Climate change impacts on biodiversity and freshwater ecosystems values: meta-analytical results from a European case study

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1. Introduction

Freshwater ecosystems have long been recognized as sources of important services and goods for humans. The range of benefits encompasses the provisioning of goods such as water, fuel wood, materials, and fish for commercial exploitation, regulating flood events and water quality processes, providing the setting for recreational activities and amenity values, and supporting a rich biological diversity.

Both the level of provisioning of ecosystem services and their impact on human welfare are threatened by climate change, which has the potential to affect both the equilibrium of the ecological services relied upon, and the patterns of human exploitation. Overall, the impact of climate change on human welfare due to changes in the levels of provision and exploitation of freshwater ecosystem services is poorly understood.

In this study, we use meta-analysis as a tool (i) to investigate the provision of services of freshwater ecosystems from an economic perspective, (ii) to scale up freshwater ecosystem services values in the EU-17 countries and (iii) to provide a monetary estimate of how climate change may affect European freshwater ecosystems services. In particular, we investigate how the climatic but also social and economic changes involved in three IPCC scenarios (A2, B1 and B2) may affect the flow of values. In doing so, we explicitly restrict our analysis to those conditions where climate change does not lead ecosystems to exceed threshold-inducing disruptions in the ecological structure and discontinuities in the provision of ecosystem services.

The remainder of this work is organized as follows. In Section 2 an overview is given of the use of meta-analysis in environmental economics and of the model used in this study. The dataset of valuations upon which the meta-analysis relies is also described. Section 3 presents the econometric results of the regression. Section 4 investigates the scaling up of values at a European scale and the potential impact of climate change on monetary values of freshwater ecosystems under the conditions defined by the IPCC scenarios. The shift in values in the EU-17 countries is assessed and the underlying policies evaluated from the perspective of the values of ecosystem services. The final section concludes.

2. Materials and methods: meta-analysis and the dataset of freshwater ecosystems valuations

2.1 The use of meta-analysis in environmental economics

Meta-analysis has been extensively used in environmental economics as a tool to synthesize the findings of a well-defined collection of results from primary valuation studies by means of a statistical analysis (Bal & Nijkamp 2001). The cross-sectional comparison provided by meta-analysis is a quantitative review technique that results in a rigorous synthesis of the results of previous studies. This synthesis can be used for various purposes, including benefit transfer to policy sites with unobserved values (Bergstrom & Taylor 2006; Rosenberger & Loomis 2000b), the testing of hypotheses that may never have been tested in the primary studies, and the overall acquisition of new scientific knowledge (Johnston et al. 2003). While the results of empirical studies are conditioned by a series of factors such as the method used, the particular temporal and spatial dimensions considered, and the hypotheses tested – which generate the issue of whether the results can be used for induction to other unexplored cases – meta-analysis may mitigate the impacts of these problems and represent a tool for theorization (Bal & Nijkamp 2001). Meta-analysis has been implemented for the investigation of a wide range of ecosystems – e.g., wetlands (Brander et al. 2006; Ghermandi et al. 2008) and forests (Nunes et al. 2009) – and ecosystem services – e.g., recreational activities (Bateman & Jones 2003) and biodiversity enhancement or conservation (Loomis & White 1996). Best-practice guidelines for meta-analysis were developed (Nelson & Kennedy 2008; Stanley 2005) in order to deal with potential issues related to the heterogeneity of the environmental resources and economic instruments considered (Smith & Pattanayak 2002), selection bias (Hoehn 2006), heteroscedasticity, and correlation between observations (Rosenberger & Loomis 2000a).

2.2 The data set of freshwater ecosystem values

In this study we use statistical meta-analysis to predict wetland values based on 236 independent observations from 103 valuation studies that encompass 123 distinct freshwater wetlands, riverine or lacustrine ecosystems worldwide. Fig 1 and Fig 2 illustrate the geographical distribution of the ecosystems in the dataset and the year of publication of the valuation studies.

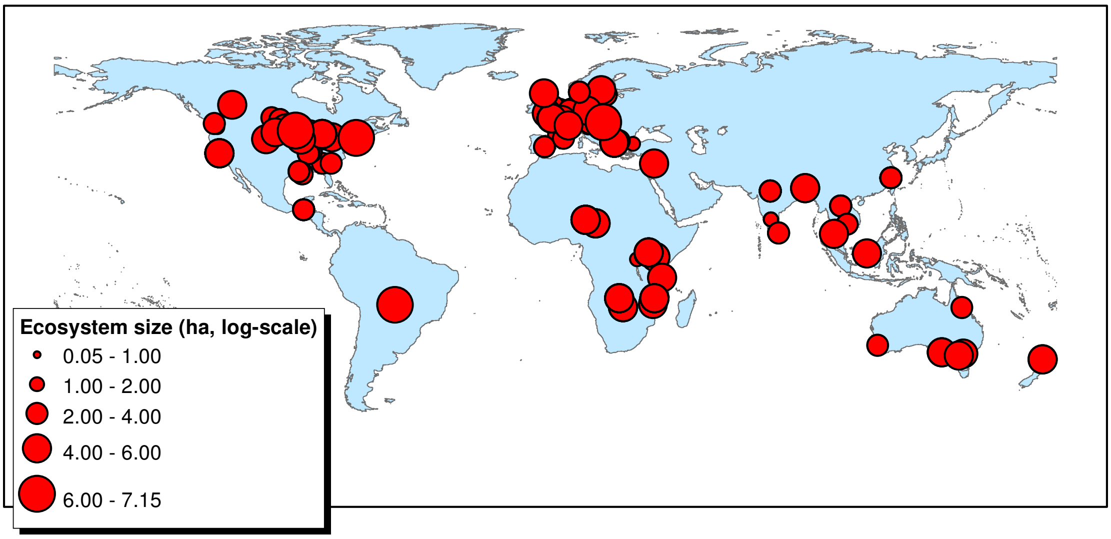

Fig 1. Geographical location of valued ecosystems and their size

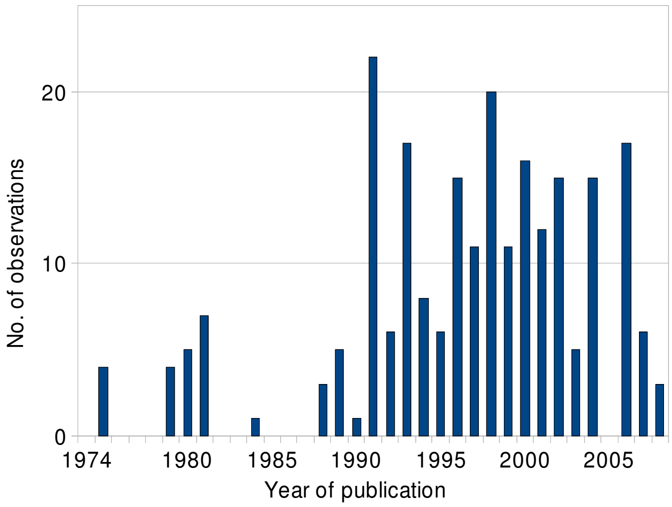

Fig 2. Year of publication of valuation studies in the dataset

All continents are represented in the data set. The largest number of observations pertains to North America (90) and Europe (63), but a significant fraction comes from Africa (37) and Asia (32). Australasia (8) and South America (6) are somewhat under-represented. Table 1 illustrates the European freshwater ecosystems in the data set.

All studies considered are primary valuation studies and no observation based on value transfer is included in the data set. 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 were 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 (12) are relatively low when compared to the total number of observations used in the analysis (236). As such, multiple sampling bias is expected to have a limited influence on the results of the investigation.

