The economic and ecological benefits of saving ecosystems to protect services

Felipe S. Campos[a], João David[a], Ricardo Lourenço-de-Moraes[b], Pedro Rodrigues[a], Bruno Silva[a], Carina Vieira da Silva[c], Pedro Cabral[a]

[a] NOVA Information Management School (NOVA IMS), Universidade Nova de Lisboa, Campus de Campolide, 1070-312, Lisboa, Portugal

[b] Programa de Pós-Graduação em Ecologia e Monitoramento Ambiental (PPGEMA), Universidade Federal da Paraíba, Campus IV - Litoral Norte, 58297-000, Rio Tinto, Brazil

[c] Nova School of Business and Economics (NOVA SBE), Universidade Nova de Lisboa, Campus de Carcavelos, 2775-405, Carcavelos, Portugal

This is the accepted author *manuscript of the following article published by Elsevier:*

Campos, F. S., David, J., Lourenço-de-Moraes, R., Rodrigues, P., Silva, B., Silva, C. V. da & Cabral, P. (2021). The economic and ecological benefits of saving ecosystems to protect services. *Journal of Cleaner Production*, 311, 127551. https://doi.org/10.1016/j.jclepro.2021.127551

The economic and ecological benefits of saving ecosystems to protect services

Felipe S. Campos [a*], João David [a], Ricardo Lourenço-de-Moraes [b], Pedro Rodrigues [a], Bruno Silva [a], Carina Vieira da Silva [c], Pedro Cabral [a]

[a] NOVA Information Management School (NOVA IMS), Universidade Nova de Lisboa, Campus de Campolide, 1070-312 Lisboa, Portugal.

[b] Programa de Pós-Graduação em Ecologia e Monitoramento Ambiental (PPGEMA), Universidade Federal da Paraíba, Campus IV - Litoral Norte, 58297-000 Rio Tinto, Brazil.

[c] Nova School of Business and Economics (NOVA SBE), Universidade Nova de Lisboa, Campus de Carcavelos, 2775-405 Carcavelos, Portugal

[*] Corresponding author:

E-mail address:, fcampos@novaims.unl.pt (F.S. Campos)

NOVA Information Management School (NOVA IMS), Universidade Nova de Lisboa, Campus de Campolide, 1070-312 Lisboa, Portugal.

ORCIDs:

Felipe S. Campos (0000-0001-7415-0202)

João David (0000-0002-0192-098X)

Ricardo Lourenço-de-Moraes (0000-0001-6055-5380)

Carina Vieira da Silva (0000-0002-9580-3011)

Pedro Cabral (0000-0001-8622-6008)

Abstract

The concept of Ecosystem Services (ES) defines the nature benefits in an anthropocentric way for sustainable development goals. However, a conservation dilemma arises from the question of how much the ES cost and which ES should be prioritized in effective landscape planning. Thus, we test how the balance of economic and ecological values can be useful for improved conservation outcomes. Under a comprehensive meta-analytical approach, we address the monetary values of ES and incorporate habitat quality maps for setting national conservation targets in mainland Portugal. As a practical pathway to achieve sustainability from local to macro scales, we design an integrative approach showing that prioritization models focused on ES can encompass economic and ecological values in balance with the landscape. We find 72 studies with 167 economic estimates based on biophysical, socio-cultural and environmental features. Our results indicate that ES values in Portugal can represent about 12% of its total Gross Domestic Product (GDP), which in turn can ensure key conservation sites for multiple ecosystems. Combining the trade-offs and synergies between ecological and economic benefits of ES, we suggest an integrative strategy to save ecosystems and protect services through cost-effective conservation models. Given the economic and ecological interface of this approach, our findings can be helpful to bridge the gap between environmental economics and conservation science, following three main components – most economic benefits, best habitat quality and less land requirements. This would bring market values on realistic scales, where stakeholders are expecting positive returns.

Keywords:

Habitat quality, environmental economics, meta-analysis, land cost-effective, conservation planning, Portugal

1. Introduction

In a world where conservation action is often limited by land-use costs (Lawler and White, 2008), the inclusion of economic factors is crucial to determine effective priorities for applied conservation (Silvertown, 2015; Sutton et al., 2016; Buchmann-Duck and Beazley, 2020). In most cases, the relationships between environmental economics and conservation science require practical policies to achieve sustainable development strategies (Frank and Schlenker, 2016; Naeem et al., 2016; Seddon et al., 2016). In an attempt to justify conservation attention, cost-effective strategies based on Ecosystem Services (ES) are increasingly being implemented at different scales (Banks-Leite et al., 2014; Campos et al., 2017; Yang et al., 2020).

From an anthropocentric view of the biodiversity benefits (Silvertown, 2015), the monetization of ES has been associated in systematic conservation planning as a practical way to connect environmental concerns to the policy agenda (Adams, 2014; Kallis et al., 2013; McCauley, 2006). Systematic conservation planning is a high-benefit strategy in which social, economic and political requirements can use scientific predictions at different landscapes (Margules and Pressey, 2000). Every ecosystem provides key functions in primary production and nutrient cycling, which support other ES and biodiversity interactions that contribute to human well-being, such as the provisioning of clean water, fertile soils, timber and food (Cardinale et al., 2006; Daily and Matson, 2008). Biodiversity can be defined as the sum of all biotic variables together–from genes to ecosystems, as well as, all ecological and evolutionary processes beyond the species distribution (Purvis and Hector, 2000).

Human-made changes on biodiversity emerge from the relationship between people and nature, in which ecosystem functioning influences both public health and conservation issues (Campos and Lourenço-de-Moraes, 2020). Ecosystem functions and services are shaped by their biodiversity, which allows an intuitive perspective that should be linked to human use of natural resources, from research to practice (Naeem et al., 2016). Effective conservation strategies need time, space and money (Naeem et al., 2016), and a multifaceted framework is crucial to ensure ES in balance with the landscape (Pollock et al., 2017).

Although ES assessments have been key to achieve sustainable development goals (Griggs et al., 2013), there is still a research gap involving their economic potential to bridge biophysical and socio-economic indicators (Olander et al., 2017). In landscape planning, cost-effective conservation should consider the maximum economic benefits of nature to ensure the effectiveness of different forms of land-use policies (Brooks et al., 2006; Lee and Jetz, 2008; Yang et al., 2020). This context suggests the need to develop conservation plans that optimally balance economic and ecological goals (Petersen et al., 2016).

In this paper, we explore the trade-offs between economic and ecological benefits, suggesting an innovative way to save ecosystems and protect services, following an integrative modelling approach. The originality of this research aims to converge the economic perspective of ES into an ecological interface, providing a practical pathway to connect biodiversity concerns in land-use planning. Our assumption is that there is a spatial mismatch between economic and ecological values of ES that should be integrated for improved conservation outcomes.

To support an efficient landscape planning, we design an innovative approach that combines monetary values of ES with habitat quality estimates, proposing three priority models that balance economic and ecological values in mainland Portugal. The resulting spatially-explicit maps allow us to thoroughly identify cost-effective priority areas and setting national coverage targets for ES provision and biodiversity conservation. Furthermore, we quantify to which extent the ES values can be represented in the national Gross Domestic Product (GDP). Our findings contribute to achieve the Convention on Biological Diversity

(CBD) post-2020 targets and to monitor the United Nations Sustainable Develop Goals that aims to protect, restore and promote sustainable use of ecosystems.

2. Material and methods

2.1. Literature review

We conduct a systematic literature review on the economic valuation of ES in Portugal, using the scientific databases ISI Web of Science Core Collection, Scopus and Wiley Online Library (Timespan: 1990–2018). We select peer-reviewed articles dedicated to different ecosystems according to The Economics of Ecosystems and Biodiversity classification (TEEB, 2013). For the literature search, we use the topics "ES" AND "Portugal" AND "Coastal Systems" OR "Coastal Wetlands" OR "Croplands" OR "Forest" OR "Fresh Water" OR “Grasslands” OR "Inland Wetlands" OR "Woodlands" in title, abstract and keywords. To filter relevant papers for depth review, we only consider studies with economic values applied to Portugal or at a European level (Table S1).

2.2. Data collection

We use the CORINE Land Cover (CLC) for the 2018 reference year, according to the Copernicus Land Monitoring Service from the European Environmental Agency (EEA, 2018), with a minimum mapping unit of 25 ha and a spatial resolution of 100 m. We reclassify 41 CLC classes into nine ecosystem categories from the TEEB database (i.e., Coastal Systems, Coastal Wetlands, Croplands, Forest, Fresh Water, Grasslands, Inland Wetlands, Woodlands and Urban) (Fig. 1; Table S2). For the ES valuation processes, we exclude the urban category and base all analyses on natural and rural landscapes. We do not include urban areas to leaving out artificial surfaces and construction lands, which can have a negative effect on the provisioning of ES by human pressures (Evans et al., 2014; Mascarenhas et al., 2019). However, we keep the CLC types classified as green urban areas considering them as Woodlands, according to the TEEB categories(TEEB, 2013), due to their high potential capacity for ES supply in urban ecosystems (Randrup and Persson, 2009).

