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ASSESSING THE VALUE OF ECOSYSTEM SERVICES IN CENTRO REGION, PORTUGAL FROM 2000 TO 2018

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ABSTRACT

This paper estimates the economic value of seven ecosystem services in Portugal's Centro region from 2000 to 2018. Employing hectare-level satellite data, GIS mapping and a valuation method based on a meta-analytic regression and market prices, the research provides spatially explicit results. The findings include an area growth for artificial areas and an area decrease for natural ecosystems. Moreover, the estimated economic value for five of the seven ecosystem services increased over the timespan, decreasing for the other two. This study underscores the need for informed environmental stewardship, as well as an ecological and economic balance.

Key words: Ecosystem Services; Land Use and Land Cover Change; Benefit Transfer; Economic Valuation; Portugal

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1. INTRODUCTION

Catching up in popularity vis-à-vis the well-discussed climate crisis, the biodiversity crisis is a comparably imminent threat to the planet's living beings and ecosystems. The term biodiversity, i.e. biological diversity, refers to the variety of life on our planet that has developed from evolution over the last 4.5 billion years, including everything from genes to ecosystems (Dasgupta 2021, 51). The two crises are distinct, but inherently interlinked; climate change is one of the main drivers of biodiversity loss, every additional degree of warming perpetuating further extinction of species, the spread of diseases, and the loss of crucial ecosystems. Vice versa, healthy ecosystems are essential for the absorption of greenhouse gases, limiting the extent of destruction caused by fossil fuel emissions (United Nations, n.d.).

Seen through an anthropocentric lens, both the global economy and human wellbeing exhibit a high dependency on healthy ecosystems, as well as goods and services provided by the natural environment. The concept known as ecosystem services (ES) was coined around four decades ago (Ehrlich and Ehrlich 1981), although it was not until the mid-1990s that the concept gained recognition in economic theory (Gómez-Baggethun et al. 2010). ES have been defined as "the benefits people obtain from ecosystems" (Levin 2013) and were catalogued into four categories by the Millennium Ecosystem Assessment: supporting, provisioning, regulating, and cultural services (MEA 2003, see Appendix I for a list of examples). Given that most nature-based goods and services are non-exclusive public goods free of cost, the value of nature is invisible in most cost-benefit analyses, leading to a free-rider problem of overexploitation. With the aim to foster nature's visibility in economic decision-making processes, controversial discussions around the economic valuation of ES have arisen, in which critics have voiced concern with the ethics of reducing nature to a monetary value, as well as with the ability to assign a substantive price on irreplaceable natural capital (Liu et al. 2010). Thus, it is crucial to acknowledge that the analysis conducted within the scope of this thesis will not be evaluating non-use values, including the existence or bequest value of nature, but only some use values. Use values can be separated into direct and indirect use values, the former being defined as directly consumable outputs and service such as crops, and the latter as indirect benefits such as carbon sequestration or pollution (De Valck et al. 2023).

In the context of Portugal, the consequences of both the climate and the biodiversity crises are becoming increasingly noticeable. According to Ursula von der Leyen's statement at a 2019 European Council meeting, it is considered as one of the countries most severely impacted by climate change (von der Leyen 2019). Extreme weather events (e.g. wildfires, heat waves, droughts, heavy precipitation), sea level rise, coastal erosion, and desertification are just a few of the most pressing ecosystem and climate-related issues Portugal had to face in recent years. Socioeconomically, the expected implications include a reduction in agricultural productivity caused by desertification and water scarcity. posing a risk to food security (Schleussner et al. 2020). Moreover, coastal erosion is projected to affect several economic sectors including fishing and tourism, given that around 80% of touristic activities are centered around, and more than half of the population lives in coastal areas (FFMS 2020).

Portugal's Centro region ("Região do Centro") is of specific interest when looking at the intersection of biodiversity, human activities, and climate risk. In terms of biodiversity and nature Centro is a diverse region, comprising coastal wetlands, various kinds of forests, moors, heathlands, among many other types of ecosystems. Regarding human activities, Centro has attracted significant tourism, fishing, and maritime activity, all of which have been exerting amplified pressure on the natural environment, leading to heightened climate risk (e.g. coastal erosion) (NOVA Faculty of Sciences and Technology 2021).

To best advise decision-making and develop welfare enhancing EBM, it is crucial to assess and attempt to value the contribution nature is making to wellbeing. To verify whether or not the degradation of ecosystems and the services they provide to humans is leading to economic costs, adding a time dimension could support the argument of a persisting trend over a given timespan (Li et al. 2022). Focusing on Centro region, the analysis conducted within the scope of this work will answer the following question: To what extent has the value of different ecosystem services in Portugal's Centro region changed from 2000 to 2018 and what are the implications? By means of Geographic Information System (GIS) mapping, the changes in economic values as a consequence of changing land cover and ecosystem service supply levels will be determined. Thus, the analysis aims to offer a compelling rationale for the necessity of action and serve as a foundation to determine the most suitable NbS and EBM tools to be employed.

2. LITERATURE REVIEW

2.1. Economic valuation of ecosystem services (EVES)

Constanza et al. (1997) introduced the world to assigning a monetary value to ES, providing the first global database for 16 marine and terrestrial biomes and 17 different ES including climate regulation, water purification, and pollination, in 1994US$/ha/yr. Biomes are defined as "major biogeographic regions consisting of distinctive plant life forms (e.g., forest, grasslands, desert, etc.)" (Fath 2019). Ever since, the extent to which ecosystems contribute to human welfare has gained popularity in the field of economics, e.g. through the aforementioned Millennium Ecosystem Assessment (MEA 2003) and the foundation of The Economics of Ecosystems and Biodiversity (TEEB 2008).

Nonetheless, EVES has considerable limitations, as pointed out by critics since its establishment. One of the main arguments is monetary reductionism, i.e. the critique of assigning a monetary value to nature, which is not an economic asset. Values are determined based on anthropocentric utilitarianism and efficiency, lacking considerations for fairness or sustainability and failing to accurately capture the intrinsic value of the existence of healthy ecosystems (Liu et al. 2010). Another argument regards the methodology underlying EVES, both in terms of purpose and precision. In terms of purpose, EVES has been criticized as merely effective to evaluate the change of ecosystem services, rather than providing a functional estimate of their total (global) value (Bockstael et al. 2000). Regarding precision, EVES studies have been criticized for their lack of accuracy, a sentiment expressed by Spangenberg and Settele (2010) : “The risk of valuation is to get the figures wrong, and it is unavoidable.” Several other critical voices have listed the failure to account for inter- and intragenerational justice, inferring from local levels to a global scale, double counting of ES (e.g. including both pollination and final harvested crop), and many other shortcomings (Lele et al. 2013). Despite these limitations and critiques, the TEEB report (2010) justifies the need to integrate nature into conventional economics by highlighting the alternative, i.e. the current economic system in which the degradation of nature has no consequence for those causing it. Thus, while acknowledging that any monetary value placed on nature is inherently imperfect, TEEB cites “the long-term benefits of imperfectly informed action” as its preference over inaction at the cost of the natural environment.

