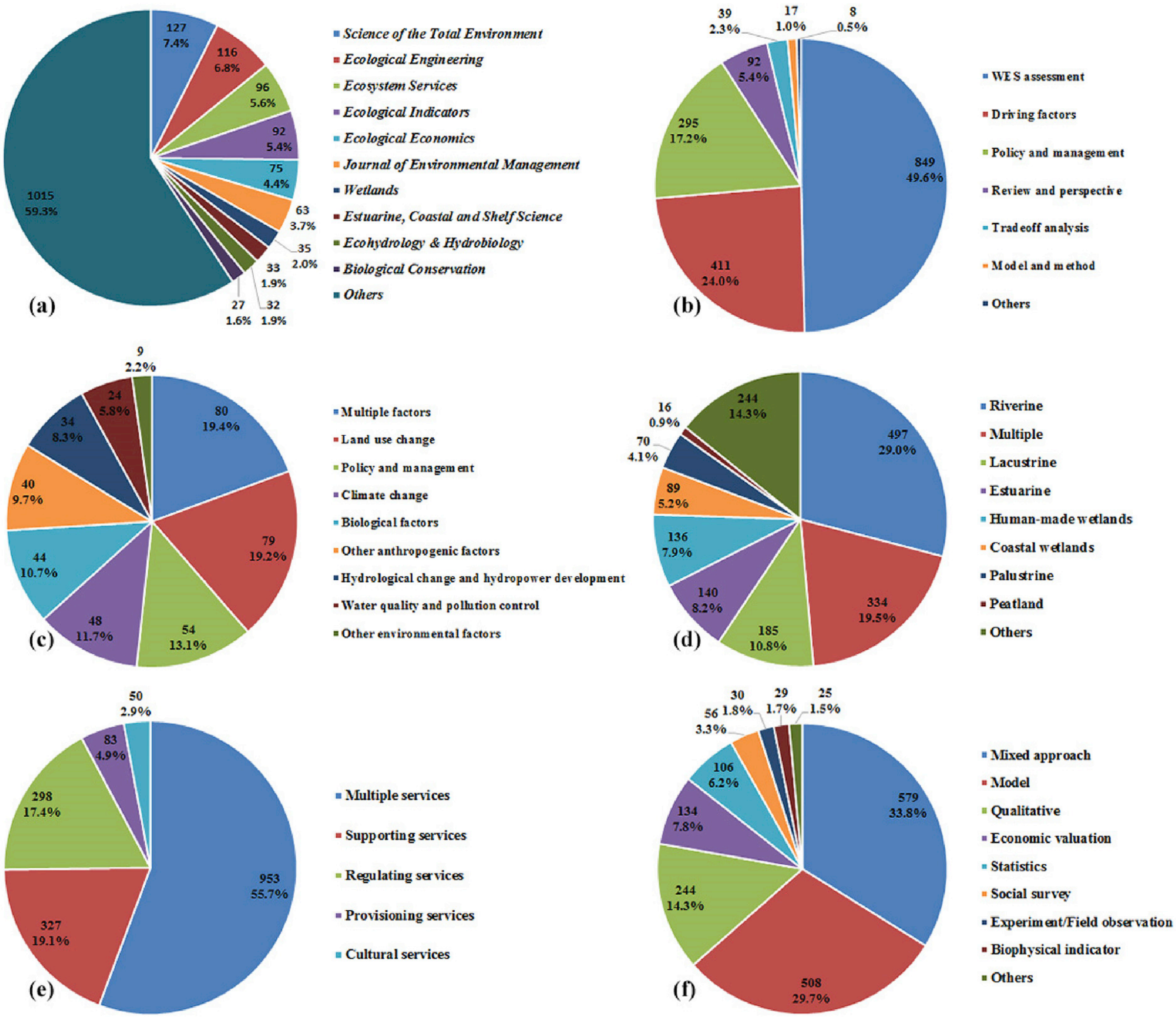

Fig. 2. (a) Major published journals, (b) topics, (c) driving factors, (d) wetland types, (e) ecosystem services types, and (f) applied methods in the wetland ecosystem services studies.

Biophysical methods and qualitative methods were the main methods for studying different wetland types. The research on economic valuation was mainly focused on the valuation of rivers, multiple wetland types, and lakes, accounting for 56.7% of the total publications on economic valuation. Among these studies, the valuation methods for rivers and lakes mainly included willingness to pay and multiple economic valuation methods, while the valuation methods for multiple wetland types mainly included willingness to pay and benefit-transfer methods.

For different WES types, except for cultural services, the research trends in the other four ES type studies agreed with the overall trend, which was to employ mainly biophysical and qualitative methods, followed by economic valuation methods, social sciences methods, and other methods. Meanwhile, the research methods for cultural services mainly included biophysical methods, economic valuation methods, and social sciences methods. For the economic valuation methods of a single ES type, willingness to pay and travel cost methods were more frequently used in research on water purification and waste treatment, habitat provisioning, and recreation and ecotourism, while the economic valuation methods for other ES types were more limited (one to two publications).