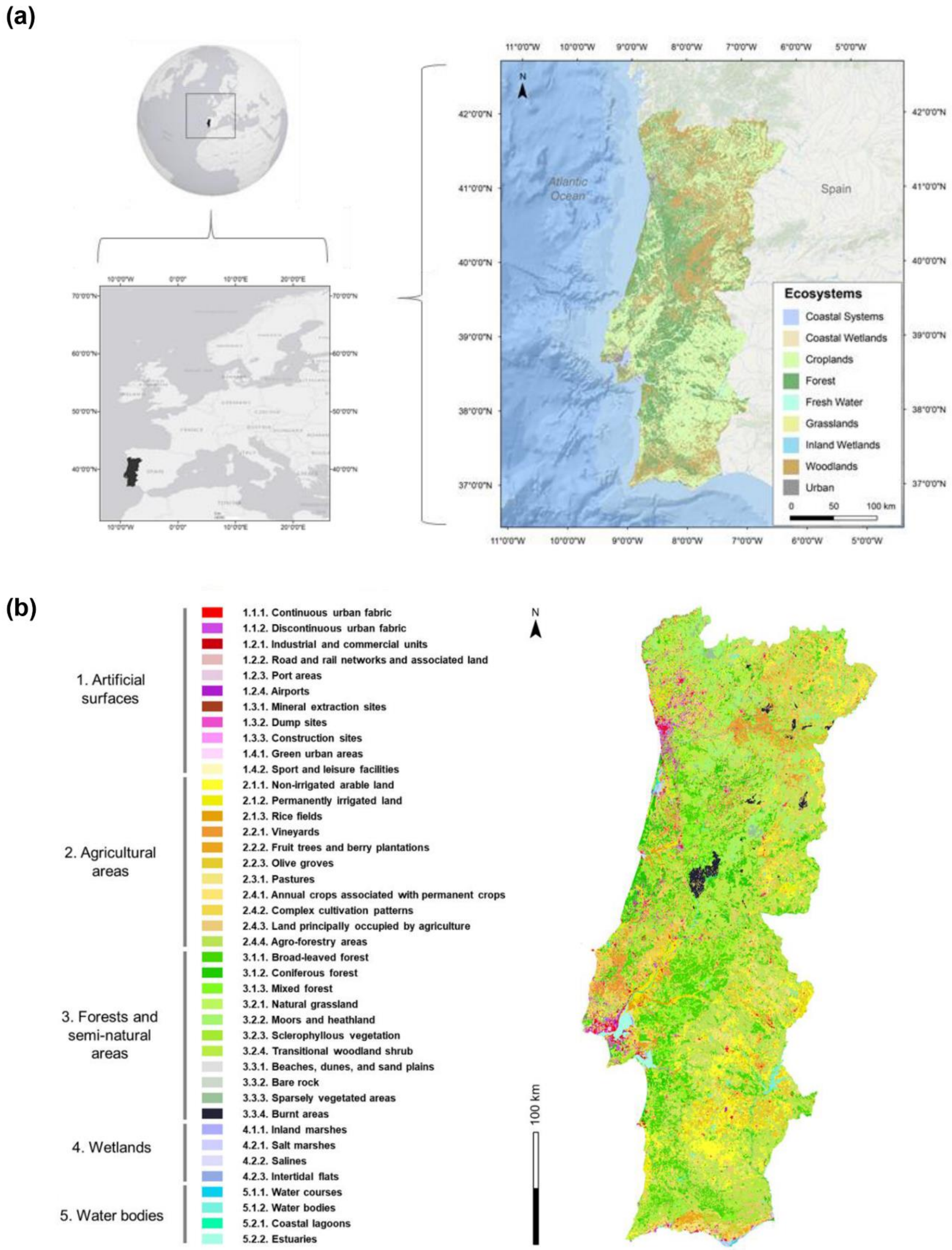

Fig. 1. Map of study area showing the distribution of ecosystems according to The Economics of Ecosystems and Biodiversity classification (TEEB, 2013) (a); and the CORINE Land Cover (EEA, 2018) in mainland Portugal (b).

2.3. Economic valuation

The economic valuation of ES is key for applying conservation decisions based on ecological importance and social significance in landscape planning (Daily et al., 2009; de Groot et al., 2012). To estimate the ES' values for Portugal, we conduct a benefit transfer approach, that relies on the estimates of past studies to obtain the monetary values for similar ecosystems in new policy and geographic contexts (Rosenberger and Loomis, 2000; Johnston and Rosenberger, 2010). Benefit transfer is a widely applied method in environmental economics to estimate the value of non-market environmental goods and services (Richardson et al., 2015), having crucial implications for land-use policy decisions (Liu et al., 2010; Wilson and Hoehn, 2006). Benefit transfer is subject of a vast literature on economic valuation and cost-benefit analysis, and despite its shortcomings, is widely used when time and financial constraints prevent primary valuation studies (Eigenbrod et al., 2010; Johnston and Rosenberger, 2010; Richardson et al., 2015). Under such limiting factors, benefit transfer is considered a cost-effective approach to ES valuation (Baker and Ruting, 2014; Johnston et al., 2018; Subroy et al., 2019), and therefore, we choose this method to estimate the ES' values in Portugal.

From the several economic approaches identified by the literature review, we convert all the monetary values into common metrics based on EUR per hectares/year, using 2018 as the base year. The currency standardization and the total Gross Domestic Product (GDP) values applied for Portugal in 2018 follows the official exchange rates from the EuroStat database (http://epp.eurostat.ec.europa.eu/). As a complementary data resource, we use the Ecosystem Service Valuation Database (ESVD) (de Groot et al., 2012), following the same strategy adopted in the literature review for the reclassified ecosystems through a spatially explicit transfer approach (Liu, 2018). After standardizing the monetary values, we apply an average value transfer to estimate the economic value of each ES, following the TEEB classification (TEEB, 2013). We also calculate the total value per hectare per year for each ecosystem, according to the sum of means of values for the 17 ES considered: (i) Provisioning (food, raw materials, water supply, and medical resources); (ii) Regulating (local climate and air quality, carbon sequestration and storage, moderation of extreme events, waste-water treatment, erosion prevention and soil fertility, pollination, and biological control); (iii) Supporting (habitats for species, and maintenance of genetic diversity); (iv) Cultural (recreation, tourism, aesthetics, and spiritual). We also build a pairwise matrix between the ES and ecosystem types to identify the most and least economically valuable services for each ecosystem, using the "lattice" package (Sarkar, 2017), in R software (R Core Team, 2020). To obtain the values for the Portuguese ecosystems, we use the following formula adapted from Frélichová et al. (2014):

$$V_E = A_y \times V_{ES} \tag{1}$$

where V_E is the value of the ecosystem evaluated, A_y is the area of the ecosystem represented in hectares, and V_{ES} is the correspondent value of the ecosystem per hectare.

2.4. Meta-analysis

We apply the log-transformed response ratio (*LnRR*) as an effect size measure for assessing the role of benefit transfer in ES valuation in Portugal. In the meta-analysis, effect sizes based on response ratios estimate the change in the means of treatment and control groups (Hedges et al., 1999). Response ratio as standardized mean effect size is the most published meta-analysis in ecology (Gurevitch et al., 2018; Koricheva and Gurevitch, 2014;

Nakagawa and Santos, 2012). Using this weighted meta-analytical approach to investigate the variance of benefits from the protection of ecosystems, we consider PAs (areas under protection) as the treatment group and non-PAs (areas under no protection) as the control group. We use the Natura 2000 network regarding the spatial distribution of PAs, provided by the Portuguese Institute for Nature Conservation and Forests (ICNF, 2020). Therefore, we calculate the effectiveness of a treatment (i.e. the intervention through the establishment of PAs) in relation to a control group (i.e. the absence of intervention, non-PAs) on the economic valuation of ES. Thus, the calculation of the log-transformed response ratio is the following:

$$LnRR = Ln \frac{\overline{X}_T}{\overline{X}_C} \tag{2}$$

where $\overline{X}_T$ represents mean values for the protected ecosystems (i.e. treatment group) and $\overline{X}_C$ represents the mean values for the unprotected ecosystems (i.e. control group). The variance associated with the response ratio estimates is:

$$Var(LnRR) = \frac{S_T^2}{N_{(T)}X_T^2} + \frac{S_C^2}{N_{(C)}X_C^2} \tag{3}$$

where S_T^2 and $N_{(T)}$ are the variance and the sample size estimated for the ecosystems inside the PAs and S_C^2 and $N_{(C)}$ are the variance and the sample size estimated for the ecosystems outside the PAs. To estimate the total amount of residual heterogeneity (Q_T) in the effect sizes, we use restricted maximum-likelihood to assess the covariance among responses (Viechtbauer, 2010), indicating the significance of the heterogeneity (Borenstein et al., 2010). Accounting for the normality of residual distribution under mixed and random-effects models through Quantile-Quantile (QQ) plots, we adopt a confidence interval of 95%. To conduct this meta-analysis procedure, we use the R "metafor" package (Viechtbauer, 2010), in the R software (R Core Team, 2020).

2.5. Habitat quality assessment

To evaluate the conservation status of the ecosystems, we use the InVEST Habitat Quality (HQ) model (Sharp et al., 2014) as an ecological proxy for the biodiversity responses to human-induced landscape changes, also defined as habitat suitability. In our case, the suitability values are affected by three main threat factors: (i) the relative sensitivity of each land cover class to each threat (i.e. mainly built-up areas and artificial surfaces); (ii) the relative impact of each threat for the ecosystems; (iii) the relative distance between ecosystems and threats across the landscape, according to a distance-decay rate over the spatial scale under investigation (Sharp et al., 2014). The equation of the HQ model is as follows:

$$Q_{xj} = H_j\left(1 - \left(\frac{D_{xj}^z}{D_{xj}^z + K^z}\right)\right) \tag{4}$$

where Q_{xj} is the score of habitat quality computed for a raster dataset (x) in the land cover (j), D_{xj} is the total threat level of (x) in (j), H_j is equal to the habitat suitability, (K) is half of the maximum value of (D_{xj}), and (z) is a scaling parameter (by default $z = 2.5$). The HQ outputs range from 0 (not suitable) to 1 (suitable), where 1 indicates the highest habitat suitability values (Leh et al., 2013). Data parameters used to run the HQ model is described in the Supplementary data (Tables S3–S4).

