doi:10.20944/preprints202106.0497.v1

Article

A global meta-analysis for estimating local ecosystem service value functions

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Abstract: Meta-analysis has increasingly been used to synthesize the ecosystem services literature, with some testing of the use of such analyses to transfer benefits. These are typically based on local primary studies. However, meta-analyses associated with ecosystem services are a potentially powerful tool for transferring benefits, especially for environmental assets for which no primary studies are available. In this study we use the Ecosystem Service Valuation Database (ESVD), which brings together 1350 value estimates from more than 320 studies around the world, to estimate meta-regression functions for provisioning, regulating & maintenance and cultural ecosystem services across 12 biomes. We tested the reliability of these meta-regression functions and found that even using variables with high explanatory power, transfer errors could still be large. We show that meta-analytic transfer performs better than simple value transfer and, in addition, that local meta-analytical transfer (i.e. based on local explanatory variable values) provides more reliable estimates than global meta-analytical transfer (i.e. based on mean global explanatory variable values). Thus, we conclude that when taking into account the characteristics of the study area under analysis, including explanatory variables such as income, population density and protection status, we can determine the value of ecosystem services with greater accuracy.

Keywords: Ecosystem services; Benefit transfer; Meta-analysis; Meta-regression function.

1. Introduction

Jean-Baptiste Say poses the idea of nature's services as costless, free gifts of nature as follows: “the wind which turns our mills, and even the heat of the sun, work for us; but happily no one has yet been able to say, the wind and the sun are mine, and the service which they render must be paid for” [1]. However, currently it is possible to observe that the overuse or misuse of some natural resources poses direct impacts on society. In the face of this problem came the concept of ecosystem services (ES), defined as the benefits that humans obtain from the natural environment and from properly functioning ecosystems. Hence, authors [2,3,4,5,6,7,8] argue that sustainable management of natural resources requires correct valuation of the ecosystem defining their services to the society.

Ecosystem services support human life every day and contribute to human well-being in many ways, which are hard to define in a single notion. Hence, the Millennium Ecosystem Assessment [9] and the Common International Classification of Ecosystem Services [10] differentiate between the following ecosystem services: a) provisioning services (such as supply of food via fishery production, fuel wood, energy resources, and natural products); b) regulating & maintenance services (such as shoreline protection, nutrient regulation, carbon sequestration, detoxification of polluted waters, and waste disposal); and; c) cultural services (such as tourism and recreation).

Ecosystems have a great importance with many dimensions (ecological, socio-cultural and economic) [5]. Thus, expressing the value of ecosystem services in monetary units (i.e. ecosystem service values; ESV), can prove to be of utmost importance to help raise consciousness and convey the (relative) importance of ecosystems and biodiversity to decision makers. Indeed, monetized valuation pushes for a more efficient use of limited resources and helps selecting where protection and regeneration is economically more important and can be delivered at least cost [11,12]. It can also assist determining "a fair compensation" to be paid for a loss of ES in liability regimes [5].

Historically, in the late 1990s and early 2000s, the concept of ES slowly found its way into the policy arena, e.g., through the "Ecosystem Approach" and the Global Biodiversity Assessment. In 2005, the concept of ES got wider interest after the publication of Millennium Ecosystem Assessment [9] – a four-year, 1300-scientist study by the United Nations for policymakers [4]. ES are also entering the consciousness of mainstream media and business, namely through the World Business Council for Sustainable Development that has actively supported and developed this concept [13]. Many projects and groups are currently working toward better understanding, modeling, valuing, and managing ES and natural capital [4].

An increasing number of papers seeking the valuation of ES has been published over the last decades. Assessments have been conducted at local [14;15,16], national [17,18,19], continental [20,21] and global [6,4,5] scales. In the same way, databases compiling data from these primary valuation studies were created to aggregate information and facilitate public debate and policy action. Some examples of such databases include the Economic Valuation Reference Inventory [22], and the Ecosystem Service Valuation Database [23].

Since the early 1990s several researchers have investigated the applicability and the precision of benefit transfer. However, these past studies were primarily concerned with traditional methods of benefit transfer (in particular value transfer), replacing values directly from the study site to the policy site without amendments [24]. However, in the late 1990s meta-analysis started to be used, with multivariate regression being investigated for use in benefit transfer [25].

Meta-analysis (MA) is a technique that uses statistical models (meta-regressions) to summarize and evaluate previous research results. In benefit transfer, meta-regression results may be used qualitatively, to corroborate new primary results, or to transfer estimated values [26]. Meta-regression in benefit transfer summarizes the weight of the evidence and characterizes the degree of uncertainty about quality-adjusted ecosystem values. In meta regression the value estimates from primary valuation studies are thereby treated as individual observations [27]. Meta-regression also extends the range of primary valuation studies by allowing the estimation of values for services and functions that are constant within each primary valuation study but vary across different valuation studies [28]. Meta-analyses have been performed for specific ecosystem services, biomes, and locations. There is a study which assessed the cultural value of surface water quality in the United States using 131 willingness-to-pay (WTP) estimates from 18 studies [15]. Similarly, another synthesized 127 WTP estimates from 22 different studies that provided estimations for preservation, forest restoration, and freshwater restoration also in United States [29]. In another study, was performed a meta-analysis to determine the values of goods and services provided by wetland ecosystems, using 418 value observations derived from 170 valuation studies and186 wetland sites worldwide [30]. Other study, realized a marine recreational meta-analysis estimation, using 311 distinct value observations from 96 primary valuation studies [31]. Nevertheless, there are no studies with a broader analysis, that estimate global meta-regression functions for provisioning, regulating & maintenance and cultural ecosystem services across biomes and continents. In addition, testing the reliability of estimated meta-regression functions is relatively rare, e.g. [32,33]. One of the main challenges is developing equations for ES that capture the local/regional characteristics of the biome and provide reliable values.

Hence, the objective of this study is to estimate meta-regression functions for different ecosystem services able to determine the value for 12 different types of biomes, with

doi:10.20944/preprints202106.0497.v1

the possibility of these estimates being applied at the global scale. In this study, we provide the results of a Meta-Analysis of the monetary values provided by the Ecosystem Service Valuation Database [23] for 3 Ecosystem Services (Provisioning; Regulating & Maintenance; Cultural), supplied by 12 main land covers (Coastal systems; Coastal wetlands; Coral reefs; Cultivated areas; Desert; Fresh water; Grasslands; Inland Wetlands; Open Ocean; Temperate/Boreal Forests; Tropical Forests; Woodlands). In addition, complementary explanatory variables from the World Bank Data [34] and FAOSTAT [35]. were gathered. Based on this review and analysis, we aim to provide recommendations for future research that may enhance the use of ecosystem service valuation for policy analysis.

The remainder of this paper is structured as follows. The next section details the MA application and use in ES studies as well as the theoretical specification and validation method. Next, in "Materials and Methods", the ESVD database and other variables used to build the models are presented. In turn, we expose and analyze the functional forms of the models for the three ecosystem services. The "Results" section presents the application of the models and discusses the results. Finally, in the "Conclusions and recommendations" section, concluding remarks and observations are presented.

