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Nabila Arfaoui - Amandine Gnonlonfin

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The economic value of NBS restoration measures and their benefits in a river basin context: A meta-analysis regression

Nabila Arfaoui - University Catholic of Lyon, ESDES- -10 place des Archives, 69002 Lyon, France, narfaoui@univ-catholyon.fr

Amandine Gnonlonfin – IMREDD- 61-63 Avenue Simone Veil, 06200 Nice, France, a.gnonlonfin@gmail.com

Abstract

The study collects original monetary estimates for Nature Based Solutions (NBS) and benefits, with restoration approach in a basin context. A database of 187 monetary estimates is constructed to perform the first meta-analysis, which will assess how individuals value the NBS restoration measures and their primary and co-benefits. Demonstrating the monetary value of these benefits should improve decision-making in promoting the adoption of NBS and lead to greater protection of ecosystems. We find that individuals value, in particular, global climate regulation, local environmental regulation, recreational activities, and habitat and biodiversity benefits. We find also that NBS measures aimed at floodplains and river streams are more highly valued. The results of this study suggest that the Willingness-to-pay (WTP) is weakly influenced by the methodological variables. We found that primary studies using the contingent valuation method report higher WTP compared to those using choice experiment method. Moreover, the payment modes (local-tax, national-tax, donation and water bill) and econometric estimation methods (parametric, semi-parametric and non-parametric) have only a marginal effect. Indeed most of these variables are insignificant with the exception of local-tax, water-bill and parametric variables which are significantly negative. Survey modes (internet, face to face and mix) are never significant. Finally, the coefficients of America and Europe are significantly positive, indicating that the monetary value of river restoration is higher in countries in these areas.

Keys words: Nature Based Solution (NBS), Meta-Analysis, Ecosystem services, Willingness To Pay.

JEL Codes: Q51, Q57, O13

Introduction

Over the years, river ecosystems have dried up and/or been damned to allow land development. In periods of heavy rainfall, there may be costly and even catastrophic flood risks. On the other hand, high temperatures over a long period lead to drought risks which are equally damaging. The ongoing climate change is highlighting the need to resort to Nature Based Solutions (NBS) to reduce flood and drought risks and build a resilient environment. Since the early 2000s, various NBS have been proposed by practitioners and policies, in relation to sustainable exploitation of nature to address societal challenges and provide benefits and co-benefits (Eggermont et al., 2015). NBS group a variety of measures such as natural systems agriculture, natural solutions, ecosystem-based adaptation and mitigation, ecosystem services, green or blue infrastructures, ecological engineering or catchment systems engineering, natural capital, etc. (Eggermont et al., 2015; Nesshöver et al., 2017). (Nesshöver et al., 2017)In contrast to alternative solutions which "are designed and managed to be as simple, replicable and predictable as possible" (Eggermont et al., 2015, p. 243), NBS are complex solutions to addressing complex problems of socio-ecological systems resilience, climate change or sustainability goals. Moreover, Albert et al. (2019) put it that the provision of co-benefits is the key advantage of NBS over the alternatives solutions. In this context, scientific scholarships have an important role to better understanding this new concept and their co-benefits.

Indeed, policy makers need a reliable evaluation of the impacts of NBS to inform their decisions. This is an essential step for scaling up implementation of NBS. However, evaluation of the benefits of NBS is not straightforward. First, these benefits are several. According to Nesshöver et al. (2017), involving stakeholders in the design of NBS brings various benefits. It provides: "substantive" benefits since as stakeholders' perspectives, conditions and knowledge inform and improve planning; "instrumental" benefits since the process is better understood by and is more acceptable to stakeholder, and, hence, better supported by them; and "normative" benefits since stakeholder involvement increases the legitimacy of the process and generally supports democracy. NBS also reduce risks and increase resilience through the provision of additional Ecosystem Services (ES), and provides societal advantages including adaptions to climate change, food security, improved human health and economic and social development (Cohen-Shacham et al., 2016). Hence, NBS have a primary benefit (targeted benefit - e.g., water risk reduction) and other benefits or co-benefits.

Second, evaluation of the benefits of NBS must take account of people's lexicographic preferences, which has led some authors to advocate a value pluralism perspective on these benefits (Arias-Arévalo et al, 2018; Gómez-Baggethun & Martín-López, 2015; O'Neill & Spash, 2000). However, others advocate economic valuation as the pragmatic choice (Gómez-Baggethun & Martín-López, 2015). In addition, from the perspective of conflicting land use alternatives and limited public financial resources, economic valuations need to demonstrate the importance of NBS.

Third, despite the practical advantages of an economic valuation, most NBS benefits are not tradeable in the market due to the public good characteristics of many ES, governance benefits and societal advantages. This highlights the need for different methodologies for the evaluation of the primary benefit and co-benefits induced by NBS (De Groot et al., 2012; Grizzettie et al., 2016). Since this is costly in terms of competences, time and money, there is increased interest among policy makers and academics in transferring the value from existing evaluations to the implementation of new and expensive primary surveys (Brander et al., 2012; Chaikumbung et al., 2016). This would allow evaluation of a wider the set of the benefits of NBS, at lower cost.

The literature includes numerous examples of meta-analyses and transfer function benefits, conducted to assess the economic value of ecosystems. For example, Chaikumbung et al. (2016) report 17 valuation meta analyses for wetlands and Barrio and Loureiro (2010) report 4 forest land studies. Pettinotti et al. (2018) conduct meta-analyses of other types of ecosystems (coral reefs, mangroves, coastal and marine ecosystems) and propose an analysis for water related ES in Africa. Two river restoration studies in urban and rural areas have been conducted (Brouwer and Sheremet, 2017; Bergstrom et al., 2017) and four studies focus on green infrastructures in urban areas (Bockarjova & Botzen, 2017; Bockarjova et al., 2018; Brander & Koetse, 2011; Perino et al., 2014). However, use of these transfer value functions to evaluate NBS is not relevant because none of these studies specifies the type of NBS evaluated in the primary studies. It is important to consider similar NBSs to achieve consistency (Chaikumbung et al., 2016) and reduce generalization errors in the Meta-Analysis Regressions (MRA) (Rosenberger & Stanley, 2006). To our knowledge, only Bockarjova and Botzen (2017) and Bockarjova et al. (2018) studied NBS specifically in urban areas. These authors study the main factors determining NBS values in an urban context: for example, socio-economic characteristics, location characteristics, methodology used to estimate original values, and NBS-specific characteristics. To our knowledge, none of the published research is focused on NBS for river restoration in a river basin context. We try to fill this gap by: (i) identifying and classifying NBS restoration measures in primary studies; (ii) analysing how individuals value these measures and their benefits; (iii) assessing how individuals assign particular importance to projects giving more room to the nature; and (iv) considering a large number of NBS benefits in order to include a wider set of ES.

