Ecological Engineering xxx (2013) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

Economic valuation of regulating services provided by wetlands in agricultural landscapes: A meta-analysis

Luke Brander[a,b,*], Roy Brouwer[a], Alfred Wagtendonk[c]

[a] Department of Economics, Institute for Environmental Studies, VU University Amsterdam, The Netherlands
[b] Division of Environment, Hong Kong University of Science and Technology, Hong Kong
[c] Department of Spatial Analysis and Decision Support, Institute for Environmental Studies, VU University Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 5 November 2011
Received in revised form 31 October 2012
Accepted 12 December 2012
Available online xxx

Keywords:
Wetlands
Regulating services
Agricultural landscapes
Valuation
Meta-analysis

ABSTRACT

This paper presents a meta-analysis of the economic valuation literature on ecosystem services provided by wetlands in agricultural landscapes. We focus on the value of three regulating services, namely flood control, water supply and nutrient recycling. We construct a database containing 66 value estimates, mainly for wetlands in the US and Europe but also a substantial number in developing countries. Values are standardised to USD per hectare per year. The mean (median) values are found to be 6923 (427) USD/ha/yr for flood control; 3389 (57) USD/ha/yr for water supply; and 5788 (243) USD/ha/yr for nutrient recycling. The values of these services are highly variable across individual wetland sites due to, amongst other factors, differences in wetland type, size, the scarcity or abundance of other wetlands in the surrounding landscape, and the socio-economic characteristics of the beneficiaries of these services. We include explanatory variables in the meta-analysis to account for these influences on estimated wetland values. GIS is used to quantify potentially important spatial variables. The meta-regression is used to produce a value function for wetland regulating services, which can be used to transfer values to other wetland sites while controlling for site and context specific characteristics. An illustrative value transfer exercise is conducted to estimate global values for wetland regulating services in agricultural landscapes.

1. Introduction

Wetlands in agricultural landscapes provide many valuable ecosystem services (ES) that contribute to human wellbeing, including provisioning (e.g., food, fuelwood, water), regulating (e.g., flood control, water quality, water supply), habitat (e.g., biodiversity), and cultural services (e.g., recreation, aesthetic, non-use) (TEEB, 2010). Many of these wetland services have the characteristics of 'public goods' such that beneficiaries cannot be excluded from receiving the service provided and that the level of consumption by one beneficiary does not reduce the level of service received by another. This is generally the case for services such as flood control, nutrient removal and groundwater recharge. Due to these characteristics (non-excludability and non-rivalry in consumption), the potential for private incentives to sustainably manage wetland services is limited and markets for such services do not exist. As a result, wetland ES may be undervalued in decisions regarding the conversion of privately owned wetlands to other productive uses that generate marketable goods and services (e.g., agriculture). The lack of understanding of, and information on, the value of wetland services has generally led to their omission in public decision making regarding the conservation of wetlands. Without information on the economic value of wetland services that can be compared directly against the monetary value of alternative public investments, the importance of wetland natural capital has tended to be ignored.

In response to this lack of information on the market value of wetland services, there is a large and expanding literature that employs non-market valuation approaches to estimate the economic value of wetland services.[1] Reviews and meta-analyses of this literature are provided by Brouwer et al. (1999), Woodward and Wui (2001), Brander et al. (2006) and Ghermandi et al. (2010). As expected, the estimated values for wetland ES have

* Corresponding author at: Unit 2408, Block F, 9-11 Hong Shing street, Quarry Bay, Hong Kong. Tel.: +852 6114 3126.
E-mail address: lukebrander@gmail.com (L. Brander).

[1] Detailed information on the underlying theory and practical implementation of non-market valuation techniques can be found in a number of texts including Braden and Kolstad (1991), Hanley and Spash (1993), Pearce et al. (1994) Bromley (1995), and Freeman (2003).

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http://dx.doi.org/10.1016/j.ecoleng.2012.12.104

been shown to vary enormously and these earlier meta-analyses have attempted to identify factors that help explain this variation. A potential critique of these earlier studies is that they have attempted to incorporate values for too broad a range of wetland ES, which are difficult to compare and in some cases overlap. It is possible that the values of different ES will be influenced by different determining factors or even that certain factors might have opposing effects on values for different ES. There is a need, therefore, for analyses of limited sets of wetland services in order to reduce the considerable heterogeneity in the value data and identify ES specific determinants of value. For this reason, we focus the analysis presented in this paper on three regulating services, namely flood control, water supply and water quality. The objective of this meta-analysis is to identify and quantify the factors that influence the value of wetland regulating services in agricultural landscapes and to examine the potential for using the resulting value function to "transfer" values to currently unvalued wetland sites in an agricultural setting.

The structure of the paper is as follows. Section 2 provides an overview of the available economic valuation literature on wetland regulating services in agricultural landscapes; Section 3 presents a statistical meta-analysis of this data and interprets the results; Section 4 examines the potential for using the estimated meta-regression model for value transfer and conducts an illustrative transfer exercise for global wetlands; Section 5 discusses the policy applications for valuation information in general and provides some conclusions.

