An indicator-based approach to analyse the effects of non-native tree species on multiple cultural ecosystem services

Ana Sofia Vaz[a,b,*], Pilar Castro-Díez[c], Oscar Godoy[d], Álvaro Alonso[c], Montserrat Vilà[e], Asunción Saldaña[c], Hélia Marchante[f,g], Álvaro Bayón[e], Joaquim S. Silva[a,g,h], Joana R. Vicente[a,i], João P. Honrado[a,b]

[a]Research Network in Biodiversity and Evolutionary Biology, Research Centre in Biodiversity and Genetic Resources (InBIO-CIBIO), Universidade do Porto, Campus Agrário de Vairão, Rua Padre Armando Quintas, PT4485-661 Vairão, Portugal
[b]Faculdade de Ciências, Universidade do Porto, Rua do Campo Alegre, s/n, PT4169-007 Porto, Portugal
[c]Departamento de Ciencias de la Vida, Unidad Docente de Ecología, Facultad de Biología, Ciencias Ambientales y Química, Universidad de Alcalá, E-28805, Alcalá de Henares, Spain
[d]Instituto de Recursos Naturales y Agrobiología de Sevilla (IRNAS-CSIC), E-41080 Sevilla, Spain
[e]Department of Integrative Ecology, Estación Biológica de Doñana (EBD-CSIC), Avda. Américo Vespucio 26, Isla de la Cartuja, E-41092 Sevilla, Spain
[f]Centre for Functional Ecology, Department of Life Sciences, University of Coimbra, Calçada Martim de Freitas, 3000-456, Coimbra, Portugal
[g]Escola Superior Agrária, Instituto Politécnico de Coimbra, Bencanta, 3045-601, Coimbra, Portugal
[h]Centre for Applied Ecology "Prof. Baeta Neves" (InBIO-CEABN), Instituto Superior de Agronomia, Universidade de Lisboa, Tapada da Ajuda, PT1349-017 Lisboa, Portugal
[i]Laboratory of Applied Ecology, CITAB – Centre for the Research and Technology of Agro-Environment and Biological Sciences, University of Trás-os-Montes e Alto Douro, Vila Real, Portugal

*Corresponding author: asofia.vaz@fc.up.pt
Email addresses: P. Castro-Díez: mpilar.castro@uah.es; O. Godoy: ogodoy@irnas.csic.es; A. Alonso: alvaro.alonso@uah.es; M. Vilà: montse.vila@ebd.csic.es; A. Saldaña: asuncion.saldana@uah.es; H. Marchante: hmarchante@gmail.com; Á. Bayon: alvarobayon@gmail.com; J. S. Silva: jss@esac.pt; J. R. Vicente: jsvicente@fc.up.pt; J. P. Honrado: jhonrado@fc.up.pt

Abstract

Limitations in the assessment of cultural ecosystem services through objective and quantifiable approaches have constrained our knowledge of how these services can be determined by drivers of global change, such as non-native tree species. Here, we address this caveat by evaluating the effects of non-native tree species, in comparison to native ones, on several categories of cultural services (recreation and ecotourism, aesthetics, inspiration, and cultural heritage). We propose an indicator-based approach that includes the use of a meta-analysis statistics, the odds ratio, to evaluate photographic, internet and catalogue data, and infer on the effects of non-native trees on cultural services. We apply our approach to the Iberian Peninsula, exploring potential environmental and socio-economic predictors of non-native tree effects across NUTS-2 administrative regions. Overall, non-native trees presented contrasting effects within and among categories of cultural services. For recreation and ecotourism, results varied with the data type: positive effects on information systems of official tourism entities, but negative effects on nature route users. For aesthetics, non-native trees contributed positively to inventories of urban parks, but negatively to catalogues of ornamental plant dealers in Portugal, in contrast to Spain. Non-native trees also showed positive effects on cultural heritage, but no significant effects were observed on inspiration services. The magnitude of positive effects of non-native trees was higher in regions with lower levels of development (in terms of income, employment and education) and of life satisfaction. We suggest that management should emphasise awareness on non-native trees, including the risks involved in promoting the expansion of potentially invasive species. Efforts to raise awareness should prioritise official tourism entities and ornamental plant dealers, with a special focus on less developed regions. Our proposed approach represents a step forward to quantify non-native tree effects on cultural ecosystem services and to support strategic management. The focus on widely available data sources enables reproducibility and application in assessments worldwide.

Highlights

We assessed the effects of non-native trees on cultural ecosystem services
The proposed approach was applied at the regional scale in Portugal and Spain
Effects were service- and country-dependent, varying along different predictors
The results elucidate important relations to support informed management
The approach can be extended to other geographical areas and environmental challenges

Keywords

Aesthetics; alien plants; cultural heritage; inspiration; meta-analysis; recreation and ecotourism

1. Introduction

The growing recognition of nature's contributions to human well-being has fostered research on ecosystem services (Blicharska et al. 2017; MEA 2005; Schröter et al. 2016). Besides provisioning (e.g., drinking water, secure food) and regulating (e.g., hazard mitigation, pollination) services, ecosystems also provide cultural services. The *Millennium Ecosystem Assessment* (MEA 2005; p. 40) defines cultural ecosystem services as the "*nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences"*, including inspiration and cultural heritage values (see also Chan et al. 2012; Fish et al. 2016).

Cultural ecosystem services are highly important in various governance contexts, such as land tenure and management, recreation revenues, and human identity and traditions (Carruthers et al. 2011; Plieninger and Bieling 2012). However, difficulties in the assessment of cultural services, arising mostly from their subjectivity and difficult quantification, have hampered their application in decision-making (Chan et al. 2012; Fish et al. 2016; Schröter et al. 2016). Examples of emerging methodological approaches to asses cultural services include: the use of historical records and vegetation mapping to obtain quality indices of landscape aesthetics or heritage (e.g., Tengberg et al. 2012); public opinion polls to identify cultural benefits (e.g., Poe et al. 2016); monetary evaluations of ecosystem properties (e.g., van Berkel and Verburg 2014); and consideration of ecosystem features per se as surrogates of cultural services (e.g., birds, coloured flowers; Soliveres et al. 2016). The use of social media, namely photographic and internet information, has also been suggested as a promising approach (e.g., Oteros-Rozas et al. 2017). Coupled with traditional data sources (e.g., land cover), social media data can offer novel insights on human-nature relations (Figueroa-Alfaro and Tang 2017).

Understanding how cultural services may be altered by social-ecological drivers of global change, such as the occurrence of non-native tree species, is a challenge requiring attention (Hernández-Morcillo et al. 2013; Milcu et al. 2013; Oteros-Rozas et al. 2017). Non-native trees can be defined as tree species that were introduced by humans to new geographic areas (Richardson and Rejmánek 2011). Non-native trees have been introduced for various purposes, mainly wood production, landscape restoration, and ornamental values (Dickie et al. 2014; Kueffer and Kull 2017; Kull et al. 2011). They provide key resources worldwide, supporting daily basic needs of local communities and economic revenue from forestry and agro-forestry systems (Kull et al. 2011; Vaz et al. 2017a).

Several environmental factors influence the performance and impacts of non-native trees in introduced areas (Brundu and Richardson 2016; Carruthers et al. 2011). Climate and land cover, among others, shape habitat conditions that may constrain or promote non-native tree occurrence and performance (Richardson et al. 2014; van Wilgen et al. 2011; Vicente et al. 2016), and thus their potential for altering ecosystem services. For example, the aesthetic value of non-native trees is influenced by their occurrence, abundance and physiology (Kueffer and Kull 2017), which are ultimately determined by environmental conditions (Richardson et al. 2014; Vicente et al. 2016).

Non-native trees can also trigger undesirable effects on ecosystem services, especially when spreading outside plantations and becoming invasive (Brundu and Richardson 2016; Krumm and Vítková 2016; Vilà and Hulme 2017). Many studies have highlighted the effects of non-native trees on provisioning and regulating services, from deregulation of soil and water services, to promotion of wildfires and competition with service-provider native species (e.g., Castro-Díez et al. 2014a; Carruthers et al. 2011; Dickie et al. 2014). However, compared to other types of ecosystem services, effects on cultural services have seldom been investigated (Kueffer and Kull 2017; Vilà and Hulme 2017).

It has been suggested that the cultural value of non-native trees depends on visual attributes, such as landscape monotony and homogenisation (e.g., large plantations or invasions) or “out-of-normal” and “exotic” features (e.g., large leaves, colourful flowers; Kueffer and Kull 2017). Non-native trees have also been valued as historical or scientific assets (e.g., from overseas expeditions; Carruthers et al. 2011; Crews 2003). Most research so far has focused on narratives related to heritage, folklore and tradition (e.g., Carruthers et al. 2011; Kueffer and Kull 2017; Kull et al. 2011). Examples include the use of non-native species as monumental trees in Italy (Asciuto et al. 2015); the adoption of *Eucalyptus* species in South Africa, *Pinus* species in New Zealand, and *Rhamnus* and *Salix* species in Australia for leisure activities (Dickie et al. 2014); or the use of *Acacia* species in South Africa for cultural ceremonies (Kull et al. 2011).

The cultural value of non-native trees depends on socio-economic (e.g., education, market values) and welfare factors that influence human perceptions, judgements and attitudes towards these species (Brundu and Richardson 2016; Krumm and Vítková 2016). For instance, wealthy countries are more likely to foster the trade and maintenance of non-natives (also Humair et al. 2015; Vilà and Pujadas 2001), and thus their association to cultural services. Education and awareness also influence the way non-native species, and respective cultural services, are perceived by people (Carruthers et al. 2011; Kueffer and Kull 2017). Understanding the interactions between non-native trees and cultural services across relevant environmental and socio-economic factors could contribute to better management (Dickie et al. 2014; Vaz et al. 2017a). Specifically, it could help in weighting and deliberating risks and opportunities associated to non-native trees (Carruthers et al. 2011; Kueffer and Kull 2017), while converging with sustainability goals and human well-being (Ghosh and Traverse 2005; Vaz et al. 2017b).

