Scaling-up ecosystem service values: Using GIS and meta-analysis for value transfer

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Abstract

There is a growing policy and academic interest in transferring ecosystem service values from existing valuation studies to other ecosystem sites at a large geographic scale. This paper proposes a methodology for scaling up ecosystem service values to estimate the welfare effects of ecosystem change at a national or regional level. The procedure is illustrated with a case study valuing wetland change in the Baltic countries and the Netherlands for the period 2000-2006. The proposed methodology makes use of meta-analysis to produce a value function. The parameters of the value function include spatial variables on wetland location, size, type, abundance, GDP per capita, and population density. A GIS is used to construct a database of wetland sites in the case study countries with information on these spatial variables. Site-specific ecosystem service values are subsequently estimated using the meta-analytic value function. The proposed method is shown to be practicable and to enable the adjustment of transferred ecosystem service values to reflect variation in important spatial variables.

1. Introduction

It is well established that human well-being is dependent upon ecosystem services provided by nature (MA 2005, TEEB 2008). The term ecosystem services (ES) covers the broad range of connections between the environment and human well-being, including, supporting services (e.g. nutrient cycling, soil formation), provisioning services (e.g. food, fresh water), regulating services (e.g. climate regulation, flood attenuation), and cultural services (e.g. recreational, spiritual, aesthetic) (MA 2005). Ecosystems face a variety of pressures resulting from population growth, urbanisation, and climate change but due to the public good characteristics of many ES, they are typically under-valued in both private and public decision-making relating to their use and conservation. As a result most ecosystems are continually being degraded.

Policy makers require to be informed about the economic consequences of the decisions they take (or don't take). Cost-benefit analysis, firmly grounded in economic theory, has traditionally been a major tool to inform politicians, although it is limited by the need for monetised inputs. However, in the case of climate change and probably even more pronounced in ecosystem loss, goods and services not traded in markets and therefore non-priced are dominant components in any economic assessment. In response to this need for information on the value of environmental impacts, there is a vast literature on the valuation of non-market commodities, including goods and services provided by ecosystems. However, primary valuation research is time and money intensive, and results are still limited. For this reason there is both a policy and academic interest in transferring values from existing valuation studies to other sites[1]. 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. Value transfer methods can be divided into four categories: 1. unit value transfer; 2. adjusted unit value transfer; 3. value function transfer ; and 4. meta-analytic function transfer. For a number of reasons the application of any of these value transfer methods may result is significant transfer errors, i.e. that transferred values may differ significantly from the actual value of the ecosystem under consideration.[2] There exists a sizeable literature that tests the accuracy of value transfer. Rosenberger and Stanley (2006), Eshet et al. (2007), and Johnston and Rosenberger (2009) provide useful overviews of this literature. Although some studies find very high transfer errors (e.g. Downing and Ozuna, 1996; Kirchhoff, 1998) most studies find transfer errors in the range of 0-100%.

Spatial scale is recognised as an important issue to the valuation of ecosystem services (Troy and Wilson 2006; Hein et al. 2006). The spatial scales at which ecosystem services are supplied and demanded contribute to the complexity of ecosystem valuation and management. On the supply-side, ecosystems themselves vary in spatial scale (e.g. small individual patches, large continuous areas, regional networks) and provide services at varying spatial scales. The services that ecosystems provide can be both on- or off-site. For example, a forest might provide recreational opportunities (on-site), downstream flood prevention (local off-site), and climate regulation (global off-site). On the demand-side, beneficiaries of ecosystem services also vary with location in terms of socio-economic characteristics, preferences, and culture. Using spatial data in value transfer to establish the location of both ecosystems and the beneficiaries of their services may correct for economic and cultural differences, improve values that are directly dependent on distances, and incorporate the effects of distance decay.[3]

[1] See e.g. S. Navrud and R. Ready (2007).

[2] Rosenberger and Stanley (2006) provide a description of the three general sources of error in the values estimated using value transfer.

[3] The term distance-decay (DD) describes the (expected) negative relationship between WTP for a certain ecosystem site and the distance between the site and the beneficiary. See Loomis (1996, 2000); Pate and Loomis (1997); Bateman et al. (2004); Hanley et al. (2003) for studies that examine the nature of distance decay effects.

