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The economic value of wetland conservation and creation: A meta-analysis

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SIEV – Sustainability Indicators and Environmental Valuation

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The Economic Value Of Wetland Conservation and Creation: A Meta-Analysis

Summary

The rationale for conservation and creation of wetlands stems from the recognition of both their ecological and economic values. This paper examines the welfare impacts of goods and services provided by wetlands. We collected 385 estimates of the economic value of 181 natural and man-made wetlands from 167 studies worldwide. The resulting database is less biased towards North America than previous reviews of the literature. The relative importance of characteristics of the valuation study, of the wetland site, and of the socio-economic and geographical context is estimated by means of a meta-regression analysis of wetland values. Provision of amenities, flood control and storm buffering, and water quality improvement are the most highly valued wetland services. The relevance of the socio-economic and geographical context clearly emerges from the analysis and, in particular, the proximity to other wetland sites is negatively correlated with valuations. An analysis of the effect of environmental stress on wetland value shows that the latter increases with stress from human development activities and uses. In addition to the basic meta-regression model, the influence of authorship effects and of the geographic regions is examined by means of a multi-level approach. A second extended meta-regression model including cross-effects shows that the valuations of specific services vary according to the type of wetland producing them.

Keywords: Constructed Ecosystems, Economic Valuation, Man-Made Wetlands, Meta-Regression, Wetland Values

JEL Classification: C81, Q24

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1. Introduction

Efforts to preserve and create wetland ecosystems depend on the recognition of their ecological as well as economic values. From an ecological perspective, wetlands are valuable as they are among world's most productive ecosystems and host a large amount of biological diversity. Countless species of birds, mammals, reptiles, amphibians, fish and invertebrate species depend on water and wetland vegetation for their survival (Mitsch and Gosselink, 2000).

The valuation of wetlands from an economic perspective, on the other hand, requires embracing an anthropocentric analysis. The value of an environmental asset is determined by the production and consumption opportunities it provides to humans, i.e. by its impacts on human welfare. The economic rationale for conserving and creating wetland ecosystems is thus linked to the services and goods they provide, which have been recognized to be extremely valuable welfare constituents to many people worldwide (Millennium Ecosystems Assessment, 2005).

Nevertheless, policy- and decision-making often fail to fully account for the total economic value of wetland ecosystems. Market failures resulting from the public good character of many wetland services and goods or from ill-defined property rights in or near wetland areas lead decision-makers to overlook many wetland values. This may in turn result in an inefficient allocation of resources, which is an important reason why in many regions of the world wetland ecosystems are, despite increased conservation efforts, still under threat.

The monetary valuation of the market and non-market benefits of wetlands has been the subject of a large number of primary valuation studies. Since the publication of the first wetland valuation study in 1974 (Hammack and Brown, 1974), the number of studies aimed at estimating the value of wetlands has steadily grown. The large number of closely related and comparable studies has stimulated the use of a research synthesis technique known as meta-analysis. Three meta-analyses of wetland valuation studies have been published:

- Brouwer et al. (1999) analyze the results of contingent valuation method (CVM) studies of temperate climate zone wetlands. The definition of wetlands used in this study is very broad and the meta-analysis includes a number of valuation estimates for open water (rivers and lakes). The focus on estimates from CVM studies in developed countries, mainly the United States, narrows the sample size to 92 valuations derived from 30 studies.
- Woodward and Wui (2001) similarly restrict the scope of their meta-analysis to include valuation studies for North American and European wetlands only. They use a more narrow definition of what constitutes a wetland than Brouwer et al. (1999) while also including wetland

values obtained with valuation techniques other than CVM. The resulting data set contains 65 valuations taken from 39 studies.

- Brander et al. (2006) assembled a dataset of 215 value observations obtained from 80 studies. Their analysis includes studies from temperate and tropical regions, for different wetland types (including mangroves), and for a broader set of wetland functions and valuation methods. An important element of this meta-analysis is the addition of external socio-economic variables like GDP per capita and population density. In spite of the broad geographical scope adopted, the distribution of primary valuation studies is still very much biased by the practice and availability of natural resource valuation studies rather than by the actual geographical distribution of wetlands. In particular, studies from North America accounted for half of the total number of observations.

In this study, we build on the lessons of previous research to provide an original contribution to the assessment and explanation of wetland values using statistical meta-analysis. For this study, we substantially extended the data set used in Brander et al. (2006) to include by far the largest number of primary valuation studies used in a meta-analysis of wetland values to date: namely, 385 independent observations derived from 167 studies. With respect to previous meta-analyses, there is an extension of the geographical coverage of the studies, which is less biased towards developed Western countries. A substantial increase in recent years in the number of wetland valuation studies in Africa, Asia and Europe is identified, while the number of new studies from North America – where wetland valuation was first widely used – shows a downward trend. In addition, man-made wetlands are included for the first time in a meta-analysis of wetland values.

Three meta-regression models are investigated. The basic meta-regression model extends the model by Brander et al. (2006). The innovative contributions of this model include the recognition of substitute wetland sites and environmental pressure as important explanatory variables of wetland values. Estimated wetland values are shown to significantly decrease when substitute sites are present in the vicinity of the valued wetland. Furthermore, the presence of human pressures on the wetlands is taken into account in the analysis by means of an index of environmental stress and is recognized to lead to higher values. Two extended meta-regression models are examined as well. A model including cross-effect variables is implemented to examine the distribution of the values of wetland services according to wetland types. A second extended model makes use of the multi-level modeling technique to relax the assumption of independent observations and investigate the presence of authorship effects and the similarity of estimates derived from the same geographic region.

The organization of the remainder of this paper is as follows. In Section 2 the characteristics of the data set used are described by means of descriptive statistics (Section 2.1) and the basic meta-regression model is illustrated (Section 2.2). Section 3 discusses and interprets the meta-regression results obtained and provides a comparison with the previous meta-analyses of wetland values. Section 4 illustrates the results obtained with the extended meta-regression models. The final section concludes and summarizes the main findings of this study.