2.6. Cost-effective conservation models

Considering both the spatial distribution of ES economic value (EUR/ha/yr) and the habitat quality estimates, we create three priority models for balancing economic and ecological trade-offs in Portugal. To illustrate the trade-offs between Economic Benefits (EB) and Habitat Quality (HQ), we provide three priority models with complementary levels of conservation scenarios:

$$Model\ 1_{(70-100\%)} = \left\{\left[EB \geq \left(\frac{0.7\ (\sum_{i=1}^{n} EB)}{N_{EB}}\right)\right] + \left[HQ \geq \left(\frac{0.7\ (\sum_{i=1}^{n} HQ)}{N_{HQ}}\right)\right]\right\} - PAs \tag{5}$$

$$Model\ 2_{(40-70\%)} = \left\{\left[EB \geq \left(\frac{0.4\ (\sum_{i=1}^{n} EB)}{N_{EB}}\right) - EB \leq \left(\frac{0.7\ (\sum_{i=1}^{n} EB)}{EB}\right)\right] + \left[HQ \geq \left(\frac{0.4\ (\sum_{i=1}^{n} HQ)}{N_{HQ}}\right) - HQ \leq \left(\frac{0.7\ (\sum_{i=1}^{n} HQ)}{N_{HQ}}\right)\right]\right\} - PAs \tag{6}$$

$$Model\ 3_{(10-40\%)} = \left\{\left[EB \geq \left(\frac{0.1\ (\sum_{i=1}^{n} EB)}{N_{EB}}\right) - EB \leq \left(\frac{0.4\ (\sum_{i=1}^{n} EB)}{N_{EB}}\right)\right] + \left[HQ \geq \left(\frac{0.1\ (\sum_{i=1}^{n} HQ)}{N_{HQ}}\right) - HQ \leq \left(\frac{0.4\ (\sum_{i=1}^{n} HQ)}{N_{HQ}}\right)\right]\right\} - PAs \tag{7}$$

where the Model 1 refers to a high priority scenario, with EB and HQ values between 70–100% of the total observed (N); Model 2 refers to a medium priority scenario, with EB and HQ values between 40–70% of the total observed; and Model 3 refers to a low priority scenario, with EB and HQ values between 10–40% of the total observed. We do not consider areas with values of EB and HQ lower than 10% of the total observed, which we assume as least concern for environmental management. We also exclude all the PAs available to evaluate only non-PAs, considering that the current PAs do not need additional priority for conservation efforts.

3. Results

We find 72 research papers on the economic valuation of ES at the European level once duplicates were removed (Table S1). After fully reviewing the relevance of each paper, we obtain a total of 167 monetary values estimated for biophysical, socio-cultural and ecological features, using an area-based approach for the ecosystem categories accessed in Portugal (i.e. EUR/ha/yr). Our literature review shows that most of the studies are based on national scales from 19 countries (65%), with the remaining focused on the whole European continent (35%). Considering the period of 29 years evaluated (1990–2018), 2014 has the highest number of studies published, whereas the years of 1993, 1998, 2001, 2002 and 2005 have no publications (Fig. 2).

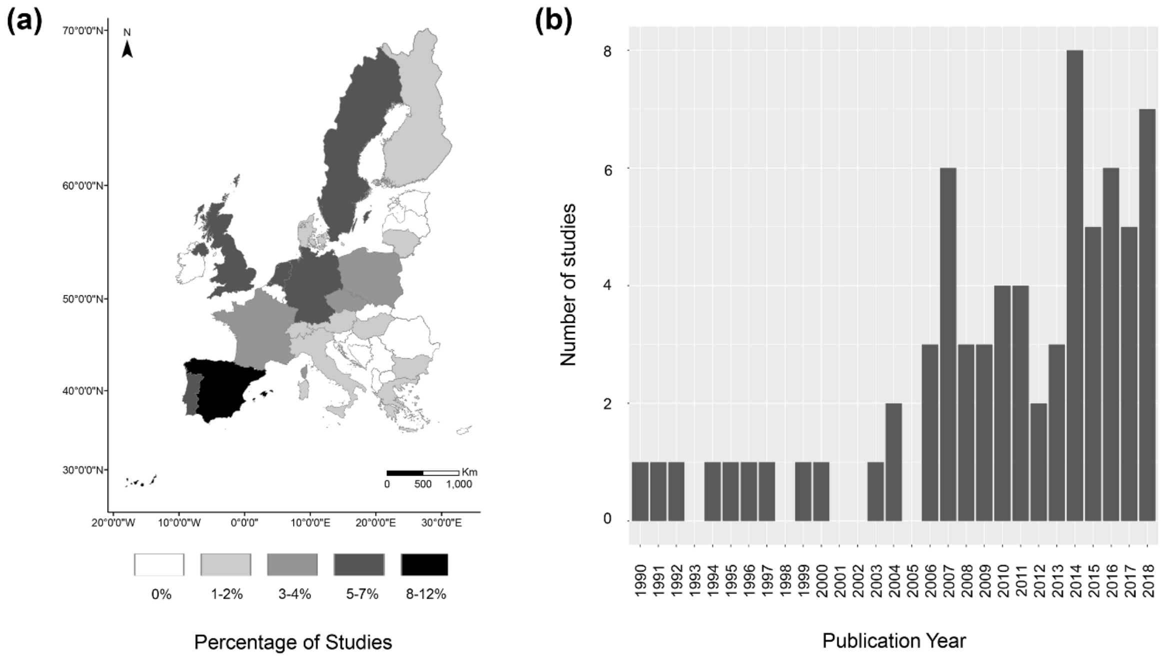

Fig. 2. Geographic distribution of 72 studies on the economic valuation of ES at European level (a). Barplot indicates the number of studies published between 1990 and 2018 (b).

Focusing on mainland Portugal, we show a different intensity level of the spatial relationship between the ES and the ecosystems (Fig. 3a). The pairwise percentage scores indicate that Croplands, Forest and Woodlands have the highest levels of carbon sequestration and storage, and pollination. Almost all agriculture and forest-related ecosystems contribute to all ES, with generally lower levels for cultural services (i.e. recreation, tourism, aesthetics and spiritual). It is also possible to observe that Coastal Systems, Coastal Wetlands, Fresh Water, Grasslands and Inland Wetlands are the most representative ecosystems for tourism ES.

Considering the mean economic values for the multiple ES distributed at the country level, we find the highest values for regulating services (12,165.44 EUR/ha/yr; SD = 2,509.51), and the lowest values for cultural services (8.58 EUR/ha/yr; SD = 655.34) (Fig. 3b). Using these monetary values from the benefit transfer approach, we show a proportional relation between the values obtained in the present study and the five highly cited papers on ES valuation in Europe (Fig. 4).

Assessing how effective are the ES valuation for the Portuguese ecosystems, we highlighted research trends and mismatches of the investigative efforts based on the concept of benefit-transfer values. The response ratio for the economic values provided by each ecosystem evaluated indicates that Forest (20.08%), Croplands (18.66%) and Fresh Water (17.03%) have the greatest effects on the ES values. The lowest effects are provided by Coastal Wetlands (4.19%) and Coastal Systems (6.69%). According to the reviewed studies, the meta-analysis results show high predicted levels of correlation among the variables related to the ecosystems under mixed and random-effects models. Positive effect sizes indicate a conservation improvement as a result of the benefits from the protected area interventions for ES valuation (Fig. 5).