The objective of this paper is to conduct a MRA to derive value functions to evaluate different NBS restoration measures and their benefits. More specifically, we analyse and identify the determinants of the Willingness To Pay (WTP) for NBS, based on primary studies that use stated preferences such as Contingent Valuation Method (CVM) and Choice Experiment (CE). We build a dataset of 187 observations from 52 studies, conducted in 20 countries in America, Europe and Asia-Oceania, which evaluate the impacts of restoration projects (real or hypothetical) on provision of ES since the 1990s.

The paper is organized as follows. Section 1 discusses the analytical framework. Section 2 describes the data selection, standardization and coding to perform the MRA. Section 3 presents and analyses the results of MRA models and Section 4 discusses the findings and offers some conclusions.

1 The analytical framework

In this section, we outline our proposed MRA framework, used to estimate the economic value of the impacts of NBS on changes to the provision of ES in a river basin context.

1.1 Scoping NBS and their benefits

Adopting a value transfer approach to a valuation of NBS requires identification of the type of NBS evaluated in primary studies. This respects the requirement for commodity consistency[1] in benefit

[1] This requirement is satisfied by the inclusion of estimated values for goods and services that are similar across studies.

transfer studies (Chaikumbung et al., 2016) and reduces generalization errors[2] (Rosenberger & Stanley, 2006). It is important to define a similarity criterion since NBS is an "umbrella concept" that emerged at the interface between science, policy and practice (Nesshöver et al., 2017).[3]

Different scholars and practitioners highlight different criteria to propose a non-exhaustive NBS typology. Eggermont et al. (2015) define NBS regarding the number of ES and stakeholder groups targeted. Three types of NBS result from these criteria: NBS allowing "better use of natural or protected ecosystems"; NBS that allow "sustainable and multifunctional managed ecosystems"; and "design and management of new ecosystems". Cohen-Shacham et al. (2016) refer to the societal challenge targeted by NBS (water security, food security, human health and disaster risk reduction, climate change) and the ecosystem-based approaches adopted (restoration, issue-specific and green or natural infrastructures). Maes and Jacobs (2017) refer to the land use targeted (urban, forest and agriculture). Finally, Nesshöver et al. (2017) highlight two important criteria related to problem solving techniques or land-use problems (Ecological Engineering and Catchment Systems Engineering, Green/Blue Infrastructure) and their management (Ecosystem Approach; Ecosystem-based, Adaptation//Mitigation; Ecosystem Services Approach/Framework; Natural Capital).

Our study specifically targets NBS using an ecosystem restoration approach in a river basin context – that is, NBS for river restoration). These solutions aim, mainly, to restore the river ES to its pre-existing natural state. These NBS can be categorized as "Ecological Engineering and Catchment Systems Engineering" approaches, which, according to Nesshöver et al. (2017), include a range of measures including ecological restoration and natural alternatives to complement technology-based infrastructures. We distinguish among several ecological restoration measures identified in the literature, related to the physical properties of river ecosystems (Zingraff-Hamed et al., 2017). Table 2 groups NBS measures evaluated in primary studies into four types: river stream (e.g., stream bed restoration, dam removal), riparian vegetation (e.g., riparian buffers, natural bank

[2] Generalization errors are related inversely to the degree of correspondence between study and policy location.

[3] The European Commission defines NBS as living solutions that are inspired by and are supported continuously by and use nature, that are designed to address various societal challenges in a resource-efficient and adaptable manner and provide simultaneous economic, social and environmental benefits (Maes & Jacobs, 2017) while IUCN defines NBS as actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (Cohen-Shacham et al., 2016).

stabilization), floodplain (e.g., wetland restoration, floodplain restoration) and other (e.g., ecological management, sewage interception).

In addition to the intended benefit, NBS often provide multiple or co-benefits. These include monetary benefits, such as environmental goods and services, and non-monetary benefits such as stakeholder involvement (Eggermont et al., 2015; Cohen-Shacham et al., 2016; Maes & Jacobs, 2017; Nesshöver et al., 2017). We adopt the ecosystem services framework (Millennium Ecosystem Assessment, 2003) and the Common International Classification of Ecosystem Services (CICES, V5.1, 2017)[4] to identify relevant monetary benefits of NBS for river restoration (Table 1).

The primary studies have been examined via the definition of seven benefits (see Table 1), constituting a bundle of ES affected by river restoration projects. These benefits can be classified according to value type and potential beneficiaries. Some of these benefits are direct use benefits (e.g., food and materials, water regulation and recreation), others are indirect use benefits (e.g., local environmental regulation, global climate regulation and aesthetic properties) while other can be classed as non-use benefits (e.g., habitats and biodiversity). Hydrological ES are considered a primary target because we investigate NBS in a river basin context and, hence, consider water regulation as primary benefit, distinct from other regulating and maintenance ES which are considered co-benefits. We identify three types of potential beneficiaries: residents living in the river basin area, visitors to the area and the population worldwide.

[4] https://cices.eu/

Table 1: Benefits of NBS for river restauration

Benefits	ES categories of CICES	Definition	Values and Potential beneficiaries
Water regulation (primary benefit)	Regulating and maintenance	Hydrological cycle and water flow regulation, including drought and flood.	Non-consumptive use value for residents
Food & Material (co-benefit)	Provisioning	Cultivated or wild plants, reared or wild animals for nutritional or processing purposes	Consumptive use and option value for residents and visitors
Local environmental regulation (co-benefit)	Regulating and maintenance	Resilience of local environment to stresses including high temperature, fires, sandstorms, land salinization, erosion, pollutants, and mass movement.	Indirect use value for residents
Global climate regulation (co-benefit)	Regulating and maintenance	Carbon storage	Indirect use value for the worldwide population
Habitat quality and species diversity (co-benefit)	Regulating and maintenance	Maintaining nursery populations and species protection	Non-use value for residents and visitors
Recreation (co-benefit)	Cultural	Activities promoting health and enjoyment for residents or tourists (swimming, water sports, angling, etc.)	Non-consumptive use value for residents and visitors
Aesthetic appreciation (co-benefit)	Cultural	Natural landscape providing aesthetic benefits.	Indirect use value for residents and visitors

1.2 Economic value of NBS for river restoration

The concept of Total Economic Value (TEV) is widely used to define and evaluate the value derived by society from natural resources or ecosystems. TEV includes several types of value including use and non-use values. Applying this concept within an ES framework allows the attribution of at least one type of value to each ES (Hein et al., 2006; Pascual et al., 2010). Several methods have been used to attribute economic value to ES (de Groot et al., 2012; Grizzetti et al., 2016); in essence, all of these methods are based on observed, revealed or stated preferences approaches (Pascual et al., 2010).