The Iberian Peninsula (Portugal and Spain) has been the target of many introductions of non-native tree species. Some of these species are restricted to urban areas as ornamentals e.g., *Jacaranda mimosifolia* D.Don, but many others, such as *Ailanthus altissima* (Mill.) Swingle (tree of heaven), *Eucalyptus globulus* Labill. (tasmanian blue gum), *Acacia longifolia* (Andrews) Willd. (long-leaved wattle), *Pinus radiata* D. Don (monterey pine), *Pseudotsuga menziesii* (Mirb.) Franco (douglas fir), *Quercus rubra* L. (red oak) and *Robinia pseudoacacia* L. (black locust), have become widespread (e.g., Castro-Díez et al. 2014a; Sanz Elorza et al. 2004; Vicente et al. 2016). Concern on non-native tree species (either planted, naturalised or invasive) is growing, as they can compete with native biodiversity and alter provisioning and regulating services (e.g., soil structure development, litter decomposition, nutrient cycling; Castro-Díez et al. 2014b; Godoy et al. 2010; Morais et al. 2017; Vicente et al. 2016). However, to our knowledge, no studies have assessed how non-native tree species affect cultural services in Iberia.

In this study, we propose an indicator-based approach to evaluate the effects of non-native trees on recreation and ecotourism, aesthetics, inspiration and cultural heritage (MEA 2005). The approach includes the use of a meta-analysis statistics, the odds ratio, to evaluate photographic, internet and catalogue data types considered as relevant to infer on the effects of non-native trees in cultural ecosystem services. We apply the proposed approach at the regional level in the Iberian Peninsula (i.e., NUTS-2 administrative regions in Portugal and Spain). We compare the effects of non-native trees between countries, and test the observed regional variations against predictors related to land cover and management, socio-economy, human well-being, and climate. We explore the results for Portugal and Spain in the context of land management. Finally, we discuss the reproducibility and scalability of our indicator-based approach as well as its application to other social-ecological challenges.

2. Material and methods

2.1. Data collection

2.1.1. Non-native and native tree species

We compiled information on the occurrence and abundance (represented as cover area) of non-native and native tree species in NUTS-2 administrative regions (Eurostat 2015a) of the Iberian Peninsula (southwest Europe). We focused on Continental Portugal (15 % of Iberian land area) and Spain, including the Balearic Islands (85 % of land area). We considered the whole naturalization-invasion continuum of tree species in both countries (including planted, naturalised and invasive species; Richardson and Pysek 2006). Archeophytes and hybrids between non-native and native species were not considered. The lists of non-native trees were obtained from Almeida and Freitas (2006) for Portugal, and from Sanz Elorza et al. (2004) for Spain. The lists of native species were obtained from ICNF (2013a) for Portugal, and from Cela et al. (2013) for Spain.

In total, we considered 159 non-native and 55 native tree species for Portugal; and 266 non-native and 65 native tree species for Spain. Species nomenclature followed Castroviejo et al. (1986-2010), and was updated following The Plant List (2013). For Portugal, the area covered by non-native and native trees was obtained from the National Land Cover Map - COS 2007 (DGT 2017), and complemented with information from the sixth National Forest Inventory (ICNF 2013b). For Spain, the cover area was obtained from the third National Forest Inventory - IFN3 1997-2007 (MAPAMA 2014) and complemented with information from Beltrán et al. (2013). Details on the lists of non-native and native tree species, and on cover areas are shown in Appendices A and B, respectively (Supplementary material).

2.1.2. Cultural ecosystem services

Grounded on the *Millennium Ecosystem Assessment* (MEA 2005), we considered four categories of cultural ecosystem services: recreation and ecotourism, aesthetics, inspiration and cultural heritage. Although other typologies for cultural services are available (e.g., *Common International Classification of Ecosystem Services*), we followed the MEA typology to allow comparability of our results with previous research on cultural services (Hernández-Morcillo et al. 2013; Milcu et al. 2013). For each category of cultural services, we focused on distinct data types and sources. These were selected through a participatory approach implemented under the Cost Action FP1403: *Non-native tree species for European forests - experiences, risks and opportunities* (http://nnext.boku.ac.at/). It involved several academics worldwide as well as literature reviews and consultation with external experts. The selection of data types and sources relied on their cost- and time-efficiency, availability, ease of dissemination and coverage across countries worldwide.

Our dataset was obtained through the systematic screening of photographic, internet and catalogue information (following e.g. Hernández-Morcillo et al. 2013; Figueroa-Alfaro and Tang 2017; Oteros-Rozas et al. 2017). For recreation and ecotourism, we focused on two data types: tourism information systems and nature routes. For tourism information systems, data sources comprised official websites of regional tourism. For nature routes, data sources included online nature routes from the “wikiloc” application (http://www.wikiloc.com). In each data source, we counted the number of photographs dominated by non-native or native trees. We used a minimum threshold of 50 % coverage of a tree to be considered as dominant in the photograph. Aesthetics were evaluated from two data types: catalogues of ornamental plants (online and printed catalogues of local plant dealers), and tree inventories of urban parks (available on the web, books, municipality archives, in-situ panels, and personal surveys). In each data source, we counted the number of non-native and native trees. Inspiration services were assessed from collective websites on nature photography for which the location of each photograph was provided. We counted the number of photographs in which non-native or native trees were dominant. Finally, for cultural heritage we counted the number of non-native and native trees indicated in the official lists of monumental tree species of Portugal and Spain.

All data were prior to year 2016 and considered as representative of each one of the 21 NUTS-2 regions of the Iberian Peninsula. More information on data types and respective sources is shown in Table 1, and further details are provided in Appendix C (Supplementary material).

Table 1. Categories of cultural ecosystem services considered, with their respective data types and rationale. The number of data sources (n) considered for each data type is shown. The table also describes the components (A-D: equations 1-6) of the indicator proposed for evaluating non-native tree effects on cultural services (see section 2.2. Data analyses).

		Components of the indicator			
Data types	**Rationale**	**Amount of non-native trees in the service (A)**	**Amount of native trees in the service (B)**	**Amount of non-native trees in the region (C)**	**Amount of native trees in the region (D)**
Recreation and ecotourism					
Tourism information (n = 21)	Photographs from tourism websites have the potential to attract tourists	Number of photographs dominated by non-native trees	Number of photographs dominated by native trees	Cover of non-native trees in the region	Cover of native trees the region
Nature routes (n = 161)	Geo-referenced nature routes shared with the public translate society preferences for recreation	Number of photographs dominated by non-native trees	Number of photographs dominated by native trees	Cover of non-native trees in the region	Cover of native trees in the region
Aesthetics					
Catalogues of plant dealers (n = 28)	Tree species offered by plant dealers are appreciated mostly by ornamental values	Number of non-native tree species offered in catalogues	Number of native tree species offered in catalogues	Total number of non-native tree species in the country	Total number of native tree species in the country
Urban parks (n = 45)	Trees exhibited in urban parks are selected mostly based on their aesthetics	Number of non-native tree species present in inventories	Number of native tree species present in inventories	Total number of non-native tree species in the country	Total number of native tree species in the country
Inspiration					
Nature photographs (n = 12)	Artistic photographs reflect the choice of inspiring motifs from nature	Number of photographs dominated by non-native trees	Number of photographs dominated by native trees	Cover of non-native trees in the region	Cover of native trees in the region
Cultural heritage					
Monumental trees (n = 21)	Monumental trees are symbols of human culture, sense of place, and history	Number of non-native tree species present in the list	Number of native tree species present in the list	Cover of non-native trees in the region	Cover of native trees in the region

2.1.3. Environmental and socio-economic predictors

Based on previous knowledge and data availability, a first set of 24 predictors was considered to explain the observed variations of effects of non-native trees on cultural services. The predictors expressed regional patterns of land cover and management, socio-economy, human well-being and climate across the Iberian Peninsula. Land cover and management predictors derived from governmental data and cartography (ICNF 2013b, for Portugal; MAPAMA 2014, for Spain). Socio-economic predictors were obtained from Eurostat (2015b), with the human influence index being obtained from WCS and CIESIN (2005), and the development index from Hardeman and Dijkstra (2014). Human well-being indicators were derived from the OECD regional well-being indices (OECD 2013). The mean values of climatic predictors per region were calculated from maps of the "Iberian Climate Atlas" (Ninyerola et al. 2005), using ArcGIS 10.1 (ESRI 2012).

All continuous predictors were tested for pair-wise correlations using the non-parametric Spearman test. We excluded 12 predictors from subsequent analyses, due to correlation values above 0.60 when tested against the remaining predictors (Quinn and Keough 2002). The final set of considered predictors is shown in Table 2. Details on all predictors and on correlation tests can be found in Appendix D and E, respectively.

Table 2. Final set of predictors used to explain the variation of effects of non-native tree species on cultural ecosystem services across Iberian NUTS-2 regions.

