

Global effects of non-native tree species on multiple ecosystem services

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ABSTRACT

Non-native tree (NNT) species have been transported worldwide to create or enhance services that are fundamental for human well-being, such as timber provision, erosion control or ornamental value; yet NNTs can also produce undesired effects, such as fire proneness or pollen allergenicity. Despite the variety of effects that NNTs have on multiple ecosystem services, a global quantitative assessment of their costs and benefits is still lacking. Such information is critical for decision-making, management and sustainable exploitation of NNTs. We present here a global assessment of NNT effects on the three main categories of ecosystem services, including regulating (RES), provisioning (PES) and cultural services (CES), and on an ecosystem disservice (EDS), i.e. pollen allergenicity. By searching the scientific literature, country forestry reports, and social media, we compiled a global data set of 1683 case studies from over 125 NNT species, covering 44 countries, all continents but Antarctica, and seven biomes. Using different meta-analysis techniques, we found that, while NNTs increase most RES (e.g. climate regulation, soil erosion control, fertility and formation), they decrease PES (e.g. NNTs contribute less than native trees to global timber provision). Also, they have different effects on CES (e.g. increase aesthetic values but decrease scientific interest), and no effect on the EDS considered. NNT effects on each ecosystem (dis)service showed a strong context dependency, varying across NNT types, biomes and socio-economic conditions. For instance, some RES are increased more by NNTs able to fix atmospheric nitrogen, and when the ecosystem is located in low-latitude biomes; some CES are increased more by NNTs in less-wealthy countries or in countries with higher gross domestic products. The effects of NNTs on several ecosystem (dis)services exhibited some synergies (e.g. among soil fertility, soil formation and climate regulation or between aesthetic values and pollen allergenicity), but also trade-offs (e.g. between fire regulation and soil erosion control). Our analyses provide a quantitative understanding of the complex synergies, trade-offs and context dependencies involved for the effects of NNTs that is essential for attaining a sustained provision of ecosystem services.

Key words: biological invasions, cultural ecosystem services, exotic trees, forestry, global assessment, meta-analysis, provisioning ecosystem services, regulating ecosystem services.

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I. INTRODUCTION

Humans rely on the multiple services that ecosystems provide (MEA, 2005). Tree species play a key role in delivering ecosystem services, as they provide products (i.e. provisioning services, PES) such as timber, firewood, fibre, pulp or fodder. They also contribute to regulatory processes (regulating services, RES), such as climate regulation (*via* carbon uptake), soil formation and stabilization, and nutrient and water cycling (MacDicken, 2015; MacDicken *et al.*, 2015). Trees also offer non-material benefits (cultural services, CES), such as aesthetic or inspiration values; they are featured in the folklore, tales and legends of most human cultures, and contribute to people's sense of place (Kueffer & Kull, 2017; Mason *et al.*, 2017).

With the increasing global demands of tree-derived ecosystem services (MacDicken *et al.*, 2015), many fast-growing, stress-tolerant or simply beautiful tree species have been extensively planted beyond their native ranges (Brundu & Richardson, 2016; Dickie *et al.*, 2014a; Evans, 2009). Examples include non-native conifers being planted worldwide for timber and pulp (Brundu & Richardson, 2016); *Acacia*, *Eucalyptus* or *Pinus* boosting land reclamation and sand dune stabilization worldwide (Evans, 2009; Griffin *et al.*, 2011); legume trees (e.g. *Acacia*, *Gleditsia* or *Prosopis*) being used to prevent desertification and provide fodder or firewood in arid and impoverished regions of Africa and Asia (Shackleton *et al.*, 2014; Witt, 2017); and shade and ornamental trees (e.g. *Ailanthus*, *Jacaranda*, *Prosopis*, *Platanus* and *Robinia*) providing amenities to rural and urban populations worldwide (Dickie *et al.*, 2014a). Yet, many non-native tree (NNT) species also contribute to landscape homogenization, reduce native biodiversity, and alter ecosystem functioning in undesirable ways (Cardinale *et al.*, 2012; Gaertner, Richardson & Privett, 2011; Gamfeldt *et al.*, 2013). NNTs may even result in direct negative impacts on human well-being (i.e. ecosystem disservices, EDS) (Shackleton *et al.*, 2016), such as toxicity or allergenicity. Therefore, NNTs also create threats to people's livelihoods and human well-being, such as depletion of soil nutrients and water reserves (Castro-Díez *et al.*, 2012; Le Maitre *et al.*, 1996; Shackleton *et al.*, 2014), increased fire hazard (D'Antonio, 2000; Gaertner, Le Maitre & Esler, 2017; Nagler *et al.*, 2005), damage to infrastructure and archaeological remains (Booy *et al.*, 2017; Celesti-Grapow & Blasi, 2004), or harm to human health (Nentwig, Mebs

& Vilà, 2017; Schindler *et al.*, 2015). These costs may be exacerbated when NNTs naturalize, and especially if they become invasive by spreading outside the areas where they were planted (Brundu & Richardson, 2016; Richardson & Rejmánek, 2011). Understanding how NNTs affect multiple (dis)services and how these effects correlate with each other is essential for enabling policy makers to balance costs and benefits, and manage conflicts over the use of NNTs (Dickie *et al.*, 2014a; Pejchar & Mooney, 2009).

Most of our knowledge on the effects of NNTs on ecosystem services derives from local or regional studies, but these effects likely depend on the environmental conditions, history and cultural background of each region (Castro-Díez *et al.*, 2014a; Corbin & D'Antonio, 2011; Kueffer & Kull, 2017). Moreover, current knowledge is biased towards easy-to-study services and the most widely distributed NNTs (Hernandez-Morcillo, Plieninger & Bieling, 2013; Hulme *et al.*, 2013). Furthermore, many costs and benefits caused by NNTs are reported by different actors with multiple disciplinary backgrounds (e.g. foresters *versus* conservation biologists) using distinct publication types (e.g. scientific papers, reports or social media) (Krumm & Vítková, 2016). This paper presents the first global assessment of NNT effects on multiple ecosystem (dis)services, covering the three main categories of ecosystem services: regulating, provisioning and cultural services (de Bello *et al.*, 2010; Haines-Young & Potschin, 2013; MEA, 2005), and an ecosystem disservice. Specifically, we (i) evaluate the overall magnitude and direction of the effects that NNTs have on multiple ecosystem (dis)services, using native vegetation as a control; (ii) explore the role of environmental, geographical and socio-economic factors as potential predictors of the variation of NNT effects on (dis)services; and (iii) identify synergies and trade-offs among NNT effects on different ecosystem (dis)services. We address these questions through a global meta-analysis of a comprehensive data set gathered from published scientific literature, country-level economic and forestry reports, and social media.

II. MATERIALS AND METHODS

Given that different stakeholders may perceive the same service change as beneficial or detrimental, we avoid

the value-laden term ‘impact’ and use the more neutral one ‘effect’ to document objectively the changes produced by NNTs on ecosystem (dis)services (Jeschke *et al.*, 2014). Thus, although throughout the manuscript we describe an effect as an increase/decrease of a (dis)service (Pyšek *et al.*, 2012), we merely inform on the direction of the change, rather than judging the value of the change.

(1) Data compilation

We focused on NNTs worldwide. We defined trees as ‘perennial woody plants with many secondary branches supported clear of the ground on a single main stem or trunk with clear apical dominance (including palms)’ (Richardson & Rejmánek, 2011, p. 789). ‘Non-native’ trees were defined as tree species introduced (accidentally or intentionally) by humans to new geographic areas, considering the whole introduction–naturalization–invasion continuum (i.e. planted, naturalized and invasive species) (Richardson, Pyšek & Carlton, 2011). The ‘non-native’ status of a tree was stated at the species level (i.e. ignoring the distribution of subspecies or varieties) and at the country scale, following regional and national floras and checklists (see online Supporting information, Appendix S1). For Brazil, USA and Canada however, non-native status was considered at the state level due to their large size and environmental and biogeographic heterogeneity. Archaeophytes (i.e. species introduced before 1492) were excluded because in many cases they could not be clearly assigned to native tree (NT) or NNT at a country level. Hybrids between NTs and NNTs were also excluded for the same reason.

We covered the three most widely recognized categories of ecosystem services (de Bello *et al.*, 2010; Haines-Young & Potschin, 2013; MEA, 2005), i.e. regulating (RES), provisioning (PES) and cultural (CES) ecosystem services. We also considered an ecosystem disservice (EDS) – i.e. a negative impact on human well-being (Shackleton *et al.*, 2016) – specifically pollen allergenicity, which can be treated as a potential drawback from NNTs to human health (Vaz *et al.*, 2017b). The selection of variables and data sources for each ecosystem (dis)service was achieved through an international participatory approach under the COST Action FP1403: *Non-native tree species for European forests – experiences, risks and opportunities* (<http://nnext.boku.ac.at>), and relied on the possibility of worldwide coverage, cost and time efficiency, availability, and ease of communication across multiple countries. Data for RES were derived from an extensive scientific literature review, while data for PES, CES and EDS were collected from a thorough information search on reports and websites, among other sources (see Sections II.1a–d).

(a) Regulating ecosystem services (RES)

We agreed on a list of 10 relevant RES that cover the benefits that people obtain from the capacity of ecosystems to regulate climate, floods, disease, waste, and water (de Bello *et al.*, 2010; Haines-Young & Potschin, 2013; MEA, 2005). For

each RES, we identified a set of underlying target variables which covered ecosystem properties, processes, and/or traits of dominant species that underpin the capacity of ecosystems to regulate processes and mitigate effects of disturbances (de Bello *et al.*, 2010; Quetier *et al.*, 2007) (Table 1). We performed a literature search of scientific publications, using *ISI Web of Knowledge* (<http://webofknowledge.com/>) and *Scopus* (<https://www.scopus.com>). The search was carried out in December 2015 and updated in December 2016, covering the period between 1904 and 2015 with no restriction on language. Our search string included: (Exotic* OR Alien* OR invas*) AND (*native*) AND (tree*) AND the set of key words shown in Table 1 combined with ‘OR’.

Publications retrieved from our searches were filtered according to the following criteria: (i) the study compares any target variable between a site dominated by a NNT and a control site with native vegetation; (ii) the NNT site and the control site are close to each other and have similar environmental conditions, according to the authors of the papers; and (iii) the paper provides means, deviation and sample size of the target variable. The final number of selected papers was 135 (Appendix S2).

Using data obtained from the selected publications, individual data sets were created for each RES (see Table 1). Each data set consisted of a table where rows were case studies and columns covered the mean, deviation and replication of a target variable in a NNT site and in a control site, as well as other explanatory variables, which were subsequently used to explain the variability of effect sizes (see Section II.1e). When the same paper provided measures on more than one target variable, we adopted any of the following decisions: (i) for variables associated with different ecosystem services, we kept them as independent case studies because each service was independently analysed; and (ii) for variables associated with the same service, we selected the one most directly related to the service or we aggregated all values into one to avoid pseudo-replication (see Appendix S3 for details). In total, our data set contained 1688 case studies.

For each case study we calculated a standardized effect size using Hedges’ *d* (Rosenberg, Adams & Gurevitch, 2000), i.e. the difference of mean values between the NNT and the control site, weighted by the number of replications and by the inverse of the variance (Appendix S4A). When the variable had a negative relation with the ecosystem service, we changed the sign of the effect size. A positive effect size thus indicates that the NNT site has a higher contribution to the particular ecosystem service than the control site and *vice versa*.

(b) Provisioning ecosystem services (PES)

We considered two main categories of products obtained from areas where land cover was classified as ‘forest’: timber products (any kind of goods obtained from harvesting trees) and non-timber products (any biological resource in woodland except timber) (MEA, 2005). Details on the types of products included in each category and specific sources of information for each country are shown in Appendix S5.

Table 1. Target variables used as proxies for different regulating ecosystem services (RES). Variables include quantifications of ecosystem processes, ecosystem or community properties and traits of dominant plant species. The positive or negative sign beside each variable indicates the relation with the ecosystem service. The last column shows the list of specific key words used in the search in *ISI Web of Knowledge* and *Scopus*

Regulating ecosystem services	Ecosystem processes	Target variables Ecosystem/community properties	Plant species traits	Key words used in the literature search†
<i>Climate regulation</i>	Carbon sequestration + Biomass production +	Aboveground plant mass/C + Root mass + Soil carbon + Total plant mass + Tree basal area +	Chlorophyll concentration + Photosynthetic rate + Relative growth rate + Tree height + Trunk area/diameter + Trunk diameter increment +	Carbon sequestration, Carbon storage, Primary production, RGR, Growth rate, Photosynthetic rate, Chlorophyll concentration, Microclimate, Climate regulation, Canopy temperature, Wind
<i>Fire-risk prevention</i>		Canopy fuel continuity – Canopy water content + Litter mass/depth – Litter water content + Understorey biomass –	Calorific value – Effective heat of combustion – Leaf moisture + Volatile compounds –	Fire, Fire frequency, Fire susceptibility, Fire intensity, Burning temperature, Fire spread, Forest fire, Wildfire Fire regime, Fire behavio?r, Fuel propert*, Flammability
<i>Flood regulation</i>		Flood frequency – Stream water velocity –		Flood frequency, Flood* Water velocity, River flow, Run?off, Flood protection, Flood defence, Flood storage, Flood generation, Flood detention, Flood event
<i>Plague control</i>		Forest plague frequency – Abundance insectivorous species +	Leaf lignin content + Polyphenol content +	Plague frequency, Disease frequency, Tree pathogens, Natural pest control, Pest control, Biological control, Biological pest control
<i>Pollination</i>			Pollinator visitation rate to flowers +	Pollinat*, Pollination service, Pollinator efficiency, Flower visitor, Zoophilous
<i>Pollution regulation</i>	Soil NO _x emissions –		Concentration of heavy metals in tissues + Plant isoprene emissions – Plant monoterpene emissions – Plant NO _x emissions –	Air purification, Air clean*, Pollut*, Contamination, Noise, BVOC, Biogenic emission*, Volatil*, Water quality, Water purification, Water clean*, Sequestration, Mining
<i>Soil erosion control</i>	Leaf litter production +	Litter layer mass/depth + Root mass per unit soil area + Understorey biomass +	Root depth +	Soil erosion, Weathering, Soil loss, Sediment, Root depth, Root density, Erosion protection, Soil stability, Sand stability, Root depth, Root density, Soil erodibility, Soil floor

Table 1. Continued

Regulating ecosystem services	Ecosystem processes	Target variables Ecosystem/community properties	Plant species traits	Key words used in the literature search†
<i>Soil fertility</i>		Canopy nutrient content + Carbon exchange capacity + Soil base saturation + Soil nutrient content +	Leaf nutrient content + Litter nutrient content +	N fixation, (Soil, Leaf, Leaves, Litter) AND (Nutrient*, Nitrogen, Phosphorus, CEC)
<i>Soil formation</i>	Infiltration rate of nutrients + Litter accumulation rate + Litter decomposition rate + Mineralization rate + Nutrient input by litterfall + Soil microbial activity + Soil respiration rate +	Litter layer mass/depth + Root mass per unit soil area + Soil invertebrate abundance + Soil organic matter +	Hyphal length + Litter C:N – Litter lignin – Litter lignin:N –	LMA, SLA, SLM, Nitrogen, Phosphorus, Lignin, Litter decomposition, Litter C:N, Litter C/N, Mineralization, Nitrification, Ammonification, Soil respiration, Microbial biomass, Soil organic matter, Soil compaction, RGR, Growth rate, Litter layer, Litter?fall, Soil invertebrates, Root specific length, Hyphal length
<i>Water regulation</i>	Canopy interception of rainfall + Evapotranspiration + Infiltration rate +	Canopy water content + Leaf area index + Litter layer mass/depth + Soil moisture + Water repellency –	Sap flow rate + Stomatal conductance +/– Transpiration rate + Tree water consumption rate + Water use efficiency +	Canopy water content, Soil moisture, Runoff, LAI, Litter layer, Evapotranspiration, Infiltration, Water recharge, Transpiration, Sap flow, Stomatal conductance, Water use efficiency

†Compound key words were introduced between inverted commas.

For timber products, we performed an intensive search of country reports where information on provisioning of harvested timber ($\text{m}^3 \text{y}^{-1}$) was available per species, at country or sub-country (state or administrative region) level, for the period 2007–2015. The difference between the proportion of timber provided by NNTs and by NTs was calculated as the effect size for each country/region (i.e. case study). A positive value indicates a higher timber provision by NNTs than by NTs, and *vice versa* (see Appendix S5 for further details).

For non-timber products, we considered 16 categories, following the classification of the Secretariat of the Convention on Biological Diversity (<https://www.cbd.int/doc/publications/cbd-ts-06.pdf>; Appendix S5). Fruits obtained from tree crops were excluded because they come from non-forest land cover zones. Given that production of different non-timber products is often species specific and may differ in orders of magnitude across products (e.g. cork production is expressed in $\text{t ha}^{-1} \text{y}^{-1}$, while honey and edible fungi in $\text{kg ha}^{-1} \text{y}^{-1}$) they could not be aggregated

across species. Moreover, information on productivity per species at the region/state level was generally not available for several of these 16 categories. To overcome these limitations, we compared the uniqueness in the production of non-timber products between NNTs and NTs. Uniqueness was recorded as the number of categories of non-timber products ($N = 0–16$) that could be obtained only from NNTs or only from NTs at country level (e.g. in Spain and Portugal, cork is exclusively produced by a NT, so this product counts as unique to NTs; by contrast, honey can derive from both NTs and NNTs, thus not counting as unique to any group). We compiled data for a total of 16 countries, each one representing a case study.

To assess whether NNTs have higher non-timber uniqueness than NTs in each country, we calculated the effect size using the log odds ratio under Peto's method ($\log OR_P$), which is frequently used in meta-analyses to aggregate data reported as frequencies. The $\log OR_P$ is the difference between an observed value and the value expected by chance in a contingency table (Borenstein

et al., 2009). In this case, the observed value was the number of non-timber categories unique to NNTs, while the expected value was calculated from the number of NNT and NT species present in the country, expecting that both groups have the same uniqueness for non-timber production (for further details on $\log OR_p$ calculation see Appendix S4B). A positive $\log OR_p$ value indicates that NNTs supply more unique non-timber product categories than expected according to the proportion of NNT species in the country. Specific sources of information are shown in Appendix S5.

(c) Cultural ecosystem services (CES)

CES cover non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences (MEA, 2005). These benefits were grouped under five categories: recreation and ecotourism, aesthetic, inspiration, cultural heritage and scientific interest (MEA, 2005). For each CES category we selected at least one representative source of quantitative information (Vaz *et al.*, 2018). For example, as sources for aesthetic value, we selected catalogues of ornamental plant dealers and catalogues of species present in urban parks (see Table 2 for all CES sources and Appendix S6 for further details). For each case study (e.g. each catalogue), we calculated the effect size using the $\log OR_p$ (as in Section II.1b). In this case, the observed value was the frequency of NNT species in the CES source; the expected value was calculated assuming that both NNT and NT species have the same chances of being included in the source (Appendix S4B). $\log OR_p$ values higher or lower than 0, respectively, indicate an increase or decrease in the particular CES caused by NNTs. Data on CES were collected for different regions/states for most countries. For USA, only data for Hawaii could be collected. In total, our database contained 938 case studies from 13 countries.

(d) Ecosystem disservice (EDS)

The contribution of NNTs to the EDS pollen allergenicity was assessed using the same procedure described for CES. In this case, the source of information was the *Allergome* website (www.allergome.org), which compiles worldwide information on allergenicity of plant species. For each of 62 countries/regions we counted the number of NNT and NT species with and without allergenic pollen, using the lists of tree species present in each country. We then calculated the effect size using $\log OR_p$, in which the observed value was the frequency of NNT species producing allergenic pollen. The expected value was calculated assuming that both NNTs and NTs have the same chances of being allergenic (see Table 2 and Appendix S4B). $\log OR_p$ values higher or lower than 0, respectively, indicate a higher or lower contribution from NNT species to the EDS than expected by chance.

(e) Predictors of the variation of NNT effects on ecosystem (dis) services

Based on previous knowledge (Brundu & Richardson, 2016; Castro-Díez *et al.*, 2014a; Kull *et al.*, 2011; Vilà & Pujadas, 2001) we selected a set of nine predictors to explain the variation of NNT effects on ecosystem (dis)services (Table 3). For RES, we selected one biogeographic predictor (biome), two properties of the vegetation structure (native ecosystem type and NNT stand type), one functional property of NNTs (N-fixing), and the phylogenetic relatedness between species (see Section II.2b). Biome was selected because the literature suggests that the effects of non-native plants on the nutrient cycle depend on the large-scale climatic conditions, as captured by biomes (Castro-Díez *et al.*, 2014a). The type of native ecosystem (e.g. grassland, shrubland, forest, etc., see categories in Table 3) was included to account for the gross functional distance between the NNT and the dominant control vegetation, a key factor to explain the magnitude of the impacts caused by non-native plants (Castro-Díez *et al.*, 2014a; Chapin *et al.*, 1996; D'Antonio & Corbin, 2003). The type of NNT stand (whether planted or naturalized) may explain variations in the effects of NNTs on RES because of different functioning between an artificial (planted) stand and a spontaneous self-maintained system (forest with naturalized NNTs) (Cruz-Neto *et al.*, 2018; Paz *et al.*, 2015). Finally, the N-fixing ability of NNTs was selected because of its well-known effect on soil properties and processes (Castro-Díez *et al.*, 2014a; Liao *et al.*, 2008; Vilà *et al.*, 2011). For PES, CES, and EDS we also selected biome, plus two indicators of socio-economic development (gross domestic product and human development index), two demographic predictors (population density and proportion of rural population), and an index of human disturbance (ecological footprint) (Table 3). Socio-economics and demography are recognized determinants of people's demands for resources and their perception of cultural assets from non-native plants (Kueffer, 2017; Kull *et al.*, 2011; Vaz *et al.*, 2018; Vilà & Pujadas, 2001). The numeric predictors were not significantly correlated in our data set (Spearman's rank correlation test: $r_s < 0.045$, $P > 0.05$). Information on the sources used to obtain these predictors and the rationale for their selection is shown in Appendix S7.

(2) Data analyses

(a) Computation of grand mean effect size

To assess the contribution of NNTs to the provision of each ecosystem service across RES, PES, CES and EDS (with the exception of timber provision, see below), all effect sizes (Hedges' d or $\log OR_p$) obtained for each ecosystem (dis) service were combined using a random effects meta-analysis model (REMA) to provide a grand mean effect size [either d^+ for numerical data (RES) or $\log OR_w$ for frequency data (non-timber PES, CES and EDS)], where the weight of each case study was the reciprocal of the case study variance. In a random-effects model, the variance of each study results from the variability within (i.e. sampling error) and among case studies (i.e. the random component). We calculated the latter

Table 2. Sources of information associated with different categories of cultural ecosystem services (CES) and one disservice (EDS), pollen allergenicity. Calculation of the log odds ratio under Peto's method ($\log OR_P$) was based on the difference between the observed non-native tree (NNT) value in a given source (A) and the expected NNT value under the assumption that both NNTs and native trees (NTs) have the same chances of being included in the source: $(A+B) \times (A+C) / (A+B+C+D)$. For further details see Appendices S4B and S6. Information was collected mostly at the sub-country level (state or administrative region). No., number.