Some prior meta-analyses are based on combining the findings from primary studies, but do not distinguish among valuation methods. Brander et al. (2006) acknowledge that this practice can lead to problems related to the non-comparability among estimated values. Brouwer (2000) underlines that the monetary values of public environmental goods and services, based on a stated preferences approach, are fictive and only symbolic within a broader social perspective. Also, Smith and Pattanayak (2002) highlight that the value transfer function can be inconsistent if the economic concepts being measured in primary studies are not identical. This occurs from the pooling of studies using, respectively, revealed preferences and stated preferences methods to measure Marshallian consumer and Hicksian consumer surpluses. Chaikumbung et al. (2016) note that the welfare consistency of MRA requires a Hicksian measure of welfare change. This is the the approach adopted in this paper, which focuses on stated preferences studies and assumes that these studies measure a consistent economic concept at the household or individual level. Although stated preferences has some limitations (Schläpfer, 2016), we consider it appropriate to assess NBS for river ecosystem restoration. NBS for ecosystem restoration constitute a public good, which affects the provision of ES. Some authors suggest that a stated preferences approach simulates a market for and demand for ES and induces changes to the provision of ES (Pascual et al., 2010; Jacobs et al., 2018; Kenney et al., 2012; Thomas & Blakemore, 2007). In addition, it is often the case that there is no market for certain ecosystems and their services and a stated preferences approach is the only method available to assign a monetary value to these ecosystems (Pascual et al., 2010; Qiu et al., 2006). Finally, numerous scholars have stressed that this approach is the only one able to estimate use and non-use values (Grizzetti et al., 2016; Jacobs et al., 2018, Brander 2006).

1.3 Value transfer method and model specification

Three value transfer methods have been identified in the literature: unit value transfer (valuation of a single study or an average valuation derived from administratively approved valuations from several studies - with and without adjustments for inflation); benefit function transfer (based on an estimated value function from an individual primary study); and MRA value function transfer (using a value function estimated based on the outcomes of previous primary studies) (Richardson et al., 2015). The outcomes of all of these methods are likely to include significant transfer errors (ranging between 0% and 7080%) resulting from generalization, measurement errors and publication selection bias (Rosenberger & Stanley, 2006). However, MRA is considered the most promising method since it is less sensitive to the problems related to individual studies (Rosenberger & Stanley, 2006; Chaikumbung et al., 2016). According to Chaikumbung et al. (2016, p.164), MRA has the advantage of “summarising information from several studies and can be used to generate benefit transfer functions that are more widely applicable and less sensitive to the attributes of individual studies".

To estimate the MRA functions for NBS for river systems restoration, we follow the steps in Richardson et al. (2015). We identify relevant key words to identify studies that evaluate river system restoration NBS and report the mean WTP per household per year and other relevant characteristics from these studies.[5] Barrio et al, (2010) emphasize that the mean is the most appropriate measure if the objective is to choose among efficiency criteria in the decision-making process. The selected studies consider a range of factors affecting the value an individual assigns to an ecological restoration project.

We use the vector of annual WTP per household as the dependent variable and consider three explanatory variable vector categories: (i) socioeconomic variables; (ii) methodological attributes; and (iii) project characteristics. These variables are described in the next section. We pool the observations and estimate equation 1 considering the dependent variable and the revenue expressed in logarithmic terms. This functional form has been used in previous meta-analyses of ES values (Pettinotti et al., 2018)

$$\ln y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon, \quad (1)$$

where β_0 is the usual constant term, the β vectors contain the coefficients associated to the explanatory variables to be estimated, and ε is a vector of the independently and identically distributed residuals. According to Rosenberger and Stanley (2006), measurement error can affect the accuracy of the transfer function, which, potentially, would bias the Ordinary Least Squares (OLS) estimates. Chaikumbung et al. (2016) emphasize that, ideally, the transfer function should be estimated using Weighted Least Squares (WLS). They suggest using sample size to construct a proxy for the estimated standard error since no studies report the standard error appropriate for WLS estimation. However, in their study the OLS and WLS estimates are not significantly different. Hence, we employ the classical OLS regression model with the Huber-White adjusted standard, commonly used in the environmental economics literature (Pettinotti et al., 2018). It has proven useful for correcting the correlation of errors across studies (Barrio & Loureiro, 2010).

[5] Noting that on can alternatively resort to the median WTP (Barrio & Loureiro, 2010). However, this is not relevant in our study because only very few primarily studies report the median WTP.

2 Data description

We follow a multiple step procedure to construct our database. In the first step, we identified relevant keywords. The NBS for water retention, listed on the European Natural Water Retention Measures platform,[6] were used to guide our keywords combinations. These were aimed at identifying NBS that affect hydro-morphological functioning on the catchment scale. The keywords identified are: wetland restoration, riparian forest restoration, floodplain restoration, river restoration, stream restoration, stream rehabilitation, river ecological restoration. In the second step, we searched for relevant papers in Science Direct, Springer, Wiley and Google scholar, using the previously identified keywords combined with the terms "economic valuation", "contingent valuation" and "willingness to pay". The third step consisted of selecting relevant articles, according to two criteria: that they valued the impacts of ecological restoration projects on ES provision; and that they reported an economic valuation using a stated preferences approach, based on primary and original survey data.

Thus, our final data set for the meta-analysis comes from 52 studies evaluating the impacts of river restoration projects (real or hypothetical) on the provision of ES from 1996 to 2018 (Table 2). These studies include 20 countries, four US counties, 12 European countries and 5 countries in Asia-Oceania. Most of the observations are for the US (74) followed by Brazil (20), Ireland (16), Austria (14) and China (10). The list of studies included in the database is presented in Table 2. We extracted 187 observations, corresponding to between 1 and 17 observations per study. A third of these studies (18) overlap with the those included in Brouwer and Sheremet's (2017) and Bergstrom et al.'s (2017) data. The results in the selected studies are reported in various national currencies (€, £, US$, CAN$, SEK, NZ$, RMB, etc.) and cover different periods (from 1986 to 2016). To homogenize these results and adjust for inflation, in our study, all values are expressed in 2017 US$ ppp (Purchasing Power Parity). We essentially focus on project characteristics that refer to NBS restoration measures and their benefits.[7] We also consider the survey method and respondents; socioeconomic characteristics as explanatory variables. All the variables used are

[6] http://nwrm.eu/

[7] The studies of Bergstrom and Loomis (2017) and Brouwer and Sheremet (2017) also analyze the physical characteristics of river restoration projects (miles or fraction of river restored). However, we are not able to consider this variable in our study because none primary study report this characteristic.

presented in Table 3.