The potential goals of EVES comprise efficient allocation of resources, ecological risk assessments, raising public awareness or informed decision-making by means of a cost-benefit analysis, as well as the objective of policy development in favor of conservation and restoration of ecosystems. Recommendations for improved conservation and restoration measures have followed a number ecosystem service-focused studies, including but not limited to Shrestha et al. (2023), Vaz et al. (2021), Rosário and Madureira (2022), and Ando (2022). Examples of measures suggested to be implemented by authorities include the expansion of protected areas, enhancing sustainable land use practices and measures to restore biodiversity.

2.2. Land use and land cover change (LULCC) for EVES over time

The extent of ES provision in a specific geographic area is closely interlinked with the distribution of land use and land cover types (Schirpke and Tasser 2021). Despite their similar names, the two terms refer to two different concepts: land use is characterized by the land's functions (e.g. habitat, agriculture), while land cover relates to the ground's surface covering (e.g. forests, wetlands, water) (Belay, Melese, and Senamaw 2022). Due to anthropological influences driven by a growing demand for urban, agricultural, and industrial expansion, natural ecosystems have been ubiquitously degrading (Shiferaw et al. 2021), LULCC being the most noteworthy catalyst for changes in the value of ES since the middle of the last century (Li et al. 2022). High-resolution satellite imagery has become the standard tool employed to monitor and quantify such LULCC, providing a foundation for estimating ES supply (Sieber et al. 2021).

Globally, there has been an increase in the use of LULCC data for intertemporal EVES studies, including Schirpke, Tscholl, and Tasser (2020), who assessed and predicted EVES change between 1860 and 2100 in South Tyrol, Li et al. (2022) who valued changes of EVES in the Pearl River Delta (China) between 1990 and 2020, and Anley et al. (2022), who did the same for the Upper Blue Nile Basin (Ethiopia). All three concluded an increase in agricultural and artificial areas, a reduction in forests, and an overall downward trend of the total value of ES in their regions over the three decades analyzed.

Research focusing on LULCC in Portugal includes the ASEBIO project headed by NOVA IMS (Cabral et al. 2021). The project employed a participatory stakeholder-based methodology, where ES supply in continental Portugal was estimated for the years for which CORINE Land Cover (CLC) data exists, i.e. 1990, 2000, 2006, 2012, and 2018. Based on these supply maps, Seixo et al. (2023) conducted the first comprehensive EVES for land-based ES in continental Portugal using data for 2018, which is utilized as a foundation for this thesis' analysis.

2.3. Coastal and marine ES

The Millennium Ecosystem Assessment (2003) defined all areas as marine ecosystems that are 50m or deeper below the sea surface, and considered coastal ecosystems to start where marine ecosystems end, extending all the way up to 100km from the coastline on land. Their ES include coastal erosion control, recreation and tourism activities such as surfing, food provision through fish and seafood, carbon storage and sequestration, among many others (Milon and Alvarez 2019). The coastal and marine domains are underrepresented in the general research on ES and EVES, where most researchers have focused on terrestrial ecosystems (Carrasco De La Cruz 2021). One of the potential reasons is that it is considerably challenging to conduct research in marine environments (TEEB 2010). Lack of research has led to a comparatively low amount of accumulated data for the EVES, as well as a comparatively small number of assessment tools (Carrasco De La Cruz 2021). Considering that coastal and marine ecosystems suffer from some of the highest global degradation rates due to the abundance of human activity and settlement along coastlines, decreasing this knowledge gap has been deemed essential to ensure adequate implementation of sustainable coastal and marine management, including conservation measures (Carrasco De La Cruz 2021).

An example of research in this area for Portugal is a paper by Bentes, Henriques and Gonçalves (2023). They conducted a study that provides data for the mapping of marine ES on the southern coast of Portugal, i.e. Algarve, which can be used to value them socially and economically.

2.4. Benefit transfer

When attempting to assess EVES, the issue of primary data collection is omnipresent. Gathering specific data for a site is possible but requires substantial monetary and time resources that are out of scope for most projects. Thus, benefit transfers emerged to circumvent the problem, a method of EVES that is underlying this thesis. Benefit transfer describes the act of adjusting and applying estimates of ES from one site, the study site, to another site, the policy site (Plummer 2009). In doing so, it is crucial to recognize the method's requirements: the services and biophysical characteristics at the two sites and the socioeconomic and demographic characteristics of the local population should be identical. Also, the allocation of property rights at both sites should result in the application of identical welfare measures. In reality, these criteria are seldomly fully met, but it is advised to ensure maximum adherence to achieve a sufficiently accurate estimation (Richardson et al. 2015).

There are three different types of benefit transfers to choose from when conducting a benefit transfer: unit transfers, function transfers, or meta-analysis. In the case of a unit transfer, single estimated values for specific ecosystem services are taken from a study site and directly applied to a policy site. Compared to unit transfers, function transfers are considered more sophisticated, as they entail using the functions of the value estimation at the study site for the policy site. Here, biophysical, economic, and demographic factors that contribute to the estimation are adapted to better suit the specificities of the policy site. Lastly and most complex, a meta-analysis uses a vast array of studies to obtain variations in estimates or WTP depending on several factors. Such an analysis can estimate coefficients for a function such as the following:

$$WTP = \alpha_1 + \alpha_2 * land\ cover\ type + \alpha_3 * latitude + \alpha_4 * income + \alpha_5 * pop\ density$$

where WTP refers to the willingness to pay for a certain ES, α_1 is the constant, and α_2 through α_5 are the coefficients for the corresponding example variables land cover type, latitude, income, and population density.

In conclusion, all three types are viable options depending on time and monetary resources available, although the meta-analysis is considered more ambitious and often most accurate (OECD 2018).

3. STUDY AREA

As implied by its name, Centro is a NUTS II region situated in the central part of Portugal (39.80°-40.90°N, 6.20°-8.10°W), comprising the eight NUTS III regions Beira Baixa, Beiras e Serra da Estrela, Médio Tejo, Oeste, Região de Aveiro, Região de Coimbra, Região de Leiria and Viseu Dão Lafões. It covers a total area of 28.202km^2, which represents about a quarter of the total national territory (Instituto Nacional de Estatística 2022). The landscape is characterized by the crossing of Portugal's main mountain range, the hydrographic basins of significant Iberian rivers, and forests that comprise one third of the national forested area. Moreover, it has a total coastline of around 279km, where beaches like Nazaré and Figueira da Foz attract substantial tourism (DRAP Centro 2023). As of the 2021 census, Centro has a total population of 2.227.239, a population density of 79 inhabitants per km^2, and the country's second lowest unemployment rate at 5.1% (Instituto Nacional de Estatística 2022). In 2021, Centro's GDP was €40.977.603, around 19,1% of Portugal's total GDP (PORDATA 2022). It is economically diversified with both low and high technology industries, tourism and a strong potential for renewable energy production (NOVA Faculty of Sciences and Technology 2021).