2. Description of data set and basic meta-regression model

2.1 The data set of wetland values

In this study we use statistical meta-analysis to predict wetland values based on 385 independent observations from 167 valuation studies and concerning 181 natural and man-made wetlands worldwide. This is by far the largest data set used in a study of this kind. All studies considered are primary valuation studies and no observation based on value transfer is included in the data set.

Due to the large scope of this meta-analysis, the primary studies and the ecosystems included in the analysis show a large variation. Relative to the most widely and internationally accepted definition of wetlands provided by the Ramsar Convention on Wetlands of International Importance, we adopted a relatively strict definition of what constitutes a wetland when selecting primary studies in order to avoid the inclusion of ecosystems that are not generally considered as wetlands. According to the Ramsar definition any area of "marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static of flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" is to be considered a wetland site. This very inclusive definition encompasses a large number of ecosystem types and can potentially be assumed to comprise all areas of rice cultivation, coral reefs, sea-grass beds, most rivers and shallow lakes (Scott and Jones, 1995). Such ecosystem types were excluded from the current analysis.

The data set used by Brander et al. (2006) provided the starting point for the analysis. The original data set is substantially enlarged with new observations from the most recently published studies. In order to limit the risk of introducing publication bias, the investigation is not limited to the analysis of publications in the "official scientific literature", but also explores the "grey literature" (such as reports for both public and private institutions and consultancy studies) and unpublished research results. Efforts were also made to include studies that are not published in the English language.

The average number of observations per study (2.3) and the maximum number of observations for a single study (10) are relatively low if compared to the total number of observations used in the

analysis (385). As such, multiple sampling bias is expected to have a limited influence on the results of the investigation.

All continents are represented in the data set. The largest number of observations pertains to North America (129), but a significant fraction comes from Asia (89), Europe (80) and Africa (53). South America (18) and Australasia (16) are somewhat underrepresented. The database is significantly less biased towards North American studies than those underlying the previous meta-analyses. In particular, the inclusion of the most recent observations allows for the identification of a significant shift in the geographical distribution of wetland valuation studies in recent years. Figure 1 illustrates how the number of observations from North America has steadily decreased over the last fifteen years, while the number of European, Asiatic and African observations increased over the same period of time.

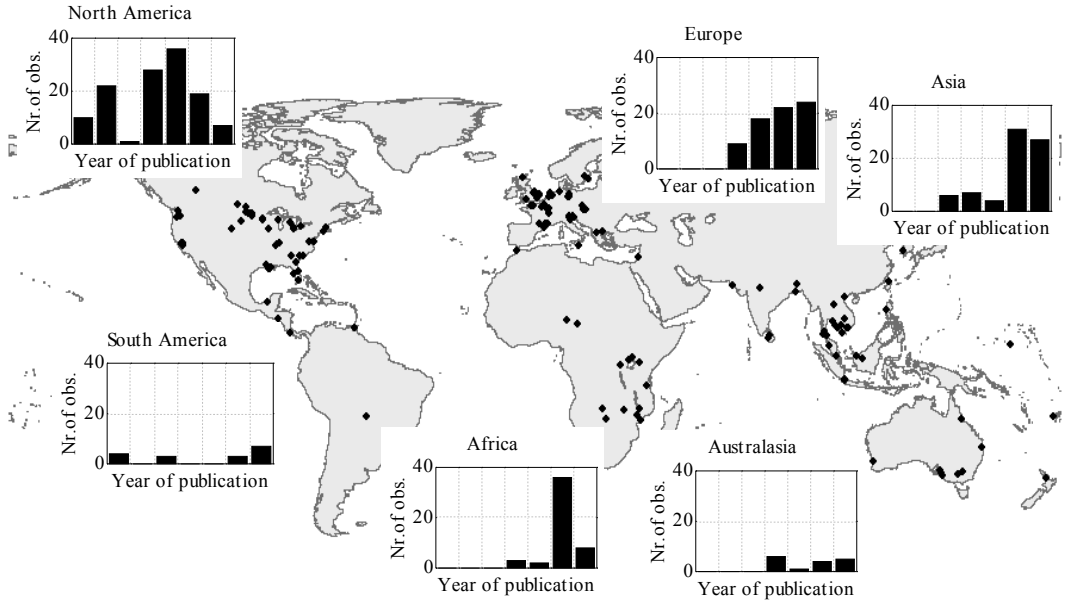

Figure 1. Number of observations of wetland values in intervals of five years from 1972 to 2007 and geographical location of valued wetlands

A relevant contribution of the current study is that the analysis is not limited to natural wetlands but also covers 38 observations on man-made wetlands. A comparison of natural and man-made wetlands shows that they express similar ecological functions, but that man-made wetlands tend to resemble degraded natural wetlands rather than undisturbed reference wetlands (Campbell et al., 2002; Brooks et al., 2005; Balcombe et al., 2005; Confer and Niering, 1992; Spieles and Mitsch, 2000). Man-made wetlands are created with the aim of (i) mitigating the destruction of natural

wetland habitats with artificial ones, which are meant to mimic the foregone ecological functions of the lost ecosystem, or (ii) to replicate wetland processes for human use and benefits including water storage, flood retention, and water quality improvement (Hammer and Bastian, 1989).

2.2 The meta-regression model and the explanatory variables

The basic meta-analytical regression model is specified as follows:

$$\ln(y_i) = a + b_S X_{Si} + b_W X_{Wi} + b_C X_{Ci} + u_i \quad (1)$$

where the dependent variable (y) is the wetland value standardized to 2003 US$ per hectare per year. The subscript i is an index for the 385 observations, a is a constant term, b_S, b_W and b_C are vectors containing the coefficients of the explanatory variables and u is an error term that is assumed to be well-behaved. Table 1 provides an overview of the explanatory variables. They consist of three categories, namely characteristics of (i) the valuation study X_S, (ii) the valued wetland X_W and (iii) the socio-economic and geographical context X_C. The variable type (nominal, interval or ratio) is also reported.

