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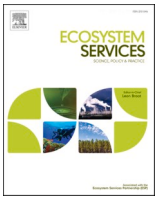

Short Communication

Accounting for the value of ecosystem services of floodplains in Germany – National studies matter

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ABSTRACT

Floodplains are among the most valuable and most threatened ecosystems. Worldwide, degradation and restoration are taking place at the same time. In Germany, more than 90% of the floodplains are degraded, and restoration is carried out through several projects because the benefits floodplains provide are already known, though not yet quantified. Decision makers and politicians are still in need of economic values, e.g. for cost-benefit analyses. Therefore, we sought to conduct a review of ecosystem services (ES) in German floodplains to provide a policy-relevant summary of estimated ES valuation efforts. While there are many reviews and *meta*-analyses in the scientific literature, they use data on an international scale. While international synthesis has value, assuming internationally synthesized values can be used to represent local or national values can be problematic due to unknowable transfer errors. In focusing on only German studies, we found that there were not enough data available for a German floodplain *meta*-analysis or review that could produce locally policy-relevant information. Only five floodplain ES were investigated in 14 studies between the years 2000 and 2021 within Germany, which provided enough data and study descriptions for a comparison of homogenized values. In total, ES of more than 4000 €^{2015}/ha/yr were provided for German floodplains, which is much lower than global reviews, however, because of which and how ES are considered. There is an urgent need for representative studies examining how ecosystem values are generated and perceived to provide locally relevant information. There is a strong focus within *meta*-analytical studies on the international scale to overcome the data scarcity issue at the expense of local relevance. This is a fundamental trade-off that must be acknowledged.

1. Introduction

The importance of floodplains is well known, both with respect for their nature as hotspots of biodiversity and ecological functioning and also ethnocentrically through e.g., flood risk management or recreational benefits (EEA, 2016; IPCC, 2022). Despite this importance, floodplains have become heavily degraded and are one of the most threatened ecosystems globally (de Groot et al., 2012), as land has been converted from its natural state. Germany is a typical example of floodplain loss and degradation that started centuries ago, where 90 % of floodplains (Koenzen and Günther-Diringer, 2021)have currently been lost behind dikes and transferred to non-natural land-use. Non-natural land-use meets tangible human needs, while floodplains tend to provide intangible or indirect benefits (Bellver-Domingo et al., 2016; de Groot et al., 2012; Fisher et al., 2009). The benefits provided by floodplains are known as ecosystem services (ES), and are significant with a global estimated value of nearly $ 26,000/ha/yr (Costanza et al., 2014). The concept of ES helps make the multifunctionality of floodplains visible by categorizing benefits which can then have monetary values associated with them. This process allows the benefits of intact floodplains to be more easily considered, understood, and digested by a range of different user groups. This demonstration of value (even if anthropogenic) is an important informational starting point. Then robust ES monetary values can serve as inputs for cost-benefit analyses (CBA) that underpin many policy frameworks, e.g. the national Blue Belt program(Heyden and Natho, 2022).

Therefore, a great deal of research into anthropocentric ES values has been conducted, globally (e.g. Brander et al., 2006; Brouwer et al., 1999; Costanza et al., 2014; Ghermandi et al., 2010; Natural Capital Germany – TEEB DE, 2018; Perosa et al., 2021; Woodward and Wui, 2001). Often these studies produce singular values for the ES provided, aggregating estimated monetary values across a range of socio-ecological contexts.

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The implementation of TEEB (the economics of ecosystems and biodiversity) in Germany has resulted in a comprehensive review (Natural Capital Germany – TEEB DE, 2018) of existing efforts and projects involving German floodplains (BfN, 2009; BMU and BfN, 2015; Scholz et al., 2012), but no direct studies have been conducted. Another later effort by a large scientific consortium to map and compare ES (RESI: river ecosystem service index) did not report transferable monetary values, but rather provided support for practitioners in deciding which ES to focus on when designing floodplain policy (Hornung et al., 2019; Podschun et al., 2018).