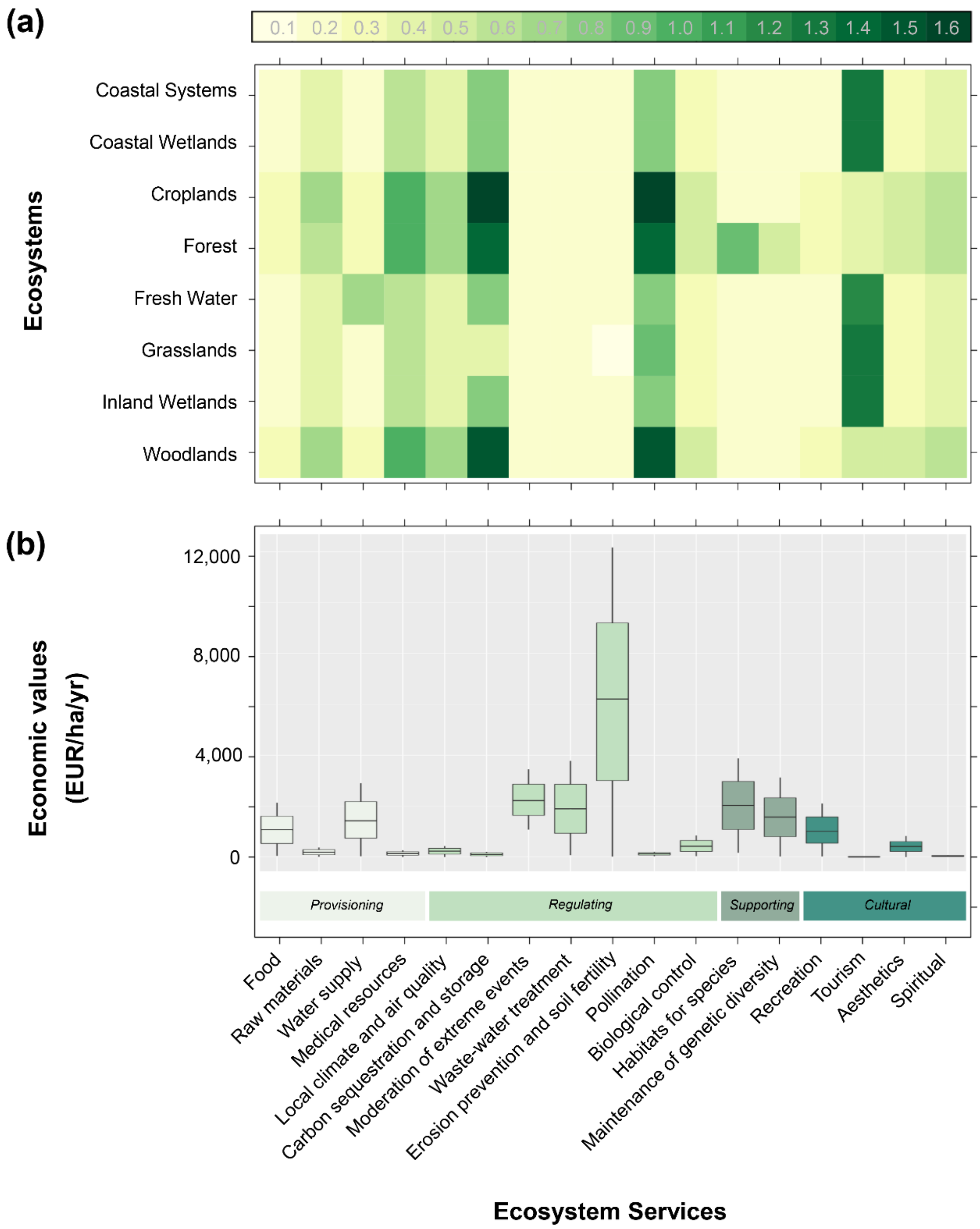

Fig. 3. ES distribution by ecosystems and economic values. Level-plot of the relationship between ES and ecosystems according to their percentage score ranking (a). Boxplots of the mean economic values (EUR/ha/yr) for multiple ES (b).

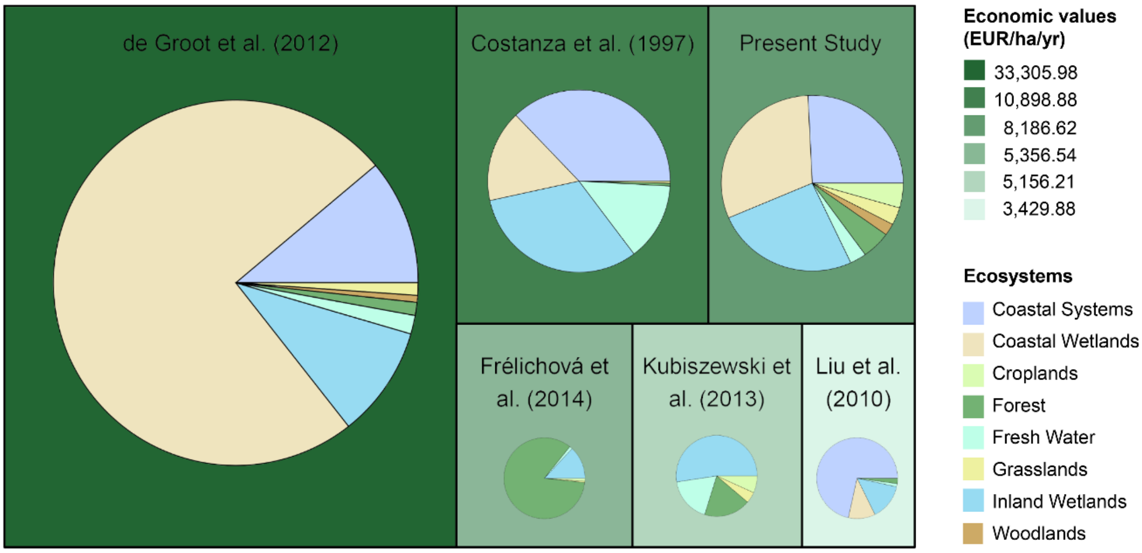

Fig. 4. Treemap representation for comparing the ES valuation between five highly cited papers and the present study.

Analysing the habitat quality estimates for the ecosystems assessed, we observe the uniqueness and irreplaceability of each ecosystem in providing suitable conditions to deliver ES in the landscape. These estimates show that Croplands, Forest and Woodlands are responsible for about 90% of the habitat quality values and their economic benefits distributed at the national level. Considering all economic benefits together, the monetary estimates of ES values can represent about 12% of the total GDP of Portugal, using 2018 as the base year (Table 1). On the other hand, when we compare the average of monetary values per area per year (EUR/ha/yr), we find that the most economically valued ES are delivered by water-related ecosystems (i.e., Coastal Systems, Coastal Wetlands and Inland Wetlands). The remaining ecosystems cover larger areas, and their representativeness on the habitat quality and economic benefits are proportional to their spatial distribution across the country.

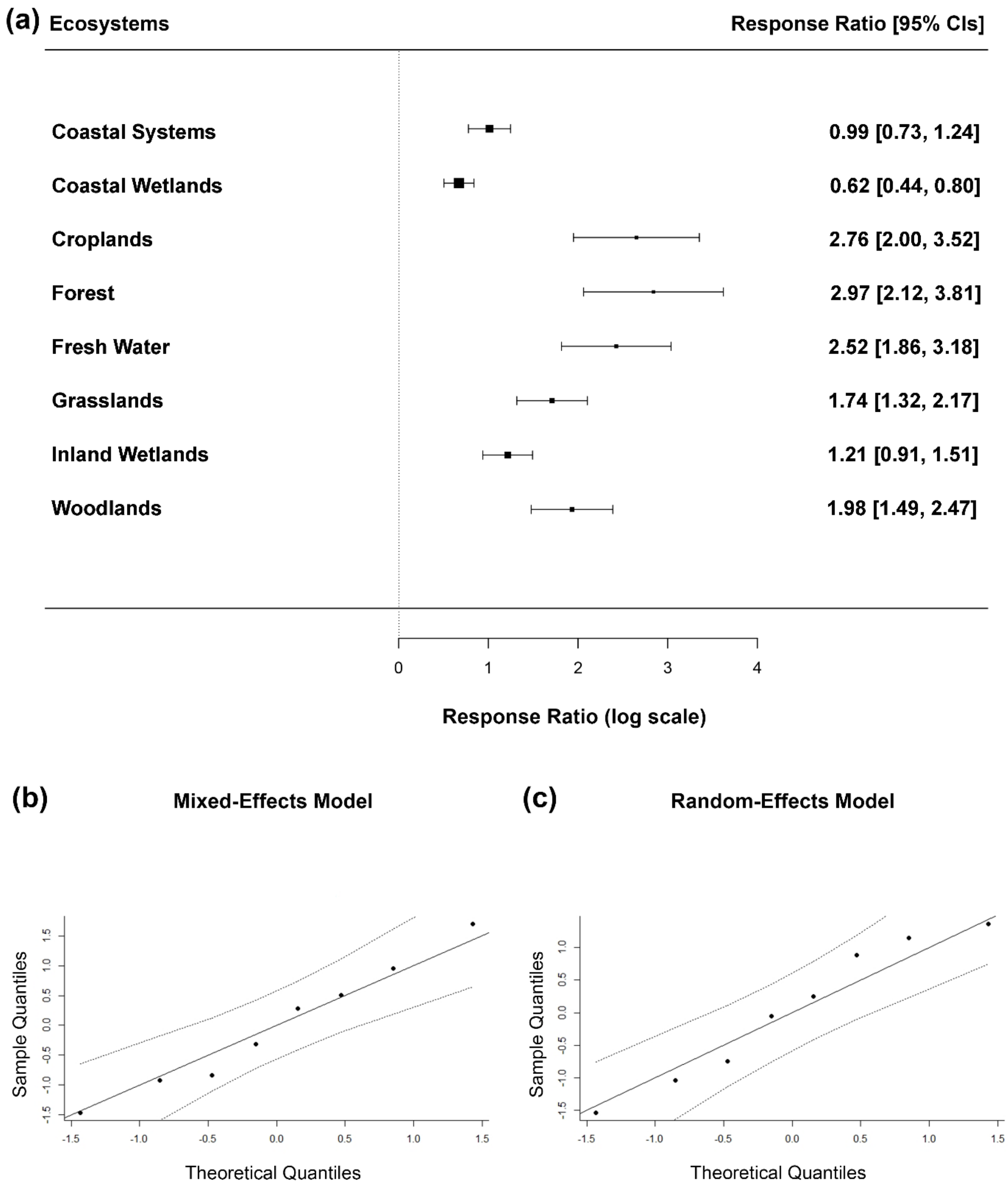

Fig. 5. Meta-analysis on the effects of ES valuation. Forest plot indicate the Response Ratio estimates using Confidence Intervals (CIs) of 95% (a). Quantile–quantile plots indicate the normality of residual distribution under mixed (b) and random-effects models (c).

Table 1. Representativeness of the efficiency of ecosystems, according to their estimates of area, habitat quality, economic benefits, monetary values and percentage of the total Gross Domestic Product (GDP) of Portugal in 2018.