Large scale assessments of environmental impacts, such as the Stern report on climate change (Stern 2007) and the TEEB report on ecosystems and biodiversity (TEEB 2008) bring a new dimension to value transfer. Both studies analyse global economic effects. In this study we make an important distinction between value transfers that estimate the value of an individual ecosystem site and the scaling-up of values that measure the value of the entire stock of an ecosystem within a large geographic area. In a scaling-up exercise, economic values from study sites are transferred to another geographical scale, for instance to the entire stock of an ecosystem at a landscape, regional, national or global scale. Local values are thus not applied in another local context, but are used to estimate the values of all ecosystems of similar characteristics in a certain region. While site level value-transfer is already complex, scaling-up values is accompanied by even more complexity, methodological difficulties and uncertainty.

At the level of an individual ecosystem site, unit values for ecosystem services are likely to vary with the characteristics of the ecosystem site (area, integrity, and type of ecosystem), beneficiaries (number, income, preferences), and context (availability of substitute and complementary sites and services). For scaling-up ecosystem values to estimate the total economic value of the stock of ecosystems in a large geographic area, in addition to controlling for other spatial variables, it is necessary to account for the non-constancy of marginal values across the stock of an ecosystem. This consideration is also important for valuing large-scale changes to the stock of ecosystems. At the margin, a small change in ecosystem service provision (e.g. the loss of a small area) will not affect the value of services from other ecosystem sites. Non-marginal changes in ecosystem service provision, however, will affect the value of services from the remaining stock of ecosystems. As the ecosystem service becomes scarcer, its marginal and average values will tend to increase. This means that simply multiplying a constant per unit value by the total quantity of ecosystem service provision is likely to underestimate total value. Appropriate adjustments to marginal values to account for large-scale changes in ecosystem service provision need to be made.

Meta-analytic function transfer appears to offer a relatively accurate approach to value transfer by allowing differences in site and context variables to be controlled for (Rosenberger and Phipps 2007). In addition, this approach is well suited to valuing large numbers of diverse policy sites in that the estimated value function can be applied to a database containing information on ecosystem and socio-economic characteristics of each site. In this paper we propose a methodology for using a meta-analytic value function combined with spatial data derived from a GIS to transfer values for ecosystem change at a large spatial scale. We illustrate this methodology in a case study of wetland change in the Baltic states and the Netherlands for the period 2000 to 2006.

The structure of the remainder of the paper is as follows. Section 2 describes our proposed methodology for using meta-analytic value transfer to estimate the value of ecosystem change on a large spatial scale. Section 3 illustrates this method with a case study on wetland change in the Baltic states and the Netherlands, and includes a description of the wetland value meta-analysis, the GIS procedures used to construct spatial information on wetland sites, and the valuation results. Finally, section 4 provides conclusions.

2. Methodology for scaling up ecosystem service values

In this section we outline our proposed method for using value transfer to estimate the value of changes in ecosystem service provision at large spatial scales.

Conceptually, the economic value of a loss in the provision of an ecosystem service can be expressed as the surface under the social demand curve for the service that is bounded by the pre-change level of provision and the post-change level of provision, everything else being equal. The demand and supply schedule in Figure 1 is taken from Mullan and Kontoleon (2008), who, in their turn refer to Turner et al. (2003).