2. Overview of values for wetland regulating services

Building on the databases of economic value estimates for wetland ES developed and described by Brander et al. (2006) and Ghermandi et al. (2010), we conduct a review of the current available knowledge on the value of wetland regulating services in agricultural landscapes.

Of the 400 wetland valuation studies reviewed, we find 38 that provide estimates of values for regulating services that can be directly compared in a statistical meta-analysis. The criteria for determining the inclusion of a study in the meta-analysis are: (1) the study provides one or more estimates of value for regulating services that can be standardised in terms of monetary units per area of wetland; (2) each estimated value is for a single regulating service or combination of regulating services[2]; (3) the wetland study site is located in an agricultural landscape[3]; and (4) the geographic coordinates for the location of the wetland study site are provided or can be determined from the location description.[4]

The locations of the 38 selected wetland study sites are presented in Fig. 1, illustrating that some regions are better represented in the data than others. There are 11 studies each for North American and European wetlands, 10 studies for African wetlands, 5 studies for South Asian wetlands, and a single study included in the data for freshwater wetlands in the Island of Kosrae in the Federated States of Micronesia. We were unable to include any studies for Latin America, most of Asia and Oceania.[5] The spatial distribution of valuation studies is not a representative sample of the stock of global wetlands.

Table 1
Primary valuation studies and wetland regulating services valued.

Author	Year	Flood control	Water supply	Water quality
Acharya	2000		X	
Acharya and Barbier	2000		X	
ACSA	1996	X	X	X
Barbier et al.	1997		X	
Barbier et al.	1991		X	
Benessiah	1998		X	
Breaux et al.	1995			X
Byström	2000			X
Cardoch et al.	2000			X
Costanza et al.	1989	X		
de Groot	1992	X		X
Drew et al.	2005		X	
UK Environment Agency	2000	X		
UK Environment Agency	1999	X		
Emerton et al.	1998		X	X
Farber	1987	X		
Folke	1991		X	X
Gerrard	2004	X		X
Gren et al.	1995	X		
Gren and Söderqvest	1994			X
Gupta and Foster	1975	X	X	
Hovde and Leitch	1994	X		
Islam and Braden	2006		X	
IUCN	2005		X	
Karanja et al.	2001		X	X
King and Lester	1995	X		
Ko et al.	2004			X
Ledoux	2003	X		
Leitch and Hovde	1996	X	X	X
Leschine et al.	1997	X		
Loth	2004		X	
Meyerhoff and Dehnhardt	2004			X
Schultz and Leitch	2001	X		
Schuyt	2002		X	
Thibodeau and Ostro	1981	X		X
Turpie et al.	1999	X	X	X
Verma	2001		X	X
Vidanage et al.	2004		X	

From the 38 selected studies we are able to obtain 66 separate value estimates. Multiple value estimates are taken from single studies if they represent different wetlands or services. These are distinctions that are explicitly controlled for in the meta-analysis. Table 1 lists the primary valuation studies included in the meta-analysis and the wetland ES that are valued.

In terms of the valuation methods used to estimate regulating service values, the most commonly applied approach has been to estimate the cost of replacing the service with man-made infrastructure. For example, the retention of flood water by a wetland might be valued as the cost of constructing flood control measures that provide the same level of protection; or the value of water quality improvement by a wetland might be estimated using the cost of equivalent water treatment methods. The estimation of avoided damage costs due to flood water retention by wetlands has been used in a small number of cases. Market prices have also been used as a proxy for the value of wetland regulating services. This is particularly the case for the valuation of the role wetlands play in the supply of water. The production function and net factor income valuation methods, which value ES as inputs in the production of marketed goods, have been used primarily for valuing

[2] Value estimates for bundles of ES that combine regulating services with other ES were excluded. For this reason, a number of values estimated using the contingent valuation method that also capture direct use values such as recreation were excluded from the meta-analysis.

[3] This was determined from the wetland study site description provided in each study.

[4] The location of each study site is subsequently used to quantify a number of spatially defined context variables using a GIS. These variables are described in Section 3.

[5] This is in part due to our inability to access study results for these regions that are not in English.