Ecosystem	Area (ha)	Habitat Quality (%)	Economic Benefits (%)	Monetary Values (EUR/ha/yr)	GDP (%)
Coastal Systems	62,884.12	1.06	4.39%	16,874.73	0.52
Coastal Wetlands	27,948.60	0.51	2.32%	20,104.72	0.28
Croplands	4,081,475.08	61.07	50.27%	2,977.53	5.95
Forest	2,012,806.33	23.63	28.13%	3,378.57	3.33
Fresh Water	79,475.71	0.25	0.63%	1,919.33	0.07
Grasslands	176,630.27	3.12	1.54%	2,109.47	0.18
Inland Wetlands	1,653.31	0.01	0.11%	16,698.25	0.01
Woodlands	2,130,166.34	10.34	12.60%	1,430.42	1.49

Through mapping and calculating the spatial distribution of habitat quality and economic benefits nationally, we show high values in the west-central region, the north-western coast, and in the extremely south-eastern portion of the country (Fig. 6a–b). Our three prioritization models illustrate complementary scenarios for ES assessments (i.e., Model 1 = High Priority: 70–100%; Model 2 = Medium Priority: 40–70%; and Model 3 = Low Priority: 10–40%) of ecological (i.e., Habitat Quality) and monetary attributes (i.e., EUR/ha/yr) (Fig. 6c). Although our results are area-dependent (ha), we show co-benefits and trade-offs between the monetary values and the overall land surface covered by each model. Applying these models in the ES landscape context of Portugal, we suggest that the Model 1 has the greater capability to safeguard economic and ecological benefits from the minimum effective land coverage to the maximum potential for ES supply (Table 2).

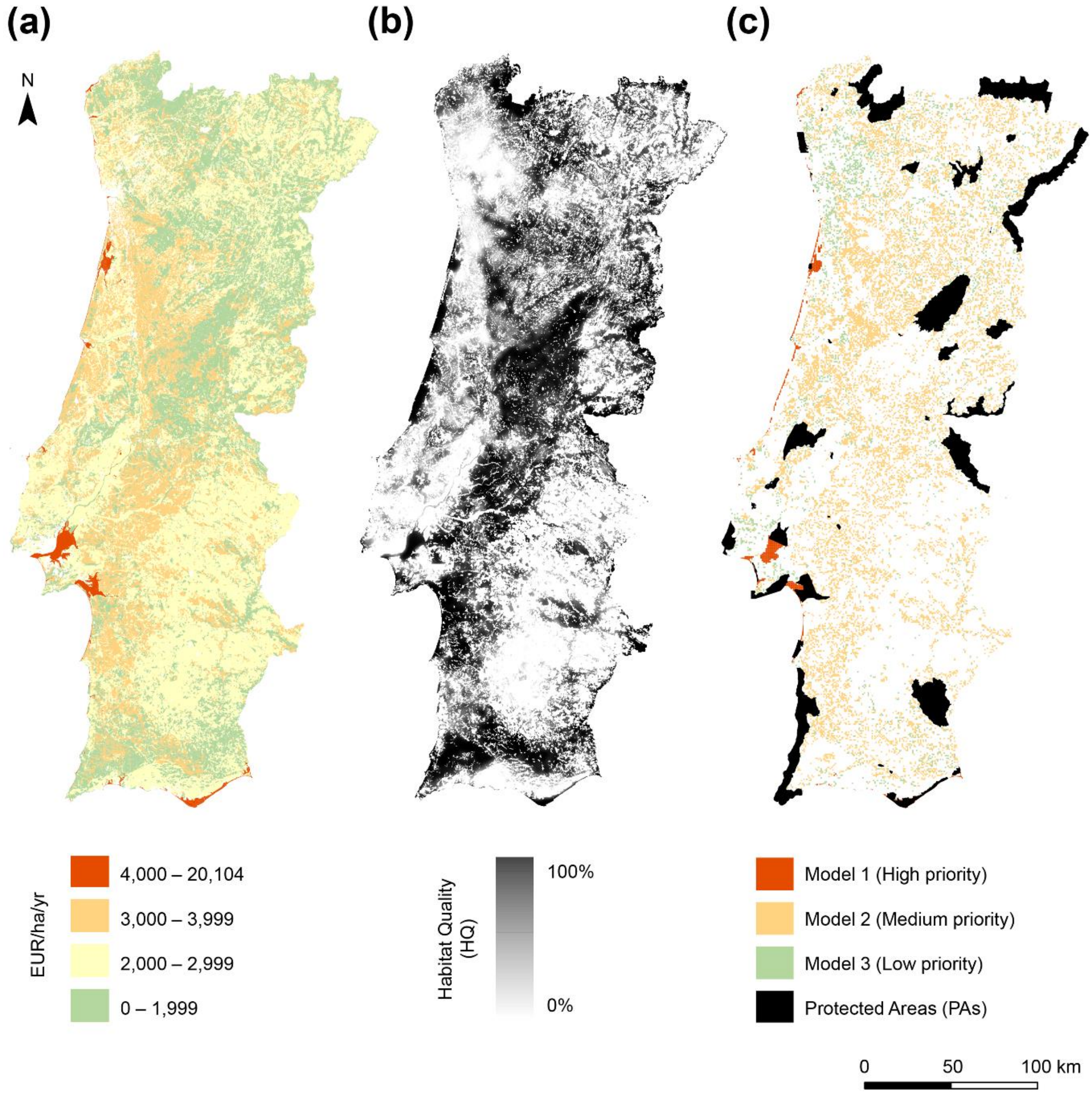

Fig. 6. Integrative modelling approach for Portugal. Spatial distribution of the economic benefits of ES (a). Habitat Quality (HQ) estimates (b). Prioritization models for balancing economic and ecological values (c). Priority ranking is based on areas with values (EUR/ha/yr and HQ) between 70–100% – Model 1 (High priority), 40–70% – Model 2 (Medium priority), and 10–40% – Model 3 (Low priority).

Table 2. Economic benefits of the ecosystems covered by the three priority models for balancing economic and ecological values in Portugal. Priority ranking is based on areas with values (EUR/ha/yr and HQ) between 70–100% – Model 1 (High priority), 40–70% – Model 2 (Medium priority), and 10–40% – Model 3 (Low priority).

Ecosystem	Model l		Model 2		Model 3	
	ha (%)	EUR/ha/yr	ha (%)	EUR/ha/yr	ha (%)	EUR/ha/yr
Coastal Systems	68.94	11,633.71	0.00	0.00	0.00	0.00
Coastal Wetlands	10.29	2,069.77	0.00	0.00	0.00	0.00
Croplands	6.30	187.71	91.58	2,726.78	75.03	2,234.12
Forest	10.12	341.96	5.35	180.60	1.97	66.42
Fresh Water	0.06	1.11	0.06	1.14	0.07	1.26
Grasslands	0.46	9.76	2.22	46.89	17.10	360.79
Inland Wetlands	0.06	9.66	0.00	0.00	0.00	0.00
Woodlands	3.76	53.78	0.79	11.36	5.83	83.43
Total	100	14,307.45	100	2,966.76	100	2,746.02

4. Discussion

Our results show that integration between economic and ecological values can be a helpful strategy for a sustainable planning in mainland Portugal, with key implications for conservation decisions. There is an increasing demand for information on ES values to inform decision-making (Naeem et al., 2016). Monetary dimensions of ES assessments that consider the diversity of values of nature and its contribution to people's well-being are critical to achieve sustainable development goals (Griggs et al., 2013; Bennet et al., 2015). Multiple ES assessments have been applied at different landscape scales, showing that economic valuation can indeed inform public-sector decision making (Nelson et al., 2009; Schaefer et al., 2015), and be integrated into ecosystem-based management (Bateman et al., 2011; Hanley and Barbier, 2009). There are several approaches for integrating values to inform decision-making, such as multi-criteria analysis, deliberative or integrated modelling approaches (Pascual et al., 2017). However, the challenge lies in how to integrate the different value dimensions in a coherent and transparent way (Martín-López et al., 2014).

Despite the great effort of economists and ecologists in advancing valuation methods to translate the contribution of ES to human welfare into monetary values, their research has not kept pace with the increasing demand for this information (Bateman et al., 2011; Parks and Gowdy, 2013; Paul et al., 2020). Additionally, interdisciplinary research often needed for primary ES valuation studies is not feasible due to budget and time constraints (O'Bryan et al., 2020). This shortfall has led to the widespread use of secondary data for ES valuation (Richardson et al., 2015). As such, benefit transfer applications are increasingly being used to inform policymaking since it allows us to estimate ES values more quickly and at a lower cost (Frélichová et al., 2014; Iovanna and Griffiths, 2006; Mandle et al., 2020). Our meta-analysis results account for differences in explanatory variables of the primary studies valuing a particular ES to estimate a value function for multiple ES. Evidence of the higher accuracy of the economic benefits of ES using meta-analysis over other approaches is well-documented studies in the literature (e.g., Frélichová et al., 2014; Johnston and Bauer, 2020; Quintas-Soriano et al., 2016).