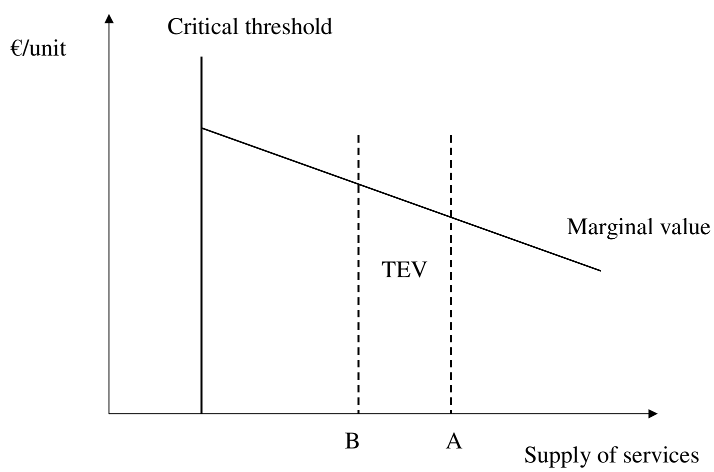

Figure 1. Valuing changes in the provision of ecosystem services

Figure 1 shows a downward sloping demand curve for the flow (or supply) of ecosystem services. The value of a small loss of services (e.g. from A to B) can be evaluated as the area under the demand curve.

A meta-analytic value function can provide information on the slope of the demand curve, i.e., the increase in marginal value as the supply of the ecosystem services decreases. A meta-analytic value function can be used to relate value per unit area of an ecosystem site to a number of explanatory variables, including the size of the site and a regional measure of ecosystem abundance. Using such a meta-analytic value function for value transfer allows estimated values to be adjusted for site specific characteristics including size and the availability of substitute ecosystem sites in the region. Change in the size of an ecosystem site is expected to affect the flow (and value) of services from the ecosystem site itself and the value of surrounding ecosystem sites (in the form of a change in ecosystem scarcity). It is therefore necessary to control for both of these effects when considering landscape scale changes in ecosystem service provision. The important point for scaling-up values for landscape level changes in ecosystem service provision is that the effect of change in ecosystem abundance is accounted for.

The steps in our proposed method for estimating the value of ES change are:

1. Construct a database of primary valuation estimates for the ecosystem of interest. Standardise value estimates in terms of monetary units per unit area of ecosystem per year (e.g. Euros per hectare per year).
2. Estimate a meta-analytic value function for the ecosystem in question. The dependent variable in the value function is the standardised value. The estimated value function should include explanatory variables that capture site characteristics (i.e. size, services provided); context characteristics (i.e. abundance of the ecosystem in the region); socio-economic characteristics of beneficiaries (i.e. population, income); and study characteristics (i.e. valuation method used to produce each primary value estimate included in the meta-analysis).
3. Construct a database of ecosystem sites in the region of interest using a GIS to include information on: size of each ecosystem site, scarcity of the ecosystem within the vicinity of each site, population in the vicinity of each site, and income level of the population. The database should contain values for each of these variables at pre- and post-change in ecosystem levels, i.e. at two different points in time or for two different policy scenarios.
4. For each ecosystem site, estimate the value per hectare at the pre-change and post change levels. This is done by "plugging in" pre- and post-change variable values into the meta-analytic value function. Calculate the average of the pre-change and post-change values per hectare for each site.[4]
5. Multiply the average value per hectare for each site by the change in area for each site. This gives an estimate of the value of the change in size of each ecosystem site.
6. The value of the change in each ecosystem site can then be aggregated to the regional or national level. This gives the annual value of the change in ecosystem service provision at that scale.

Some important limitations on the scale at which this methodology can be applied are recognised. Firstly, changes in supply of ecosystem services can be evaluated in this way up until the point that a critical threshold is reached (vertical line in Figure 1). A critical threshold is usually understood to be the point at which an ecosystem ceases to function. As an ecosystem is gradually altered (loss of area, species, material/water input, etc.) its ecological functioning and provision of services may gradually decline up to a point where the ecosystem collapses and the provision of ecosystem services abruptly cease – the level of supply at which this occurs is a threshold. There is usually quite a high degree of uncertainty regarding the nature and location of ecological thresholds and it is difficult (and in some cases not relevant) to define critical thresholds for every ecosystem service. Our proposed method does not apply to changes in ecosystem service provi-

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[4] This step assumes a linear demand curve. Provided that the evaluated change is "small", linearisation of the demand curve will in general be a reasonable approximation of the unknown true curvature of the demand curve.

sion that exceed ecological thresholds. Indeed, it is no longer possible to obtain meaningful economic values for changes in critical natural capital that exceeds ecological thresholds (Mullan and Kontoleon, 2008).