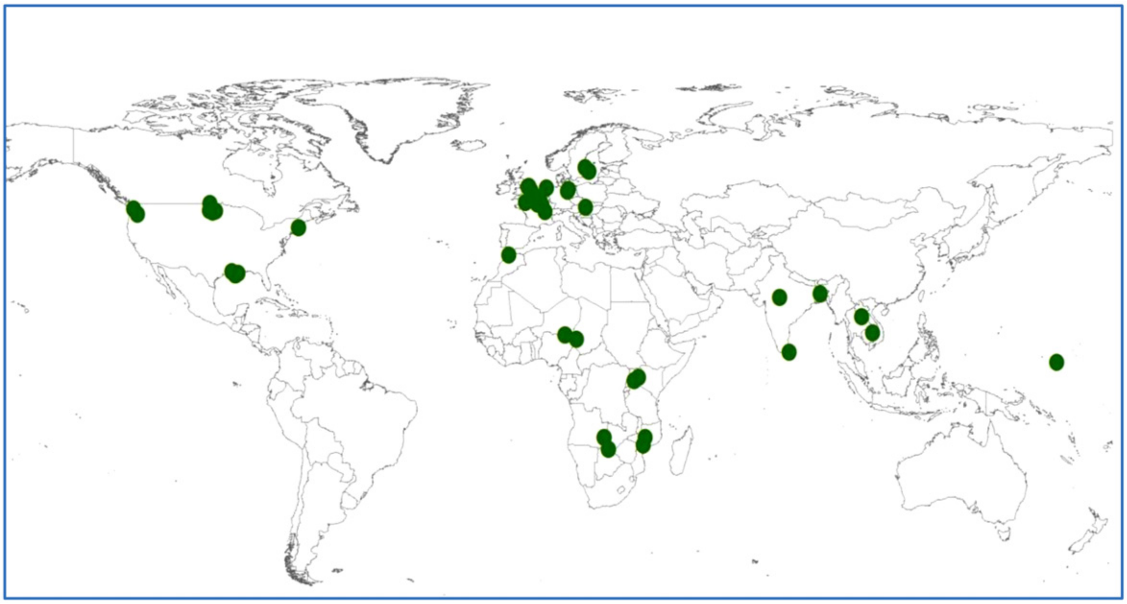

Fig. 1. Location of valuation study sites.

water supply as an input to agriculture. It is recognised that certain valuation methods are applied predominantly to value one ES; this potentially has implications for identifying separate effects in the meta-analysis due to collinearity.

It is noted that the valuation methods that have been applied to value wetland regulating services do not all have a sound basis in economic welfare theory. An important distinction is made between those valuation techniques that estimate benefits directly and those that estimate costs as a proxy for benefits. For instance, estimating replacement costs or damage costs avoided as part of an economic valuation exercise suggests that the costs are a reasonable approximation of the benefits that society attributes to the resources in question. The underlying assumption, which may not always be valid, is that the benefits are at least as great as the costs involved in repairing, avoiding or compensating for damage. These techniques are widely applied due to the relative ease of estimation and availability of data, but it is important to be aware of the limitations in terms of the information they convey with respect to economic benefits.

Regarding the wetland regulating services that have been valued, we find that the number of estimations in our sample for flood control, water supply and water quality services is almost equal. Table 2 gives the number of value observations for each service together with the mean and median values. The valuation results of the primary studies are reported in a variety of different currencies, units and price levels. We standardised values to USD/ha/year in 2007 prices using purchasing power parity (PPP) adjusted exchange rates and GDP deflators from the World Bank World Development Indicators (World Bank, 2010). 2007 was used as the base year as this is the most recent year for which all necessary conversion factors were available. In a small number of cases, value estimates are for a bundle of two or more services and for this reason the sum of estimates in Table 2 is higher than the sample size used in the meta-analysis. For all three regulating services, the mean value is considerably higher than the median, suggesting that the distribution of values is skewed to the right with a tail of high values. This also suggests that values for these services are highly variable, and it is the determinants of this variability that we attempt to identify in the meta-analysis.

Table 2
Mean and median values by wetland regulating service and continent (US$/ha/year; 2007 prices).

	N	Mean	S.E. of mean	Median
Flood control	26	6923	3186	427
Water supply	26	3389	2015	57
Water quality	27	5788	3131	243
North America	20	4224	1543	583
Europe	19	15,339	5692	3706
Africa	20	393	336	13
Asia	6	2937	1460	1470
Australasia	1	2049	-	2049

3. Meta-analysis of values for wetland regulating services

Meta-analysis is a method of synthesising the results of multiple studies that examine the same phenomenon, through the identification of a common effect, which is then 'explained' using regression techniques in a meta-regression model (Stanley, 2001). Meta-analysis was first proposed as a research synthesis method by Glass (1976) and has since been developed and applied in many fields of research, not least in the area of environmental economics (Nelson and Kennedy, 2009). It is widely recognised that the large and increasing literature on the economic value of ES has become difficult to interpret and that there is a need for research synthesis techniques, and in particular statistical meta-analysis, to aggregate information and insights (Stanley, 2001; Smith and Pattanayak, 2002; Bateman and Jones, 2003). In addition to identifying consensus in results across studies, meta-analysis is also of interest as a means of transferring values from studied sites to new policy sites (Rosenberger and Phipps, 2007); this potential application of meta-analysis is addressed in detail in Section 4.