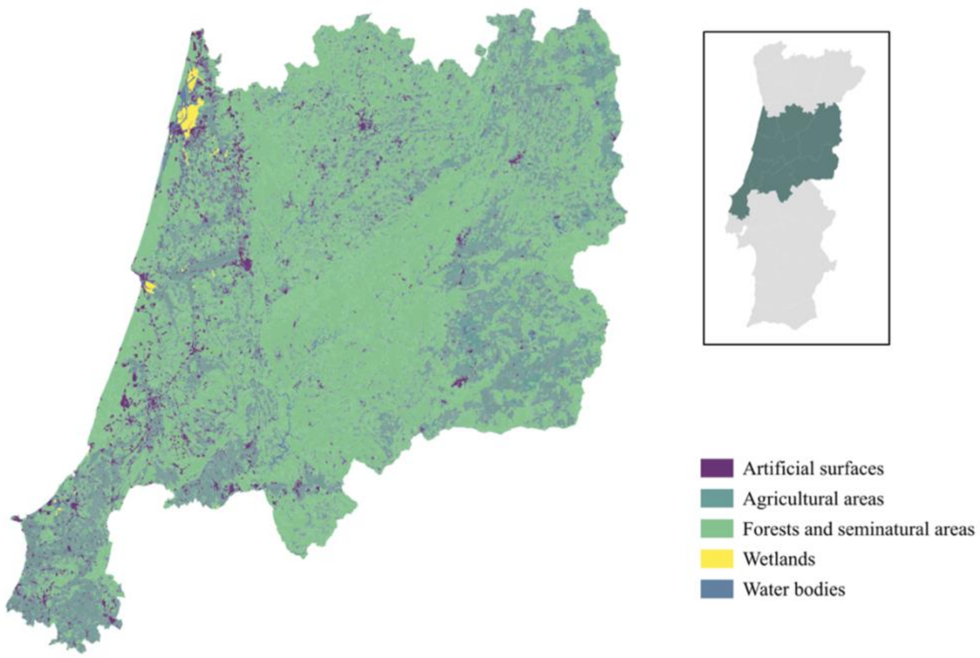

Figure 1: Map of study area incl. land cover types for 2018

4. DATA & METHODS

As previously mentioned, this thesis aims to assess and compare the EVES of several ES in Centro region between 2000 and 2018. To this end, two sets of data are required. Firstly, the supply levels of each ES for the two specified years are needed. Secondly, a method to estimate the economic value based on the supply levels is required. To analyze LULCC in the entire region, Corine Land Cover (CLC) data is used (Copernicus 2018). CLC is a satellite imagery-based "pan-European land cover and land use inventory with 44 thematic classes (see Appendix II), ranging from broad forested areas to individual vineyards" that is published every six years (Copernicus 2018). These thematic classes can be summarized in five broader categories, namely (1) artificial surfaces, (2) agricultural areas, (3) forests and semi-natural areas, (4) wetlands, and (5) water bodies. The datasets for 2000 and 2018 both have a spatial resolution of 100m, a thematic accuracy of more than 85%, and are used to map the LULCC of 42 of the 44 thematic classes (excl. intertidal flats and sea and ocean due to incomplete data) in Centro region in the given timespan.

4.1. Data and variables

The seven ES values encompass estimates for climate regulation (ClimReg), drought regulation (DrouReg), erosion prevention (EroPrev), food supply (FoodSup), pollination (Polli), recreation (Rec), and water purification (WaterPur). For the first three, the estimated economic value is based on market prices and the other four were given a value estimate based on a meta-analytic regression and benefit transfer function. All economic values and estimates are given in PT2018€. The market prices are taken from Seixo et al. (2023) and held constant for the year 2000. Their respective supply levels were taken from the open-source ES supply maps by ASEBIO (Cabral et al. 2021). The mapping was produced using the InVEST software by Stanford University (n.d.) for ClimReg, DrouReg, EroPrev, Polli and WaterPur and using spatial analysis and modelling for FoodSup and Rec.

For ClimReg, the average 2018 EU ETS (Emissions Trading System) price of €15.50 was multiplied by the amount of carbon dioxide stored in t/ha (Seixo et al. 2023). The amount of carbon sequestered was estimated by considering four different carbon reservoirs (soil, dead organic matter, aboveground & belowground biomass) (Cabral et al. 2021).

For DrouReg, the *Entidade Reguladora dos Serviços de Águas e Resíduos'* value for the municipal water tariff was used and averaged for the Centro region, leading to a value of approximately €2.30 (Seixo et al. 2023). The value was multiplied by the amount of water supplied in m^3/ha, which was estimated using a water yield model that calculates the annual mean amount of water generated by a watershed (Cabral et al. 2021).

For EroPrev, the value was taken from Marta-Pedroso et al. (2007), a study conducted in Portugal that provides price estimates that mirror the costs associated with each ton of soil lost due to declines in phosphorus and potassium, and adjusted to PT2018€. For the supply levels, a sediment retention model was set up, which uses the Universal Soil Loss Equation to estimate annual soil degradation and the ability of land to retain sediment (Cabral et al. 2021).

For FoodSup, the ASEBIO supply values are binary, taking one if the land cover type is classified as an agricultural area in CLC, and zero if not. For Polli, Rec and WaterPur, the supplies are given as indices. For Polli, a crop pollination model based on pollinator prevalence was used for estimation. For Rec, an analysis of recreation capacity was created based on variables such as occurrence of protected areas, proximity to residential areas or the coast. For WaterPur, a nutrient retention model mapped the amount of nitrogen retained, depicting the estimated pollution prevention (Cabral et al. 2021).

The four non-ES-related variables encompass Lat, Inc, PopDen, and ProtectedAreas. Lat is the value of the latitude taken from the centroid of a given square, generated in QGIS. Inc is 2018 disposable household income in Centro region in current prices in euros (PT2018€) (OECD 2023). For PopDen, the logarithm of values from the Instituto Nacional de Estatística (n.d.) was considered. ProtectedAreas uses a map from the UNEP (2021) to determine if the majority of a 100x100m square overlaps with a protected area. If so, it takes the value 1, if not, it takes the value 0. The protected area map for 2018 was used for both years, as no map for the year 2000 was obtained. As mentioned above, the CLC codes were also included in the dataset as a variable. All these variables will be used to perform the benefit transfer of the value of ES that is derived from the meta-analytic approach.