Secondly, primary valuation studies generally measure the value of ecosystem services around present levels of overall provision (studies generally focus on single sites, with the implicit or explicit assumption that the level of provision of services from substitute sites is not changed). Large changes in the overall level of provision are therefore beyond the domain of our observations and are therefore principally unknown. This makes the assessment of the value of a large scale or complete loss of an ecosystem service impossible. Our proposed method for valuing changes in ecosystem service provision is therefore limited to measuring "small" changes in ecosystem extent.

3. Application to changes in ecosystem services from European wetlands

In this section we apply the methodology set out in section 2 to estimate the value of changes in wetland ecosystem services in the Baltic countries and the Netherlands for the period 2000 to 2006. Section 3.1 describes the meta-analytic value function for wetland ecosystem services; Section 3.2 provides a description of the GIS procedures and the spatial data on wetlands in the study areas; Section 3.3 presents the results and provides a discussion.

3.1. Meta-analytic value function for wetlands

The data set used to estimate the meta-analytic value transfer function contains 264 independent observations of wetland values for temperate climate zone wetlands (mainly from the US and Europe). For an overview of this data set see Ghermandi et al (2007). All observations are from primary valuation studies.

The meta-analytical regression model is given in equation 1.

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

The dependent variable (y) in the meta-regression equation is the vector of the wetland values standardized to 2003 US$ per hectare per year. The subscript i assumes values from 1 to 264 (number of observations), a is the constant term, b_s, b_w and b_c are vectors containing the coefficients of the explanatory variables and u is a vector of residuals. The explanatory variables consist of three categories, namely characteristics of (i) the valuation study X_S, (ii) the valued wetland X_{Wi} and (iii) the socio-economic and geographical context X_C. The meta-regression results are presented in Table 1.

Table 1. Meta-regression model of wetland values

	Variable	**Coefficient**	**p-value**
	(constant)	–3.078	0.187
Study variables	Contingent valuation methods	0.065	0.919
	Hedonic pricing	–3.286***	0.006
	Travel cost method	–0.974	0.112
	Replacement cost	–0.766	0.212
	Net factor income	–0.215	0.706
	Production function	–0.443	0.523
	Market prices	–0.521	0.317
	Opportunity cost	–1.889**	0.035
	Choice experiment	0.452	0.635
	Marginal	1.195***	0.008
Wetland variables	Inland marshes	0.114	0.830
	Peatbogs	–1.356**	0.014
	Salt marshes	0.143	0.778
	Intertidal mudflats	0.110	0.821
	Wetland size	–0.297***	0.000
	Flood control and storm buffering	1.102**	0.017
	Surface and groundwater supply	0.009	0.984
	Water quality improvement	0.893*	0.064
	Commercial fishing and hunting	–0.040	0.915
	Recreational hunting	–1.289***	0.004
	Recreational fishing	–0.288	0.497
	Harvesting of natural materials	–0.554	0.165
	Fuel wood	–1.409**	0.029
	Non-consumptive recreation	0.340	0.420
	Amenity and aesthetics	0.752	0.136
	Biodiversity	0.917*	0.053
Context variables	GDP per capita	0.468***	0.001
	Population in 50km radius	0.579***	0.000
	Wetland area in 50km radius	–0.023	0.583

OLS results. $R^2 = 0.49$; *Adj.* $R^2 = 0.43$. Significance is indicated with ***, **, and * for 1, 5, and 10% statistical significance levels respectively.

The estimated coefficients on the context variables all have expected signs. The coefficient on the wetland abundance variable (measured as the area of wetland within a 50km radius of the valued wetland site) is negative, indicating that in regions that are more abundant with wetlands, the value of a hectare of wetland tends to be lower. Similarly, the coefficient on size of the wetland site is negative, indicating diminishing returns to scale with wetland size. In other words, the value of adding an additional hectare to a large wetland is worth less than adding an additional hectare to a small wetland. The coefficients on GDP per capita and population are both positive, indicating a positive relationship between these variables and wetland values.

3.2. Wetland change in the Baltic states and the Netherlands 2000-2006

Geographic information systems can be used to help link valuation data with information on the physical (ecosystem size, availability of substitute sites etc.) and socio-economic (income, population, education) characteristics of the policy site.