In this paper we conduct a meta-analysis to identify and quantify the key determinants of the economic value of regulating services from wetlands in agricultural landscapes. Based on the specifications of previous meta-analyses of wetland values and on theoretical expectations we define three groups of explanatory variables that represent different determinants of variation in value, namely the characteristics of each wetland site, characteristics of the bio-physical context of each wetland,

and the socio-economic characteristics of the population of ES beneficiaries.[6]

Regarding study site characteristics, we define variables indicating the type of wetland,[7] the ES that is valued, and the size of the wetland in hectares. Our expectations for the effect of wetland type on the value of regulating services is that created wetlands will tend to have higher values than natural wetlands, largely because created wetlands have been specifically designed and located for this purpose in the agricultural landscape. We have no a priori expectations for the relative value of the three services that we examine in the analysis. There is also no clear a priori expectation for the sign of the relationship between wetland size and its value per unit area. On one hand there may be diminishing marginal returns to increases in wetland area for regulating services, but on the other hand most ES require minimum thresholds of wetland area, which implies that values would increase with scale.

For the bio-physical context characteristics we use GIS to define three potentially important spatial variables for the vicinity of each study site, namely the total area in hectares of other wetlands, the human appropriation of net primary product,[8] and the density of roads.[9] These variables were defined at three spatial scales (within 10, 20 and 50 km radii of the centre of each study site) since a priori we do not know at what scale these potential determinants of wetland service value operate. We then test alternative scales of measurement in the meta-regression to empirically determine the appropriate scale for each variable.[10] The total area of other wetlands in the vicinity of a valued site represents the abundance (or conversely the scarcity) of substitute wetland sites that might provide the same service. We would therefore expect that the value of wetland services provided by each valued site will tend to be lower when the abundance of other wetlands is higher. The variable measuring the human appropriation of net primary product potentially reflects the degree of human disturbance in the landscape or the intensity of agricultural production. As such, we might expect on the one hand a positive relationship between this variable and the value of regulating services since the flood control, water supply and water quality functions of wetlands are also likely to be more intensively utilised. On the other hand, a negative relationship could also be possible if the wetland service is degraded due to overexploitation and hence less productive. The density of roads variable is intended to capture fragmentation effects on the provision of regulating services, and as such we expect a negative relationship between road density and value.[11]

The variables representing the socio-economic characteristics of the beneficiaries of wetland regulating services are the population[12] (again defined within 10, 20 and 50 km radii of the centre of each study site) and the gross cell product (GCP), which is a spatially disaggregated measure of economic activity equivalent to gross domestic product (GDP).[13] The population variable is intended to capture the number of people that potentially benefit from regulating services provided by each study site. As such we expect a positive relationship between population and wetland value. The GCP variable provides a crude measure of income for beneficiaries of ES within the vicinity of each study site and we therefore expect to find the theoretically derived, and empirically supported, positive relationship between income and the provision of normal goods. GCP may also reflect the value of economic activity that is protected by wetlands from flood damage, in which case we would also expect a positive relationship with this regulating service value.

A number of alternative model specifications were investigated before defining the estimated meta-regression model given in Eq. (1). The dependent variable (y) in the meta-regression is a vector of values in US$ per hectare per year in 2007 prices. The explanatory variables are the site characteristics X^S (i.e., wetland type, service, wetland size), the bio-physical context characteristics X^C (i.e., area of wetland substitute sites),[14] and the socio-economic characteristics of the service beneficiaries X^E (i.e., population within 50 km, Gross Cell Product). The vectors β^S, β^C and β^E contain the estimated coefficients on the respective explanatory variables; α is the constant term; and μ is a vector of residuals with assumed well behaved underlying errors (i.e., normally and independently distributed with a mean of zero and constant variance). The natural logarithms of the continuous variables (indicated in Table 3) were used in order to improve model fit and mitigate heteroskedasticity.

$$y = \alpha + \beta^S X^S + \beta^C X^C + \beta^E X^E + \mu \qquad (1)$$

The results for the estimated meta-regression model are given in Table 3. A series of diagnostic tests were performed in order to test the robustness of the OLS estimation. The Shapiro–Wilk test (p level = 0.684) does not reject the assumption of normally distributed residuals. Similarly, the null hypothesis of homogenous variance of the residuals cannot be rejected by White's test for heteroskedasticity (White's statistic = 11.414). The adjusted R^2 statistic indicates that almost 60% of the variation in the dependent variable is explained by the explanatory variables, which is relatively high

[6] It is also common practice in meta-analyses of economic valuation results to include a set of explanatory variables that capture the methodological characteristics of each valuation study (e.g. valuation method, sample size, author etc.). We did not include methodological variables in this analysis for two reasons: (1) for the data that we use, valuation methods are found to be highly correlated with the wetland service valued and resulted in problems of multicollinearity in the meta-regression analysis (low collinearity tolerance, none of the estimated coefficients on the method variables were statistically significant, the statistical significance of the ES variables declined, and the adjusted R^2 statistic also declined); (2) such variables are not directly applicable in value transfer exercises, i.e. are not used to predict values for new policy sites.

[7] Three alternative classifications were used, the first distinguishes between wooded wetland, freshwater marsh, salt/brackish marsh, and unvegetated sediment; the second distinguishes estuarine, marine, riverine, palustrine, and lacustrine; and the third makes the distinction between natural and constructed wetlands.