2. Materials and Methods

2.1 Literature on Meta-analysis

Benefit transfer (BT) is an economic valuation tool, with the goal to adapt value estimates from past research to assess the value of a similar, but separate, change in a different resource [36]. Technically, BT uses valuation estimates from other areas (study sites) and applies them to a similar location (policy site) [3]. It's a technique that relies on primary studies and, therefore, allows for the reduction of field research constraints, both in terms of time and infrastructure. However, it can lead to over/underestimated values while the accuracy of an ESV estimate is determined by the quality of the reference studies used. Thus, peer reviewed empirical studies from similar biophysical and socioeconomic contexts are preferred over any other type of data source [32].

The BT is useful when the estimation of the economic service value cannot be obtained due to time and/or budget constraints and to, therefore, make the best possible use of the existing literature in order to evaluate the economic importance of a natural area [19]. This is possible by adapting and applying estimates from existing studies that best suit the new context, using one or more of the following BT methods: i) benefit estimate or value transfer, which is the extrapolation of estimates from one site to another (i.e. values are directly transposed from the study site to the policy site without amendments), ii) benefit function transfer, which is the transfer of economic functions between the sites (i.e. coefficients are used to determine the policy site values), iii) meta-analysis, which combines the findings of independent studies related to the research topic as to summarize the body of evidence relating to a particular issue, and iv) preference calibration, which uses existing benefit estimates derived from different methodologies and combines them to develop a theoretically consistent estimate for policy site values [37].

The Meta-Analysis (MA) technique can help reduce deviations in value estimates [26]. This technique was first put forward by, as a research synthesis method, and has since been developed and applied in many fields of research, other than the area of environmental economics [38,39]. It is widely recognized that the large and increasing literature on economic valuation of ES and environmental impacts has become difficult to interpret and that there is a need for research synthesis, especially in statistical MA, to aggregate information and insights [27,40;41].

MA is by definition a quantitative analysis of statistical summary indicators reported in a series of similar empirical studies. It's a commonly used method for compiling and analyzing the data from studies towards the creation of a value function. This is a method of synthesizing the results of multiple studies that examine the same phenomenon, through the identification of a common effect, which is then "explained" using regression

doi:10.20944/preprints202106.0497.v1

techniques in a meta-regression model [40]. In the realm of environmental resource valuation, MA is commonly used in benefit transfer endeavors due to its usefulness in incorporating a structural utility framework with less strictly economic information [27;42].

2.2 Specification of the Meta-regression

Established based on consumer rationality and reasonableness, the microeconomic theory of consumer is explained by two different approaches: the indifference curve approach and the utility function approach [43]. Indifference curves represent all combinations of goods and services that provide the same level of satisfaction to an individual (i.e. the same level of global utility). Implicit in an indifference curve is the marginal rate of substitution, which expresses the maximum amount of a good that one is willing to give-up in exchange for one additional unit of another good, at the same level of satisfaction [43]. Utility functions represents the degree of profitability or satisfaction that we get from using things, related to a measure of satisfaction relative to an economic agent. The analysis of its variation allows to explain the behavior that results from the decisions taken by each agent to increase his/her satisfaction.

Any meta-analytic benefit transfer (MA-BT) must be based on the ecosystem service valuation theory and the utility functions theory (see Eq. 1), specific to microeconomics [42]. The general form of a MA-BT underlying the utility function, is given by [24]:

$$U_i = f(P_i, Y_i, Q_i, Ql_i, Sub_i, H_i, I_i) \tag{1}$$

Where U_i is the utility (satisfaction) obtained by individual i, P_i is the general price level faced by individual i, Y_i is the individual revenue, Q_i is the quantity of ES available to individual i, Ql_i is the global quality of ES available to individual i, Sub_i represents the substitutes for Q available to individual i, H_i refers to other non-income attributes of individual i, and I_i is the information available to individual i.

Resorting to this microeconomic theoretic, we organize the MA-BT utility theory into three axes: the “strong structural utility theoretic (SSUT) approach”, the “weak structural utility theoretic (WSUT) approach” and the “non-structural utility theoretic (NSUT) approach” (of which they only endorse the first two) [42].

Following the microeconomics reasoning, we assume that MA-BT is based on the utility function (see Eq. 2) and opt for analyzing the WSUT. Under the WSUT, each individual might choose between two alternative environmental options – *ceteris paribus*, a damaged ecosystem (Q_0) and a restored ecosystem (Q_1), which will assure an equilibrium situation (the maximum utility) [42,7], represented by:

$$U_i\,(P_i, Y_i, Q_0) = U_i\,(P_i, Y_i, -ESV, Q_1) \tag{2}$$

Where U_i is the utility obtained by individual i, P_i is general price level faced by individual i, Y_i is individual revenue, Q_0 quality/quantity of ES available to individual *i* in the absence of any payment, ESV is ecosystem service value paid by individual i, and Q_1 is the quality/quantity of ecosystem available to individual *i* after having paid for these ES.

Microeconomics utility theory will hold if both sides of this parity are equal. That is, an individual will stay at the same indifference curve if he/she gets the same level of satisfaction by consuming Q_0 with no payment or by consuming Q_1 and paying ESV in exchange. That is, the ESV the individual is willing to give-up must be counterbalanced by an increase in Q. Thus, $Q_1 > Q_0$ after the amount has been spent.

In this study we adopt the WSUT approach, where variables are added in the bid-function, (assumed to be derived from some unidentified utility function) but keeping the flexibility to incorporate other explanatory variables into the ESV model, such as study-site characteristics, local price levels or local individual income [7]. This is the approach used in most previous MA-BT studies [7,31,44]. Our general theoretical model will focus on estimating the ESV (see Eq. 3), as a function of various explanatory variables according to the general form of the underlying conditional indirect utility function:

$$ESV = f(B_l, SQ_l, C, QQ_r, I_r, P_r) \quad (3)$$

Where, B_l is the biome and SQ_l the quality status for the location under analysis (l), C is the continent where the study area is located, and QQ_r is the quality/quantity of protected areas, , I_r is the income and P_r is population density in the region (r) where the study area is located.

The meta-modelling approach has several advantages for BT as compared to other methods (such as value transfer or function transfer). Different from those, which are based on single studies, MA resorts to information from a collection of studies and, thus, provides more rigorous measures of central tendencies that are sensitive to the distributions of underlying study values [24].

2.3 Validity and reliability of a meta-analytic benefit transfer

The validity and reliability of the MA-BT can be assessed by applying the concept of transfer error (TE), defined as [32]:

$$TE = \frac{|ESV_P - ESV_B|}{ESV_B} \quad (4)$$

Where ESV_P is the predicted value from the study site (s) and ESV_B is the base value ("benchmark") at the policy site. The TE is often used as a validity measure of the acceptability of meta-models. Traditionally, validity requires that the values, or the value functions generated from the study site, be statistically identical to those estimated at the policy site [8]. The main objective is to find a target value of TE=0, confirming that the estimated values from the MA-BT values are similar to those arising from the database.