The meta-analytic value function for wetlands includes a number of variables that have a spatial dimension, including:

- Wetland size in hectares for each individual wetland site.
- Wetland type (classified as inland marshes, peatbogs, salt marshes, salines, and intertidal mudflats)
- Wetland abundance (total area of an ecosystem type within 50km radius of the centre of each ecosystem site).
- Population within 50km radius of the centre of each ecosystem site.
- Income per capita of the population in the vicinity of each ecosystem site.

To determine the surface area of each wetland site we have used the Corine seamless vector land cover data (CLC2000). The sizes of the areas of individual wetland sites have been calculated with the calculate geometry function in ArcGIS. We also calculated the centre-points of the areas of the wetland sites.

The *wetland abundance* is defined as the summed area of wetlands within 50km of the centre-point of each wetland site. The map in Figure 2 shows an example of how wetland abundance was calculated for each site. It shows the centre-point (red point) of an intertidal mudflat in Northern Ireland with a surface of 805ha, surrounded by 147,406 hectares of other wetland areas in a circular 50 km zone.

The population in the vicinity of each wetland site (defined within radius of 50km of the centre of each wetland) was calculated using the Gridded Population of the World dataset (GPWv3) of the Socioeconomic Data and Applications Center (SEDAC). The process by which this data can be generated is described in Wagtendonk and Omtzigt (2003).

The income per capita figures for the NUTS2 regions in which each wetland is located were calculated by combining Eurostat statistics for Gross Domestic Product (GDP) in 2003 at current market prices at NUTS level 2 with the administrative map units downloaded from the EEA data service.

Wetland change over the period 2000-2006 has been assessed on the basis of Corine Land Cover (CLC) maps. The summed total area of wetlands in the Netherlands in 2000 according to the downloadable CLC seamless vector data base (EEA dataservice) within ERM[5] country borders is 279.893 hectares. The summed total area of wetlands in the Netherlands in 2006 according to the new CLC land use map 2006 is 281.352 ha. Indicating an increase in wetland area between 2000 and 2006 of 1,459 hectare.

[5] EuroRegionalMap (ERM) country boundaries extracted by European Environment Agency from PolbndA layer, version 2.2. scale 1: 250000.

