water

Review

Review of the Ecosystem Services of Temperate Wetlands and Their Valuation Tools

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Abstract: Wetlands constitute important habitats that provide several ecosystem services (ES). Wetlands have been termed the kidneys of the world for their water purification services and contain 20–25% of total soil organic carbon. This paper is a review of published studies dealing with the ES of temperate wetlands. Wetlands are among the ecosystems with the most valuable ES, with regulating services being the most important for inland wetlands. While the number of articles on the ES of wetlands has increased exponentially over the past 10 years, more research is needed to achieve a methodological homogenisation in the quantification and valuation of the ES of wetlands. More attention should also be targeted to specific ES of wetlands, and for the geographical distribution of studies. It is also evident that ES have not been valued for some categories of wetlands, such as intermittent karst lakes (poljes/turloughs) which may require more bespoke methodologies to quantify certain aspects of their ES due to their unique annual flooding behaviour.

Keywords: temperate wetlands; ecosystem services; ecosystem service valuation; intermittent wetlands

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1. Introduction

1.1. Definitions and Objectives

Although there is no global agreement on the definition of "wetland", the Ramsar convention provides a well-accepted one by defining them as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tides does not exceed six metres" [1]. The definition was then expanded to include "... riparian and coastal zones adjacent to the wetlands and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands" [2]. This definition will be considered in this article.

The main classes of wetlands are swamps, fens, bogs, and marshes. Other distinctions are then drawn, such as tidal and non-tidal, coastal, inland, freshwater, brackish or salt, or according to their substrate type (rock bottom, unconsolidated, rocky shore, unconsolidated shore, streambed, reef, [3]).

The total area occupied by wetlands is still subject to debate with recent estimates varying between about 12×10^6 km^2 and 17×10^6 km^2, with the lower value being probably the more accurate [4].

Examples of the biggest temperate wetlands are the Mississippi river delta in North America and the Danube delta and the Scottish Flow Country in Europe. Another notable example is the Norfolk Broads with habitats ranging from the open water of shallow lakes to flooded reedbeds and from boggy marshes and fens to wet 'carr' woodland with willows and alders [5]. Irish and Scottish bogs, together with the temperate parts of the mountain peatlands and lake littoral wetlands of Scandinavia and Finland, represent the widest expanses of peatlands in Europe.

Blankespoor et al. [6] estimate that with a 1 m sea level rise due to climate change, approximately 64% of the freshwater marsh, 72% of coastal wetlands, and 61% of brackish/saline wetlands in 86 developing countries are at risk. In light of these threats to wetlands, conservation efforts are being made worldwide and restoration is also underway for many different kinds of wetlands. One tool that can help with these efforts is the concept of ecosystem services (ES). ES were originally defined as the conditions and processes through which natural ecosystems sustain and fulfil human life [7] and are classified as provisioning, regulating, supporting and cultural. Although covering only 6 to 8% of the global land space, wetlands account for a disproportionate amount of the total value of the ES of all biomes (possibly around 36% [8]) This testifies to the importance of these habitats, with valuations of their ES growing worldwide.

About half of global wetland areas have been lost and much of the remaining wetland areas are degraded [9]. It is, therefore, crucial that we have accurate estimations of the value of wetlands, in order to be able to make a stronger case for their preservation.

In this study, an overview is given of the ES that have been considered for different types of wetlands and of the state-of-the-art methods that have been developed and used in the quantification of wetland ES, particularly over the past 10 years, in which interest in such an approach to characterise wetlands has burgeoned. Another aim of this review is to provide a background and appropriate methodologies for assessing the ES of wetland types that do not seem to have undergone formal ES assessments to date (e.g., intermittent wetlands in karst areas).

1.2. ES Definition

The concept of ES originates from economic studies in the late 1970s, which have become more mainstream with increasing interest in methods of quantifying their economic benefit [10,11]. A common definition of ES as "the benefits that people obtain from ecosystems" has been provided by the Millennium Ecosystem Assessment (MEA) [12], which offers the four categories of provisioning, regulating, supporting, and cultural ES. Another definition describes ES as the functions of ecosystems that provide benefits to people [13]. A unifying classification system has been brought forward with the Common International Classification for Ecosystem Services (CICES), defined here as the contributions that ecosystems make to human well-being [14]. This builds on the approach of the MEA, but with the difference that, in the CICES classification, supporting services are classed as intermediate services. The CICES classification uses three main categories with some sub-categories: provisioning, regulating, and cultural ES. This classification is based on the cascade model, which proceeds from the biophysical structures and functions of ecosystems, to produce the final services, which in turn generate goods and benefits, as shown in Figure 1, illustrating how value is generated in this way.

The concept of ES has come under scrutiny and critique because of it being seen as anthropocentric in nature; therefore potentially promoting further exploitation of nature and undermining conservation efforts. It has been counter-argued that the concept of ES includes non-monetary and intrinsic values, which can help to reconnect humans with nature and it overlaps with the biodiversity concept [15]. Notwithstanding this debate, it is undeniable that the ES framework is being applied more and more in research as well as becoming mainstream in policy and planning; it provides increased awareness, communication, and participation, as well as spatially referenced knowledge [16]. The ES concept can help compare different management and policy options and choose the one with the least impact or that which promotes the highest level of ES [17]. Equally, it can be used to raise awareness of relative changes over certain time frames [18]. The Economics of Ecosystems and Biodiversity (TEEB, [17]) and the UK National Ecosystem Assessment (UKNEA, [19]) both highlighted the danger of loss of ES, including those associated with wetlands and peatlands in particular [20]. The Mapping of Ecosystems and their services (MAES) is also central to the European Biodiversity Strategy 2020 [21]. Among the ES frequently associated with wetlands are water supply and purification, flood and erosion control, carbon storage and sequestration, and habitat preservation [12].

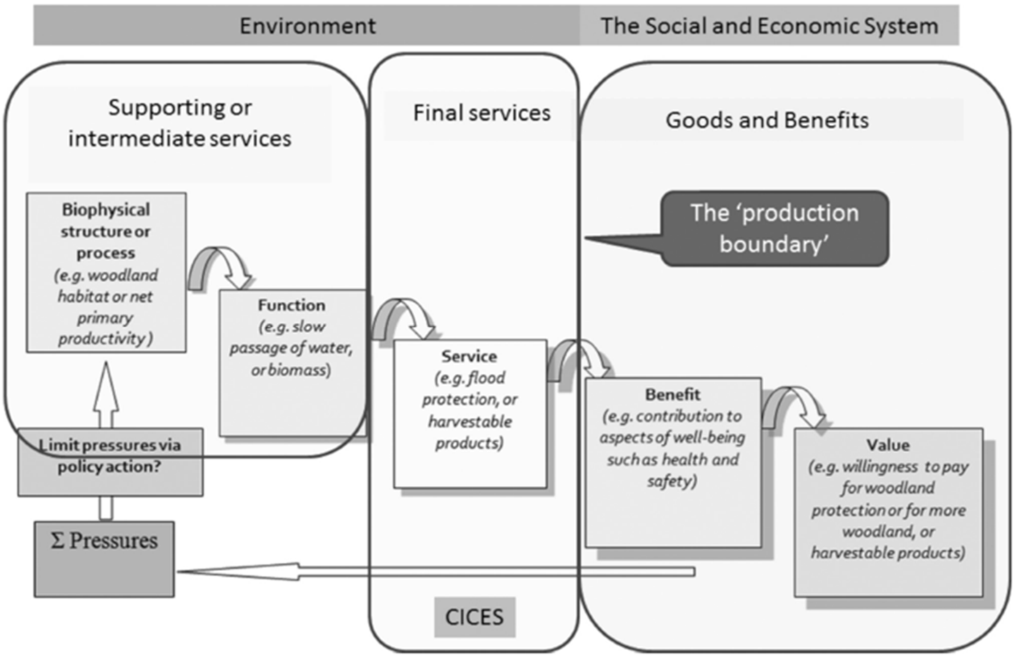

Figure 1. The CICES cascade framework for ecosystem services (ES). Reprinted with permission from, [14]. Copyright 2018, Potschin-Young et al.

1.3. Quantification and Valuation of ES

As defined by the MEA (2005) [12], value is "the contribution of an action, or object to user-specific goals, objectives, or conditions". More specifically, the value of ES can be defined as the contributions of the ecosystem to supporting sustainable human wellbeing [22]. Different values can be highlighted depending on the frame of reference and on the stakeholders considered. It is important not to restrict valuation only to economic values but be aware of the other values such as inherent, fundamental, and eudemonistic [23].