Table 1. European freshwater ecosystems in the valuation dataset

Country	Site name	Reference
Austria	Donau-Auen	Kosz 1996
Czech Republic	Wetland in Jihovýchod	Gren & Soderqvist 1994
France	Plaine alluviale de la Bassée	Bureau d'Etudes ACSA 1996
	Plaine alluviale de la Marne	Bureau d'Etudes ACSA 1996
	Nogentais	Bureau d'Etudes ACSA 1996
	Basse vallée de la Vire	Bureau d'Etudes ACSA 1996
	Saone floodplains	Bureau d'Etudes ACSA 1996
	Moyenne vallée de l'Oise	Bureau d'Etudes ACSA 1996
	Forets riveraine de la Garonne	Amigues & B. Desaigues 1999
	Cotentin	Bonnieux & Le Goff 1997
	Lac du Der	Scherrer 2003
	Lac de la Forêt d'Orient (Etang de la Morge	Desaigues 1991
	étang du Canet - Saint Nazaire	Dabat & Rudloff 1999
	Ile de Rhinau	El Yousfi et al. 2006
Germany	Elbe river	Meyerhoff & Dehnhardt 2007
	Sandau	Meyerhoff & Dehnhardt 2007
	Rogaetz	Meyerhoff & Dehnhardt 2007
	Donau floodplain (Straubing and Vilshofen)	Hanusch et al. 2000
Greece	Cheimaditida	Birol et al. 2006
	Lake Kerkini	Oglethorpe & Miliadou 2000
	Zazari-Cheimaditida	Ragkos et al. 2006
Italy	Vincheto di Cellarda	Marangon et al. 2002
	Oasi dei Quadris di Fagagna	Marangon et al. 2002
Netherlands	De Vechtstreek	Bos & Bergh 1998
	Oostvaardersplassen	de Groot & Velthuijsen 1998
	de Wieden	Hein et al. 2006
Norway	Lake Vegår and river Storelv	Navrud 1993
Spain	Aiguamolls de l'Empordà	Seguí 2004
	Parc national des Tablas de Daimiel	Júdez et al. 1998
Sweden	Wetlands in Sweden	Byström 2000
	Martebo mire	Folke 1991
	Oxeloesund	Cravener 1995
UK	Flow country	Hanley & Craig 1991
	Halvergate marshes	Turner & Brooke 1988
	River Ancholme	Posford Duvivier Environment 1999
	River Nar	Posford Duvivier Environment 2000
	Somerset Levels and Moors ESA	Garrod et al. 1994
Various countries	Danube floodplain	Gren et al. 1995

2.3 The meta-regression model

The meta-analytical regression model used in this study is specified as follows:

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

where the dependent variable (y) is the value standardized to 2003 US$ per hectare per year; X_{Vi}, X_{Si} and X_{Ci} are the vectors of the explanatory variables and b_V, b_S and b_C the respective coefficients; a is a constant term; and u is an error term that is assumed to be well-behaved. The subscript i is an index that characterizes the 236 independent value observations used for the regression.

The selected explanatory variables are chosen to represent characteristics of the valuation study (X_{Vi}), of the specific valued ecosystem site (X_{Si}) and characteristics of the socio-economic, geographical and climatic context in which the valued ecosystem is located (X_{Ci}). Table 2 illustrates the explanatory variables that are considered for inclusion in the meta-regression model.

Table 2. Explanatory variables of the meta-regression model

Group	Variable	Units and measurement	Mean (SD)
Study (X_{Vi})	Stated preference method	Binary (range: 0 or 1)	0.28 (0.45)
	Revealed preference method	Binary (range: 0 or 1)	0.15 (0.36)
	Market-based method	Omitted category	0.56 (0.50)
	Mixed valuation method	Binary (range: 0 or 1)	0.01 (0.11)
	Marginal	Binary (range: 0 or 1)	0.13 (0.34)
	Average	Omitted category	0.87 (0.34)
Site (X_{Si})	River and river floodplain [a]	Binary (range: 0 or 1)	0.45 (0.50)
	Lake [a]	Binary (range: 0 or 1)	0.38 (0.49)
	Other freshwater wetland [a]	Binary (range: 0 or 1)	0.39 (0.49)
	Provisioning [a]	Binary (range: 0 or 1)	0.37 (0.48)
	Regulating [a]	Binary (range: 0 or 1)	0.27 (0.44)
	Cultural services: recreation [a]	Binary (range: 0 or 1)	0.42 (0.49)
	Cultural services: passive [a]	Binary (range: 0 or 1)	0.23 (0.42)
	Ecosystem size	Natural log of hectares	8.29 (3.06)
	Latitude below 35°N	Omitted category	0.56 (0.50)
	Latitude within 35–45°N	Binary (range: 0 or 1)	0.34 (0.47)
	Latitude within 45–55°N	Binary (range: 0 or 1)	0.23 (0.42)
	Latitude above 55°N	Binary (range: 0 or 1)	0.05 (0.21)
Context (X_{Ci})	Real GDP per capita [b]	Natural log of 2003 I$ (PPP)	9.51 (1.30)
	Total freshwater ecosystems area [c]	Natural log of hectares	16.44 (2.76)
	Population density per country [c]	Natural log of inhabitants per km^2	3.90 (1.22)
	Total known bird species [c]	Natural log of number of species	6.58 (0.34)
	Threatened bird species [c]	Natural log of number of species	3.41 (0.86)
	Minimum monthly temperature [c]	Degrees Celsius	3.59 (12.05)
	Maximum monthly temperature [c]	Degrees Celsius	21.51 (4.29)

[a] The variables identifying ecosystem types and services are not mutually exclusive, since individual observations may pertain to two or more ecosystem types or services; [b] At country level, but for the USA and EU countries where it is evaluated at state and NUTS2 level respectively; [c] At country level.

2.3.1 Study variables

Study characteristics accounted for in the model include the valuation method used and a dummy distinguishing between marginal and average values. A range of valuation methods were used in the primary studies for the assessment of the values of wetlands and freshwater ecosystems. Valuation methods are grouped in four categories: stated preference methods (i.e., contingent valuation method and choice experiment), revealed preference methods (i.e., travel cost method and hedonic pricing), market-based methods (i.e., market prices, replacement cost, net factor income, production function and opportunity cost), and mixed valuation methods, which combine different methodologies (e.g. contingent behaviour method). A dummy for each of the categories is included in the meta-regression model to account for the heterogeneity of methods, as they produce estimates of different welfare measures and not all of them have a strong basis in welfare theory. Market-based values is the omitted variable in the regression. Fig. 3 illustrates the distribution of valuation methods according to the four categories of methods.

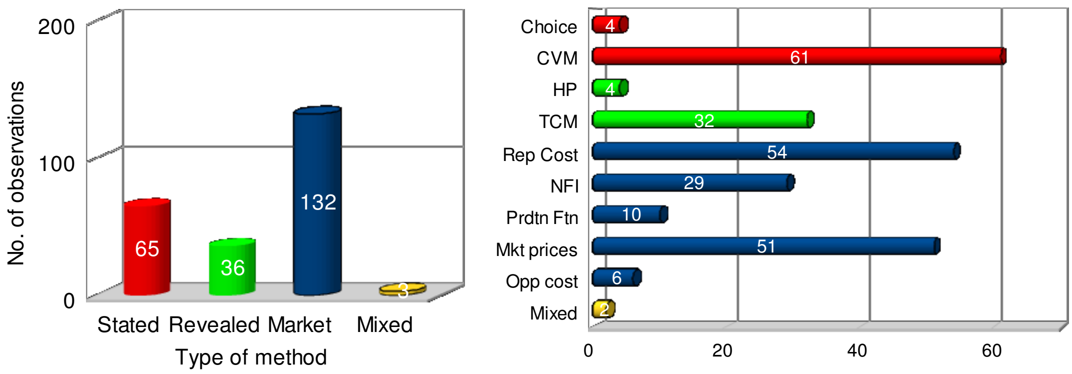

Fig. 3 Number of observation per type of method and single valuation methods (Choice = choice experiment, CVM = contingent valuation method, HP = hedonic pricing, TCM = travel cost method, Rep Cost = replacement cost, NFI = net factor income, Prdtn Ftn = production function, Mkt price = market prices, Opp cost = opportunity cost)

The largest number of observations was derived using market-based valuation methods (132). The most frequently implemented market-based method was market prices (51) followed by net factor income (29). Production function and opportunity cost were used in 10 and 6 observations respectively. Some studies used a combination of market-based methods. Stated preference methods were used in 65 observations, contingent valuation method (61) being more frequently implemented than choice experiment (4). Revealed preference methods (i.e., travel cost method (32) and hedonic pricing (4)) were used in 36 observations.

To distinguish between marginal and average per hectare values, a dummy variable is introduced, which assumes a value equal to one for marginal values (34) and equal to zero otherwise (202).

2.3.2 Site variables

Characteristics of the valued ecosystem accounted for in the meta-regression model are the type and size of the ecosystem, and the services provided. Three dummies identifying rivers and floodplains (106 observations), lakes (89 observations) and other types of freshwater wetlands (93 observations) are introduced in the model. Some value observations may pertain to several ecosystem types.

Three types of freshwater ecosystems were considered: rivers (and river floodplains), lakes, and other types of freshwater wetlands, such as palustrine wetlands, swamps, peat bogs and wet forests. River deltas, estuaries, coastal salt marshes and lagoons were not included in the dataset. Fig. 4 illustrates the distribution of the observations across the three main ecosystem types considered. Since a value estimate may pertain to an ecosystem with mixed characteristics or to a group of ecosystems of different types, the sum of observations for the categories in Fig. 4 is larger than the total number of observations.