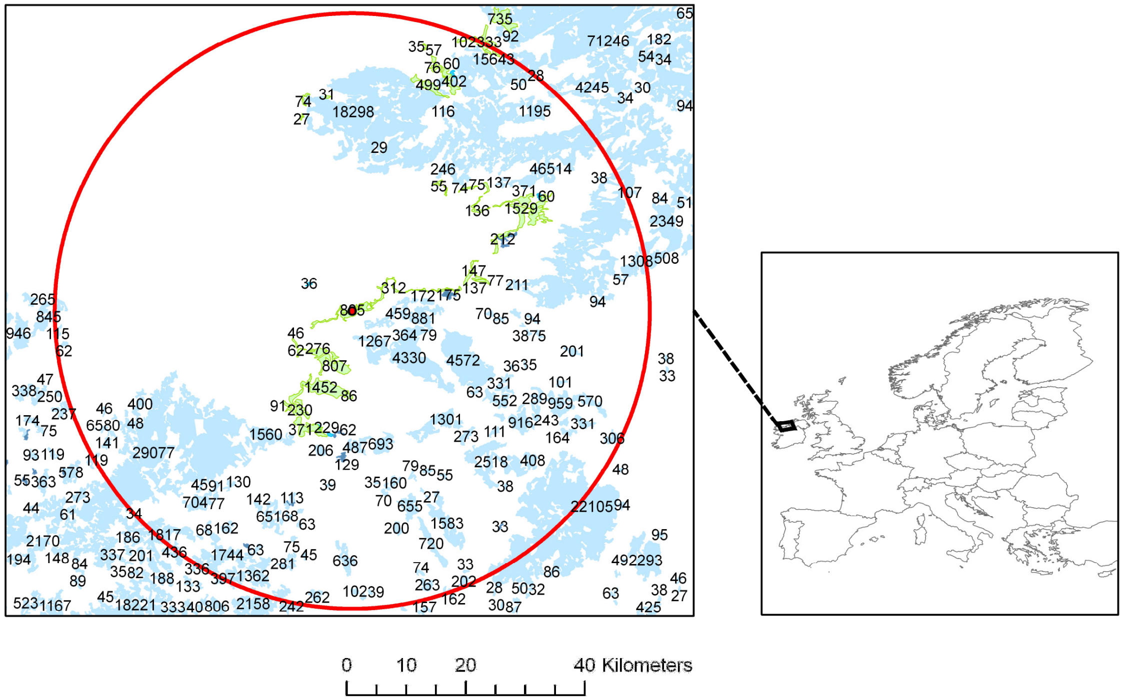

Figure 2. Example of wetland abundance calculation

Most wetland gain (75%) results from the transition from agricultural land use to wetlands. This conforms to Dutch policy objectives, e.g. with respect to the "Space for Rivers" (Ruimte voor de rivier) program. The second largest class of land use change to wetlands is formed by forests (9%) and by sea and ocean (9%), and construction sites (7%) form the reminder. Wetland loss results mainly (57%) from the transition from wetlands to water bodies or sea and ocean.[6] The reminder of wetland loss is due to transformation into construction sites (37%) and sport and leisure facilities (5%).

For the Baltic countries, we find net increases in wetland areas for Estonia (+ 611 ha) and Lithuania (+ 47 ha), and a net decrease of wetland area in Latvia (- 178 ha). See Table 3.

3.3. Value transfer results

An analysis of the welfare changes resulting from changes of the provision of wetland services in the Netherlands and the Baltic States was carried out according to the methodology described in section 2. We use the meta-analytic value function to assign site specific per-hectare values to all wetlands in 2000 and 2006, evaluating them at 2006 population densities and per-capita incomes, but taking account of the differences in wet-

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[6] As the difference between wetlands and water bodies is rather fuzzy, it would be advisable to check that these transitions are not simply the result of classification errors (e.g. by manually comparing aerial photographs of both periods and searching for reports concerning physical planning for these areas).

land scarcity and wetland size between these years.[7] We then multiply the change in area of each wetland with the site specific *average* per-hectare value.

For the purposes of illustration, Table 2 shows the values of key variables used in the calculation of the value of change in a single wetland in the Netherlands. Over the period 2000-2006, the wetland reduced in size from 1,614 ha to 1,529 (a change of 85 ha). The abundance of wetlands within a 50km radius of the wetland also declined slightly over the same period. These values, together with the population within a 50km radius and the GDP per capita for the NUTS3 region in 2006, are plugged into the meta-analytic value function to estimate per hectare values for the wetland in it's 2000 'state' and it's 2006 'state'. The changes in wetland area and abundance cause the value per hectare of the wetland to increase slightly from 5,355 to 5,444 €/ha (the average value per hectare between the two states is therefore 5,400 €/ha). Multiplying the average value by the change in area gives the value of the change: - €459,938. Note that this is an annual value, i.e. it is the value of the annual flow of ecosystem services that are lost due to the reduction in wetland size.

Table 2. Example numbers used in calculation for an individual wetland in the Netherlands

Variable	**Value**
Wetland area 2000 (ha)	1,614
Wetland area 2006 (ha)	1,529
Wetland abundance 2000 (ha)	8,795
Wetland abundance 2006 (ha)	8,755
Population 2006	6,330,324
GDP per capita (2006 USD PPP)	27,582
Value per hectare 2000 (2005 EUR)	5,355
Value per hectare 2006 (2005 EUR)	5,444
Average per hectare value (2005 EUR)	5,400
Change in wetland area (ha)	-85
Value of change (2005 EUR)	-459,938

Table 3 presents the results of the calculations for all wetland changes in the Netherlands and the Baltic States for the period 2000-2006.

[7] Since we do not have information regarding the wetland ecosystem services produced by each wetland site in the database we assume that each wetland provides the average levels of ecosystem service observed in the wetland valuation database, i.e. the meta-analytic value function is set to estimate the value of the average level of ecosystem service provision. Similarly, we set the meta-analytic value function to estimate the value produced by the average valuation method in the data underlying the meta-regression.