Code	**Predictors**
Land cover and management (Vilà and Pujadas 2001; Vicente et al. 2016)	
Forests	Proportion of forest area
Protected areas	Proportion of protected areas
Socio-economy (Vilà and Pujadas 2001; Krumm and Vítková 2016)	
Country	The country where the data sources were located (Portugal or Spain)
Tourism	Number of arrivals at tourist accommodation establishments
Development	EU regional human development index (based on life expectancy, mortality, education, income, and employment)
Impact	Global human influence index (based on human settlement, accessibility, landscape transformation, and electric power infrastructures)
Human well-being (OECD 2013; Ghosh and Traverse 2005; Vaz et al. 2017a)	
Life	Life satisfaction, a subjective well-being index of how people evaluate their life (based on citizens' questionnaires)
Jobs	Job availability, a well-being index of material conditions (based on both employment and unemployment % rates)
Housing	Housing, an index of material conditions for well-being (based on the % ratio of the number of rooms per person)
Environment	Environmental quality, an index of human life quality (based on the estimated average exposure to air pollution in PM2.5 µg/m)
Climate (Gassó et al. 2009; Vicente et al. 2016)	
Temperature	Minimum temperature of the coldest month (°C)
Precipitation	Total annual precipitation (mm)
Radiation	Annual solar radiation (W/m^2)

2.2. Data analyses

2.2.1. An indicator of non-native tree effects on cultural services

We propose an indicator of non-native tree effects on cultural ecosystem services, based on the calculation of the odds ratio. The odds ratio is an effect size statistic often applied in meta-analysis as a measure of association between an exposure and an outcome, against the frequency of such outcome if expected by chance (Borenstein et al. 2008). In our case, the odds ratio was assumed to express the direction of effects of non-native tree species (i.e., exposure) in each data source of cultural services (i.e., outcome), compared to the effects of native trees (i.e., non-exposure), and considering the proportion of non-native and native trees in the region under analysis (i.e., expected by chance). For computing the indicator, we first organised the information of each data source (Table 1) in contingency tables (Table 3).

Table 3. Example of a contingency table used for calculating the indicator of non-native tree effects on cultural services, based on the odds ratio.

		Exposure (E)/Non-exposure	
		Amount of non-native trees	Amount of native trees
Outcome (O)	Observed values in the data source of cultural services	*A*	*B*
	Expected values in the region under analysis	*C*	*D*

For each data source, we then calculated the odds ratio in its logarithmic form (logOR), using the Peto's method, since some sources showed the absence of non-native or native trees (Borenstein et al. 2008; Viechtbauer 2010; eqs. 1-5).

$\Psi = \exp(O\text{-}E/V)$ Eq. 1

$O = A$ Eq. 2

$E = (A+B)/(A+C)/n$ Eq. 3

$V = (A+B)(C+D)(A+C)(B+D)/n\hat{}2(n\text{-}1)$ Eq. 4

$zp = O\text{-}E/\sqrt{V}$ Eq. 5

$CI = \exp((O\text{-}E)\pm z_{\alpha/2}\sqrt{V})/V)$ Eq. 6

In equations 1-6, Ψ is the Peto's odds ratio, zp is the asymptotically normal test statistic, CI is the 100(1-a)% confidence interval and $z\alpha/2$ is a quantile from the distribution. V is both weighting factor and variance for the difference between observed and expected values of A, O-E (see Appendix F for details).

2.2.2. Evaluating the effects of non-native trees on cultural services

For each data type of cultural services, the logORs of all data sources were aggregated in a weighted logOR using the DerSimonian-Laird random effects model (Viechtbauer 2010). We used this model since it accounts for the variation in logOR across all sources of each data type, in addition to sampling error (Viechtbauer 2010). We further assessed the statistical significance of each weighted logOR through non-parametric permutation tests with 1000 iterations (Viechtbauer 2010). Weighted logOR values higher or lower than 0 indicate that the contribution of non-native trees to a data type, in comparison to the contribution of native trees, is respectively higher or lower than their proportion in the analysed region. In other words, weighted logOR values higher or lower than 0 respectively indicate a positive or negative significant effect of non-native trees on a cultural service. Weighted logOR equal to 0 indicate no significant effects of non-native trees.

To test for significant bias in each data type, we calculated the Rosenberg fail-safe number (Rothstein et al. 2005). The fail-safe number estimates the number of additional sources that would be needed to change the results of the weighed logOR, from significant to non-significant. When the fail-safe number was larger than $5N + 10$ (where N is the number of data sources), the weighted logOR could be interpreted as a reliable estimate of true effects (Rothstein et al. 2005). Details on the weighted logOR computation and bias analysis are provided in Appendix G.

2.2.3. Testing the observed variation of non-native tree effects against predictors

For each data type of cultural services, we assessed whether the variation of non-native tree effects could be explained by the 12 predictors (see Table 2). The heterogeneity of logOR across all data sources (expressing the variation of non-native tree effects) was tested using the Q statistic under a chi-square distribution, with n-1 degrees of freedom (Borenstein et al. 2008; Viechtbauer 2010). Values for the Q statistic greater than expected by sampling error suggest an underlying structure of effects in the data type (Borenstein et al. 2008).

When the Q statistic showed significant values, we performed a structured meta-analysis (Viechtbauer 2010). Specifically, for the categorical predictor of country, we computed the weighted logOR of each data type (Peto's method under the DerSimonian-Laird random effects model) for Portugal and Spain, individually. For the continuous predictors, we used a weighted least squares regression to test for significant relations between the predictors and the values of logOR across the sources of each data type. When the regression showed significant values, we assessed the regression slope and its significance. Positive or negative significant regression values, respectively indicate positive or negative relations between the predictor and the effects of non-native trees (Viechtbauer 2010).

All statistical procedures were implemented in R software (R Core Team 2014), using the package *metafor* (Viechtbauer 2010).

3. Results

3.1. Effects of non-native trees on cultural ecosystem services

We found contrasting effects of non-native trees on the data types of cultural services in the Iberian Peninsula (Fig. 1). Positive weighted logOR values were obtained for tourism information systems (recreation and ecotourism) and for monumental trees (cultural heritage). Conversely, negative values were found for nature routes (recreation and ecotourism), catalogues of plant dealers (aesthetics) and inventories of urban parks (aesthetics). Fail-safe numbers were higher than $5N + 10$ (see Appendix G for full results), meaning that these significant results translate reliable estimates of non-native tree effects. No significant values were obtained for nature photographs (inspiration; Fig. 1).

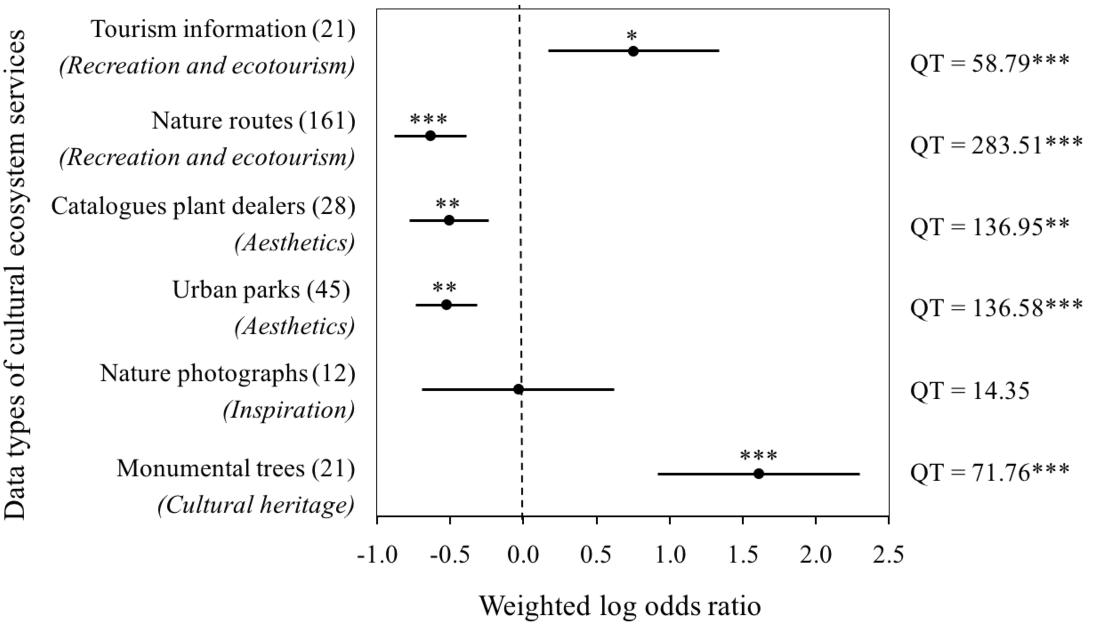

Fig. 1. Weighted log odds ratio (Peto's method under the DerSimonian-Laird random effects model) and respective confidence intervals (permutation tests under 1000 iterations) for each

data type of cultural ecosystem services (number of data sources are shown in brackets). Values higher or lower than 0 respectively suggest positive or negative effects of non-native trees. Values on the right indicate the heterogeneity (QT) of the log odds ratio across data sources of each data type, tested by means of the Q statistics. Statistical significance: *p < 0.05; **p < 0.01; ***p < 0.001.
(This should be a 1.5-column fitting image)

3.2. Predictors of non-native tree effects on cultural ecosystem services

Significant regional variations of logOR ($p < 0.05$) were observed for most data types, except again for nature photographs (Figs. 1 and 2).

The categorical predictor of country (Portugal or Spain) significantly explained part of logOR variation for catalogues of plant dealers, nature routes and inventories of urban parks. Positive values were found for catalogues of plant dealers for Portugal (0.48; $p < 0.05$), but negative values were obtained for Spain (-0.69; $p < 0.001$). Negative weighted logORs were also found for nature routes and urban park inventories, but only for Spain (weighted logOR = -0.95 and -0.70; $p < 0.001$, respectively). No significant values were found for tourism information nor for monumental trees (Table 4; see also Appendix G for full results).