[8] Human appropriation of net primary product (HANPP) is defined as the difference between the amount of net primary product (NPP) that would be available in an ecosystem in the absence of human activities and the amount of NPP which actually remains in the ecosystem, or in the ecosystem that replaced it under current management practices. The definition and data for HANPP is described by Haberl et al. (2007).

[9] Road density is defined as the length of road in kilometres within a specified radius of each study site. The data source is FAO – UN SDRN Roads of the World (2002) http://www.fao.org:80/geonetwork?uuid=c208a1e0-88fd-11da-a88f-000d939bc5d8

[10] Arguably the scale at which these spatially defined variables influence the value of wetland regulating services will vary across contexts and services but an examination of this is beyond the scope of the present meta-analysis given the limited sample size.

[11] For other ES that require access by beneficiaries (e.g. recreation), the opposite effect might be expected.

[12] LandScan (2005) Global Population Database http://www.ornl.gov/sci/landscan/index.shtml

[13] The conceptual basis of gross cell product (GCP) is the same as gross domestic product (GDP) as developed in national income accounts. The basic measure of output is gross value added in a specific geographical region; gross value added is defined as total production of market goods and services less purchases from other businesses. Under the principles of national economic accounting, GCP will aggregate up across all cells within a country to GDP (Nordhaus et al., 2006).

[14] We tested a series of meta-regressions that included the variables for human appropriation of net primary product and road density measured at three different spatial scales. These variables were not found to be statistically significant at any scale, did not affect the magnitude or statistical significance of the other explanatory variables, and caused the adjusted R^2 statistic to decline. We therefore opted to exclude these variables from the meta-regression.

Table 3
Meta-regression model.

Variable	Variable definition	Coefficient	S.E.
Wetland value	US$/ha/year; 2007 prices (ln)		
Constant		3.74*	1.93
Constructed	Dummy variable for constructed wetlands	0.45	0.78
Water supply	Dummy variable for water supply ES	−1.30**	0.62
Water quality	Dummy variable for water quality ES	−0.80	0.59
Wetland area	Area of wetland study site (ha; ln)	−0.37***	0.08
Wetland abundance	Total area of wetlands within 50 km (ha; ln)	−0.30***	0.08
Population	Population within 50 km (ln)	0.45***	0.15
Gross cell product	Gross cell product (ln)	0.27**	0.15
N	66		
Adjusted R^2	0.58		

* Statistical significance is indicated with 10% level.
** Statistical significance is indicated with 5% level.
*** Statistical significance is indicated with 1% level.

compared with similar meta-analyses of the wetland valuation literature (e.g. Brander et al., 2006; Ghermandi et al., 2010).

In this double log model, the coefficients on the dummy variables measure the constant proportional change in the dependent variable for a given binary change in the value of the explanatory variable. The coefficients on the continuous variables expressed in logarithms can be interpreted as elasticities, i.e. the percentage change in the dependent variable given a percentage point change in the explanatory variable.

The dummy variable indicating that a wetland is constructed, as opposed to natural, is not found to be statistically significant. This result in itself is noteworthy given that constructed wetlands are generally designed and located in the landscape to provide regulating services. We find, however, that the values of regulating services from constructed wetlands are not significantly different to those from natural wetlands. Regarding the dummy variables indicating the service that is valued, the estimated coefficients for water supply and water quality are both negative, although only water supply is statistically significantly different from flood control (the omitted category variable).

The estimated coefficient on wetland area is negative and statistically significant, indicating diminishing returns to scale, i.e. the value per hectare is lower in larger wetlands. In other words, adding a hectare to a large wetland is of lower value than adding a hectare to a small wetland. Note that the total value of a wetland increases with its size but at a diminishing rate as the per hectare value decreases. The estimated coefficient shows an inelastic relationship between area and value, in which a 1% change increase in area results in a 0.37% decrease in per hectare value.[15]

The variable measuring the abundance of other wetlands in the vicinity of the valued sites is also found to have a negative effect on wetland value. As the area of other wetlands increases, the value per hectare of the valued site tends to decrease. Conversely this can be interpreted as the effect of scarcity; as wetlands become more scarce within a given area, the value of the regulating services from the remaining wetlands increases. The estimated elasticity indicates that a 1% increase in the area of other wetlands results in a 0.3% decrease in wetland value per hectare. The selected scale of measurement for this variable is a 50 km radius from each study site based on the significantly higher explanatory power of the variable in the regression at this scale.

The two variables representing the socio-economic characteristics of beneficiaries both follow prior expectations. The estimated coefficient on the population variable is positive and statistically significant, indicating that wetland regulating service values are higher in areas with larger populations. A 1% increase in population results in a 0.45% increase in wetland value per hectare. The population variable is also found to be best measured at a scale of 50 km radius from each study site. Gross cell product has a positive but less than proportional relationship with wetland value – suggesting an inelastic effect of income on the value of wetland regulating services. A 1% increase in gross cell product results in a 0.27% increase in value per hectare.