A common approach is also to consider the Total Economic Value (TEV), which includes not only use and non-use value, but also non-direct values [24]. Non-direct values are the benefits provided by a good or service that are used indirectly by an economic agent (like water purified by a wetland and enjoyed further down in the catchment). The different kinds of value include:

- Social value: benefits are received by a group, not an individual. Examples are improved water quality and flood protection.
- Option value: the value for the conservation of a public asset or service even if it is not likely that it will be used and ensuring future availability.
- Existence value: the value deriving from the simple knowledge that the valued resource exists, even if it will never be used.
- Altruistic value: the value of ecosystems to others.
- Bequest value: the value associated with the satisfaction of preserving natural or cultural heritage for future generations.

Different methods have therefore been used to try to estimate the different components of TEV when a direct market and price are not available, as follows.

1.3.1. Market Prices

This approach estimates the value of an ecosystem good or service and its price on a market on which it is bought or sold. The value is determined by measuring the change in producer and consumer surplus after applying a change in production or price. Adjustments should be made to correct for market distortions, such as taxes and subsidies [25].

1.3.2. Cost-Based Methods

These methods are not a strict evaluation of the economic value of ecosystem service and assume that these values can be estimated by analysing the costs incurred in substituting them or avoiding damage. Examples are replacement cost, opportunity costs, the avoided damage cost, defensive expenditures, replacement/substitute costs, net factor income, travel cost, hedonic pricing, and restoration costs methods [26]. The replacement cost method requires the evaluation of the cheapest price that should be paid for the replacement of the function under scrutiny. This method has the advantage of being accepted by traditional economists. It also gives higher valuations than the other methods. Uncertainties remain though as to whether all the services provided at the moment would be replaced.

1.3.3. Stated Preference Approaches (Contingent Valuation and Choice Modelling)

Both methods involve using a hypothetical or contingent market in the absence of a free market for non-market goods. For the contingent valuation method, originally proposed by Davis (1963) [27], the value is then the amount that society would be willing to pay to produce and/or use a good beyond the value it already pays. Choice modelling involves the public in choosing between alternatives, thus having them reveal or state their willingness to pay for a good or service. It can be traced back to consumer studies by Thurston in the 1920s and to random utility theory [28]. This was then developed by Daniel Mc Fadden in economics [29] and by Duncan Luce [30] and Anthony Marley [31] in mathematical psychology.

1.3.4. Revealed Preference Methods

These methods imply gathering data linked to the preference of the public for a good linked to a specific ecosystem service. The main ones are hedonic pricing and travel cost methods. The hedonic pricing method (HPM) uses a surrogate market (usually the housing market) to quantify the revealed preference of the public in living in a certain area affected by an ecosystem good or service [32].

1.3.5. Production Function

The production function method estimates changes in producer and consumer surplus due to quantity or quality changes in an environmental good or services which is part of a production process. If the price does not change, only the producer surplus is affected [33].

1.3.6. Value Transfer

This method consists of using estimates from previous studies to value services provided by the studied ecosystems. This method takes two different approaches. In direct value transfer a value for an ecosystem service is directly transferred to the studied site. Ideally the two sites have similar characteristics, otherwise corrections should be applied. The other approach uses transfer functions, the terms of which have ideally been determined through a meta-analysis of valuation literature [34].

The total revenue, opportunity and replacement cost methods are not based on sound economic theory and therefore will tend to under- or overestimate values [34]. Brander et al. (2006) [33] also found that value transfers tend to have an average transfer error of 74%, which might be justified however, in light of the higher cost of primary valuations.

The TEV does not, however, represent the whole value of ecosystems, as other sets of values are provided by ecosystems. These represent the role of wetlands in the natural system and are usually presented in terms of biodiversity.

More inclusive estimations of values should be used, as to try to incorporate non-economic ecosystem values, such as inherent, contributory, primary, and infrastructure values [26]. One of these approaches is the eco-price, which considers both biophysical and economic valuation [35].

1.3.7. Valuation Tools Used for the Different ES

ES valuation is performed in different phases and using different tools, depending on the ES present and on the scale of the assessment (Table 1). A biophysical quantification of ES is a prerequisite of carrying out an economic one. It can use direct measurement of the variables of interest, though this can be costly, and therefore indicators or proxy data and spatial models are often used. Indicators can be primary (when they directly refer to the ES quantified, e.g., number of tourists visiting a natural area), or secondary, when they indirectly help quantify said ecosystem service (e.g., accessibility or naturalness as a proxy for touristic value). The most used indicators for mapping ES are land cover, soil, vegetation, and nutrient related indicators (Table 2). Egoh et al. (2012) [36], found that land cover is an important secondary indicator for all the categories of ES. Nutrient fluxes and soil characteristics are other important secondary indicators. Vegetation maps are useful for carbon sequestration and water regulation.

Table 1. Economic valuation methods of the different ecosystem services (ES). CV: Contingent Valuation/Choice Modelling; DE: Defensive Expenditures/Averting Behaviour/Avoided Costs; HPM: Hedonic Pricing Method; MA: Market Analysis; PF: Production Function; RC: Replacement/Restoration Costs; TC: Travel Cost. Adapted with permission from [26]. Copyright 2012, Georgiou & Turner.

ES	**Valuation Methods**
Provisioning	
Water for residential use, livestock watering, and food manufacture processing	MA; PF; RC; CV; DE, HPM
Water for landscape, turf, and agricultural irrigation	MA; PF; RC; DE; CV
Food, reeds, grass/hay or timber harvesting, pharmaceuticals, and other products used in industry	MA; PF; CV
Regulating	
Habitat preservation	MA; PF; RC; CV; TC; DE, HPM
Climate regulation	MA; PF; RC; CV; DE; HPM
Waste removal	MA; PF; RC; CV; DE; HPM
Nutrient and toxicant retention	MA; PF; RC; CV; DE; HPM
Saltwater intrusion	MA; PF; RC; DE; CV
Erosion prevention, flood and storm protection, and shoreline stabilisation	MA; PF; RC; DE; CV; HPM
Cultural	
Recreational fishing, boating, hunting, trapping, and plant gathering	MA, PF, RC, CV, TC, DE, HPM
On and off-site observation for leisure, education, and scientific activities	MA; PF; RC; DE; CV; TC
Cultural, historic and aesthetic value provision	CV

Table 2. Indicators for ES assessment. Adapted with permission from [37]. Copyright 2016, Grizzetti et al.

ES	**Indicators**
Fisheries and aquaculture	Fish production or fish catch; status of fish populations; aquaculture production; wild vegetation used in gastronomy, cosmetic or pharmaceutical uses; number of fishermen
Water for drinking purposes	Water consumption for drinking; water abstracted; surface water availability; water exploitation index (WEI); nitrate-vulnerable zones
Water purification	Indicators of surface water quality (nitrate, phosphates, coliforms ...); indicators of groundwater quality; nutrient loads; nutrient concentration; nutrient retention; trophic status; ecological status; area occupied by riparian forests; potential mineralisation or decomposition; number and efficiency of treatment plants; wastewater treated
Erosion prevention	Sediment retention; groundwater evolution
Flood prevention	Flood risk maps; water holding capacity of soils; conservation of river and lakes banks; groundwater level evolution; flood plains area (and record of annual floods); area of wetlands located in flood risk zones; conservation status of riparian wetlands

Table 2. *Cont.*

ES	Indicators
Maintaining habitats	Biodiversity value (species diversity or abundance, endemics or red-listed species . . .); ecological status; hydromorphological status
Recreation	Number of visitors to natural places; number of visitors to attractions; National Parks and Natura 2000 sites; number of bird-watching sites; number of bathing areas and beaches; fish and waterfowl abundance; quality of fresh waters for fishing; number of waterfowl hunters and anglers; number of fishing licenses and fishing reserves; tourism revenue
Intellectual and aesthetic appreciation	Sites monitored by scientists; number of scientific projects, articles, studies; classified sites (e.g., World Heritage . . .); Number of visitors; National Parks and Natura 2000 sites; cultural sites and number of annual cultural events; contrasting landscapes; proximity to urban areas of scenic rivers or lakes.

Provisioning services can be quantified by primary data; however, usually indirect indicators are used (e.g., landscape cover for food production). Regulating services such as carbon sequestration and water quantity regulation are usually quantified through models, given their complex nature [36].