In this study, our integrative modelling approach provides a macroecological ES assessment that also includes their economic benefits. Model 1 best represents the highest-priority regions for ES conservation in the national landscape context. Those regions are mostly located along the coastland and they represent only a minor area considering mainland Portugal, but their ecological economic benefits worth three times more than Model 2 and 3 together. A big portion of those areas are found nearby some of the protected areas, evidencing a spatial relationship between effective based conservation clusters. Preserving these emphasize regions bear an efficient high cost-benefit guaranteed. Model 2 and 3 have similar outcomes in terms of the total economic valuation provided by each Model. However, Model 2 has a much larger area when compared to model 1 and 3, which while protecting more ecosystems, needs a higher investment. Finally, Model 3 has a scattered spatial pattern essentially aggregated in the North of the country and close to intensive agricultural regions. Its low priority areas stand neighbouring artificial surfaces with lower conservation concerns. Coastal Systems, Coastal Wetlands and Forest are the main ecosystems contributing for the economic valuation in the highest-priority areas (i.e., model 1). Forest is still an important ecosystem to consider for Model 2 and 3, but the same is not valid for Coastal Systems, which have no impact on the medium and low priority models. Croplands and Grasslands are the other two most relevant ecosystems providing economic benefits, yet both differ in terms of spatial dimension. If Croplands by itself yield a majority presence on both Model 2 (~90%) and Model 3 (~75%), Grasslands only account to about 2% and 17% respectively. The absence of a priority strategy may jeopardize the full economic and ecological potential of natural ecosystems and their services. Hence, our modelling approach reveals geographically ranked areas in where conservation efforts should be addressed according to a priority status.

On the implications of our cost-effective conservation models for sustainability improvement, we show a new strategy of how to use this modelling approach in landscape planning. However, is useful to note some important caveats that do need careful consideration when interpreting our results. Our priority models consider both economic and ecological values together, so all the assumptions underlying the InVEST HQ model and the economic valuation methodology may influence our findings. The application of HQ outputs has a spatial limitation related to the small number of land cover classes converted into ecosystems, which is mainly dependent on the scale of the study (i.e., national). The HQ input data resolution could also tend to oversimplify the habitat complexity at a macroscale due to the lack of field-observed data (e.g., Schulp et al., 2014; Sallustio et al., 2017). Regarding the economic valuation of ES, we assume that the value of an ES can be uniform for a particular land cover (i.e., regardless of its condition, composition and management history). We know however that these characteristics are very unlikely the same across all the geographical contexts. Thus, the ES provided by croplands will not be constant within croplands, resulting in uniformity errors (Eigenbrod et al., 2010). Moreover, we have not adjusted our estimates according to potential differences between the characteristics of our study site (Portuguese mainland ES) and the original study sites, such as socio-economic and demographic characteristics or market differences. This can introduce some practical limitations in ES values mapping and thus undermine the identification of priority areas for conservation (Eigenbrod et al., 2010). Benefit transfer is far from perfect and is subject of an ongoing academic debate over its validity (Wilson and Hoehn, 2006). On the other hand, due to a lack of primary data, we assume that estimating ES values through this method is very useful to show the potential benefits of ES for land-use policies at national levels (Johnston and Bauer, 2020; Mandle et al., 2020).

In practice, sustainable land-use policies can be achieved only if best ES practices are applied across the public, scientific and private sectors. Integrated approaches such as the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services – IPBES (http://www.ipbes.net) can advance multiple pathways for improving the effectiveness of the science-policy interface on decision-making processes (Ruckelshaus et al., 2020). There is a constant political debate on whether ES should be viewed as economic assets (Barbier, 2013), but avoided costs of ES loss are frequently underestimated or even neglected by politicians (Challender et al., 2015). Spatial prioritization models for ES conservation priorities can be used as a comprehensive framework to link economic and ecological values for incorporating research evidence into policy decisions (Dinerstein et al., 2020). A growing number of evidence-based approaches on the economic benefits of ES around the world have shown many opportunities for investments at different spatial scales (Liu, 2018; Mandle et al., 2020; Ouyang et al., 2016; Salzman et al., 2018). Following these many opportunities of investments, our findings introduce potential conservation parameters that set new priorities for the ES supply in mainland Portugal. We argue for the use of Model 1 (i.e., high priority) as an indicator of key conservation areas for ES values with cost-effective implications for a sustainable economy. This integrative modelling approach in balance with the landscape may be used to assess how human activities can be spatially managed to reduce land-use impacts on ES supply by cost-effective conservation actions.

5. Conclusions

Time and space are running out for natural ecosystems, and one of the most effective options for conservation planning is to incorporate economic benefits into decision making (O'Bryan et al., 2020). The ES scientific community has a consensus that integrating ecology and economy is a key argument to safeguard biodiversity at national, regional and global scales (Paul et al., 2020; Strassburg et al., 2020). However, the people needs in economics, environment and sustainable development are growing faster than new species are being discovered, leaving out their relationships with the ecosystems and human welfare (Chaplin-Kramer et al., 2019). At the same time, evidence on how new investments in nature benefitting people can enhance sustainable development practices in the face of people needs around the world (Polasky et al., 2019). The urgent need for an ambitious global conservation agenda arises from the question of how much it costs and which are the targets that should be selected for a cost-effective landscape planning (Hannah et al., 2020; Tallis et al., 2018). Therefore, the response to conservation must be quick. Connecting economic and ecological benefits of ES, our results suggest a strategy to value, and at the same time, conserve all biodiversity components quickly and effectively, because our targets are ecosystems. The example given for Portugal can be expanded to other regions of the world, including biodiversity-rich areas in the Tropics aimed to protect multiple ES with limited resources. Our study highlights the call for comprehensive approaches to uncertainty in ecological-economic research to improve the future economic valuation of biodiversity.

Acknowledgments

We thank V. Otrachshenkoc, M. Cunha-e-Sá and L. Nunes for useful comments on the manuscript. This work is supported by the Portuguese Science Foundation – FCT under the Information Management Research Center – MagIC (UIDB/04152/2020) and by the FCT research project ASEBIO – Assessment of Ecosystem Services and Biodiversity in Portugal (PTDC/CTA-AMB/28438/2017). R.L.M. is supported by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Finance Code 001 (CAPES, Brazil).

Appendix A. Supplementary data

Supplementary data to this article can be found online.

References

Adams, W.M., 2014. The value of valuing nature. Science 346, 549–551. https://doi.org/10.1126/science.1255997

Baker, R., Ruting, B., 2014. Environmental Policy Analysis: A Guide to Non-Market Valuation. Productivity Commission Staff Working Paper, Canberra, Australia.

Banks-Leite, C., Pardini, R., Tambosi, L.R., Pearse, W.D., Bueno, A.A., Bruscagin, R.T., Condez, T.H., Dixo, M., Igari, A.T., Martensen, A.C., Metzger, J.P., 2014. Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. Science 345, 1041–1045. https://doi.org/10.1126/science.1255768

Barbier, E.B., 2013. Wealth accounting, ecological capital and ecosystem services. Environ. Dev. Econ. 18, 133–161. https://doi.org/10.1017/S1355770X12000551

Bateman, I.J., Mace, G.M., Fezzi, C., Atkinson, G., Turner, K., 2011. Economic analysis for ecosystem service assessments. Environ. Resour. Econ. 48, 177–218. https://doi.org/10.1007/s10640-010-9418-x

Bennett, E.M., Cramer, W., Begossi, A., Cundill, G., Diaz, S., Egoh, E., Geijzendorffer, I.R., Krug, C.B., Lavorel, S., Lazos, E. et al., 2015. Linking ecosystem services to human well-being: three challenges for designing research for sustainability. Curr. Opin. Environ. Sustain. 14, 76–85. https://doi.org/10.1016/j.cosust.2015.03.007

Borenstein, M., Hedges, L. V., Higgins, J.P.T., Rothstein, H.R., 2010. A basic introduction to fixed-effect and random-effects models for meta-analysis. Res. Synth. Methods. 1, 97–111. https://doi.org/10.1002/jrsm.12

Brooks, T.M., Mittermeier, R.A., Da Fonseca, G.A.B., Gerlach, J., Hoffmann, M., Lamoreux, J.F., Mittermeier, C.G., Pilgrim, J.D., Rodrigues, A.S.L., 2006. Global biodiversity conservation priorities. Science 313, 58–61. https://doi.org/10.1126/science.1127609

Buchmann-Duck, J., Beazley, K.F., 2020. An urgent call for circular economy advocates to acknowledge its limitations in conserving biodiversity. Sci. Total Environ. 727, 138602. https://doi.org/10.1016/j.scitotenv.2020.138602.

Campos, F.S., Lourenço-de-Moraes, R., 2020. Ecological Fever: The Evolutionary History of

Coronavirus in Human-Wildlife Relationships. Front. Ecol. Evol. 8, 575286. https://doi.org/10.3389/fevo.2020.575286.

Campos, F.S., Lourenço-de-Moraes, R., Llorente, G.A., Solé, M., 2017. Cost-effective conservation of amphibian ecology and evolution. Sci. Adv. 3, e1602929. https://doi.org/10.1126/sciadv.1602929

Cardinale, B.J., Srivastava, D.S., Duffy, J.E., Wright, J.P., Downing, A.L., Sankaran, M., Jouseau, C., 2006. Effects of biodiversity on the functioning of trophic groups and ecosystems. Nature 443, 989–992. https://doi.org/10.1038/nature05202

Challender, D.W.S., Harrop, S.R., MacMillan, D.C., 2015. Towards informed and multi-faceted wildlife trade interventions. Glob. Ecol. Conserv. 3, 129–148. https://doi.org/10.1016/j.gecco.2014.11.010

Chaplin-Kramer, R., Sharp, R.P., Weil, C., Bennett, E.M., Pascual, U., Arkema, K.K., Brauman, K.A., Bryant, B.P., Guerry, A.D., Haddad, N.M., Hamann, M., Hamel, P., Johnson, J.A., Mandle, L., Pereira, H.M., Polasky, S., Ruckelshaus, M., Shaw, M.R., Silver, J.M., Vogl, A.L., Daily, G.C., 2019. Global modeling of nature's contributions to people. Science 366, 255–258. https://doi.org/10.1126/science.aaw3372

European Environment Agency – EEA, 2018. Corine Land Cover – CLC, Copernicus. https://land.copernicus.eu/pan-european/corine-land-cover/clc2018.