Cultural ecosystem (dis)services	Sources of information	Rationale	Values observed in the source associated with a given (dis)service		Values used as control	
			NNT in the source (A)	NT in the source (B)	NNT in the control (C)	NT in the control (D)
<i>Aesthetics</i>	Catalogues of ornamental plant dealers	Tree species offered by plant dealers are appreciated mostly for their aesthetic values	No. of NNT species offered in catalogues	No. of NT species offered in catalogues	No. of NNT species present in the country	No. of NT species present in the country
	Tree inventories of urban parks	Tree species exhibited in urban parks are included mostly for their aesthetic values	No. of NNT species present in inventories	No. of NT species present in inventories	No. of NNT species present in the country	No. of NT species present in the country
<i>Recreation and ecotourism</i>	Official tourism websites	Photographs from tourism websites were selected for the potential of NTs or NNTs to attract tourists, constituting motivations for tourism	No. of photographs dominated by NNTs	No. of photographs dominated by NTs	NNT cover in the region	NT cover in the region
	Nature routes from <i>Wikiloc</i>	Geo-referenced nature routes shared with the public were a mean of assessing society preferences for recreation and tourism	No. of route photographs dominated by NNTs	No. of route photographs dominated by NTs	NNT cover in the region	NT cover in the region
<i>Cultural heritage</i>	Official lists of monumental trees	Monumental trees represent symbols of culture and history, relating to human 'sense of place'	No. of NNTs in the list	No. of NTs in the list	NNT cover in the region	NT cover in the region
	Collective websites of artistic nature photographs	Artistic photographs reflect the choice of inspiring motifs from nature	No. of photographs dominated by NNTs	No. of photographs dominated by NTs	NNT cover in the region	NT cover in the region
<i>Scientific interest</i>	<i>Scopus</i> database of peer-reviewed scientific literature	The number of scientific publications on NNT or NT species in a country indicates the scientific interest on these species groups in that country	No. of publications on NNTs	No. of publications on NTs	No. of NNT species present in the country	No. of NT species present in the country
<i>Pollen allergenicity</i>	Pollen allergenicity from the database allergome.org	The allergenic potential of a tree reduces the benefit of human–nature interactions	No. of NNT species producing allergenic pollen	No. of NT species producing allergenic pollen	No. of NNT species not producing allergenic pollen	No. of NT species not producing allergenic pollen

Table 3. Predictors used to explain the variation of non-native tree (NNT) effect size on ecosystem (dis)services across case studies. The last column indicates the category of ecosystem service to which the predictor was applied (RES, regulating; PES, provisioning; CES, cultural ecosystem services; EDS, ecosystem disservice).

Acronym	Description	Predictor categories	Applied to ecosystem service category
<i>(Bio)Geographic context</i>			
1. Biome	Biome of the study site or dominating in the country	Tropical forest* Subtropical forest Subtropical desert Mediterranean Temperate forest Temperate grassland/desert Boreal forest	RES, PES, CES, EDS
<i>Stand and species properties</i>			
2. Ecosystem	Native ecosystem type	(Semi)desert Grassland shrubland Open forest Forest Urban	RES
3. Stand type	NNTs in forest plantations or naturalized	NNTs in planted stands NNTs in naturalized stands	RES
4. N-fixation	NNT is N-fixing or not	NNTs N-fixing NNTs not N-fixing	RES
<i>Socio-economic development</i>			
5. GDP	Nominal gross domestic product (US Dollars)	Numeric data	CES, PES, EDS
6. HDI	Human Development Index (ranking values)	Numeric data	CES, PES, EDS
<i>Demography</i>			
7. PopDens	Population density (km ⁻²)	Numeric data	CES, PES, EDS
8. RurPop	Proportion of rural population (%)	Numeric data	CES, PES, EDS
<i>Human disturbance</i>			
9. EFP	Ecological footprint (ranking values)	Numeric data	CES, PES, EDS

*The term 'forest' is used here in a broad sense, including also savannahs and woodlands.

using the restricted maximum-likelihood estimation (REML) for numeric data, and the DerSimonian-Laird (DL) model for frequency data (Borenstein *et al.*, 2009; Viechtbauer, 2010), using the *rma()* function implemented in the R package *metafor* (Viechtbauer, 2010). This function also provides the 95% confidence intervals for each grand mean effect size and a two-tailed parametric test checking whether the effect size differs from zero. Given the non-normal distribution of the residuals of some models, we additionally assessed the two-tailed significance of each grand mean effect size through non-parametric permutation tests under 1000 iterations using the *permutest()* function from package *metafor* (Viechtbauer, 2010).

In our data sets some case studies were derived from the same publication (RES), or refer to the same NNT species (RES), or come from the same country (RES, PES and CES), and thus may be more closely related to each other than to other case studies. To explore if non-independence affected the results, we additionally assessed the grand mean effect size and its significance using multi-level meta-analysis models (MLMAs), each including one source of non-independence

(publication, NNT species or country) as random factor (Nakagawa & Santos, 2012). These models allow for different variations of effect sizes between case studies within the same level of the random factor. MLMA models were fitted using the *rma.mv()* function in *metafor*. Differences in fit between the REMA and MLMA models were assessed using the Akaike Information Criterion corrected for small sizes (*AIC_c*), so that the more complex models (MLMAs) are considered to be an improvement on the simplest one (REMA) if they result in a reduction of *AIC_c* of two points or more (Burnham & Anderson, 2004; Senior *et al.*, 2016).

In the case of timber provision, the effect size of each case study was the difference between the proportions of timber provided by NNTs and by NTs, with no associated variance. Case studies were in most cases the largest administrative regions below the country level (equivalent to European NUTS-2), but for six countries (Bulgaria, Czech Republic, Chile, Ireland, New Zealand, and Portugal) data were only available at the country level. The grand mean effect size ($\pm 95\%$ confidence intervals) was calculated as the weighted median (due to non-normal distribution) across all case

studies. The weighting factor was the proportion of all global timber produced by each country/region (multiplied by 1000 for scaling reasons), so that country/regions with larger annual timber harvest (NNT+NT) contributed more to the grand mean effect size. A two-tailed Wilcoxon rank test was computed to assess whether the grand mean effect differed from zero, using the *wilcox.test()* function in R.

(b) Computation of heterogeneity and structured meta-analyses

For each grand mean effect size calculated with REMA (either d^+ or $\log OR_w$), we computed the heterogeneity across effect sizes using several statistics: (i) the Q_T statistic is the sum of squares of the deviations of each effect size from the grand effect size, weighed by the inverse of the effect sizes' variances. Q_T was tested against a chi-squared distribution with $n-1$ degrees of freedom (n = number of case studies) to assess whether the observed heterogeneity is greater than expected by chance (Borenstein *et al.*, 2009). The caveat of the Q_T statistic is that its reliability and significance depend on the number of case studies (Borenstein *et al.*, 2009; Nakagawa & Santos, 2012). Thus, we computed two additional statistics; (ii) T^2 which is the estimate of the between-case study variance; and (iii) I^2 which is the proportion (in %) of the total variation in effect sizes that is due to the between-study variance (T^2) (Borenstein *et al.*, 2009; Nakagawa *et al.*, 2017). The three statistics were calculated using the *rma()* function of the *metafor* R package. In the case of the MLMA models, we partitioned I^2 between the random factor level and the case study level following Nakagawa & Santos (2012).

We further assessed whether the variation of effect sizes could be explained by the predictors (fixed factors) shown in Table 3. We performed random-effects (REMA) structured meta-analyses using the *rma()* function, which allows incorporating predictors and returns coefficients and an omnibus test assessing whether the coefficient differs from zero. For continuous predictors, the function also provides the regression slope and its significance. Given the non-normal distribution of residuals in many cases, we additionally assessed the two-tailed significance of the predictors over 1000 iterations with the *permutest()* function (Viechtbauer, 2010).

In the case of RES, we also tested for a phylogenetic signal on the NNT effects using the *Phytools* R package (Revell, 2012). We first constructed a phylogeny of NNT species, starting from the time-calibrated molecular phylogeny of Zanne *et al.* (2014). We selected the taxa of our study (at genus level) using the *congeneric.merge()* function; then we pruned the phylogeny with the *drop.tip()* function to obtain a separated NNT phylogeny for each RES with a minimum of 10 species (otherwise the statistical power was considered too low). The phylogenetic signal was assessed using two common comparative metrics (Blomberg's K and Pagel's λ) (Blomberg, Garland & Ives, 2003; Pagel, 1999). Although the rationale behind these metrics is different, both approach 1 when the species phylogenetic signal approximates predictions under a Brownian motion model

of evolution, and approach 0 when there is no phylogenetic signal.

To explain the variation of NNT effects on timber provision, separate linear models were conducted with the R function *lm()* to assess the effects of the biome and socio-economic predictors in Table 3. In some cases, effect sizes were aggregated at the country level before performing the linear models to match the scale at which predictors were available. Country was tested as an additional predictor, as this data set did not allow us to perform a MLMA with country as a random factor (see Section II.2a). In the analysis of country, the six countries where timber provision was only available at country level were removed from the analyses. To improve homoscedasticity, the effect size (the difference between the proportions of timber provided by NNTs and by NTs) was transformed according to the formula: $\arcsin(\text{sign}(x) \times \sqrt{\text{abs}(x)})$. To compensate for the different contribution of each case study to global timber production, the weighting factor was included in all linear models with the R function *offset()*.

(c) Publication bias

Meta-analysis results may be affected by publication bias, i.e. the selective publication of articles finding significant effects over those which find non-significant effects (Begg, 1994). Publication bias for each RES was investigated by exploring asymmetry in a funnel plot, with effect sizes on the x -axis and standard error of effect sizes on the y -axis. In the absence of publication bias, this plot is expected to be a symmetric funnel shape, with a larger dispersion of effect sizes for studies with smaller sample size, i.e. those with large standard errors of effect size (Borenstein *et al.*, 2009). We assessed funnel asymmetry using the random/mixed-effects version of the Egger's test, which performs a structured meta-analysis with the standard error as predictor, and returns its slope and significance (Sterne & Egger, 2005). This test was implemented using the *regtest()* function of the *metafor* package (Viechtbauer, 2010). A significant relationship implies asymmetry in the funnel plot, which may be an indication of publication bias due to missing values on one side of the funnel. However, there are other reasons for funnel asymmetry besides publication bias, such as heterogeneity (Nakagawa & Santos, 2012; Viechtbauer, 2010). Thus, when the Egger's test on the meta-analysis without predictors indicated asymmetry, we repeated the test on the meta-analysis with the predictor which explained more heterogeneity. If this test still reported asymmetry, we assessed the impact of publication bias by removing case studies responsible for funnel asymmetry (Borenstein *et al.*, 2009), and by applying the trim-and-fill method (Duval & Tweedie, 2000). This method uses an iterative procedure to remove the most extreme small studies from the asymmetric side of the funnel plot, then adds the original studies back into the analysis, imputes a mirror image for each one, and re-computes the meta-analysis. If the new grand mean effect size retains the same sign and significance, then we conclude that publication bias has a trivial or modest impact, but

if there is a shift of the sign or significance of the grand mean effect size, then the impact of publication bias may be substantial (Nakagawa & Santos, 2012).

(d) Synergies and trade-offs between ecosystem (dis)services

Some variables are simultaneously involved in multiple services, which may lead to synergies and trade-offs among services within and among categories (Cord *et al.*, 2017; de Groot, Wilson & Boumans, 2002). For instance, depth of the litter layer is positively related to soil formation but negatively to fire-risk prevention (see Table 1), which may lead to trade-offs between these services. We checked for the existence of positive and negative relationships among the effects of NNTs on different ecosystem (dis)services. Given that the unit of observation differed across types of ecosystem (dis)services (NNT species for RES *versus* country or administrative region for PES, CES and EDS), associations were evaluated through two separate analyses. For RES, we computed the mean effect size (d^+) of each NNT species on each service and tested for significant correlations among the effects of the same NNT species on different RES. For PES, CES and EDS, we calculated the mean effect size ($\log OR_w$) for each country/region, and analysed the correlations among the NNT effects found in the same countries/regions on different PES, CES and EDS. We used pairwise Spearman rank correlation tests in R software.

R codes and part of the data used in this study are available in the repository *Consortio Madroño* (doi: 10.21950/EGM8SE).

III. RESULTS

(1) Description of the data set

We analysed a total of 1683 case studies (529 on RES, 154 on PES, 938 on CES, and 62 on the EDS pollen allergenicity). Data covered 44 countries (33 on RES, 22 on PES, 13 on CES and 13 on EDS), all continents except Antarctica, and seven biomes (Fig. 1). Continents with developed countries, such as Europe, were over-represented with respect to their size, whereas large continents such as Asia and Africa were under-represented (Fig. S1). Temperate, mediterranean and tropical biomes accounted for most case studies, while other biomes were less (boreal forest, subtropical forest and desert, and temperate grassland/desert) or not (polar) represented (Fig. S2).

The best represented ecosystem services were soil formation (RES), soil fertility (RES), timber provision (PES), recreation and ecotourism (CES), and aesthetics (CES), with more than 115 case studies each. The least represented ecosystem services were pollution regulation (RES), pollination (RES), non-timber provision (PES) and scientific interest (CES), with less than 20 case studies each (Fig. 2). For plague control and flood regulation (RES), no valid case studies were found.

Our RES data set covered a total of 125 NNT species. Among them, four species (*Ailanthus altissima* (Mill.) Swingle,

Pinus radiata D. Don, *Robinia pseudoacacia* L., and *Falcata moluccana* (Miq.) Barneby & J.W. Grimes) were the best represented, with 20–22 case studies; four additional species (*Acacia saligna* (Labill.) Wendl., *A. longifolia* (Andrews) Willd., *Eucalyptus globulus* Labill., and *Ligustrum lucidum* W.T. Aiton) were represented by 10–17 case studies. At the other extreme, 44 NNT species were each represented by a single case study (Table S1). The PES, CES and EDS data sets covered the (dis)services provided by all NNT *versus* all NT species of a country or region (see Section II.1); thus, the list of NNT species was not specified in this case.

(2) Effects of non-native tree species on regulating ecosystem services

Our random-effects meta-analysis (REMA) of 529 case studies obtained from the scientific literature revealed that NNTs increased climate regulation, soil fertility, soil formation and soil erosion control, but decreased fire-risk prevention (Fig. 2A). Asymmetry in funnel plots (Fig. S3) and Egger's tests suggest the presence of publication bias for climate regulation, soil fertility and fire-risk prevention; however, the asymmetry of the latter disappeared when ecosystem type was included as predictor (Table S2). For climate regulation and soil fertility, the trim-and-fill procedure did not change the mean effect size, suggesting that the impact of publication bias was trivial (Table S2). In addition, the removal of the six case studies responsible for the funnel asymmetry in the soil fertility data set (see Fig. S3) resulted in a smaller, but still significant, mean effect size (d^+ shifted from 0.63, $P = 0.012$ to 0.46, $P = 0.027$). For pollution regulation, pollination and water regulation we found no significant effects of NNTs (Fig. 2A).

Compared with REMA, MLMA including either reference, country or NNT species as a random factor, generally improved the model's explanatory power (AIC_c reduction ≥ 2). However, results were largely consistent between REMA and the MLMA. The only exceptions were soil fertility and soil formation, which were not significantly affected by NNTs when NNT species (soil fertility) or country (both RES) were added as random factor in MLMA (Table S3).

The heterogeneity of NNT effects across case studies was high ($I^2 > 80\%$) for all RES except pollination, Fig. 2A, Table S3). Biome explained the heterogeneity of effects on climate regulation, soil formation and soil erosion control (Table S4), with larger effects in low-latitude biomes (tropical and subtropical forests) than in middle-latitude biomes (mediterranean and temperate forest) (Fig. 3A–C). Fire-risk prevention was more decreased by NNTs in shrublands than in grasslands and forests (Fig. 3D). The increase of soil fertility and formation by NNTs was greater in stands of naturalized NNTs than in NNT plantations (Fig. 3E, F). Finally, higher increases of soil fertility, soil formation, soil erosion control, and water regulation were found when NNTs were N-fixing (Fig. 3G–J). The remaining effects of predictors on RES were non-significant (Table S4). The ability of the Fabaceae clade (encompassing N-fixing species) to contribute most to soil fertility and soil formation was

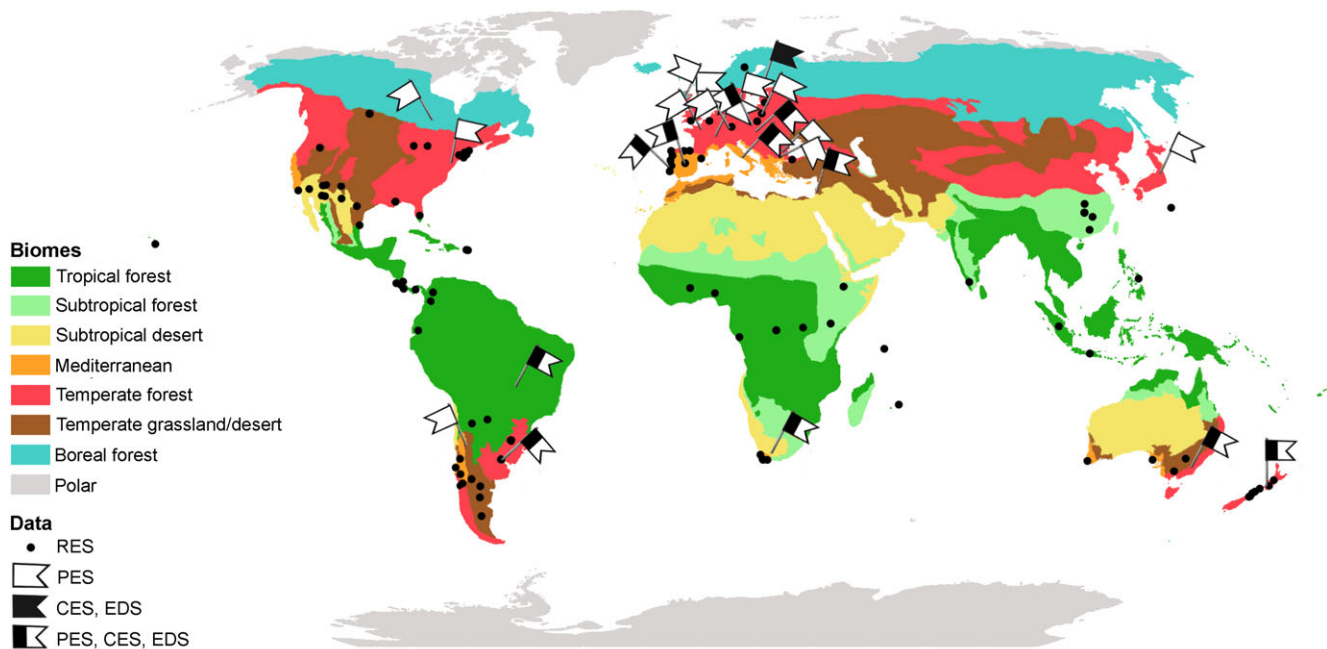


Fig. 1. Simplified representation of the distribution of case studies. Data were collected to evaluate worldwide effects of non-native tree species on regulating (RES), provisioning (PES) and cultural (CES) ecosystem services and ecosystem disservices (EDS). For simplicity only RES are represented at the local scale (dots), whereas data for PES, CES and EDS are represented at the country scale (flags). The map shows the biomes considered in this study for illustrative purposes (simplified from the FAO Global Ecological Zones). The term ‘forest’ is used in a broad sense, including also savannahs and woodlands.

also reflected in the significant values of Pagel’s λ , which indicated a phylogenetic signal in these effects. However, for the rest of RES, neither Pagel’s λ nor Blomberg’s K show a phylogenetic signal attributable to a Brownian model of evolution (Table 4).

(3) Effects of non-native tree species on provisioning ecosystem services

From our global data set of 144 case studies obtained from worldwide forestry reports, we found that the proportion of timber obtained from NTs was slightly higher than that obtained from NNTs (Fig. 2B). ANOVA tests showed large differences in NNT effects across biomes ($F = 6.07$, $P < 0.001$), and across countries ($F = 17.91$, $P < 0.001$). Timber production in the subtropical forest biome relied mostly on NNTs while temperate and boreal biomes relied more on NTs (Fig. 4A). Some countries obtained timber mostly from NNTs (Argentina, Chile, Ireland, New Zealand, South Africa, UK), while others relied almost exclusively on NT (Austria, Bulgaria, Canada, Czech Republic, Germany, Japan, Switzerland, USA – with the exception of Hawaii) (Fig. 4B).

Among the five uncorrelated socio-economic and demographic predictors, only the proportion of rural population was negatively related to the effect size (slope = -0.04 , $P = 0.002$), indicating that regions with a higher proportion of rural population rely less on NNTs for timber provision (Table S5).

On the basis of the information collected for 16 countries, we found less uniqueness of non-timber products in NNTs than NTs, i.e. there are more categories of non-timber products that are exclusively obtained from NTs than from NNTs (Fig. 2B).

(4) Effects of non-native tree species on cultural ecosystem services

Our global data set revealed that NNTs have a wide range of effects on the five CES categories considered. According to REMA results, NNTs increased aesthetic values determined from catalogues of plant dealers and inventories of urban parks. For recreation and ecotourism, NNTs were present more often in ecotourism websites, but less in nature routes than NTs than expected by chance (Fig. 2C). NNTs increased cultural heritage (i.e. they were over-represented in catalogues of monumental trees) but have less scientific interest (i.e. they are the subject of fewer scientific publications, according to the *Scopus* database) than NTs (Fig. 2C). We found no effects of NNTs on inspiration (assessed from the frequency of occurrence in artistic photographs) (Fig. 2C). Including country as a random factor in MLMA improved all models (i.e. explained a high proportion of the residual between-case studies variance (I^2) and decreased the AIC_c by at least two units, Table S6), but results were consistent with those of REMA for most CES. The only exception was recreation and ecotourism, where the negative selection of NNTs for nature routes was not

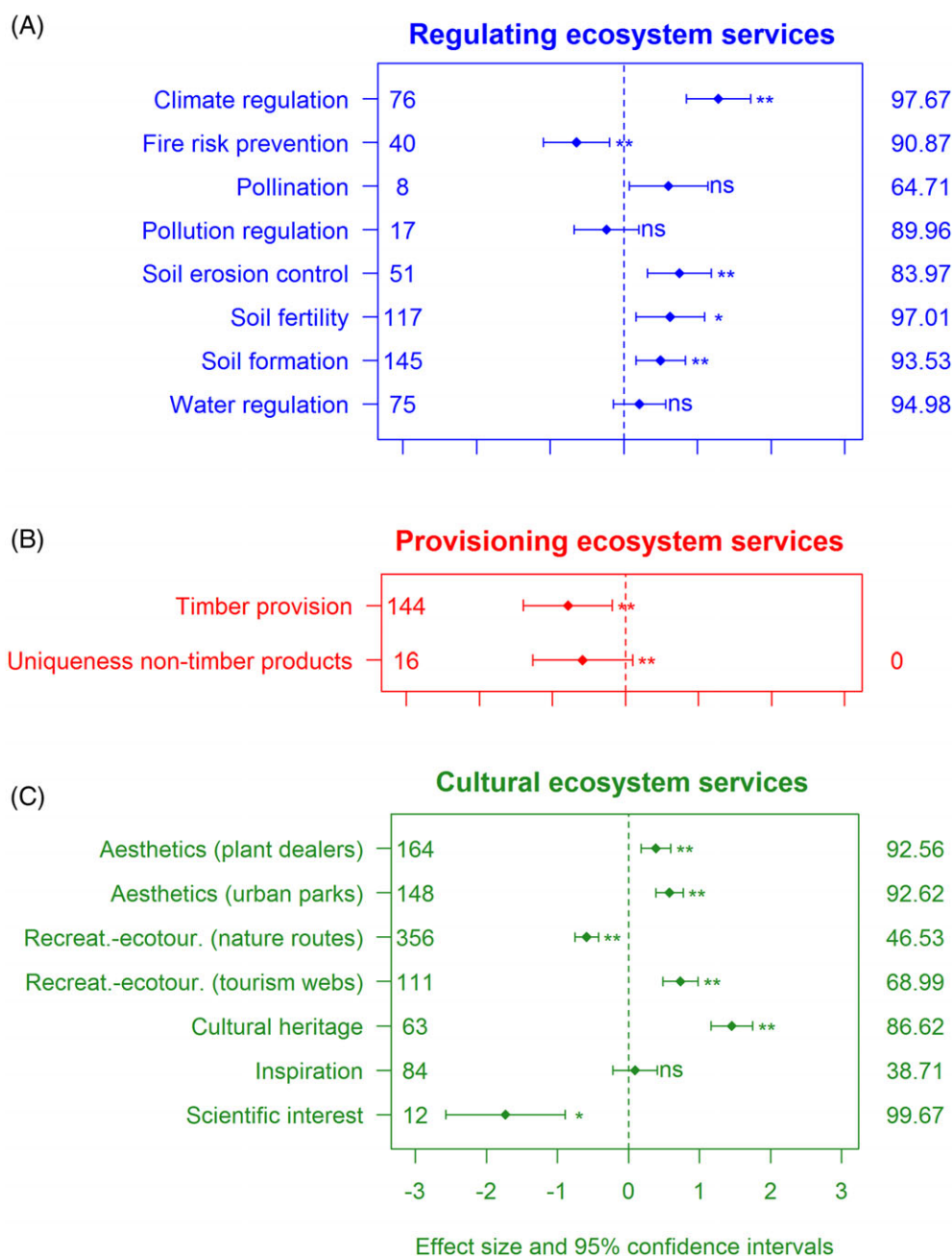


Fig. 2. Effects of non-native tree (NNT) species on ecosystem services assessed using the random-effects model (REMA). The mean effect size of NNTs and 95% confidence intervals are depicted across the set of case studies considered for each regulating (A), provisioning (B) and cultural (C) ecosystem services (sample sizes are indicated next to each service). Positive or negative mean effect sizes, respectively, indicate that NNTs (or sites dominated by NNTs) had greater or smaller scores for the service, compared to native tree (NT) species or to control sites dominated by native vegetation. Asterisks to the right of the bars indicate that the mean effect size differs significantly from zero according to a permutation test with 1000 iterations. Values on the right axis indicate the heterogeneity I^2 , which is the proportion (in %) of the total variation in effect sizes that is due to between-study variance.

significant when country was included as random factor in MLMA (Table S6).