The spatial and temporal scales of valuations should also be considered. Spatially, the amount of population affected by an impact under investigation must be determined. Direct uses of the wetland concern existing and potential users of the resource. Indirect uses values may not be site-specific; for example, the benefits provided by flood risk reduction further down the catchment. Non-use benefits are valued over a wider geographical area but are also subject to decrease with distance from the site of interest. The temporal scale entails considering a trade-off between short-term and long-term benefits. Many projects consider a long-term timescale and issues such as future demand for a particular service and discount rates must be considered.

Recently, several studies made a distinction between ES supply and demand ([38,39]). Supply can be defined as the capacity of an ecosystem to provide ES within a certain timeframe, while demand can be described as the sum of all ecosystem goods and services currently consumed or used in a particular over a given time period ([38,40]). The analysis of supply and demand of ES is important to assess the sustainability of ES provision.

2. Methods for the Analysis of the Literature on ES Quantification and Valuation

The research literature was searched to identify studies on the quantification and/or valuation of ES of temperate wetlands. Articles published between 1980 and 2020 were searched for (up to 31 December 2020) on Scopus (being one of the largest curated abstract and citation databases, [41]) using different combinations of the terms: "wetlands, ecosystem services, ecosystem functions, natural capital, carbon sequestration, carbon storage, water provision, water regulation, flood risk, habitat preservation, recreation, cultural services, social services".

Preliminary search results were filtered to include only temperate wetlands and studies where a quantification and/or valuation had been performed, or a valuation method was presented. This resulted in a database of 1062 articles that were reviewed. The categories of data gathered included:

- Year of publication (see Figure 2)
- Author
- Typology of wetland This followed the Cowardin classification [3], modified to highlight mires (bogs and fens), seasonal and temporary wetlands and groundwater dependent wetlands (see Figure 3)
- Country where the studied wetland was located (see Figure 4)
- Typology of study This included a simple quantification/valuation of one or more ES, review papers, evaluation of policies and restoration plans, ES interactions and trade-offs, land use and climate change effects, articles on valuation methodology,

changes in ES over space and time, payment for ecosystem services (PES), ES value change over time, and scenario comparison (see Figure 5).

- Data used The data used in ES studies has been classified as "primary" where the bio-physical or value information was gathered directly by researchers. When information was retrieved from old studies, or indirectly, literature data, land-use maps, remote sensing maps, and photographs were used (see Figure 6).
- ES analysed Following the CICES classification the various provisioning, regulating and cultural ES were identified. (see Figure 7).
- Valuation techniques These were either economic or ecological methods (see Figure 8).
- Software tools used (see Figure 9).

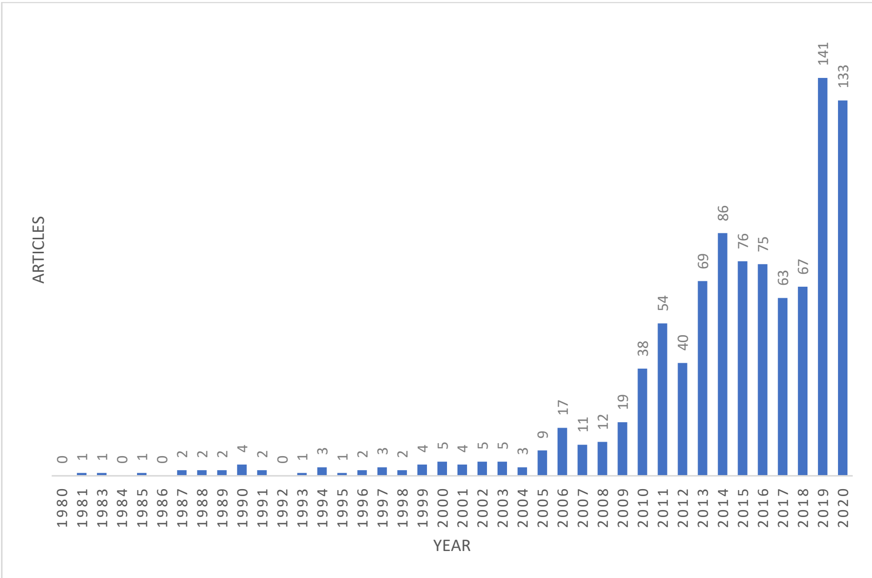

Figure 2. Number of ES articles published per year from a search of journals in SCOPUS between 1980 and 2020 using the wetland-related keywords detailed in Section 2.

Wetland type	Number of articles	% of total
Riverine	73	8.0
Lacustrine	56	6.1
Palustrine, of which:	173	18.8
• mires	34	
• depressional	20	
• marshes	47	
• swamps	22	
Coastal	255	27.8
Several types of wetlands	233	25.4
Wetlands and other types of ecosystems	128	13.9

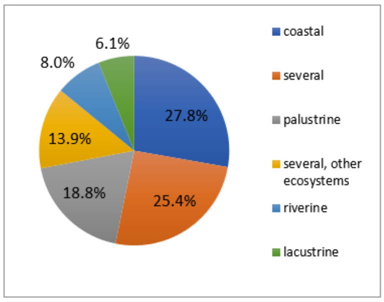

Figure 3. Number of ES articles for each wetland type from a search of journals in SCOPUS between 1980 and 2020 using wetland-related key words.

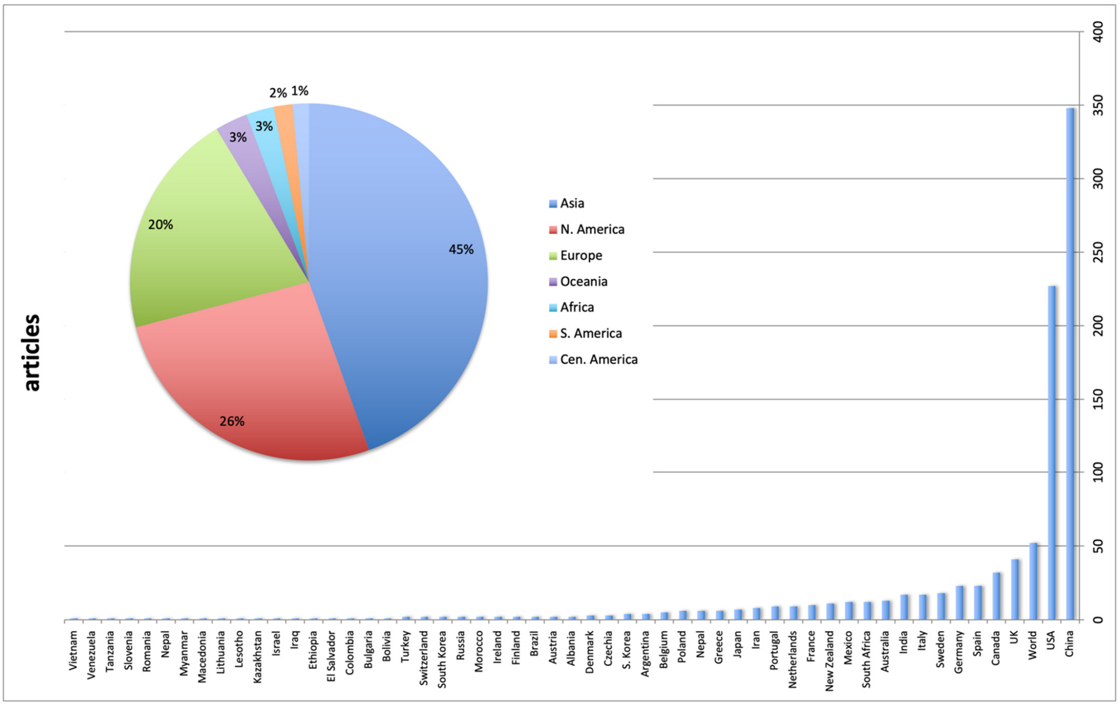

Figure 4. Location of studies from the wetland-related key word search of journals in SCOPUS (between 1980 and 2020). The category "World" includes methodological studies not referring to a specific location.