However, while international studies and global values have merit in reinforcing floodplain importance, they lose usefulness when employed as an informational input at local, regional, or national levels. This is because ES value is anthropogenic, and differences according to location, floodplain status (e.g., intact floodplains generate more ES than degraded floodplains), socio-economic context, subjective value perceptions, etc. mean that floodplain value is not fixed and requires further studies that are time consuming, and potentially expensive.

One compromise is to use value transfer to aggregate existing information. A simple value transfer (i.e., directly using another study's value, or the mean value of several studies) is simple yet inaccurate due to "transfer errors." Transfer errors occur because values taken from outside a particular context can significantly differ from the true value and thus generate inaccurate information (Brander et al., 2006). However, inaccuracy can be reduced through the use of transfer-equations, which use multiple studies and their input factors, to adapt an estimated ES value to the policy, environmental, and social context in which it will be used (Newbold et al., 2018).

In this context, we sought to review the literature on ES of German floodplains to conduct a *meta*-analysis and establish a transfer equation for the total floodplain value that could be used to generate monetary ES values for specific floodplains that can account for more local nuances and factors, rather than assuming that all floodplains in Germany provide the same value per hectare, by exploiting the variability among published works. In doing so, however, we identified a scarcity of studies, which prevented the use of *meta*-analytic approaches and a robust transfer equation for German floodplains. Instead, we communicate the lack of existing research and its potential limitations.

2. Methods

2.1. Systematic literature search

We consider floodplains as ecotones comprising aquatic and terrestrial ecosystems of rivers and adjacent areas that are influenced by frequent inundation, following the definition given by Naiman and Décamps (1997). Therefore, floodplains and riparian zones are treated as the same but with varying land cover.

We employed the following, pre-defined **inclusion criteria**: a) studies from the years 2000 to October 2021 b) involving German observations c) examining floodplain relevant ecosystems, e.g., riparian wetlands, riparian forests, floodplains, wetlands, rivers, etc. and d) reporting monetary values convertible to the unit €/ha/yr. These conditions were used to find the studies that fit our focus on the German context, even if not fully within Germany.

Table 1 provides a summary of the database and the sparse relevant literature. Additionally, a further search was conducted using the Ecosystem Services Valuation Database (Brander et al., 2023) using the "Germany" and "Floodplain" tags. However, no additional studies were added to our database. Each monetary value used represents 1 data point.

2.2. Data processing

Monetary ES values were reported in very different formats, e.g., €/year, €/ha/year, €/household/year or even €/trip/year. To account for this, reported information on the study area, relevant users or household/population density was used to recalculate the monetary value to €/ha/year (see also Ghermandi et al. (2010)) for consistency across studies. In cases where data were missing, similar studies were used to deduce the missing information (e.g., related study by the same author) or authors were contacted directly.

All prices were converted into 2015 values using the consumer price index baseline. Further study-specific, site-specific, and context-specific variables (Perosa et al., 2021) were extracted from the studies (Table 2), including the valuation method, the year of estimation, the spatial scale, and the ES category according to TEEB.

Table 1
Summary of a literature search from September 2021; * databases were constructed via systematic literature reviews – where the content was outside Germany only studies considering German floodplains were selected.

Databases*	Systematic literature review	Result:
van der Ploeg and de Groot (2010)	15 rounds in Clarivate Web of Science with different combinations of the search terms (topics) floodplain, flood plain, wetland, water, economic value, recreational value, replacement value, economic valuation, flood control, Europe, ecosystem. "Germany" was used in the refinement option for the region	**1000** paper titles checked
Förster et al. (2019)		**85** papers read
Perosa et al. (2021)		**27** papers/reports included in this study **14** studies with 36 data points that could be considered for statistical analysis