Heterogeneity of effect sizes across case studies was high for most CES ($I^2 > 80\%$, except for recreation/ecotourism and inspiration, Fig. 2C, Table S6). Biome contributed to explaining the variation of NNT effects on aesthetics and

recreation and ecotourism (Table S7). NNTs contributed more to aesthetics in tropical and temperate biomes than in mediterranean and boreal ones, and NNTs were used more in tourism websites in the mediterranean than in other biomes (Table S8). In countries with higher gross domestic products, NNTs contributed more to aesthetics, and were

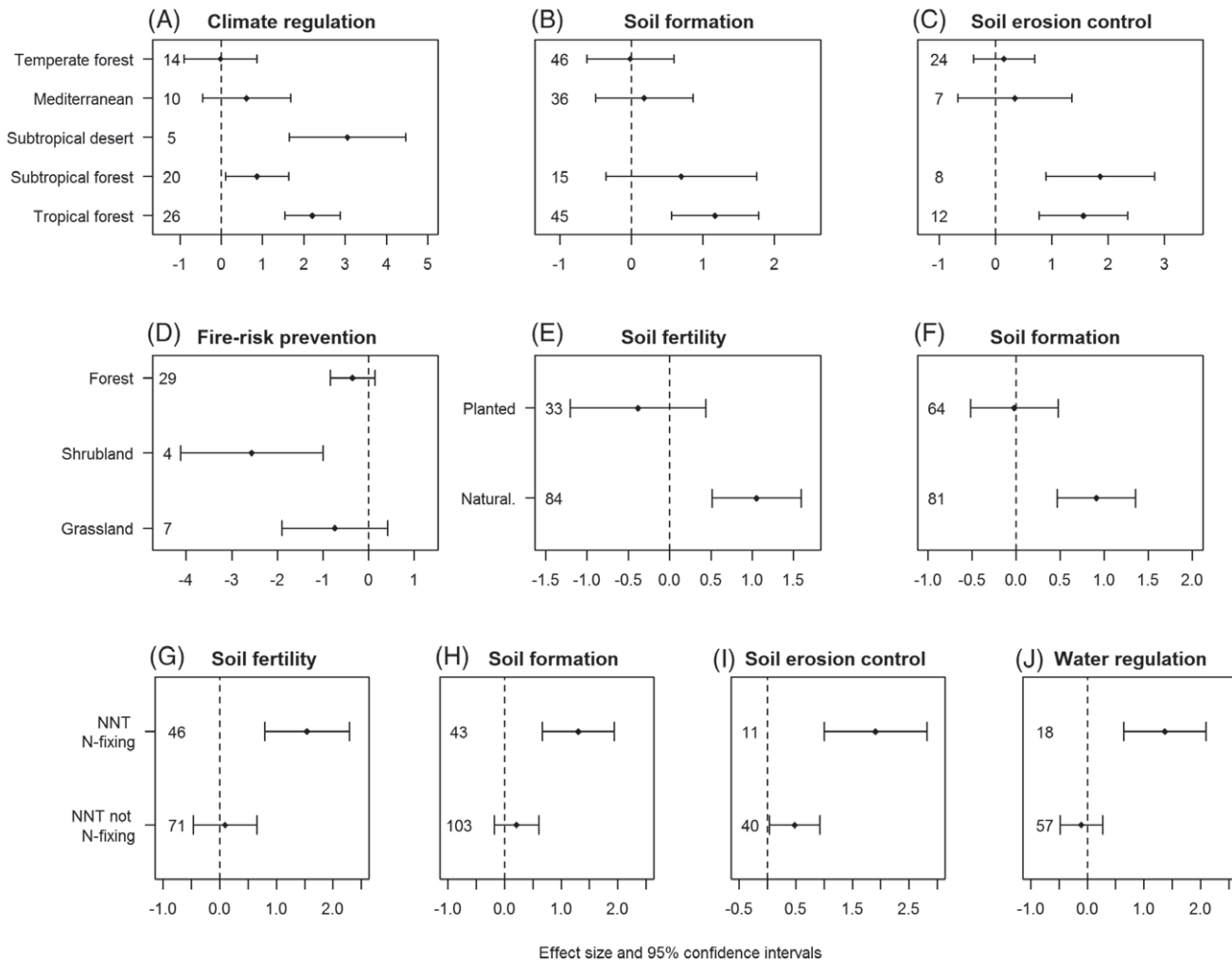


Fig. 3. Predictors explaining the effects of non-native tree (NNT) species on regulating ecosystem services (RES) under random-effects structured meta-analysis: biome (A–C), native ecosystem type (D), stand type (E, F) and N-fixation of the NNT (G–J). The figure shows the mean effect size (d^+) of NNTs and 95% confidence intervals across the set of case studies considered for each predictor category. Positive or negative mean effect sizes, respectively, indicate that sites dominated by NNTs had a greater or smaller score of the RES than control sites with native vegetation.

Table 4. Results from two common metrics used in comparative analyses (Blomberg's K and Pagel's λ) to test for a significant phylogenetic signal in the effects of non-native trees (NNTs) on regulating ecosystem services (RES). Each cell contains the value of the metric and its significance (P) according to the expectation of a Brownian model of evolution. N represents the number of NNT species in each RES. Significant results ($P < 0.05$) are indicated with asterisks.

Metric	Climate regulation	Fire-risk prevention	Pollution regulation	Soil erosion control	Soil fertility	Soil formation	Water regulation
Blomberg's K (P)	0.025 (0.859)	0.184 (0.289)	0.456 (0.588)	0.056 (0.686)	0.543 (0.091)	0.063 (0.687)	0.087 (0.661)
Pagel's λ (P)	0.000 (1.000)	0.001 (1.000)	0.001 (1.000)	0.117 (0.326)	1.006** (0.001)	0.393* (0.037)	0.001 (1.000)
N	54	35	14	37	56	79	57

more used in tourism websites, but they were selected less often for nature routes. In countries with higher values of the human development index, NNTs had less effect on aesthetics and recreation and ecotourism services, suggesting larger effects in less-developed countries. In countries with higher population density or with a higher proportion of rural

population, NNTs contributed less to aesthetics but more to recreation and ecotourism. The contribution of NNTs to cultural heritage declined at higher population density. NNTs were less selected as recreation and ecotourism, and inspiration assets in countries with larger ecological footprints (i.e. human disturbance, Table S7).

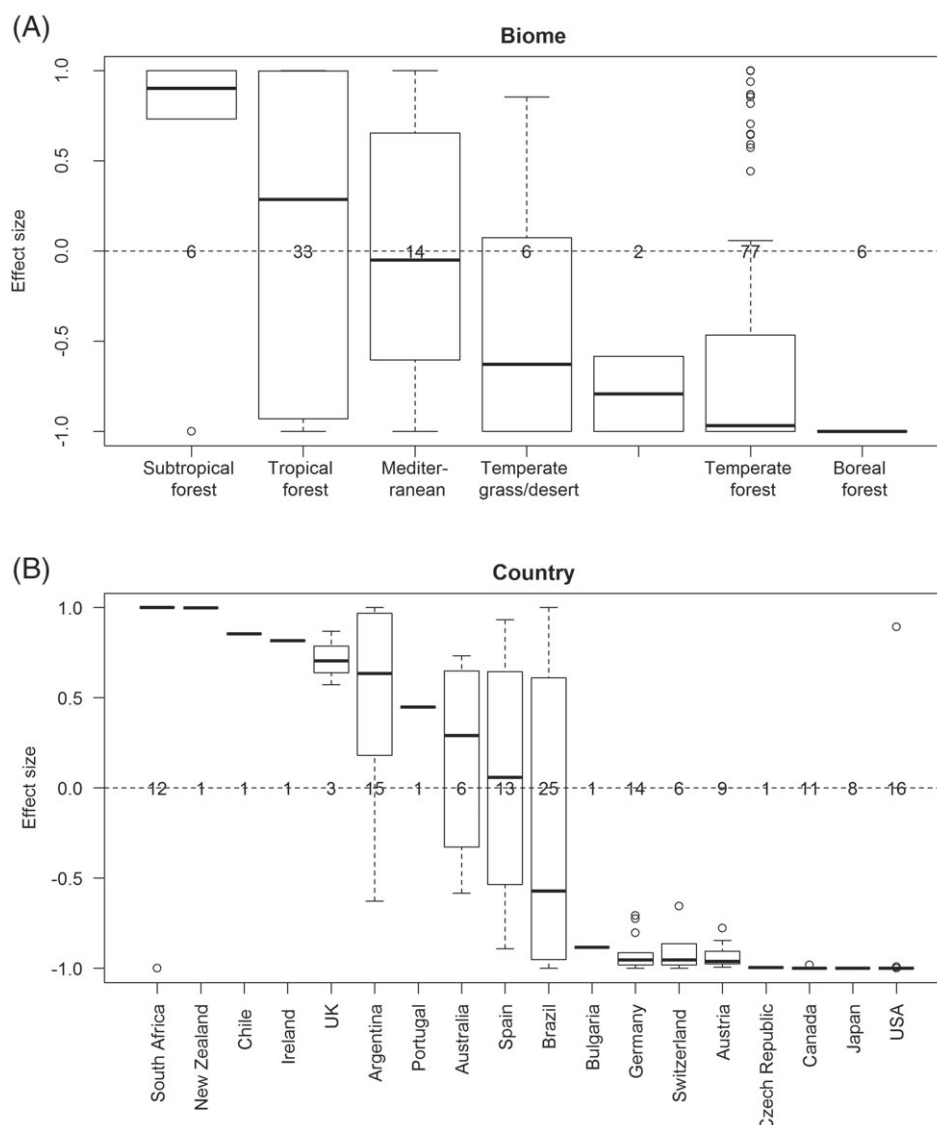


Fig. 4. Effect size of non-native trees (NNTs) on timber provision across biomes (A) and across countries (B). For each biome/country the horizontal band represents the median; box limits are defined by the 25th and 75th percentiles; upper whiskers are the smallest of the maximum country/biome value and 75th percentile + $1.5 \times$ box extension; lower whiskers are the largest of the smallest biome/country value and 25th percentile - $1.5 \times$ box extension. Circles indicate extreme values outside the whisker interval. The number of case studies in each biome/country is indicated (biomes/countries with less than three case studies were not included in the statistical analysis).

(5) Effects of non-native tree species on the ecosystem disservice

Overall, NNTs producing allergenic pollen were not more frequent than expected, either using REMA or MLMA with country as a random factor ($\log OR_w \pm SE = 0.093 \pm 0.197$ and 0.587 ± 0.365 , with REMA and MLMA, respectively, $P > 0.05$, $N = 62$, Table S6). Nevertheless, NNT effects on pollen allergenicity varied widely with context ($I^2 = 91\%$). In tropical and temperate biomes, NNTs contributed more to pollen allergenicity than in mediterranean and boreal ones (Table S8). Higher NNT contribution to pollen allergenicity was also associated with countries with higher gross domestic

products. Finally, pollen allergenicity was increased less by NNTs in countries with a higher proportion of rural population (Table S7).

(6) Relationships between ecosystem services

The effects of NNTs on several RES were correlated with each other. Most Spearman correlations were positive [i.e. among soil fertility, soil formation and erosion control, as well as climate regulation, and water regulation ($R_s = 0.41-0.68$, $P = 0.010-0.001$)]. However, fire-risk prevention was negatively correlated with other RES

($R_S = -0.69$ and -0.67 , $P < 0.001$ for soil erosion control and water regulation, respectively, Table S9).

The overall effects of NNTs on PES, CES and EDS within countries/regions were somewhat correlated. The most significant was a positive correlation between the two sources of information used for aesthetics, i.e. catalogues of plant dealers and urban parks ($R_S = 0.89$, $P > 0.001$). Aesthetics was also positively correlated with pollen allergenicity ($R_S = 0.56$ – 0.65 , $P = 0.01$), suggesting that many ornamental NNTs produce allergenic pollen. Uniqueness of non-timber products was negatively related to pollen allergenicity ($R_S = -0.71$, $P = 0.03$). Although marginally significant, countries where the contribution of NNTs to pollen allergenicity was higher tended to show higher scientific interest in NNTs ($R_S = 0.58$, $P = 0.06$, Table S10).

IV. DISCUSSION

(1) The data set

Our study is the first comprehensive global analysis of the effects of NNTs on ecosystem (dis)services that brings together information from a broad spectrum of scientific subjects, as well as from online sources. Despite the global scope, information was more abundant for developed countries, mediterranean and temperate forest biomes, and for tree species with high societal interest. This geographical and taxonomic bias is well documented in the ecological literature (Hulme *et al.*, 2013; Martin, Blossey & Ellis, 2012; Pyšek *et al.*, 2008; Wilson *et al.*, 2007). Human population and forest cover are unevenly distributed across biomes, and scientific institutions are more abundant in wealthy regions (Wilson *et al.*, 2007). Our RES data set covered one third of the 430 NNT species known to be invasive (Rejmánek & Richardson, 2013), of which just 22 species accounted for half of the case studies. This fact highlights that scientists repeatedly target the few species with known large impacts on social-ecological systems (Hulme *et al.*, 2013; Pyšek *et al.*, 2008). The coverage of ecosystem services was limited by the need to find measures suitable for pairwise comparisons and by the need to harmonize data across multiple countries. Despite these limitations, this study offers the most complete and up-to-date analysis of current knowledge on NNTs worldwide, and allowed us to identify key gaps for future research.

(2) Effects of non-native trees on ecosystem services

Overall, we found more increases than decreases in ecosystem services attributable to NNTs. This result is consistent with many NNTs having been deliberately introduced to create or enhance particular ecosystem services (Brundu & Richardson, 2016; Evans, 2009; Potgieter *et al.*, 2017). The increase in several RES due to the presence of NNTs may be attributed to their high productivity,

a trait often selected for NNT introduction (Richardson, 1998; Woziwoda, Kopec & Witkowski, 2014). Increased productivity of forests may promote climate regulation (*via* carbon uptake), and soil formation, fertility and erosion control (through higher root growth and/or the supply of more organic matter to the soil) (Evans, 2009; Mori, Lertzman & Gustafsson, 2017). The decrease in both timber and non-timber PES by NNT was unexpected, given that the purpose of many tree introductions is the supply of particular products (Brundu & Richardson, 2016; Evans, 2009; MacDicken, 2015). In the case of timber, this is because many temperate regions rely almost exclusively on NTs. The lower uniqueness of non-timber products found for NNTs suggests that many of these species were introduced to increase the quality or quantity of products already supplied by NTs, rather than to produce novel products (Krumm & Vitková, 2016). Regarding CES, the ornamental value of non-native plants was previously reported to be associated with the human preference for novelty and unusual features, e.g. the colourful or large flowers of *Jacaranda* and *Magnolia*, the crown shape and size of *Sequoia* and *Ficus* (Kueffer & Kull, 2017; van Wilgen & Richardson, 2012). This may explain the selection of NNTs as aesthetic, tourist and heritage assets (Vaz *et al.*, 2018). However, this does not explain the reduced touristic value of nature routes caused by NNTs. Ornamental NNTs are usually confined to gardens or urban parks. Outside these areas, NNTs can occur because they were planted for non-aesthetic purposes (e.g. timber production or land reclamation), or as naturalized escapes from plantations. The traits that promote non-aesthetic uses of NNTs (e.g. fast growth; Richardson, 1998), or those associated with naturalization success (e.g. profuse seed production or resprouting capacity; Castro-Díez *et al.*, 2011; Richardson & Rejmánek, 2004) can lead to monotonous and homogenized landscapes which are apparently less attractive to users of nature routes. Despite the growing number of studies on non-native species (Hulme *et al.*, 2013), the scientific interest in NNTs was overwhelmingly lower than for NTs. This may be because ecological interest in non-native species and their impacts is recent compared to the long history of research on pristine habitats and native species (Hulme *et al.*, 2013; Vaz *et al.*, 2017a).

Given that biodiversity often promotes multiple ecosystem services in forests (Gamfeldt *et al.*, 2013; Mori *et al.*, 2017; Poorter *et al.*, 2015), the increase of ecosystem services by NNTs found here seems at odds with the low biodiversity usually found in NNT-dominated systems (Gaertner *et al.*, 2011; Pyšek *et al.*, 2012; Vilà *et al.*, 2011). Our results may have been exacerbated by the fact that the baseline for comparison may include degraded or non-forest ecosystems. Moreover, replacing NTs with NNTs may maximize a particular ecosystem service at the expense of reducing the ecosystem's capacity to provide multiple services (Dickie *et al.*, 2014a; Evans, 2009; van Wilgen & Richardson, 2012), and most studies covered herein focus on single, rather than multiple, ecosystem services. We also note that maximizing some particular ecosystem services may not

always be beneficial for society or ecosystem functioning. For example, in the naturally infertile soils of some parts of Hawaii and the South African fynbos, the increase of soil nitrogen driven by the introduction of N-fixing NNTs is disrupting ecosystem functioning and altering several ecosystem services, such as soil fertility and water supply (Gaertner *et al.*, 2011; Le Maitre *et al.*, 1996; Vitousek & Walker, 1989). Thus, focussing environmental policies on ecosystem services may overlook the intrinsic value of nature and leave biodiversity under-protected (Dee *et al.*, 2017; McCauley, 2006; Silvertown, 2015).

(3) Variability of non-native tree effects on ecosystem services worldwide

NNT effects in most ecosystem (dis)services showed medium to high heterogeneity, with I^2 values above 80% in most cases. This high heterogeneity is typical of ecological studies, where effect sizes derive from different species and different contexts (Senior *et al.*, 2016). Nevertheless, we were able to explain part of this heterogeneity. Nitrogen-fixing NNTs had especially strong effects on soil fertility, in agreement with previous studies (Castro-Díez *et al.*, 2014a; Liao *et al.*, 2008; Vilà *et al.*, 2011). Compared with non-N-fixing NNTs, N-fixing NNTs may attain a higher production in infertile or degraded soils, explaining their contribution to soil formation (by supplying more organic matter to the soil), and to erosion control and water regulation (by a denser protective cover of the soil and a greater net of roots belowground). Accordingly, the low proportion of N-fixing NNTs among planted stands (9.1–14.1%), compared with naturalized stands (41.5–51.2%), may explain the larger effect size of NNTs on soil fertility and formation found in naturalized stands. Certain RES were more affected by NNTs in low-latitude biomes than in temperate biomes, possibly related to the stronger effect of non-native plants on the nitrogen cycle in benign climates reported previously (Castro-Díez *et al.*, 2014a). Many NNTs are selected primarily for their high potential productivity (Richardson, 1998; Woziwoda *et al.*, 2014), a trait that underpins many ecosystem services. However, that high potential productivity would be realized more in environments where the favourable period for plant growth is longer (e.g. tropical forests) (Castro-Díez *et al.*, 2014a).

The degree of phylogenetic relatedness among species showed a small role in explaining variation of NNT effects on RES. This means that closely and distantly related species have similar effects. The only phylogenetic signal was found for the effects of NNTs on soil fertility and soil formation, and is associated with the phylogenetic proximity among N-fixing NNTs, which had greater effects on these RES.

The great cross-country and cross-biome variation observed in the contribution of NNTs to timber provision might be explained by several non-exclusive arguments. First, regions with high availability or variety of NT species (e.g. USA, Brazil) have less need to introduce NNTs to supply their timber needs. Second, regions with a non-profitable

pool of NT species (e.g. because of prevailing slow growth rates, as occurs in the Mediterranean Basin) may have favoured plantations of profitable NNTs. Third, some former European colonies (e.g. Argentina, Australia, Chile, New Zealand or South Africa) have a stronger tendency to plant NNTs, due to the colonial ethos of ‘national development’, to cultural links with the colonists’ home countries or with other colonies, or to the loss of native cultures that were more dependent on native species (Carruthers *et al.*, 2011; Speziale *et al.*, 2012). Thus, a complex interaction of environmental, social and historical factors seems to have shaped species selection for PES (Kueffer, 2017). This also explains the poor role of socio-economic and demographic predictors when considered alone. Nonetheless, regions with a small proportion of rural population (or more urbanised regions) seem to rely more on NNTs for timber. This suggests that rural societies tend to rely more on native assets, because the populace has a closer connection with the environment or less need of resources (Carruthers *et al.*, 2011; Shackleton *et al.*, 2007; Speziale *et al.*, 2012).

Our results showed that NNTs contributed more to CES in countries with greater nominal gross domestic products. Wealthy regions foster the trade and maintenance of non-native plants (Gavier-Pizarro *et al.*, 2010; Humair *et al.*, 2015; Vilà & Pujadas, 2001), and thus their contribution to CES (Vaz *et al.*, 2018). Nevertheless, NNT contribution to aesthetics, and to recreation and ecotourism decreased in regions with higher human development index (i.e. higher life expectancy, education level, and income), a trend previously observed in the Iberian Peninsula (Vaz *et al.*, 2018). This suggests a higher awareness of the risks associated with NNTs, and thus a higher preference for NTs as ornamental and tourism assets in more developed regions (Nuñez & Pauchard, 2010; Vaz *et al.*, 2018). Finally, we found a lower contribution of NNTs to tourism and inspiration services in regions with larger ecological footprint, suggesting that a higher pressure on natural resources makes people prefer NTs as inspirational and tourism assets.