There is no agreement on maximum TE levels for BT being reliable for different policy applications. The TE analysis is not supposed to judge which levels should be considered acceptable, or even conduct traditional statistical tests of BT validity. Instead, it remains a measure of reliability, especially if TE estimates are compared across meta-model specifications and restrictions, and between alternative ways of conducting BT based on the same data [7].

Therefore, we perform the following comparisons between the estimates from the meta-model and the original observations from the database:

(a) "Value transfer" compares each ESV estimate in the database with the corresponding global mean ESV;

(b) "Global meta function transfer" compares each ESV estimate in the database with the estimates produced by the meta-model, using mean global values for the explanatory variables;

(c) "Local meta function transfer" compares each ESV estimate in the database with the estimates produced by the meta-model, using mean national values for the explanatory variables.

2.4 Background and data

In general, MA in environmental valuation is based on brief statistics and analytical conclusions taking a group of studies as data. Therefore, MA estimates can reduce the time spent to acquire data – both in the case of older studies and unpublished work (where data may not be available) and current studies (where authors may be slow to disclose data). However, even within the same methodology, combining primary data is not always possible due to conflicting data structures and different estimation procedures [42]. This might limit MA studies representativeness.

A solution to this problem is the use of specialized ESV databases, which offer a wide range of detailed information about the studies taken into account, beyond the results found in the assessment. These databases give information on other factors crucial for the delimitation of a MA model, such as: the year of the study, protection status, location, type of environment and method. In this analysis we use the Ecosystem Service Valuation Database [23], one of the biggest databases containing real values for a range of ES and biomes where the value estimates are systematized in monetary units (€/ha/year).

The ESVD was built to process and analyze the monetary estimates of ES values from different biomes in a way that it is easily used by various end-users, worldwide. Composed by 267 studies and 1310 value estimates, the ESVD links various types of information from different studies with the value estimates and case study sites. These value estimates are organized by biome, ES and country. The main biomes are "Coastal System" (*CSys*), "Coastal Wetland" (*CWet*), "Coral Reef" (*CoRf*), "Cultivated Area" (*CuAr*), "Desert" (*Dser*), "Grassland" (*Gras*), "Inland Wetland" (*InWt*), "Marine" (*Mari*), "Temperate or Boreal Forest" (*TeFo*), "Tropical Forest" (*TrFo*), "Fresh Water" (*FrWa*) and "Woodland" (*Wood*). The ES are Provisioning; Regulating & Maintenance and; Cultural services, divided in 14 types of services (see in Figure 1). Finally, a total of 80 countries are included, 217 values from Africa; 352 values from Asia, 208 values from Europe, 180 values from Latin America and the Caribbean; 122 values from North America, 116 from Oceania, and 114 from the whole world.

Initial criteria for selecting studies from the general ESVD database were: (1) original nature of case study data (i.e. not based on Value Transfer or Total ecosystem Value); (2) the provision of a complete set of information, including study site location, surface area and the scale of the study (i.e. not based on a "world" scale location); (3) clear characterization of valuation methodologies used (i.e. not unknown valuation methods); (4) clear mentioning of the surface area for which the ecosystem service valuation study is applied (so that estimates of monetary values per hectare can be obtained); and (5) ES or subservice monetary value directly linked to a specific biome/ecosystem and unit (i.e. not per person or household). Besides information on the location of each case study, the ESVD includes information on protection status and the size of the research area, enabling for the verification of whether more estimates about the same case study location are available from other sources or publications. Together with supplementary variables, coming from complementary socio-economic databases that are added to ESVD, these variables allow for further socio-economic interpretation of the monetary output values.

In order to relate an estimate of an ecosystem service to the socio-economic context of a case study site, two additional variables were included in the Country table – namely Gross National Income (*GNI*) per capita (based on purchasing power parity in current international prices) and average Population density (*PDen*; people per square kilometer). This information was obtained from the World Bank Data, which provides world development indicators by country [34]. Collected values were obtained for the years in which the studies were carried out.

Regarding protection status, many of the data points in the ESVD pertain to case studies in protected areas. This information allows to assess the influence of protection status on ES value, testing whether protection excludes the user's access to the site and consequently to the services generated or, alternatively, whether it allows for ecosystem conservation and subsequent appreciation of the services. Protection status is classified into 3 categories: Fully Protected (*FProt*), Partially Protected (*PProt*), Not Protected (*NProt*). Other complementary variables collected from the World Bank Data, in order to verify the study-site protection status, were: Terrestrial Protected Areas (*TProt*; the percentage of protected land by country) and Marine Protected Areas (*MProt*; the percentage of protected territorial waters). From the Food and Agriculture Organization (FAO) statistical database [35], information on the land use characteristics was collected. Namely percentage of forest area (*FPer*) and percentage of agricultural land (*APer*), which helped to understand land use and occupation characteristics with emphasis on agricultural activities and state of preservation/conservation of nature.

For each biome in the ESVD, 14 ES were identified and classified into the 3 main classes: Provisioning, Regulating & Maintenance and Cultural services (Figure 1). This classification constitutes an important step in the linkage between ES and human well-being and will be used as a basis to perform MA-BT for ecosystem valuation.

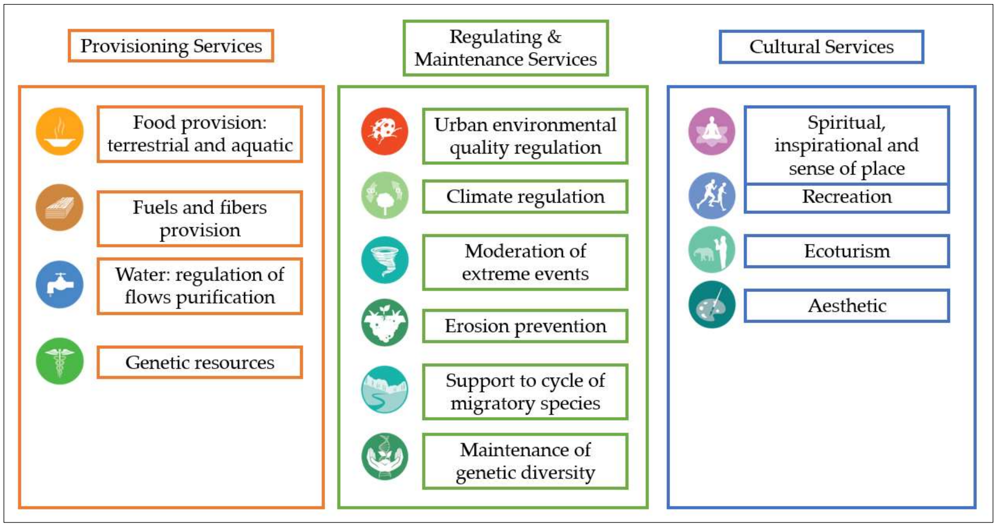

Figure 1. Ecosystem service values division [45].

Provisioning Services (ESV_{Prov}): Provisioning services are mainly composed of food provision, water provision (including regulation of water flows and water purification), fuels and fibers provision, and genetic resources provision [45]. This is an ES highly valued by humans, because of the direct impact on our day-to-day life.