Study characteristics (X_S). Study characteristics accounted for in the model include the valuation method used, the year of publication and a dummy distinguishing between marginal and average values (cf. Brander et al., 2006).

A wide array of valuation methods has been used in the primary studies for the assessment of the different values of wetlands. These include market-based methods (i.e., market prices (130), replacement cost (64), net factor income (53), production function (27) and opportunity cost (9)), revealed preference methods (i.e., travel cost method (43) and hedonic pricing (5)), and stated preference methods (i.e., contingent valuation method (76) and choice experiment (9)). A dummy for each of the valuation methods is included in the meta-regression model to account for the heterogeneity of methods, as not all of them have a strong basis in welfare theory and produce estimates of different welfare measures.

The year of publication is accounted for by a variable representing the number of years elapsed since the publication of the first wetland valuation study in 1974. This variable attempts to capture possible shifts of preferences in time and temporal effects associated with specific valuation methods. An example of such effects is the impact of the publication of the influential NOAA Panel recommendations (Arrow et al., 1993) on the design of contingent valuation studies.

To distinguish between marginal and average per hectare values, following Brander et al. (2006), a dummy variable is introduced, which assumes a value equal to one for marginal values (51) and equal to zero otherwise (334).

Table 1. Explanatory variables used in the basic meta-regression model

Group	Variable	Variable type	Levels / measurement unit	N
Study (X_S)	Valuation method	Nominal	Contingent valuation method	76
			Hedonic pricing	5
			Travel cost method	43
			Replacement cost	64
			Net factor income	53
			Production function	27
			Market prices	130
			Opportunity cost	9
			Choice experiment	9
	Year of publication	Interval	0 (= 1974), 1, …, 33 (= 2007)	385
	Marginal / average	Nominal	Average	334
			Marginal	51
Wetland (X_w)	Wetland type	Nominal	Estuarine	127
			Marine	96
			Riverine	128
			Palustrine	114
			Lacustrine	81
			Man-made	38
	Wetland size	Ratio	Hectares (ln)	385
	Urban / rural	Nominal	Rural	304
			Urban	81
	Service provided	Nominal	Flood control and storm buffering	51
			Surface and groundwater supply	39
			Water quality improvement	48
			Commercial fishing and hunting	98
			Recreational hunting	66
			Recreational fishing	59
			Harvesting of natural materials	69
			Fuel wood	33
			Non-consumptive recreation	83
			Amenity and aesthetics	42
			Biodiversity	42
	Environmental pressure	Ratio	[0–3]	385
Context (X_C)	GDP per capita[a]	Ratio	2003 US$ person^{-1} year^{-1} (ln)	385
	Population density	Ratio	Inhabitants in 50 km radius in year 2000 (ln)	385
	Wetland abundance	Ratio	Hectares in 50 km radius (ln)	385

N = number of observations for each variable or variable level

Note: Observations for the variables valuation method, wetland type, and service provided do not add up to 385. This is due to the fact that to individual observations may pertain two or more levels.

[a] At country level. State level for observations from the US.

Wetland characteristics (X_W). Characteristics of the valued wetland site that are accounted for in the meta-regression model are the type and size of the wetland, the services provided, its characteristics of either urban or rural wetland and the level of pressure exercised on it by human activities.

The wetlands in the database are classified according to the basic hierarchical unit of the Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al., 1979), which identifies five basic wetland systems: marine, estuarine, riverine, lacustrine and palustrine. A sixth category for man-made wetland was added to these, following the approach adopted in the Ramsar classification. As large wetlands may include areas with very different characteristics, the

same observation may be classified under two or more wetland systems. The distribution of wetland observations in the data set is quite balanced among the five categories. Most of the wetlands in the database are riverine (128) or estuarine (127). A large number of observations concerns palustrine wetlands (114), while fewer observations are available for marine (96) and lacustrine (81) wetland ecosystems. A total of 38 observations for man-made wetlands are included.

The large diversity of the wetland sites included in the data set is also reflected by their size. Most of the wetlands for which value estimates are available are medium to large size wetland areas. Examples of large valued sites, covering hundreds of thousands of hectares are the coastal wetlands of Louisiana (Gosselink et al., 1974), the Pantanal (Shrestha et al., 2002), the Everglades (Milon and Scrogin, 2006), the Sundarban in Bangladesh (Ahmad, 1984) and the Danube floodplain (Gren et al., 1995). In some cases aggregate values are estimated for all wetlands located within a certain administrative region, such as Minnesota (Sip et al., 1998), South Dakota (Johnson, 1984), New South Wales (Streever et al., 1998) or all mangrove wetlands in Indonesia (Burbridge and Koesoebiono, 1984). Although the majority of the valuation studies so far has comprehensively focused on large sites, small wetlands are also represented. Some examples are small wetlands in the North Dakota prairie (Leitch and Hovde, 1996), Louisiana (Breaux et al., 1995), Italy (Marangon et al., 2002) and England (Ledoux, 2003). All these wetlands are below hundred hectares in size. Although there is no clear *a priori* expectation of the influence of wetland size on its value, the previous meta-analyses agree on the relevance of size as a significant factor to explain the variability of wetland values.