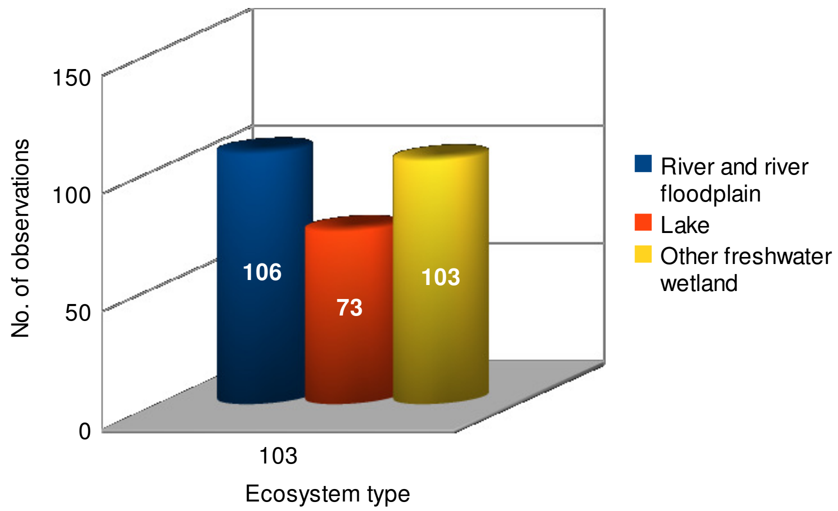

Fig. 4. Number of valuations for rivers, lakes and freshwater wetlands ecosystems

The services and goods provided by the investigated ecosystems are classified according to the Millennium Ecosystem Assessment (2005) approach into the categories of provisioning, regulating and cultural services. Within the category of cultural services a distinction is made between recreational services (i.e., recreational hunting, recreational fishing, and other non-consumptive recreational activities such as walking, cycling, swimming and boating) and passive uses (i.e., biodiversity and amenity values). The number of observations for the identified ecosystem services is illustrated in Fig. 6. The largest number of observations is for recreational cultural services as well (98). A relatively large number of observations are available for provisioning services (88) such as commercial fishing and hunting, harvesting of natural materials, water supply and fuel wood. Regulating services such as flood control, storm buffering and water quality improvement were provided by 63 observations. Slightly less information is available in the literature for passive uses (54 observations).

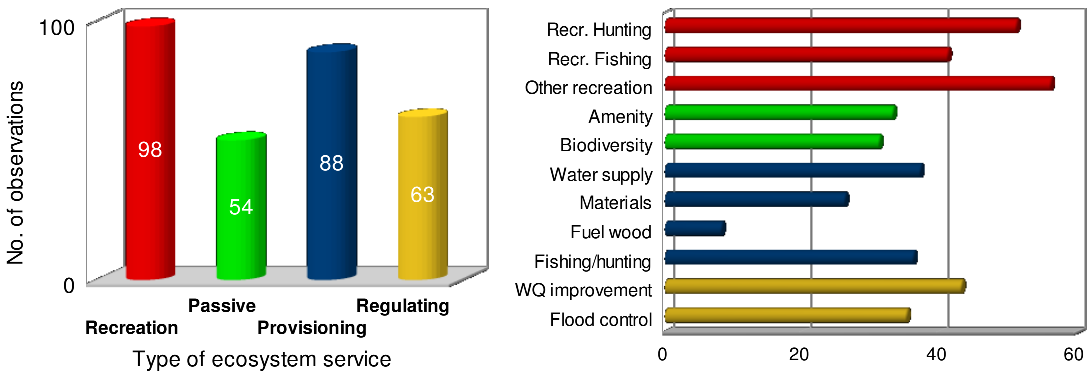

Fig. 6. Number of observation per type of ecosystem service and single services (Recr. Hunting = recreational hunting, Recr. Fishing = recreational fishing, Fishing/hunting = commercial fishing and hunting, WQ improvement = water quality improvement, Flood control = storm buffering and flood control)

The size of the ecosystems has been estimated in hectares and shows large variability. The ranked distribution in the size of the valued ecosystems is illustrated in Fig. 7. The median size is 3,455 ha, while the average size is 187,875 ha with a standard deviation equal to 1,299,594 ha. Examples of large valued sites covering hundreds of thousands of hectares are the wetlands of Louisiana (Gosselink & Pope 1974), the Pantanal (Shrestha et al. 2002), and the Danube floodplain (Gren et al.

1995). Although the majority of the valuation studies so far have comprehensively focused on large sites, small-size ecosystems are also represented. Some examples are small wetlands in the North Dakota prairie (Leitch & Hovde 1996), Louisiana (Leitch & Hovde 1996), Italy (Marangon et al. 2002) and England (Ledoux 2003). All of these wetlands are below one hundred hectares in size. Although there is no clear *a priori* expectation of the influence of size on its value, previous meta-analyses of ecosystem values agree on the relevance of size as a significant factor in the explanation of the variability of values.

Finally, the latitude at which the valued ecosystems are located is included in the model as a categorical predictor with four levels. The four categories considered are chosen so as to distinguish between different biomes in European countries: Mediterranean (between 35°N and 45°N), temperate (between 45°N and 55°N), and Baltic-Scandinavian ecosystem types (at latitudes higher than 55°N). The omitted category in the regression identifies freshwater ecosystems that are located at latitudes equal to or lower than 35°N.

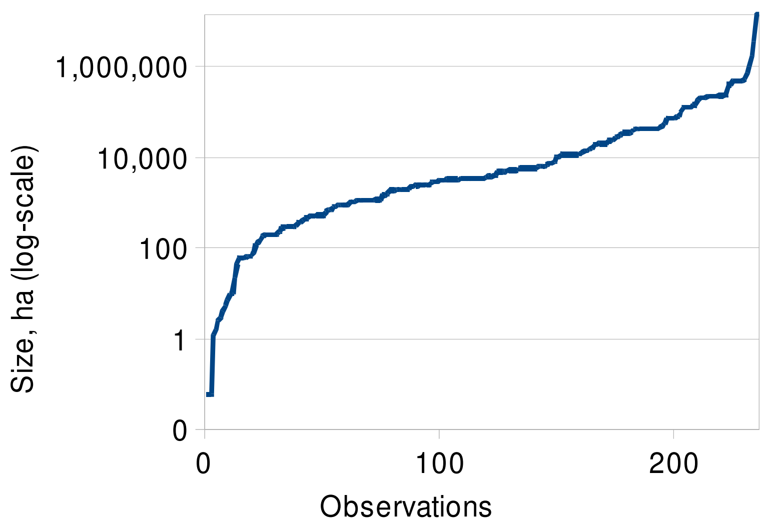

Fig. 7. Ranked distribution in the size of the valued ecosystems

2.3.3 Context variables

Environmental valuation studies carried out at different geographical sites and involving populations with different socio-economic characteristics and consumer preferences generally produce different outcomes (Brouwer 2000). Context characteristics are expected to significantly influence the valuation estimates.

A series of context variables are included in the meta-regression model. Gross Domestic Product (GDP) per capita and the population living in the surroundings of the valued ecosystem are introduced to capture some characteristics of the socio-economic context where the valued sites are located. The presence of income effects and the influence of population density in the surroundings of the valued environmental asset in the determination of the results of the valuation study were identified in previous meta-analyses (Brander et al. 2006). The GDP value is calculated at country level for all countries except for European countries and the USA, where it is estimated at NUTS2[1] and state level respectively. GDP per capita values were expressed in Purchase Power Parity (PPP) units and standardized to I$ 2003 per year following the procedure described in Ghermandi et al. (2008). The population density and total area of freshwater ecosystems abundance of wetland ecosystems at country level are included in the meta-regression model in order to capture the fact that a high population density around the valued sites may contribute to a transformation of potential values into actual benefits as well as potential substitution effects (Ghermandi et al. 2008). The total area of wetlands for each country is calculated based on the georeferenced information provided in the Global Lakes and Wetlands Database (Lehner & Döll 2004).

A series of geo-climatic and biodiversity variables were considered for their possible influence on the estimated values. The biodiversity variables considered include the total number of bird (mammal) species and threatened bird (mammal) species at country level as derived from the Little Green Data Book (World Bank 2007). The geo-climatic variables evaluated for inclusion in the model include the average, minimum and maximum monthly temperature and the average yearly precipitation at country level. The geo-climatic and biodiversity data used in the model refers to the baseline year 2003.

2.3.4 Standardization of values

To allow for a comparison between ecosystem 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 I$ per hectare per year. Values referring to different years were deflated using appropriate factors from the World Bank Millennium Development Indicators (World Bank 2006), while differences in purchasing power among the countries were accounted for by the PPP index provided by the Penn World Table (Heston et al. 2006).

3. Meta-regression results of current values

3.1 Econometric results and regression diagnostics

The results obtained from the meta-regression model described in equation (1) using ordinary least squares (OLS) are presented in Table 3. In the 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.

Some of the variables listed in Table 3 were dropped from the model after a preliminary meta-regression analysis due to statistical insignificance. This is the case , in particular the number of threatened bird species and the minimum monthly temperature. The total number of mammal species and the number of threatened mammal species were excluded from the model due to high correlations with the bird biodiversity variables.