Regulating & Maintenance Services ($ESV_{Reg\&Main}$): Ecosystems provide several environmental regulation services of importance for human well-being, and for the conservation of living spaces for plants and animals. Usually invisible and taken for granted, they help maintaining air and climate quality, moderating extreme events, maintaining soil quality, and preventing erosion [45].

Cultural Services (ESV_{Cult}): Influenced by non-material benefits that people obtain from an ecosystem, cultural ES refer to aesthetic inspiration, recreation and tourism, and spiritual experience related to a natural environment [45].

All monetary values in the ESVD values are converted into a common reference unit, specifically 2015 'International' €/ha/year, using the Purchasing Power Parity (PPP) units expressed in Euros [3445].

3. Results

3.1. Data summary

Based on the above-mentioned criteria, the total number of monetary value estimates included in our sample amount to 636 observations. In this study ES value functions are estimated for Provisioning, Regulating & Maintenance and Cultural services (see Section 5). The estimation of each ES value function draws on a different number of observations (see Table 1): Provisioning Services (302; 47.5%), Regulating & Maintenance Services (225; 35.4%), and Cultural Services (109; 17.1%).

Table 1. Number of valuation studies, by service and biome, from the ESVD included.

Service[1]/Biome[2]	*CSys*	*CWet*	*CoRf*	*CuAr*	*Dser*	*FrWa*	*Gras*	*InWt*	*Mari*	*TeFo*	*TrFo*	*Wood*	Total
ESV_{Prov}	18	55	37	6	2	5	10	75	6	8	63	17	302
$ESV_{Reg\&Main}$	6	58	26	7	-	1	9	36	4	16	51	11	225

doi:10.20944/preprints202106.0497.v1

ESV_{Cult}	7	14	42	-	-	4	2	11	4	10	14	1	109

Note: [1] ESV_{Prov} = Provisioning Ecosystem Values; $ESV_{Reg\&Main}$ = Regulating & Maintenance Ecosystem Values; ESV_{Cult} = Cultural Ecosystem Values; [2] *CSys* = Coastal System; *CWet* = Coastal Wetland; *CoRf* = Coral Reef; *CuAr* = Cultivated Area; *Dser* = Desert; *FrWa* = Fresh Water; *Gras* = Grassland; *InWt* = Inland Wetland; *Mari* = Marine; *TeFo* = Temp./Bor. Forest; *TrFo* = Tropical Forest; *Wood* = Woodland.

Table 2 lists and describes the main variables used in the MA. Table 3 provides summary statistics for each of these variables for every service, with exception for the dummy variables.

Table 2. Meta-Analysis Variables Description.

Variables	Description	
APer	Agricultural land that refers to the share of land area that is arable, under permanent crops, and under permanent pastures, by percentage of land area.	
FPer	Forest area with natural or planted stands of trees of at least 5 meters in situ, by percentage of land area.	
MProt	Percentage of marine protected areas, from territorial waters of a country.	
TProt	Percentage of terrestrial areas totally/partially protected, designated by national authorities.	
GNI	Gross National Income per capita, using purchasing power parity rates.	
PDen	Population density is midyear population divided by land area in square kilometres.	
	Dummies	
CSys; CWet; CoRf; CuAr; Dser; FrWa; Gras; InWt; Mari; TeFo; TrFo; Wood	**Biomes:** Coastal System; Coastal Wetland; Coral Reef; Cultivated Area; Desert; Fresh Water; Grassland; Inland Wetland; Marine; Temp./Bor. Forest; Tropical Forest; Woodland.	= 1 if the study area belongs to = 0 if the study area does not belong
Euro; Asia; Ocea; LaAm; NoAm; Afric	**Continents:** Europe; Asia; Oceania; Latin America and Caribbean; North America; Africa.	
FProt; PProt; NProt	**Protection Status:** Fully Protected; Partially Protected; Not Protected.	

According to Table 3, the common variables in all models (Provisioning; Regulating & Maintenance; Cultural) are population density (*PDen*) and gross national income per capita (*GNI*). These variables show the largest mean, minimum and maximum dispersion, representing the large differences in population and wealth in countries around the world.

Additional variables were created to describe potentially influential study site characteristics. In the case of Provisioning services, these were: the cropland produced (*APer*) and the terrestrial protected areas (*TProt*). The former represents the food, fuels and fibres provisioned, and the latter represents regulation of flows and purification provided. In the case of Regulating & Maintenance services, these were: the natural area (*Fper*) and the terrestrial (*TProt*) and marine (*MProt*) protected areas. These variables express the quality/quantity of natural resources that directly influence their prevention, moderation, and support. In the case of Cultural services, these were the marine protected areas (*MProt*), which represent quality, namely related to the sea.

Table 3. Summary statistics for meta-regression variables in ecosystem services.

Variables[1]	Mean	Stand. Dev.	Min	Max
Provisioning Services				
TProt	14.94	8.53	0.00	6.27
APer	42.78	18.99	6.27	80.89
PDen	124.60	143.77	1.70	1 130.40
GNI	7 481.06	10 021.30	430.00	44 740.00
Regulating & Maintenance Services				
FPer	35.20	20.57	0.24	91.34
MProt	12.54	17.12	0.00	74.70
TProt	14.73	7.56	0.00	36.84
PDen	115.70	127.07	2.40	502.30
GNI	14 471.44	14 036.35	430.00	48 420.00
Cultural Services				
MProt	15.52	17.63	0.00	74.82
PDen	105.23	116.90	2.30	478.30
GNI	16 750.05	13 484.39	840.00	48 420.00

Note: [1] See Table 2 for variable descriptions.

3.2. Meta-regression model specification

We adopt a semi-log functional form specification for the ES value functions, which implies that the marginal effect of a change in ESV depends on income and population density [15].

The Provisioning ES value function is given by:

$$\ln(ESV_{Prov}) = \alpha_0 + \alpha_1 * D_{Biome} + \alpha_2 * D_{Continet} + \alpha_3 * TProt + \alpha_4 * APer + \alpha_5 * \ln(PDen) + \alpha_6 * \ln(GNI) \quad (5)$$

Where α_0 is a constant, α_1 and α_2 are dummy regression estimates, and α_3 to α_6 are variable regression estimates. Determined by the type of biome (D_{Biome}), location of the continent ($D_{Continent}$), terrestrial protected area (*TProt*) [46], percentage of agricultural land (*APer*) [47], population density (*PDen*) [5], and income (*GNI*) [15].

The Regulating & Maintenance ES value function is given by:

$$\ln(ESV_{Reg\&Main}) = \beta_0 + \beta_1 * D_{Biome} + \beta_2 * D_{Continet} + \beta_3 * FProt + \beta_4 * FPer + \beta_5 * MProt + \beta_6 * TProt + \beta_7 * \ln(PDen) + \beta_8 * \ln(GNI) \quad (6)$$

Where β_0 is a constant, β_1 and β_2 are dummy regression estimates, and β_3 to β_8 are variable regression estimates. Determined by the type of biome (D_{biome}), location of the continent ($D_{Continent}$), level of protection in study area (*FProt*) [15], the terrestrial (*TProt*) and marine (*MProt*) protected area [46], percentage of Forest land (*FPer*) [47], population density (*PDen*) [5], and income (*GNI*) [15].