Wetlands provide a number of services and goods that are of value to humans. The economic services of wetlands are derived from, but should not be confused with, their ecological and physical functions. The classification of wetland functions and services was the object of a large number of studies. Wetland values have generally been classified on the basis of the underlying wetland functions (Barbier, 2006), the characteristics of use and non-use values (Barbier et al., 1997), the provision of intermediate, final or future goods and services (Leschine et al., 1997), or private versus public or social values (Whitten and Bennett, 1998). In this paper, we follow the approach proposed in the Millennium Ecosystem Assessment (2005), which is based on classification of ecosystem services into the categories of supporting, provisioning, regulating and cultural services. Table 2 illustrates the main wetland economic services and goods together with the valuation methods most commonly used for the estimation of their impact on human welfare. For some of the wetland services in Table 2 – i.e., appreciation of uniqueness to culture/heritage, educational, support of pollinators, sediment retention, micro-climate stabilization, and regulation of greenhouse gases – no direct valuation study could be found in the literature. The largest number

of observations is for commercial fishing and hunting (98) and non-consumptive recreation (83). A relatively large number of observations is available for harvesting of natural materials (69), recreational hunting (66), recreational fishing (59), and flood control and storm buffering (51). Relatively less information is available in the literature for water quality improvement (48), amenity and aesthetics (42), biodiversity (42), surface and groundwater supply (39), and fuel wood (33).

Table 2. Principal services and goods provided by wetlands and valuation methods commonly used to estimate their value

Category	Wetland service	Valuation methods
Cultural	Amenity and aesthetics	CVM (27), HP (5), TCM (5)
	Non-consumptive recreational activities	CVM (49), TCM (19)
	Appreciation of uniqueness to culture/heritage	-
	Educational	-
	Recreational hunting	TCM (23), CVM (19)
	Recreational fishing	CVM (25), TCM (14)
Supporting	Biodiversity	CVM (26), choice experiment (7), market prices (7)
	Support of pollinators	-
Provisioning	Commercial fishing and hunting	Market prices (39), NFI (30), production function (16)
	Harvesting of natural materials	Market prices (36), NFI (22)
	Fuel wood	Market prices (20), NFI (10)
	Surface and groundwater supply	Replacement cost (17), NFI (8)
Regulating	Flood control and storm buffering	Replacement cost (23), CVM (17)
	Sediment retention	-
	Water quality improvement	Replacement cost (31), CVM (16)
	Micro-climate stabilization	-
	Regulation of greenhouse gases	-

HP = hedonic pricing; CVM = contingent valuation method; TCM = travel cost method; NFI = net factor income

Note: In brackets is the number of observations for each wetland service according to the most commonly used valuation methods

The ecological status of a wetland may respond to the presence of environmental stressors. Since direct observations on this are lacking for most of the wetlands in the data set, an index accounting for the degree of pressure exerted by human activities on the wetland is constructed and introduced as one of the wetland characteristics in the meta-regression model. The index may be interpreted as a broad, landscape assessment of ecological conditions of a wetland (Fennessy et al., 2004). The index is a composite one that takes into account, with equal weights, the presence of alterations in the natural hydrologic regime of the wetland (as induced, for instance, by the construction of dikes to regulate the water level in the wetland), the density of urban and agricultural area in the immediate surroundings of the wetland, and the status of protection of the site (viz. Ramsar site, national park, nature reserve or not protected). The index assumes a minimum value equal to zero for unaffected wetlands and a maximum value equal to 3 for the most heavily impacted ones. Table 3 describes in more detail the scoring procedure followed for each of the three criteria on which the

index is based. Scores are aggregated using simple additive weighting, equal weights being given to each criterion.

Table 3. Suggested criteria for assessing the presence of environmental stressors on the valued wetland sites

Criterion	Variable type	Values	
Hydrology	Nominal	= 0	for natural hydrology
		= 1	for heavily modified hydrology
Level of protection	Ordinal	= 0	for Ramsar sites and national parks
		= 0.5	for natural reserves
		= 1	for not protected wetland sites
Urban and agricultural land uses	Ratio	density of urban and agricultural areas within a distance of twice the average wetland radius from the wetland centre[a]	

[a] Density calculated applying GIS techniques to the Global Land Cover 2000 map (JRC, 2003)

The capacity of a wetland to support high biodiversity levels is among the wetland functions that are potentially affected by the presence of stressors. In Figure 2, biodiversity at the species level is plotted against the index of pressure in the wetlands for which this information is available. The index is negatively correlated with the number of species of fish and mammals present in the wetlands. The correlation with amphibians/reptiles species and bird species is low and not statistically significant. For bird species, this may be due to the fact that they are less sensitive to the ecological conditions in the wetlands due to their higher mobility.

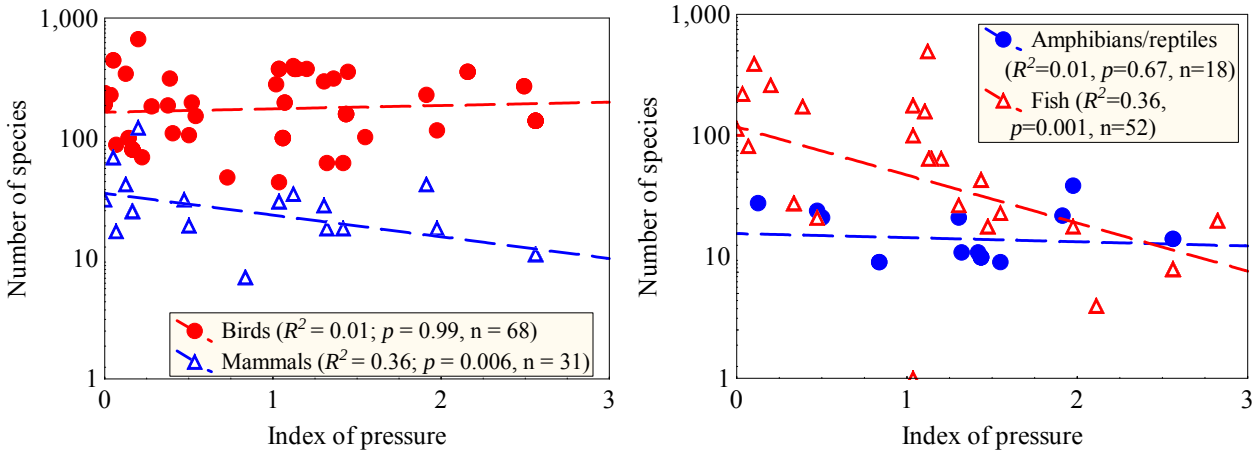

Figure 2. Index of environmental pressure plotted against the animal biodiversity at species level (n = number of wetlands for which biodiversity data is available)