For coastal and marine ES, a unit transfer was planned, where the ES coastal erosion prevention, food supply through fisheries (both are not specifically included in Seixo et al. (2023)), and tourism could have been economically valued. Given that Seixo et al. (2023) focused on land-based ecosystem services and there have been no other similar extensive studies for the region, it would have been more difficult to find data of comparable quality and attribute similarity that could have been applied for Centro in terms of coastal and marine EVES. However, the main obstacle is the fact that there is no data for supply levels of these marine and coastal ES in the region, which is why it would have required some primary research to estimate any economic value. Even though no economic estimates will be obtained, there will nonetheless be an examination of the change in the quantity and extent of those services, based on LULCC.

4.2. Methodology for 2018

For land-based ES in 2018, data provided by Seixo et al. (2023) derived from a meta-analytic benefit transfer function was employed, which already included the supply levels. Seixo et al. (2023) estimated EVES for the seven land-based ES in 2018 for the entire country of Portugal, a dataset made available for the underlying valuation. Hence, the provided supply data was cut to the Centro region using QGIS and plugged into the function for economic valuation, as described in the following subsection.

4.3. Methodology for 2000

To estimate the EVES of land-based ES in 2000, the supply of the individual ES for the given year had to be obtained first. The ES supply maps by ASEBIO (Cabral et al. 2021) provide the amount of an ES supplied as TIFF image files, which store images in high quality and with great detail. These supply maps are loaded into QGIS and vectorized to create polygons, a step that is required to ensure geometric analysis can be conducted with the data, leading to seven layers for the seven ES. Once this is done for all ES, all maps are clipped to the spatial extent of the Centro region. A grid made up of 100x100m squares is created, which is also clipped to the Centro region's extent. By loading all ES layers into that grid, the values of the seven supply maps are mapped per 100x100m square, providing a supply level per hectare per ES. In addition to the ES supply maps, a latitude value is assigned to every square, as well as a value for protected areas and a land cover type. To determine the land cover type, the aforementioned CLC data is used.

The grid-based data is then exported from QGIS as a CSV file, to which the income and population density values are added in Stata. Given that Centro has an area of 28.202 km^2, this leads to around 2.800.000 supply observations per year to be valued depending on the different characteristics.

After the supply has been mapped, the data necessary for the economic valuation is complete. For DrouReg and EroPrev, the EVES was conducted as per equation (1):

$$y_{ij}^{*} = q_{ij} * p_{ij} \tag{1}$$

where y_{ij}^{*} is the estimated value of an ES i at policy site j, q_{ij} is its supply, and p_{ij} is its price. For ClimReg, the same function was used, including an atomic conversion rate of 3.67 of carbon to carbon dioxide for the supply level.

For FoodSup, the supply map value takes 1 if it falls on agricultural areas. For Polli, Rec and WaterPur, the indexed supply levels were weighted to harmonize the monetary values derived from the transfer with the mean supply level of each ES within the context of Portugal (see Seixo et al. (2023)). By multiplying these weights by the corresponding supply of an ES, an adjusted supply level was generated, which was then plugged into a function of the form of equation (1) for these four ES.

FoodSup, Polli, Rec and WaterPur, the ES for which there were no available market prices, meta-analytic benefit transfer functions, as in equation (2) were used to conduct the EVES:

$$y_j^* = \alpha + v_k\beta_1 + x_k\beta_2 + r_k \tag{2}$$

where y_j^* is the estimated EVES at policy site j, v_k denotes the characteristics that are identical at the study and policy sites (e.g. land cover types as per CLC), x_k denotes attributes shared between the study and policy sites dependent on the specific ES under consideration (e.g. pollinator types, income, population density, share of agriculture in GDP), and r_k is the error term consisting of an i.i.d error term and a measurement error that tends to average out to 0 for a sufficient amount of data from study sites. The estimation was conducted with ordinary least squares (OLS). The meta-regression models' coefficient estimates (see Appendix III) were then plugged into the benefit transfer function to derive values for each land cover type that is present in the dataset.

5. RESULTS

Since LULCC is frequently used as a foundation to assess the economic value change of ES in a given region over time (Sieber et al. 2021), the first comparison performed within this thesis was between the total area that was occupied by the five land cover classes in 2000 and 2018, as can be seen in Figure 2 (see Appendix IV for values) Between the data for 2000 and 2018, there is a total difference of -671.69 ha or -0.02%, which can be linked to measurement inconsistencies.

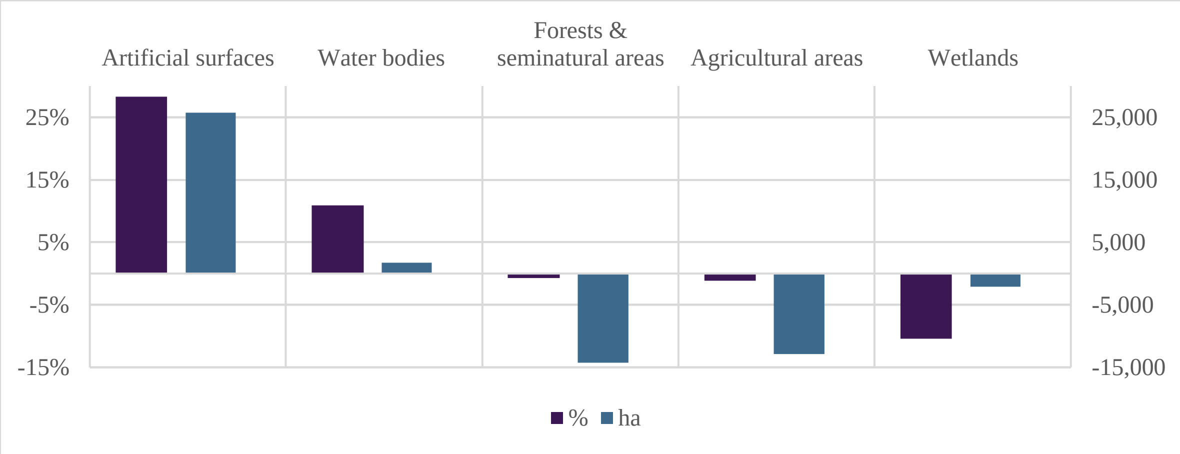

Figure 2: Land use change in Centro region between 2000 and 2018 by CLC category (in ha and %)

Broadly speaking, the CLC category with the highest registered growth is artificial surfaces with 28,26% or 25.755,54 ha of additional area between 2018 and 2000. The other class that witnessed an area increase is water bodies, with 10,88% or 1.731,44 ha. Unfortunately, due to missing data for the year 2000, the category water bodies does not comprise the sea and ocean, which explains the comparatively low values. The three classes showing an area decrease between 2000 and 2018 are agricultural areas, forests & seminatural areas, and wetlands, shrinking by 12.898,27 ha (-1,19%), 14.276,34 ha (-0,75%) and 2.082,43 ha (-10,40%) respectively.