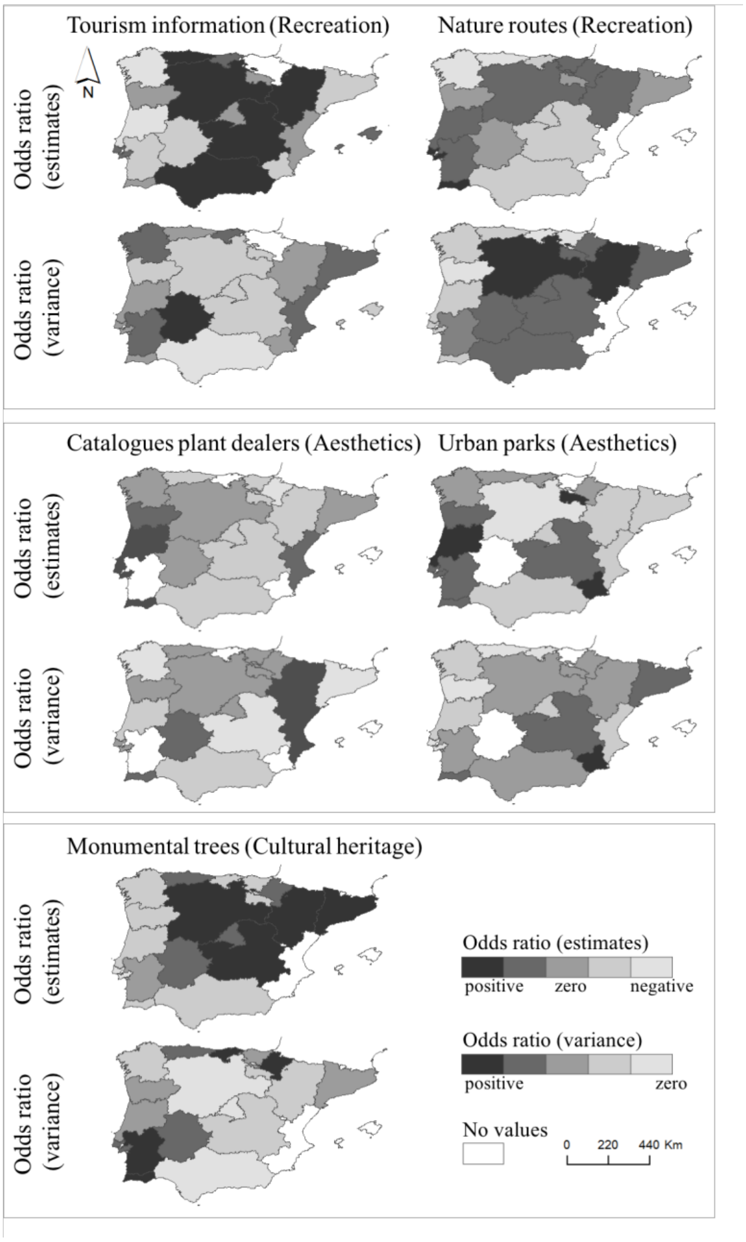

Fig. 2. Representation of the spatial distribution of averaged estimates and variances of the log odds ratio for each Iberian NUTS-2 region. Information on nature photographs is not represented since it showed no significant logOR values.
(This should be a 1-column fitting image)

Continuous predictors (see Table 2) also contributed to explain the variation of logOR values for most data types, except for monumental trees (Table 4). Job availability was negatively related to logOR values for tourism information, nature routes and urban park inventories. Life satisfaction held a negative relation with values for nature routes, catalogues of plant dealers, and urban park inventories. Proportion of forests (negative relation), total annual precipitation (negative) and solar radiation (positive) also explained variation in logOR values for nature routes. Minimum temperature related positively with logOR values for catalogues of plant dealers and urban park inventories. Human development held a negative relation with values for catalogues of plant dealers, as did tourism rates with values for urban park inventories (Table 4; see also Appendix H for full results).

Table 4. Results of the structured meta-analysis assessing the covariation between the considered predictors (Table 2) and the effects of non-native trees (expressed by logORs) on data types of cultural services. The table shows the heterogeneity explained by each predictor and its significance based on a chi-square distribution with n-1 degree of freedom. Values in brackets show the regression slopes and respective significance for continuous predictors (see Appendix H for full results). Statistical significance: *p < 0.05; **p < 0.01; ***p < 0.001.

	Recreation and ecotourism		**Aesthetics**		**Cultural heritage**
	Tourism information	***Nature routes***	***Catalogues dealers***	***Urban parks***	***Monumental trees***
Land cover and management					
Forests	0.065	13.567** (-0.037**)	2.536	3.354	0.952
Protected areas	0.101	3.992	1.342	3.997	0.496
Socio-economy					
Country	9.593	52.901***	21.099*	34.731***	23.613
Tourism	2.846	2.199	0.542	11.756** (-0.001***)	0.059
Development	0.024	0.424	5.146* (-0.007*)	0.188	0.323
Impact	0.461	0.640	1.373	2.313	2.978
Human well-being					
Life	1.362	9.389** (-0.590**)	9.147** (-0.651**)	4.637* (-0.407*)	1.774
Jobs	5.063* (-0.285*)	25.257** (-0.268**)	0.939	6.644* (-0.134*)	1.289
Housing	0.024	1.616	0.003	0.035	0.256
Environment	0.000	0.223	0.639	4.302	4.083
Climate					
Temperature	0.288	1.929	5.069* (0.133*)	6.624* (0.130*)	5.301
Precipitation	0.475	5.939* (-0.0001*)	0.797	2.029	0.465
Radiation	0.031	8.178** (0.014**)	1.030	0.431	0.089

4. Discussion

4.1. Non-native tree effects on cultural ecosystem services

We developed an indicator-based approach grounded in meta-analytical techniques, and applied it to evaluate the effects of non-native trees on cultural ecosystem services in the Iberian Peninsula. We found that the effects of non-native trees were service-dependent, highlighting the plurality of societal preferences towards the appropriation of cultural services (Chan et al. 2012; Ghosh and Traverse 2005; Martín-López et al. 2012). We also found that the contribution of non-native trees was country-dependent and determined by environmental and socio-economic factors. Although holding common geographic and historical features, Portugal and Spain still differ in their climate, demography, politics, culture and economy. These differences could therefore play a role in how non-native trees affect cultural services (after Humair et al. 2015; Krumm and Vítková 2016), as previously highlighted for provisioning and regulating services (Brundu and Richardson 2016; Carruthers et al. 2011; Kull et al. 2011).

We found contrasting contributions from non-native trees on cultural services related to recreation and ecotourism. Non-native trees were over-represented (in comparison to native trees and to their occurrence in the analysed region) in information systems ruled by official tourism entities, but under-represented in photographs from nature routes experienced by local users, particularly in Spain. In the case of official entities, publicity on Iberian touristic destinations tends to adopt photographs covering iconic standard features from nature (Santos 2004), which often include non-native species (e.g., palm trees in coastal areas, pines or sequoias in forest areas). Nature route users, however, may pursue landscapes with more pristine nature features. In both Portugal and Spain, monotonous and homogeneous landscapes dominated by non-native trees (e.g., *Eucalyptus globulus*, *Pinus radiata*, *Robinia pseudoacacia*, or *Acacia* species) seem to be less attractive to people (Humair et al. 2015; Kueffer and Kull 2017; Richardson et al. 2014).

We found negative contributions of non-native trees on aesthetics. Still, we found no significant influence of non-natives on the pool of tree species in urban parks in Portugal. This is in contrast to Spain, where legal considerations on the adoption of non-native trees have been explicitly taken for urban areas (Royal Decree-Law 630/2013: 5th disposition). We also found an over-representation of non-native trees (compared to native ones) in catalogues of plant dealers in Portugal, suggesting a market preference for these species. This is of relevance considering that these catalogues include sets of ornamental plants commonly traded in horticulture. Despite legal constraints on the trade of non-native species in both countries (Decree-Laws 565/99 and 630/2013; EU Regulation 1143/2014), horticultural trade is still a main introduction pathway and distribution channel of non-native plants that may become invasive (Hulme et al. 2017; Humair et al. 2015). This is often due to a lack of awareness and information on the non-nativeness of traded ornamental species among sellers, customers, and regulatory entities (Andreu et al. 2009; Carruthers et al. 2011).

Non-native trees held a positive effect on cultural heritage in the Iberian Peninsula. Monumental trees are part of the cultural heritage at regional and national levels, often representing symbols of human identity for local communities (Asciuto et al. 2015; Crews 2003). In both Portugal and Spain, the monumental status of a tree can be declared due to historical and cultural backgrounds, regardless of a native or non-native status (Decree-Law 53/2012: Ordinance 124/2014). Many non-native trees have become monumental trees in Iberia after being introduced as botanical curiosities or research assets during past transatlantic expeditions (e.g., *Camellia japonica* L.), or due to their long-term economic symbolism (e.g., *Eucalyptus globulus*; see also Asciuto et al. 2015; Crews 2003).

We found no significant effects of non-native tree species on inspiration cultural services, suggesting no preference for native or non-native trees in nature photography. The notion of species nativeness is mostly used by scientists and academics (Kueffer and Kull 2017), and may not influence inspirational preferences of the public. Still, as previously highlighted by Oteros-Rozas et al. (2017) and by van Berkel and Verburg (2014) for rural landscapes, evaluating nature inspiration from photographic contents depends not only on the subjective preferences of the photographer, but also on the reader's interpretation. Other data sources should be explored, namely art museum databases and catalogues, photography literature, and other social media (e.g., Flickr, Panoramio; Figueroa-Alfaro and Tang 2017), to further elucidate inspiration preferences towards non-native trees.