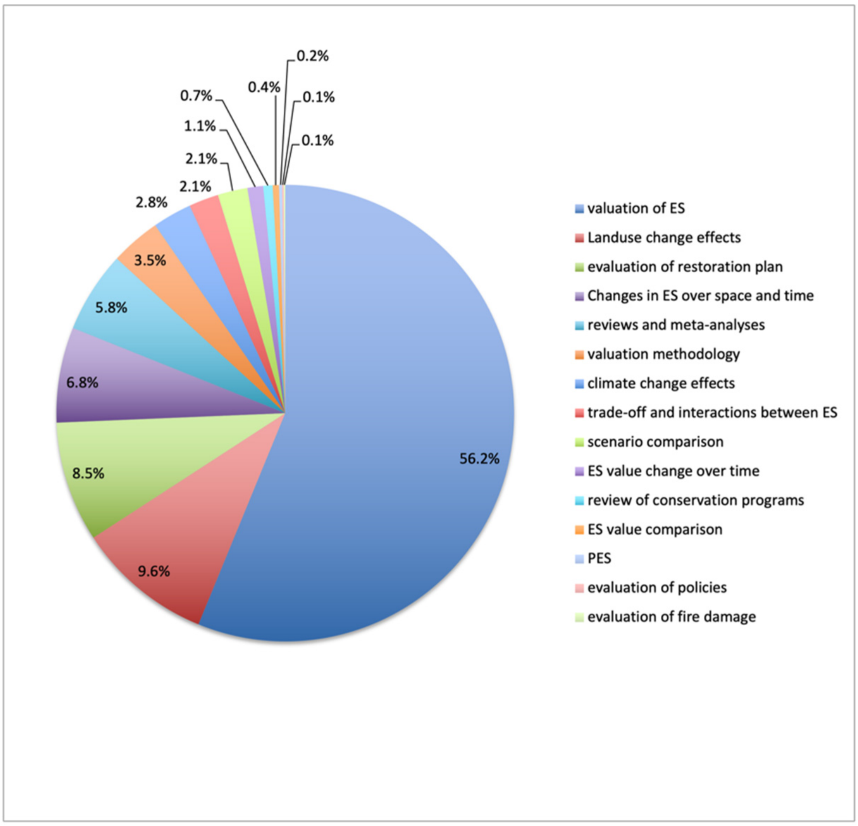

Figure 5. The key focus of the ES wetland studies of studies from the wetland-related key word search of journals in SCOPUS (1980 and 2020). PES: Payments for Ecosystem Services.

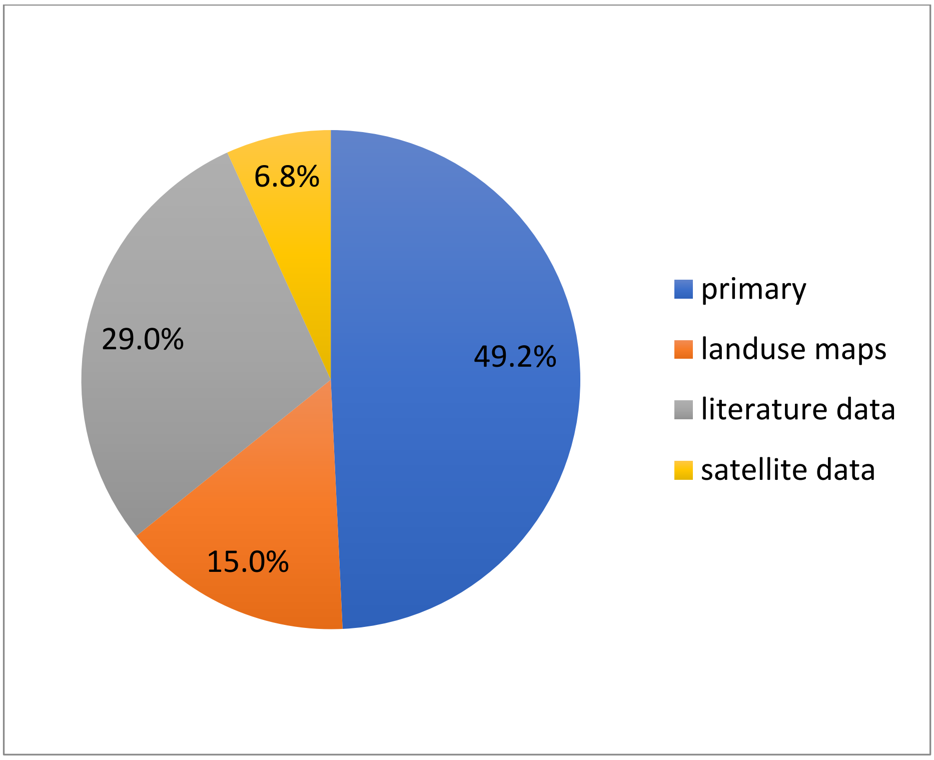

Figure 6. Typology of data used for the wetland-related ES studies identified in SCOPUS (between 1980 and 2020).

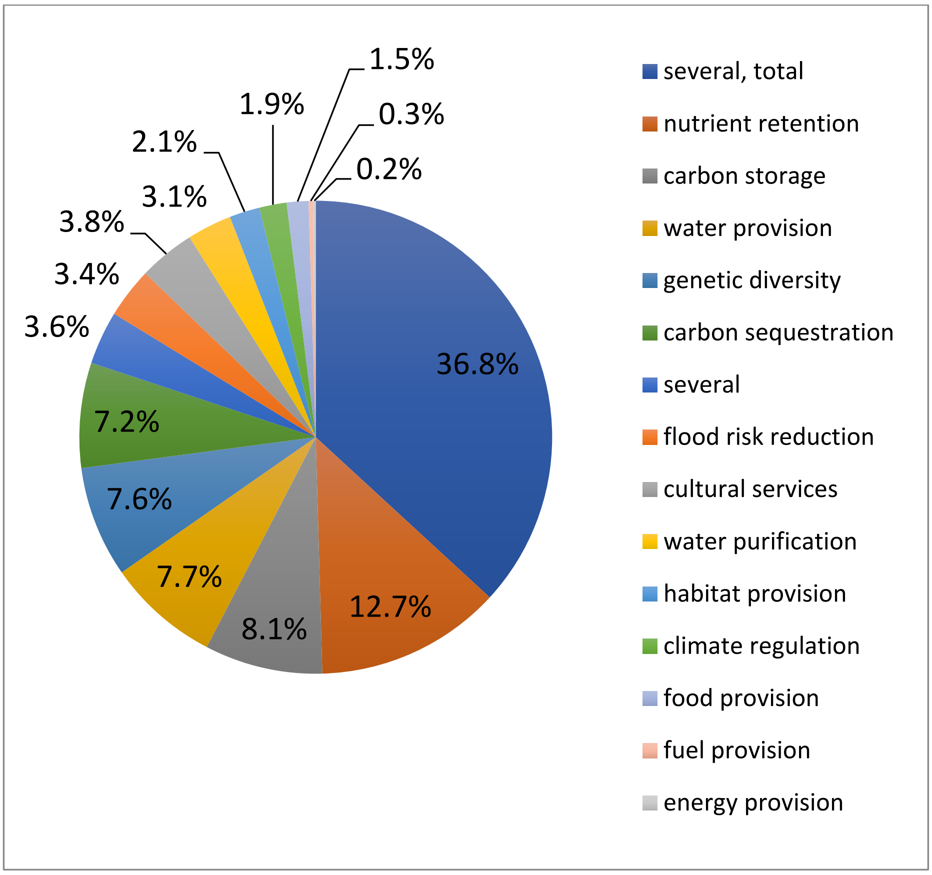

Figure 7. Wetland ES studied from the wetland-related key word search of journals in SCOPUS (between 1980 and 2020).