Daily, G.C., Matson, P.A., 2008. Ecosystem services: From theory to implementation. Proc. Natl. Acad. Sci. U. S. A. 105, 9455–9456. https://doi.org/10.1073/pnas.0804960105

Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision making: Time to deliver. Front. Ecol. Environ. 7, 21–28. https://doi.org/10.1890/080025

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., ten Brink, P., van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosyst. Serv. 1, 50–61. https://doi.org/10.1016/j.ecoser.2012.07.005

Dinerstein, E., Joshi, A.R., Vynne, C., Lee, A.T.L., Pharand-Deschênes, F., França, M., Fernando, S., Birch, T., Burkart, K., Asner, G.P., Olson, D., 2020. A "global safety net" to reverse biodiversity loss and stabilize earth's climate. Sci. Adv. 6, eabb2824. https://doi.org/10.1126/sciadv.abb2824

Eigenbrod, F., Armsworth, P.R., Anderson, B.J., Heinemeyer, A., Gillings, S., Roy, D.B., Thomas, C.D., Gaston, K.J., 2010. The impact of proxy-based methods on mapping the distribution of ecosystem services. J. Appl. Ecol. 47, 377–385. https://doi.org/10.1111/j.1365-2664.2010.01777.x

Evans, C.D., Bonn, A., Holden, J., Reed, M.S., Evans, M.G., Worrall, F., Couwenberg, J., Parnell, M., 2014. Relationships between anthropogenic pressures and ecosystem functions in UK blanket bogs: Linking process understanding to ecosystem service valuation. Ecosyst. Serv. 9, 5–19. https://doi.org/10.1016/j.ecoser.2014.06.013

Frank, E.G., Schlenker, W., 2016. Balancing economic and ecological goals. Science 353, 651–652. https://doi.org/10.1126/science.aaf9697

Frélichová, J., Vačkář, D., Pártl, A., Loučková, B., Harmáčková, Z. V., Lorencová, E., 2014. Integrated assessment of ecosystem services in the Czech Republic. Ecosyst. Serv. 8, 110–117. https://doi.org/10.1016/j.ecoser.2014.03.001

Griggs, D., Stafford-Smith, M., Gaffney, O., Rockström, J., Öhman, M.C., Shyamsundar, P., Steffen, W., Glaser, G., Kanie, N., Noble, I., 2013. Policy: Sustainable development goals for people and planet. Nature 495, 305–307. https://doi.org/10.1038/495305a

Gurevitch, J., Koricheva, J., Nakagawa, S., Stewart, G., 2018. Meta-analysis and the science of research synthesis. Nature 555, 175–182. https://doi.org/10.1038/nature25753

Hanley, N., Barbier, E.B., 2009. Pricing nature: Cost-Benefit analysis and environmental policy, Pricing Nature: Cost-Benefit Analysis and Environmental Policy. Edward Elgar Publishing, England. https://doi.org/10.1093/erae/jbq042

Hannah, L., Roehrdanz, P.R., Marquet, P.A., Enquist, B.J., Midgley, G., Foden, W., Lovett, J.C., Corlett, R.T., Corcoran, D., Butchart, S.H.M., Boyle, B., Feng, X., Maitner, B., Fajardo, J., McGill, B.J., Merow, C., Morueta-Holme, N., Newman, E.A., Park, D.S., Raes, N., Svenning, J.C., 2020. 30% land conservation and climate action reduces tropical extinction risk by more than 50%. Ecography 43, 943–953. https://doi.org/10.1111/ecog.05166

Hedges, L. V., Gurevitch, J., Curtis, P.S., 1999. The meta-analysis of response ratios in experimental ecology. Ecology 80, 1150–1156. https://doi.org/10.1890/0012-9658(1999)080[1150:TMAORR]2.0.CO;2

Iovanna, R., Griffiths, C., 2006. Clean water, ecological benefits, and benefits transfer: A work in progress at the U.S. EPA. Ecol. Econ. 60, 473–482. https://doi.org/10.1016/j.ecolecon.2006.06.012

Johnston, R.J., Bauer, D.M., 2020. Using Meta-Analysis for Large-Scale Ecosystem Service Valuation: Progress, Prospects, and Challenges. Agric. Resour. Econ. Rev. 49, 23–63. https://doi.org/10.1017/age.2019.22

Johnston, R.J., Rolfe, J., Zawojska, E., 2018. Benefit transfer of environmental and resource values: Progress, prospects and challenges. Int. Rev. Environ. Resour. Econ. 12, 177–266. https://doi.org/10.1561/101.00000102

Johnston, R.J., Rosenberger, R.S., 2010. Methods, trends and controversies in contemporary benefit transfer. J. Econ. Surv. 24, 479–510. https://doi.org/10.1111/j.1467-6419.2009.00592.x

Kallis, G., Gómez-Baggethun, E., Zografos, C., 2013. To value or not to value? That is not the question. Ecol. Econ. 94, 97–105. https://doi.org/10.1016/j.ecolecon.2013.07.002

Koricheva, J., Gurevitch, J., 2014. Uses and misuses of meta-analysis in plant ecology. J. Ecol. 102, 828–844. https://doi.org/10.1111/1365-2745.12224

Lawler, J.J., White, D., 2008. Assessing the mechanisms behind successful surrogates for biodiversity in conservation planning. Anim. Conserv. 11, 270–280. https://doi.org/10.1111/j.1469-1795.2008.00176.x

Lee, T.M., Jetz, W., 2008. Future battlegrounds for conservation under global change. Proc. R. Soc. B Biol. Sci. 275, 1261–1270. https://doi.org/10.1098/rspb.2007.1732

Leh, M.D.K., Matlock, M.D., Cummings, E.C., Nalley, L.L., 2013. Quantifying and mapping multiple ecosystem services change in West Africa. Agric. Ecosyst. Environ. 165, 6–18. https://doi.org/10.1016/j.agee.2012.12.001

Liu, J., 2018. An Integrated Framework for Achieving Sustainable Development Goals Around the World. Ecol. Econ. Soc. 1, 11–17. https://doi.org/10.37773/ees.v1i2.32

Liu, S., Costanza, R., Troy, A., D'Aagostino, J., Mates, W., 2010. Valuing New Jersey's ecosystem services and natural capital: A spatially explicit benefit transfer approach. Environ. Manage. 45, 1271–1285. https://doi.org/10.1007/s00267-010-9483-5

Mandle, L., Shields-Estrada, A., Chaplin-Kramer, R., Mitchell, M.G.E., Bremer, L.L., Gourevitch, J.D., Hawthorne, P., Johnson, J.A., Robinson, B.E., Smith, J.R., Sonter, L.J., Verutes, G.M., Vogl, A.L., Daily, G.C., Ricketts, T.H., 2020. Increasing decision relevance of ecosystem service science. Nat. Sustain. 3, 1–9. https://doi.org/10.1038/s41893-020-00625-y

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature 405, 243–253. https://doi.org/10.1038/35012251

Martín-López, B., Gómez-Baggethun, E., García-Llorente, M., Montes, C., 2014. Trade-offs across value-domains in ecosystem services assessment. Ecol. Indic. 37, 220–228.

https://doi.org/10.1016/j.ecolind.2013.03.003

Mascarenhas, A., Haase, D., Ramos, T.B., Santos, R., 2019. Pathways of demographic and urban development and their effects on land take and ecosystem services: The case of Lisbon Metropolitan Area, Portugal. Land use policy 82, 181–194 . https://doi.org/10.1016/j.landusepol.2018.11.056

McCauley, D.J., 2006. Selling out on nature. Nature 443, 27–28. https://doi.org/10.1038/443027a

Instituto da Conservação da Natureza e Florestas – ICNF, 2020. Red Natura 2000 em Portugal continental. European Environment Agency – EEA, RN2000. http://www2.icnf.pt/portal/pn/biodiversidade/rn2000/rn-pt/rn-contin

Naeem, S., Chazdon, R., Duffy, J.E., Prager, C., Worm, B., 2016. Biodiversity and human well-being: An essential link for sustainable development. Proc. R. Soc. B Biol. Sci. 283, 20162091. https://doi.org/10.1098/rspb.2016.2091

Nakagawa, S., Santos, E.S.A., 2012. Methodological issues and advances in biological meta-analysis. Evol. Ecol. 26, 1253–1274. https://doi.org/10.1007/s10682-012-9555-5

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, D.R., Chan, K.M.A., Daily, G.C., Goldstein, J., Kareiva, P.M., Lonsdorf, E., Naidoo, R., Ricketts, T.H., Shaw, M.R., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front. Ecol. Environ. 7, 4–11. https://doi.org/10.1890/080023

O'Bryan, C.J., Allan, J.R., Holden, M., Sanderson, C., Venter, O., Di Marco, M., McDonald-Madden, E., Watson, J.E.M., 2020. Intense human pressure is widespread across terrestrial vertebrate ranges. Glob. Ecol. Conserv. 21, e00882. https://doi.org/10.1016/j.gecco.2019.e00882

Olander, L., Polasky, S., Kagan, J.S., Johnston, R.J., Wainger, L., Saah, D., Maguire, L., Boyd, J., Yoskowitz, D., 2017. So you want your research to be relevant? Building the bridge between ecosystem services research and practice. Ecosyst. Serv. 26, 170–182. doi:10.1016/j.ecoser.2017.06.003.