[1] NUTS2 is one of the Nomenclature of Territorial Units for Statistics levels used in the European Union to identify regional administrative divisions within member states.

Table 3. Results of the basic meta-regression model

Type	Variable	Coefficient		St.error
	Constant	–0.182		5.052
Study	Stated preference	0.518		0.363
	Revealed preference	–1.206	**	0.532
	Mixed	–0.899	*	0.545
	Marginal	0.891	**	0.421
Site	Size (ln)	–0.356	***	0.051
	Latitude 35°N-45°N	1.124	**	0.538
	Latitude 45°N-55°N	–1.966	***	0.664
	Latitude higher than 55°N	–2.576	***	0.907
	Cultural services: recreation	–0.536		0.401
	Cultural services: passive	0.649		0.429
	Provisioning	–1.051	**	0.434
	Regulating	0.452		0.407
Context	Real GDP per capita (ln)	0.444	*	0.228
	Population density (ln)	0.519	***	0.170
	Total freshwater ecosystem area	–0.380	**	0.154
	Total known bird species	1.900	*	1.066
	Maximum monthly temperature	–1.432	**	0.056

OLS results. R^2 = 0.45; *Adj.* R^2 = 0.40. Significance is indicated with ***, ** and * for 1, 5 and 10% statistical significance levels respectively. Robust standard errors calculated with Huber-White estimators.

A series of diagnostic tests were performed in order to investigate the robustness of the regression results. The normality of residuals was investigated by analyzing the Kernel density plot of the residuals (see Fig. 8), the standardized normal probability plot and quantiles of residuals plotted against the quantiles of a normal distribution (see Fig. 9), and by means of the Shapiro-Wilk W test for normality.

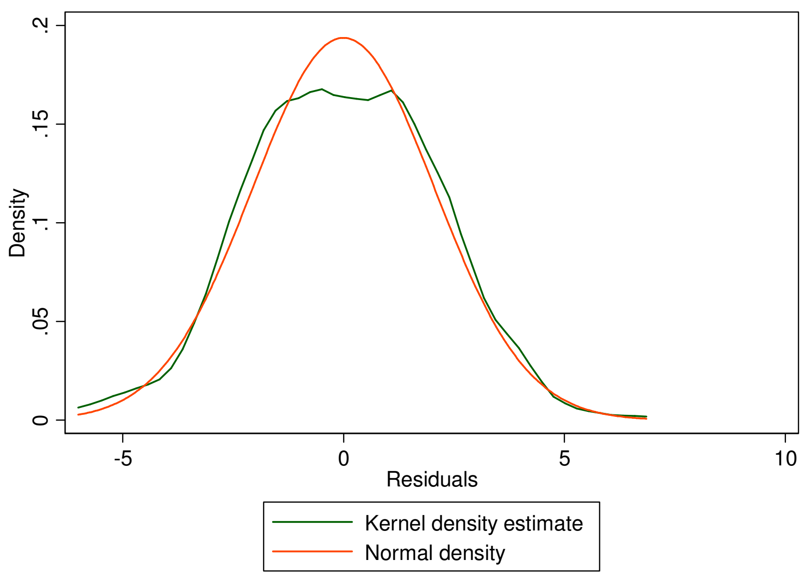

Fig. 8. Kernel density plot of residuals

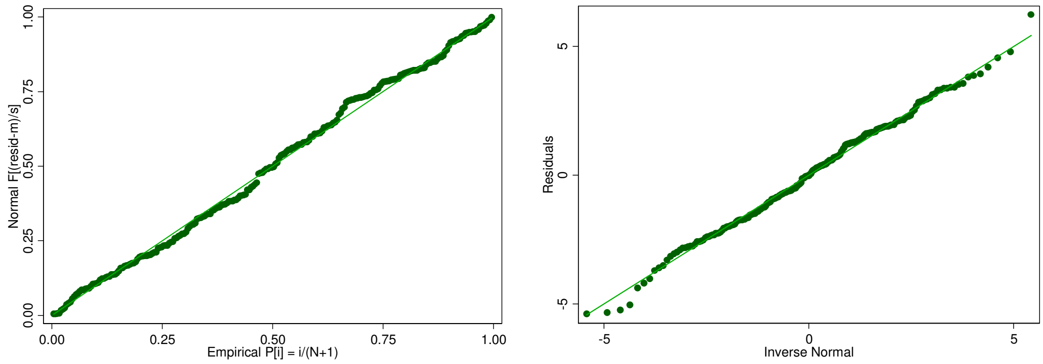

Fig. 9. Standardized normal probability plot (*left*) and quantiles of residuals plotted against quantiles of normal distribution (*right*)

The Kernel density plot and quantiles of residuals show a certain deviation from the normal distribution in the middle range of data and in the lower tail. Nevertheless the distribution seems quite close to a normal distribution. This is confirmed by the Shapiro-Wilk test, which does not reject the null hypothesis of a normal distribution (Prob > z = 0.6518).

The homoskedasticity of the distribution of residuals is investigated by visual investigation of the plot of residuals versus fitted values (Fig. 10) and by means of both White's test and the Breusch-Pagan test. Both tests do not reject the null hypothesis of the homoskedastic distribution of residuals (p-level = 0.7097; Prob > F = 0.9117).

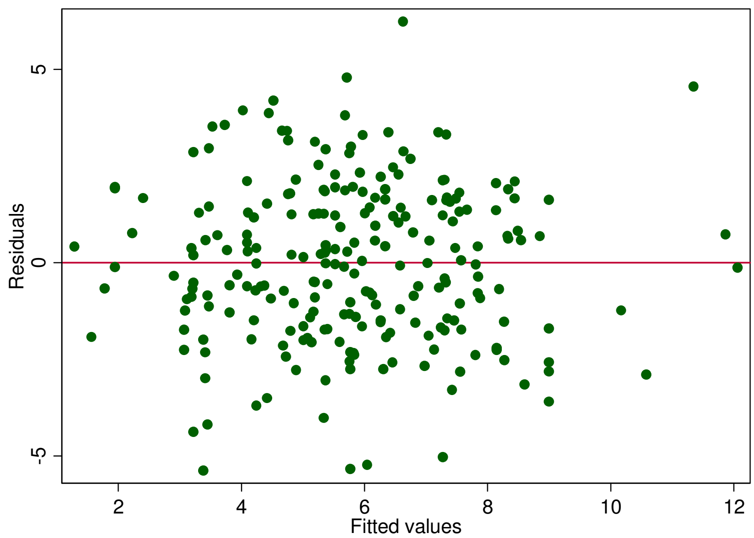

Fig. 10. Plot of residuals versus fitted predicted values

The presence of multicollinearity between predictor variables was investigated by means of the variance inflation factor (VIF). Table 4 illustrates the values of VIF and tolerance (1/VIF) for the regression variables. All values of VIF are lower than 10 and tolerance is higher than 0.1, which suggests that none of the variables can be expressed as a linear combination of other variables; multicollinearity is therefore not present here.

Table 4. Variance inflation factor (VIF) and tolerance

Variable	VIF	1/VIF
Stated preference	2.06	0.486
Revealed preference	2.10	0.475
Mixed	1.16	0.864
Marginal	1.37	0.730
Size (ln)	1.28	0.782
Latitude 35°N-45°N	3.88	0.258
Latitude 45°N-55°N	4.43	0.225
Latitude higher than 55°N	2.30	0.434
Cultural services: recreation	1.97	0.508
Cultural services: passive	1.71	0.584
Provisioning	2.02	0.496
Regulating	1.58	0.632
Real GDP per capita (ln)	4.31	0.232
Population density (ln)	2.00	0.500
Total freshwater ecosystem area	6.97	0.144
Total known bird species	5.06	0.198
Maximum monthly temperature	2.85	0.351
Mean VIF	2.77	

In terms of the model specification, both the link test for model specification (p-value of _hatsq = 0.669) and the regression specification error test for omitted variables (Prob > F = 0.167) do not suggest specification errors. Finally, we tested for dependencies between observations from the same study by running the regression with a clustering of studies. Overall, the results are consistent with what is shown in Table 3, apart from the standard errors of some of the variables which are modestly enlarged rendering the coefficients statistically insignificant. Such variables are 'Latitude 35°N-45°N' (p-level = 0.104), 'mixed' (p-level = 0.179), 'Real GDP per capita' (p-level = 0.110), and 'Total known bird species' (p-level = 0.160).

3.2 Results interpretation and implications for current values

Most of the explanatory variables included in the model are statistically significant in explaining the current values of freshwater ecosystems. Of the study characteristics, revealed preference methods produce significantly lower results than market-based methods and marginal values are higher than average ones. When compared with the results of previous meta-analyses of wetland values, such results are consistent with the findings of Brander et al. (2006) and Ghermandi et al. (2008) who found high values for studies with stated preference methods and marginal values, and only partially contrasts with those of Woodward & Wui (2001), who observed high values for studies using hedonic pricing and replacement cost as valuation method.