Generally, since artificial areas predominantly include industrial and commercial units, continuous and discontinuous urban fabric, it is expected from these LULCC insights that the economic value of most ES should have decreased, due to a shrinking of natural ecosystems while artificial, human made fabric increased. When breaking down the five categories and looking at the more specific CLC codes (see Appendix V), the reason for this assumption becomes clearer. Of 11 CLC codes relating to artificial surfaces, all have increased except for the one associated with construction sites. Within agricultural areas half of the categories show an area increase, although the largest growth was identified in pastures at 19.487,29 ha, which relates to land used for fodder production (Copernicus 2018) and thus does not contribute to the FoodSup ES estimation. The other half saw a decrease in area, with non-irrigated arable land reducing by 22.857,37 ha. Regarding forests and seminatural areas, of the 12 land cover types all witnessed an area decrease except three of them. One of the three land cover types that increased is burnt areas, which almost tripled in size, the other two being moors and heathland (+66%), and transitional woodland-shrub (+59%). Thus, all types of forests (-30%), beaches, dunes, sands (-18%), and natural grasslands (-74%) shrunk in size, and glaciers and perpetual snow disappeared altogether. All types of wetlands, i.e. salines, salt marshes, inland marshes, and water courses, lost area between 2000 and 2018. Lastly, the water bodies CLC types estuaries and coastal lagoons both contracted by 14% and 22% respectively, while water bodies increased by 33%.

Nonetheless, when plugging this information into the benefit transfer functions to calculate the EVES per 100x100m square alongside the ES supply maps and the socioeconomic data, the results diverge from the anticipated decline of EVES for the majority of ES, as illustrated in Figures 3 and 4.

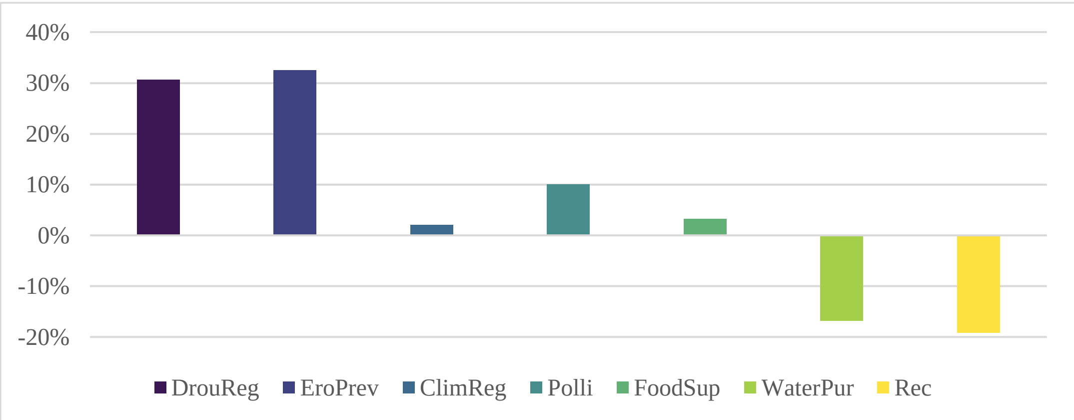

Figure 3: Percentage changes of the economic values per ES between 2000 and 2018

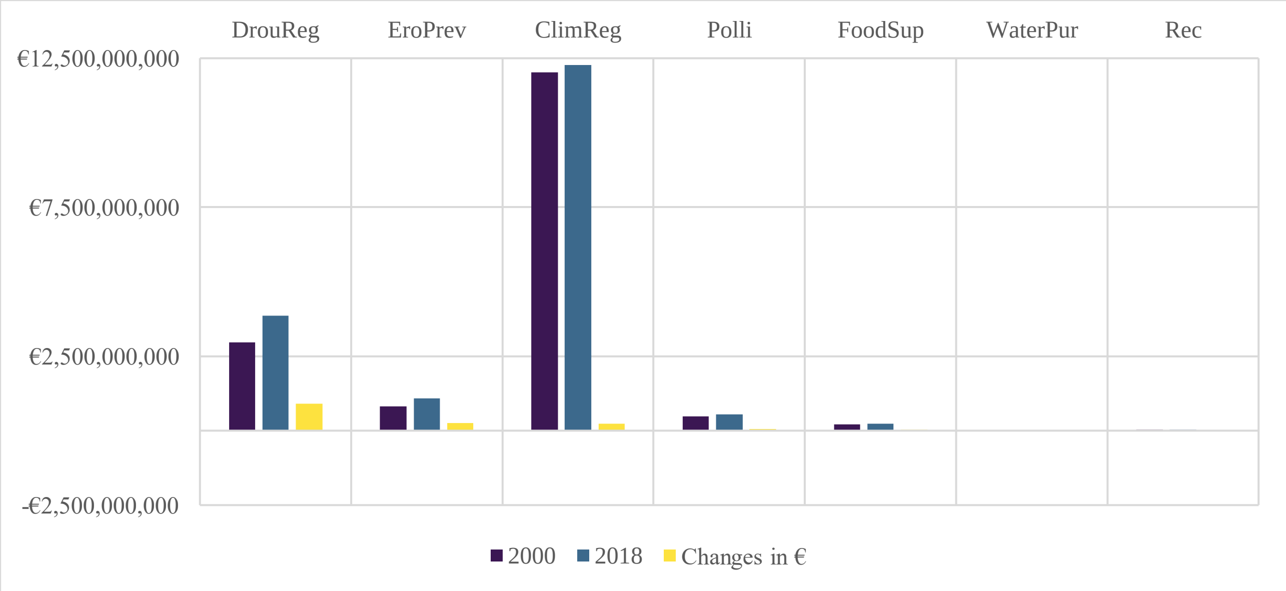

Figure 4: Economic values per ES in PT2018€

All estimates are given in PT2018€. Based on the results obtained, a few remarks are in order. Firstly, it is crucial to point out that the economic values of the seven ES are spread across a sizeable range. While the estimates for WaterPur remain below €1.000 for the entire region in both 2000 and 2018, the estimates for ClimReg surpass €12 billion in both years. However, the absolute values are of less importance in the context of this thesis, since the aim is to estimate the values' changes.

Secondly, the economic value of five of the seven ES increased in the period from 2000 to 2018, which are the five ES with the highest economic value according to the obtained estimates. Examining the market-price-based ES, the economic value of EroPrev increased by almost a third, i.e. €266.157.952,00, DrouReg rose by 30,62%, i.e. €904.443.392,00, and ClimReg by 2,03%, i.e. €244.405.248,00. Since these values were estimated by multiplying supply map values by market prices, the only factor contributing to the value changes is supply levels, which considers on CLC land use change. Thus, the values' increases are proportional to the growth in ES supply from 2000 to 2018. To exemplify, the supply of ClimReg, i.e. the amount of carbon dioxide sequestered in Centro, increased from 211.541.952t in 2000 to 215.838.432t in 2018.