Ouyang, Z., Zheng, H., Xiao, Yi, Polasky, S., Liu, J., Xu, W., Wang, Q., Zhang, L., Xiao, Yang, Rao, E., Jiang, L., Lu, F., Wang, X., Yang, G., Gong, S., Wu, B., Zeng, Y., Yang, W., Daily, G.C., 2016. Improvements in ecosystem services from investments in natural capital. Science 352, 1455–1459. https://doi.org/10.1126/science.aaf2295

Parks, S., Gowdy, J., 2013. What have economists learned about valuing nature? A review essay. Ecosyst. Serv. 3, e1–e10. https://doi.org/10.1016/j.ecoser.2012.12.002

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R.T., Dessane, E. B., Islar, M., Kelemen, E. et al., 2017. Valuing nature’s contributions to people: the IPBES approach. Curr. Opin. Environ. Sustain. 26, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006

Paul, C., Hanley, N., Meyer, S.T., Fürst, C., Weisser, W.W., Knoke, T., 2020. On the functional relationship between biodiversity and economic value. Sci. Adv. 5, eaax7712. https://doi.org/10.1126/sciadv.aax7712

Petersen, A.H., Strange, N., Anthon, S., Bjørner, T.B., Rahbek, C., 2016. Conserving what, where and how? Cost-efficient measures to conserve biodiversity in Denmark. J. Nat. Conserv. 29, 33–44. https://doi.org/10.1016/j.jnc.2015.10.004

Polasky, S., Kling, C.L., Levin, S.A., Carpenter, S.R., Daily, G.C., Ehrlich, P.R., Heal, G.M., Lubchenco, J., 2019. Role of economics in analyzing the environment and sustainable development. Proc. Natl. Acad. Sci. U. S. A. 116, 5233–5238. https://doi.org/10.1073/pnas.1901616116

Pollock, L.J., Thuiller, W., Jetz, W., 2017. Large conservation gains possible for global biodiversity facets. Nature 546, 141–144. https://doi.org/10.1038/nature22368

Purvis, A., Hector, A., 2000. Getting the measure of biodiversity. Nature 405, 212–219. https://doi.org/10.1038/35012221

Quintas-Soriano, C., Martín-López, B., Santos-Martín, F., Loureiro, M., Montes, C., Benayas, J., García-Llorente, M., 2016. Ecosystem services values in Spain: A meta-analysis. Environ. Sci. Policy. 55, 186–195. https://doi.org/10.1016/j.envsci.2015.10.001

R Core Team. 2020. R: a language and environment for statistical computing. R Founda-tion for Statistical Computing, Vienna, Austria. https//www.R-project.org/

Randrup, T.B., Persson, B., 2009. Public green spaces in the Nordic countries: Development of a new strategic management regime. Urban For. Urban Green. 8, 31–40. https://doi.org/10.1016/j.ufug.2008.08.004

Richardson, L., Loomis, J., Kroeger, T., Casey, F., 2015. The role of benefit transfer in ecosystem service valuation. Ecol. Econ. 115, 51–58. https://doi.org/10.1016/j.ecolecon.2014.02.018

Rosenberger, R.S., Loomis, J.B., 2000. Using meta-analysis for benefit transfer: In-sample convergent validity tests of an outdoor recreation database. Water Resour. Res. 36, 1097–1107. https://doi.org/10.1029/2000WR900006

Ruckelshaus, M.H., Jackson, S.T., Mooney, H.A., Jacobs, K.L., Kassam, K.A.S., Arroyo, M.T.K., Báldi, A., Bartuska, A.M., Boyd, J., Joppa, L.N., Kovács-Hostyánszki, A., Parsons, J.P., Scholes, R.J., Shogren, J.F., Ouyang, Z., 2020. The IPBES Global Assessment: Pathways to Action. Trends Ecol. Evol. 35, 407–414. https://doi.org/10.1016/j.tree.2020.01.009

Sallustio, L., De Toni, A., Strollo, A., Di Febbraro, M., Gissi, E., Casella, L., Geneletti, D., Munafò, M., Vizzarri, M., Marchetti, M., 2017. Assessing habitat quality in relation to the spatial distribution of protected areas in Italy. J. Environ. Manage. 201, 129–137. https://doi.org/10.1016/j.jenvman.2017.06.031

Salzman, J., Bennett, G., Carroll, N., Goldstein, A., Jenkins, M., 2018. The global status and trends of Payments for Ecosystem Services. Nat. Sustain. 1, 136–144. https://doi.org/10.1038/s41893-018-0033-0

Sarkar, D., 2017. Lattice: trellis graphics for R. R Package Version 0.20–34. R Core Team. https://cran.r-project.org/web/packages/lattice/index.html

Schaefer, M., Goldman, E., Bartuska, A.M., Sutton-Grier, A., Lubchenco, J., 2015. Nature as capital: Advancing and incorporating ecosystem services in United States federal policies and programs. Proc. Natl. Acad. Sci. U. S. A. 112, 7383–7389. https://doi.org/10.1073/pnas.1420500112

Schulp, C. J., Burkhard, B., Maes, J., Van Vliet, J., Verburg, P. H., 2014. Uncertainties in ecosystem service maps: a comparison on the European scale. PloS ONE 9, e109643. https://doi.org/10.1371/journal.pone.0109643

Seddon, N., Mace, G.M., Naeem, S., Tobias, J.A., Pigot, A.L., Cavanagh, R., Mouillot, D., Vause, J., Walpole, M., 2016. Biodiversity in the anthropocene: Prospects and policy. Proc. R. Soc. B Biol. Sci. 283, 20162094. https://doi.org/10.1098/rspb.2016.2094

Sharp, R., Tallis, H.T., Ricketts, T., Guerry, A.D., Wood, S.A., Chaplin-Kramer, R., Nelson, E., Ennaanay, D., Wolny, S., Olwero, N., others, 2014. InVEST user's guide. Nat. Cap. Proj. Stanford. https://naturalcapitalproject.stanford.edu/software/invest

Silvertown, J., 2015. Have Ecosystem Services Been Oversold? Trends Ecol. Evol. 30, 641–648. https://doi.org/10.1016/j.tree.2015.08.007

Strassburg, B.B.N., Iribarrem, A., Beyer, H.L., Cordeiro, C.L., Crouzeilles, R., Jakovac, C.C., Braga Junqueira, A., Lacerda, E., Latawiec, A.E., Balmford, A., Brooks, T.M., Butchart, S.H.M., Chazdon, R.L., Erb, K.-H., Brancalion, P., Buchanan, G., Cooper, D., Díaz, S., Donald, P.F., Kapos, V., Leclère, D., Miles, L., Obersteiner, M., Plutzar, C., de M. Scaramuzza, C.A., Scarano, F.R., Visconti, P., 2020. Global priority areas for ecosystem restoration. Nature 586, 724–729. https://doi.org/10.1038/s41586-020-2784-9

Subroy, V., Gunawardena, A., Polyakov, M., Pandit, R., Pannell, D.J., 2019. The worth of wildlife: A meta-analysis of global non-market values of threatened species. Ecol. Econ. 164, 106374. https://doi.org/10.1016/j.ecolecon.2019.106374

Sutton, N.J., Cho, S., Armsworth, P.R., 2016. A reliance on agricultural land values in conservation planning alters the spatial distribution of priorities and overestimates the acquisition costs of protected areas. Biol. Conserv. 194, 2–10. https://doi.org/10.1016/j.biocon.2015.11.021

Tallis, H.M., Hawthorne, P.L., Polasky, S., Reid, J., Beck, M.W., Brauman, K., Bielicki, J.M., Binder, S., Burgess, M.G., Cassidy, E., Clark, A., Fargione, J., Game, E.T., Gerber, J., Isbell, F., Kiesecker, J., McDonald, R., Metian, M., Molnar, J.L., Mueller, N.D., O'Connell, C., Ovando, D., Troell, M., Boucher, T.M., McPeek, B., 2018. An attainable global vision for conservation and human well-being. Front. Ecol. Environ. 16, 563–570. https://doi.org/10.1002/fee.1965

The Economics of Ecosystems and Biodiversity – TEEB, 2013. Guidance Manual for TEEB Country Studies. Version 1.0. United Nations Environment Programme. http://teebweb.org/our-work/country-studies/what-is-tcs/guidance-manual

Viechtbauer, W., 2010. Conducting meta-analyses in R with the metafor. J. Stat. Softw. 36, 1–48. https://doi.org/10.18637/jss.v036.i03

Wilson, M.A., Hoehn, J.P., 2006. Valuing environmental goods and services using benefit transfer: The state-of-the art and science. Ecol. Econ. 60, 335–342. https://doi.org/10.1016/j.ecolecon.2006.08.015

Yang, R., Cao, Y., Hou, S., Peng, Q., Wang, X., Wang, F., Tseng, T.-H., Yu, L., Carver, S., Convery, I., Zhao, Z., Shen, X., Li, S., Zheng, Y., Liu, H., Gong, P., Ma, K., 2020. Cost-effective priorities for the expansion of global terrestrial protected areas: Setting post-

2020 global and national targets. Sci. Adv. 6, eabc3436.
https://doi.org/10.1126/sciadv.abc3436