Some predictors that explain the heterogeneity of NNT effects relate to intrinsic properties of individual NNTs (e.g. N-fixation ability) or to the environments in which they occur (e.g. biome). Other predictors relate more to the social dimension, such as socio-economy, demography, and cultural background. Whereas ecological conditions are expected to be more or less stable in the long term, the social dimension (e.g. human perceptions, norms and values, social memory, institutions and rules) is more prone to changes in a few generations. This has important consequences for the way in which NNTs affect ecosystem services through time (Kueffer & Kull, 2017; Kull *et al.*, 2018; Shackleton *et al.*, 2016). There are many examples of people embracing introduced species in their practices and traditions in preference to native species used previously (i.e. the ‘shifting baseline syndrome’; Kueffer & Kull, 2017; Nuñez & Simberloff, 2005; Speziale *et al.*, 2012). This poses an additional risk to focusing environmental policies solely on

ecosystem services, whose values for people are changeable over short time frames (Silvertown, 2015).

Despite the patterns of variation in NNT effects on ecosystem services revealed here, a large proportion of variation remains unexplained. This suggests that other predictors that were not considered in our analysis are important, such as NNT functional traits (e.g. plant size, seed mass or leaf habit; Castro-Díez *et al.*, 2014a; Pyšek *et al.*, 2012), or the historical factors accounting for the cultural and trade relations between distant regions through time (Speziale *et al.*, 2012). Other potential predictors may operate at local scales, and thus could not be included in our global-scale analysis (e.g. silvicultural practices, individual choices, attitudes, and behaviours; Grove *et al.*, 2006; Kull *et al.*, 2018).

(4) Synergies and trade-offs among the effects of non-native trees on ecosystem services

The correlations found among most RES can be explained by the fact that some tree traits simultaneously contribute to different RES. In particular, the potential growth rate of trees may underpin many of the identified links across the effects of NNTs on RES: fast-growing trees can be important carbon sinks and thus contribute to climate regulation, while simultaneously promoting erosion control and soil formation through rapid development of a protective soil cover, enhancing soil organic matter, and contributing to regulation of the water cycle. Yet, trade-offs across RES may also arise when the same trait contributes positively to some services and negatively to others (Potgieter *et al.*, 2017). Thus, some fast-growing trees can also increase fire risk by supplying a high quantity of fuel to the system, and because they invest less resources in protection against disturbances (Herms & Mattson, 1992). Regarding CES, we identified a strong correlation between the two sources of aesthetic information (i.e. catalogues of ornamental plant dealers and tree inventories of urban parks) indicating strong consistency between them. By contrast, the lack of correlation between the two indicators of recreation and ecotourism (i.e. official tourism websites and nature routes) indicates that they capture different aspects of ecotourism attraction: tourism websites may tend to highlight the ‘unusual’ or the ‘spectacular’ to attract visitors (e.g. a plantation of sequoias in northern Spain or conifers along the Garden Route in South Africa), whereas users of nature routes appreciate more ‘pristine’ nature dominated by native species (Vaz *et al.*, 2018). We also found a synergy between aesthetics and pollen allergenicity, suggesting that NNTs with aesthetic value may also exhibit traits that promote pollen allergenicity (e.g. wind pollination, which was found to increase with urbanization; Williams, Hahs & Vesk, 2015). This result converges with others showing high allergenicity in non-native air-borne pollen from ornamental NNTs (Belmonte & Vilà, 2004; Bosch-Cano *et al.*, 2011). Unfortunately, differences in scale of study used for RES compared with PES, CES and EDS precluded us from exploring other synergies and trade-offs across different categories of ecosystem services.

(5) Methodological limitations and future perspectives

Publication bias in the scientific literature may have affected our RES analysis. Funnel plot asymmetry suggests that the positive effects of NNTs on climate regulation and soil fertility may have been inflated by publication bias. However, the two methods applied (trim and fill and removal of case studies from the extreme of the funnel) suggest consistent results. Future updates might minimize publication bias, e.g. by extending the literature search to grey literature (Borenstein *et al.*, 2009).

Another methodological issue in meta-analysis is non-independence among case studies (Nakagawa & Santos, 2012; Noble *et al.*, 2017). Although partly removed by aggregating related case studies, non-independence remained in our data sets due to multiple case studies derived from the same publication, the same NNT species, or the same country. The impact of non-independence on results may be assessed by comparing the results from the two meta-analysis models, MLMA and REMA (with and without the source of non-independence as a random factor). Only three ecosystem services (soil fertility, soil formation and touristic value of nature routes) changed from being affected by NNTs (REMA) to a non-significant effect (MLMA with country as random factor, and also with NNT species in the case of soil fertility). This indicates that results for these services cannot be extended to any random set of case studies. For instance, the increase in soil fertility by NNTs was due to N-fixing trees; thus, a data set with fewer N-fixing NNTs would be likely to return a non-significant result. Also, the effect of NNTs on the touristic value of nature routes varied across countries (e.g. it was decreased in Australia and Spain, but increased in Italy and South Africa). Thus, the overall decrease may be attributed to the high proportion of case studies from Australia and Spain (Appendix S6). Future studies should account for this bias by representing each country with a number of case studies proportional to its population or size.

In the case of CES, EDS and non-timber PES, we used a novel indicator-based approach, previously described in Vaz *et al.* (2018). This approach allows assessing whether NNTs are preferred or rejected for particular services, using the ‘offer’ (i.e. availability) of NNTs in the region as a reference value. This approach has the advantage of integrating multiple sources of information, allowing reproducibility and updates as the sources expand (Vaz *et al.*, 2018). In addition, sources of information from social media (e.g. tourism, image-sharing, or commercial websites) have a much wider coverage than traditional scientific media (Richards & Friess, 2015; Wood *et al.*, 2013). Yet, the approach has some caveats: lower data quality (e.g. potential mistakes in species names in catalogues); low resolution of the analysis (effect sizes are calculated for a group of NNTs of a country/region, rather than for particular species); sensitivity of the effect size metric ($\log OR_p$) to the choice of data types and control data (Vaz *et al.*, 2018); or the inability to compare magnitudes of $\log OR_w$ across ecosystem

(dis)services with data sources provided in different units (e.g. species counts, species cover, or number of photographs). In summary, this novel approach is useful to obtain preliminary insights on the directions of effects of NNTs on certain ecosystem (dis)services assessed poorly by scientific media, and to cover spatial and temporal scales not attainable through traditional scientific methodologies. Future studies should validate our results for specific contexts using other methodologies (Hernandez-Morcillo *et al.*, 2013).

Our understanding of how NNTs, and non-native species in general, influence several ecosystem services simultaneously is poor (Vilà & Hulme, 2017). The approach used here to identify associations among responses of ecosystem services to NNTs represents a first crude exploration. Unfortunately, differences in scale of study used for RES (species), and for PES, CES and EDS (countries/regions), together with the limited number of species or countries common to many ecosystem services, precluded us from using a multivariate approach (Spake *et al.*, 2017). Such an approach would allow identifying bundles of services according to their response to NNTs (Raudsepp-Hearne, Peterson & Bennett, 2010), knowing how the impact on such bundles changes in space (Spake *et al.*, 2017) and thus identifying areas most at risk from NNTs.

V. CONCLUSIONS

(1) Our comprehensive worldwide review revealed more increases than decreases in ecosystem services attributable to NNTs. However, the strong context dependency of the effects, and the limitations of the concept of ‘ecosystem services’, means that these results must be interpreted with caution. The anthropocentric view of nature prominent in recent conservation literature may encourage the maximization of a few ecosystem services in the short term at the expense of long-term sustainability and multifunctionality.

(2) Part of the variation in NNT effects across case studies is explained by stable factors (e.g. biogeography, traits of NNTs), but some is due to changeable socio-economic and demographic factors.

(3) Trade-offs and synergies between ecosystem services emerge because they may be associated with the same plant traits.

(4) This review revealed some key knowledge gaps that need attention, such as the lack of information from large areas of Africa and Asia, and for many NNT species whose contribution to ecosystem services has not yet been documented.

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VII. AUTHOR CONTRIBUTIONS

P.C.-D. and O.G. produced the study idea; P.C.-D., A.S.V., O.G., J.S.S., M.V.L., A.A. and A.S. designed the research; all authors contributed to data collection; P.C.-D., A.S.V. and O.G. organized and analysed the data; P.C.-D. led the writing and A.S.V., O.G., J.S.S., M.V.L., D.M.R. and M.V. contributed to the first draft; all authors contributed to the final version of the manuscript.

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IX. SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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Appendix S1. Sources of information used to obtain the list of native and non-native tree species

We followed Richardson & Rejmánek (2011, p. 789) to define trees as “*perennial woody plants with many secondary branches supported clear of the ground on a single main stem or trunk with clear apical dominance*”, including palms. We also considered small trees, i.e. perennial woody plants developing an arboreal structure with a distinguishable bole, even if multi-stemmed. Non-native tree species (NNTs) were defined as those tree species that were introduced (accidentally or intentionally) by humans to new geographic areas (following Richardson *et al.*, 2011). Archeophytes were excluded from our data set so that only NNT introductions after 1492 (when the Columbian exchange began) were analysed.

The native or non-native status of a tree species was stated at the country level and at species level (ignoring subspecies or varieties). This avoided the problem of a tree being considered as a NNT on a continent but as a native tree (NT) species in the islands (and *vice versa*). For this reason, oceanic islands were not considered in this study. For Brazil, USA and Canada, however, data were pooled by state rather than by country owing to the magnitude of habitat heterogeneity across these countries.

All scientific names were validated following official floras of each country (see details below). Unresolved names were excluded. Hybrids were considered as NTs or NNTs when both parental species were NTs or NNTs. NT × NNT hybrids were excluded.

Specific data sources for each country:

Argentina: the list of NNTs was originated by gathering all species provided by plant dealers; for NTs we used the “Primer Inventario Nacional de Bosques Nativos”:

<http://www.ambienteforestalnoa.org.ar/userfiles/nodo/informenacionalpinbn.pdf>, Sanz (2001), and <http://www.darwin.edu.ar/Proyectos/FloraArgentina/fa.htm>.

Australia: the list of NNTs was obtained by first downloading the entire list of recorded flora from the Atlas of Living Australia (www.ala.org.au). Then, Margie Mayfield and Dan Metcalfe systematically went through the list, coding trees as native or non-native based on personal knowledge and information about each species found in regional floras and published species descriptions. We subsequently checked NNT status using Randall (2007) and various regional floras.

Austria: the list of NNT species was first obtained from Essl & Rabitsch (2002) (<http://www.umweltbundesamt.at/fileadmin/site/publikationen/DP089.pdf>) and complemented by all NNT species found in catalogues of plant dealers. The list of NTs was obtained from Fischer *et al.* (2008). The potential for pollen allergenicity of each species was first checked in the Austrian database (<https://www.pollenwarndienst.at/en/current-data.html>). When the particular species was not available in the national database, its pollen allergenicity was checked through “Allergome” (available at: <http://www.allergome.org>).

Brazil: the lists of NNTs and NTs for each Brazilian state were gathered from “Flora of Brazil” (<http://reflora.jbrj.gov.br/reflora/listaBrasil/ConsultaPublicaUC/ResultadoDaConsultaNovaConsulta.do>). Data did not include palm trees.

Czech Republic: the list of NTs was obtained from <http://www.pylovasluzba.cz/atlas>; NNTs were obtained from Pysek *et al.* (2002), complemented by NNTs found in catalogues for plant dealers, urban parks, and monumental trees.

Finland: NT and NNT lists were obtained directly from the lists of catalogues of plant dealers. We considered plant dealers who were known to have local tree production (not considering plant importers).

Hawaii: the list of NT species was obtained from vascular plant species checklists (e.g. Imada, 2012) and the forest tree species inventory (<https://www.fs.fed.us/pnw/rma/>). The list of NNT species was derived from catalogues of ornamental plant dealers and monumental trees and cross-referenced with the previous vascular plant species checklist as well as a forest tree species inventory.

Israel: the NT species list was compiled from Flora of Israel Online (<http://flora.org.il/en/avinoam-danin-2/>). The list of NNT species was derived from the KKL-JNF database on afforestation tree species, catalogues of ornamental plant dealers, information from urban parks, street trees guides, and the Israeli Ministry of Environmental Protection (<http://www.sviva.gov.il/English/Pages/HomePage.aspx>).

Italy: the list of NNT species was derived from Celesti-Grapow (2005) and Celesti-Grapow *et al.* (2009, 2010). The list of NNTs was complemented with information from urban parks, catalogues of ornamental plant dealers, and monumental trees. The distributions of each NNT across Italian regions were obtained from the second Italian National Forest Inventory (INFC2005). The list of NTs in Italy was obtained from Ferrari & Medici (2008).

New Zealand: the list of NNT species was collated from all tree species found in catalogues of ornamental plant dealers. The list of NT species was that compiled by McGlone *et al.* (2010).

Portugal: the list of NNTs was based on Almeida & Freitas (2006), complemented with information from catalogues of plant dealers, urban parks, Pereira *et al.* (2016), and official information on exotic species for Portugal (<http://www.icnf.pt/portal/naturaclas/patrinatur/especies/n-indig/n-ind>). The list of NT species was extracted from ICNF (2013a,b).

South Africa: for NNTs we used data from Glenn & van Wyk (2016); for NTs, we used data from <http://www.treetags.co.za/indigenous-south-african-trees/numbered-FSA-tree-species-list-19-april-2010.pdf>, verified with data from Venter & Venter (2012) and van Wyk *et al.* (2011).

Spain: the list of NNT species was derived from Sanz Elorza *et al.* (2004) complemented with information from urban parks, catalogues of ornamental plant dealers, and monumental trees. The distribution of each NNT across NUTS-2 regions was obtained from the SIVIM dataset (<http://www.sivim.info/sivi/>). The list of NTs was obtained from “Arboles ibéricos” (<http://www.arbolesibericos.es/>). The distribution of NTs across NUTS-2 regions was obtained from SIVIM and “Mapas de regiones de procedencia” (http://www.mapama.gob.es/es/desarrollo-rural/temas/politica-forestal/recursos-geneticos-forestales/rgf_regiones_procedencia.aspx).

Appendix S2. List of references identified by our search criteria for regulating ecosystem services

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Appendix S3. How we dealt with pseudo-replicates in regulating ecosystem services.

In the original database of regulating ecosystem services, there were several cases of pseudo-replication, i.e. case studies which were not independent from each other. Here we explain each of these cases and how we dealt with them to avoid pseudo-replication.

CASE 1a: several control values for a single non-native tree (NNT) species value

In this case the study provided valid data for one NNT species and for several native tree (NT) species, i.e. there was more than one potential control for the NNT. To obtain a single case study, data from all potential controls were merged before computing the effect size. The sample size (n_1), mean ($\bar{X}_1$) and standard deviation of the combined control (S_1) were calculated using equations 23.1, 23.2 and 23.3 from Borenstein *et al.* (2009), as follows:

$$n_1 = n_{11} + n_{12},$$

(S1)

$$\bar{X}_1 = \frac{n_{11} \bar{X}_{11} + n_{12} \bar{X}_{12}}{n_{11} + n_{12}},$$

(S2)

$$S_1 = \sqrt{\frac{(n_{11} - 1) S_{11}^2 + (n_{12} - 1) S_{12}^2 + \frac{n_{11} n_{12}}{n_{11} + n_{12}} (\bar{X}_{11} - \bar{X}_{12})^2}{n_{11} + n_{12} - 1}},$$

(S3)

This aggregation was performed using the R script “mul_control.R”

CASE 1b: several values for the same NNT compared with a single control

In this case the same study provided more than one value for the NNT species derived from independent observations (e.g. several sites) but only one for the control. Here we combined the NNT values into a single value as above, using equations 23.1, 23.2 and 23.3 from Borenstein *et al.* (2009).

CASE 2: several values for the same comparison between NNT and NT species

In this case the same NNT–control comparison was studied in more than one location and results were given for each one. Sites cannot be simply aggregated, as there is certain variation across sites. If sites were distant from each other and represent different environmental conditions, we considered each site as an independent case study (Borenstein *et al.*, 2009). If sites were close to each other and share environmental conditions, we computed a composite effect size across them by performing a random-effect meta-analysis on the sites of the study, and used their cumulative effect size as the single effect size for the study (Borenstein *et al.*, 2009).

The formulae used to calculate a composite effect size among several cases within a single study, using a random-effect meta-analysis, were obtained from Borenstein *et al.* (2009, p. 72).

$T^2 = \frac{Q - df}{C}, \quad (S4)$	Estimate of the between-studies variance (T^2), considering df (degrees of freedom) (This parameter was calculated using <code>rma()</code> function of metaphor package in R: <code>\$tau2</code>)
$Q = \sum_{i=1}^k W_i Y_i^2 - \frac{\left(\sum_{i=1}^k W_i Y_i \right)^2}{\sum_{i=1}^k W_i},$ $df = k - 1, \quad (S5)$	Q = parameter needed to calculate T^2 Y_i = effect size of study i W_i = weight of study $i = 1/V_i$ (in a fixed-effects model) V_i = within-study variance of study i
$C = \sum W_i - \frac{\sum W_i^2}{\sum W_i}. \quad (S6)$	C = parameter needed to calculate T^2
$W_i^* = \frac{1}{V_{Y_i}^*}, \quad (S7)$	W_i^* = weight assigned to study i in a random-effects model.
$V_{Y_i}^* = V_{Y_i} + T^2. \quad (S8)$	$V_{Y_i}^*$ = within-study variance (V_{Y_i}) plus between-study variance (T^2)
$\begin{aligned} n_{NNT}(\text{pooled}) &= \sum_i n_{NNTi} \\ n_{NT}(\text{pooled}) &= \sum_i n_{NTi} \end{aligned} \quad (S9)$	Pooled sample size for NNT (n_{NNT}) and control (n_{NT}) across i cases within a single study
$M^* = \frac{\sum_{i=1}^k W_i^* Y_i}{\sum_{i=1}^k W_i^*}, \quad (S10)$	M^* = weighted mean across studies under a random-effects model. (This parameter was calculated using <code>rma()</code> function of metaphor package in R: <code>\$b</code>).
$V_{M^*} = \frac{1}{\sum_{i=1}^k W_i^*}, \quad (S11)$	V_{M^*} = variance of the summary effect under a random-effect model. (Calculated with a R routine, using equations S7 and S8)

This aggregation was performed using the R script “mul_site_time.R”

CASE 3: the same study provides several variables related to the same ecosystem service (multiple outcomes within a study)

In this case, the study provides values for more than one variable related to the same ecosystem service, and one cannot be preferred over the other (if the two variables are correlated with each other by trade-offs, e.g. litter decomposition rate and litter C/N content, we select that with the most direct link with the ecosystem service, i.e. litter decomposition rate). For instance, soil nitrogen and phosphorous content may be reported for the same samples in a NNT site and a control site; both variables relate to ‘fertility’ and come from the same samples, so they cannot be treated as independent samples. In this case we compute a combined effect size across all outcomes as follows:

- 1) We calculated the effect size and the variance for all outcomes (changing the sign if any of the variables were negatively related to the ecosystem service).
- 2) We computed a composite effect size as the mean of all outcomes (eq. 24.4 from Borenstein *et al.*, 2009).

$\bar{Y} = \frac{1}{m} \left(\sum_j^m Y_j \right),$ (S12)	$\bar{Y}$ = composite effect size within a study with m outcomes
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- 3) Finally, we compute the composite variance across outcomes (eq. 24.5 from Borenstein *et al.*, 2009). In this case we need r , i.e. the correlation between each pair of outcomes. As this correlation is usually unknown, we can assume that several variables within the same category are positively correlated. We performed the calculation for a range of r values (0.25, 0.50, 0.75) and checked whether the results of the final meta-analysis were consistent. If so, we only show results for $r = 0.50$ (Borenstein *et al.*, 2009).

$V_{\bar{Y}} = \left(\frac{1}{m} \right)^2 \text{var} \left(\sum_{j=1}^m Y_i \right) = \left(\frac{1}{m} \right)^2 \left(\sum_{j=1}^m V_i + \sum_{j \neq k} (r_{jk} \sqrt{V_j} \sqrt{V_k}) \right)$ (S13)	$V_{\bar{Y}}$ = variance of the composite effect size
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- 4) The combined effect size and variance were used to calculate the overall effect size.

This aggregation was performed using the R script “mul_outcome.R”

Appendix S4. Detailed protocols for statistical analysis

(A) Metrics used to calculate the effect size for quantitative data

Regulating ecosystem services (RES) were assessed with quantitative variables, i.e. for each case study we had a mean value ($\bar{X}$), the standard deviation (S), and the replication of the measurement in the site dominated by a non-native tree (NNT) species and the control site with native tree (NT) vegetation. For each case study, Hedges' d was used to estimate the effect size because: (1) it weights cases by their number of replications and the inverse of their variance, and (2) it accounts for the effects of small sample sizes (Rosenberg *et al.*, 2000). Hedges' d was calculated as:

$$d = \frac{(\bar{X}^{NNT} - \bar{X}^{NT})}{S} J \quad (S14)$$

where S is the pooled standard deviation and J is a weighting factor based on the number of replicates (N) in each case. J was calculated as:

$$J = 1 - \frac{3}{4(N^{NT} + N^{NNT} - 2) - 1} \quad (S15)$$

The variance of Hedges' d was computed as:

$$Vd = \frac{N^{NT} + N^{NNT}}{N^{NT} N^{NNT}} + \frac{d^2}{2(N^{NT} + N^{NNT})} \quad (S16)$$

Hedges' d ranges from $-\infty$ to $+\infty$. Large effect sizes come from those situations in which case studies show low variability, and those cases with a large difference between the NNT and the control site. When the variable was negatively related to the ecosystem service, we changed the sign of Hedges' d . A positive value of d indicates that an ecosystem service has a larger value in the site dominated by NNTs than in the control site.

(B) Metrics used to calculate the effect size for frequency data

Cultural ecosystem services (CES) and uniqueness of non-timber products [within provisioning ecosystem services (PES)] were assessed using qualitative information. For each case study we created a contingency table as shown in Table S4.1.

Table S4.1. Example of a contingency table for collecting qualitative indicators of ecosystem services (CES, and non-timber PES).

	NNT	NT	Total
Values of non-native tree (NNT) and native tree (NT) species in the source associated with a given ecosystem service	A	B	$N_{service} = A+B$
Control or expected values of NNT and NT	C	D	$N_{random} = C+D$
Total	$A+C$	$B+D$	$N_t = A+B+C+D$

The control values express the 'availability' of NNTs and NTs, and may refer to the area covered by NNTs and NTs in the country/region or to the number of NNT or NT species present in the country/region (see Table 2 in the main text). Also, because none of the two control values (C and D) can be zero (Sweeting *et al.*, 2004), if a given country/region has a NNT cover = 0 or NNTs are absent, that region must not be included in the analysis.

The log odds-ratio was computed under Peto's method ($\log OR_p$) because it allows one zero across the observed values (A or B in Table S4.1) (Sweeting *et al.*, 2004; Borenstein *et al.*, 2009; Viechtbauer, 2010). Calculations were as follows:

$$\log OR_p = \frac{O - E}{I} \quad (S17)$$

Where O is the observed value, i.e. the count for NNTs in the source (A in Table 1), and E is the expected value, calculated as:

$$E = \frac{(A + B)(C + D)}{N} \quad (S18)$$

and

$$I = \frac{(A + B)(C + D)(A + C)}{N} \quad (S19)$$

Positive and negative values of $\log OR_p$ indicate that NNTs are respectively increasing or decreasing the service of interest, while $\log OR_p$ values close to zero indicate random effects of NNTs (Borenstein *et al.*, 2009).