4.2. Predictors of non-native tree effects: considerations for management

We found that the positive effects of non-native trees on aesthetics, and recreation and ecotourism increased in NUTS-2 regions with lower socio-economic conditions (job availability, development level, tourism rates) and lower life satisfaction levels. Positive contributions on these services were also found in warmer and drier regions with less forested land. Developed countries are known to host more non-native plant species than developing ones (Humair et al. 2015; Vilà and Pujadas 2001). Our results add that non-native trees seem to be more used (than native trees) for aesthetic and recreational purposes in less developed regions (i.e., under lower income and educational levels). A higher preference for non-natives in these regions may be due not only to intrinsic preferences by people, but also to lower awareness on the notion of non-native trees and related risks (following Carruthers et al. 2011; Hulme et al. 2017; Kueffer and Kull 2017). In Iberia, these less developed regions are mostly under warmer and drier climates, and hold fewer forested areas. This is of importance considering that climate change is expected to increase the likelihood of naturalization for many ornamental plants, and thus their capacity to alter cultural (and other) ecosystem services (Dullinger et al. 2017; see also Seebens et al. 2015).

Effects of non-native trees on cultural heritage and inspiration services could not be observed or explained by the considered predictors. The heritage value attributed by people to non-native species relates with subjective human interests and relationships, as well as with cultural traditions and symbolic representations, which are difficult to assess outside their regional context (Kull et al. 2011). Inspirational preferences and choices towards non-native trees also derive from the psychological and cognitive dimensions (e.g., long-term associations, personal affections; van Berkel and Verburg 2014; Kueffer and Kull 2017). Other factors, such as past human history or species residence time, not available for our analyses, might contribute to explain the variation of non-native tree effects.

Our results highlight four main ideas to be considered in the management of non-native trees in Iberia. First, the direction of non-native tree effects on cultural services depends on people's preferences towards visual features. In Iberia, visual attributes of non-native trees are often associated to homogenised, monotonous landscapes (Kueffer and Kull 2017), explaining the lower consideration of these species for recreation and ecotourism by the general public. Second, the idea of "out-of-normal" features, as well as of testimonies of historical and cultural events, is often attributed to non-native tree species (Carruthers et al. 2011; Crews 2003). In Portugal and Spain, this can justify the consideration of non-native trees as attractions for recreation and ecotourism by official tourism entities, and as monumental assets in cultural heritage. Third, awareness of the notion of "non-native" associated to tree species depends on the social-ecological context (Kueffer and Kull 2017), and it can influence the ornamental and market value of potentially traded species. Fourth, people from developed socio-economic (and educational) contexts are expected to be more aware of risks associated to non-native species (Vilà and Pujadas 2001; Marchante and Marchante 2016). In Iberia, this can explain why we found a more positive effect of non-native trees on cultural services in less developed regions.

We suggest that management strategies targeting non-native trees should promote awareness, e.g. by means of environmental education programmes, public outreach and further information campaigns (Marchante and Marchante 2016). In Iberia, these campaigns should prioritize tourism entities and ornamental trade, especially in less developed regions. Biosecurity efforts should thus be reinforced among managers, sellers and local residents, who influence interactions among non-native species, social media and market values (Hulme et al. 2017; Humair et al. 2015; Marchante and Marchante 2016). Also, since our research considered non-native trees as a whole, local perceptions towards individual species should be further considered, as they may differ among species and regions (Kueffer and Kull 2017). Researchers and managers should examine the motivations underlying the choices and preferences towards non-native ornamental trees (Hulme et al. 2017; Seebens et al. 2015). Promoting risk awareness and strengthening biosecurity efforts, specially focusing on the fact that some of non-natives may naturalize and become invasive (e.g., *Acacia longifolia*, *Pseudotsuga menziesii*, *Robinia pseudoacacia*), could prevent undesirable effects on ecosystem services (Andreu et al. 2009; Hulme et al. 2017; Vaz et al. 2017a).

4.3. Expanding the approach

The proposed indicator-based approach, based on the calculation of the odds ratio from multiple data sources, has advantages compared to previous estimations of cultural services. First, it gives insights on how cultural services can be affected by drivers of global change (Blicharska et al. 2017), such as non-native species. It is also able to integrate multiple data types from widely available sources, allowing reproducibility and the inclusion of further information as data sources expand (Zhang et al. 2016). Our approach is easily applicable to other taxonomic groups, biodiversity measures (e.g., species richness, abundance), social-ecological drivers and geographic contexts. Therefore, it has the potential to be extended to a multitude of temporal and spatial scales, and thus support the management of cultural ecosystem services (Blicharska et al. 2017; Hernández-Morcillo et al. 2013; Schröter et al. 2016).

Our study considered the most relevant available data to quantify the relations between non-native trees and cultural ecosystem services, contributing to promote biosecurity in the Iberian Peninsula. Still, further advancing and expanding the proposed indicator-based approach will involve addressing some possible limitations. The odds ratio methodology may be sensitive to the choice of data types and control data (represented in our study by the proportion of native and non-native trees in each NUTS-2 region). We thus encourage the investigation of alternative and complementary types and sources of information (following e.g., Figueroa-Alfaro and Tang 2017; Oteros-Rozas et al. 2017; van Berkel and Verburg 2014). When extending this approach to other regions or scales, particular attention should be given to data types that may not always be available, or that did not yield significant results in our study (e.g. artistic nature photographs). Future studies should also examine information at different time periods, targeting other social-ecological challenges (besides non-native trees) in distinct geographic areas, and consider practical ways to cross-check and validate results in specific contexts (Hernández-Morcillo et al. 2013; Milcu et al. 2013).

5. Conclusions

We presented and tested a new indicator-based approach to analyse patterns and drivers of cultural ecosystem services. The methodology combines meta-analytical techniques with the collection of different types of information from multiple sources. We used this approach to conduct a systematic evaluation of the effects of non-native tree species on cultural services in the Iberian Peninsula. We recorded significant effects on most cultural services (namely on recreation and ecotourism, aesthetics, and cultural heritage). Those effects also differed among services and countries. In short, for recreation and ecotourism, we observed positive effects from official tourism information systems, and negative effects from nature routes. For aesthetics, we observed a positive effect of non-native trees in catalogues of ornamental plant dealers from Portugal, in contrast to Spain. We also found positive effects of non-native trees on cultural heritage, expressed on catalogues of monumental trees. Overall, non-native trees contributed more positively to cultural services in less developed regions (i.e., under lower income and educational levels) with lower life satisfaction indices.

Our approach and our results support new insights into the cultural dimension of non-native trees. We recommend that management and biosecurity actions should promote awareness and outreach campaigns on non-native trees. A special focus should be provided to official entities of regional tourism and to ornamental plant dealers, as well as customers and authorities, especially in less developed regions. We call for studies that further expand the approach and explore the effects of global change processes on cultural ecosystem services.

Acknowledgements

The authors thank Dr. Javier Benayas, for his feedback on the selection of potential indicators of cultural ecosystem services at the initial stage of the study, Carlos Vila-Viçosa (CIBIO-InBIO) and Paulo Alves (CIBIO-InBIO) for reviewing the classification and taxonomy of Iberian tree species, and Helena Santos (CIBIO-InBIO) for manuscript revisions. Funding: A. S. Vaz was supported by the FSE/MEC and FCT (PhD grant PD/BD/ 52600/2014); J.R. Vicente by POPH/FSE and FCT (Post-Doc grant SFRH/ BPD/84044/2012); O. Godoy by EU H2020 research and innovation program (Marie Sklodowska-Curie grant agreement No 661118-BioFUNC); Á. Bayon by Plan Estatal I+D+i (Spain) and ESF through a pre-doctoral contract. This work was supported by the FPS COST Actions FP1403 NNEXT: *Non-native tree species for European forests - experiences, risks and opportunities*, and TD1209 AlienChallenge: *European Information System for Alien Species*; and by the IMPLANTIN project (CGL2015-65346-R) of the *Ministerio de Economía y Competitividad* of Spain, and the REMEDINAL3-CM MAE-2719 network (Comunidad de Madrid).

Role of the funding sources

FPS COST Action FP1403 NNEXT supported the mobility of participants for the study design and for data collection. This and other funding sources were not involved on data analysis and interpretation, in the writing of the manuscript, or in the decision to submit the paper for publication.

References

Almeida, J.D., Freitas, H., 2006. Exotic naturalized flora of continental Portugal – A reassessment. Botanica Complutensis 30, 117-130.

Andreu, J., Vilà, M., Hulme, P.E., 2009. An assessment of stakeholder perceptions and management of noxious alien plants in Spain. Environmental Management 43, 1244.

Asciuto, A., Borsellino, V., D'Acquisto, M., Di Franco, C.P., Di Gesaro, M., Schimmenti, E., 2015. Monumental trees and their existence value: case study of an Italian natural park. Journal of Forest Science 61, 56-61.

Beltrán, M., Vericat, P., Piqué, M., 2013. Evaluación de los recursos forestales por CC.AA. REDFOR proyecto piloto en el marco de la Red Rural Nacional, 2011. Centre Tecnològic Forestal de Catalunya, Solsona, Lleida.

Blicharska, M., Smithers, R.J., Hedblom, M., Hedenås, H., Mikusiński, G., Pedersen, E., Sandström, P., Svensson, J., 2017. Shades of grey challenge practical application of the cultural ecosystem services concept. Ecosystem Services 23, 55-70.