Context characteristics (X_C). Environmental valuation studies carried out at different geographical sites and involving populations with different socio-economic characteristics and consumer preferences typically produce different outcomes (Brouwer, 2000). Context characteristics are

expected to significantly influence the valuation estimates. Three context variables are included in the meta-regression model: Gross Domestic Product (GDP) per capita, population living in the surroundings of the wetland, and wetland abundance.

The values of GDP per capita used in the meta-regression are estimated in US$ referring to the year 2003 and calculated at country level with the exception of observations from the US, for which values are calculated at the state level (World Bank, 2006). The socio-economic characteristics of the population residing in the vicinity of the wetlands in the database vary across different observations. This is reflected by the large variations in average real GDP per capita, which ranges from 616 US$ 2003 per person per year in Cambodia[1] to 47,547 US$ 2003 per person per year in Massachusetts, US.

The total population living in a radius of 50 km around the wetland centre is estimated applying GIS techniques to the Global Demography Project map (CIESIN, 2005), which contains geographically referenced information of world population in the year 2000.

The total wetland area in a radius of 50 km around the wetland centre reflects the uniqueness of a wetland environment and may explain the influence of people's perceptions and preferences due to the presence of other sites that can act as a substitute for some of the services provided. The area of nearby wetlands was estimated applying GIS techniques to the Global Lakes and Wetlands Database map (Lehner and Döll, 2004). This study is the first to account for the possible impact of substitution effects in determining economic values of wetlands.

Unlike previously published meta-analyses of wetland valuation, in this study the geographical location of the wetland site is not included in the meta-regression model. Significant correlations are found in fact between the geographical location, the services and goods valued and the valuation method applied. For instance, studies valuating the recreational hunting service tend to be concentrated in North America, while provision of materials and fuel wood are valued in South America, Asia and Africa more often than in North America and Europe. The possible influence of the geographic location on the values estimated with the meta-regression is assessed in more detail in Section 4.

Standardization of values. To allow for a comparison between wetland values that have been calculated in different years and expressed in different currencies and metrics – e.g. willingness to pay (WTP) per household per year, capitalized values, and marginal value per acre – standardization to common metric and currency is needed. WTP per household per year cannot be used as a common metric since several of the valuation methods used in the literature – e.g. net factor income, opportunity cost, replacement cost, and market prices – do not produce WTP per

person estimates. On the other hand WTP per person can be converted to a value per hectare per year if the relevant population is known. Values were thus standardized to 2003 US$ per hectare per year, following Woodward and Wui (2001) and Brander et al. (2006). Values referring to different years were deflated using appropriate factors from the World Bank Millennium Development Indicators (World Bank, 2006), while differences in purchase power among the countries were accounted for by the Purchase Power Parity index provided by the Penn World Table (Heston et al., 2006).[2]

Figure 3 provides some summary descriptive statistics of the variability of wetland values, expressed in 2003 US$, according to wetland size and context characteristics. Positive correlation with the wetland value is found for GDP per capita and total population living in a 50 km radius around the wetland centre, and negative correlation for wetland size and wetland area within a 50 km radius. As indicated by the low values of the goodness of fit (R^2), however, none of the variables alone can explain a large proportion of the variation in the values.