For some ecosystem services, the observed and the control values differed in orders of magnitude and/or were expressed in different units (e.g. for recreation and ecotourism the observed values were the number of photographs showing NNTs and NTs, whereas the control values were the cover areas of NNTs and NTs in the region, see Table 2 in the main text), resulting in unbalanced contingency tables (i.e. $A+B$ and $C+D$ in the contingency table differed in orders of magnitude). Since Peto's method may fail in unbalanced contingency tables (Sweeting *et al.*, 2004), we calculated expected control values (C_e and D_e) by dividing the control values C and D (e.g. number of photographs showing NNTs and NTs) by a constant that makes $C_e + D_e$ equal to $A + B$ while keeping the same ratio of the original values ($C_e / D_e = C/D$). This was attained using the following formulae:

$$\frac{C_e}{D_e} = \frac{C}{D} \quad (S20)$$

$$\frac{C_e}{D_e} = \frac{C}{D} \quad (S21)$$

This correction did not affect the direction of NNT effects, but it may affect the magnitude of effect size (normally decreasing it). Thus, the magnitudes of effect sizes in the data from contingency tables (CES and non-timber PES) should not be compared among each other.

Appendix S5. Description of data sources for provisioning ecosystem services

Provisioning ecosystem services (PES) were aggregated into two categories following the *Millennium Ecosystem Assessment* (MEA, 2005): Timber and Non-Timber products. The rationale and details for each PES data source are indicated below.

1. TIMBER PRODUCTS

Timber products were considered as any kind of goods obtained from harvesting trees, which implies the death of the individual tree. Timber goods can have different transformation processes and include from almost raw material (e.g. poles) to heavily transformed material (e.g. wood pulp). We followed the categories included in the FAO yearbook of forest products (<http://www.fao.org/forestry/statistics/80570/en/>; accessed: 12th January 2017) to define what it is considered a timber product. We searched for information in reports providing reasonably accurate estimates of harvested timber provisioning at the sub-country level according to the administrative regions of each country. We selected national reports that explicitly provided information at the species level, which allowed us to classify information between native tree (NT) and non-native tree (NNT) species. All compiled information is detailed below (Table S5.1).

Table S5.1. Data on harvested timber from non-native tree (NNT) and native tree (NT) species according to country/region. The year interval, the biome of the country/region, the source of the data and the website are shown. Note that, although in some of these regions/states the dominant biome may be different to that shown in the Biome column, we indicate the biome of the area providing timber.

Country	Region/state	Harvested timber from NNT ($\text{m}^3 \text{y}^{-1}$)	Harvested timber from NT ($\text{m}^3 \text{y}^{-1}$)	Year interval of the values	Biome	Source	Website
Argentina	Buenos Aires	430131	0	2014	temperate forest	Information provided by Norma Esper (Forestry statistic area, Ministerio de Ambiente y Desarrollo Sustentable)	
	Chubut	30668	26439	2014	temperate grassland/desert		
	Córdoba	467133	14611	2014	temperate forest		
	Corrientes	4423490	2187	2014	temperate forest		
	Entre Ríos	1900937	0	2014	temperate forest		
	Jujuy	70847	39232	2014	tropical forest		
	La Pampa	2238	9783	2014	temperate grassland/desert		
	Mendoza	123883	23604	2014	mediterranean		
	Misiones	4364166	1266192	2014	tropical forest		
	Neuquén	89094	22887	2014	temperate forest		
	Río Negro	51136	206480	2014	temperate forest		
	Santa Fe	138016	10821	2014	temperate grassland/desert		
Australia	New South Wales	4496183	953986	2013–2014	temperate forest	Data provided by the Australian Government Department of Agriculture and Water Resources (ABARES)	http://www.agriculture.gov.au/abares/publications
	Queensland	1882679	289711	2013–2014	subtropical forest		
	South Australia	2375628	706052	2013–2014	mediterranean forest		
	Tasmania	1125475	2218394	2013–2014	temperate forest		
	Victoria	3976835	3664674	2013–2014	temperate forest		
	Western Australia	895634	3403409	2013–2014	subtropical desert		
Austria	Burgenland	897	239360	2015	temperate forest	Holzeinschlagsmeldung über das Kalenderjahr 2016	https://www.bmlfuw.gv.at/dam/jcr:4be1feae-84ff-432c-8707-b333920f2f40/Holzeinschlag_2016%2520CI%2520mit%2520BF.pdf&prev=search
	Carinthia	23380	1169875	2015	temperate forest		
	Lower Austria	83187	1658763	2015	temperate forest		
	Salzburg	6713	537846	2015	temperate forest		

	Styria	32991	2193876	2015	temperate forest	
	Tyrol	9221	847275	2015	temperate forest	
	Upper Austria	94308	1118965	2015	temperate forest	
	Vienna	533	4255	2015	temperate forest	
	Voralberg	4809	171370	2015	temperate forest	
Brazil	Acre	0	1459761	2011–2013	tropical forest	IBGE (2014) Produção da Extração Vegetal e da Silvicultura – PEVS
	Alagoas	17804	65367	2011–2013	tropical forest	
	Amapá	1401123	863877	2011–2013	tropical forest	
	Amazonas	3013	1778909	2011–2013	tropical forest	
	Bahia	16855650	7972093	2011–2013	tropical forest	
	Ceará	20449	4201051	2011–2013	tropical forest	
	Espírito Santo	5741070	17392	2011–2013	tropical forest	
	Federal District	18747	0	2011–2013	tropical forest	
	Goiás	3216730	777132	2011–2013	tropical forest	
	Maranhão	3086493	5560925	2011–2013	tropical forest	
	Mato Grosso	1484198	5052149	2011–2013	tropical forest	
	Mato Grosso do Sul	7981997	2452571	2011–2013	tropical forest	
	Minas Gerais	50733398	2202498	2011–2013	tropical forest	
	Pará	2143847	8553981	2011–2013	tropical forest	
	Paraíba	0	505729	2011–2013	tropical forest	
	Paraná	42282061	1981098	2011–2013	subtropical forest	
	Pernambuco	142	2190478	2011–2013	tropical forest	
	Piauí	113581	3061339	2011–2013	tropical forest	
	Rio de Janeiro	701746	2517	2011–2013	tropical forest	
	Rio Grande do Norte	68886	1233571	2011–2013	tropical forest	
	Rio Grande do Sul	22482717	1185680	2011–2013	subtropical forest	
	Rondônia	70943	2881518	2011–2013	tropical forest	
	Roraima	6623	224510	2011–2013	tropical forest	
	Santa Catarina	27050698	1351925	2011–2013	subtropical forest	
	São Paulo	38090324	25398	2011–2013	tropical forest	
	Sergipe	25518	119845	2011–2013	tropical forest	
	Tocantins	2421	1179886	2011–2013	tropical forest	
Bulgaria	Bulgaria	328260	5380342.9	2012–2015	temperate forest	Data Provided by Krasimira Petkova, University of Forestry Sofia, according to the Executive Forest Agency Bulgaria

Canada	Alberta	283312	28064000	2015	temperate forest	Canadian National Forestry Database	http://nfdp.ccfm.org/index_e.php
	British Columbia	1354000	67970000	2015	temperate forest		
	Manitoba	0	1496000	2015	temperate forest		
	New Brunswick	0	9363000	2015	temperate forest		
	Newfoundland and Labrador	0	1392000	2015	boreal forest		
	Northwest Territories	0	18000	2015	boreal forest		
	Nova Scotia	0	3749000	2015	temperate forest		
	Ontario	0	15829000	2015	boreal forest		
	Prince Edward Island	0	371000	2015	temperate forest		
	Quebec	0	28559000	2015	boreal forest		
	Saskatchewan	0	3712000	2015	temperate forest		
	Yukon	0	17000	2015	boreal forest		
Chile	Chile	3429134	219946	2014–2015	temperate forest	Estadísticas Forestales, Ministerio de Agricultura, Gobierno de Chile	http://wef.infor.cl/estadisticas_regionales/estadisticasregionales.php
Czech Republic	Czech Republic	49382	16162645	2015	temperate forest	Czech Statistical Office	https://www.czso.cz/csu/czso/lesnictvi-2015
Germany	Baden-Württemberg	218585	4811716	2012	temperate forest	Third German Forest Inventory	https://bwi.info/inhalt1.3.aspx?Text=6.03%20Tree%20species%20group&prRolle=public&prInv=BWI2012&prKapitel=6.03
	Bayern	66823	6870310	2012	temperate forest		
	Brandenburg + Berlin	41121	4194672	2012	temperate forest		
	Hamburg + Bremen	5514	34662	2012	temperate forest		
	Hessen	136102	3160018	2012	temperate forest		
	Mecklenburg-Vorpommern	32952	1980398	2012	temperate forest		
	Niedersachsen	133452	4100217	2012	temperate forest		
	Nordrhein-Westfalen	82042	2516763	2012	temperate forest		
	Rheinland-Pfalz	402553	2339874	2012	temperate forest		
	Saarland	29858	274446	2012	temperate forest		
	Sachsen	4506	999066	2012	temperate forest		
	Sachsen-Anhalt	0	1641103	2012	temperate forest		
	Schleswig-Holstein	8552	517063	2012	temperate forest		
	Thüringen	5429	1406960	2012	temperate forest		
Ireland	Ireland	3615800	364000	2012	temperate forest	Ireland's National Forest Inventory (DAFM)	https://www.agriculture.gov.ie/nfi/nfisecondcycle2012/nationalforestinventoryresultsdata2012/
Japan	Chubu	0	1629000	2015	temperate forest	Annual Report on Forest and Forestry for 2014, Forestry Agency, Ministry of Agriculture, Forestry and Fisheries, Japan	http://www.rinya.maff.go.jp/j/kikaku/hakusyo/26hakusyo/index.html
	Chugoku	0	1145000	2015	temperate forest		
	Hokkaido	0	2637000	2015	temperate forest		

	Kansai	0	959000	2015	temperate forest		
	Kanto	0	1138000	2015	temperate forest		
	Kyushu & Okinawa	0	4348000	2015	temperate forest		
	Shikoku	0	1318000	2015	temperate forest		
	Tohoku	0	4452000	2015	temperate forest		
New Zealand	New Zealand	24771800	15200	2009–2016	temperate forest	NZ Forest Owners Association Inc & MPI	https://www.nzfoa.org.nz/
Portugal	Portugal	7968071	3025443	2011–2015	mediterranean	ICNF-Divisão de Apoio à Produção Florestal e Valorização dos Recursos Silvestres (DAPFVRS)	http://www.icnf.pt/portal
South Africa	Central Districts	418806	0	2010	subtropical forest	Department of Agriculture, Forestry and Fisheries (DAFF)	https://goo.gl/tD2Gc1
	Eastern Cape	575730	0	2010	subtropical forest		
	Garden Route/Southern Cape	0	1500	2010	temperate forest		
	KwaZulu Natal Midlands, KwaZulu Natal	1525866	0	2010	tropical forest		
	Limpopo Province	842253	0	2010	tropical forest		
	Mpumalanga North	3297297	0	2010	tropical forest		
	Mpumalanga South	711857	0	2010	tropical forest		
	Northern KwaZulu Natal	132266	0	2010	tropical forest		
	Southern Cape	540828	0	2010	temperate forest		
	Southern KwaZulu Natal	4374528	0	2010	tropical forest		
	Western Cape	173651	0	2010	mediterranean		
	Zululand, KwaZulu Natal	5980292	0	2010	tropical forest		
Spain	Andalucia	78287	316401	2011	mediterranean	Inventario Forestal Anual, Ministerio de Agricultura, Alimentación y Medio Ambiente, Gobierno de España	http://www.magrama.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2011.aspx
	Aragon	54238	11276	2011	mediterranean		
	Asturias	561484	121022	2011	temperate forest		
	Cantabria	410247	29264	2011	temperate forest		
	Castilla la Mancha	27495	478232	2011	mediterranean		
	Castilla Leon	385248	1271967	2011	mediterranean		
	Cataluña	155227	489960	2011	mediterranean		
	Euskadi	784258	27038	2011	mediterranean		
	Extremadura	78803	180813	2011	mediterranean		
	Galicia	4931872	1900809	2011	temperate forest		
	La Rioja	28469	25304	2011	temperate forest		
	Madrid	3581	24935	2011	mediterranean		

	Navarra	197522	107588	2011	mediterranean		
Switzerland	Eastern Central-Alps	7500	264500	2009–2013	temperate forest	The Swiss National Forest Inventory NFI	http://www.lfi.ch/lfi-en.php
	Jura	0	1290000	2009–2013	temperate forest		
	Northen Alps	16000	1686000	2009–2013	temperate forest		
	Plateau	67500	3536500	2009–2013	temperate forest		
	Southern Alps	9500	128500	2009–2013	temperate forest		
	Western Central-Alps	24000	115000	2009–2013	temperate forest		
United Kingdom	England	717000	182400	2015	temperate forest	Forestry Commission UK	https://www.forestry.gov.uk/
	Scotland	1917000	663000	2015	temperate forest		
	Wales	362000	26100	2015	temperate forest		
United States*	Alaska	0	366392	2011 and 2015	boreal forest	The University of Montana's Bureau of Business and Economic Research (BBER), Alaska's Forest Products Industry and Timber Harvest, 2015	http://www.bber.umt.edu/FIR/S_AK.asp
	Arizona	0	143219	2007 and 2012	temperate forest	Sorenson, Colin B.; Hayes, Steven W.; Morgan, Todd A.; Simmons, Eric A.; Scudder, Micah G.; McIver, Chelsea P.; Thompson, Mike T. 2016. The Four Corners timber harvest and forest products industry, 2012. Resour. Bull. RMRS-RB-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.	http://www.bber.umt.edu/FIR/S_AZ.asp
	California	0	3352852	2012	mediterranean	The University of Montana's Bureau of Business and Economic Research (BBER), Alaska's Forest Products Industry and Timber Harvest, 2015	http://www.bber.umt.edu/FIR/S_ID.asp
	Colorado	0	198828	2007 and 2012	temperate grassland/desert	Sorenson, Colin B.; Hayes, Steven W.; Morgan, Todd A.; Simmons, Eric A.; Scudder, Micah G.; McIver, Chelsea P.; Thompson, Mike T. 2016. The Four Corners timber harvest and forest products industry, 2012. Resour. Bull. RMRS-RB-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.	http://www.bber.umt.edu/FIR/S_AZ.asp
	Florida	0	10901897	2009	subtropical forest	Johnson, T.G. Nowak, J. (2011). Florida's timber industry-an assessment of timber product outpus and use, 2009. Resour.Bull, SRS-180. Asheville, NC: U.S. Department of Agriculitures Forest Service, Souther Research Station. 31 p.	https://www.fs.usda.gov/treesearch/pubs/38649
	Hawaii	1634390	91917	2013	tropical forest	Department of Land and Natural Resources (DNLN)	http://dlnr.hawaii.gov/forestry/files/2013/02/Hamakua-Report.pdf ; http://dlnr.hawaii.gov/forestry/files/2013/02/Hawaii-Island-Supplemental-Inventory-Report.pdf ; http://dlnr.hawaii.gov/forestry/files/2013/02/Waiakea.pdf ; http://dlnr.hawaii.gov/forestry/files/2013/02/Molokai-Report.pdf ; http://dlnr.hawaii.gov/forestry/files/2013/02/Kaureport.pdf ;
	Idaho	0	2635089	2015	temperate forest	Sorenson, Colin B.; Hayes, Steven W.; Morgan, Todd A.; Simmons, Eric A.; Scudder, Micah G.; McIver, Chelsea P.;	http://www.bber.umt.edu/FIR/S_ID.asp

Kentucky	0	4601858	2009	temperate forest	Thompson, Mike T. 2016. The Four Corners timber harvest and forest products industry, 2012. Resour. Bull. RMRS-RB-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.	
Minnesota	789	6393980	2009	temperate forest	Cooper, Jason A.; Johnson, Tony G.; Nevins, Christopher G. 2011. Kentucky's timber industry—an assessment of timber product output and use, 2009. Resour. Bull. SRS-177. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 32 p.	
Montana	0	901161	2014	temperate forest	Walters, Brian F.; Vongroven, Steve; Piva, Ronald J. 2016. Minnesota timber industry: an assessment of timber product output and use, 2010. Resour. Bull. NRS-101. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 75 p.	http://www.bber.umt.edu/FIR/S_AZ.asp
New Mexico	0	68058	2012	subtropical desert	Sorenson, Colin B.; Hayes, Steven W.; Morgan, Todd A.; Simmons, Eric A.; Scudder, Micah G.; McIver, Chelsea P.; Thompson, Mike T. 2016. The Four Corners timber harvest and forest products industry, 2012. Resour. Bull. RMRS-RB-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.	http://www.bber.umt.edu/FIR/S_AZ.asp
Oregon	44175	9800565	2013	temperate forest	Sorenson, Colin B.; Hayes, Steven W.; Morgan, Todd A.; Simmons, Eric A.; Scudder, Micah G.; McIver, Chelsea P.; Thompson, Mike T. 2016. The Four Corners timber harvest and forest products industry, 2012. Resour. Bull. RMRS-RB-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.	http://www.bber.umt.edu/FIR/S_AZ.asp
Utah	0	41132	2012	temperate grassland/desert	Sorenson, Colin B.; Hayes, Steven W.; Morgan, Todd A.; Simmons, Eric A.; Scudder, Micah G.; McIver, Chelsea P.; Thompson, Mike T. 2016. The Four Corners timber harvest and forest products industry, 2012. Resour. Bull. RMRS-RB-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.	http://www.bber.umt.edu/FIR/S_AZ.asp
West Virginia	0	5026432	2007	temperate forest	Piva, Ronald J.; Cook, Gregory W. 2011. West Virginia timber industry: an assessment of timber product output and use, 2007. Resour. Bull. NRS-46. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 58 p.	
Wisconsin	0	7369034	2008	temperate forest	Haugen, David E. 2013. Wisconsin timber industry--an assessment of timber product output and use, 2008. Resour. Bull. NRS-78. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 110 p.	
Wyoming	0	159012	2014	temperate forest	Sorenson, Colin B.; Hayes, Steven W.; Morgan, Todd A.; Simmons, Eric A.; Scudder, Micah G.; McIver, Chelsea P.; Thompson, Mike T. 2016. The Four Corners timber harvest and forest products industry, 2012. Resour. Bull. RMRS-RB-21. Fort Collins, CO: U.S. Department of Agriculture, Forest Service,	http://www.bber.umt.edu/FIR/S_AZ.asp

* For the United States we selected a representative sample of states, geographically distributed through the country.

2. NON-TIMBER PRODUCTS

We considered non-timber products as any biological resources in woodland except timber. These include collecting parts of the trees without logging individuals (e.g. flowers, cork), collecting organisms that live in association with trees (e.g. mushrooms) as well as other organisms that need the forest for living and reproducing (e.g. game, medicinal herbs). We considered 16 different categories of non-timber products following the classification of the Secretariat of the Convention on Biological Diversity (CBD) (<https://www.cbd.int/doc/publications/cbd-ts-06.pdf>) (Table S5.2).

Table S5.2. The 16 different categories of non-timber forest products according to the CBD classification.

Category	Important products (lists not exhaustive)
Food products	Nuts: Brazil nuts, pine nuts, malva nut, walnuts, chestnuts Fruits: jujube, sapodilla, ginkgo, bush mango Edible fungi: morels, truffles and other mushrooms Vegetables: bamboo shoots, reindeer moss, various "green" leaves, palm hearts, wild onions (ramps) Starches: sago Birds' nests Oils: shea butter, babassu oil, illipe oil Sap and resin: maple syrup, birch syrup
Spices, condiments and culinary herbs	Nutmeg and mace, cinnamon, cassia, cardamom, bay leaves, oregano, etc
Industrial plant oils and waxes	Tung oil, neem oil, jojoba oil, kemiri oil, akar wangi, babassu, oiti cica and kapok oils Carnauba wax
Plant gums	Gums for food uses: arabic, tragacanth, karaya and carob gums Technological grade gums: talha and combretum gums
Natural plant pigments	Annatto seeds, logwood, indigo
Oleoresins	Pine oleoresin Copal, damar, gamboge, benzoin, dragon's blood, and copaiba oil Amber
Fibres and flosses	Fibres: Bamboo, rattan, xateattap, aren, osier, raffia, toquilla straw products, cork, esparto, erica and other broom grasses Flosses: kapok
Floral greenery	Beargrass, boughs, club moss, galax leaves, grape vine, Lycopodium, mistletoe, Rhododendron, salal, white birch bark
Vegetable tanning materials	Oak, mimosa, chestnut and catha/cutch
Latex	Natural rubber, gutta percha, jelutong, sorva and chicle
Insect products	Natural honey, beeswax, lac and lac-dye, mulberry and non-mulberry silks, cochineal, aleppo galls, kermes
Incense woods	Sandalwood, gaharu
Essential oils	Eucalyptus, canaga oil (ylang-ylang), aniba, sandal oil
Plant insecticides	Pyrethrum, Derris, Medang and Peuak Bong
Medicinal plants	Around 5000 to 6000 entering world market every year
Animals and animal products	Ivory, trophies, bones, feathers, butterflies, live animals and birds, bushmeat, etc

Information on non-timber products, and more specifically, whether the uniqueness in providing non-timber products differed between non-native and native tree species, was collected at the country level. We did not separate between administrative regions as we did with timber products. We list below the specific sources of information. In addition, we relied on expert knowledge for those countries where information was not available information online.

Argentina: <http://ambiente.gob.ar/wp-content/uploads/ANUARIO-2014.pdf>

Australia: <http://www.agriculture.gov.au/abares/forestsaustralia/Documents/criterion6-web.pdf>

Austria:

https://nachhaltigwirtschaften.at/resources/fdz_pdf/endbericht_0817b_nachh_waldbewirtschaftung.pdf, and sources cited therein

Brazil: expert knowledge

Czech Republic: <http://eagri.cz/public/web/file/426635/ZZ2014.pdf>

France: http://nnext.boku.ac.at/images/FP1403/00-all/00-2-reports/2017/NNEXT_Country_Reports_E3.pdf

Germany: http://nnext.boku.ac.at/images/FP1403/00-all/00-2-reports/2017/NNEXT_Country_Reports_E3.pdf

Israel: expert knowledge

Italy: <https://aisfdotit.files.wordpress.com/2016/02/658-669-facciotto.pdf>

New Zealand: <https://www.mpi.govt.nz/document-vault/9530>

Poland: http://nnext.boku.ac.at/images/FP1403/00-all/00-2-reports/2017/NNEXT_Country_Reports_E3.pdf

Portugal: <http://www.florestar.net/pinheiro-silvestre/pinheiro-silvestre.html>

Romania: http://nnext.boku.ac.at/images/FP1403/00-all/00-2-reports/2017/NNEXT_Country_Reports_E3.pdf

South Africa: Cunningham & Shackleton (2004); Shackleton *et al.* (2011); Shackleton *et al.* (2015); Gyan & Shackleton (2005).

Spain: http://www.magrama.gob.es/es/biodiversidad/estadisticas/forestal_anuario_2011.aspx

UK: http://nnext.boku.ac.at/images/FP1403/00-all/00-2-reports/2017/NNEXT_Country_Reports_E3.pdf

Appendix S6. Description of data sources of cultural ecosystem services and the disservice pollen allergenicity.

The cultural ecosystem services (CES) were aggregated into four categories following the *Millennium Ecosystem Assessment* (MEA, 2005): Aesthetic, Recreation and ecotourism, Cultural heritage, Inspiration, and Scientific interest. We considered also an ecosystem disservice (EDS; Vaz *et al.*, 2017b), expressed by pollen allergenicity. The rationale and details of each CES data source are indicated below.

1. AESTHETICS

Aesthetic CES were represented by two different data sources: catalogues of ornamental plant dealers and inventories from urban parks. The rationale and methods underlying each source are described below.

1.1. CATALOGUES OF ORNAMENTAL PLANT DEALERS

Rationale: we assume that catalogues from ornamental plant dealers offer those ornamental species that are sold easily to the public. Therefore, tree species included in these catalogues can be appreciated for their aesthetic values.