Table 2: Authors, NBS measures, country and number of observation for each individual study included in the database

N°	Author	NBS measures in primary studies	Types of NBS measures	Country	Obs.
1	Adams et al., 2004	Dam removal, riparian buffers.	Riparian vegetation and River stream	USA	1
2	Amigues et al., 2002	Riparian buffers.	Riparian vegetation	France	5
3	Bae, 2011	Natural stream restoration and recreational facilities	River stream	South Korea	2
4	Barak and Katz, 2015	Stream rehabilitation	River stream	Israel	1
5	Beaumais et al., 2009	Floodplain restoration	Floodplain restoration	France	1
6	Bell et al., 2003	Restoration for Coho Salomon recovery	River stream, other	USA	10
7	Berrens et al., 1996	Measures for protecting minimum instream	Other	USA	1
8	Bliem et al., 2012	Floodplain restoration, reconnecting tributaries	Floodplain restoration	Austria	6
9	Bliem & Getzner, 2012	Wetland restoration, reconnecting floodplain, removal of stabilizing blocks of rock	Floodplain restoration, River stream	Austria	4
11	Broadbent et al., 2015	Measures for water resource management and ecological management of riparian forests	Riparian vegetation, Other	USA	3
12	Brouwer et al., 2016	Re-establishing connectivity, removing barriers, enlarging floodplains	Floodplain restoration, River stream.	Austria, Hungary and Romania	12
13	Che et al., 2014	Ecological restoration of river network	Other	China	6
14	Chen et al., 2014	Ecological restoration of riparian meadows	Riparian vegetation	Belgium	1
15	Colby & Orr, 2005	Conservation of Riparian buffers	Riparian vegetation.	USA	1
16	Collins et al., 2005	Stream restoration	River stream	USA	4
17	Doherty et al., 2014	Ecological restoration of water bodies	Other	Ireland	16
18	Farber & Griner, 2000	Ecological restoration of watershed	Other	USA	2
19	Giraud et al., 2001	Preservation of endangered fish species	River stream	USA	6
20	Hanley et al., 2006	Restoration of the ecological status of the river under Water Framework Directive	Other	United Kingdom	3
21	Hanemann et al., 1991	Measures for wetland maintenance and improvement, contamination and salmon improvement	Floodplain restoration, River stream.	USA	10

22	Holmes et al.,2004	Restoration of riparian buffers and natural bank stabilization	Riparian vegetation	USA	4
23	Johnston et al., 2011	Restoration of migratory fish passage, dam removal	River stream.	USA	5
24	Jørgensen et al., 2013	Measures for water quality restoration	Other	Denmark	1
25	Kahn et al., 2017	Restoration of riparian vegetation and regulation measures	Riparian vegetation	Brazil	2
26	Kenney et al., 2012	Restoration of riparian vegetation and meadows	Riparian vegetation, Floodplain restoration	Belgium	2
27	Kim et al., 2015	Measures for ecological restoration	Other	South Korea	1
28	Lehtoranta et al., 2017	Restoration of the original status of the stream, restoration of riparian forests	River stream, Riparian vegetation	Finland	1
29	Loomis, 1996	Dam removal	River stream.	USA	3
30	Loomis et al., 2000	Restoration of riparian buffers, conservation easement, water withdrawing reduction, wetlands restoration	Riparian vegetation, Floodplain restoration, Other	USA	1
31	Mansfield et al., 2012	Dam removal, water withdrawal regulation, fish restoration	River steam, Other	USA	9
32	Meyerhoff & Dehnhardt, 2007	Floodplain restoration, pollution reduction, construction of fish ladders	Floodplain restoration, River stream.	Germany	1
33	Milon & Scrogin, 2006	Change in land use from agriculture for natural reserve, water use restriction	Floodplain restoration.	USA	6
34	Ndebele & Forgie, 2017	Measures for ecological restoration	Other.	New Zealand	2
35	Nelson et al., 2015	Measures for ecological restoration	Other.	USA	2
36	Ojeda et al., 2008	Restoration of wetlands and riparian buffers	Floodplain restoration and Riparian vegetation.	Mexico	1
37	Pattison et al., 2011	Measures for wetlands restoration.	Floodplain restoration.	Canada	3
38	Paulrud & Laitila, 2013	Measures for recreational angling	Other.	Sweden	1
39	Polizzi et al., 2015	Stream restoration	River stream.	Finland	2
40	Ramajo-Hernández & Saz-Salazar, 2012	Measures for water resource management	Other.	Spain	3
41	Rezende et al., 2015	Extending mangrove area, vegetation planting	Riparian vegetation.	Brazil	17
42	Saz-Salazar et al., 2009	Measures for ecological restoration	Other.	Spain	2
43	Schaafsma et al., 2012	Measures for ecological restoration	Other.	Netherlands	1
44	Seeteram et al., 2018	Hydrological and species restoration	River stream.	USA	1
45	Senzaki et al., 2017	Measure for ecological restauration	Other	Japan	4
46	Thomas &	Riparian corridor management	Riparian vegetation.	USA	1

	Blakemore, 2007	and fencing			
47	Trenholm et al., 2013	Restoration of riparian buffers	Riparian vegetation	Canada	4
48	Vollmer et al., 2015	Measures for ecological restoration	Other.	Indonesia	3
49	Wang & He, 2018	Sewage interception, waterway dredging	River stream, Other	China	1
50	Weber & Stewart, 2009	Restoration of riparian forests and wetlands, bank removal	Riparian vegetation, Floodplain restoration, River stream	USA	5
51	Zhao et al., 2013	Restoration of riparian vegetation and channel morphology	Riparian vegetation	China	2
52	Zhongmin et al., 2003	Restoration of natural vegetation	Riparian vegetation	China	1

2.1 Socioeconomic variables vectors

We observe that none of studies report population density, but all provide details of revenue and geographic location of the rivers. We include these two socioeconomic variables in our MRA study. The mean revenue of the survey respondents is US$43,689 and we can distinguish three geographic locations: America (54%), Europe (34%) and Asia (12%).