4. Transferring values to unstudied wetlands

In this section we explore the potential for using the value function estimated in the meta-regression analysis to transfer values to wetland sites for which there is no value information available. We explain the procedure for meta-analysis based value transfer and provide an illustrative exercise in valuing regulating services provided by wetlands in agricultural landscapes.

Value transfer is the procedure of estimating the value of an ecosystem (or goods and services from an ecosystem) by borrowing an existing valuation estimate for a similar ecosystem (Navrud and Ready, 2007). The ecosystem of current policy interest is often called the "policy site" and the ecosystem from which the value estimate is transferred is called the "study site". This procedure is often termed benefit transfer but since the values being transferred may also be estimates of costs or damages, the term value transfer is arguably more appropriate (Brouwer, 2000).

The use of value transfer to provide information for decision making has a number of advantages over conducting primary research to estimate ecosystem values. From a practical point of view it is generally less expensive and time consuming than conducting primary research. Value transfer can also be applied on a scale that would be unfeasible for primary research in terms of valuing large numbers of sites across multiple countries. Value transfer also has the methodological attraction of providing consistency in the estimation of values across policy sites (Rosenberger and Stanley, 2006).

Value transfer methods can be divided into three categories: transfer of unit values (without or with adjustments – usually for price level and income differences); transfer using a value function estimated from an individual primary study); and transfer using a value function estimated through a meta-analysis of the results of multiple primary studies. Each approach has its advantages[16] but meta-analytic function transfer appears to offer the most promising means to explicitly control for the specific characteristics of each policy site in the transfer process. By utilising information from a collection of studies, a meta-analytic value function includes greater variation in both site characteristics (e.g. size, service provision) and context characteristics (e.g. availability of substitute sites, socio-economic variables) that cannot be generated from a single primary valuation study.

For a number of reasons the application of value transfer may result is significant transfer errors, i.e., that transferred values differ

[15] We also included a variable defined as the square of wetland area in order to test for a quadratic functional form for which we would expect the value per unit area to initially increase with wetland area and then decline. The estimated coefficient on this variable was not statistically significant, did not affect the magnitude or statistical significance of other explanatory variables, and did not affect the explained variation in the dependent variable. We therefore omitted this variable from the estimated model.

[16] See Rosenberger and Stanley (2006), Eshet et al. (2007), Lindhjem and Navrud (2008), and Johnston and Rosenberger (2009) for overviews and assessments of the accuracy of alternative value transfer methods.

significantly from the actual value of the ecosystem under consideration. There are three general sources of error in the values estimated using value transfer: (1) errors associated with estimating values at the study site(s). Measurement error in primary valuation estimates may result from weak methodologies, unreliable data, analyst errors, and the whole gamut of biases and inaccuracies associated with valuation methods; (2) errors arising from the transfer of study site values to the policy site. So-called generalisation error occurs when values for study sites are transferred to policy sites that are different without fully accounting for those differences. Such differences may be in terms of population characteristics (income, culture, demographics, education etc.) or environmental/physical characteristics (quantity and/or quality of the good or service, availability of substitutes, accessibility etc.). There may also be a temporal source of generalisation error in that preferences and values for ES may not remain constant over time; (3) Study selection bias may result in an unrepresentative stock of knowledge on ecosystem values. The processes through which study sites are selected and results are disseminated may be biased towards certain locations, services, methods and findings, which results in an available stock of knowledge that is not representative of the resource under consideration and does not meet the information needs of value transfer practitioners.

The use of unit values or a value function estimated for study site that is identified as being similar to the policy site in question may produce lower transfer errors in cases where highly similar sites are available. When this is not the case, meta-analytic value transfer offers a means to more fully adjust transferred values to reflect the characteristics and context of policy sites. Given the limited information base on primary valuations of wetland regulatory services for large parts of the world, the use of a meta-analytic value function is likely to be more appropriate for the application presented in this paper. In addition, the use of a meta-analytic value function provides a consistent and practical means of operationalising value transfers to a very large number of policy sites.

Given the potential errors in applying value transfer, it is useful to examine the scale of these errors in order to inform decisions related to the use of value transfer. In making decisions based on transferred values or in choosing between commissioning a value transfer application or a primary valuation study, policy makers need to know the potential errors involved. To this end we conduct an in-sample value transfer exercise and compute the absolute percentage transfer error for each value observation, i.e. we use the meta-analytic value function to predict each observation in the valuation database. Absolute percentage errors are calculated as the difference between predicted and observed values, divided by observed values. The mean and median absolute percentage error for the 66 observations in our sample are 175% and 92% respectively, which is high but of a similar magnitude to previous analyses of transfer errors for ES values (Rosenberger and Stanley, 2006).