The main methods for analysis of driving mechanisms, land use change, and policy and management included biophysical methods and economic valuation methods, while the methods for the study of other drivers of wetland change were mainly biophysical methods and qualitative methods. Economic valuation methods were mostly used to study land use change and policy and management, accounting for 80% of the total publications using economic valuation methods, and mainly included the benefit-transfer method, willingness to pay, and multiple economic valuation methods.

4. Discussion

4.1. Main findings and limitations

4.1.1. Main findings

This study clearly revealed the spatial distribution of publications (country and research institution), journal distribution, wetland types, WES types, research themes, and applied approaches of WES studies based on a systematic literature review through the WOS and ScienceDirect. It showed that studies on WES increased rapidly from 1995 to 2017, with increasingly diversified studies. This indicates that scholars are paying increasing attention to WES, as well as the global distribution, as illustrated in Fig. 1. The remarkable heterogeneity of the spatial distribution was mainly influenced by two aspects. First, the spatial distribution of relevant research institutions was determined by the institution of the first author, thereby leading to no or a relatively small number of research institutes in northern Asia, Africa, and southeastern Asia, which contain vast wetlands. Second, the applied search strategy might have led to this bias because we only considered publications in WOS and ScienceDirect. Thus, the spatial distribution of publications (Fig. 1) cannot fully reflect the importance of wetlands in various countries, and the location of the wetlands under study needs to be analyzed in the future.

Existing studies on WES mainly focus on WES evaluation, drivers of wetland change, and policy and management (Jiang and Xu, 2019). The willingness to pay and benefit-transfer methods are two main methods of economic valuation. The key challenges of successfully applying the ES concept in wetland conservation lie in providing scientifically rigorous information about the changes in WES, identifying the mechanisms driving its dynamics, and implementing WES into planning and policy (Xu et al., 2018). Two limitations in the current studies should be noted as follows.

4.1.2. Lack of unified wetland ecosystem services indicators

There is a lack of unified indicators for assessing WES in current studies (Rasmussen et al., 2016; Turner et al., 2016; Xu et al., 2018). Most of the existing WES studies also confuse intermediate ES with final ES, thereby leading to double counting of the economic value that ecosystems provide to beneficiaries (Sinha et al., 2018; Lamothe and Sutherland, 2018). The diversified indicators lead to poor comparability of specific services in different geographical studies, thereby hindering aggregation and scaling over larger spatial and temporal scales (Turner et al., 2016). Although ES modeling has become a focus among communities of scientists and practitioners, there are still many limitations (e.g., data gaps and model complexity) in applying some of the traditional ecological process-based models to ES assessment (Shoyama et al., 2017). The lack of consensus on selecting appropriate methods (Boerema et al. 2017) and the difficulty in considering both the ecological and socioeconomic aspects of ES also hinder policy makers regarding WES governance (Mitsch et al., 2013; Rasmussen et al., 2016).

4.1.3. Lack of comprehensive wetland ecosystem services studies

This review indicated that current WES studies mostly focus on supporting services (e.g., habitat provisioning and nutrient cycling) and regulating services (e.g., water purification and waste treatment, water regulation, and climate regulation). In comparison, studies on provisioning services (e.g., food and fiber and freshwater) (4.9%) and cultural services (e.g., recreation and ecotourism) (2.9%) are relatively lacking. On one hand, wetland ecosystems provide more types of support and regulating services than provisioning and cultural services (de Groot et al., 2012;Ramsar Convention on Wetlands, 2018). On the other hand, the lack of research on provisioning and cultural services is also due to data gaps and the complexities associated with understanding how cultural ES are created, communicated, and calculated (Fish et al., 2016). Except for the studies on economic valuation of WES using the benefit-transfer method, the lack of comprehensive studies on the four major WES types of the MEA is largely due to the limitations in data, monitoring, and models (Costanza et al., 2014, 2017; de Groot et al., 2012; Xu et al., 2018; Davidson et al., 2019).

The other key finding in our review was that WES studies mainly focus on WES assessment and driving mechanism analysis (73.6%), while WES trade-off analysis (13.6%) and policy and management application (3.7%) are not sufficiently addressed. Greater focus on involving comprehensive WES evaluation and stakeholder participation in wetland management is required (Xu et al., 2018).