2.2 Methodological attributes vectors

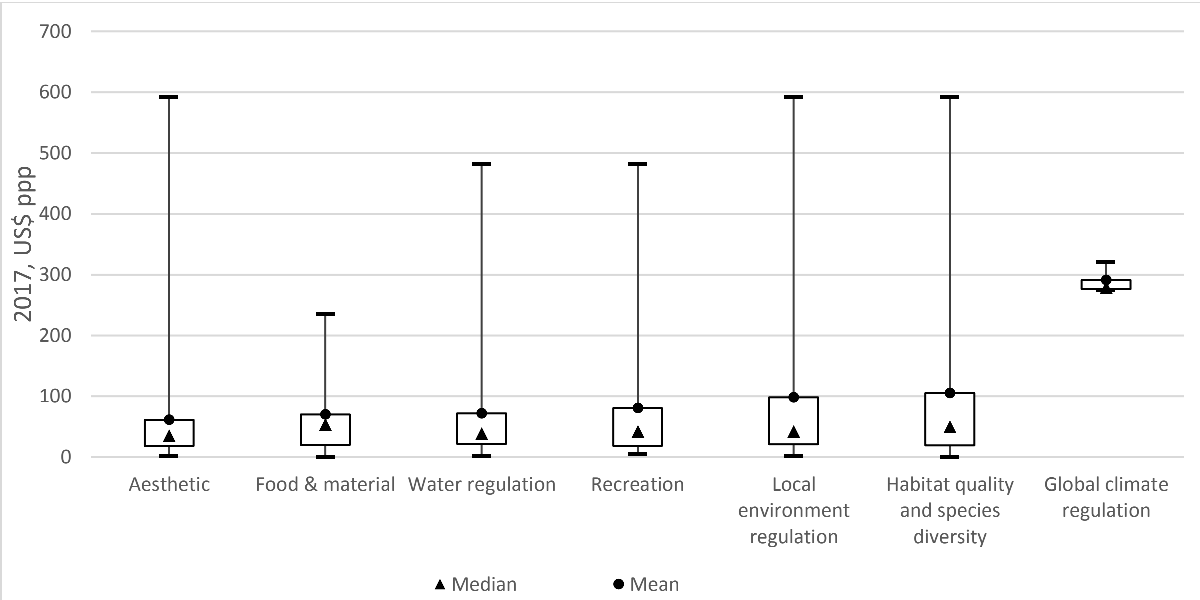
Two main economics valuation methods are used in the stated preferences approach: CVM and CE which we coded 1 (primary study employs CVM) or 0 (primary study uses CE). CVM is used in 46% of the observations. We also considered the different payment means in the primary studies, for example, local tax, national tax, utility bill and donation. National tax, local tax and utility bill are the most frequent, each representing more than a quarter of the observations. We also included the econometric method used to derive the mean WTP, distinguishing among non-parametric, semi-parametric and parametric models. This allows us to control for the underlying distribution of WTP in the primary studies. Finally, we include three survey characteristics: sample size, response rate and survey mode – this last distinguishing among face to face, internet and mix of each.

2.3 Project characteristics vectors

Prior meta-analytical studies generally consider ecosystem characteristics. As already stated, our study targets NBS projects for river restoration and their impact on the natural properties of river systems and their provision of ES. Hence, we focus not on the characteristics of the actual ecosystem, but on the effects of the restoration project on the ecosystem. We consider three aspects. The first is the seven benefits provided by NBS, which constitute the bundle of ES evaluated in the primary studies (Table 1). Food and materials, water regulation, recreational activities and aesthetic appreciation are classified as direct use values; local environment and global climate regulation are considered indirect use values; and habitats and biodiversity are considered non-use values. A primary study highlighting at least one of these identified benefits was coded 1 and 0 otherwise. Note that the benefits categories are not mutually exclusive; most studies attempt to value multiple ES. Also, most studies highlight the benefit related to habitats and biodiversity (73%) followed by local environment regulation (63%), recreational facilities (38%), aesthetic appreciation (33%), water regulation (27%) and food and materials (23%).

Figure 1 shows the distribution of the WTP in our meta-data, across the different benefits provided by river restoration projects. Note that although climate change regulation has the highest mean value, this is based on only three observations. In relation to the other benefits, the mean WTP for aesthetic appreciation, food and materials, and water regulation have fairly similar values of, respective, US$61, US$70 and US$71. We observe some differences if we compare these mean values to the mean values for recreation (US$81), local environmental regulation (US$98) and habitats and biodiversity (US$105).

Figure 1: Distribution of the WTP cross benefits



Number of observations for each benefit: Aesthetic (64), Food and material (32); Water regulation (51); Recreation (72); Local environment regulation (111); Habitat quality and species diversity (136); Global climate regulation (3).

The second aspect we consider is the project ambition. Some studies evaluate two level of the ambition in river restoration; one giving more room to the nature and more importance to the benefits. We assigned the value 1 to the most ambitious projects (0 otherwise). About 27% of the observations in the meta-data are considered to represent more ambitious NBS measures.

The third aspect considered is type of NBS measure. We distinguish among three types of measures depending on which part of the river system is affected: the river stream (e.g., stream bed restoration, dam removal), riparian vegetation (e.g., riparian buffers, natural bank stabilization) and floodplain (e.g., wetland restoration, floodplain restoration). The categories of measures are not mutually exclusive. They represent respectively 31%, 27% and 26% of the observations in our meta-data.

Table 3: Descriptive statistics

Variable names	Variable description	Mean	Std. Dev
Dependent variable			
Lnwtp	Annual value of the WTP per household in 2017 US$ in logarithmic form	3.62	1.53
Socioeconomic variables			
Income	Annual revenue per household in 2017 US$ in logarithmic form	10.46	0.77
America	=1 if the location of the restoration project is in America and 0 otherwise.	0.54	0.50
Europe	=1 if the location of the restoration project is in Europe and 0 otherwise.	0.34	0.47
Asia	=1 if the location of the restoration project is in Asia and 0 otherwise. Baseline category	0.12	0.33
Methodological variables			
CVM	=1 if contingent valuation method and 0 otherwise	0.46	0.50
CE	=1 if choice experiment method and 0 otherwise. Baseline category.	0.54	0.50
Donation	=1 if voluntary participation is the payment vehicle, 0 otherwise.	0.10	0.32
Utility bill	=1 if water bill or utility tax is the payment vehicle, 0 otherwise.	0.27	0.47
Local tax	=1 if local tax is the payment vehicle, 0 otherwise.	0.24	0.43
National tax	=1 if national or income tax is the payment vehicle, 0 otherwise.	0.26	0.44
Unspecified taxes	=1 if the payment vehicle is not specified, 0 otherwise. Baseline category.	0.16	0.36
Internet	=1 if web is the survey mode, 0 otherwise	0.42	0.49
Face	=1 if face to face is the survey mode, 0 otherwise	0.33	0.47
Mix	=1 if two or more survey modes are combined, 0 otherwise. Baseline category.	0.25	0.43
Sample	The size of the sample (number)	1,250	1,377
Response rate	The response rate of the survey (%)	0.67	0.32
Parametric	=1 if a parametric model is used for the estimates, 0 otherwise.	0.57	0.50
Semi-parametric	=1 if a semi-parametric model is used for the estimates, 0 otherwise	0.37	0.48
Non-parametric	=1 if a non-parametric model is used for the estimates, 0 otherwise. Baseline category.	0.06	0.24
Project's characteristics variables			
Food & material	=1 if the project impacts the food and material benefit, 0 otherwise. Baseline category	0.23	0.42
Local environmental regulation	=1 if the project impacts the local environment regulation benefit, 0 otherwise.	0.59	0.49
Global climate regulation	=1 if the project impacts the global climate regulation benefit, 0 otherwise.	0.02	0.12
Water regulation	=1 if the project impacts the water regulation benefit, 0 otherwise.	0.27	0.45
Habitats and biodiversity	=1 if the project impacts the water regulation benefit, 0 otherwise.	0.73	0.45
Recreation	=1 if the project impacts the water regulation benefit, 0 otherwise.	0.38	0.49
Aesthetic appreciation	=1 if the project impacts the Aesthetic benefit, 0 otherwise.	0.33	0.47
Level of ambition	= 1 if the most ambitious restoration, 0 otherwise.	0.27	0.44
Riparian vegetation	=1 if the project impacts the riparian vegetation, 0 otherwise.	0.27	0.44
Floodplain	=1 if the project impacts the floodplain, 0 otherwise.	0.26	0.44
River stream	=1 if the project impacts the river bed, 0 otherwise.	0.31	0.47
Other	=1 if the project impacts agricultural land or other management practices. Baseline category.	0.33	0.47