For the purposes of illustrating the potential of value transfer for estimating spatially variable ES values, we conduct a value transfer exercise to estimate the economic values of regulating services provided by wetlands in agricultural areas. The geographic scope of the analysis is global. The first step in this exercise is the selection of wetland "policy sites" to which values are transferred. A GIS was used to select wetland sites that are located in cultivated/agricultural areas using a spatial selection of all centroids of the wetlands in the Global Lakes and Wetlands Database (Lehner and Döll, 2004) that are within a distance of 5 km of a cultivated/agricultural area of at least 5 km^2 in size. Cultivated/agricultural areas are defined by the land cover classes 13, 16, 17 and 18 from the Global Land Cover 2000 database (EC-JRC, 2004).[17] This results in a selection of approximately 36% of all wetland sites in the database. The number and area of selected wetland sites by world region[18] are given in the second and third columns of Table 4. The selection of wetlands is considered conservative and represents a lower bound estimation of the number and area of wetlands in agricultural landscapes. Given the coarse resolution of the global wetlands data, small wetland patches (<1 km^2) within agricultural landscapes are not included in the analysis. GIS is subsequently used to quantify the spatial variables that are included in the value function for each selected wetland "policy site". These variables are wetland size, abundance of other wetlands, population, and gross cell product per capita; the latter three variables are measured for a 50 km radius of the centroid of each wetland site.

The second step in the value transfer exercise is to estimate site specific unit values (US$ per hectare/year) for each wetland "policy site" by substituting site specific variables into the meta-analytic value function given in Table 3.[19] Unit values are subsequently multiplied by the area of each wetland site to provide an estimate of the total annual value of regulating services provided by each wetland. Summary statistics for wetland values (mean unit values and total values) are presented in columns 4 and 5 of Table 4. In order to represent the uncertainty associated with these estimated values, we compute the lower and upper 95% prediction interval values following the method proposed by Osborne (2000) – columns 6 and 7 in Table 4. The prediction intervals are large and emphasise the need to treat transferred values with caution.

Considering the mean unit values for each region, it is apparent that there is considerable spatial variation in the value of regulating services from wetlands. Mean unit values are estimated to be low in countries that have sparsely populated agricultural areas and have relatively abundant stocks of wetlands (e.g. Canada and Russia), and are high in countries that are densely populated and have relatively few wetlands (e.g. Japan). These results again highlight the potential inaccuracy of using fixed unit values to assess ecosystems located in very different bio-physical and socio-economic contexts. The global mean unit value would be a very poor predictor of regional mean unit values, which in turn is likely to be a poor predictor of values for individual wetlands within that region.

In terms of total values for wetland regulating services in agricultural landscapes, we estimate the global annual value of this flow of services to be just over 26 billion US$, with a 95% prediction interval of 20–45 billion US$. The distribution of this total value across world regions is highly varied and determined by the quantity of wetlands in each region and the magnitude of estimated unit values. We find that wetland regulating services have a notably high annual value of approximately 4.5 billion US$ (95% PI: 4–5 billion US$) in West Africa, a region that is highly dependent on wetlands for ground water recharge and flood control (Zwarts et al., 2005).

[17] These classes represent: 13 – closed-open herbaceous cover (which includes extensive cultivated grasslands); 16 – cultivated and managed areas; 17 – mosaic: cropland/tree cover/other natural vegetation; 18 – mosaic: cropland/shrub and/or grass cover. To check consistency in our definition of agricultural areas, we make a comparison between the selected land cover classes and the 'Cultivated Systems' map of the Millennium Ecosystem Assessment (MA, 2005). We find an acceptable correspondence in which the largest differences are caused by the inclusion of specific forest classes in the MA map that are not selected in our GLC2000 classification.

[18] We use the 24 World regions defined for the IMAGE-GLOBIO model (Netherlands Environmental Protection Agency, 2010).

[19] The variable for wetland type is set to represent natural wetlands. The variables indicating the provision of each regulating service are set to represent the average level of provision observed in the "study site" wetlands underlying the meta-analysis. We treat the three regulating services as non-overlapping and non-mutually exclusive so that it is reasonable to sum their values within an individual wetland ecosystem.

Table 4
Estimated values for wetland regulating services in agricultural landscapes.

Region	Number of wetland sites	Area (ha; millions)	Mean unit value (USD/ha/yr)[a]	Total value (USD/yr; millions)	Lower 95% CI (USD/yr; millions)	Upper 95% CI (USD/yr; millions)
Canada	3560	8	223	261	231	375
USA	1528	59	1490	1809	1334	6125
Mexico	259	0	2599	197	156	263
Cent. America and Carib.	463	1	2505	381	300	486
Brazil	1402	59	810	1370	436	6629
Rest of South America	1733	20	1283	1059	602	2100
North Africa	1524	3	1126	905	806	1012
West Africa	8719	32	911	4533	3989	5105
East Africa	2430	8	983	1812	1563	2063
Southern Africa	1585	13	1029	1512	1037	2081
Western Europe	696	2	2353	661	550	869
Central Europe	40	1	1743	114	8	477
Turkey	28	0	5289	105	30	325
Ukraine Region	84	2	2089	261	61	1003
STANs	3292	6	752	789	721	893
Russia and Caucasus	13,197	37	297	1641	1426	1901
Middle East	5501	8	914	2001	1839	2164
South Asia	1529	2	5956	2252	2071	2451
Korea Region	32	0.32	4205	231	53	822
China Region	2742	7	1502	2061	1714	2457
South East Asia	506	8	2856	1338	662	2528
Indonesia	530	17	676	896	388	2215
Japan	48	0.10	5817	193	123	284
Oceania	1124	1	512	134	124	146
Antarctica	42	0.04	24	1	0	1
World	52,594	294	978	26,514	20,223	44,773

[a] Mean wetland values per hectare are computed for each region across wetland sites without weighting by wetland area.