The estimated economic values of the other four ES, based on the meta-analysis, witnessed less extensive percentual changes over the eight-year period. Polli experienced growth of exactly 10% amounting to €48.863.744,00. Simultaneously, the observed pollination potential experienced an 8% rise in supply, with additional emphasis placed on the expanding agricultural areas in the benefit transfer function. FoodSup increased by 3,24%, from €217.396.320,00 to €224.440.848,00, although the supply levels remained roughly the same. The only two ES that decreased in economic value are WaterPur and Rec. While the changes in monetary terms are by far the smallest, representing a decrease by €141,11 and €6.977,01, their percentage changes of 16,78% and 19,18% respectively are considerable.

With respect to coastal and marine ES, only few comments can be made without economic values. As previously mentioned, the area measured under CLC code "beaches, dunes, sands" decreased by 785,93 ha (18%), and coastal lagoons as well as estuaries also shrunk in size. Moreover, when looking at the EroPrev values along Centro's coast, the monetary values are low in comparison to the rest of the region. Finally, the values for FoodSup are also comparatively low along the coast, despite the value added by fisheries in the area. The ASEBIO FoodSup supply maps only take areas categorized as agricultural areas into account, which does not include marine ecosystems (Copernicus 2018).

6. DISCUSSION

Contrary to the anticipated decline of EVES inferred from the analysis of LULCC, most of the results from the estimation/meta-analytic benefit transfer are not aligned with those expectations. By only adapting the ES supply levels and the CLC codes per 100x100m square between the two years and holding all other variables constant, the goal was to estimate how land cover and supply level changes potentially affected the EVES. While it is possible that these results are accurate, there is reason to assume that they do not accurately depict the reality of EVES change between 2000 and 2018. Starting with ClimReg, one of the authors that contributed to the ASEBIO project coauthored another paper that estimated that the amount of carbon that can be stored by the land cover category forests and seminatural areas is around 17 times higher than that of artificial areas (Cabral et al. 2016). Given that, in absolute terms, those are the two categories that respectively lost and gained the largest amount of area between 2000 and 2018, it seems that the EVES ClimReg might have decreased.

Regarding DrouReg, the water supply levels also grew from 2000 to 2018, according to the supply maps. It seems unlikely for a water supply increase to be the case, considering that there have been severe droughts since the beginning of the century that have impacted the entirety of mainland Portugal. Moreover, a general decreasing trend in the annual amount of precipitation has been measured, while also observing a rise in heavy rainfalls (Schleussner et al. 2020). More profound research into the dynamics of water supply, precipitation and droughts in the Centro region would have to be conducted to assess the accuracy of the DrouReg EVES results.

In terms of EroPrev, the estimated economic value as well as the supply levels did not take the specific case of coastal erosion into account. The central Portuguese region is one of the areas that suffers the most from coastal erosion in Europe. In fact, some beaches show a coastline retreat of 7.1 meters annually between 2000 and 2018 (Magalhães Filho, Roebeling, and Coelho 2023). The CLC data from the results above also identified a decrease in beaches, dunes, and sands. Thus, an accurate comparison of the EVES of EroPrev in Centro region could be considered incomplete without taking this factor into account

The EVES and supply levels for both Polli and FoodSup grew, despite agricultural areas shrinking. The economic value of FoodSup is only estimated for those 100x100m squares that fall into the CLC category agricultural areas, and the economic estimates of Polli are higher in those areas. Thus, a decline in both values would have been anticipated. Given that their supply levels increased according to the ASEBIO supply maps, there might be some other factor that affected their supply to become higher or more productive. As shown by Wentling et al. (2021), pollinator abundance increased in vast parts of Centro region between 1990 and 2018, which could explain the higher Polli EVES level in 2018. One crucial approach to expand the valuation of FoodSup to marine ecosystems would be to include fish supply. According to an OECD (2021) report on fisheries and aquaculture in Portugal there has been a downwards trend, where "the quantity produced decreased by 18%, while its value decreased by 5%" from 2008 to 2018. Including these estimates in the economic valuation of FoodSup would add to a more holistic and informed estimation of the economic values provided by this ES.

In line with the previously stated expectations, the results depict a decrease in the values for Rec and WaterPur. However, as laid out by Seixo et al. (2023), differences in land cover are not statistically significant, implying that the negative change is unlikely to be linked to LULCC. For WaterPur, the covariate income is statistically significant at a 1% level with a positive impact. Primary WTP studies from the literature mirror similar results, since an increase in income typically leads to higher disposable income available for conservation measures (Meyerhoff, Boeri, and Hartje 2014). Moreover, population density is also statistically significant at a 1% level for both Rec and WaterPur. Given that Centro does not have many densely populated areas, the values for Rec and WaterPur are likely to be lower there than in other, more densely populated areas of the country. This stems from the fact that people tend to have a higher WTP to ensure the provision of the ES recreation and water purification when their quality is comparatively low, which is more common in densely populated areas (Meyerhoff, Boeri, and Hartje 2014).

To conclude, it is important to stress that the results obtained from the LULCC analysis must be handled with care. In this case, it might be incorrect to conclude that the economic values of some ES increased in light of e.g. growing artificial areas and decreasing forests and seminatural areas. However, it is more likely that other factors led to the unexpected increase in EVES. Since the supply value increases in the periods from 2000 to 2018 in line with the increase in economic values, a positive correlation between the two is certain for the market-based ES and likely for the meta-analysis-based ES.

There are several limitations inherent to the chosen method for this analysis. To start on a general note, it is important to point out the limitations that come with the usage of benefit transfers to economically value ES. While benefit transfers are common in EVES, and meta-analyses are considered the most sophisticated version thereof, a benefit transfer is unlikely to achieve the same level of accuracy that could be obtained by location-specific primary research (OECD 2018). However, as previously mentioned, time, monetary and data resources are too scarce for it to be employed in the underlying case. Using the meta-analytic data is thus the closest approximation to the actual state of the EVES in Centro identified for the purpose of this thesis.

Another limitation lies in the selection of the ES values, which was strongly influenced by the ones chosen by Seixo et al. (2023), given that those were the ES most detailed data was available for. There would have been a large quantity of other terrestrial ES to choose from, including but not limited to habitat quality, natural resources, and disease prevention. Moreover, the original plan was to include the ES coastal erosion prevention, marine food supply and coastal and marine tourism in the overall EVES in Centro. While the level of detail would have been significantly lower than the detail from the Seixo et al. (2023) data, it could have added estimated values to make the value these ES provide to the Portuguese economy more visible. Nonetheless, since no data for the supply of these ES was identified through data research, they were left out of the valuation. The assumption is that adding any ES to the valuation process would have increased the total value, but it cannot be said how adding them would have affected the change of total values between 2000 and 2018.