Borenstein, M., Hedges, L.V., Higgins, J.P.T., Rothstein, H.R., 2008. Introduction to meta-analysis. Wiley.

Brundu, G., Richardson, D.M., 2016. Planted forests and invasive alien trees in Europe: A Code for managing existing and future plantings to mitigate the risk of negative impacts from invasions, In: Daehler, C.C., van Kleunen, M., Pyšek, P., Richardson, D.M. (Eds), Proceedings of 13th International EMAPi conference, Waikoloa, Hawaii. NeoBiota, pp. 5-47.

Carruthers, J., Robin, L., Hattingh, J.P., Kull, C.A., Rangan, H., van Wilgen, B.W., 2011. A native at home and abroad: the history, politics, ethics and aesthetics of acacias. Diversity and Distributions 17, 810-821.

Castro-Díez, P., Godoy, O., Alonso, A., Gallardo, A., Saldaña, A., 2014a. What explains variation in the impacts of exotic plant invasions on the nitrogen cycle? A meta-analysis. Ecology Letters 17, 1-12.

Castro-Díez, P., González-Muñoz, N., Alonso, A., 2014b. Los árboles exóticos de las riberas españolas. ¿Una amenaza para estos ecosistemas? Servicio de Publicaciones de la Universidad de Alcalá, Alcalá de Henares, Madrid.

Castroviejo, S., Laínz, M., González, G.L., Montserrat, P., Garmendia, F.M., Paiva, J., Villar, L., 1986-2010. Flora iberica. Plantas vasculares de la Península Ibérica e Islas Baleares. Real Jardin Botánico, CSIC.

Cela, P.G., Gamarra, R.G., Viñas, J.I.G., Díaz, S.A., 2013. Árboles Ibéricos. http://www.arbolesibericos.es/ (accessed 10.06.17).
Chan, K.M.A., Guerry, A.D., Balvanera, P., Klain, S., Satterfield, T., Basurto, X., Bostrom, A., Chuenpagdee, R., Gould, R., Halpern, B.S., Hannahs, N., Levine, J., Norton, B., Ruckelshaus, M., Russell, R., Tam, J., Woodside, U., 2012. Where are cultural and social in ecosystem services? A framework for constructive engagement. BioScience 62, 744-756.
Crews, J., 2003. Forest and tree symbolism in folklore. In: Perlis, A. (Eds), Perceptions of forests. FAO - Food and Agriculture Organization of the United Nations, Rome, Italy.
DGT, Direção-Geral do Território, 2017. Cartografia de uso e ocupação do solo. http://mapas.dgterritorio.pt/ (accessed 10.06.17).
Dickie, I., Bennett, B., Burrows, L., Nuñez, M., Peltzer, D., Porté, A., Richardson, D., Rejmánek, M., Rundel, P., van Wilgen, B., 2014. Conflicting values: ecosystem services and invasive tree management. Biological Invasions 16, 705-719.
Dullinger, I., Wessely, J., Bossdorf, O., Dawson, W., Essl, F., Gattringer, A., Klonner, G., Kreft, H., Kuttner, M., Moser, D., Pergl, J., Pysek, P., Thuiller, W., van Kleunen, M., Weigelt, P., Winter, M., Dullinger, S., 2017. Climate change will increase the naturalization risk from garden plants in Europe. Global Ecology and Biogeography 26, 43–53.
ESRI, 2012. ArcGIS 10.1. Environmental Systems Research Institute Inc.
Eurostat, 2015a. Regions in the European Union. Nomenclature of territorial units for statistics NUTS 2013/EU-28. European Union Editions, Luxembourg.
Eurostat, 2015b. Eurostat database. European Comission. http://ec.europa.eu/eurostat/web/regions/data/database (accessed 04.07.2017).
Figueroa-Alfaro, R.W., Tang, Z., 2017. Evaluating the aesthetic value of cultural ecosystem services by mapping geo-tagged photographs from social media data on Panoramio and Flickr. Journal of Environmental Planning and Management 60, 266-281.
Fish, R., Church, A., Winter, M., 2016. Conceptualising cultural ecosystem services: A novel framework for research and critical engagement. Ecosystem Services 21B, 208–217.
Gassó, N., Sol, D., Pino, J., Dana, E.D., Lloret, F., Sanz-Elorza, M., Sobrino, E., Vilà, M., 2009. Exploring species attributes and site characteristics to assess plant invasions in Spain. Diversity and Distribution 15, 50-58.
Ghosh, A., Traverse, M., 2005. Cultural Services. In: Chopra, K., Leemans, R., Kumar, P., Simmons, H. (Eds), Ecosystems and human well-being: policy responses. Island Press, pp. 401-422.
Godoy, O., Castro-Díez, P., Van Logtestijn, R. S., Cornelissen, J. H., Valladares, F., 2010. Leaf litter traits of invasive species slow down decomposition compared to Spanish natives: a broad phylogenetic comparison. Oecologia 162, 781-790.
Hardeman, S., Hardeman, S., 2014. The EU Regional Human Development Index. JRC Science and Policy Reports. Luxembourg: Publications Office of the European Union.
Hernández-Morcillo, M., Plieninger, T., Bieling, C., 2013. An empirical review of cultural ecosystem service indicators. Ecological Indicators 29, 434-444.
Hulme, P.E., Brundu, G., Carboni, M., Dehnen-Schmutz, K., Dullinger, S., Early, R., Essl, F., González-Moreno, P., Groom, Q.J., Kueffer, C., Kühn, I., Maurel, N., Novoa, A., Pergl, J., Pyšek, P., Seebens, H., Tanner, R., Touza, J.M., van Kleunen, M., Verbrugge, L.N.H., 2017. Integrating invasive species policies across ornamental horticulture supply-chains to prevent plant invasions. Journal of Applied Ecology. Doi: 10.1111/1365-2664.12953.
Humair, F., Humair, L., Kuhn, F., Kueffer, C., 2015. E-commerce trade in invasive plants. Conservation Biology 29, 1658-1665.
ICNF, 2013a. Espécies arbóreas indígenas em Portugal Continental. Ministério da Agricultura, do Mar, do Ambiente e do Ordenamento do Território.
ICNF, 2013b. Relatório do Inventário Florestal Nacional 6. Ministério da Agricultura, do Mar, do Ambiente e do Ordenamento do Território.
Krumm, F., Vítková, L., 2016. Introduced tree species in European forests: opportunities and challenges. European Forest Institute.
Kueffer, C., Kull, C., 2017. Non-native species and the aesthetics of nature, In: Vilà, M., Hulme, P. (Eds), Impact of biological invasions on ecosystem services. Springer, pp. 311-324.

Kull, C.A., Shackleton, C.M., Cunningham, P.J., Ducatillon, C., Dufour-Dror, J.-M., Esler, K.J., Friday, J.B., Gouveia, A.C., Griffin, A.R., Marchante, E., Midgley, S.J., Pauchard, A., Rangan, H., Richardson, D.M., Rinaudo, T., Tassin, J., Urgenson, L.S., von Maltitz, G.P., Zenni, R.D., Zylstra, M.J., 2011. Adoption, use and perception of Australian acacias around the world. Diversity and Distributions 17, 822-836.

MAPAMA, Ministerio de Agricultura y Pesca, Alimentación y Medio Ambient, 2014. http://www.mapama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/ifn3_bbdd_descargas.htm.aspx (accessed 10.06.17)

Marchante, E., Marchante, H., 2016. Engaging society to fight invasive alien plants in Portugal - one of the main threats to biodiversity. In: Castro, P., Azeiteiro, U.M., Bacelar-Nicolau, P., Filho, W.L., Azul, A.M. Biodiversity and Education for Sustainable Development. Springer International Publishing, pp. 107-122.

Martín-López, B., Iniesta-Arandia, I., García-Llorente, M., Palomo, I., Casado-Arzuaga, I., Amo, D.G.D., Gómez-Baggethun, E., Oteros-Rozas, E., Palacios-Agundez, I., Willaarts, B., González, J.A., Santos-Martín, F., Onaindia, M., López-Santiago, C., Montes, C., 2012. Uncovering ecosystem service bundles through social preferences. PLOS ONE 7, e38970.

MEA, 2005. Ecosystems & Human Well-being: Synthesis (Millennium Ecosystem Assessment). Island Press, Washington, DC.

Milcu, A.I., Hanspach, J., Abson, D., Fischer, J., 2013. Cultural Ecosystem Services: A literature review and prospects for future research. Ecology and Society 18, 44.

Morais, M., Marchante, E., Marchante, H., 2017. Big troubles are already here: risk assessment protocol shows high risk of many alien plants present in Portugal. Journal for Nature Conservation 35, 1-12.

Ninyerola, M., Pons, X., Roure, J.M., 2005. Atlas climático digital de la Península Ibérica. Metodología y aplicaciones en bioclimatología y geobotánica, Barcelona.

OECD, 2013. OECD Guidelines on measuring subjective well-being, OECD Publishing. Available at: http://dx.doi.org/10.1787/9789264191655-en (last accessed 27th May, 2017).

Oteros-Rozas, E., Martín-López, B., Fagerholm, N., Bieling, C., Plieninger, T., 2017. Using social media photos to explore the relation between cultural ecosystem services and landscape features across five European sites. Ecological Indicators http://dx.doi.org/10.1016/j.ecolind.2017.02.009

Plieninger, T., Bieling, C., 2012. Resilience and the cultural landscape: understanding and managing change in human-shaped environments. Cambridge University Press, UK.