Finally, the Cultural ES value function is given by:

$$\ln(ESV_{Cult}) = \gamma_0 + \gamma_1 * D_{Biome} + \gamma_2 * D_{Continet} + \gamma_3 * \mathrm{PProt} + \gamma_4 * MProt + \gamma_5 * \ln(PDen) + \gamma_6 * \ln(GNI) \quad (7)$$

Where γ_0 is a constant, γ_1 and γ_2 are dummy regression estimates, and γ_3 to γ_6 are variable regression estimates. Determined by the type of biome (D_{biome}), location of the continent ($D_{Continent}$), level of protection in study area (*PProt*) [15], marine protected area (*MProt*) [46], population density (*PDen*) [5], and income (*GNI*) [15].

3.3. Meta-regression model results

Table 4 reports regression results for two model specifications, the "Full" model in which all the variables are included and, the "Restricted" model in which not significant explanatory variables were excluded in a stepwise procedure (applying a cut-off significance level of 20% for the *t*-test). The following base values for the dummies are considered: Grassland (*Gras*) for biomes; Not protected (*NProt*) for protection status; and (*Euro*) for continents.

The main explanatory variables presented in all "Restricted" models were Population Density (*ln_PDen*) and Gross National Income (*ln_GNI*), with positive coefficient values and high significance (*t*-test < 9.0%), which implies that an increase in population or income results in an increase ESV. As we adopt the logarithmic form for these variables, the marginal increase in ESV is decreasing in population or income.

We adopted additional explanatory variables for environmental quality, being *MProt* and *TProt*, the percentage of, respectively, terrestrial and marine protected areas. Specifically, for the Provisioning model the *APer*, percentage of agricultural land, and for the Regulating & maintenance model the *FPer*, Percentage of forest land, were used.

The Provisioning ES model provides a reasonable fit to the data, although it is the model with the smallest R^2 (0.19) and with the statistics of 0.01 in ANOVA for the restricted model. The signs of the explanatory variables are, as expected, positive for D_{biome}, *LaAm*, *ln_PDen* and *ln_GNI*, and negative for *TProt*. This confirms that the other land covers analyzed tend to have a higher value than Grassland (used as a base for the dummy biomes) and that areas located in Latin America generate larger provisioning ecosystem service values, while the ecosystem service value decreases with an increase in the percentage of protected terrestrial area. The variable *Aper* is an exception (Coef = -0.04 and *t*-test < 1.0%), presenting a negative coefficient, for which a positive sign was expected – which could be explained by the fact that countries with larger agricultural areas present a greater supply of provisioning services though lower productivity levels. Significant explanatory variables present *t*-test < 0.19, the remaining variables were dropped. Evaluating the dummy variables for biomes, the one that presented the highest coefficient for the ESV_{Prov} was *CuAr* (Coef = 3.69 and *t*-test < 1.0%), indicating that the cultivated area is the key variable explaining provisioning service values.

The Regulating & Maintenance ES model provides a good fit to the data, being the model with the highest R^2 (0.46) and with the statistics of 0.01 in ANOVA for the restricted model. The sign of the explanatory variables is as expected positive for D_{biome}, *ln_PDen* and *ln_GNI*, and negative for *AFric*. This confirms that, as mentioned before, the other land covers analyzed tend to have a higher value than Grassland and that areas located in Africa tend to have a lower value for this type of service (due to the lower aggregate income). The variables related to nature protection: *FProt* (Coef = -1.73 and sig < 1.0%), *FPer* (Coef = -0.02 and *t*-test < 5.0%), *MProt* (Coef = -0.02 and *t*-test < 19.0%) and *TProt* (Coef = -0.05 and *t*-test < 5.0%), present negative coefficients, for which a positive sign was expected, revealing the theory that protected areas, which generally have low population density or are even inaccessible to the population, represent a low monetary value (i.e. people do not fully perceive the value of this service being generated). Significant explanatory variables present *t*-test < 0.19, the remaining variables were dropped. In the $ESV_{Reg\&Main}$ the largest coefficient for biome was observed in *InWt* (Coef = 4.77 and *t*-test < 1.0%), although many others such as *CoRf*, *CWet* and *CSys*, (Coef = 4,68; 4,19; 3,98 and *t*-test < 1.0%, respectively) also presented high values, these biomes hold a series of important services, such as climate moderation, erosion prevention, maintenance, and support for different species.

The Cultural ES model also presents a good fit to the data, with a R^2 (0.38) and with the statistics of 0.01 in ANOVA for the restricted model. The sign of the explanatory variables is as expected positive for *PProt*, *ln_PDen* and *ln_GNI*, *LaAm* and negative for *MProt*, *Asia*, *Ocea*. This explains that partially protected areas make it possible for people to access and benefit from the services generated. Moreover, Latin America is the area that presents largest Cultural ES (mainly on the Caribbean coast). The D_{biome} variables *Mari* (Coef = -2.47

and *t*-test < 12.0%) and *TeFo* (Coef = -3.09 and *t*-test < 1.0%), present negative coefficients, for which a positive sign was expected, due to the small number of studies related to cultural services involving these land covers in the ESVD. In the ESV_{Cult} the largest coefficient was *CoRf* (Coef = 2.48 and *t*-test < 1.0%), explaining the high value of services associated with the coral reef biome, which provides services such as ecotourism, recreation and aesthetics, receiving thousands of tourists annually.

Table 4. Meta-regression results for Provisioning (ESV_{Prov}), Regulating & Maintenance ($ESV_{Reg\&Main}$) and Cultural (ESV_{Cult}).