3. Results

Fourteen studies with 36 data points were considered (cf. Appendix 2), of which 13 data points were collected along the Elbe River while 9 data points considered all of Germany, and the remaining 14 focused on a range of rivers (e.g. the Weser, Fulda, Werra, Spree etc.) or wider river basins (e.g. the Danube, Rhine, etc.). 57 % of the database was locally focused, while 17 % was nationally focused. The remaining 26 % was generated on an unclear scale between the local and national scales, and areal extent varied between 3 ha and assumptions of 35,800,000 ha due to unclear reporting. In terms of study age, 25 % of the estimates were from studies conducted before 2002, 50 % between 2010 and 2014, and 25 % between 2015 and 2018. Although we focused on floodplains, only 68 % of the studies were self-defined as studying floodplains. While 15 % classified themselves as "rivers and water," 11 % were self-stated studies on "forests" and 6 % were self-classified as "wetlands." Five ES from three ecosystem categories could be considered (Fig. 1), whereas provisioning ES were not reported at all. Habitat was approached with 3

Table 2
Database of descriptive statistics.

Group	Name	Type	Description & source
dependent	adjusted ES value [€^{2015}/ha/yr]	continuous	various sources, see Appendix 1
study-specific	valuation method	categorical	Classification according to TEEB
	year of estimation	continuous	Number of years since 2021
	ES category	categorical	Classification according to TEEB into four ES classes: provisioning, regulating, habitat, and cultural
	ES	categorical	original name from study
site-specific	river	categorical	name of analyses' rivers
	area [ha]	continuous	The size of the floodplain considered
	spatial scale	categorical	local/national
	ecosystem	categorical	aggregated original names end up as floodplain, forest, and wetland, as well as river and floodplain

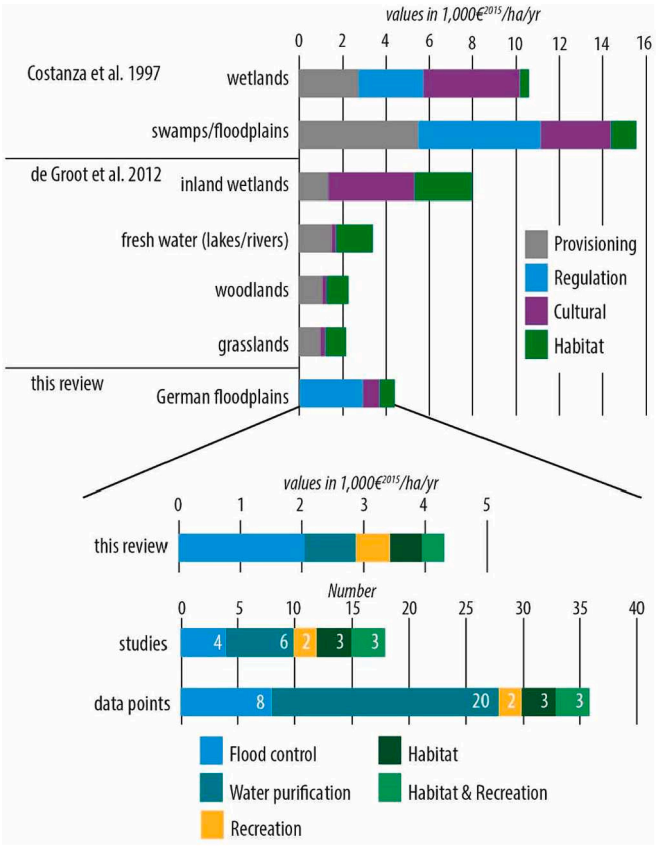

Fig. 1. Number of monetary values of each ecosystem service category (blue = regulating, yellow = cultural, green = habitat ES).

data points from 3 studies, whereas water purification was most often reported (20 data points from 6 studies) in the category of regulating ES considering nitrogen a nutrient to be removed by either a waste water treatment plant or an agricultural scenario, or nitrogen and phosphorus if no separation was possible, but not phosphorus alone (Born et al., 2012; Bräuer and Margraf, 2004; Grossmann et al., 2010; Horbat et al., 2016; Meyerhoff and Dehnhardt, 2007; Wüstemann et al., 2014). Further regulating ES were flood protection and water retention which we combined as flood control, though valued via different approaches. Water retention used the value of technical substitutes for retaining an equal amount of water (Barth and Doell, 2016; Mehl et al., 2018), while flood protection use the value of damages avoided (Barth and Doell, 2016; de Kok and Grossmann, 2010; Horbat et al., 2016). Recreation as a cultural ES was represented by 2 data points,(Fig. 1), while there were 3 data points where recreation and habitat ES were not separated (Horbat et al., 2016; Riepe et al., 2019; Symmank et al., 2020).