Poe, M.R., Donatuto, J., Satterfield, T., 2016. "Sense of Place": human wellbeing considerations for ecological restoration in puget sound. Coastal Management 44, 409-426.

Quinn, G.P., Keough, M.J., 2002. Experimental design and data analysis for biologists. Press Syndicate of the University of Cambridge, UK.

R Core Team, 2014. R: a language and environment for statistical computing. R Foundation for Statistical Computing.

Richardson, D.M., Pyšek, P., 2006. Plant invasions: merging the concepts of species invasiveness and community invasibility. Progress in Physical Geography 30, 409-431.

Richardson, D.M., Hui, C., Nuñez, M.A., Pauchard, A., 2014. Tree invasions: patterns, processes, challenges and opportunities. Biological Invasions 16, 473-481.

Richardson, D.M., Rejmánek, M., 2011. Trees and shrubs as invasive alien species – a global review. Diversity and Distributions 17, 788–809.

Rothstein, H., Sutton, A., Borenstein, M., 2005. Publication bias in meta-analysis: prevention, assessment and adjustments. John Wiley & Sons Ltd, West Sussex PO19 8SQ, England.

Santos, C.A., 2004. Framing Portugal: representational dynamics. Annals of tourism research 31, 122-138.

Sanz Elorza, M., Sánchez, E.D., Vesperinas, E.S., 2004. Atlas de las plantas alóctonas invasoras en España. Dirección General para la Biodiversidad. Ministerio de Medio Ambiente, Madrid.

Schröter, M., Albert, C., Marques, A., Tobon, W., Lavorel, S., Maes, J., Brown, C., Klotz, S., Bonn, A., 2016. National ecosystem assessments in Europe: a review. BioScience 66, 813-828.

Seebens, H., Essl, F., Dawson, W., Fuentes, N., Moser, D., Pergl, J., Pyšek, P., van Kleunen, M., Weber, E., Winter, M., Blasius, B., 2015. Global trade will accelerate plant invasions in emerging economies under climate change. Global Change Biology 21, 4128-4140.

Soliveres, S., van der Plas, F., Manning, P., Prati, D., Gossner, M.M., Renner, S.C., Alt, F., Arndt, H., Baumgartner, V., Binkenstein, J., Birkhofer, K., Blaser, S., Blüthgen, N., Boch, S., Böhm, S., Börschig, C., Buscot, F., Diekötter, T., Heinze, J., Hölzel, N., Jung, K., Klaus, V.H., Kleinebecker, T., Klemmer, S., Krauss, J., Lange, M., Morris, E.K., Müller, J., Oelmann, Y., Overmann, J., Pašalić, E., Rillig, M.C., Schaefer, H.M., Schloter, M., Schmitt, B., Schöning, I., Schrumpf, M., Sikorski, J., Socher, S.A., Solly, E.F., Sonnemann, I., Sorkau, E., Steckel, J., Steffan-Dewenter, I., Stempfhuber, B., Tschapka, M., Türke, M., Venter, P.C., Weiner, C.N., Weisser, W.W., Werner, M., Westphal, C., Wilcke, W., Wolters, V., Wubet, T., Wurst, S., Fischer, M., Allan, E., 2016. Biodiversity at multiple trophic levels is needed for ecosystem multifunctionality. Nature 536, 456-459.

Tengberg, A., Fredholm, S., Eliasson, I., Knez, I., Saltzman, K., Wetterberg, O., 2012. Cultural ecosystem services provided by landscapes: assessment of heritage values and identity. Ecosystem Services 2, 14-26.

The Plant List, 2013. Version 1.1. Published on the Internet; http://www.theplantlist.org/ (accessed 25th May, 2017).

van Berkel, D.B., Verburg, P.H., 2014. Spatial quantification and valuation of cultural ecosystem services in an agricultural landscape. Ecological Indicators 37A, 163-174.

van Wilgen, B.W., Dyer, C., Hoffmann, J.H., Ivey, P., Le Maitre, D.C., Moore, J.L., Richardson, D.M., Rouget, M., Wannenburgh, A., Wilson, J.R.U., 2011. National-scale strategic approaches for managing introduced plants: insights from Australian acacias in South Africa. Diversity and Distributions 17, 1060-1075.

Vaz, A.S., Kueffer, C., Kull, C.A., Richardson, D.M., Vicente, J.R., Kühn, I., Schröter, M., Hauck, J., Bonn, A., Honrado, J.P., 2017a. Integrating ecosystem services and disservices: insights from plant invasions. Ecosystem Services 23, 94-107.

Vaz, A.S., Kueffer, C., Kull, C.A., Richardson, D.M., Schindler, S., Muñoz-Pajares, A.J., Vicente, J.R., Martins, J., Hui, C., Kühn, I., Honrado, J.P., 2017b. The progress of interdisciplinarity in invasion science. AMBIO. doi:10.1007/s13280-017-0897-7

Vicente, J.R., Alagador, D., Guerra, C., Alonso, J.M., Kueffer, C., Vaz, A.S., Fernandes, R.F., Cabral, J.A., Araújo, M.B., Honrado, J.P., 2016. Cost-effective monitoring of biological invasions under global change: a model-based framework. Journal of Applied Ecology 53, 1317-1329.

Viechtbauer, W., 2010. Conducting meta-analyses in R with the metafor Package. Journal of Statistical Software 36, 1-48.

Vilà, M., Hulme, P.E. (Eds), 2017 Impact of biological invasions on ecosystem services. Springer.

Vilà, M., Pujadas, J., 2001. Land-use and socio-economic correlates of plant invasions in European and North African countries. Biological Conservation 100, 397–401.

WCS, CIESIN, 2005. Global Human Influence Index Dataset. Last of the Wild Project, Version 2, 2005: Wildlife Conservation Society and Center for International Earth Science Information Network Columbia University. Palisades, NY: NASA Socioeconomic Data and Applications Center.

Zhang, G., Yang, Y., Zhai, X., 2016. Public cultural big data analysis platform. In: 2016 IEEE Second International Conference on Multimedia Big Data. pp. 398-403.