Method: for each country, we searched for online and printed catalogues of plant dealers of ornamental plants operating locally (i.e. considering local plant dealers and avoiding international plant dealers). Additional contact by e-mail and visits to nurseries were carried out to complement the information. Our searching was evenly distributed across countries (depending on size and amount of forest area). For each catalogue, we counted the number of tree species (i.e. NNTs and NTs). Different varieties, subspecies or cultivars within the same species were counted as one species. Fruit or forestry species were not considered, since they may not be representative of an aesthetic choice. The data set included 11 data sources for Argentina, 16 for Australia, 5 for Austria, 27 for Brazil, 5 for Czech Republic, 18 for Finland, 6 for Hawaii, 9 for Israel, 21 for Italy, 11 for New Zealand, 8 for Portugal, 7 for South Africa, and 20 for Spain.

Specific data sources:

For Argentina, the total number of NNTs offered in the catalogues listed below was 110.

<http://www.perikos.com/vivero/productos.html>

<http://www.viveromischa.com.ar/arboles.html>

<http://botanicasur.com.ar/tienda/index.php?controller=sitemap>

<http://viverorauli.com.ar/>

<http://www.losleonesriogallegos.com/147777995>

<http://jardinesdelapatagonia.com/tiendaonline/>

<http://www.viverolosmaitenes.com.ar/catalogo/index.html>

Personal visit to the nurseries of La Araucaria

Personal visit to the nurseries of Paisajes

Personal visit to the nurseries of Aljaba

Catalogue "Vivero Provincial José L. Puel" was sent by email

For Australia, the total number of NNTs was 160 from the following catalogues:

<http://www.buyplantsonline.com.au/>

<https://www.arborwest.com.au/>
<http://www.kulgoa.com.au>
<http://www.natives.net.au/docs/AATStocklist2010.pdf>
<http://www.onlinetrees.com.au/>
<http://www.greenhillnursery.com.au/stocklist.html>
<http://www.darwinplants.com.au/>
<http://theplantweb.com.au/collections/all-trees>
<http://www.madaboutplants.com.au/General-Public/Trees>
<http://lakesideplants.com/product-category/trees/>
<http://www.heritagegardens.com.au>
<http://www.freshfordnurseries.com.au>
<http://www.advancedtrees.com.au/>
<http://www.woodleanursery.com.au/catalogue.pdf>
<http://www.onlineplantsnt.com.au>
<http://www.winterhill.com.au/plant-range/>

For Austria, the total number of NNTs was 167 from the following catalogues:

<https://www.prskac.at/>
<http://www.baumschule-stoeckl.at/> (printed catalogue was used)
<http://www.baumschule-bauer.at>
<http://www.baumschule-brillinger.at>
<http://www.baumschule.at/teuffenbach/index.php> (printed catalogue was used)

For Brazil, the total number of NNTs ranged between 5 and 196, depending on the state. The following catalogues were considered:

<http://www.seivanet.com.br/index.html>
<http://www.viveiropertoamazonas.com.br/Árvores%20Nativas%20e%20Exóticas/>
http://www.viveiroipe.com.br/?page_id=4
<http://www.goianiagarden.com.br/produtos/arvores>
<http://www.viveiroespacobotanico.com.br/institucional>
<http://www.tirolplantas.com.br/loja/>
<http://www.viveirocaa.com.br/mudas-e-sementes/>
<http://www.atacadaodasarvores.com.br/plantas/>
<http://www.luanreflorestamento.com.br/especies/2-arvores/>
<http://www.viveirostropica.com/principal/index.php>
<http://www.viveiirrosario.com.br/>
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo37.pdf
http://www.belvedereplantas.com.br/?page_id=378
<http://arvoresguaratiba.com.br/index.html>
<http://www.chacaratropical.com.br/index.html>
<http://botanicaviveiro.com.br/categoria/arvores/>
<http://www.viveirozimmer.com.br>
<http://www.scheid-viveiro.com.br/SCHEID%20-%20viveiro%20de%20mudas%20florestais.pdf>
<http://www.viveirolidomar.com.br/variadas.php>
<http://viveiroamazonia.com.br/produtos>
<http://mondiniplantas.com.br/produtos/ornamentais/3>
<http://www.tocadoverde.com.br/sementes/arvores/ornamentais.html?subcategoria=156>
<http://www.viveirochapeco.com.br/principal>
<http://www.viveirodafelicidade.com.br/default.asp>
<http://www.belavistaplantas.com.br/index.php>
http://www.fazendacitra.com.br/site/index.php?option=com_wrapper&view=wrapper&Itemid=3
<http://www.mudasfrutabella.com.br/index.html>

For the Czech Republic, the total number of NNT species offered in the catalogues was 181.

The following catalogues were considered:

<http://www.lesoskolky.cz/nase-nabidka/>
<http://www.lesymb.cz/nabidka-sazenic-jaro-2010.html?id=233>
<http://eshop.starkl.com/jehlicnany/>

www.senkerik.cz/katalog.doc
<http://www.bakker-cz.com/stromy-a-kere/stromy-;/pgid=H8h6SgKliStSR06Gch8GQmep0000vapGoCFG;sid=5Z4CKU9xKbMGKRmI3FgQB0x7BaOvadX3cyk=>

For Hawaii, a total number of 159 NNT species was derived from the following catalogues of plant dealers:

<http://www.kanoahawaii.com/>
<http://www.bigislandplants.com/>
<http://kauaieascapesnursery.com/>
<http://kauai-ranch.com/nursery/>
<http://www.palmsinkona.com/catalog.asp>
<http://www.store.hawaiiantropicalplants.com/>

For Israel, the total number of NNT species offered in the catalogues was 1073, from the following catalogues:

<http://www.yagurgan.co.il/HTMLs/home.aspx>
http://shtiley-har.co.il/index.asp?site_lan=he
<http://www.gardens.co.il/>
<http://www.alon-yiron.co.il/catalog.html>
<http://www.shatil.co.il/>
<http://www.shlomit1.co.il/>
<http://druyan.com/> (list provided through phone call)
<http://www.karkash.com/> (list provided through phone call)
Kaduri (list provided through phone call)

For Italy, the total number of NNT species offered in the catalogues was 321, from the following catalogues:

<http://www.vivaio.parcourunci.it/prodotti-vivaio.html>
<http://www.vivaivignolini.it/catalogo.asp>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/2147>
<http://www.umbraflor.it/LISTINO/catalogo.pdf>
<http://www.allasiaplantmg.it/>
<http://www.savif.it/la-nostra-produzione/piante-certificate.html>
<http://alasiafranco.com/>
<http://www.vivaimichelini.it/vivaio/alberi-e-arbusti/>
<http://www.vivaidelaurentiis.com/>
<http://www.sgaravattiland.it/>
<http://www.giorgiotesigroup.it/>
<http://www.noarovivaio.it/>
<http://www.vivaitorsanlorenzo.it/catalogo.htm>
<http://www.ilgiardino.it/>
http://www.lambo.it/piante_e_vivai.html
<http://www.florsilva.it/it/catalogo-prodotti/itemlist/category/9-conifere.html>
<http://www.zelari.it/it/catalogo-on-line/catalogo-on-line.asp?idcategoria=1>
<http://www.piantemati.com/>
http://covilifranco.it/Listino_Covili.pdf
<http://www.gruppotorisanlorenzo.com/contatti.html>
<http://www.piantefaro.com/>

For New Zealand, the total number of NNT species offered in the catalogues was 581, from the following catalogues:

<https://www.bunnings.co.nz/our-range/garden/plants/trees-shrubs/trees>
<http://www.diacks.co.nz/products-and-services/trees-and-shrubs/>
<http://www.waimeanurseries.co.nz/our-products/ornamentaltrees/>
<http://www.blackbridgenurseries.co.nz/>
<http://www.awanursery.co.nz/>
<http://www.icontrees.co.nz/>

<http://appletons.co.nz>
<http://nhbigtrees.co.nz/trees>
<http://www.greenleafnurseries.co.nz/>
<http://www.wairere.co.nz/>
<https://www.southernwoods.co.nz/>

For Finland, the total number of NNT species offered in the catalogues was 90. The plant dealers were identified from the site “www.suomalainentaimi.fi” which lists the dealers of the “Finnish Elite – plants that are known to survive in a given planting zone within Finland”. The following catalogues were considered:

<http://www.mattilantaimistot.fi>
<http://www.barkholtintaimisto.com>
<http://www.hongistontaimisto.fi>
<http://www.taimet.fi>
<http://www.mustilantaimitarha.com>
<http://www.vuorelanpuutarha.fi>
<http://www.vihertalovarpula.fi>
<http://www.toijalantaimitarha.fi>
<http://www.paratiisintaimitarha.fi>
<http://www.pinsiontaimisto.fi>
<http://www.huutokoski.fi>
<http://www.blomqvistintaimisto.com>
<http://www.merilapintaimi.fi>
<http://www.taimisto.net>
<http://www.vihertaimisto.fi>
<http://www.lassilantaimisto.fi>
<http://www.sarkanperannataimisto.fi>
<http://www.ahosentaimisto.fi>

For Portugal, the total number of NNT species offered in the catalogues was 159. The following catalogues were considered:

<http://www.vcastramil.pt/>
<http://www.alfredomoreiradasilva.com/gestor/catalogo.php?cat=2>
<http://www.silvoplante.com>
<http://www.arborlusitania.com/>
<http://www.jardimdaceleste.com/>
<http://www.plantalivre.pt/>
<http://www.hortodorossio.com/>
<http://ecossistemasol.com/>

For South Africa, a total number of 1950 NNT species was offered through the following catalogues of plant dealers:

<http://www.plantsinstock.co.za>
www.gardengoods.co.za
<http://www.egardens.co.za>
<http://tulbaghnursery.co.za/>
<http://www.capegardencentre.co.za/>
<http://www.trees-sa.co.za/>
<http://www.habitattreenursery.co.za/>

For Spain, a total number of 266 NNT species was distributed through the following catalogues of plant dealers:

<http://www.viveroszuame.es>
<http://www.viverossevilla.com>
<http://viverosveron.com>
<http://www.viverosibanez.es>
<http://www.delsueve.com>

<http://viverossanchez.com>
<http://viverosferca.com>
<http://www.campogrande.es>
<http://viverosbarra.es>
<http://www.corma.es/intranet/products/search>
<http://www.urkiondo.com>
<http://viveroscanos.com>
<https://plantamus.com>
<http://www.coplant.es>
<http://www.viverosborrazas.com>
<http://viverosperica.com/es/catalogo-viveros-perica>
<http://www.viverosruca.es>
http://www.viverosametza.com/productos/listado_1.html
<http://www.viverosbargues.com/arboles.html>
<http://www.alberolaviveros.com>

1.2. INVENTORIES OF URBAN PARKS

Rationale: species planted in urban parks can be appreciated by people for their aesthetic value.

Method: within each country we searched for inventories of urban parks for which the catalogue of tree species was available online or in any other official source (books, archives of municipalities, *in-situ* panels, among others). We used the maximum number of urban parks within each region for which information was available. For each urban park inventory we counted the number of NNT and NT species. Additional personal surveys and visits to urban parks were carried out to complement the information. The data set included 14 data sources for Argentina, 12 for Australia, 4 for Austria, 40 for Brazil, 6 for Czech Republic, 3 for Israel, 8 for Italy, 2 for New Zealand, 10 for Portugal, 14 for South Africa, and 35 for Spain.

Specific data sources:

Official inventories for urban parks from Argentina were obtained by email, from:
 Secretario de Ambiente, Municipalidad de Esquel: cgbuduba@gmail.com;
 Subsecretaría de espacios verdes, Municipalidad de Neuquén: erocca@muninqn.gov.ar
 Subsecretario de Medio Ambiente, Municipalidad de Junín de los Andes: pablo.rosano@junindelosandes.gov.ar;
 Municipalidad de General Roca: mbarriga@generalroca.gov.ar
 Additional surveys were also conducted in the following urban parks: Lago Puelo, Perito Moreno, Plaza Costera, Uruguay, España, 3 de mayo, La Llave, Malvinas, Modesta Victoria, and Pehuenes.

For Australia, information was gathered from Council's Urban Tree Strategies documents, specifically from:
<https://www.brisbane.qld.gov.au/environment-waste/natural-environment/plants-trees-gardens/brisbanes-trees/street-trees/types-street-trees>
http://www.cityofsydney.nsw.gov.au/__data/assets/pdf_file/0017/130238/STMP2011_150501-PartB.PDF
<https://www.melbourne.vic.gov.au/SiteCollectionDocuments/urban-forest-diversity-guidelines.pdf>
<http://yourvoicelaunceston.com.au/streettreestrategy2011>
http://www.tccs.act.gov.au/__data/assets/pdf_file/0007/794770/Tree-Species-List-Table-Draft-Only-Sept-2015.pdf
http://www.alicesprings.nt.gov.au/sites/default/files/policies/175_Rural_Roads_Management_Policies_0.pdf
<https://www.perth.wa.gov.au/sites/default/files/documents/Street%20Tree%20Framework.pdf>
http://www.prospect.sa.gov.au/webdata/resources/files/street_tree_manual.pdf
http://www.marion.sa.gov.au/webdata/resources/files/marion_street_tree_strategy_-_tree_descriptions.pdf

<http://www.newcastle.nsw.gov.au/getmedia/5ef2b4dd-c970-4947-8fa1-064502c7eb6f/Street-Tree-Selection-Manual.aspx>
http://www.cairns.qld.gov.au/__data/assets/pdf_file/0011/83729/Part-C-Tree-Selection.pdf
<http://www.bendigo.vic.gov.au/media/240>

For Austria, the inventories for urban parks were obtained from:

<https://www.wien.gv.at/umweltgut/public/grafik.aspx?ThemePage=11>
<https://geodaten.graz.at/WebOffice/synserver?client=flex&project=baumkataster>
<http://webgis.linz.at/rpweb/Baumkataster.aspx?site=GMSC&project=Baumkat&lang=de-de>

The list of all tree individuals for Gardens in Innsbruck was provided by H. Bacher (head of Austrian Federal Gardens in Innsbruck).

For Brazil, the inventories for urban parks were obtained from:

http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo125sn-publicacao.pdf
<http://periodicoscientificos.ufmt.br/ojs/index.php/nativa/article/viewFile/3180/pdf>
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo162-publicacao.pdf
<http://www.botanica.org.br/trabalhos-cientificos/64CNBot/resumo-ins19021-id3247.pdf>
<http://www.conhecer.org.br/enciclop/2012a/ambientais/avaliacao%20de%20especies.pdf>
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo150-publicacao.pdf
<http://www.conhecer.org.br/enciclop/2015c/agrarias/Riqueza%20floristica.pdf>
<http://www.ibeas.org.br/congresso/Trabalhos2012/VI-020.pdf>
<http://revista.grupointegrado.br/revista/index.php/sabios2/article/view/1962>
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo341sn-publicacao.pdf
<http://periodicos.ufsm.br/reget/article/view/7695/pdf>
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo160-publicacao.pdf
http://www.ifmg.edu.br/site_campi/g/images/arquivos_governador_valadares/TCC_Janaina.pdf
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo108-publicacao.pdf
http://www.epamig.br/index.php?option=com_docman&task=cat_view&gid=193&Itemid=116&limit=10&limitstart=0&order=date&dir=ASC
http://www.cstr.ufcg.edu.br/grad_eng_florest/mono_ef/mono_rosevelt.pdf
https://www.researchgate.net/profile/Daniela_Biondi/publication/288157786_Invasive_tree_species_in_urban_parks_landscaping_of_Curitiba_PR/links/56868f7808ae051f9af40399.pdf
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo118-publicacao.pdf
http://www.ifmg.edu.br/site_campi/v/images/arquivos_governador_valadares/tccMoris.pdf
<http://www.unicap.br/simcbio/wp-content/uploads/2014/09/INVENT%C3%81RIO-FLOR%C3%8DSTICO-DAS-PRA%C3%87AS-DO-BAIRRO-DO-RECIFE-PE.pdf>
<https://www.scienciaplana.org.br/sp/article/viewFile/1008/530>
<http://www.revista.ufpe.br/rbgfe/index.php/revista/article/viewArticle/1519>
<https://www.scienciaplana.org.br/sp/article/view/1007/529>
<http://www.ufrgs.br/seerbio/ojs/index.php/rbb/article/viewFile/600/505>
<http://www.scielo.br/pdf/floram/v22n1/2179-8087-floram-22-1-23.pdf>
http://www.natal.rn.gov.br/bvn/publicacoes/GILCP_monografia.pdf
http://www.lapa.ufscar.br/pdf/caracterizacao_ambiental_de_um_parque_urbanoLongines_MalinowskiZANIN.pdf
<http://www.proamb.com.br/downloads/cm1lyf.pdf>
<http://www.lume.ufrgs.br/bitstream/handle/10183/55195/000562229.pdf?sequence=1>
<http://www.anchietano.unisinos.br/publicacoes/botanica/botanica59/artigo17.pdf>
<http://livros01.livrosgratis.com.br/cp062547.pdf>
<https://repositorio.ufsc.br/xmlui/handle/123456789/159743>
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo143-publicacao.pdf
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo138-publicacao.pdf
<http://www.bibliotecadigital.unicamp.br/document/?code=vtls000412927&fd=y>
http://sites.unisanta.br/ppgecomar/dissertacoes/Dissertacao_Graciana.pdf
http://repositorio.unesp.br/bitstream/handle/11449/118356/borges_bd_tcc_rcla.pdf?sequence=1
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo130-publicacao.pdf
<http://www.scielo.br/pdf/rarv/v35n6/a12v35n6.pdf>
http://www.revsbau.esalq.usp.br/artigos_cientificos/artigo71sn-publicacao.pdf

For Czech Republic, the inventories for urban parks were obtained from:

- Faltova, K., 2011. Dendro-ecological characteristics of trees in the castle park in Rajec nad Svitavou. Thesis. Mendel University in Brno. 92pp.
- Mihula, K., 2011. Inventarization and management of woody tree species in castle park in Slavcin. Final theis. Mendel University. 70pp.
- Mouchova, S., 2014. Inventarization and management of woody tree species in a forest park 'Maloles' in Zlin. Final theis. Mendel University. 51pp.
- Oplistolova, I., 2014. Inventarization and management of park in Paseky u Prosece. Final theis. Mendel University, Brno. 51pp.
- Kalousova, I., 2014. Inventarization of woody species at park in Chocen. Final theis. Mendel University. 60pp.
- Hejdova, D., 2011. Trees of a park in Buchlovice. Final theis. Palacky University, Olomouc. 60pp.

For Israel, the inventories for urban parks were obtained from:

- <https://www.tel-aviv.gov.il/Residents/Environment/Pages/Trees.aspx>
- http://www.moag.gov.il/yhidotmisrad/shaham/publication/2013/documents/street_trees_guide_2013.pdf
- <http://www.yehud-monosson.muni.il/html5/web/9007/37296ImageFile3.pdf>

For Italy, the inventories for urban parks were obtained from:

- <http://dryades.units.it/torlonia/index.php?procedure=list>
- <https://www.comune.roma.it/PCR/resources/cms/documents/VillaCelimontana.pdf>
- <https://www.comune.roma.it/PCR/resources/cms/documents/VillaPamphiljcorretto.pdf>
- <http://www.lorenzograssi.it/sinopoli/documenti/schedasinopolialberi.pdf>
- https://it.wikipedia.org/wiki/Villa_Borghese
- <https://www.google.it/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8&q=alberi++parco+degli+acquedotti>
- <http://www.comune.torino.it/verdepubblico/patrimonioverde/parchi-giardini/valentino/valentino.shtml#patrivege>
- <http://www.grandigiardini.it/eventi-scheda.php?id=1827>

For New Zealand, the inventories for urban parks were obtained using the following sources:

- Albert Park Trees, by Lance Goffart-Hall (1999)
- Gisbourne Botanic Gardens Management Plan, June 2009

For Portugal, the following sources were used:

- <http://www.serralves.pt/pt/parque/>
- <https://listasverdes.wordpress.com/2010/10/22/lista-especies-parque-da-cidade-porto/>
- <http://www.icnf.pt/portal/florestas/gf/pgf/resource/doc/2010/mn-choupal/Anexo1%20-%20Flora.pdf>
- <http://www.ipcb.pt/sites/default/files/upload/esa/files/agroforum/33.pdf>
- http://www.monumentos.pt/Site/APP_PagesUser/SIPA.aspx?id=2067
- http://www.monumentos.pt/Site/APP_PagesUser/SIPA.aspx?id=17304
- http://www.monumentos.pt/Site/APP_PagesUser/SIPA.aspx?id=28138
- Soares, A. L. and C. Castel-Branco. 2007. As árvores da Cidade de Lisboa. Pages 289-334 in J. S. Silva, editor. Árvores e Florestas de Portugal, Vol. VII Floresta e sociedade - uma história em comum. Público/FLAD/LPN, Lisboa.
- Jardim da Estrela: Personal survey by the authors
- Jardim do Principe Real: Personal survey by the authors

For South Africa, the following sources were used:

- <http://www.saaao.ac.za/>
- <http://www.arternegardens.org.za/>
- <http://www.dewaalpark.co.za/>
- <http://wikivillage.co.za/companys-garden/blog>
- McConnachie, M.M., Shackleton, C.M., McGregor, G.K., 2008. The extent of public green space and alien plant species in 10 small towns of the Sub-Tropical Thicket Biome, South Africa. Urban Forestry and Urban Greening 7, 1–13. (From this book we obtained data for gardens of the following towns: Bisho, Butterworth, Fort Beaufort, Graaff-Rienet, Grahamstown, Jeffrey's Bay, King Williams, Mossel Bay, Port Alfred, Zwelitsha).

Official inventories for urban parks from Spain were obtained from:

https://es.wikipedia.org/wiki/Senda_Bot%C3%A1nica_del_Retiro
<http://vivirlosparques.blob.core.windows.net/vlp-parques-acorunamendeznunez/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-agricultura/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-alcazar/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-castellonribalta/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-centrepoblenou/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-ciudadela/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-ciudadrealgasset/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-ciudadrealpilar/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-cordobaasomadilla2/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-huescauniversidad/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-jardindelicias/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-marialuisa/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-miguelservet/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-miguelservet/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-miguelservet/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-murciafloridablanca/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-murciafloridablanca/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-murillo/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-olivocoslada/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-oviedosanfrancisco2/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-pamplonayamaguchi/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-pamplonaciudadela2/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-pamplonataconera/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-parquedelagua/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-parquedelagua/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-parquegrande/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-santanderlasllamas/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-valenciamonforte/index.html>
<http://vivirlosparques.blob.core.windows.net/vlp-parques-viverosvalencia/index.html>
<http://www.granada.es/internet/arboles.nsf/lugc/32>
<http://www.parquealamedasantiago.com/parque-de-la-alameda>
http://www.visitvalencia.com/es/Datos/IdiomaNeutral/PDF/parque_metropolitano.pdf
<http://xarxa018-1.edubcn.cat/fem/materialsaplec/arbresparcciadella.pdf>
 Parque de Quevedo, León, Spain: Information collected by the authors from an information panel within the park.

2. RECREATION AND ECOTOURISM

Recreation and ecotourism were assessed by means of two data sources: official tourist websites and nature routes.

2.1. OFFICIAL TOURISM WEBSITES

Rationale: photographs used in tourism websites represent the ‘brands’ of a place and aim to attract tourists to a region, so we assume that official tourism entities select those photographs that are more attractive for recreation and ecotourism.