Explanatory variables[1]	**Model specification**											
	Provisioning Serv. Model				**Regu. & Main. Serv. Model**				**Cultural Serv. Model**			
	Full		Restricted		Full		Restricted		Full		Restricted	
	Coef	*t-test (sig)*	*Coef*	*t-test (sig)*	*Coef*	*t-test (sig)*	*Coef*	*t-test (sig)*	*Coef*	*t-test (sig)*	*Coef*	*t-test (sig)*
CONSTANT	-3.80	0.36	-6.41	0.01	-7.97	0.03	-3.46	0.19	-12.37	0.07	-7.37	0.03
CSy	1.93	0.19	2.68	0.01	5.10	0.01	3.98	0.01	2.09	0.40	-	-
CWet	1.51	0.24	2.22	0.01	5.31	0.01	4.19	0.01	4.70	0.05	1.35	0.20
CoRf	-0.85	0.53	-	-	5.28	0.01	4.68	0.01	5.83	0.01	2.48	0.01
CuAr	3.07	0.11	3.69	0.01	4.28	0.01	3.07	0.01				
Dser	1.24	0.66	-	-								
FrWa	1.41	0.49	2.17	0.19	2.79	0.28	-	-	7,08	0,00	-	-
Gras[2]	-	-	-	-	-	-	-	-	-	-	-	-
InWt	1.29	0.31	2.03	0.01	5.53	0.01	4.77	0.01	5.04	0.04	1.48	0.20
Mari	1.08	0.57	2.18	0.15	2.07	0.17	-	-	1.44	0.58	-2.47	0.12
TeFo	-1.46	0.42	-	-	4.80	0.01	3.35	0.01	0.81	0.75	-3.09	0.01
TrFo	1.37	0.29	2.06	0.01	3.47	0.01	2.40	0.01	4.80	0.04	1.20	0.20
Wood	-0.33	0.83	-	-	1.69	0.12	-	-	6.28	0.08	-	-
FPro	-0.18	0.80	-	-	-1.83	0.01	-1.73	0.01	-0.42	0.75	-	-
PProt	-0.25	0.66	-	-	-0.24	0.63	-	-	0.78	0.53	1.17	0.05
NProt[2]	-	-	-	-	-	-	-	-	-	-	-	-
Euro[2]	-	-	-	-	-	-	-	-	-	-	-	-
Asia	-1.05	0.44	-	-	0.43	0.59	-	-	-1.09	0.49	-1.75	0.06
Ocea	-0.77	0.60	-	-	1.53	0.13	-	-	-0.81	0.59	-1.33	0.16
LaAm	0.82	0.55	1.76	0.01	1.14	0.23	-	-	2.55	0.17	1.33	0.18
NoAm	-0.97	0.53	-	-	0.66	0.41	-	-	0.98	0.46	-	-
Afric	-1.20	0.45	-	-	-0.79	0.49	-2.12	0.01	0.66	0.74	-	-
APer	-0.04	0.02	-0.04	0.01	-	-	-	-	-	-	-	-
FPer	-	-	-	-	-0.01	0.24	-0.02	0.05	-	-	-	-
Mprot	-0.02	0.33	-	-	-0.02	0.25	-0.02	0.19	-0.06	0.01	-0.05	0.01
TProt	-0.05	0.14	-0.05	0.10	-0.04	0.15	-0.05	0.06	-0.03	0.40	-	-
ln_*GNI*	0.81	0.01	0.87	0.01	0.65	0.02	0.49	0.03	1.21	0.02	1.04	0.01
ln_*PDen*	0.54	0.03	0.59	0.01	0.91	0.01	0.66	0.01	0.53	0.12	0.48	0.09
N	302				225				109			
R^2	0.20		0.19		0.47		0.46		0.48		0.38	

p- Value in ANOVA[3]	0.01	0.01	0.01	0.01	0.01	0.01

Notes: Dependent variable is ln_ESV_i. [1] See Table 2 for variable descriptions.[2] variable used as the basis for analysis of the dummies; [3] F-test of joint restriction that coefficients of excluded variables are equal to zero.

The model with the least good fit (i.e. lowest R^2) was the "Provisioning Serv. Model" ($R^2 = 0.19$), followed by the "Cultural Serv. Model" with a reasonable fit ($R^2 = 0.38$) and the "Regu. & Main. Serv. Model" with a reasonably good fit ($R^2 = 0.46$) for the restricted models. Although these values are low as compared to other ESV meta-analysis studies (see Table 5), a great variability is observed in these studies, with R^2 between 0.25 and 0.87. The explanation for these values is related to the large number of observed studies that presented different characteristics like the location, valuation method and different years in which the study was performed. For example, [24,30,31] presented large samples, with 682, 416 and 311 observations, respectively. In addition, these studies were applied in wide areas, covering several countries.

Table 5. Studies applying the meta-analysis for ESV.

Authors	**Location**	**Ecosystem Service**	**Biome**	**R^2**	**Samp. size**	**Cut-off in *t*-test[1]**
[24]	United States and Canada	Outdoor activities	-	0.26	682	0.20
[41]	British Forest – Great Britain	Recreation	Woodlands	0.71	77	0.38
[15]	United States	Water quality	-	0.59 - 0.61	131	0.10
[7]	Norway, Sweden and Finland	Non-use values related to biodiversity	Forests	0.81 - 0.87	72	0.20
[30]	World	Flood protection, water quality, and water storage and supply	Wetlands	0.49-0.46	416	0.10
[29]	United States	Forest and freshwater restoration	Forests and Freshwaters	0.58 - 0.60	127	0.18
[44]	World coastal area	Shoreline protection	Coastal Areas	0.44 - 0.45	90	0.10
[31]	World	Recreation services	Coastal Areas	0.25 - 0.65	311	0.10

Note: [1] Values presented for the final/best model presented.

As previously exposed, the cut-off for the significance level adopted in the t-student test for the model variables was 20%, which eventually diminished the reliability of the models (i.e. it is common to use "cut-off points" of 0.5%, 1%, 5% or even 10%). Nevertheless, authors such as [7,24, 29,41] used t-values close to those adopted in our research. It will be demonstrated, in the next section, that the transfer errors obtained using these value functions are smaller than those obtained using other benefit transfer techniques.

3.4. Value function transfer errors and estimates

The validity of environmental benefit transfer has been the subject of a number of studies [7,48,49]. In all of them, the validity has been tested by stating a null hypothesis of no difference between an original study result and a benefit transfer estimate [50]. As in those studies, in this study we seek to verify the differences between the estimated values from MA-BT with the values from the ESVD database, using the Transfer Error technique.

3.4.1. Transfer errors

To assess the accuracy of the estimated ES value meta-models, in order to justify their adoption in future research covering different locations with varied characteristics, we determined the transfer errors associated with Value transfer, Global meta function transfer and Local meta function transfer (see Section 2.3). This is done for the Provisioning, Regulating & Maintenance, and Cultural ES value functions (see Tables 6, 7 and 8, respectively).

Table 6. Comparison of values and transfer errors (TE) per biome for Provisioning ES, based on Value transfer, Global meta function transfer and Local meta function transfer (in 2015 €/ha/yr).

	Value transfer		**Global meta function transfer**		**Local meta function transfer**	
Biome[1]	**Value**	**TE (ETE1)**	**Value**	**TE (ETE2)**	**Value**	**TE (ETE3)**
CSys	1 336.0	926.2	81.9	56.7	185.7	11.4
CWet	362.7	1 228.2	30.7	103.9	66.0	10.1
CoRf	1 463.7	$7.0 * 10^{6}$	10.3	$5.0 * 10^{4}$	23.1	$1.6 * 10^{4}$
CuAr	2 795.2	$4.2 * 10^{5}$	141.7	$2.2 * 10^{4}$	741.8	$1.4 * 10^{4}$
Dser	82.5	106.2	1.5	2.0	1.5	2.0
FrWa	594.9	107.3	59.7	10.7	120.5	15.6
Gras	164.9	$4.5 * 10^{4}$	2.8	769.9	8.1	106.3
InWt	176.8	2 013.6	6.2	71.0	15.8	54.7
Mari	50.8	2.76	27.6	1.4	48.0	4.0
TeFo	68.1	203.2	10.8	32.1	14.3	41.0
TrFo	277.3	297.8	31.2	33.3	58.3	19.6
Wood	110.6	$1.1 * 10^{6}$	4.6	$2.7 * 10^{6}$	15.4	$6.5 * 10^{6}$

Note: [1] *CSys* = Coastal System; *CWet* = Coastal Wetland; *CoRf* = Coral Reef; *CuAr* = Cultivated Area; *Dser* = Desert; *FrWa* = Fresh Water; *Gras* = Grassland; *InWt* = Inland Wetland; *Mari* = Marine; *TeFo* = Temp./Bor. Forest; *TrFo* = Tropical Forest; *Wood* = Woodland.