4.2. Uncertainty in the literature review

Although our systematic literature review was conducted by searching the “topic” domain using the combined keywords “ecosystem service” OR “ecosystem services” and “wetland” through the WOS and ScienceDirect, there was still some relevant literature that was not acquired. For example, some studies on specific wetland types (e.g., lakes and rivers) with some ecological functions or specific services (e.g., global climate mitigation) but without the term “wetland” or “ecosystem services” in the title or abstract or not included in the above two databases could not be effectively searched. In addition, a large number of non-native English publications were not considered in this study. The limitation of this search strategy could not only lead to some uncertainty in the integrity and representativeness of the analytical literature, but also result in a biased geographical distribution of the publications, e.g., no or very few studies from northern Asia, Africa, and southeastern Asia (Fig. 1). Thus, the search strategy of considering other specific wetland types (e.g., lakes and rivers) and some specific ES needs to be further extended in future studies.

Meanwhile, during the classification of "research themes," the literature involving both WES assessment and analysis of driving forces was roughly divided according to the focus and highlights of the articles, which could lead to some uncertainty in the classification between WES assessment and analysis of driving forces. In addition, the topics of studies with more than one category of driving factors and WES type (four MEA categories of ES types) were roughly classified as multiple factors and multiple WES types, respectively, which need to be further subdivided and analyzed in the future. Moreover, the drivers of wetland change were roughly classified into nine categories in this study, and the underlying and proximate drivers (e.g., land management and land use change) were not separated, which likely resulted in confusing the real contributions of the various drivers. Thus, quantifiable evaluation of the differences from different approaches and the strength of the various drivers should be further extended in future studies to more reliably understand the drivers and mechanisms of WES.

4.3. Future suggestions

(a) Generalization. Unified WES evaluation indicators are helpful for providing a guide for integrating WES evaluation data in different geographical regions to improve the reliability of horizontal studies (Janse et al., 2019; Xu et al., 2018; Darrah et al., 2019; Davidson et al., 2019). Scientists are developing ecological characteristics and final WES indicators, but there are no standardized criteria for selecting variables (Wong et al., 2015). Studies of similar geographical regions in which the same WES are examined could be evaluated to develop standardized indexes for WES across different geographical regions. For example, the changes and economic valuation criteria of WES on the basis of such case studies can be derived by applying meta-analysis methods (Ghermandi et al., 2010; Brander et al., 2013; Reynaud and Lanzanova, 2017).

(b) Monitoring. A long-term monitoring program on WES with field observations and remote sensing will assist in gathering big data for evaluation, analysis, and management of WES. Measuring ecosystem services directly can be extremely difficult (Stephens et al., 2015), which has stimulated the widespread application of benefit-transfer method for measuring WES at one place and time (i.e., study site) and applying it to another place and time (i.e., policy site) (Plummer, 2009). Benefit-transfer method was frequently used to estimate ecosystem services in a relatively inexpensive and timely manner (Eigenbrod et al., 2010; Van der Biest et al., 2015), while this approach might be poor when neglecting the underlying ecological processes (Wong et al., 2015). If the basic requirements of an initial comprehensive database can be met (Wong et al., 2015) and the required empirical relationships between wetland ecosystem characteristics and final WES can be established from multiple primary studies and meta-data (Brander et al., 2013), then the results of the study site can be accurately transferred to other case studies (Luederitz et al., 2015; Costanza et al., 2017). Long-term monitoring data on wetland ecosystem characteristics and final WES of specific wetland ecosystems across spatiotemporal scales will significantly improve the credibility of benefit-transfer methods and process models (Bagstad et al., 2013; Janse et al., 2019; Xu et al., 2018).

(c) Stakeholder participation. Exploring trade-offs among ES and linking them with stakeholders can help to determine the potential losers and winners of wetland management (Guida et al., 2016). For effective implementation of the management options, various types of stakeholders should be involved to help refine the management options. First, if the stakeholders are the main beneficiaries or suppliers of the WES, then the involvement of the stakeholders would effectively guarantee the implementation of the management activities, especially for the payments for ES (Xu et al., 2018). Second, the main aim of management options is to guarantee that the WES provided can meet the requirements of the management goals. The participation of stakeholders could help to identify the demands of WES (e.g., biodiversity conservation, water purification, water regulation, and fiber production). Last, the participation of stakeholders could help to determine the ecological endpoints (Wong et al., 2015), which could then help to select the variables of wetland ecosystem characteristics and final WES.

5. Conclusion

This paper provides a systematic review that enhances our understanding of the considerable progress made on WES. Current studies focus on WES evaluation, analysis of driving forces, wetland management, and policy design, and biophysical, qualitative, and economic valuation methods are the main evaluation approaches. Existing studies mainly focus on riverine wetlands, multiple wetland types, lacustrine wetlands, and their relevant supporting and regulating services. There is also some uncertainty in the representativeness of the analytical literature and the classification of research themes, driving forces, and WES types in this study. There are two main limitations in current studies, including a lack of unified WES indicators and comprehensive WES studies. Generalization of WES evaluation indicators for cross-sectional studies and upscaling, creation of a long-term monitoring program to gather big data for wetland ecosystem characteristics and final WES, and stakeholder participation to design the payments for ES programs are suggested as major future directions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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