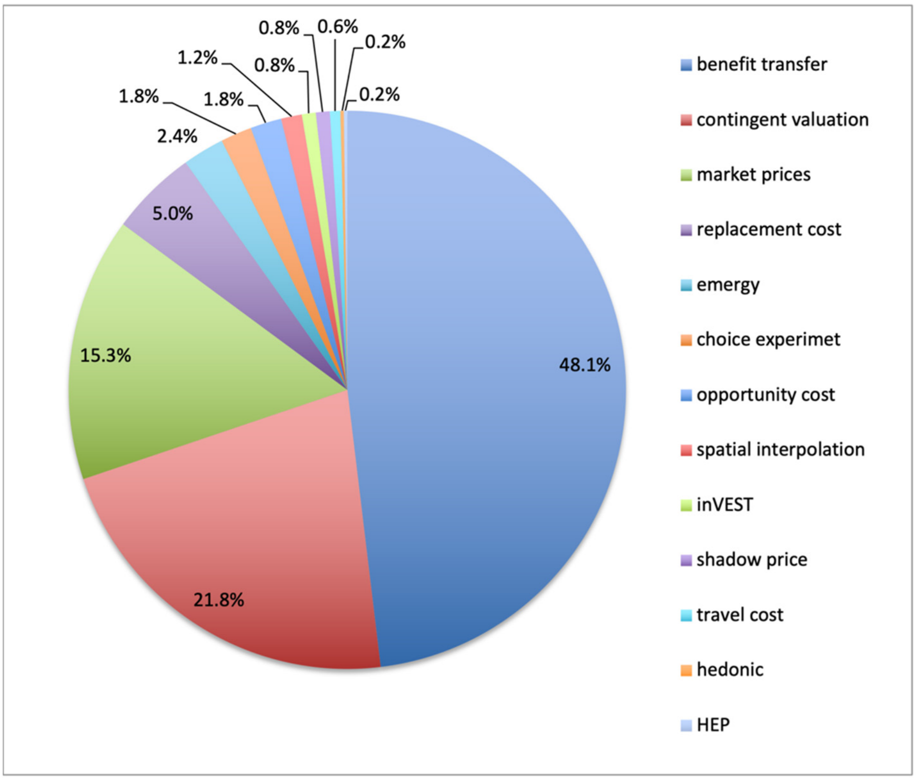

Figure 8. Valuation techniques used for the wetland-related ES studies identified in SCOPUS (between 1980 and 2020) (see Section 1.3 for a description of the valuation techniques).

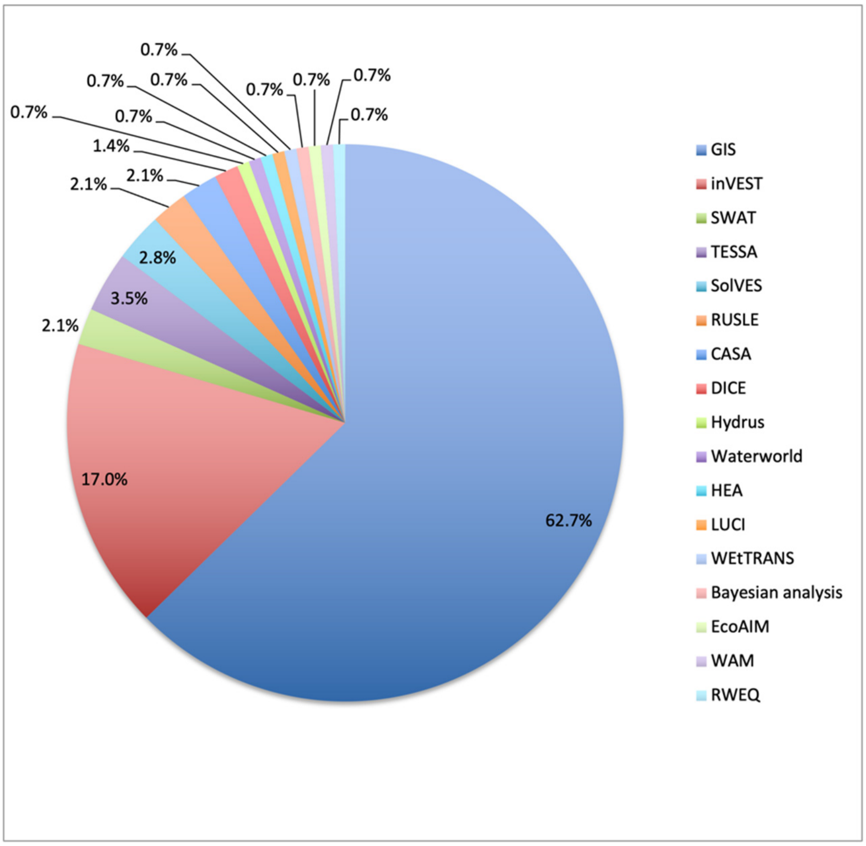

Figure 9. Software tools used for the wetland-related ES studies identified in SCOPUS (between 1980 and 2020). (see Appendix A, Table A1 for an explanation of the acronyms and the use of the tools).

3. Results

3.1. Quantitative Results

The 1062 journal articles identified were published between 1980 and 2020, during which period there was a continuous increase in the number of publications, as can be seen in Figure 2.

The most studied wetlands were coastal ones, with studies involving more than one class of wetland ('several') and also involving other types of ecosystems ('several, other ecosystems') coming next (Figure 3).

In terms of location, Asia produced the highest number of wetland studies (45%) with China heading that continent's share, followed by North America (26%) and Europe (20%) (Figure 4).

The subject area with the highest number of the ES wetland studies (56.2%) was the valuation of one or more ES, with the evaluation of trade-offs and interactions between ES coming next (9.6%), as shown in Figure 5.

Studies using primary data (Figure 6) were the most abundant (49.2%), while 36.8% of the studies considered more than one ES (Figure 7). Benefit transfer represented the valuation technique most used (48.1%, Figure 8) with Geographic Information Systems (GIS) the software tool of choice of most of the studies (62.7%, Figure 9). Finally, an economic or ecological valuation was performed in just 57.2% of cases.

3.2. Summary of the Literature

Costanza et al. (1997) [11] provided the first valuation of the value of ES worldwide and sparked big controversies. Balmford et al. (2002) [42] for example, argued that rather than considering the total value of the ecosystem we should rather focus on net marginal benefits.

Several reviews of the ES of wetlands have since then been published, testifying to the already established awareness of the importance of these ecosystems. The most relevant worldwide are Brouwer et al. (1999) [43] on contingent valuation studies, Woodward and Wui (2001) [44] and Brander et al. (2006) [33].

Brouwer et al. (1999) [43] focused on temperate wetlands in developed countries, reviewing 30 studies that used the contingent valuation method. This method consists of interviewing members of the public or experts and eliciting the value they attach to a service by asking about their willingness to pay (WTP). They found that the highest WTP was for flood prevention, probably due to the risk to life and assets, followed by water provision, and water quality improvement.

Woodward and Wui (2001) [44], reviewing 46 studies on temperate wetland valuations, found some evidence that the method used affected the resulting value, with contingent valuation giving lower estimates.

Brander et al. (2006) [33] identified 190 valuation studies providing 215 value observations. They found that socio-economic variables, such as income (which are often neglected), are important in explaining wetland value. They also found that benefit transfer is associated with 74% average error and that contingent valuation and revealed preference give roughly similar value estimates. Brander et al. (2013) [34] estimated the total world value of the regulating services of wetlands within agricultural areas at USD 26 billion per year. For European wetlands they found an average value per hectare of USD 15,339 and a median value of USD 3706.

A milestone for the definition of the ecosystem service concept has been the already mentioned MEA [12], with other important initiatives being the TEEB [17] and MAES [21]. The TEEB analysed the literature on valuation studies and found a total of 364 studies (also comprising tropical areas). This study estimated the value of inland wetlands as up to USD 44,000 per hectare per year, ranking as one of the highest values among all biomes.

Costanza et al. (2014) [22] updated their previous valuations [11] and estimated the value of the world's ecosystems at USD 125–145 trillion, with wetlands worth 26.4 trillion, or 140,174 USD/ha/year. Tidal marsh/mangrove unit values were particularly high, due to new studies on storm protection, erosion protection, and waste treatment values of these tidal wetlands. The valuation was based on a simple benefit transfer function. This valuation was again controversial yet highlighted the sheer amount of benefit that humans derive from such environments and made the wider public aware of it. It also highlights the growing awareness worldwide of the benefits provided by wetlands which started with the declaration of the Ramsar convention in 1971 [1].

This study also showed that inland swamps and flood plains were significantly more valuable than lakes, rivers, forests, and grasslands. Only coastal estuaries had higher unit values. However, Brander et al. (2006) [33] found that freshwater marshes had lower average values and they also found an inverse correlation between value and size of wetlands. Similarly, De Groot et al. (2012) [8] show that values of both coastal and inland wetland ES are typically higher than for other ecosystem types (Figure 10) and generally higher than those of terrestrial ecosystems. For example, the study showed that the total value of a freshwater marsh in Canada had a total value of USD 8800/ha, about 2.4 times the value of the swamp converted to intensive agriculture.