The ecosystem service values and transfer errors per biome related to the estimates for the Provisioning ES are presented in Table 6. Overall, it can be concluded that the transfer error is reduced when moving from Value transfer to Global meta function transfer and, in turn, that the transfer error is further reduced when moving to Local meta function transfer. Notable exception holds for *Wood*, which demonstrates the lowest transfer error when using Value transfer. This is explained by the fact that this variable was dropped from the restricted model (not significant according to *t*-test). Also, in some cases the transfer error increases slightly when moving from Global meta function transfer to Local meta function transfer (such as for *FrWa*, *Mari* and *TeFo*), which is explained by the large variation of values in the ESVD database that contained studies from different countries, continents and years, and in the case of those biomes, ranging from 1.5 to 3 000.0 €/ha/year.

Table 7. Comparison of values and transfer errors (TE) per biome for Regulating & Maintenance ES, based on Value transfer, Global meta function transfer and Local meta function transfer (in 2015 €/ha/yr).

	Value transfer		**Global meta function transfer**		**Local meta function transfer**	

Biome[1]	Value	TE (ETE1)	Value	TE (ETE2)	Value	TE (ETE3)
CSys	941.9	7.6	258.3	1.8	1 381.8	3.8
CWet	5 088.3	267.3	430.6	22.5	943.2	12.3
CoRf	7 074.0	3189.4	383.9	173.0	1 236.6	18.6
CuAr	425.6	20.0	134.4	6.2	215.0	1.7
Dser	-	-	-	-	-	-
FrWa	115.5	0.0	29.8	0.7	29.8	0.7
Gras	111.9	1 464.9	11.7	153.3	22.2	37.2
InWt	1 660.2	1 430.5	188.8	162.6	747.4	17.6
Mari	748.3	260.8	18.0	6.2	28.7	1.4
TeFo	641.8	44.9	94.7	6.4	197.2	5.4
TrFo	135.7	111.0	16.4	13.1	48.4	9.6
Wood	199.0	117.5	17.9	10.7	41.4	25.0

Note: [1] See Table 6 for variable descriptions.

Table 7 presents the ecosystem service values and transfer errors per biome associated with the estimates for the Regulating & Maintenance ES. According to the analysis of the previous table, the TE is reduced when moving from Value transfer to Global meta function transfer and then moving to Local meta function transfer. In this table, the exceptions hold for *CSys* and *Wood*, which demonstrate the lowest transfer error when using Global meta function transfer. This is explained by the variation of the values presented in the ESVD database for these biomes. No transfer error is observed for *FrWa* when using value transfer, as only one observation for this biome is available in the ESVD. Finally, no value estimate and transfer error were calculated for *Dser*, because there are no primary value estimates data for this biome in the ESVD.

Table 8. Comparison of values and transfer errors (TE) per biome for Cultural ES, based on Value transfer, Global meta function transfer and Local meta function transfer (in 2015 €/ha/yr).

	Value transfer		Global meta function transfer		Local meta function transfer	
Biome[1]	**Value**	**TE (ETE1)**	**Value**	**TE (ETE2)**	**Value**	**TE (ETE3)**
CSys	156.9	156.3	90.6	90.0	186.9	33.7
CWet	3 099.8	119.3	152.6	5.6	267.0	5.1
CoRf	5 340.9	2 138.0	308.9	123.6	1 695.3	17.1
CuAr	-	-	-	-	-	-
Dser	-	-	-	-	-	-
FrWa	651.4	0.5	16.1	1.0	36.2	0.9
Gras	1.4	0.2	48.6	35.3	58.2	46.4
InWt	681.5	15.3	142.4	3.0	234.0	3.3
Mari	311.8	316.9	7.4	7.2	20.6	1.6
TeFo	878.8	$1.9 * 10^4$	9.1	204.8	13.2	180.5
TrFo	275.4	38.3	38.0	5.1	85.6	6.2
Wood	3840.5	0.0	196.7	0.9	196.7	0.9

Note: [1] See Table 6 for variable descriptions.

doi:10.20944/preprints202106.0497.v1

Finally, Table 8 presents the ecosystem service values and transfer errors per biome associated with the estimates for the Cultural ES. Again, it can be observed that the transfer error is reduced when moving from Value transfer to Global meta function transfer and next, to Local meta function transfer. Although there are exceptions like *FrWa*, *InWt* and *TrFo*, which presented TE very close when comparing Global to Local meta function transfer. One prominent exception holds for *Gras*, which demonstrates the lowest transfer error when using Value transfer. This is justified because it contained only two observations for this biome in the database. No transfer error is observed for *Wood* when using value transfer, as only one observation for this biome is available in the ESVD. Finally, no value estimates and transfer errors were calculated for *CuAr* and *Dser*, because there are no primary value estimates for these biomes in the ESVD.

Hence, it can be concluded that transfer errors are reduced significantly when using Global meta function transfer and, in particular, Local meta function transfer as compared to Value transfer. This is justified because value function transfers allow the analyst greater control over differences across sites, they can yield lower transfer errors than simple mean value transfers [51]. In fact, by comparison, value functions give a greater reflection of the variability of a sample, because the study is dealing with a database with great variability. For this reason, finding a model that, for the most part, has obtained a superior result than other benefit transfers techniques, is an advance that justifies its application given the heterogeneity of the data.

Value functions should thereby draw upon common drivers of preferences reflected in economic theory, including only those variables applicable to all sites [52]. Economic theory suggests that the benefits from environmental improvements should be determined by [53]: i) change in provision, ii) distance to the site, iii) distance to substitute sites, and iv) characteristics of the valuing individual (in particular income). That is why Local meta function transfer presents the lowest TE, for addressing these preferences and reflecting the context of each country.

3.4.2. Local value function transfer estimates

Ecosystem service value estimates per biome for Provisioning (ESV_{Prov}), Regulating & Maintenance ($ESV_{Reg\&Main}$) and Cultural (ESV_{Cult}) ecosystem services, are presented in Table 9. Value estimates are thereby based on the restricted models presented in Table 4, using local value function transfer and mean values for the explanatory variables (from Table 3).

The values found in the Table 9 show great variability, with values ranging from ESV_{Total} = 3.0 €/ha/year for Desert areas to ESV_{Total} = 1 913.5 €/ha/year for Coral reefs. The biomes that provide largest total economic value are Coral Reefs (*CoRf* = 1 913.6 €/ha/year), Inland Wetlands (*InWt* = 1 004.2 €/ha/year) and Coastal Wetlands (*CWet* = 757.7 €/ha/year). These biomes, in addition to standing out for providing a great diversity of ecosystem services, are also the smallest biomes in terms of area around the globe and, consequently, the scarcest and, thus, most valuable. In fact, in studies that analyzed ES globally [5,4,54], these biomes were also those with the highest value.