Site-specific characteristics significantly affect ecosystem values. The negative coefficient on wetland size indicates decreasing returns to scale (cf. Brander et al. 2006; Ghermandi et al. 2008; Woodward & Wui 2001). Ecosystems located at temperate Northern latitudes between 35°N and 45°N provide statistically higher values than ecosystems at higher latitudes, in proximity to the Equator or at temperate climates in the Southern hemisphere. Of the ecosystem services, the coefficient of provisioning services is negative indicating low values for commercial fishing and hunting, and the provision of materials and fuel wood, while both regulating services and passive values have positive – though not statistically significant – coefficients.

All context variables are significant in explaining the values of freshwater ecosystems. Both real GPD per capita and population density are positively related to ecosystem values indicating an inelastic income effect and high values where a large population may easily access the sites. The negative value on the total area of freshwater ecosystems suggests that substitution effects may take place and thus high values for ecosystems that are more unique in their environment. Such results confirm the previous findings in Ghermandi et al. (2008).

An important additional contribution of this meta-analysis is the recognition of the role of geo-climatic and biodiversity variables in determining ecosystem values. Both the coefficients of the maximum monthly temperature and total number of bird species are significant. Values tend to be high in areas of high biodiversity and decrease at high temperatures. How such findings may affect values under various climate change scenarios will be investigated in the following section.

4. Evaluation of climate change scenarios

4.1 The IPCC scenarios and their inclusion in the meta-regression model

To investigate the potential economic effects of climate change and different policy scenarios on freshwater ecosystem values in European countries we rely on the IPCC storylines. Three of the four scenario families of the Fourth Assessment Report (A2, B1 and B2) are assessed[2], which differ in their assumptions of carbon dioxide emissions, global average surface temperature increase and patterns of economic development (see Table 5). Scenario A2 represents a world differentiated into a series of consolidated economic regions characterized by low economic, social, and cultural interactions, uneven economic growth, and an income gap between industrialized and developing countries that does not narrow. In scenario B1, environmental and social consciousness are combined in a more sustainable development path. Although no specific climate policy is included, the technological shift towards renewable energy plays an important role. A more equitable income distribution than in scenario A2 is achieved. Similarly to scenario B1, scenario B2 is environmentally oriented with a focus on both environmental and social sustainability. Government policies and business strategies show a trend toward local self-reliance and stronger communities while international institutions decline in importance. Technological development plays a smaller role than in scenario B1 and innovations are also regionally more heterogeneous. For the three scenarios, the average global surface air temperature increase ranges between 2.1 and 3.1 °C for scenarios B2 and B1 respectively.

Table 5. The specifications of the four IPCC scenario families

Scenarios by 2050	Climatic model (HadCM3)			
	A1FI	A2	B1	B2
Storyline	Global economic	Local economic	Global environmental	Local environmental
CO_2 concentration (ppm)	779	709	518	567
Δ Temperature (°C)	4,4	2,8	3,1	2,1
Socio-economic dimensions	High savings, high rate of investments & innovation	Uneven economic growth, high per capita income	High investment in resource efficiency	Human welfare, equality, environmental protection

Source: adapted from: IPCC 2001; Schroeter et al. 2005

[2] Scenarios from the A1 family could not be evaluated due to a lack of data on the trends of GDP per capita and total population in the IIASA GGI Scenario Database.

In the first step of the scenario analysis, we estimated the current total ecosystem value of freshwater ecosystems in each of the EU-17 countries. Each country was classified within one of the latitude categories following the distribution of biome types within Europe (see Fig. 11). Although located largely at latitude higher than 55°N, Denmark was classified in the category of Central-Northern European countries (35°N - 45°N) since its biome types are more similar to those countries than to Scandinavian regions.

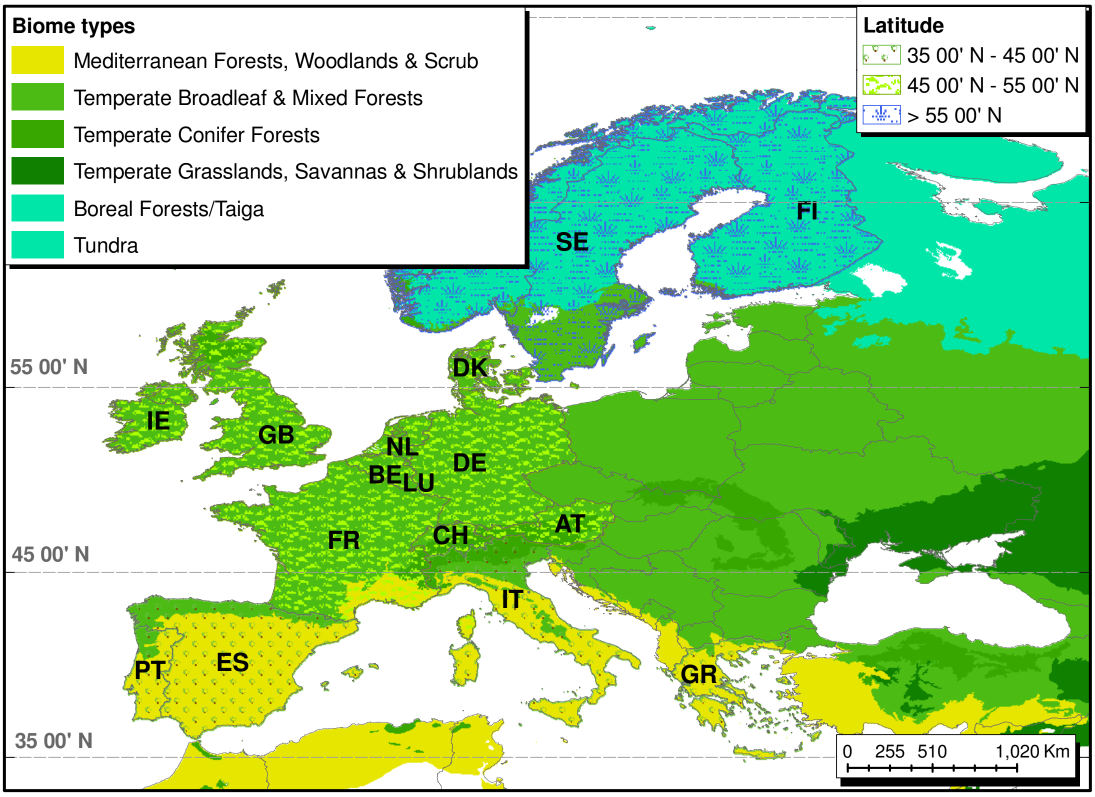

Fig. 11. Distribution of terrestrial biomes in Europe and classification of EU-17 countries in latitude categories

The context variable accounting for the total area of freshwater ecosystems in each country was evaluated by means of GIS analysis from the Global Lakes and Wetlands Database (Lehner & Döll 2004). However, since the Corine dataset (Büttner et al. 2002) provides a more refined land use classification for European countries, , the total area for the aggregation of the values was estimated based on the categories of inland marshes, peatbogs, water courses and inland water bodies in the Corine classification. The average size of freshwater ecosystems in European countries was derived from Brander et al. (2008), who created a dataset of 50,533 individual

European coastal and freshwater wetlands with GIS analysis from the Corine land cover. The binary variables identifying valuation methods and ecosystem services were estimated at the sample mean for the scaling up of values, with the exception of the variable 'marginal' which was set equal to zero in order to estimate average values.

To evaluate the impact of the climate change scenarios on the value estimates, we largely rely on previous research findings to assess how climate change might affect the values of the context explanatory variables in the model.

- Real GDP per capita and population density. For the values of GDP per capita and total population in 2050 in European countries we rely on the work of the International Institute for Applied System Analysis (IIASA 2008) that estimated trends under different climate change scenarios. Real GDP per capita was calculated from its value in market exchange rates assuming that PPP across countries will remain unchanged with respect to year 2003;

- Total freshwater ecosystem area. Since to the best of our knowledge there is no estimate of how climate change will affect the distribution of freshwater ecosystems in Europe and since information on the past land use changes shows conflicting trends for freshwater wetlands and other types of inland water bodies (EEA 2008), the value of the total freshwater ecosystem area in each country remains unchanged in the scenarios. The sensitivity of the model to changes in the value of this variable was assessed.

- Total number of bird species. The variation in biodiversity was included in the scenario analysis through the estimates of the variation of the total number of bird species in EU countries in the frame of the Advanced Terrestrial Ecosystem Analysis and Modelling project (Schroeter, et al. 2004);

- Maximum monthly temperature. The maximum monthly temperature for each country and IPCC storyline was assumed from the HadCM3 climate change scenarios relative to the expected average maximum monthly temperature during 2040-2069 (available at http://www.ipcc-data.org/sres/hadcm3_download.html). The sensitivity of the model to variations in this parameters was assessed.