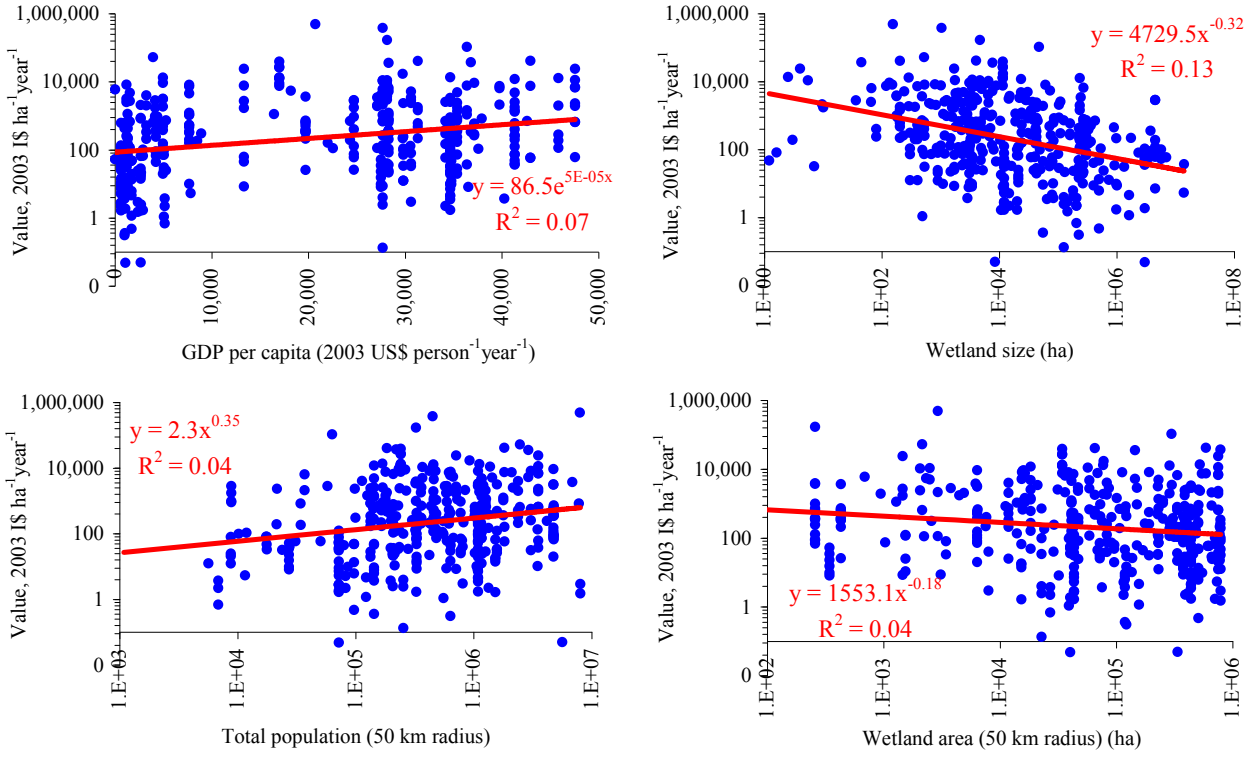

Figure 3. Standardized wetland value plotted against real GDP per capita (above left), *wetland size* (above right), *total population* (below left) *and total wetland area* (below right) *in a 50 km radius from the center of the valued wetland site.*

3. Results of the basic meta-regression model and comparison with the previous meta-analyses

The results obtained with the meta-regression model described in equation (1) using ordinary least squares (OLS) are presented in Table 4. In this (largely) semi-logarithmic model, the coefficients measure the constant proportional or relative change in the dependent variable for a given absolute change in the value of the explanatory variable. For the explanatory variables expressed as logarithms, the coefficients represent elasticities, that is, the percentage change in the dependent variable given a one-percentage change in the explanatory variable.

Table 4. Results obtained with the basic meta-regression model of wetland values

	Variable	Coefficient	*p*-value
	Constant	3.522*	0.059
Study variables	Contingent valuation method	0.092	0.871
	Hedonic pricing	–2.959**	0.011
	Travel cost method	–0.440	0.424
	Replacement cost	–0.724	0.180
	Net factor income	–0.301	0.545
	Production function	–0.780	0.170
	Market prices	–0.684	0.149
	Opportunity cost	–1.417*	0.091
	Choice experiment	0.340	0.704
	Year of publication	–0.048**	0.011
	Marginal	0.955**	0.015
Wetland variables	Estuarine	0.320	0.303
	Marine	1.110***	0.000
	Riverine	0.308	0.275
	Palustrine	–0.191	0.526
	Lacustrine	0.336	0.296
	Man-made	1.230***	0.004
	Wetland size	–0.241***	0.000
	Urban	0.970***	0.003
	Flood control and storm buffering	0.704*	0.054
	Surface and groundwater supply	0.100	0.804
	Water quality improvement	0.625	0.122
	Commercial fishing and hunting	0.206	0.471
	Recreational hunting	–1.115***	0.003
	Recreational fishing	0.124	0.745
	Harvesting of natural materials	–0.309	0.318
	Fuel wood	–1.320***	0.002
	Non-consumptive recreation	0.121	0.737
	Amenity and aesthetics	0.725	0.110
	Biodiversity	0.426	0.305
	Environmental pressure	0.444***	0.005
Context variables	GDP per capita	0.239**	0.048
	Population in 50km radius	0.275***	0.000
	Wetland area in 50km radius	–0.146***	0.000

OLS results. $R^2 = 0.48$; *Adj.* $R^2 = 0.43$. Significance is indicated with ***, ** and * for 1, 5 and 10% statistical significance levels respectively.

The values of R^2 (= 0.48) and adjusted R^2 (= 0.43) are reasonably high. With respect to the previously published meta-analyses, the explanatory power is higher than in Brouwer et al. (1999) (R^2 = 0.38) and slightly lower than those of Woodward and Wui (2001) (R^2 = 0.58 for meta-regression model C) and Brander et al. (2006) (R^2 = 0.55; *Adj.* R^2 = 0.45).

Of the study characteristics, the valuation methods are not statistically significant with the exception of hedonic pricing and opportunity cost, whose coefficients are both significant and negative. The number of studies applying these methods is, however, small (5 and 9 observations respectively). Table 4 shows relatively high values for studies with stated preference methods (contingent valuation and choice experiment). This confirms the observation by Brander et al. (2006) who found high values for contingent valuation studies, but contrasts with the results of Woodward and Wui (2001) who observed high values for studies using hedonic pricing and replacement cost as valuation method.

The coefficient on the year of publication is slightly negative, which indicates that valuation studies published in recent years tend to provide smaller estimates than older studies. This might reflect changes occurred in the valuation techniques – e.g. contingent valuation method – or changes in people's preferences with respect to wetland services. Marginal values are higher than average values (cf. Brander et al., 2006).

Wetland type significantly affects the value. Palustrine wetlands produce low values compared to the other kinds of wetlands, whose coefficients are all positive. Man-made and marine wetlands are the most highly valued wetland types. A possible explanation for the high value of man-made wetlands is that artificial ecosystems are usually constructed with the goal of providing a specific service for human use and benefits. The coefficients on wetland types confirm the finding by Brander et al. (2006) that marine wetlands have higher values than natural freshwater wetlands, but are in contrast with the results by Brouwer et al. (1999), who found comparable values for the two types of wetlands.

The negative coefficient on wetland size indicates decreasing returns to scale and urban wetlands have higher values than rural wetlands. Both these observations confirm the results obtained by previous meta-analyses (cf. Woodward and Wui, 2001; Brander et al., 2006).