Table 3 Area and value of wetland change in Estonia, Latvia, Lithuania, and the Netherlands, 2000-2006.

	Estonia	Lithuania	Latvia	Netherlands
Loss in area (ha)	- 6,222	- 348	- 479	- 9,044
Gain in area (ha)	+ 6,834	+ 396	+ 302	+10,503
Net change in area (ha)	+ 612	+ 48	- 178	+ 1,459
Welfare loss (€)	-378,224	-67,319	-79,362	- 28,604,015
Welfare gain (€)	+ 281,507	+166,100	+ 86,155	+ 28,417,856
Net change in welfare (€)	- 96,717	+98,781	+ 6,793	- 186,158

These calculations suggest that the welfare gains and losses due to wetland change in the period 2000-2006 have more or less cancelled out for the countries under analysis. In absolute terms, the largest gains and losses occurred in the Netherlands. The calculations also show that a *net* increase in wetland area does not always lead to a net welfare gain (e.g. Estonia, Netherlands). Apparently, in these countries, more valuable wetlands have been replaced by less valuable wetlands (but the difference in monetary terms is quite small).

4. Conclusions

The paper proposes a methodology for scaling up values for changes in ecosystem service provision at large spatial scales and illustrates the procedure with a case study on wetland change in the Baltic states and the Netherlands. The proposed methodology makes use of meta-analytical value transfer to produce a value function that is subsequently applied to estimate values of individual ecosystem sites. Site-specific, study-specific and context-specific variables are used to define a price vector that captures differences between sites. The proposed method is shown to be practicable and to enable the adjustment of transferred ecosystem service values to reflect variation in important spatial variables. There are, however, a number of issues that require further discussion and research.

Points of strength of the proposed meta-analytic value transfer technique are its ability to explicitly account for context variables which are relevant in understanding people's perceptions and preferences but are often neglected in primary valuation studies because constants of the analysis. Context variables included in the case study aim at assessing the influence of income effects, substitute sites, and population density on wetland values. Their spatial variability is captured on a scale based either on administrative boundaries (as for the variable real GDP per capita) or distance from the ecosystem centre (as for wetland abundance and population density).

An important area for improvement in the proposed value transfer method is the treatment of ecosystem quality. As currently proposed, the method deals primarily with the quantity or area of ecosystems and does not deal well with changes in quality. To incorporate ecosystem quality into the value transfer process would require the definition and inclusion of quality variables in both the valuation data underlying the meta-analysis and in the data on ecosystem networks to which values are transferred. In the case of wetlands, several methods are available for assessing their ecological integrity (Fennessy et al., 2004). Most of them, however, are not practicable for the type of analysis that the present study aims at as they rely on local biological and physio-chemical measurements which are not available for most of the study and policy wetland sites. Some methods, however, use estimates of the anthropogenic pressures in the surrounding of the wetland as a proxy for its ecological status assuming that this strongly depends on them. Such methods are usually referred to as landscape assessments.

A further limitation of our proposed method is that it does not differentiate between services to take account of different demand and supply characteristics. In terms of demand, population and income effects are the same across all services. Regarding supply, we implicitly assume that the provision of all ecosystem services is equally proportional to the geographical size of the ecosystem sites. A service-specific value transfer approach could take account of differences, but this would require service specific meta-analytic value functions. It is, however, unlikely that the quantity and quality of primary valuation data would allow for the estimation of such detailed meta-analytic value functions.

Another issue that requires further work is the incorporation of missing components of economic value in estimating ecosystem values. Value transfer is inevitably restricted by the availability of primary valuation studies for the specific ecosystems and services of policy interest. While there may be a large and growing number of ecosystem service valuation studies available, there are still gaps in the knowledge. In the case of wetlands, there are no valuation studies that explicitly only capture non-use values. Therefore the wetland value transfer function and resulting estimated values do not reflect non-use values. Filling such gaps in the available value information would require targeted primary valuation studies.

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