5. Discussion and conclusion

Wetlands have long been regarded by society as having very little or even negative value, often being described as wastelands or sources of disease. As a result, they have been drained and converted into other uses, especially in agricultural landscapes, while the essentially open nature of wetland systems has made them susceptible to indirect damage from other human activities. This has led to the stock of wetlands being substantially diminished. Wetlands continue to be under particular pressure worldwide because of the extensive drainage of lowland areas for agriculture, forestry, peat exploitation and urban development, together with the impacts of river system regulation for power generation, water storage and flood control, and the maintenance of navigation channels.

Over the past decades, it has become apparent that wetlands, far from being valueless, provide a wide array of goods and services that can be of considerable value to society. The physical assessment of the functions performed by a wetland is an essential prerequisite to any evaluation of a wetland's worth to society, but simply identifying these functions is insufficient. Where a wetland is under pressure from human activity that provides measurable economic benefits to society, it will be necessary to illustrate the economic value of the functions performed by the wetland through the goods and services provided. The provision of such economic information is essential if an efficient level of wetland resource conservation, restoration or re-creation is to be determined.

Wetlands play an important role in the implementation of European legislation such as the Water Framework Directive (WFD) (2000/60/EC), adopted in 2000, where wetlands are considered as part of a cost-effective programme of measures in integrated river basin management plans to improve water quality. The role of wetlands in nitrogen reduction, for example, has been relatively well studied (Gren et al., 1997), and is also of great interest in the more recent implementation of the European Marine Strategy Directive (2008/56/EC), adopted in 2008. This Directive aims to reduce pollution loads in coastal waters and the marine environment and achieve good environmental status of European marine waters by 2020. Another recent piece of European legislation is the Floods Directive (2007/60/EC) on the assessment and management of flood risks, which entered into force end of 2007. This Directive requires Member States to assess if water courses and coastlines are at risk from flooding and take adequate and coordinated measures to reduce this flood risk. Here too wetlands and floodplains are increasingly considered as more sustainable cost-effective options alongside technical engineering and infrastructure approaches to control future flood risks.

Maintaining or restoring a wetland, however, will almost always involve costs. There will be costs associated with foregoing other uses of the land or with limiting activities that might impinge upon the ability of the wetland to continue functioning. Hence the importance of making explicit the value of the multiple functions that wetlands provide to society and of assessing this value within a framework which allows comparison with the gains to be made from activities that might threaten wetlands. This should serve not only to better protect these threatened ecosystems, but also to improve decision-making for the benefit of society.

In 1997, a first attempt was made to put a monetary value on the various goods and services provided by the world's ecosystems, including wetlands (Costanza et al., 1997). This study has had a substantial impact on the recognition of the value of ES but is limited by its use of constant unit values. An important step forward in our analysis is the estimation of a meta-value function, which allows us to transfer existing economic values across wetland sites, accounting for site and context specific characteristics. Such a function was not available at the time Costanza et al. conducted their global transfer exercise. We show that transferring values using the estimated meta-analytic value function still results in considerable estimation error despite the function's relatively high explanatory power. Our results therefore have to be interpreted with the necessary care, and more research is needed to improve the accuracy and reliability of predicting economic values for wetland ES. The information base from which we estimate the meta-analytic value function comprises only 66 estimates derived from 38 studies. There is a need for more primary valuation studies that assess the value of wetland ES, and particularly studies that fill the existing gaps in the geographic distribution of value information.

Regarding future research directions, there is also a need for collaborative research that combines wetland ecology and economics to jointly model the provision and value of ES from wetlands. For the value transfer analysis presented in this paper, we have modelled the variation in the economic value of ES but make the assumption that the provision of wetland regulating services is a constant across all wetland sites (the value of this constant is informed by the level of service provision observed at the study sites reviewed in the meta-analysis). There is a need to include ecological understanding of the co-provision or conflicting provision of different ES in future analyses. The value transfer analysis should therefore be revisited when (modelled) data on the provision of regulating services from wetlands in agricultural landscapes becomes available.

The analysis presented in this paper focuses only on the value of wetland regulating services and as such does not provide estimates of all components of total economic value of wetlands. There is therefore a need to reproduce the analysis to address other wetland services (e.g. cultural services), which may potentially have higher values.

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