Method: we selected official tourism websites (avoiding those of private companies and particular accommodation services, among others), in order to standardize the search across countries. Within each website, we focused on nature sections (e.g. natural areas, nature routes, outdoor sports) and selected pictures dominated by identifiable trees. For each tourism website, we counted the number of photographs dominated by NNT and NT species. The data set included 6 data sources for Argentina, 20 for Australia and Italy, 1 for Austria and Czech Republic, 7 for Brazil, 13 for Hawaii, 10 for New Zealand, 5 for Portugal, 17 for South Africa, and 16 for Spain.

Specific data sources:

Data for Argentina were collected from the following official tourism websites:

<http://turismoushuaia.com/galeria-de-imagenes>
<https://junindelosandesturismo.wordpress.com/>
<http://www.barilocheturismo.gob.ar/>
<http://www.sanmartindelosandes.gov.ar/turismo/galeria/fotos/paisajes.html>
<https://villalaangostura.gov.ar/turismo/galeria>
<http://neuquentur.gob.ar/>

Data for Australia were collected from the following tourism websites:

http://www.westernaustralia.com/en/Pages/Welcome_to_Western_Australia.aspx
<http://www.kimberleytravel.com.au/>
<https://www.margaretriver.com/towns/margaret-river/>
<https://www.queensland.com/>
<http://www.southernqueenslandcountry.com.au/>
<https://www.queensland.com/en-id/explore-queensland/tropical-north-queensland>
<http://www.visitgoldcoast.com/places-to-see/lamington-national-park>
<http://www.tourismwhitsundays.com.au/>
<http://www.visitnsw.com/>
<http://northernterritory.com/>
<http://parksaustralia.gov.au/uluru/visual-journey.html>
<http://www.alicesprings.nt.gov.au/living/tourism>
<http://www.discovertasmania.com.au/about/regions-of-tasmania/hobart-and-south#articles|page-1>
<http://www.discovertasmania.com.au/about/regions-of-tasmania/west-coast>
<http://www.nationalparks.nsw.gov.au/conservation-and-heritage/our-parks>
<http://www.discovertasmania.com.au/about/regions-of-tasmania/east-coast>
<http://southaustralia.com/en/travel-ideas/adventure>
<http://www.visitvictoria.com/Things-to-do/Nature-and-wildlife>
<http://www.australia.com/en/things-to-do/nature-and-wildlife.html>
<https://visitcanberra.com.au/outdoors-and-nature>

Data for Austria were collected from the following official tourism websites:

<http://www.austria.info/at>

Data for Brazil were collected from the following tourism websites:

<http://bancodeimagens.expressaostudio.com.br/BncSecTur/index.php?p=Y3NkdmRVNw==>
<http://www.feriasbrasil.com.br/fotos/>
<http://visiteminasgerais.com.br>
<http://www.turismo.pr.gov.br>
<http://turismo.sc.gov.br>
<http://www.turismo.rs.gov.br>
<http://www.turismo.rs.gov.br>

Data for the Czech Republic were collected from the following official tourism websites:

<http://www.kampocesku.cz/>

Data for Hawaii were not collected from official tourism websites, prompting inclusion of the following trustable public websites:

<https://portal.ehawaii.govpage/photos/>
<https://www.hawaii.com>
<https://www.discoverhawaiitours.com>
<https://gohawaii.com>
<https://www.robertshawaii.com>
<https://www.hawaii-guide.com>
<https://www.gohawaii.com/kauai>
<https://www.gohawaii.com/oahu/>
<https://www.gohawaii.com/maui>
<https://www.gohawaii.com/lanai/>

<https://www.gohawaii.com/molokai/>
<https://www.gohawaii.com/bigisland/>
<https://www.tripadvisor.com/hawaii/>

Data for Italy were collected from the following official tourism websites:

<http://fototeca.enit.it/Abruzzo>
<http://fototeca.enit.it/Basilicata>
<http://fototeca.enit.it/Calabria>
<http://fototeca.enit.it/Campania>
<http://fototeca.enit.it/EmiliaRomagna>
<http://fototeca.enit.it/FriuliVeneziaGiulia>
<http://fototeca.enit.it/Lazio>
<http://fototeca.enit.it/Liguria>
<http://fototeca.enit.it/Lombardia>
<http://fototeca.enit.it/Marche>
<http://fototeca.enit.it/Molise>
<http://fototeca.enit.it/Piemonte>
<http://fototeca.enit.it/Puglia>
<http://fototeca.enit.it/Sardegna>
<http://fototeca.enit.it/Sicilia>
<http://fototeca.enit.it/Toscana>
<http://fototeca.enit.it/TrentinoAltoAdige>
<http://fototeca.enit.it/Umbria>
<http://fototeca.enit.it/ValleDAosta>
<http://fototeca.enit.it/Veneto>

Data for New Zealand were collected from the following official tourism websites:

<https://www.northlandnz.com/visit>
<http://www.aucklandnz.com>
<http://www.bayofplentynz.com>
<http://www.centralotagonz.com/>
<http://www.christchurchnz.com>
<http://www.westcoast.co.nz/>
<http://www.visit.taranaki.info/>
<http://www.nelsonnz.com/>
<http://www.hamiltonwaikato.com/>
<http://southlandnz.com>

Data for Portugal were collected from the following official tourism websites:

<http://www.portoenorte.pt/>
<http://www.turismodocentro.pt/pt/>
<http://www.visitlisboa.com/>
<http://www.visitalentejo.pt/en/>
<http://www.turismoalgarve.pt/home.html>

Data for South Africa were collected from the following official tourism websites:

<http://www.tourismnorthwest.co.za>
http://www.sa-venues.com/north_province.htm
<http://www.gauteng.net/>
<http://www.southafrica.net>
<http://www.capetown.travel/category/visitors/city-areas/south-peninsula>
<http://www.findtripinfo.com>
<http://www.aboutcapetown.com>
<http://www.cometocapetown.com>
<http://www.gardenroutemeander.co.za/>
<http://active-escapes.co.za/>

<http://www.sa-venues.com/mpumalanga.htm>
http://www.sa-venues.com/free_state.htm
http://www.sa-venues.com/northern_cape.htm
http://www.sa-venues.com/eastern_cape.htm
<http://www.ectour.org.za/>
<http://www.golimpopo.com/>
<https://www.tripadvisor.co.za/>

Data for Spain were collected from the following official tourism websites:

<http://www.andalucia.org/es/destinos/>
<http://www.turismodearagon.com/es/tipo-de-actividad/espacios-naturales#.WCxwJLLhAnQ>
<https://www.turismoasturias.es/descubre/naturaleza>
<http://www.illesbalears.es/esp/islasbalears/naturaleza.jsp?SEC=NAT>
<http://www.turismodecantabria.com/disfrutala/recursos-naturales/>
<http://www.turismocastillalamancha.es/naturaleza/animales-y-bosques/>
<http://www.turismocastillayleon.com/>
<http://clicat.gencat.cat/clicat/AppJava//galleries.do?idColeccio=96ae8a85-868e-4c58-90da-f93f0703ef1a>
<http://www.turismodecastellon.com/> + <http://www.valenciaturisme.org/es/>
<http://www.turismoextremadura.com/>
<http://www.turismo.gal/>
<https://lariojaturismo.com/comunidad/larioja>
<http://turismomadrid.es/es/naturaleza/10101-espacios-naturales.html>
<https://www.murciaturistica.es/es/naturaleza/>
<http://www.turismo.navarra.es/esp/organice-viaje/mapa.aspx?idioma=es>
<http://turismo.euskadi.eus/es/naturaleza/>

2.2. NATURE ROUTES

Rationale: people show preference for specific nature areas for recreation and ecotourism. There are websites where people can upload their geo-referenced routes (along with photographs taken along the route) to share them with the public. These routes and photographs allow evaluation of whether people choose areas covered by NNTs or NTs or whether there is no clear preference.

Method: we obtained data from Wikiloc (available at <http://www.wikiloc.com>), because it covers routes worldwide. We selected routes more related to nature (including, hiking, cycling, walking), evenly distributed through the forest area of each country. We then examined the photographs of the route. The selected routes were uploaded before the year 2016 and had a minimum of 10 photographs dominated by identifiable tree species. When this assumption was not justified, we considered another route nearby. Among the selected routes, we provided the number of photographs dominated by NNTs or by NTs. For each route, we counted the number of pictures dominated by NNT and NT species in each wikiloc route. The data set included 25 data sources for Argentina, 138 for Australia, 8 for Austria, 13 for Czech Republic, 5 for Israel, 10 for Italy, 2 for New Zealand, 24 for Portugal, 6 for South Africa, and 137 for Spain.

Specific data sources:

For Argentina, data were collected from the following nature routes:

<https://www.wikiloc.com/wikiloc/view.do?id=8824491#morePhotos>
<https://www.wikiloc.com/wikiloc/view.do?id=8824522>
<https://www.wikiloc.com/wikiloc/view.do?id=8822171>
<https://www.wikiloc.com/wikiloc/view.do?id=8863761>
<https://www.wikiloc.com/wikiloc/view.do?id=9037215>
<https://www.wikiloc.com/wikiloc/view.do?id=3895858>

<https://www.wikiloc.com/wikiloc/view.do?id=1112683>
<https://www.wikiloc.com/wikiloc/view.do?id=15803223>
<https://www.wikiloc.com/wikiloc/view.do?id=11158793>
<https://www.wikiloc.com/wikiloc/view.do?id=8420327>
<https://www.wikiloc.com/wikiloc/view.do?id=3805795>
<https://www.wikiloc.com/wikiloc/view.do?id=6697998>
<https://www.wikiloc.com/wikiloc/view.do?id=3304333>
<https://www.wikiloc.com/wikiloc/view.do?id=11650037>
<https://www.wikiloc.com/wikiloc/view.do?id=11649502>
<https://www.wikiloc.com/wikiloc/view.do?id=11359686>
<https://www.wikiloc.com/wikiloc/view.do?id=4218986>
<https://www.wikiloc.com/wikiloc/view.do?id=11735372>
<https://www.wikiloc.com/wikiloc/view.do?id=8552255>
<https://www.wikiloc.com/wikiloc/view.do?id=1112875>
<https://www.wikiloc.com/wikiloc/view.do?id=2430274>
<https://www.wikiloc.com/wikiloc/view.do?id=2430545>
<https://www.wikiloc.com/wikiloc/view.do?id=11649675>
<https://www.wikiloc.com/wikiloc/view.do?id=2430603>
<https://www.wikiloc.com/wikiloc/view.do?id=11649502>

For Australia, a limited number of routes evenly distributed through forest area of each state were available. All Wikiloc routes which met the selection criteria of 10 photographs dominated by identifiable trees species were used. Wherever available, routes from WalkingMaps (available at <https://walkingmaps.com.au>) were also included if they met the selection criteria. The following routes were considered:

<http://www.wikiloc.com/wikiloc/view.do?id=8864653>
<http://www.wikiloc.com/wikiloc/view.do?id=14472012>
<http://www.wikiloc.com/wikiloc/view.do?id=14471128>
<http://www.wikiloc.com/wikiloc/view.do?id=6646651>
<http://www.wikiloc.com/wikiloc/view.do?id=6031012>
<http://www.wikiloc.com/wikiloc/view.do?id=8594644>
<http://www.wikiloc.com/wikiloc/view.do?id=5143079>
<http://www.wikiloc.com/wikiloc/view.do?id=4639037>
<http://www.wikiloc.com/wikiloc/view.do?id=13288718>
<http://www.wikiloc.com/wikiloc/view.do?id=11801214>
<http://www.wikiloc.com/wikiloc/view.do?id=15380067>
<http://www.wikiloc.com/wikiloc/view.do?id=11106323>
<http://www.wikiloc.com/wikiloc/view.do?id=11464138>
<http://www.wikiloc.com/wikiloc/view.do?id=11588598>
<http://www.wikiloc.com/wikiloc/view.do?id=6855038>
<http://www.wikiloc.com/wikiloc/view.do?id=11242451>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=5675627>
<http://www.wikiloc.com/wikiloc/view.do?id=5292296>
<http://www.wikiloc.com/wikiloc/view.do?id=12618611>
<https://walkingmaps.com.au/walk/320>
<http://www.wikiloc.com/wikiloc/view.do?id=7234730>
<http://www.wikiloc.com/wikiloc/view.do?id=7212679>
<http://www.wikiloc.com/wikiloc/view.do?id=5191560>
<http://www.wikiloc.com/wikiloc/view.do?id=14207532>
<http://www.wikiloc.com/wikiloc/view.do?id=14191872>
<http://www.wikiloc.com/wikiloc/view.do?id=14582031>
<http://www.wikiloc.com/wikiloc/view.do?id=11065049>
<http://www.wikiloc.com/wikiloc/view.do?id=11845490>
<http://www.wikiloc.com/wikiloc/view.do?id=11187619>
<http://www.wikiloc.com/wikiloc/view.do?id=11037582>
<http://www.wikiloc.com/wikiloc/view.do?id=9023071>
<http://www.wikiloc.com/wikiloc/view.do?id=14760209>
<http://www.wikiloc.com/wikiloc/view.do?id=11242466>

<http://www.wikiloc.com/wikiloc/view.do?id=11037373>
<http://www.wikiloc.com/wikiloc/view.do?id=12710690>
<http://www.wikiloc.com/wikiloc/view.do?id=11037790>
<http://www.wikiloc.com/wikiloc/view.do?id=14177423>
<http://www.wikiloc.com/wikiloc/view.do?id=11809057>
<http://www.wikiloc.com/wikiloc/view.do?id=10483239>
<http://www.wikiloc.com/wikiloc/view.do?id=13100396>
<http://www.wikiloc.com/wikiloc/view.do?id=15319432>
<http://www.wikiloc.com/wikiloc/view.do?id=14945085>
<http://www.wikiloc.com/wikiloc/view.do?id=13816430>
<http://www.wikiloc.com/wikiloc/view.do?id=11037445>
<http://www.wikiloc.com/wikiloc/view.do?id=14910155>
<http://www.wikiloc.com/wikiloc/view.do?id=8777860>
<http://www.wikiloc.com/wikiloc/view.do?id=913585>
<http://www.wikiloc.com/wikiloc/view.do?id=8082844>
<http://www.wikiloc.com/wikiloc/view.do?id=4681431>
<http://www.wikiloc.com/wikiloc/view.do?id=15032521>
<http://www.wikiloc.com/wikiloc/view.do?id=8555104>
<http://www.wikiloc.com/wikiloc/view.do?id=14354130>
<http://www.wikiloc.com/wikiloc/view.do?id=3277561>
<http://www.wikiloc.com/wikiloc/view.do?id=6827338>
<http://www.wikiloc.com/wikiloc/view.do?id=11242335>
<http://www.wikiloc.com/wikiloc/view.do?id=9967142>
<http://www.wikiloc.com/wikiloc/view.do?id=12778667>
<http://www.wikiloc.com/wikiloc/view.do?id=12664161>
<http://www.wikiloc.com/wikiloc/view.do?id=14340888>
<http://www.wikiloc.com/wikiloc/view.do?id=5080871>
<http://www.wikiloc.com/wikiloc/view.do?id=3245760>
<http://www.wikiloc.com/wikiloc/view.do?id=9343650>
<http://www.wikiloc.com/wikiloc/view.do?id=15017559>
<http://www.wikiloc.com/wikiloc/view.do?id=14558557>
<http://www.wikiloc.com/wikiloc/view.do?id=14642781>
<http://www.wikiloc.com/wikiloc/view.do?id=11036629>
<http://www.wikiloc.com/wikiloc/view.do?id=12454331>
<http://www.wikiloc.com/wikiloc/view.do?id=11037476>
<http://www.wikiloc.com/wikiloc/view.do?id=7679601>
<http://www.wikiloc.com/wikiloc/view.do?id=12778672>
<http://www.wikiloc.com/wikiloc/view.do?id=15071304>
<http://www.wikiloc.com/wikiloc/view.do?id=4651809>
<http://www.wikiloc.com/wikiloc/view.do?id=3657644>
<http://www.wikiloc.com/wikiloc/view.do?id=5094855>
<http://www.wikiloc.com/wikiloc/view.do?id=8082890>
<http://www.wikiloc.com/wikiloc/view.do?id=6499599>
<http://www.wikiloc.com/wikiloc/view.do?id=8082862>
<http://www.wikiloc.com/wikiloc/view.do?id=12454355>
<http://www.wikiloc.com/wikiloc/view.do?id=13078470>
<http://www.wikiloc.com/wikiloc/view.do?id=1028961>
<http://www.wikiloc.com/wikiloc/view.do?id=12727435>
<http://www.wikiloc.com/wikiloc/view.do?id=9748314>
<http://www.wikiloc.com/wikiloc/view.do?id=13474068>
<http://www.wikiloc.com/wikiloc/view.do?id=15055537>
<http://www.wikiloc.com/wikiloc/view.do?id=15093185>
<http://www.wikiloc.com/wikiloc/view.do?id=15092497>
<https://walkingmaps.com.au/walk/2612>
<http://www.wikiloc.com/wikiloc/view.do?id=15332012>
<http://www.wikiloc.com/wikiloc/view.do?id=15370326>
<http://www.wikiloc.com/wikiloc/view.do?id=3045537>
<http://www.wikiloc.com/wikiloc/view.do?id=15290271>
<http://www.wikiloc.com/wikiloc/view.do?id=15268639>

<http://www.wikiloc.com/wikiloc/view.do?id=15109651>
<http://www.wikiloc.com/wikiloc/view.do?id=8179472>
<http://www.wikiloc.com/wikiloc/view.do?id=10704192>
<http://www.wikiloc.com/wikiloc/view.do?id=13113332>
<https://walkingmaps.com.au/walk/3351>
<https://walkingmaps.com.au/walk/1109>
<https://walkingmaps.com.au/walk/2692>
<https://walkingmaps.com.au/walk/3087>
<https://walkingmaps.com.au/walk/1101>
<https://walkingmaps.com.au/walk/446>
<https://walkingmaps.com.au/walk/2691>
<https://walkingmaps.com.au/walk/3479>
<https://walkingmaps.com.au/walk/1741>
<https://walkingmaps.com.au/walk/1107>
<https://walkingmaps.com.au/walk/1212>
<https://walkingmaps.com.au/walk/2687>
<https://walkingmaps.com.au/walk/336>
<https://walkingmaps.com.au/walk/1095>
<https://walkingmaps.com.au/walk/231>
<https://walkingmaps.com.au/walk/1959>
<https://walkingmaps.com.au/walk/3376>
<https://walkingmaps.com.au/walk/1469>
<https://walkingmaps.com.au/walk/1106>
<https://walkingmaps.com.au/walk/301>
<https://walkingmaps.com.au/walk/327>
<https://walkingmaps.com.au/walk/3214>
<https://walkingmaps.com.au/walk/523>
<https://walkingmaps.com.au/walk/3425>
<https://walkingmaps.com.au/walk/2431>
<https://walkingmaps.com.au/walk/417>
<https://walkingmaps.com.au/walk/3429>
<https://walkingmaps.com.au/walk/517>
<https://walkingmaps.com.au/walk/307>
<https://walkingmaps.com.au/walk/2915>
<https://walkingmaps.com.au/walk/715>
<https://walkingmaps.com.au/walk/2546>
<https://walkingmaps.com.au/walk/1814>
<https://walkingmaps.com.au/walk/404>
<https://walkingmaps.com.au/walk/1743>
<https://walkingmaps.com.au/walk/701>
<https://walkingmaps.com.au/walk/1193>
<https://walkingmaps.com.au/walk/372>
<http://www.wikiloc.com/wikiloc/view.do?id=10669324>
<http://www.wikiloc.com/wikiloc/view.do?id=10741477>
<http://www.wikiloc.com/wikiloc/view.do?id=14581900>
<http://www.wikiloc.com/wikiloc/view.do?id=10596545>

Data for Austria were collected from the following nature routes:

<http://www.wikiloc.com/wikiloc/imgServer.do?id=6113288>
<http://www.wikiloc.com/wikiloc/view.do?id=7521622>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=6100180>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=756237>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=6674724>
<http://www.wikiloc.com/wikiloc/view.do?id=7262122>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=333666>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=2424487>

Data for the Czech Republic were collected from the following nature routes:

<http://www.wikiloc.com/wikiloc/view.do?id=1226463>
<http://www.wikiloc.com/wikiloc/view.do?id=11149257>
<http://www.wikiloc.com/wikiloc/view.do?id=1221921>
<http://www.wikiloc.com/wikiloc/view.do?id=1220399>
<http://www.wikiloc.com/wikiloc/view.do?id=3518226>
<http://www.wikiloc.com/wikiloc/view.do?id=9971672>
<http://www.wikiloc.com/wikiloc/view.do?id=1969222>
<http://www.wikiloc.com/wikiloc/view.do?id=10589111>
<http://www.wikiloc.com/wikiloc/view.do?id=9744527>
<http://www.wikiloc.com/wikiloc/view.do?id=11809750>
<http://www.wikiloc.com/wikiloc/view.do?id=4269236>
<http://www.wikiloc.com/wikiloc/view.do?id=10589136>
<http://www.wikiloc.com/wikiloc/view.do?id=11022865>

Data for Israel were collected considering all nature routes available that met the selection criteria, from the following nature routes:

<https://www.wikiloc.com/wikiloc/view.do?id=3325654>
<https://www.wikiloc.com/wikiloc/view.do?id=13618235>
<https://www.wikiloc.com/wikiloc/view.do?id=3437989>
<https://www.wikiloc.com/wikiloc/imgServer.do?id=9932623>
<https://www.wikiloc.com/wikiloc/view.do?id=15152815>

Data for Italy, we used all available routes that met the selection criteria:

<http://www.wikiloc.com/wikiloc/view.do?id=11247890>
<http://www.wikiloc.com/wikiloc/view.do?id=4718373>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=404743>
<http://www.wikiloc.com/wikiloc/view.do?id=6095181>
<http://www.wikiloc.com/wikiloc/view.do?id=2519775>
<http://www.wikiloc.com/wikiloc/view.do?id=7898045>
<http://www.wikiloc.com/wikiloc/view.do?id=3369267>
<http://www.wikiloc.com/wikiloc/view.do?id=7925680>
<http://www.wikiloc.com/wikiloc/view.do?id=9932145>
<http://www.wikiloc.com/wikiloc/view.do?id=10061377>

Data for New Zealand were collected from the following routes:

<https://www.wikiloc.com/wikiloc/view.do?id=10181111>
<https://www.wikiloc.com/wikiloc/imgServer.do?id=6155117>

Data for Portugal were collected from the following nature routes:

<http://www.wikiloc.com/wikiloc/view.do?id=11210163>
<http://pt.wikiloc.com/wikiloc/view.do?id=10438383>
<http://www.wikiloc.com/wikiloc/view.do?id=7995197>
<http://www.wikiloc.com/wikiloc/view.do?id=11422810>
<http://www.wikiloc.com/wikiloc/view.do?id=6561975>
<http://www.wikiloc.com/wikiloc/view.do?id=8640691>
<http://www.wikiloc.com/wikiloc/view.do?id=10712934>
<http://www.wikiloc.com/wikiloc/view.do?id=6619073>
<http://www.wikiloc.com/wikiloc/view.do?id=6191040>
<http://www.wikiloc.com/wikiloc/view.do?id=8393772>
<http://www.wikiloc.com/wikiloc/view.do?id=3523100>
<http://www.wikiloc.com/wikiloc/view.do?id=10712934>
<http://www.wikiloc.com/wikiloc/view.do?id=9438806>
<http://www.wikiloc.com/wikiloc/view.do?id=6331123>
<http://pt.wikiloc.com/wikiloc/view.do?id=5482178>
<http://www.wikiloc.com/wikiloc/view.do?id=9555543>
<http://www.wikiloc.com/wikiloc/view.do?id=9756071>
<http://www.wikiloc.com/wikiloc/view.do?id=967345>