Monetary values are shown for ES categories (Fig. 1) and each ES

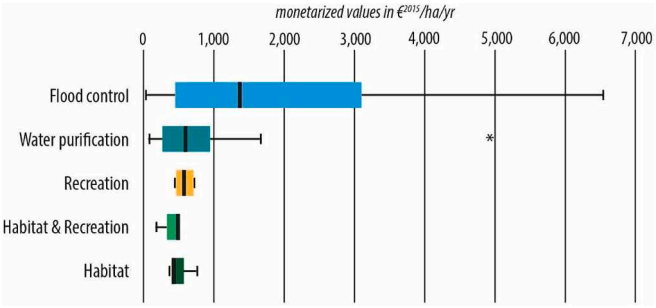

Fig. 2. Overview of standardized monetary values for ES as per-hectare value estimates.

(Fig. 2). In fact, the values are distributed over a wide span, with an average of 1,028 €^{2015}/ha/yr and a median of 603 €^{2015}/ha/yr. Moreover, there is still a great deal of variation across the monetary values for specific ES categories. For instance, regulating ES is associated with an average value of 1,185 €^{2015}/ha/yr, but the averages of both the considered regulating ES of flood control (2,055 €^{2015}/ha/yr) and water purification (877 €^{2015}/ha/yr) differ. Furthermore, the different approaches toward the ES flood control reach values of 2,740 and 1,370 €^{2015}/ha/yr on average. Only habitat averages 511 €^{2015}/ha/yr, while recreation is valued at 574 €^{2015}/ha/yr and habitat and recreation at 378 €^{2015}/ha/yr (Fig. 2).

By simply summing up averages of all ES categories, a tentative but highly uncertain average value of the considered ES in floodplains adds up to 4,355 €^{2015}/ha/yr (Fig. 1). Flood control contributes almost 50 % of the monetary value. The combination of ES recreation and habitat collectively account for 33.6 %.

About 78 % of the data points (53 % of studies) use a cost-based approach to estimate a value, while the remaining 22 % of data points (47 % of studies) are based on willingness to pay. We find that ES valued in cost-based approaches compared to willingness-to-pay contribute far more than the ES value.

4. Discussion

4.1. Challenges to overcome

In our attempt to review the value of ES in floodplains, we faced various challenges. There were issues leading to difficulties establishing a representative and consistent monetary value for ES of floodplains in Germany due to.

- the limited number of studies (only 14), which meant that it was not possible to overcome inherent uncertainty in the study outcomes, e.g., values were estimated to be between 34 and 6,542 €^{2015}/ha/yr
- the differing numbers of ES considered in the studies (5, in comparison to Costanza et al. (1997) and de Groot et al. (2012) with at least 10 ES),
- interacting, doubly counted, or competing ES that led to uncertainties around how to aggregate the values of the different ES provided by multifunctional floodplains (Dade et al., 2019; de Groot et al., 2002; King et al., 2015; Lawson et al., 2018; Onaindia et al., 2013). For instance, should we treat the total values as the linear sum of its constituent elements, or is it a more complex process?
- the limited representativeness of rivers and case studies approached by the literature (e.g. flood protection along a river in remote areas leads to smaller flood control ES values than in a city), and
- methodological differences in considering functions and monetarization approaches as well as different fundamental research objectives

4.2. Representativeness

The first challenge involves the representativeness of the spatial extent of the current research. Currently, there is a strong focus on the Elbe compared to other rivers. Given the natural variation across floodplains, it is unlikely that a value estimated for only the Elbe floodplains will be transferable to other rivers. The current literature can be considered to follow a scenario approach. For example, Riepe et al. (2019), Symmank et al. (2020), and Rayanov et al. (2018) all consider completely different spatial scales as well as different foci and levels of human involvement. This means that the studies are created to understand value in specific locations, which generates individually unrepresentative values, while we require studies in a wider range of areas.