Of the wetland functions, the coefficients on fuel wood and hunting are negative, while the coefficient on flood control and storm buffering is positive. High, positive values are found also for amenity and aesthetics, water quality improvement, and biodiversity even though the respective coefficients are not statistically significant.

The coefficient on the index of environmental pressure is positive, which indicates that a higher pressure of human activities on the wetland produces higher values. Possible explanations for this

are that human activities contribute to translate potential uses into values or that human interventions in a wetland often improve the level of provision of specific wetland services, such as water quality improvement in the case of treatment man-made wetlands. Furthermore, wetlands surrounded by densely populated areas – thus with high environmental pressure according to the index proposed in this study – are likely to be relatively easily accessible for the enjoyment of their recreational values. A high pressure of human activities on a wetland, however, raises questions about the temporal sustainability of wetland values. Such questions, regrettably, cannot be addressed with the temporal snapshots of values that can be inferred from the valuation studies.

All three context variables are statistically significant. Wetland values are positively related both to GDP per capita – the coefficient between 0 and 1 indicating an inelastic income effect – and to the population living in the surrounding of the valued wetland site. On the other hand, there is a negative relationship between the proximity of other wetlands and the value of the wetland, which suggests the presence of substitution effects for at least some of the wetland services.[3]

4. Results of the extended meta-regression models

4.1 Extended model with cross-effects: wetland types and wetland services

To further investigate the level of provision of specific wetland services according to the different kinds of wetland types included in the data set, the basic model was extended to include dummy variables capturing 66 cross-effects (11 wetland services multiplied by 6 wetland types) in addition to the study and context characteristics discussed for the basic meta-regression model. The use of cross-products in meta-analysis has been suggested to reflect the interactions between explanatory variables.

Table 5 illustrates the results obtained with the extended model. The focus is on the cross-effect variables as the signs and statistical significance of the coefficient estimates for study and context variables remain unchanged as compared to the basic meta-regression model, with the exception of the coefficients of the variables GDP per capita and marginal (which now become statistically significant at the 1% level), hedonic pricing and the constant (which become statistically insignificant), replacement cost, net factor income, market prices and opportunity cost (whose coefficients change sign but remain statistically insignificant).

Table 5. Coefficients of the cross-effects variables in the extended model

Wetland service \ Wetland type	Estuarine	Marine	Riverine	Palustrine	Lacustrine	Man-made
Flood control and storm buffering	0.35	1.28*	0.77	–0.81	–1.52	2.25**
Surface and groundwater supply	–0.48	1.37	–0.25	–0.32	1.07	1.70*
Water quality improvement	3.59***	0.86	–0.02	0.80	–0.72	0.77
Commercial fishing and hunting	0.19	0.76	1.30**	–1.79**	0.15	0.05
Recreational hunting	–0.13	–0.11	–0.82	–0.24	–0.78	0.07
Recreational fishing	0.21	–0.68	0.32	–0.37	1.29	–1.35
Harvesting of natural materials	–0.84*	0.69	–0.45	0.62	–0.40	–0.11
Fuel wood	–1.34**	–0.14	0.70	–3.40**	–2.05	- -
Non-consumptive recreation	–0.20	–0.20	0.52	0.31	0.84	0.36
Amenity and aesthetics	1.44	0.15	–0.46	0.68	–0.98	–0.62
Biodiversity	0.13	1.87*	0.07	–0.88	–0.01	1.87*

- - = not applicable. OLS results. R^2 = 0.57; *Adj.* R^2 = 0.45. Significance is indicated with ***, ** and * for 1, 5 and 10% statistical significance levels respectively.

The analysis of the results of the extended model allows making some interesting remarks both in terms of identifying (i) the wetland types that produce the highest and lowest value for a specific wetland service and (ii) the most and least valued services for each wetland type.

Focusing first on specific wetland services, it can be noted that while according to the basic meta-regression model the coefficient of 'commercial fishing and hunting' is not statistically significant, in the extended model this service is more highly valued in riverine wetlands, and less highly in palustrine wetlands.

Both 'flood control and storm buffering' and 'biodiversity' are most highly valued in marine and man-made wetland ecosystems. Riverine wetlands also provide relatively highly valued flood control services but lower biodiversity values. Palustrine and lacustrine wetlands both provide relatively low-valued and not statistically significant flood control and biodiversity services.

With regard to non-consumptive recreational activities and recreational fishing, the highest values are provided by lacustrine and riverine wetlands. Man-made wetlands provide the lowest values for recreational fishing. Marine wetlands produce low values both for non-consumptive recreational activities and recreational fishing.

Turning attention to the specific wetland types, Table 5 reveals that palustrine wetlands produce relatively high values for amenity and aesthetics, water quality improvement, and harvesting of natural materials but low values for fuel wood and commercial hunting and fishing.

Due to the fact that man-made wetlands are usually purposefully built to provide benefits such as flood control and storm buffering, surface and groundwater supply, and water quality improvement it is not surprising that these ecosystems provide high values for these services and lower values for recreational fishing, amenity and aesthetics, and harvesting of natural materials. Remarkably

though, man-made wetlands produce high values also for biodiversity enhancement, which is usually not a primary goal of the construction of such artificial ecosystems.

4.2 Multi-level extended models: authorship effect and geographic location

As a further step of the meta-analysis, a multi-level model (MLM) is used to relax the assumption of independent observations and examine hierarchies within the data, such as similarity of estimates produced by the same author or in the same geographic region. The estimated model is:

$$\ln(y_{ij}) = \alpha + \beta_S X_{Sij} + \beta_W X_{Wij} + \beta_C X_{Cij} + u_j + e_{ij} \quad (2)$$

where the subscript *i* identifies the observation and subscript *j* the author or geographic region; α is the constant term; X_S, X_W and X_C are variables capturing, respectively, characteristics of the study, wetland and context; β_S, β_W and β_C are vectors containing the coefficients of the respective explanatory variables; u_j is a vector of residuals at the second (author/region) level; e_{ij} is a vector of residuals at the first (observation) level. In this equation, both u_j and e_{ij} are random variables with means equal to zero. It is assumed that these variables are uncorrelated and that they follow a Normal distribution. Six regions are considered in the analysis: Africa, Asia, Australasia, Europe, North America and South America.