3 Results

3.1 Meta-regression results

The meta-regression results are presented in Table 4. Our empirical strategy employs ten models, combining step-wise and backward selection, to test the robustness of the estimates. Given that our primary focus is evaluating NBS river restoration measures and their benefits, we start with the baseline model that includes the NBS measures benefits and categories as explanatory variables (model 1). Then, we add the socioeconomic (models 2-3) and methodological (models 4-7) variables. Model 8 is the general model that includes all the explanatory variables. In model 9 we adopt the backward selection strategy recommended by Stanley and Doucouliagos (2012) and exclude variables with a p-value greater than 0.3 in the general model. Last, in model 10, we investigate whether NBS are normal goods by considering only income as the explanatory variable. We conducted several diagnostic tests to check the robustness of the OLS estimation. The Breusch-Pagan/Cook-Weisberg test rejects the null assumption of constant variance. The mean VIF statistic is lower than 10 (3.88), meaning that multicollinearity is not problematic. Regarding the model specification, the R^2 statistic increases across models, up to 0.50 which indicates that the null hypothesis of no omitted variables is rejected for the models. However, the estimated coefficients are robust cross the models. With the exception of the coefficients of the income variable which indicate income elasticity, the remaining coefficients measure the percentage change in the dependent variable, given a one unit change in the explanatory variables.

Starting with estimated coefficients of the benefits of NBS, the results reinforce the majority of the findings in meta-regressions studies related to ES provision via wetlands (Brander et al., 2013; Brouwer & Sheremet, 2017; Chaikumbung et al., 2016; Pettinotti et al., 2018). With the exception of food and materials and aesthetic appreciation, the other co-benefits (local environmental regulation, global climate regulation, recreational activities and habitats and biodiversity) are systematically positive and significant across models. The estimates suggest that NBS providing local environmental regulation, global climate regulation, recreational and habitat species benefits are the most highly valued. The primary benefit of water regulation is negative and insignificant in all the models, which is in line with the analyses in Brander et al. (2013), Brouwer and Sheremet (2017) and Pettinotti et al. (2018). Finally, the results indicate that the coefficients of level of ambition of the restoration project are positively robust. The mean WTP in our dataset increases up to 0.70% with the more ambitious project.

Regarding the NBS measures, the estimated coefficients of floodplain and river stream are systematically significant in all the models. In contrast, riparian vegetation measures are never significant for determining the WTP estimates. These results suggest that NBS measures affecting floodplains and river streams are more highly valued. This might be because these NBS measures provide benefits that individuals are more likely to perceive and value. Floodplains and river streams are physical parts of the river ecosystem and are more visible than riparian vegetation, which likely increases perception of their benefits.

In relation to the socioeconomic variables, these are in line with our expectations, although only the geographical location variables are robust across models 3, 8 and 9. The coefficients of America and Europe are significantly positive, indicating that the monetary value of river restoration is higher in countries in these areas. This value increases up to 1% compared to countries located in Asia. This confirms the meta-analytical findings in other studies, such as Brouwer et al. (1999), Chaikumbung et al. (2016) and Brouwer and Sheremet (2017).

In the case of the methodological variables, their inclusion allows us to control for their effect on the dependent variable rather than to test a specific hypothesis. Most of these variables are insignificant with the exception of CVM, local-tax, water-bill and the parametric variables. Primary studies using CVM report higher WTP compared to those using CE. One explanation for this is that the values reported by the latter group of studies are more specific to the ES evaluated. The CVM based studies evaluate a broader set of ES and only the most important are emphasized. Pettinotti et al. (2018) suggest that environmental valuations using non-market valuation techniques generally result in higher values compared to market-based valuations. However, prior studies (Brouwer & Sheremet, 2017; Chaikumbung et al., 2016) find mixed result regarding the CVM and CE method. Lastly, model 10 confirms that NBS for river restoration are normal goods. If income increases by 1%, mean WTP increases by 37%, which is in line with prior studies (Brander et al., 2013; Roy Brouwer & Sheremet, 2017; Chaikumbung et al., 2016; Pettinotti et al., 2018). However, this result is not robust since the coefficient is not significant in models 2 and 8.

Table 4: Meta-regression results (OLS Huber–White adjusted standard errors)