4.3. Methodological approaches and the selection of ES

Secondly, methodological differences were observed, which makes it difficult to compare or sum up the individual values. This is due to.

a) applying different costs to the same kind of substitution (compare Mehl et al. (2018) and Barth and Doell (2016)).
b) applying different calculation schemes for the same ES (compare different approaches in Dehnhardt (2002) or Meyerhoff and Dehnhardt (2007) and Schulz-Zunkel et al. (2012) as input data for Born et al. (2012), or different perspectives of flood control as presented in Barth and Doell (2016) or Mehl et al. (2018)).

Furthermore, for a representative floodplain ES value, we need to value the multifunctionality of ES floodplains rather than only attributes of their multifunctionality. For instance, most floodplains within Germany have agriculture as their main form of land use (Natho, 2021). However, the literature tends to investigate biodiversity, recreation, and nutrient retention, using a small set of evaluation methods compared to the review of Cheng et al. (2019). This produces an incomplete picture of the floodplain's value and can lead to conflicts as a result of how researchers select which ES to value and which ones are prioritized on the ground.

The five ES considered in this study present the most popular ES in Germany. The two regulating ES have shifted into the political focus as technical measures have not been sufficiently effective. For water purification, diffuse emissions are still a problem today as their reduction is not possible by technical means. For flood control, polders are effective measures but are extremely expensive and cannot replace intact floodplains, which are now protected habitats and must not be degraded. To increase flood protection and water purification nature based solutions are discussed also within the framework of many (inter-)national directives and strategies (Heyden and Natho, 2022), as is the case for natural flood management (Thaler et al., 2023). Recreation and habitat are also presented as a fifth artificial ES.

4.4. Perception of ES and assessing their value(s)

Understanding how humans perceive ES or ecosystem functions and then assess value, of both individual elements and the entire portfolio of different ES across multiple different users, is essential. Two exemplary questions are posed: I) Can ES values be summed up independently, or are there synergies that create the overall value different from the sum of individual values? II) How can place-related factors change the perceived value of environmental outcomes? Examples are in the US, where wetlands have been considered more valuable if the high biodiversity is in the form of bird rather than plant species (Kandolf and Pinto 2018) or in Germany, where there have been differences among various groups of people (Meyerhoff and Dehnhardt, 2007; Rayanov et al., 2018; Symmank et al., 2020).An element of this can be eased by using a *meta*-analysis to develop a transfer equation (Brander et al., 2006; Costanza et al., 2014) that uses the differences in observed studies and their study areas as variables to estimate ES values for non-studied areas. However, the development of such an equation requires a larger sample site and a greater consistency than what we could obtain for Germany. While a minimum number of studies is not possible to determine a priori, a common reporting framework could be developed.

Additionally, the literature assumes in effect that the values are static, while the theory underpinning economic valuation is based on subjective constructs of value and can change over time. Understanding how these subjective values can change or remain stable over time is also essential. Furthermore, as noted above, not all floodplains generate equal amounts of ES, which must also be accounted for ideally.

5. Conclusions

Floodplains are greatly valuable for both nature and humans, as can be seen in the monetary values associated with their ES. However, the process of estimating the monetary value provided by floodplain ES is a complex process, in which it is quite likely that there will be no one-size-fits-all value that is reasonable. For this reason, we need a more concentrated effort focusing on the national and regional completeness of studies to produce locally policy-relevant values. We see this as a relevant area of work for German floodplains, as only 14 studies could be identified despite the socio-ecological importance of floodplains. This is a potential limitation, because for science to inform policy in this area datasets are extended outside of the national context by including a range of extra-national studies in the meta analyses and reviews, which strengthens the potential problem of transfer errors and dilutes the immediate usefulness of the value. This creates a fundamental trade-off between the local transfer validity of the results and the ability to create robust transfer values or understandings of the process that generates ES value. Moreover, by extending the literature base, we can become less reliant on using a mean value as representative but build toward value-transfer equations that are able to use the nuances of the scientific literature to localize the ES values more accurately.

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.

Data availability

Applied data is presented in the appendix.

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