The influence of authorship effects and of the geographic regions on estimated values is examined using a likelihood ratio test, for which the null hypothesis is that the variance of the residuals *u* (σ^2_u) is equal to zero. The above estimated model is compared with a model where σ^2_u is constrained to equal zero, i.e. a single level model. If the variance of the second level error term is significantly different from zero we conclude that there is significant variation in mean values between authors or geographic regions.

The value of the likelihood ratio statistic is 1566.401 – 1477.539 = 88.862. Comparing this to a chi-squared distribution with 1 degree of freedom, it is concluded that there are real differences between the mean value estimates produced by different authors. In other words, value estimates from a particular author tend to be more similar than estimates drawn from different authors. This result contrasts with that of Bateman and Jones (2003), who find no evidence of authorship effects in their meta-analysis of woodland recreation values in the UK. On the other hand, the contribution of the geographic regions to explain the residuals at the second level is insignificant, which supports the decision not to include dummies for the geographical regions in the basic meta-regression.

5. Conclusions

The present study provides the most comprehensive review of wetland valuation studies up to date, using statistical meta-analysis techniques. It contributes to the identification of the main determinants of wetland values. The data set includes 385 observations from 180 wetland sites worldwide, which were derived from 167 studies.

The location of the valued sites reflects a shift in the geographical scope of valuation studies that occurred over the last decade. With respect to the previous literature reviews and meta-analyses of wetland values, the data set is much less biased towards North America and includes a large number of studies from other regions, in particular from Europe, Asia and Africa.

A meta-regression was performed to identify and estimate the relative importance of the determinants of wetland values. The regression function includes variables that reflect characteristics of the valuation study, the wetland site, and the socio-economic and geographical context. Three models were investigated: a basic meta-regression model and two extended models exploring the presence of interactions between wetland types and services, authorship effects, and interdependency of estimates from the same geographic region.

Of the characteristics, the valuation method used in the primary studies contributes relatively little to explaining the value of the wetlands in the data set. On the other hand, studies estimating marginal values produce higher values than studies producing average wetland values. Studies published in recent years tend to produce smaller values than older ones. This might reflect changes occurred in the evaluation techniques – e.g. contingent valuation method – or changes in people's preferences with respect to wetland services. Authorship effects also contribute to explain differences in wetland value estimates.

The importance of wetland type, size and valued service is confirmed by the statistical significance of the coefficients found for the relative explanatory variables. *Ceteris paribus*, palustrine wetlands produce lower values than other wetland types, while provision of flood control and storm buffering, amenity and aesthetics, and biodiversity are the most highly valued services. With respect to wetland size, decreasing returns to scale are identified. Urban wetlands have a higher value than rural ones most likely due to better accessibility for a large number of people.

An index of environmental pressure of human activities on wetlands was developed for this study. It leads to the conclusion that wetland values increase with human pressures and uses. This is probably linked to an improved level of provision of specific services and the intensity of use of wetlands. Questions about the sustainability of the uses and values reported in the valuation studies for wetlands with high environmental pressure cannot, however, be answered due to the temporal snapshot that such studies typically provide.

The socio-economic and geographical context is also relevant in explaining the variability of wetland values. The coefficient of the explanatory variable GDP per capita suggests an inelastic income effect. Wetland values are positively correlated with the population residing in the surrounding of the wetland. An important contribution of this paper is to show that the proximity of other wetlands negatively affects the value of the site. This suggests that nearby wetlands may act as substitute sites for at least some of the services valued.

The analysis indicates that values for specific services vary according to the type of wetland that produces them. The value of wetlands as nursery habitat for commercial hunting and fishing is higher in riverine wetlands than in palustrine ones. Lacustrine wetlands produce high values for surface and groundwater supply, non-consumptive recreational activities, and recreational fishing, while palustrine wetlands produce relatively high values for amenity and aesthetics, water quality improvement, and harvesting of natural materials.

For the first time, man-made wetlands are included in a meta-analysis of wetland values. As expected, man-made wetlands provide high benefits for flood control and storm buffering, surface and groundwater supply, and water quality improvement. On the other hand they provide low benefits for recreational fishing, amenity and aesthetics, and harvesting of natural materials. Remarkably, man-made wetlands are also found to produce high values for biodiversity enhancement, which is usually not a primary goal of the construction of such artificial ecosystems.

Notes

1. Value expressed in current market exchange rates for the year 2003.
2. This study differs from previous meta-analyses in its treatment of non-US observations that are expressed in US$ in the primary studies. Such values are first converted to local currency using exchange rates of the year of the study and only subsequently deflator factors and purchase power parity indexes are applied to obtain standardized values.
3. Since the data set and the meta-regression model used by Brander et al. (2006) provided the starting point for the analysis, we investigated how the enlargement of the data set from 202 to 385 observations would have affected the predictive power of the original model used by Brander. The results of the comparative analysis show that the goodness of fit of Brander's model is reduced after enlarging the data set (Adj. R^2 = 0.40, previously 0.45). The shift in the geographical scope obtained with the introduction of a large number of observations from Europe, Asia and Africa, affects significantly also the coefficients relative to the geographical location of the valued wetlands. The coefficient for European observations becomes statistically significant and positive. This indicates higher values for European wetlands than for North American ones – which are included as reference wetlands in the constant term of the model. The coefficients on Asian, African, and Australasian wetlands, on the other hand, decrease with respect to the results in Brander et al. (2006) and are not significantly different from the reference North American wetlands.

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