	1	2	3	4	5	6	7	8	9	10
NBS's primary benefit										
Water regulation	-0.26	-0.18	-0.11	-0.25	-0.20	-0.26	-0.20	-0.14		
	(0.27)	(0.28)	(0.28)	(0.26)	(0.28)	(0.29)	(0.30)	(0.32)		
NBS's co-benefits										
Food & Material	0.20	0.21	0.10	0.21	0.19	0.25	0.20	-0.05		
	(0.35)	(0.35)	(0.37)	(0.34)	(0.36)	(0.36)	(0.35)	(0.43)		
Local envir.	0.41*	0.44*	0.35	0.39*	0.43*	0.46*	0.42*	0.38*	0.38*	
regulation	(0.24)	(0.24)	(0.25)	(0.22)	(0.25)	(0.24)	(0.24)	(0.21)	(0.20)	
Global climate	2.26***	2.17***	2.44***	1.71***	1.65**	2.01***	2.15***	0.91	1.03**	
regulation	(0.42)	(0.42)	(0.49)	(0.41)	(0.51)	(0.47)	(0.47)	(0.57)	(0.34)	
Habitats and	0.91**	0.86**	0.91**	0.53*	0.97**	0.75**	0.91**	0.51	0.55*	
biodiversity	(0.29)	(0.31)	(0.31)	(0.27)	(0.30)	(0.29)	(0.32)	(0.32)	(0.28)	
Recreational	0.58**	0.58**	0.55**	0.49**	0.70**	0.56**	0.56**	0.62**	0.60**	
activities	(0.22)	(0.22)	(0.22)	(0.21)	(0.25)	(0.22)	(0.24)	(0.25)	(0.21)	
Aesthetic	0.04	0.04	0.07	0.13	0.11	0.12	0.05	0.21		
appreciation	(0.21)	(0.21)	(0.20)	(0.20)	(0.21)	(0.20)	(0.27)	(0.24)		
Level of ambition	0.54**	0.57**	0.51**	0.70***	0.50**	0.58**	0.58**	0.57**	0.64***	
	(0.18)	(0.18)	(0.17)	(0.19)	(0.18)	(0.18)	(0.20)	(0.19)	(0.17)	
NBS measures										
Riparian vegetation	0.12	0.15	0.33	0.11	-0.14	-0.07	0.19	-0.23		
	(0.30)	(0.29)	(0.36)	(0.29)	(0.38)	(0.30)	(0.31)	(0.43)		
Floodplain	1.07***	1.05***	1.02**	1.08***	1.18***	0.92**	1.07***	1.20***	1.08***	
	(0.29)	(0.29)	(0.31)	(0.29)	(0.29)	(0.28)	(0.30)	(0.31)	(0.22)	
River stream	1.61***	1.58***	1.93***	1.21***	1.48***	1.47***	1.65***	1.30**	1.41***	
	(0.31)	(0.32)	(0.41)	(0.31)	(0.36)	(0.33)	(0.35)	(0.49)	(0.29)	
Other	0.67**	0.69**	0.97**	0.71**	0.47	0.48	0.73**	0.74	0.75**	
	(0.34)	(0.34)	(0.39)	(0.31)	(0.35)	(0.35)	(0.33)	(0.46)	(0.24)	
Socioeconomic variables										
Income		0.15						0.01		0.37**
		(0.17)						(0.22)		(0.17)
America			0.70*					0.76**	0.74**	
			(0.39)					(0.36)	(0.33)	
Europe			0.97**					0.84*	0.90**	
			(0.36)					(0.48)	(0.31)	
Methodological variables										
CVM				1.05***				1.07***	0.99***	
				(0.24)				(0.30)	(0.25)	
Local-tax					-0.35			-0.66*	-0.56**	
					(0.37)			(0.37)	(0.28)	
National-tax					0.09			-0.11		
					(0.31)			(0.43)		
Donation					-0.19			0.13		
					(0.46)			(0.60)		
Water-bill					-0.55			-0.83*	-0.57**	
					(0.36)			(0.47)	(0.26)	
Parametric						0.75**		1.09**	1.00**	
						(0.32)		(0.53)	(0.46)	
Semi-parametric						0.15		0.84	0.72	
						(0.34)		(0.57)	(0.48)	
Internet							0.25	0.16		
							(0.33)	(0.50)		

Face-to-face							0.17	0.06		
							(0.49)	(0.56)		
Sample							0.00	-0.00		
							(0.00)	(0.00)		
Constant	1.29**	-0.26	0.36	1.17**	1.54**	1.05**	1.01	-0.10	-0.10	-0.23
	(0.47)	(1.81)	(0.62)	(0.45)	(0.55)	(0.51)	(0.85)	(2.27)	(0.63)	(1.75)
N	185	185	185	185	185	185	185	185	185	185
R^2	0.35	0.35	0.38	0.43	0.37	0.38	0.35	0.50	0.49	0.04
R^2 adjusted	0.30	0.30	0.32	0.38	0.31	0.33	0.29	0.42	0.45	0.03
LL	-301	-300	-297	-289	-298	-296	-300	-276	-278	-337

Standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < .001$. LL: Log likelihood statistics.

3.2 Fitness for value transfer

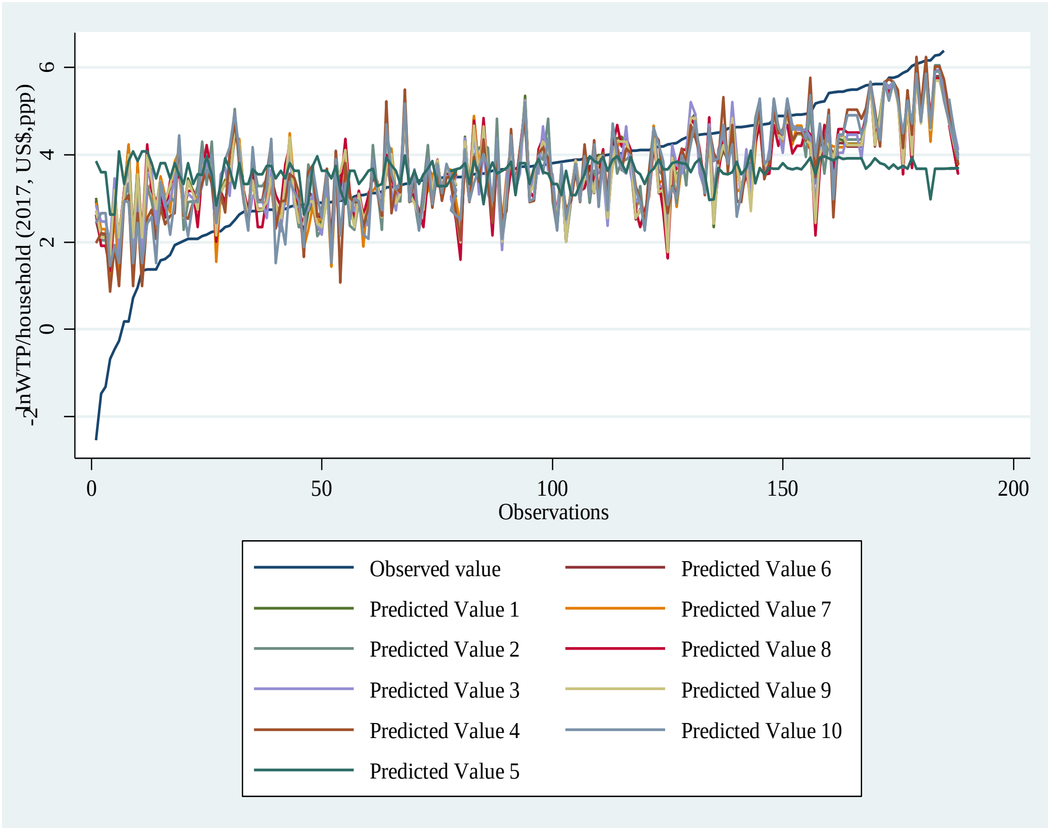
Among the three meta-analysis applications identified by Smith and Pattanayak, 2002, value transfer is the most important for policy makers since it allows reduced primary valuation study costs. Brander et al. (2013) highlight that policy makers need to be aware of the potential errors involved when commissioning a value transfer application. We identify two ways to check the fitness of meta–regression with value transfer, namely Mean Absolute Percentage Error (MAPE) and convergence validity test. The former refers to the transfer error rate, considering in-sample or out-of-sample meta-regression forecast performance, while the latter allow comparison of the value transfer estimates to value estimates, based on original primary valuation (Brander et al., 2013; Brander et al., 2006; Chaikumbung et al., 2016). Although the latter is recommended, Chaikumbung et al.'s (2016) experience using both methods shows that convergent validity provides a transfer error rate similar to the median MAPE. Here, we explore the potential of our meta-regression for value transfer via MAPE. We use all 10 models estimated in the previous section, to predict each of the observations in the database. We then compute MAPE as the difference between predicted and observed values, divided by the observed values. Table 5 presents the MAPE of the 10 models. The mean MAPE across models ranges from 49% to 71%, with the median MAPE of around 20%. In other words, the predicted values are wide of the observed values by 49%-71% on average and the error rate for 50% of observations in the valuation database is less than 20%. These are large values and mean that the transferred values must be treated with some caution. However, they are similar to those in the value transfer literature, which range from 30% to 186% for average MAPE and 15% to 21% for median MAPE.