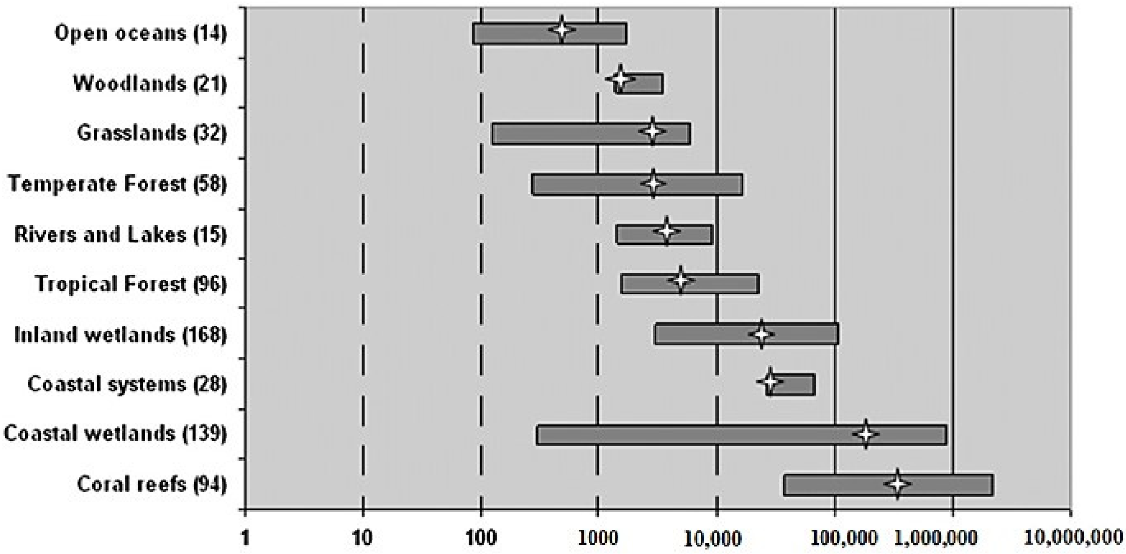

Figure 10. Summary of mean monetary values of ES per biome (values in USD/ha/year, 2007 price levels). Reprinted with permission from [8]. Copyright 2012, De Groot et al.

The ES identified by De Groot et al. 2012, [8], (values then used in Costanza et al. 2014, [22], Table 3) with the highest monetary evaluation per hectare, is waste treatment by coastal wetlands (162,125 USD/ha), followed by the nursery (10,678 USD/ha) and the genetic diversity (6490 USD/ha) services (habitat preservation), both for coastal wetlands. For inland wetlands, the single most valuable ecosystem service per hectare identified is the regulation of water flows (5606 USD/ha). Similarly, Lara-Pulido et al. (2018), [45], in a review of ES of Mexico, found that regulation services in wetlands were the most valuable ES.

Table 3. Value of different types of ES of inland wetlands in $/ha/year, 2007 prices levels. Reprinted with permission from [8]. Copyright 2012, De Groot et al.

	Inland Wetlands
Provisioning Services	1659
Regulating Services	17,364
Habitat Services	2455
Cultural Services	4203
Total Economic Value	25,682

There is a wide discrepancy on the value of flood prevention, especially for coastal wetlands, depending on the method of valuation used and possibly socio-economic factors. As already mentioned, the defensive expenditure method tends to give values which are much lower than those obtained by the avoided damage cost. For example, Ming et al. (2007) [46], calculated a value of 5700 USD/ha/yr for wetlands in a Chinese nature reserve, while Vazquez-Gonzales et al. (2019) [47], calculated values between 148,277 and 193,674 USD/ha/2007 for freshwater marshes and mangroves, respectively, for coastal plains in the Gulf of Mexico. Costanza et al. (2008) [48] calculated a value for coastal protection of 250 to 51,000 USDha^{-1}y^{-1}, with a mean of 8240 USDha^{-1}y^{-1} and 23.2 billion USDy^{-1} for total storm protection services. As for the valuation method used, Mehvar et al. (2018) [49] found that avoided damage, replacement and substitute cost methods, as well as the stated preference method are the most used valuation methods for coastal ES.

Among the wetland ES which have global relevance are flood abatement, carbon sequestration, biodiversity conservation, and water quality improvement [9].

Okruszko et al. (2011) [50], in a review of the ES of European wetlands, consider five ES as being the most important: biodiversity conservation, biomass production, nutrient removal, carbon storage, and fish production. They also found that on average, each wetland provides four ES, and that a combination of groundwater-fed fens with riparian marshes or swamp is the most fruitful in terms of ES. Climate change is likely to hit these ES with a potential loss of about half. Wetlands in central Europe are especially vulnerable. A focus on adaption strategies is therefore needed, with ES linked to flooding events needing special attention. In Europe, freshwater wetlands in Finland, Sweden, and Ireland show low per hectare value but high aggregate ES values, due to the large number of wetlands in these countries [51]. In low-income nations such as Bulgaria and Croatia, however, ES represent a bigger share of the GDP and are therefore expected to be more susceptible to degradation of habitats [52].

It also recognises the mapping of the ES of wetlands as a knowledge gap that must be filled. Campbell et al. (2018) [35], calculated a value of 9693 USD/ha for palustrine wetlands of Maryland, with wildlife habitat, nutrient retention, and stormwater runoff mitigation being the biggest contributors.

In a meta-analysis of US wetland valuation studies, Borisova-Kidder (2006) [53] found a mean value per acre for wetland services of USD 262.43 (US 648.46/ha). The ES of coastal wetlands (intertidal marshes) have been valued at USD 4291/acre (USD 10,603/ha) by Barbier (2019) [54].

There has been a relevant growth in studies made in China, the majority of which are based on land-use maps and associated ecosystem values per unit area modified from Costanza et al. [22], though adapted to the Chinese peculiarities. They are also geared toward the application to wetland conservation policies.

Davidson et al. (2019) [55], studying wetlands and using values from Costanza et al. (2014) [22] but with updated areas of the different classes of wetlands, arrived at a minimum value of $47 trillion USD annually (43.5% of the value of all natural biomes), with 57% coming from inland wetlands and 43% from coastal wetlands. 80–95% of the values of different wetlands is linked to water: water recharge nutrient retention, flood prevention, and storm abatement. Finally, Zhou et al. (2020) [56], through a meta-analysis of 134 Chinese articles using benefit transfer as the valuation technique, highlighted how it is necessary to expand wetland ES studies to include more types of wetlands, valuation methods, and a wider geographic range.

Unfortunately, ES values are declining, due mainly to land-use change. Sannigrahi et al. (2018) [57] found that wetlands' ES value per year decreased between 1995 and 2015 from 22.19 to 21.11 trillion USD/year^{-1}. Coastal wetlands have been particularly affected by reclamation. It has been found [58] that in the Yellow Sea there was a loss of 8 billion USD y^{-1} in ES value, with a high proportion of climate regulating ones (carbon sequestration).

3.3. ES of Intermittent Karst Wetlands

3.3.1. Description of Intermittent Karst Wetlands (Poljes and Turloughs)

Some wetlands are intermittent, with two notable examples, the seasonal lakes that appear in poljes and turloughs that form in karst limestone landscapes, as a result of the solutionally enlarged cave networks on which they lie, causing them to drain and fill at localised points, depending on the overall hydrological state of the catchment. They generally fill in autumn/winter and drain (at least partially) in spring/summer.

A polje is a large, flat-floored depression within karst limestone that usually floods in the winter for some months when the swallow holes/ponors (openings where surface waters enter underground passages) cannot drain the higher flows quick enough. They are 1–5 km wide and up to 16 km long [59], though the intermittent lakes of the Pivka valley in Slovenia are much smaller [60]. They are present in many karst regions (mainly tropical and subtropical) of the world and in temperate climates are common in the Dinaric Alps (Slovenia, Serbia, Croatia) and are also present in Greece and Turkey. An example and one of the largest worldwide is Livanjsko polje in Bosnia, also a Ramsar site. Provision of agricultural products is very important, as well as cattle and sheep raising and dairy products.

Water level fluctuation gives rise to disturbance to wetland vegetation succession, keeping these systems in an early productive stage of development defined as “pulse” or “water level fluctuation climax” [61]. These fluctuations, together with changes in soil properties, give rise to specific vegetation patterns [61,62].

Several studies found that increases in temperature and solar radiation, as well as intensity, timing, and extent of floods, negatively affect primary production, life cycles of animals, and mineralisation and decomposition [60,62]. In Lake Cerknica polje in Slovenia, a gradual loss of seasonality of floods and droughts and an impact on the primary productivity of common reed (Phragmites australis) due to changes in temperature and rain patterns was found by Dolinar et al. [61].