The values of the remaining model variables remain unchanged with respect to the baseline estimation. Table 6 and Table 7 illustrate the values of the context variables and temperature in the baseline year 2003 and in the three climate change scenarios considered.

Table 6. Values of context variables in baseline (2003) and climate change scenarios (2050)

Country	Population density, inhab./km^2 [a]				Real GDP per capita, I$ 2003 [b]				Total nr of bird species [c]			
	Baseline	A2	B1	B2	Baseline	A2	B1	B2	Baseline	A2	B1	B2
Austria	99.50	93.1	96.7	88.5	29,722	55,842	61,680	55,199	412	424	426	422
Belgium	347.80	354.3	362.8	338.6	27,042	49,086	55,992	48,989	427	436	438	436
Denmark	126.20	129.5	131.1	123.9	29,935	46,667	50,919	45,682	427	455	460	454
Finland	17.30	15.5	15.8	14.9	24,647	53,278	58,800	51,405	421	429	430	432
France	99.90	124.1	119.4	118.8	27,653	56,267	66,761	53,730	517	532	533	532
Germany	230.70	234.9	241.5	223.9	27,090	58,401	64,544	58,446	487	476	477	474
Greece	85.20	78.9	79.6	74.7	16,967	40,711	47,516	39,259	412	466	464	463
Ireland	62.30	75.3	69.3	72.1	29,398	32,607	43,365	35,932	408	434	432	425
Italy	199.70	158.2	164.2	149.4	24,681	56,073	61,163	61,141	478	537	540	534
Luxemburg	182.80	293.9	297.8	282.3	51,155	45,860	53,365	48,839	284	295	298	291
Netherlands	483.80	432.3	423.6	413.7	28,256	43,344	52,167	44,619	444	444	448	443
Norway	15.30	15.9	16.3	15.3	34,528	39,329	44,583	44,667	442	452	454	453
Portugal	114.90	104.5	105.9	99.4	18,936	49,169	56,677	48,078	501	620	625	619
Spain	87.20	78.5	77.6	74.1	22,530	51,536	55,044	54,944	515	612	617	608
Sweden	22.10	20.4	20.4	19.5	27,473	52,536	59,451	51,708	457	464	466	466
Switzerland	187.10	148.9	154.0	141.7	31,298	58,856	60,593	56,757	382	393	395	391
UK	250.00	285.6	285.6	274.2	28,102	47,378	55,999	45,476	557	560	563	554

Notes: [a] Source: IIASA (2008); [b] Derived from IIASA (2008) estimates applying current PPP index; [c] Source: Advanced Terrestrial Ecosystem Analysis and Modelling project (Schroeter, et al. 2004)

Table 7. Values of maximum monthly temperature in baseline (2003) and climate change scenarios (2050)[a]

Country	Baseline	A2	B1	B2
Austria	15.83	19.07	18.71	18.98
Belgium	16.94	19.83	19.30	19.04
Denmark	15.13	17.96	17.03	17.60
Finland	12.09	15.25	14.41	15.32
France	17.56	21.50	20.79	20.67
Germany	17.29	19.84	19.13	19.29
Greece	24.11	26.45	26.15	26.30
Ireland	13.97	15.60	15.22	15.00
Italy	20.89	23.53	23.05	23.48
Luxemburg	17.06	20.09	19.54	19.28
Netherlands	14.58	16.59	16.29	16.52
Norway	11.14	12.58	12.49	12.44
Portugal	20.38	26.73	25.07	25.56
Spain	20.87	26.04	25.11	25.11
Sweden	4.37	9.71	7.98	10.13
Switzerland	15.02	18.23	17.47	17.20
UK	14.75	16.77	16.35	16.07

Notes: [a] Source: HadCM3 climate change scenarios

4.2 Scenario analysis and discussion

Table 8 presents the mean value per hectare, the total area per country and the estimated aggregated value of ecosystem services provided by freshwater ecosystems for each of the EU-17 countries.

Table 8. Current value of freshwater ecosystem services in EU-17 countries

Country	Mean value [$/ha year]	Total area [ha]	Aggregated value [10^6 I$2003/year]
Austria	1,731	95,685	165.631
Belgium	10,691	24,762	264.732
Denmark	1,981	90,495	179.281
Finland	169	5,396,898	909.707
France	1,017	400,351	407.062
Germany	1,459	518,158	756.214
Greece	7,117	132,851	945.498
Ireland	823	1,271,368	1,045.970
Italy	19,076	233,984	4,463.524
Luxemburg	10,606	733	7.774
Netherlands	2,187	226,065	494.434
Norway	356	1,005,407	357.983
Portugal	26,306	55,567	1,461.730
Spain	11,228	342,307	3,843.476
Sweden	590	6,523,231	3,845.458
Switzerland	1,933	52,326	101.125
UK	1,544	747,987	1,155.084

On average, Mediterranean countries (Italy and Portugal in particular) show high mean values per hectare. This is partly due to the relative scarcity of freshwater ecosystems compared to Northern European countries. Countries with high population density such as Belgium or high values of GDP per capita such as Luxembourg also show high values. The lowest mean values per hectare are found in Scandinavian countries and Ireland, i.e., where the largest total area of freshwater ecosystems is concentrated and population density is low. We estimate thus that the highest aggregated values are in countries with high mean values per hectare, such as Italy and Spain, or with very large total ecosystem areas, such as Sweden. Despite the large area in Finland and Norway, the aggregated values for these two countries are relatively low.

Tables 9 and Figures 12–14 illustrate the predicted total and percent variation in the aggregated values of freshwater ecosystems in EU-17 countries and for the three climate change scenarios as compared to the baseline values in year 2003. The sensitivity of the predicted values to changes in land use and maximum monthly temperature are also presented. For the sensitivity analysis we considered a variation of ±5% in the total freshwater ecosystem area per country and ±1°C.

Table 9. Variation in yearly value flow for climate change scenarios

Country	Scenario A2 (2050)		Scenario B1 (2050)		Scenario B2 (2050)	
	Total value [10^6 I$2003/year]	%	Total value [10^6 I$2003/year]	%	Total value [10^6 I$2003/year]	%
Austria	141.914	-14	160.185	-3	138.027	-17
Belgium	241.287	-9	282.326	7	264.187	0
Denmark	167.484	-7	204.800	14	170.154	-5
Finland	804.392	-12	957.522	5	774.200	-15
France	377.257	-7	443.788	9	407.154	0
Germany	719.313	-5	848.430	12	753.396	0
Greece	1,218.313	29	1,357.331	44	1,176.974	24
Ireland	1,084.853	4	1,230.938	18	1,157.438	11
Italy	4,894.096	10	5,624.119	26	4,925.748	10
Luxemburg	6.637	-15	7.908	2	7.347	-5
Netherlands	426.440	-14	485.353	-2	423.834	-14
Norway	331.324	-7	361.905	1	351.751	-2
Portugal	1,293.920	-11	1,784.723	22	1,470.246	1
Spain	3,506.379	-9	4,161.990	8	3,948.795	3
Sweden	1,275.117	-38	3,244.751	-16	2,184.592	-43
Switzerland	79.675	-21	92.467	-9	87.716	-13
UK	1,190.263	3	1,373.852	19	1,238.002	7
Total	18,858.665	-8	22,622.390	11	19,749.561	-5