Figure1-R1

Click here to download high resolution image

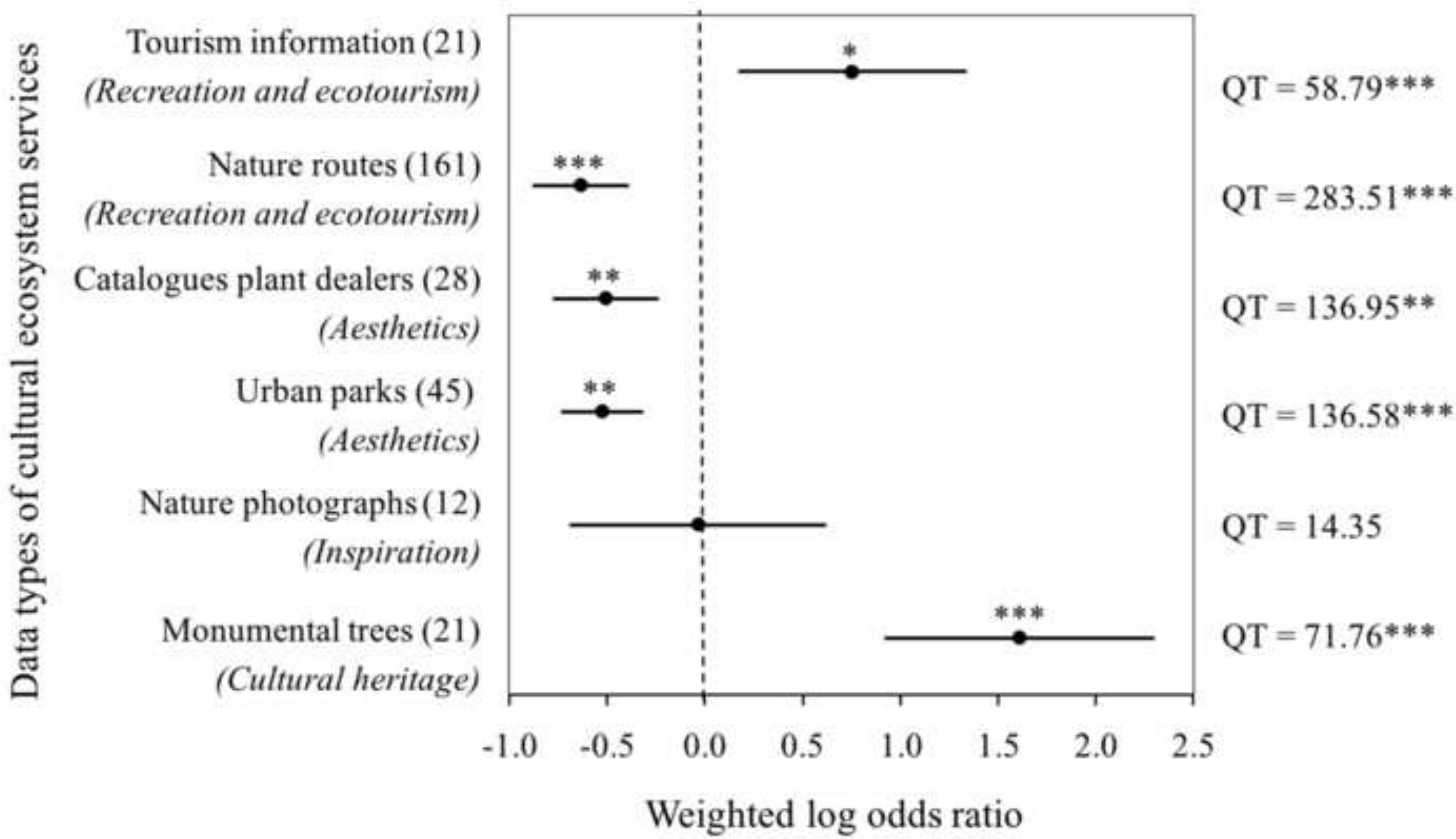

Figure2-R1
Click here to download high resolution image

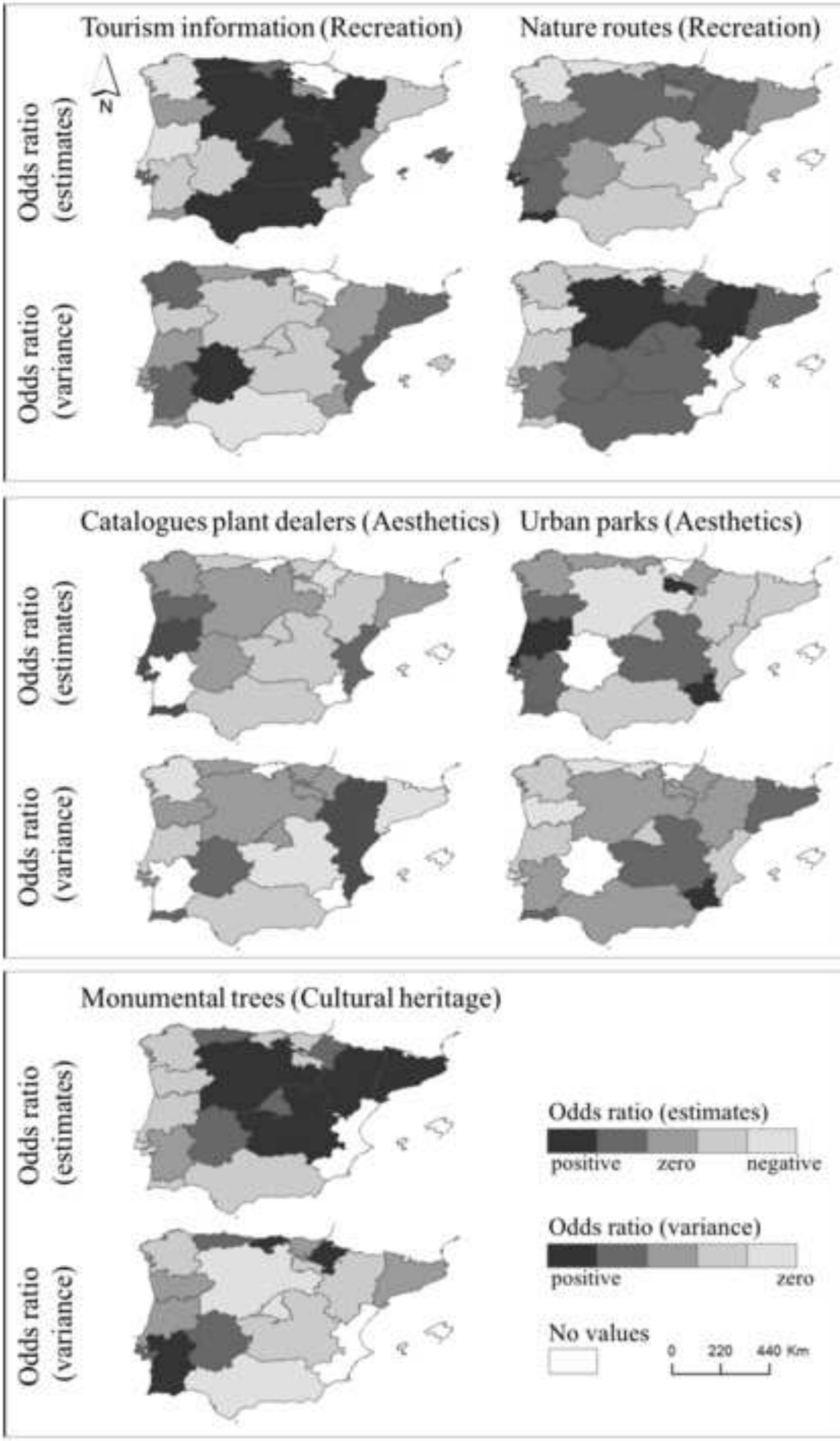

Table 1. Categories of cultural ecosystem services considered, with their respective data types and rationale. The number of data sources (n) considered for each data type is shown. The table also describes the components (A-D: equations 1-6) of the indicator proposed for evaluating non-native tree effects on cultural services (see section 2.2. Data analyses).

		Components of the indicator			
Data types	**Rationale**	**Amount of non-native trees in the service (A)**	**Amount of native trees in the service (B)**	**Amount of non-native trees in the region (C)**	**Amount of native trees in the region (D)**
Recreation and ecotourism					
Tourism information (n = 21)	Photographs from tourism websites have the potential to attract tourists	Number of photographs dominated by non-native trees	Number of photographs dominated by native trees	Cover of non-native trees in the region	Cover of native trees the region
Nature routes (n = 161)	Geo-referenced nature routes shared with the public translate society preferences for recreation	Number of photographs dominated by non-native trees	Number of photographs dominated by native trees	Cover of non-native trees in the region	Cover of native trees in the region
Aesthetics					
Catalogues of plant dealers (n = 28)	Tree species offered by plant dealers are appreciated mostly by ornamental values	Number of non-native tree species offered in catalogues	Number of native tree species offered in catalogues	Total number of non-native tree species in the country	Total number of native tree species in the country
Urban parks (n = 45)	Trees exhibited in urban parks are selected mostly based on their aesthetics	Number of non-native tree species present in inventories	Number of native tree species present in inventories	Total number of non-native tree species in the country	Total number of native tree species in the country
Inspiration					
Nature photographs (n = 12)	Artistic photographs reflect the choice of inspiring motifs from nature	Number of photographs dominated by non-native trees	Number of photographs dominated by native trees	Cover of non-native trees in the region	Cover of native trees in the region
Cultural heritage					
Monumental trees (n = 21)	Monumental trees are symbols of human culture, sense of place, and history	Number of non-native tree species present in the list	Number of native tree species present in the list	Cover of non-native trees in the region	Cover of native trees in the region

Table 2. Final set of predictors used to explain the variation of effects of non-native tree species on cultural ecosystem services across Iberian NUTS-2 regions.

Code	**Predictors**
Land cover and management (Vilà and Pujadas 2001; Vicente et al. 2016)	
Forests	Proportion of forest area
Protected areas	Proportion of protected areas
Socio-economy (Vilà and Pujadas 2001; Krumm and Vítková 2016)	
Country	The country where the data sources were located (Portugal or Spain)
Tourism	Number of arrivals at tourist accommodation establishments
Development	EU regional human development index (based on life expectancy, mortality, education, income, and employment)
Impact	Global human influence index (based on human settlement, accessibility, landscape transformation, and electric power infrastructures)
Human well-being (OECD 2013; Ghosh and Traverse 2005; Vaz et al. 2017a)	
Life	Life satisfaction, a subjective well-being index of how people evaluate their life (based on citizens' questionnaires)
Jobs	Job availability, a well-being index of material conditions (based on both employment and unemployment % rates)
Housing	Housing, an index of material conditions for well-being (based on the % ratio of the number of rooms per person)
Environment	Environmental quality, an index of human life quality (based on the estimated average exposure to air pollution in PM2.5 µg/m)
Climate (Gassó et al. 2009; Vicente et al. 2016)	
Temperature	Minimum temperature of the coldest month (°C)
Precipitation	Total annual precipitation (mm)
Radiation	Annual solar radiation (W/m^2)

Table3-R1

Table 3. Example of a contingency table used for calculating the indicator of non-native tree effects on cultural services, based on the odds ratio.

		Exposure (E)/Non-exposure	
		Amount of non-native trees	Amount of native trees
Outcome (O)	Observed values in the data source of cultural services	*A*	*B*
	Expected values in the region under analysis	*C*	*D*

Table 4. Results of the structured meta-analysis assessing the covariation between the considered predictors (Table 2) and the effects of non-native trees (expressed by logORs) on data types of cultural services. The table shows the heterogeneity explained by each predictor and its significance based on a chi-square distribution with n-1 degree of freedom. Values in brackets show the regression slopes and respective significance for continuous predictors (see Appendix H for full results). Statistical significance: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

	Recreation and ecotourism		**Aesthetics**		**Cultural heritage**
	Tourism information	***Nature routes***	***Catalogues dealers***	***Urban parks***	***Monumental trees***
Land cover and management					
Forests	0.065	13.567** (-0.037**)	2.536	3.354	0.952
Protected areas	0.101	3.992	1.342	3.997	0.496
Socio-economy					
Country	9.593	52.901***	21.099*	34.731***	23.613
Tourism	2.846	2.199	0.542	11.756** (-0.001***)	0.059
Development	0.024	0.424	5.146* (-0.007*)	0.188	0.323
Impact	0.461	0.640	1.373	2.313	2.978
Human well-being					
Life	1.362	9.389** (-0.590**)	9.147** (-0.651**)	4.637* (-0.407*)	1.774
Jobs	5.063* (-0.285*)	25.257** (-0.268**)	0.939	6.644* (-0.134*)	1.289
Housing	0.024	1.616	0.003	0.035	0.256
Environment	0.000	0.223	0.639	4.302	4.083
Climate					
Temperature	0.288	1.929	5.069* (0.133*)	6.624* (0.130*)	5.301
Precipitation	0.475	5.939* (-0.0001*)	0.797	2.029	0.465
Radiation	0.031	8.178** (0.014**)	1.030	0.431	0.089