The estimation for the year 2000 was performed based on the calculations and values provided by Seixo et al. (2023), the only difference being the change of the corresponding supply maps. Thus, there are significant limitations and different assumptions made in the comparison of the estimated values between the two years. First, by not changing value for population density, thus assuming it remained constant over the given timespan, the effect of socioeconomic changes on EVES is lost. A lack of accounting for this will inhibit the valuation from e.g. portraying the pressure that fluctuating population density puts on demand for water purification (Shi et al. 2022). The population density variable is only considered for Rec and WaterPur. Thus, any changes to the values used would only affect those to EVES. When conducting a univariate sensitivity analysis and increasing the log population density value by 15%, the result is an increase in the value for WaterPur in 2000 from €840,84 to €856,95 i.e. an increase of around 10,2%. In the total EVES for all seven ES, this change would not have had a sizeable impact.

Secondly, by not adapting the market values of the ES ClimReg, DrouReg and EroPrev, the underlying assumption is that their market value in 2000 was identical to the one in 2018, at the 2018 price level. While the lower level of accuracy inherent to this limitation is acknowledged, the root of the decision to leave them unchanged is the lack of time resources for this thesis. If they had been adapted, any increase/decrease in the market prices would have led to a proportional increase/decrease in the values of the respective ES. For example, looking at ClimReg, the EVES is based on the EU ETS price, which is partially dependent on income levels in Europe. Income levels as well as awareness of the issue typically have a positive influence on WTP for ES such as climate regulation (Baumgärtner et al. 2017). Assuming an income and climate crisis awareness increase from 2000 to 2018, this would lead to a lower hypothetical EU ETS price for 2000 than for 2018. Had the price been adapted appropriately, the growth in the economic value of ClimReg would have been proportionally larger.

Finally, with respect to the meta-analytically generated ES FoodSup, Polli, Rec and WaterPur, the year 2000 was chosen as a cut-off point by Seixo et al. (2023) to prevent inconsistencies arising from changes over an extended timespan. The main alteration to potentially increase the accuracy of the values would be to include primary studies from before 2000 in the analysis. Nevertheless, the decision to use the same values generated Seixo et al. (2023) was made due to time constraint on the one hand, and due to the limited amount of methodically sound EVES studies conducted before the cut-off year (Lele et al. 2013).

To further build on the analysis conducted within the scope of this paper, there is an array of options. For one, to break down the aggregated values for the entirety of Centro region, a potential expansion of the analysis could disaggregate the data used to evaluate EVES changes per subregion. This would highlight which areas might benefit the most from EBM efforts and NbS.

Most crucially, there should be an expansion of this analysis to the economic valuation of coastal and marine ES. While the necessary data to do so was not acquired within the scope of this thesis, an estimation of ES supply values for marine and coastal ES would prove essential to evaluate the economic value increase or decline in the 2000 to 2018 timespan. By assessing both the supply levels as well as the economic value of the considered ES, appropriate EBM tools and NbS could be identified along with geographic areas in which to implement them.

7. CONCLUSION

This thesis contributes to ongoing research by providing a comparison of the estimated total economic value for seven ES in Centro region between 2000 and 2018, based on spatially explicit supply maps on the one hand, and market prices or meta-analytic benefit transfer functions on the other hand. The seven ecosystem services chosen include climate regulation, drought regulation, erosion prevention, food supply, pollination, recreation, and water purification. LULCC from satellite data provided by CLC, as well as supply maps provided by the ASEBIO project are used as the underlying means to measure those changes.

The results from the LULCC show a decrease in the total area occupied by natural ecosystems, leading to the expectation that an economic valuation of these ES would result in a decrease in the total estimated economic value. Nonetheless, the estimated values show an increase for climate regulation, drought regulation, erosion prevention, food supply and pollination. This anomaly is likely to stem from the increase in supply values according to the ASEBIO supply maps. The estimates increased for recreation and water purification, as was expected.

Methodological limitations of the underlying analysis include the lack of primary research for the specific geographical region, as well as using (adjusted) data from the year 2018 for market prices, population density, protected areas, and other variables. Another significant limitation is posed by restricting the estimation of the economic value to terrestrial ES, resulting in the economic value of coastal and marine ES in Centro region remaining invisible.

The underlying research and results can be expanded on and used for multiple purposes. These include but are not limited to (1) breaking down the values estimates to evaluate EVES changes per subregion, (2) identifying appropriate NbS and EBM approaches for the region, and (3) including coastal and marine ES in the estimation.

In conclusion, the underlying thesis contributes to the bigger aim of incorporating natural capital and the economic value provided by ecosystems into decision-making and planning processes. While the results do not clearly underscore the benefit of protecting and conserving nature for economic purposes in Centro region, they do show that natural areas are decreasing, and artificial areas are growing. By including more ES, primary data, and the marine domain in future estimations and research, clearer conclusions could potentially made with regards to the appropriate choice of conservation and other ecologically economic measures.

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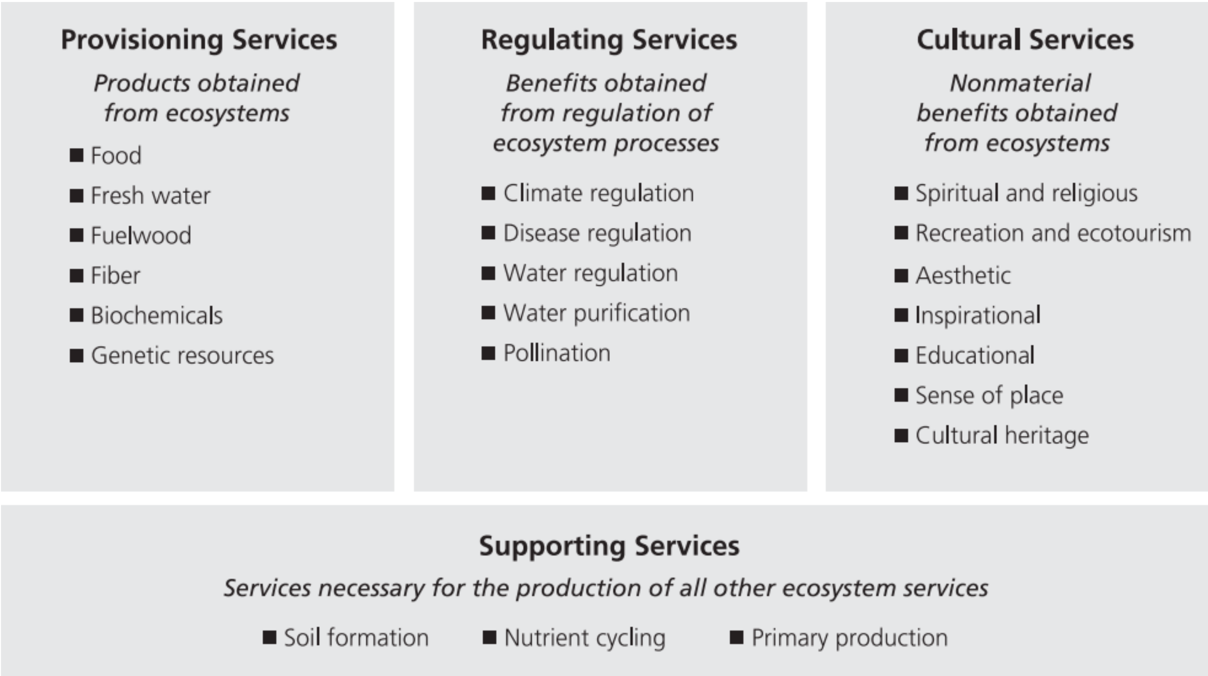
APPENDIX