Turloughs are hydrologically similar to poljes in terms of their periodic inundation and lacustrine deposits [63], though they are generally smaller than polje and their origin is more complicated [60] (Figure 11). Turloughs are present mostly in the Republic of Ireland, west of the river Shannon, with only three others present in Northern Ireland and one in South Wales.

Figure 11. Blackrock turlough, County Galway in the drained and filled phases (Photos by Laurence Gill).

They are defined as Groundwater Dependent Terrestrial Ecosystems (GWDTEs) and as such they are protected under the Water Framework Directive (WFD, Directive 2000/60/EC). As they host protected fauna and flora, they are also designated as a Priority Habitat in Annex 1 of the EU Habitats Directive (92/43/EEC) [64].

3.3.2. Existing ES Studies on Intermittent Karst Wetlands

A Scopus search (on 31 December 2020) with the keywords "ecosystem + services + turloughs" gave only one result [65], which only focused on mapping the vegetation communities in a turlough. An unpublished study [66], contains chapters on soil, water, and vegetation quality based on fieldwork at 22 Irish turloughs that could be used to estimate some ES. Similarly, McCormack et al. (2016) [67] can be used in the determination of the nutrient retention service.

A search for the ES of poljes (on 31 December 2020) on Scopus with the keywords "ecosystem + services + polje" gave one result, relating to conservation policies of a Croatian park containing a polje but does not mention any ecosystem service quantification [68]. Additionally, the impacts of climate change on the ES of the intermittent lake Cerknica were estimated in the already mentioned study by Dolinar et al. [61].

4. Discussion

4.1. Findings from This Study

There was clearly a significant increase in the number of articles regarding the ES of wetlands between 1980 and 2020. This depends in part on the growing popularity of the ES concept and also on the realisation that wetlands host some of the most valuable ecosystems. Coastal wetlands have attracted a lot of attention, which correlates with the fact that they are deemed to be among the most valuable ecosystems on Earth. Compared to previous reviews, there has been a significant increase in the number of studies from China. However, of the Chinese studies consist of secondary studies, linking land use to ecosystem value per hectare, mainly from Costanza et al. [11,22]. Benefit transfer has in general proved to be a popular technique, despite having significant application problems, probably due to its cost-effectiveness, given that primary studies are expensive. Contingent valuation remains an important tool (21.8% of the total) together with market prices (15.3%).

Of the studies, 36.8% try to value all the ES at one or more sites, though usually, cultural values are not considered. Among the classes of ES, regulating ES are the most studied, in line with the fact that they are usually the most valuable.

A monetary or energy valuation of ES was performed in only 57.2% of the studies, probably due to the fact that in most application of ES studies, a valuation is not necessary. GIS is the most used software tool, either only for the use of maps (of land use, specific ES, monetary values) or for the spatial interpolation of ES value using geostatistical tools.

4.2. ES Provided by Intermittent Karst Wetlands

Turloughs and poljes, as intermittent wetlands, show characteristics of inland wetlands and grasslands and as such, should show values of ES characteristics of these ecosystems, with possible peculiarities. It should be noted that Costanza et al. (2014) [22] estimated the average ES value for inland wetlands at 140,174 USD/ha/year, but no comprehensive ES evaluation of an intermittent karst wetland appears to have been carried out to date.

It was shown that very limited studies deal with the ES of these intermittent wetlands. The provision of unique habitats for both flora and fauna is a key ES provided by intermittent karst wetlands. Waldren et al. (2015) [66] mapped 28 different habitats in the turloughs they surveyed, which range from grassland to semi-terrestrial habitats, reed beds, fen wetland, and open water. From a habitat point of view, turloughs can be distinguished as sedge- or grass and forb-dominated. The former group is dominated by *Carex panicaea* (Class *Scheuchzerio-Caricetea fuscae*), while the latter is characterised by a *Potentilla anserina* sward (Class *Plantaginetea majoris*) [66]. The habitats are strongly linked to the fluctuation of water levels because historically they have been impacted by artificial drainage, damming and peat extraction. Similar to poljes, alterations of rainfall patterns and temperatures due to climate change, could have a significant impact on them.

Intermittent wetlands host several animal, plant, and fungal species, though none are exclusive to this habitat type. Many intermittent wetlands are important for habitat preservation, being important sites for birds, insects, amphibians and also hosting important plant species. Rahasane turlough in County Galway, for example, was defined as the most important turlough for birds in Ireland [68]. Common visitors are great white-fronted geese (*Anser albifrons flavirostris*), whooper swans (*Cygnus cygnus*), wigeon (*Mareca sp.*), teal (*Anas sp.*), and waders (order *Charadriiformes*) in winter. In general, turloughs and poljes have a combination of wetland and grassland (with some forest patches) ES; therefore, the assessment should be based on existing methods for those habitats, adapted to their peculiar ecohydrology. Pestersko and Livanjsko polje in Slovenia are both Ramsar sites. Pestersko polje developed as a lake and contains peatlands (peat is harvested at this site and it is a major conservation threat). It is important for several threatened species, such as the black tern (*Chlidonias niger*), the glossy ibis (*Plegadis falcinellus*), the aquatic warbler (*Acrocephalus paludicola*), the corncrake (*Crex crex*), and the thick shelled river mussel (*Unio crassus*).

Flood risk attenuation is expected to be significant for intermittent wetlands, as it tends to be greater in wetlands with substantial water level fluctuations and in wetlands with intermittent, temporary, semi-temporary hydrologic regimes [69]. It will also depend on the specific position of the turlough/polje in the catchment and on its hydrological regime. Turloughs have very different hydrographs, with some of them showing very flashy responses, while others exhibiting a slower, more damped seasonal behaviour [63].

In very extreme weather conditions, they can cause groundwater flooding to nearby houses, as shown by the Gort lowland karst area in south Galway, Ireland. Recent modelling of a network of 15 turloughs in this area linked to a proposed flood alleviation scheme by Morrissey et al. (2020) [70], who found that should the optimal flood alleviation schemes be implemented, there would be an impact on turlough ecosystems, though the further elevated areas might actually benefit from the flooding reduction that killed trees in past flooding events, therefore underscoring the complexity of flooding in such areas. In addition, further modelling [71], has shown that climate change is expected to exacerbate flood risk through increased winter rainfall.

Some of the turloughs have peaty soils and peat accumulating mainly in fen habitats, therefore providing climate regulation through carbon sequestration. Grassland soils in Europe are estimated to sequester carbon, though these estimates (between 1 and 45 Tg y^{-1}, [50], 101 Tg y^{-1}, [72]) are associated with large standard deviations, which could potentially mean that some of them are carbon emitters. Improved grazing practices also lead to carbon sequestration of about 0.3 Mg C ha^{-1} yr^{-1} [73]. Improved management practices could lead to the sequestration of additional 0.2–0.8 GT CO_2 yr^{-1} in grassland soils globally by 2030 [74].

The provision of food for humans during the flooded time of the year in such karst intermittent lakes is limited to forage of berries, as there are generally no fish present in them. Hunting of wildfowl is allowed outside Special Areas of Conservation (SACs) and Wildfowl Sanctuaries [75]. In the summer period, most turloughs are grazed and their central area is used as commonage, [76]. They can be an important source of water for grazing animals and therefore linked to food provision too. The grasslands in the empty turloughs are widely used as pasture for cattle and sheep, therefore providing an important service to the meat and dairy industry. The question still remains as to their water purification service (whether they are a source or sink of nutrients). McCormack et al. [67] found that nutrient loss processes were occurring within turloughs. For nitrogen, denitrification happens mainly during flooded periods, while for phosphorus, sedimentation and subsequent soil deposition is the main process. According to this study, turloughs therefore appear to be a net sink of nutrients.

Turloughs and poljes are also culturally important for local people; since they represent a feature virtually unique to Ireland, they are important for education. This can be seen for example at Moate turlough [77], where a heritage park is present, at lough Gealain, part of the Burren National Park and at Coole/Garryland, home to Lady Gregory, dramatist and folklorist and visited by poets such as William Butler Yeats, George Bernard Shaw, John Millington Synge and Sean O' Casey [78]. Some of them also have recreational and touristic value, being part of natural parks (e.g., Lough Gealain, County Clare).