Provisioning services represent lowest values and are related to the supplies of products (such as food, materials or water) with values close to their direct use values [5]. The largest provisioning ES values are provided by Cultivated Areas (*CuAr* = 121.9 €/ha/year) and Coastal System (*CSys* = 44.5 €/ha/year), while the lowest values were found for Coral Reefs, Desert, Grassland and Temp./Bor. Forest (*CoRf, Dser, Gras* and *TeFo*, with a value of 3.0 €/ha/year each).

Regulating & Maintenance services are linked to more indirect benefits, which are related to quality, moderation, and prevention in environmental factors (Rao et al., 2015). The largest reg. and main. ES values are Inland Wetlands (*InWt* = 425.8 €/ha/year), followed by Coral Reefs (*CoRf* = 389.9 €/ha/year), and Coastal Wetlands (*CWet* = 238.1 €/ha/year), demonstrating a high added value for areas in transition, notably coastal areas, while the lowest values were found for Marine and Woodland areas (*Mari* and *Wood*, with a value of 3.6 €/ha/year each).

Cultural services represent largest values, because they involve complex issues such as aesthetics, generated inspiration, spirituality, which can be considered incommensurable values as the perception about the environment varies from person to person [5,31]. The largest cultural ES values are Coral Reef (*CoRf* = 1 520.7 €/ha/year), Inland Wetlands (*InWt* = 555.3 €/ha/year) and Coastal Wetlands (*CSys* = 491.6 €/ha/year), while the lowest values were found for Marine areas (*Mari* = 10.8 €/ha/year) and Temp./Bor. Forest (*TeFo* = 5.8 €/ha/year).

Table 9. Estimated ES values per biome for Provisioning (ESV_{Prov}), Regulating & Maintenance ($ESV_{Reg\&Main}$) and Cultural (ESV_{Cult}) ecosystem services, using Local meta function transfer and mean national values for the explanatory variables (in 2015 €/ha/yr).

Ecosystem Service[1]	*CSys*	*CWet*	*CoRf*	*CuAr*	*Dser*	*FrWa*	*Gras*	*InWt*	*Mari*	*TeFo*	*TrFo*	*Wood*
ESV_{Prov}	44.5	28.0	3.0	122.0	3.0	26.7	3.0	23.1	27.0	3.0	23.9	3.0
$ESV_{Reg\&Main}$	193.2	238.1	389.9	78.1	-	3.6	3.6	425.8	3.6	103.3	39.9	3.6
ESV_{Cult}	127.1	491.6	1 520.7	-	-	127.1	127.1	555.3	10.8	5.8	420.8	127.1
ESV_{Total}	364.8	757.7	1 913.6	200.1	3.0	157.4	133.7	1 004.2	41.3	112.2	484.5	133.7

Note: [1] ESV_{Prov} = Provisioning Ecosystem Values; $ESV_{Reg\&Main}$ = Regulating & Maintenance Ecosystem Values; ESV_{Cult} = Cultural Ecosystem Values; ESV_{Total} = Total Ecosystem Services Values.

It is necessary to be cautious when valuing ecosystem services, since although the aim of the pricing is to use values in monetary units as a tool to provide a better insight into the economic benefits of ecosystem goods and services. We do not try to find the shortcomings and limitations of monetary valuation, both in relation to ecosystem services and man-made goods and services [5,55].

When the ESV's models are created, and value is associated for the biome, do not mean that this biome in question should be treated as private commodities that can be traded in private markets. Most of those ecosystem services are public goods or the product of common assets that cannot, or should not, be sold. Although the flowers, fruits, wood and leaves enter the market as private goods, the ecosystems that produce them, as for example forests and woodlands, are common assets. Their values are an estimation of the benefits to society expressed in a way that communicates with a broad audience. This can help to raise awareness of the importance of ecosystem services to society and serve as a powerful and essential communication tool to inform better, more balanced decisions regarding trade-offs with policies that enhance GDP but damage ecosystem services [4].

4. Conclusions and recommendations

The ecosystem service value (ESV) meta-models were designed to provide access to values in monetary units on ecosystem services, taking into account the local context of the country and area under analysis. With its application is possible to find values referring to 3 different types of ES, namely: Provisioning; Regulating & Maintenance; Cultural, for 12 different types of land covers (Coastal systems; Coastal wetlands; Coral reefs; Cultivated areas; Desert; Fresh water; Grasslands; Inland Wetlands; Open Ocean; Temperate/Boreal Forests; Tropical Forests; Woodlands), anywhere in the world. For this purpose, was rely on ESVD review and analysis.

The highest ES values were those associated with cultural services, followed by regulation & maintenance and, finally, provisioning services. Among the biomes with greater associated ecosystem service value highlighted, coral reefs, inland and coastal wetlands, which among other characteristics, are transitional, aquatic-terrestrial biomes, scarce and provide a great diversity of services.

It was observed that local variables, such as income, population, agricultural and forest area, and those related to the level of environmental protection explained from satisfactory manner and consequently compose the ESV's models.

As has been pointed out, the application of the meta functions, provides values with more accuracy, than the simple value transfer and, as proved by the transfer error analysis, the application of local variables (local meta function transfer) further increases this precision.

Thus, meta-analysis appears, which seeks to correct these errors, taking into account local specifications to determine the ESV's. As has been observed, there are several studies that have already used meta-models for valuation of the environment. However, we have not found such a comprehensive study in the literature that has determined the value of ecosystem services for 12 different biomes to any continent on the planet. Even considering that there are certain transfer errors with the application of meta-models, when compared to other benefit transfer techniques (such as value transfer and value function transfer) the meta-analysis has been the best way to define the value of ecosystem services.

Some caveats to this study remain. First, there are improvements that can be added to the results, such as updating the database, adopting other explanatory variables, or even a different functional form. Second, the adoption of ESVD, which although very broad, has some limitations, such as the necessity for further studies for biomes such as fresh waters, which presented only one study for regulating & maintenance ES, and woodland, which presented only one study for cultural ES. And third, it was not estimate values for urban areas, which, although important, because they have a constant relationship with human well-being, through services provided by areas such as parks, squares and green spaces, there was no access to studies analyzing that kind of land cover in the ESVD database. We expect this study to be a step further in studies that involve valuing ecosystem services and provide a basis for further research.

Finally, the valuation of ecosystem services had become an important tool to identify and create strategies for environmental planning in order to preserve natural resources. When applying benefit transfer techniques, which use previous studies in similar areas in general, there is a facilitation to apply the ESV of a particular biome.

Author Contributions: Conceptualization, L.M.F., P.R. and M.I.B.; Data curation, L.M.F., P.R., and W.R.; Formal analysis, L.M.F., P.R, and G.O.; Investigation, L.M.F., P.R. and G.O..; Methodology, L.M.F. and P.R..; Supervision, P.R.; Validation, W.R. and P.R.; Writing—original draft, L.M.F., P.R. and M.I.B.; Writing—review and editing, L.M.F., P.R., M.I.B., and W.R. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brazil (CAPES), who financed part of this work through - Finance Code 001.

Institutional Review Board Statement: Not applicable.

Acknowledgments: We would like to thank the for the financial support by CESAM (UIDB/50017/2020 and UIDP/50017/2020), to FCT/MCTES through national funds, and the co-funding by European funds when applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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