Table 5: MAPE (%)

Models	MAPE (%)				% of Obs. with MAPE<30%	% of Obs. with MAPE<50%	% of Obs. with MAPE>100%
	Mean	Median	Min	Max			
Model 1	61	17	0.30	2,190	71%	85%	9%
Model 2	61	17	0.21	2,209	73%	84%	8%
Model 3	57	16	0.55	2,216	70%	84%	8%
Model 4	56	20	0.39	1,728	70%	87%	9%
Model 5	59	16	0.28	2,064	70%	83%	8%
Model 6	58	17	0.02	2,036	75%	86%	9%
Model 7	60	18	0.09	2,087	71%	85%	9%
Model 8	49	17	0.11	1,594	75%	87%	7%
Model 9	51	17	0.20	1,600	75%	84%	7%
Model 10	71	22	0.05	2,007	68%	84%	10%

Also, as last three columns in Table 5 show, about 70% of the observations in the valuation database have error rates of less than 30%, some 85% have an error rate of less than 50% and about 10% have an error rate higher than 100%. Figure 5 plots the observed and predicted values for the 10 models, in ascending order of the observed values. It shows that our value transfer function systematically overestimates very low values and underestimates high values. It indicates, also, that the difference between observed and predicted values is more important for low observed values, which feature of the distribution of MAPE is similar to prior studies (Brander et al., 2006; Chaikumbung et al., 2016). Consequently, we believe that any of functions of our 10 models could be used to estimate NBS values related to river restoration at policy sites. Note that our meta-regression provides three advantages: commodity consistency, welfare consistency and, most important, NBS benefits and measures.

Figure 2: Observed and predicted values



4 Discussion and conclusion

The term NBS was introduced in 2008, to refer to ways to mitigate and adapt to climate change effects whilst, simultaneously, protecting biodiversity and improving sustainable livelihoods (Eggermont et al., 2015; Nesshöver et al., 2017). To promote use of these solutions requires their primary benefits and co-benefits to be demonstrated. Many river systems have dried up or been damned to allow land developments. NBS related to restoration, almost always involve costs related to the opportunity costs of land use changes and reduced economic activities. Demonstrating the monetary value of the benefits provided by NBS should lead to greater protection of ecosystems and improved decision-making.

This paper explored the possibility of relying on the value transfer function to estimate the economic value of NBS related to river restoration. It addresses a gap in the meta-analysis function literature related to this type of NBS. The present work is novel for two main reasons: 1) to our knowledge, this is the first meta-analysis of NBS and their benefits within a restoration approach in a hydrological context; 2) we consider a large number of NBS benefits in order to include a wide set of ES and allow consideration of ES trade-offs when transferring value. This ensures commodity and welfare consistency and accounts only for the relevant benefits at a particular policy site. Eggermont et al. (2015) emphasize that, although NBS have multiple advantages, there are likely to be few win-win situations of all goals being met simultaneously. Also Eggermont et al. (2015) and Nesshöver et al. (2017) highlight the importance of involving stakeholders in the design, operationalization and management of NBS in order to increase their acceptability. In our view, an economic valuation will estimate only the benefits required by stakeholders, otherwise it will provide overestimations. The aim of the present study was to identify factors determining the WTP and to use meta-regression to construct a value transfer function. To achieve this, we collected information from more than 50 valuation studies of (real and hypothetical) river restoration projects around the world. The results allow some important conclusions.

First, it has become apparent that NBS, for river restoration, are far from valueless and provide a wide array of benefits that can be of considerable value to individuals. Our estimates show that individuals particularly value co-benefits such as global climate regulation, local environmental regulation, recreational activities and habitat and biodiversity benefits. This supports consideration of the co-benefits when designing NBS. Moreover, NBS measures affecting floodplains and river streams are more highly valued for determining the WTP. The most ambitious NBS scenarios are considered to be more valuable. The analysis provides quantitative evidence that ecosystem restoration could achieve the "win–win" objectives, promised by NBS (Eggermont et al., 2015; Nesshöver et al., 2017).

Second, the results of this study suggest that WTP is influenced weakly by the methodological variables. While the CVM affects the WTP compared to studies using CE methods, the payment means and econometric method have only a marginal effect. Survey mode is never significant. Finally, we find a positive relationship between income and NBS values, emphasizing that NBS for river restoration are a normal good. The results indicate, also, that the WTP is higher in America and Europe compared to Asia.

This study suffers from some inevitable limitations. In common with most meta-analysis, the findings are not generalizable since they are valid only for the studies undertaken so far. The evidence base on which we estimate the meta-analytic value function includes only 187 observations derived from 52 studies. Therefore, our results should be interpreted with some caution. More research is needed to improve the accuracy and reliability of predicted economic values, and the fit with the convergent validity test. There is a need, also, for more detailed primary studies. Many studies provide insufficient information on the ecological and physical characteristics of the river, and socio-demographic characteristics such as education, ethnicity and density. It is difficult to obtain this information at the river basin scale, although it would greatly improve the value transfer function. Moreover, there is an emerging stream of work (e.g., Kenter et al., 2015; Primmer et al., 2018) that highlights the critical role played by people's values, beliefs and norms in the evaluation of ecosystems. According Brouwer (2000), these aspects can cause bias in the outcomes of stated preferences studies, by making the elicited value fictive and symbolic. Hence, primary studies should discuss how people's values, beliefs and norms affect the WTP for NBS. This would increase the reliability and accuracy of value transfer for decision-making. Finally, primary studies should report standard errors systematically in order to allow use of a WLS, which is more appropriate than OLS (Chaikumbung et al., 2016).

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