Several poljes are famous tourist destinations too. Both the already mentioned Perstersko and Livanjsko are popular destinations. Another relevant one is the Lonjsko polje in Croatia, a Ramsar site. This is one of the finest and largest wetland areas in the Danube River Basin. It includes peatlands, oxbow lakes, and marshy, inundated forests, [79,80]. Important is also the Popovo polje, in southern Bosnia, near the Adriatic coast, as the Trebišnjica river, which flows through the polje, is the largest in the world. The Vjetrenica cave system, located to the west/south-western parts of the valley is also notable and significant and peculiar are also the ponor (sink or swallow holes) mills it contains that harnessing the hydropower of water entering the ponor, can power flour mills, mill-stamps, and be used for irrigation [81].

The nature and magnitude of the ES of these intermittent wetlands therefore strongly depends on the specific characteristics and will vary throughout the year. Despite many of these intermittent wetlands having a relatively small size, they provide key services [82]. According to de Groot et al. (2012) [8], as inland wetlands, their most valuable ES should be the regulation of water flows and water purification. Future ES valuations should focus on integrating different methodologies of valuation. Contingent valuation could be used for example and compared with ad-hoc models to describe the single ES. The most used tools such as InVEST [83] seem of a more limited scope as turloughs and poljes have very characteristic ecohydrological functioning. Single InVEST modules such as the carbon sequestration and the habitat value ones might be tested. An additional problem with these tools is that they were devised for medium/large scale areas, while many turloughs are small in size. Benefit transfer might be attempted from other wetlands or grasslands (for the dry phase). Single ES such as climate regulation should be estimated for the whole of Ireland, as at the moment they do not make a part of the budget at a European level.

4.3. Overall Perspectives on the Valuation of Wetland ES

It is clear that the total benefits of wetlands go beyond the mere short-term monetary value of services that can be traded in a market. Some researchers highlighted the risk of the commodification of ES, which reproduces the market logic and structures and applying them to ecosystems [10]. Nonetheless, such studies surely contributed to raising the attention to the importance of such services. Several specific problems with the monetisation of ES can be highlighted. First of all, assigning values to different natural processes is linked to an anthropocentric idea rather than on physical processes. Second, the most valuable services provided by wetlands have no commercial value. Additionally, valuations will depend on complex relationships between the type of wetlands and their landscape position with respect to surrounding population and marginal areas. Equally, their valuation (particularly from a monetary perspective) may differ between different countries based on the different value systems. Lastly, a comparison of economic short-term gains with long-term value is often not appropriate.

Ghermandi et al. (2010) [84] found that relatively little information is available on the valuation of regulating services and supporting services and they found no valuations for provision of genetic materials, climate regulation, erosion protection, spiritual and educational values, and support of pollinators. Similarly, Barbier (2011) [85] found that for several important ES, no or few studies exist. Though several studies have been published in the last decade on wetland ES, gaps still need to be filled. Barbier (2019) [54], reviewing 80 valuations of coastal wetland ES, recognises that there must be more attention to a wider range of goods and services that geographical coverage has to be improved and that spatial patterns must be taken in more consideration in ES studies. While spatial patterns of ES are an aspect that has been investigated recently, few studies investigated how land-use change affects ecological changes and in turn ES [86]. As for the ES lacking valuations, Harrison et al. (2010) [87] highlighted that evidence should be gathered for the provisioning of biochemical/natural medicines and ornamental resources and the regulating services of seed dispersal, pest/disease regulation an invasion resistance in all ecosystems. Climate regulation studies were found to be lacking for forests and peatland, and pollination in agro-ecosystems, mountains and forests.

At a European level, several ES (like nutrient retention, water provision, cultural services) are not accounted in the relevant EU programmes across all habitat types (MAES [21,88]). Hence, there is also a need for more primary valuation studies of regulating ES of wetlands and for filling gaps in the geographic distribution of such studies [33].

In general, as recognised by recent studies by Costanza et al. [89,90], despite the progress made in ES, there is still a need for a less linear and much more integrated model connecting natural and human systems, and this is true for wetland ES quantification and valuation. New approaches to data are needed, such as the use of remote sensing at multiple scales and citizen science, to reflect real-time changes in stocks and flows of ES.

As highlighted earlier, some categories of wetland, such as for example depressional wetlands (and among those ephemeral karst lakes (turloughs/poljes)) have received less attention and therefore require studies on ES quantification/valuation. For these ecosystems, regulating services such as flood risk attenuation are expected to be particularly valuable.

Finally, the use of GIS tools and Big Data could bring forth a much-needed geographic and methodological homogenisation in the quantification and valuation of the ES of wetlands.

5. Conclusions

Wetlands worldwide provide a wide range and a significant number of ES. More research is needed to establish the value of the single ES, especially at the local scale and for specific classes of wetlands, such as ephemeral karst lakes. For these kinds of wetlands, bespoke methods of quantification should be used, to take into consideration their size and the characteristic hydroecology. Local studies should be carried out to have field-based quantification of ES and different valuation methods should be compared. Indices could then be developed to allow for benefit transfer functions to be developed.

Some of the wetlands at northern latitudes have been estimated to have some of the highest values in ES among wetlands. After centuries of development and exploitation their true value is finally beginning to be recognised. The ES framework can provide a useful contribution to such considerations and policy formation, for example, when assessing the potential consequences of climate change.

Several ES have either been poorly studied or not studied at all for some categories of wetlands (such as the intermittent karst lakes) and therefore much more research is required to ensure that a much more comprehensive picture of the ES provided by wetlands worldwide is developed.

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Abbreviations

ES	Ecosystem Services
PES	Payments for Ecosystem Services
MEA	Millennium Ecosystem Assessment
CICES	Common International Classification for Ecosystem Services
TEEB	The Economics of Ecosystems and Biodiversity
UKNEA	The UK National Ecosystem Assessment
MAES	Mapping of Ecosystems and their Services
TEV	Total Economic Value
HPM	Hedonic Pricing Method
CV	Contingent Valuation
DE	Defence Expenditures
MA	Market Analysis
PF	Production Function
RC	Replacement/Restoration Costs
TC	Travel Cost
WEI	Water Exploitation Index
GIS	Geographic Information Systems
GWDTE	Groundwater Dependent Terrestrial Ecosystems
WFD	Water Framework Directive
EU	European Union
SAC	Special Area of Conservation
WTP	Willingness To Pay
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs

Appendix A

Table A1. Description of software tools used in ES valuation and shown in Figure 9. Explanation of acronyms and description.

Software Tool Acronym	Description	Applications
GIS	Geographic Information Systems	Mapping of ES. The most used are ArcGIS and QGIS
inVEST	Integrated Valuation of Ecosystem Services and Tradeoffs	Modular open source ecosystem service mapping and valuation models accessed through GIS [83]
SWAT	Soil and Water Assessment Tool	Small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change [91]
TESSA	Toolkit for Ecosystem Service Site-Based Assessment	PDF manual that provides accessible guidance and low-cost methods to evaluate the benefits people receive from nature at particular sites [92]
SolVES	Social Values for Ecosystem Services	ArcGIS toolbar for mapping social values for ES based on survey data or value transfer [93]
RUSLE	Revised Universal Soil Loss Equation	Erosion models used to estimate erosion from rainfall and overland flow [94]
CASA	Carnegie-Ames-Stanford Approach	Model based on the Light Use Efficiency (LUE) index

Table A1. *Cont.*

Software Tool Acronym	Description	Applications
DICE	Climate sensitivity of disturbance regimes and implications for forest ecosystem management	Model of sensitivity of forests to climate change
Hydrus		Hydrus simulates the one-, two- or three–dimensional movement of water, heat and multiple solutes in variably saturated media [95]
WAterworld		Tool that simulates the effects of policies on water and land [96]
HEA	Habitat Equivalency Analysis	Calculates the habitat size necessary to provide similar ES to those lost because of a plan [97]
LUCI	Land Use Capability Indicator	Open source GIS toolbox to map areas providing services and potential gain or loss of services under management scenarios [98]
Wettrans		Flow path-oriented web-based decision tool [99]
Bayesian analysis		Bayesian Networks can capture the relationship between tangible and intangible ES [100]
EcoAim		Proprietary tool for mapping ES and stakeholder preferences. It was developed to quantify five ES—vista aesthetics, landscape aesthetics, recreational opportunities, habitat provisioning for biodiversity and nutrient sequestration [101]
WAM	Wetland Assessment Model	Based on wetland value indicators and scoring criteria and based on expert knowledge
RWEQ	Revised Wind Erosion Equation	Used to estimate wind erosion [102]

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