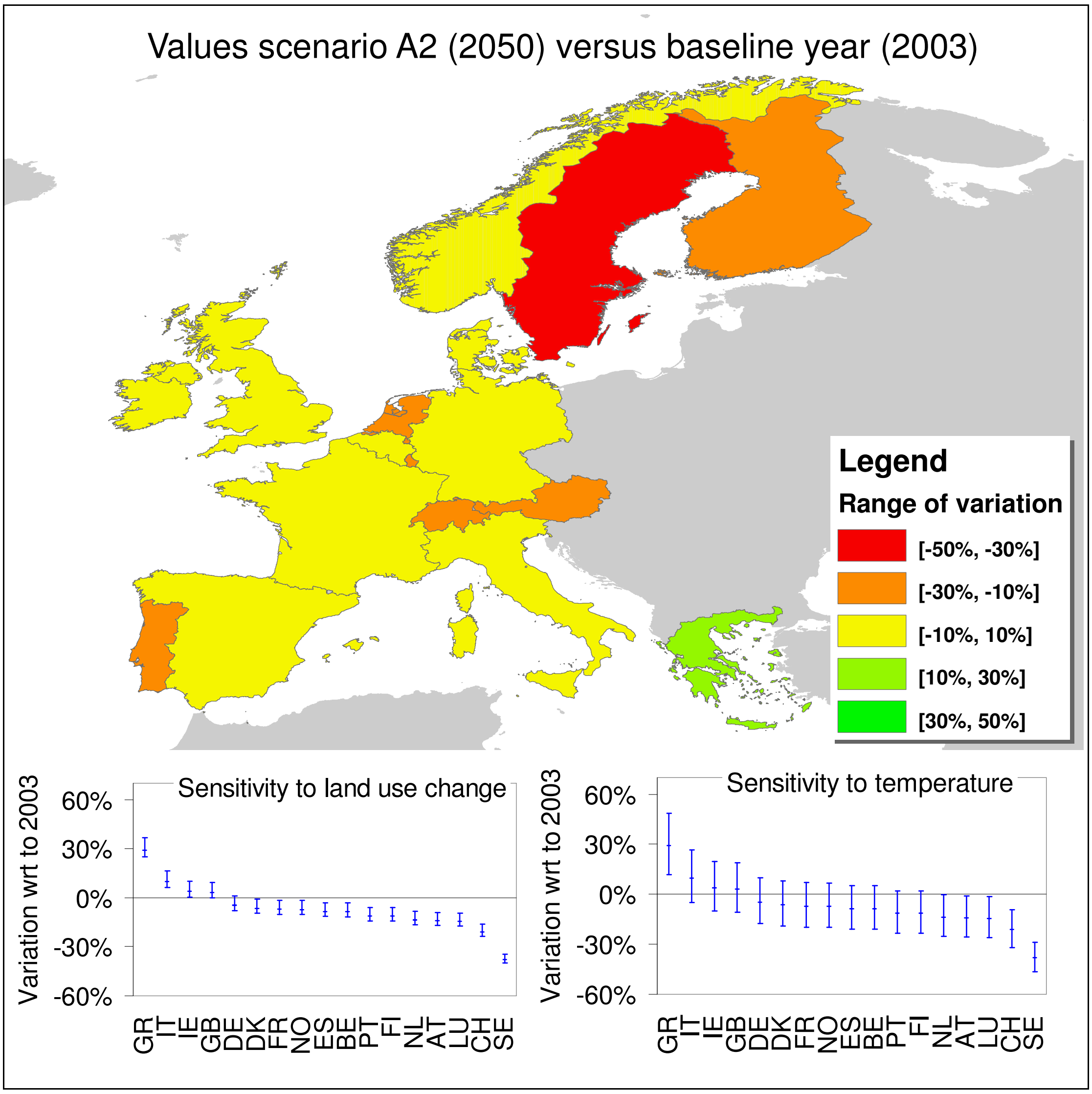

Fig. 12. Percent variation of aggregated values in A2 scenario (2050) (*above*) and sensitivity to changes in land use (*below right*) and temperature (*below left*)

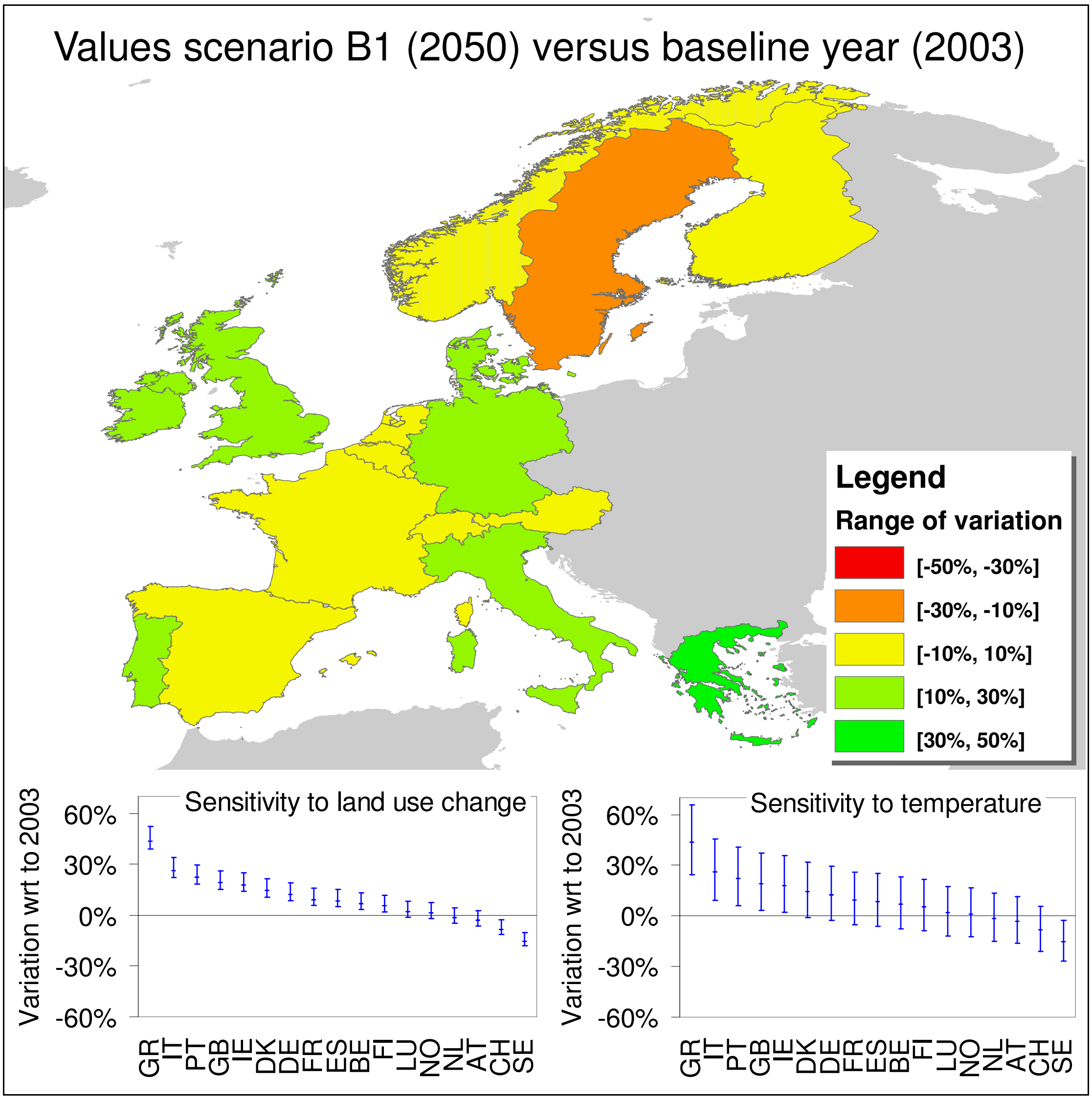

Fig. 13. Percent variation of aggregated values in B1 scenario (2050) (*above*) and sensitivity to changes in land use (*below left*) and temperature (*below right*)