Appendix I



Categories of ecosystem services incl. examples (MEA 2003)

Appendix II

Artificial surfaces	111	Continuous urban fabric
	112	Discontinuous urban fabric
	121	Industrial or commercial units
	122	Road and rail networks and associated land
	123	Port areas
	124	Airports
	131	Mineral extraction sites
	132	Dump sites
	133	Construction sites
	141	Green urban areas
	142	Sport and leisure facilities
Agricultural areas	211	Non-irrigated arable land
	212	Permanently irrigated land
	213	Rice fields
	221	Vineyards
	222	Fruit trees and berry plantations
	223	Olive groves
	231	Pastures
	241	Annual crops associated with permanent crops
	242	Complex cultivation patterns
	243	Land principally occupied by agriculture
	244	Agro-forestry areas
Forest & seminatural areas	311	Broad-leaved forest
	312	Coniferous forest
	313	Mixed forest
	321	Natural grasslands
	322	Moors and heathland
	323	Sclerophyllous vegetation
	324	Transitional woodland-shrub
	331	Beaches, dunes, sands
	332	Bare rocks
	333	Sparsely vegetated areas
	334	Burnt areas
	335	Glaciers and perpetual snow
Wetlands	411	Inland marshes
	421	Salt marshes
	422	Salines
	423	Intertidal flats
	511	Water courses
Water bodies	512	Water bodies
	521	Coastal lagoons
	522	Estuaries
	523	Sea and ocean

CORINE Land Cover nomenclature (Copernicus 2018)

Appendix III

	FoodSup[1]		*Polli*[2]		*Rec*[3]		*WaterPur*[4]	
CLC Level 2[a]								
Heterogeneous Agricultural Areas	-1.153	(1.263)	0.904	(1.261)				
Pastures	-.107	(0.664)						
Permanent Crops	-1.273**	(0.483)	5.018***	(0.56)				
Artificial non-agriculture vegetated areas					-4.266	(2.447)		
Inland Waters					-5.086**	(-0.471)		
Marine Waters					-1.25	(5.782)		
Open Spaces with Little or no Vegetation					-6.727	(1.933)		
CLC Level 3[b]								
Estuaries							-0.24593	(1.17185)
Inland Marshes							-0.76978	(0.96562)
Sea and Ocean							0.62926	(1.47252)
Water Courses							-1.43333	(0.95052)
Geographic Attributes								
Protected Areas	1.019	(**0**.653)	3.444***	(0.819)	-6.022***	(1.397)	0.94862	(0.61719)
Temperate Broadleaf & Mixed Forests	-0.817	(1.299)	**c**		0.284**	(6.131)	0.09179	(1.01017)
Asia	1.516	(**1**.942)	2.152*	(1.085)	-5.189	(7.078)	3.50486*	(2.07211)
Europe	-0.631	(0.62)	3.66	(2.76)	-7.418	(2.001)	1.62223	(1.28717)
Oceania	**d**		**d**		-10.556	(1.961)	1.37766	(1.48271)
Latitude	**e**		-0.072	(0.094)	0.125	(0.088)	**e**	
Ecosystem Service Specific Attributes								
Log of Agriculture Share of GDP	-2.028*	(1.041)						
Organic share of total farming area	-5.208	(4.805)						
Natural pollinators			-2.033	(2.303)				
Honeybee			-3.89***	(0.832)				
Native Bee			-.903	(1.907)				

Wild Insects			-4.96***	(0.75)				
Income							0.0002***	(0.00004)
Log Population Density					0.063**	(0.595)	0.843***	(0.12965)
Constant	-1.138	(3.279)	5.048	(4.188)	-19.774*	(1.457)	-14.03912***	(2.5037)

**** p<.01, ** p<.05, * p<.1*
Robust SEs are reported in parentheses
1: Baselines are Arable Land; Non-protected Areas; Mediterranean Forests, Woodlands & Shrubs; America.
2: Baselines are Arable Land; Non-protected Areas; America; Bumblebees.
3: Baselines are Forests; Non-protected Areas; Mediterranean Forests, Woodlands & Shrubs; America.
4: Baselines are Water Courses; Non-protected Areas; Mediterranean Forests, Woodlands & Shrubs; America.
a: FoodSup, Polli and Rec were estimated using CLC level 2 data.
b: WaterPur was estimated using CLC level 3 data.
c: The inclusion of this variable in the model generated collinearity problems.
d: Observations from Oceania were not available in the FoodSup and Polli services´ metadatabase.
e: The inclusion of this variable in the model generated misspecification problems.

Estimates of meta-regression model (Seixo et al. 2023)

Appendix IV

LULCC in Centro Region between 2000 and 2018

	2000 Area in *ha*	2018 Area in *ha*	Changes in *ha*	Changes in %
Artificial surfaces	91.124,87	116.880,41	25.755,54	28,26%
Water bodies	15.906,80	17.638,24	1.731,44	10,88%
Forests & seminatural areas	1.906.703,61	1.892.427,27	- 14.276,34	- 0,75%
Agricultural areas	1.087.069,76	1.074.171,48	- 12.898,27	- 1,19%
Wetlands	20.017,70	17.935,27	- 2.082,43	- 10,40%

Appendix V

Changes in the economic values of the seven ES between 2000 and 2018 (in 2018€)

	2000 Value in PT2018€	2018 Value in PT2018€	Changes in PT2018€	Changes in %
EroPrev	€819.371.904,00	€1.085.529.856,00	€266.157.952,00	32,48%
DrouReg	€2.953.958.656,00	€3.858.402.048,00	€904.443.392,00	30,62%
Polli	€488.621.440,00	€537.485.184,00	€48.863.744,00	10,00%
FoodSup	€217.396.320,00	€224.440.848,00	€7.044.528,00	3,24%
ClimReg	€12.033.563.648,00	€12.277.968.896,00	€244.405.248,00	2,03%
WaterPur	€840,84	€699,73	- €141,11	- 16,78%
Rec	€36.381,62	€29.404,61	- €6.977,01	- 19,18%
TOTAL	**€16.512.949.190,46**	**€17.983.856.936,35**	**€1.470.907.745,89**	**8,91%**