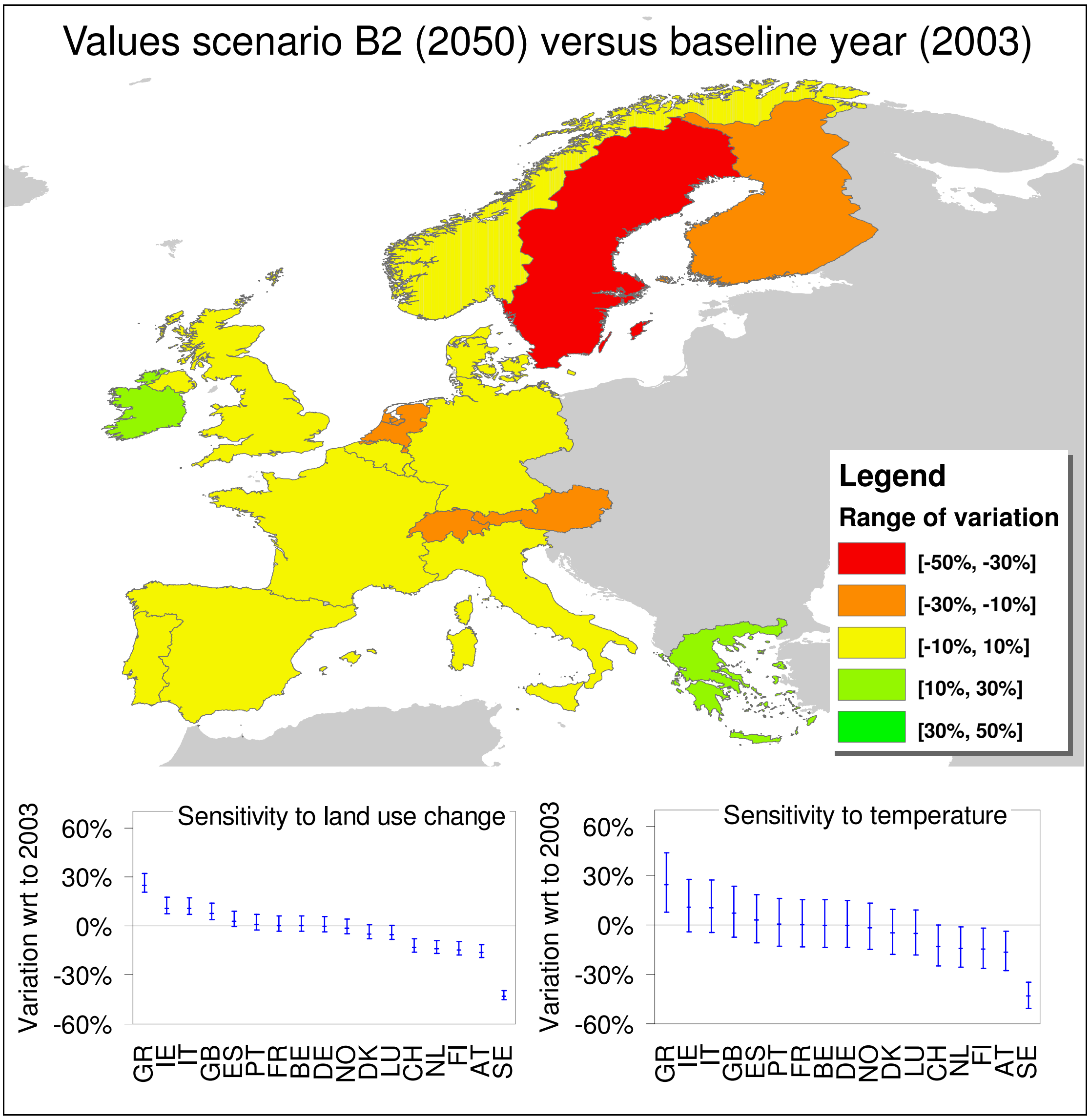

Fig. 14. Percent variation of aggregated values in B1 scenario (2050) and sensitivity to changes in land use and temperature

Whether the overall flow of values from freshwater ecosystem services in the considered European countries will increase or decrease in 2050 largely depends on which climate change scenario is taken into account. Under the assumptions of scenario A2, the total value of freshwater ecosystem services in the 17 considered countries will decrease by 8% in 2050. The most favorable conditions are those of scenario B1. Under the conditions of this scenario, the total value is predicted to increase by 11% in 2050. In all three IPCC scenarios considered, the flow of values will increase in Italy, Greece, Ireland and the United Kingdom. The largest percent increase is expected in Greece (24–44%). In absolute terms, the largest increase is in Italy (430–1,161 million 2003 I$/year). The large increments in Greece and Italy are due both to a large increase of the real GDP per capita and to an increase in biodiversity, which offset the negative effect of the increase in temperature. Decreases in the flow of values are predicted for Sweden, Finland, Austria and Switzerland. The largest losses are expected in Sweden, where values will decrease by 16-43%, which corresponds to a total loss of 600-1,660 million 2003 I$/year.

The analysis of the sensitivity of the results to changes in land use and temperature increase may affect the predictions of the model. A 5% increase or reduction in the total area of freshwater ecosystems in each of the studied countries will have a relatively small effect on the value estimates. This is due to the fact that this variable affects values in two adverse manners. On one hand, a decrease in freshwater ecosystem surface results in a reduction on the surface on which the mean values per hectare are aggregated. On the other hand, the mean value per hectare of the remaining ecosystems would increase since the abundance of freshwater ecosystems is negatively correlated with values due to substitution effects. A 1°C uncertainty in the future temperature scenarios affects the model estimates substantially. An increase of 1°C above the IPCC estimates would result in a loss of ecosystem services values in all three scenarios, ranging from -4% to -20%. On the other hand, a change in temperature limited to 1°C below the IPCC estimates would result in net gains in value flows, which are estimated to range between 7-28% above the baseline values, corresponding to an increase of 1,359–5,702 million 2003 I$/year.

In order to directly compare the value of ecosystem services flow across the different socio-economic IPCC storylines, Fig. 15 plots the percent variation in value flows for scenarios A2, B1 and B2 versus the baseline level of provision in year 2003.

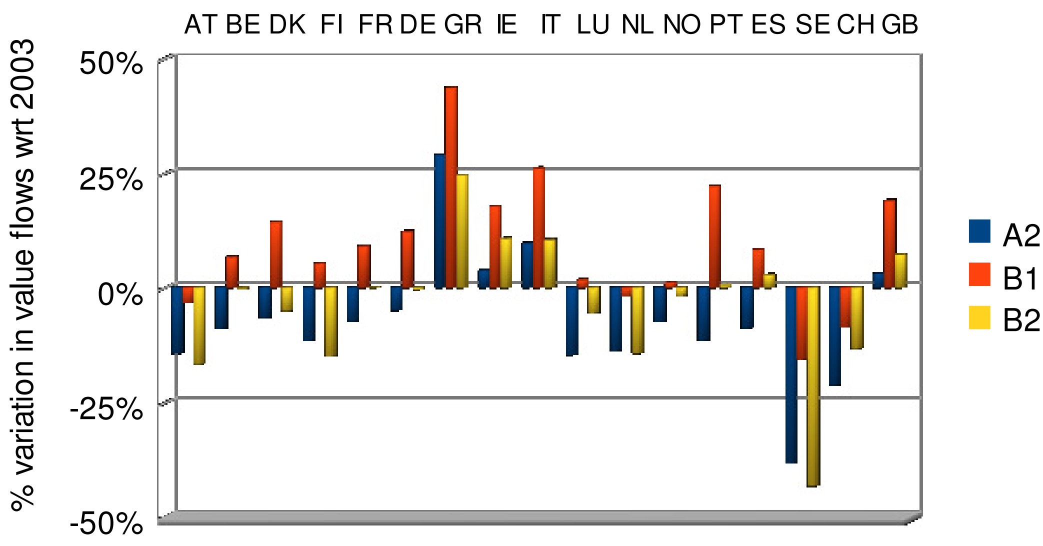

Fig 15. Comparative percent variation in value flows across IPCC storylines with respect to baseline year (2003)

The comparative analysis of IPCC scenarios demonstrated that the A2 scenario is always worse off than the B1 scenario and, with few exceptions, the B2 scenario. In other words, sustainable development practices in scenarios B1 and B2 are shown to at least partially compensate for the negative impacts of climate change on the flow of freshwater ecosystem services as calculated in scenario A2. Furthermore, according to Figure 15, the policies underlying the B1 storyline are to be preferred in all considered countries from the viewpoint of ecosystem services. The overall difference in the estimated value flows between scenario B1 and A2 amounts to 3,763 million I$/year, while the difference between scenario B2 and A2 is equal to 621million I$/year. The largest gains from shifting from scenario A2 to scenario B1 would be concentrated in Sweden (870 million I$/year), Italy (730 million I$/year), and Spain (656 million I$/year). In percentage, the largest gain would be in Portugal (a 38% increase) and Sweden (a 37% increase).

5. Conclusions

In this study we developed a framework for the economic valuation of the flow of services from freshwater ecosystems (i.e., rivers, lakes and freshwater wetlands) at the European scale. Meta-analysis is used as a tool to interpret the results of 103 primary valuation studies concerning 123 distinct ecosystems worldwide and to determine the main value drivers. We identify and quantitatively evaluate the role of income effects, substitution effects, return to scale, population density, biodiversity and geo-climatic conditions in the formation of freshwater ecosystem values.

In a first application of the results of the meta-regression, the current mean per hectare values and the aggregated yearly flow of values from freshwater ecosystems for each of the EU-17 countries are estimated. Our results show that per hectare values are high in Mediterranean and Southern European countries (e.g., Italy and Portugal) and in countries with high population density (e.g. Belgium) and are low in scarcely populated countries with a high abundance of such ecosystem types (e.g. Scandinavian countries). Aggregated values partially reflect the distribution of per hectare values, being high in Italy and Spain but also in countries with large aggregation areas such as Sweden.

Secondly, we predict the potential impact of climate change on the flow of values in the EU-17 countries by investigating the effect of the predicted shifts in the context variables of the model (i.e., air surface temperature, population density, GDP per capita and biodiversity level) for three IPCC storylines (A2, B1 and B2). We estimate that overall values will increase by 11% between the baseline year 2003 and 2050 under the conditions of scenario B2, but decrease by 5–8% under scenarios A2 and B2. The increase in values will be largely limited to Mediterranean countries such as Greece, Italy and Portugal. The results show a high sensitivity to the increase of surface air temperature. A comparative analysis of value variation in the three IPCC scenarios shows that environmentally oriented scenarios, in particular scenario B1, partially compensate for the losses that are due to climate change and result in higher values also in the countries where climate change will have a positive impact on ecosystem services values. This prompts us to conclude that the costs of policy inaction should be taken into account in the policy making process concerning freshwater ecosystems facing the threat of climate change.

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