<http://www.wikiloc.com/wikiloc/imgServer.do?id=3244001>
<http://www.wikiloc.com/wikiloc/view.do?id=10852779>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=1024710>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=5209808>
<http://www.wikiloc.com/wikiloc/view.do?id=3870514>
<http://www.wikiloc.com/wikiloc/view.do?id=1038627>

Data for South Africa: due to low availability of Wikiloc routes, we included an additional website: <http://www.gpsies.com/>, using the same protocol described for Wikiloc. The following nature routes were considered:

<https://www.wikiloc.com/hiking-trails/montagu-bloupunt-trail-11065650>
<https://es.wikiloc.com/rutas-senderismo/suspension-bridge-trail-parque-nacional-de-tsitsikamma-garden-route-sudafrica-5126995#morePhotos>
<https://www.wikiloc.com/hiking-trails/sabie-10725685#morePhotos>
<https://www.wikiloc.com/hiking-trails/xco-africa-do-sul-6904233#morePhotos>
<https://www.wikiloc.com/offroading-trails/waterfalls-mpumalanga-south-africa-680188#morePhotos>
<https://www.gpsies.com/map.do;jsessionid=E50B24410B713B3DD1F08FFB5BF11B25.fe3?fileId=ghklphkmbvkhfrew&language=da>

Data for Spain were collected from the following nature routes on the Wikiloc website:

<http://www.wikiloc.com/wikiloc/view.do?id=6076634>
<http://www.wikiloc.com/wikiloc/view.do?id=8485162>
<http://www.wikiloc.com/wikiloc/view.do?id=6587540>
<http://www.wikiloc.com/wikiloc/view.do?id=6937675>
<http://www.wikiloc.com/wikiloc/view.do?id=8101907>
<http://www.wikiloc.com/wikiloc/view.do?id=8160857>
<http://www.wikiloc.com/wikiloc/view.do?id=10697677>
<http://www.wikiloc.com/wikiloc/view.do?id=3809182>
<http://www.wikiloc.com/wikiloc/view.do?id=5872929>
<http://www.wikiloc.com/wikiloc/view.do?id=8864254>
<http://www.wikiloc.com/wikiloc/view.do?id=9529820>
<http://www.wikiloc.com/wikiloc/view.do?id=6944438>
<http://www.wikiloc.com/wikiloc/view.do?id=8536224>
<http://www.wikiloc.com/wikiloc/view.do?id=8222181>
<http://www.wikiloc.com/wikiloc/view.do?id=11628574>
<http://www.wikiloc.com/wikiloc/view.do?id=8122232>
<http://www.wikiloc.com/wikiloc/view.do?id=9039541>
<http://www.wikiloc.com/wikiloc/view.do?id=5651423>
<http://www.wikiloc.com/wikiloc/view.do?id=3672482>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=5978526>
<http://www.wikiloc.com/wikiloc/view.do?id=5239568>
<http://www.wikiloc.com/wikiloc/view.do?id=4396160>
<http://www.wikiloc.com/wikiloc/view.do?id=11540373>
<http://www.wikiloc.com/wikiloc/view.do?id=11169153>
<http://www.wikiloc.com/wikiloc/view.do?id=4131784>
<http://www.wikiloc.com/wikiloc/view.do?id=4217101>
<http://www.wikiloc.com/wikiloc/view.do?id=10461232>
<http://www.wikiloc.com/wikiloc/view.do?id=10293376>
<http://www.wikiloc.com/wikiloc/view.do?id=10307304>
<http://www.wikiloc.com/wikiloc/view.do?id=7870794>
<http://www.wikiloc.com/wikiloc/view.do?id=9528357>
<http://www.wikiloc.com/wikiloc/view.do?id=8045980>
<http://www.wikiloc.com/wikiloc/view.do?id=7335878>
<http://www.wikiloc.com/wikiloc/view.do?id=4985956>
<http://www.wikiloc.com/wikiloc/view.do?id=6784335>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=5518356>
<http://www.wikiloc.com/wikiloc/view.do?id=9680652>
<http://www.wikiloc.com/wikiloc/view.do?id=10258039>
<http://www.wikiloc.com/wikiloc/view.do?id=10933310>
<http://www.wikiloc.com/wikiloc/view.do?id=11196882>

<http://www.wikiloc.com/wikiloc/view.do?id=7276790>
<http://www.wikiloc.com/wikiloc/view.do?id=10840636>
<http://www.wikiloc.com/wikiloc/view.do?id=9252959>
<http://www.wikiloc.com/wikiloc/view.do?id=8322735>
<http://www.wikiloc.com/wikiloc/view.do?id=6553317>
<http://www.wikiloc.com/wikiloc/view.do?id=11238662>
<http://www.wikiloc.com/wikiloc/view.do?id=6089525>
<http://www.wikiloc.com/wikiloc/view.do?id=8133623>
<http://www.wikiloc.com/wikiloc/view.do?id=11629858>
<http://www.wikiloc.com/wikiloc/view.do?id=10919228>
<http://www.wikiloc.com/wikiloc/view.do?id=11576102>
<http://www.wikiloc.com/wikiloc/view.do?id=6976814>
<http://www.wikiloc.com/wikiloc/view.do?id=7595861>
<http://www.wikiloc.com/wikiloc/view.do?id=9588026>
<http://www.wikiloc.com/wikiloc/view.do?id=9579317>
<http://www.wikiloc.com/wikiloc/view.do?id=7209331>
<http://www.wikiloc.com/wikiloc/view.do?id=8233072>
<http://www.wikiloc.com/wikiloc/view.do?id=10565382>
<http://www.wikiloc.com/wikiloc/view.do?id=11186394>
<http://www.wikiloc.com/wikiloc/view.do?id=11182326>
<http://www.wikiloc.com/wikiloc/view.do?id=10220031>
<http://www.wikiloc.com/wikiloc/view.do?id=10097026>
<http://www.wikiloc.com/wikiloc/view.do?id=5712427>
<http://www.wikiloc.com/wikiloc/view.do?id=9568889>
<http://www.wikiloc.com/wikiloc/view.do?id=1240112>
<http://www.wikiloc.com/wikiloc/view.do?id=3573353>
<http://www.wikiloc.com/wikiloc/view.do?id=10591506>
<http://www.wikiloc.com/wikiloc/view.do?id=1798095>
<http://www.wikiloc.com/wikiloc/view.do?id=10484314>
<http://www.wikiloc.com/wikiloc/view.do?id=8964551>
<http://www.wikiloc.com/wikiloc/view.do?id=11508866>
<http://www.wikiloc.com/wikiloc/view.do?id=7251458>
<http://www.wikiloc.com/wikiloc/view.do?id=3641400>
<http://www.wikiloc.com/wikiloc/view.do?id=3580660>
<http://www.wikiloc.com/wikiloc/view.do?id=7919431>
<http://www.wikiloc.com/wikiloc/view.do?id=273685>
<http://www.wikiloc.com/wikiloc/view.do?id=289361>
<http://www.wikiloc.com/wikiloc/view.do?id=10015888>
<http://www.wikiloc.com/wikiloc/view.do?id=4644981>
<http://www.wikiloc.com/wikiloc/view.do?id=6844139>
<http://www.wikiloc.com/wikiloc/view.do?id=6264764>
<http://www.wikiloc.com/wikiloc/view.do?id=10303906>
<http://www.wikiloc.com/wikiloc/view.do?id=7493494>
<http://www.wikiloc.com/wikiloc/view.do?id=5499996>
<http://www.wikiloc.com/wikiloc/view.do?id=3495723>
<http://www.wikiloc.com/wikiloc/view.do?id=5238557>
<http://www.wikiloc.com/wikiloc/view.do?id=4530155>
<http://www.wikiloc.com/wikiloc/view.do?id=11335745>
<http://www.wikiloc.com/wikiloc/view.do?id=5222364>
<http://www.wikiloc.com/wikiloc/view.do?id=7568781>
<http://www.wikiloc.com/wikiloc/view.do?id=9097825>
<http://www.wikiloc.com/wikiloc/view.do?id=4646391>
<http://www.wikiloc.com/wikiloc/view.do?id=4595680>
<http://www.wikiloc.com/wikiloc/view.do?id=9570062>
<http://www.wikiloc.com/wikiloc/view.do?id=5681210>
<http://www.wikiloc.com/wikiloc/view.do?id=7948857>
<http://www.wikiloc.com/wikiloc/view.do?id=9679869>
<http://www.wikiloc.com/wikiloc/view.do?id=5416886>
<http://www.wikiloc.com/wikiloc/view.do?id=11310213>
<http://www.wikiloc.com/wikiloc/view.do?id=7655790>
<http://www.wikiloc.com/wikiloc/imgServer.do?id=5719676>
<http://www.wikiloc.com/wikiloc/view.do?id=8039508>
<http://www.wikiloc.com/wikiloc/view.do?id=9300880>

<http://www.wikiloc.com/wikiloc/view.do?id=10152184>
<http://www.wikiloc.com/wikiloc/view.do?id=9573404>
<http://www.wikiloc.com/wikiloc/view.do?id=4104880>
<http://www.wikiloc.com/wikiloc/view.do?id=3623808>
<http://www.wikiloc.com/wikiloc/view.do?id=8446663>
<http://www.wikiloc.com/wikiloc/view.do?id=3167707>
<http://www.wikiloc.com/wikiloc/view.do?id=10451352>
<http://www.wikiloc.com/wikiloc/view.do?id=8010212>
<http://www.wikiloc.com/wikiloc/view.do?id=4071624>
<http://www.wikiloc.com/wikiloc/view.do?id=11568196>
<http://www.wikiloc.com/wikiloc/view.do?id=8497789>
<http://www.wikiloc.com/wikiloc/view.do?id=9844601>
<http://www.wikiloc.com/wikiloc/view.do?id=9581364>
<http://www.wikiloc.com/wikiloc/view.do?id=8626481>
<http://www.wikiloc.com/wikiloc/view.do?id=3582200>
<http://www.wikiloc.com/wikiloc/view.do?id=7861273>
<http://www.wikiloc.com/wikiloc/view.do?id=11779822>
<http://www.wikiloc.com/wikiloc/view.do?id=11658804>
<http://www.wikiloc.com/wikiloc/view.do?id=11347063>
<http://www.wikiloc.com/wikiloc/view.do?id=8869044>
<http://www.wikiloc.com/wikiloc/view.do?id=11656304>
<http://www.wikiloc.com/wikiloc/view.do?id=7938605>
<http://es.wikiloc.com/wikiloc/view.do?id=8257559>
<http://www.wikiloc.com/wikiloc/view.do?id=10801825>
<http://www.wikiloc.com/wikiloc/view.do?id=8188436>
<http://www.wikiloc.com/wikiloc/view.do?id=6914454>
<http://www.wikiloc.com/wikiloc/view.do?id=7722717>
<http://www.wikiloc.com/wikiloc/view.do?id=3166601>
<http://www.wikiloc.com/wikiloc/view.do?id=6823841>
<http://www.wikiloc.com/wikiloc/view.do?id=9978423>
<http://www.wikiloc.com/wikiloc/view.do?id=4940829>
<http://www.wikiloc.com/wikiloc/view.do?id=5039022>
<http://www.wikiloc.com/wikiloc/view.do?id=11563128>
<http://www.wikiloc.com/wikiloc/view.do?id=6302429>

3. CULTURAL HERITAGE

This CES was expressed by information on monumental tree species for each country, as described below.

OFFICIAL LIST OF MONUMENTAL TREE SPECIES

Rationale: many countries have an official catalogue of emblematic, monumental or singular tree species. These trees are appreciated symbols of the landscape and cultural heritage.

Method: we considered official catalogues of emblematic/monumental/singular trees at the country level. For each catalogue, we counted the number of NNTs and NTs. The data set included 8 data sources for Australia, 5 for Austria, 8 for Brazil, 1 for Czech Republic, Hawaii, Israel, New Zealand and South Africa, 20 for Italy, 5 for Portugal, and 16 for Spain.

Specific data sources:

For Australia, we used the official list for monumental trees available at:

<http://www.trusttrees.org.au/> (from this link we retrieved data for Northern Territory, Western Australia, South Australia, Tasmania, Victoria, New South Wales, Australian Capital Territory and Queensland).

For Austria, we used the official list for monumental trees available at:

<https://www.wien.gv.at/umweltschutz/naturschutz/gebiet/typen.html>

http://www.land-oberoesterreich.gv.at/files/naturschutz_db/Naturschutz_in_OOE_Naturdenkmale.pdf
http://www.noel.gv.at/Umwelt/Naturschutz/Schutzgebiete-und-Naturdenkmale/Schutzgebiete_Naturdenkmale.html
<https://www.tirol.gv.at/umwelt/naturschutz/naturdenkmal-einstieg/>
List provided by Department for Environment and climate protection (Abteilung für Umwelt- und Klimaschutz, Amt der Vorarlberger Landesregierung)

For Brazil, we used the official list for monumental trees available at:

<http://www.ambiente.sp.gov.br/wp-content/uploads/decreto/1989/1989-Dec-30443.pdf>
<http://www.rio.rj.gov.br/dlstatic/10112/2565214/DLFE-240306.pdf/1.0>
<http://cm-belo-horizonte.jusbrasil.com.br/legislacao/241198/decreto-2940-76>
<https://multimedia.curitiba.pr.gov.br/2010/00086375.pdf>
<https://leismunicipais.com.br/a1/sc/f/florianopolis/decreto/1987/16/152/decreto-n-152-1987-declara-imune-ao-corte-as-arvores-que-especifica-e-da-outras-providencias?q=imunes>
http://www.mprs.mp.br/areas/ambiente/arquivos/arvores_imunes/relatorio/Listagem%20Atualizada%2020%2028-03-2014%29.pdf
http://www.uberlandia.mg.gov.br/uploads/cms_b_arquivos/6306.pdf
<http://dados.recife.pe.gov.br/dataset/arvores-tombadas/resource/0c1935f4-1a7f-4c76-b3ba-b344951d6820>

For the Czech Republic, we used the official list for monumental trees available at:

<http://drusop.nature.cz/ost/chrobjekty/pstromy/index.php?frame>

For Hawaii, while an official monumental tree catalogue was not available at the time of data collection, Hawaiian data were obtained from the following ArcGIS monumental tree species map:

<https://tocetm.maps.arcgis.com/apps/webappviewer/index.html?id=145ee53b5a964329a3bd8279f350eee1>

For Israel, we used information from the “101 Special and Amazing Trees in Israel (2008). ISBN 978-965-13-2011-8.

For South Africa, we used the 2016 list of champion trees of South Africa available at:

<http://www.nda.agric.za/doaDev/sideMenu/ForestryWeb/webapp/docs/FINAL%20CHAMPION%20TREES%20OF%20SA%202016.pdf>.

For Italy, we used the official list for monumental trees available at:

<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6310>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6311>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6312>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6313>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6314>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6315>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6316>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6317>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6318>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6319>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6320>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6321>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6322>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6323>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6324>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6325>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6326>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6327>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6328>
<http://www.corpoforestale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/6329>

For New Zealand, we used the official list for monumental trees available at:
<http://www.notabletrees.org.nz>

For Portugal, we used the official list for monumental trees available at:
<http://www.icnf.pt/portal/florestas/aip/aip-monum-pt>. (From this link we obtained information for each of the following regions: Norte, Centro, Lisboa, Alentejo, Algarve).

For South Africa, we used information from 80 champion trees in South Africa (Individual Trees and Groups of Trees Declared as Protected Under Section 12 of the National Forests Act of 1998 by the Department of Agriculture, Forestry and Fisheries)

For Spain, data were obtained from the official catalogue of monumental tree species for each region:
http://www.juntadeandalucia.es/medioambiente/site/portalweb/menuitem.7e1cf46ddf59bb227a9ebe205510e1ca/?vgnextoid=d733e6ed46a28110VgnVCM1000000624e50aRCRD&vgnnextchannel=d833a0b5f9ca5310VgnVCM2000000624e50aRCRD&lr=lang_es
<https://www.larioja.org/npRioja/default/defaultpage.jsp?idtab=524420>
http://www.madrid.org/cs/Satellite?blobcol=urldata&blobheader=application%2Fpdf&blobheadername1=Content-Disposition&blobheadervalue1=filename%3DCATALOGO_ESPECIES_2015.pdf&blobkey=id&blobtable=MungoBlobs&blobwhere=1352865924672&ssbinary=true
https://www.clh.es/docs/PDFarboles_tomo2.pdf (from this source we retrieved information for each of the following regions: Aragón, Asturias, Catabria, Castilla y León, Castilla-La Mancha, Cataluña, Valencia, Extremadura, Galicia, Islas Baleares, Murcia, Navarra, País Vasco).

4. INSPIRATION

This CES was assessed by means of artistic photographs.

ARTISTIC NATURE PHOTOGRAPHS

Rationale: paintings, pottery and artistic photographs show inspiring motifs. We can assume that an artist showing a photograph with nature motifs chooses these inspiring motifs from the nature of his/her environment.

Method: we searched for websites on artistic photographs and contests of nature photographs. We selected the category of trees/forests and photographs indicating where they were taken (at least at the country level). We used the maximum number of websites available for each country. Eligible websites compiled a selection of photographs from different authors (one-author personal websites were not valid). We selected photographs where NNTs and NTs could be identified and counted the number of photographs dominated by NNTs or NTs. For each website, we counted the number of photographs dominated by NNT and NT species in the website. The data set included 7 data sources for Argentina, 20 for Australia, 1 for Austria, 30 for Czech Republic, 4 for Hawaii, 5 for Italy and South Africa, and 6 for Spain and Portugal.

Specific data sources:

Data for Argentina were obtained from the following websites:
<http://www.jornadasforestales.org.ar>
<http://www.eliseomiciu.com/fineart/>
<https://leofridano.wordpress.com/po>
<http://www.eduardopocai.com/galerias/index.html>

<http://www.enfoquenatural.net>
<http://www.danieljara.com/portfolio/patagonia>
<http://ricardolapietra.com/gallery/>

Data for Australia were obtained from the following websites:

<http://naturephotographeroftheyear.com.au/>
<http://www.markgray.com.au/>
<http://www.kanegledhill.com.au/gallery/category/all-images/>
<https://michaelsnedic.com/>
<http://www.chockstonephotos.com/>
<http://www.naturesimage.com.au/>
<http://www.christianfletcher.com.au/>
<http://www.juliefletcherphotography.com.au/>
<http://damianjames.zenfolio.com/australia/h3D51B1F6#h3d51b1f6>
<https://benmessina.wordpress.com/category/western-australia/>
<http://www.adammonk.com/photography>
<http://www.shاونjones.com.au/galleries/full-catalogue/>
<http://www.ecolsoc.org.au/events-and-activities/photo-competition/2016-photo-competition-gallery>
<https://austravelphotography.wordpress.com/tag/tree/>
<http://estherbeaton.com/photography/stock-library/>
<http://lifeimagesbyjill.blogspot.com/p/tour-western-australia.html>
<https://www.destinsparks.com/links/australian-landscape/>
<http://www.rastanley.com.au/>
<http://www.paulchantlerphotographer.com.au/GalleryMain.asp?GalleryID=140583&AKey=WLPV2G6W>
<http://www.martinwillisphotographs.com.au/shop/landscape/outback>

Data for Austria were obtained from “www.fotografie.at”.

Data for the Czech Republic were obtained from the following websites:

<http://www.danielrericha.cz/nejnovejsi/krusne-hory-ceska-republika-750.html>
<http://www.danielrericha.cz/nejnovejsi/labske-piskovce-ceska-republika-731.html>
<http://www.danielrericha.cz/nejnovejsi/luzicke-hory-ceska-republika-727.html>
<http://www.danielrericha.cz/nejnovejsi/ceske-svycarsko-ceska-republika-666.html>
<http://www.danielrericha.cz/nejnovejsi/ceske-svycarsko-ceska-republika-661.html>
<http://www.danielrericha.cz/nejnovejsi/krusne-hory-ceska-republika-621.html>
<http://www.danielrericha.cz/nejnovejsi/krkonose-ceska-republika-608.html>
<http://www.danielrericha.cz/nejnovejsi/luzicke-hory-ceska-republika-577.html>
<http://www.michalbalada.com/krajinarska-fotografie/foto-smeda-ii-jizerske-hory/21247/>
<http://www.michalbalada.com/krajinarska-fotografie/foto-smeda-jizerske-hory/18951/>
<http://www.michalbalada.com/krajinarska-fotografie/foto-jizerske-hory-mlhave-rano-ii/232/>
<http://www.michalbalada.com/krajinarska-fotografie/foto-peklo-nad-metuji-i-orlicke-hory/106/>
<http://www.radeksevera.estranky.cz/fotoalbum/foto-tydne--photo-of-the-week-/foto-tydne-2016/>
<http://www.petrpazour.cz/foto/75/jarni-palava>
<http://www.petrpazour.cz/foto/792/palava>
<http://www.petrpazour.cz/foto/823/sumavske-chalupy>
<http://www.petrpazour.cz/foto/410/odletajici-jaro>
http://www.krasyprirody.cz/Priroda/DSC_7170.jpg
http://www.krasyprirody.cz/Priroda/DSC_4930.jpg
http://www.krasyprirody.cz/Priroda/DSC_2902.jpg
http://www.krasyprirody.cz/Priroda/DSC_3248.jpg
http://www.krasyprirody.cz/Priroda/DSC_3432.jpg
<http://www.jiristransky.com/krajina/cechy/cerna38.htm>
<http://www.fotokrajina.cz/nejnovejsi/kostel-v-sonove-148.html>
<http://www.fotokrajina.cz/nejnovejsi/podzimni-zima-na-studenci-135.html>
<http://www.susen.cz/?cube=galerie&c2=501>
<http://www.susen.cz/?cube=galerie&c2=117>
<http://www.photo-lukas.cz/fotodetail.asp?gal=/Album8&fno=11>
<http://www.photo-lukas.cz/fotodetail.asp?gal=/Album1&fno=12>

<http://www.photo-lukas.cz/fotodetail.asp?gal=/Album2&fno=23>

Data for Hawaii were obtained from the following websites:

www.smithsonianmag.com/photocontest

<https://sites.google.com/site/hawaii>

www.scottmead.photoshelter.com

www.rondahlquist.com

Data for Italy were obtained from the following websites:

http://www.nationalgeographic.it/natura/piante/2008/10/01/foto/alberi_monumentali-8930/1/#media

[https://www.google.it/search?q=Gabriele+Basilico+catalogo&espv=2&biw=1366&bih=667&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwi_qp3k-](https://www.google.it/search?q=Gabriele+Basilico+catalogo&espv=2&biw=1366&bih=667&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwi_qp3k-PLLAhUGhQ8KHWD9B1kQsAQIGw&dpr=1#tbm=isch&q=Gianni+Berengo+Gardin+catalogo)

[PLLAhUGhQ8KHWD9B1kQsAQIGw&dpr=1#tbm=isch&q=Gianni+Berengo+Gardin+catalogo](https://www.google.it/search?q=Gabriele+Basilico+catalogo&espv=2&biw=1366&bih=667&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwi_qp3k-PLLAhUGhQ8KHWD9B1kQsAQIGw&dpr=1#tbm=isch&q=Mimmo+Jodice+catalogo)

[https://www.google.it/search?q=Gabriele+Basilico+catalogo&espv=2&biw=1366&bih=667&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwi_qp3k-](https://www.google.it/search?q=Gabriele+Basilico+catalogo&espv=2&biw=1366&bih=667&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwi_qp3k-PLLAhUGhQ8KHWD9B1kQsAQIGw&dpr=1#tbm=isch&q=Mimmo+Jodice+catalogo)

[PLLAhUGhQ8KHWD9B1kQsAQIGw&dpr=1#tbm=isch&q=Mimmo+Jodice+catalogo](https://www.google.it/search?q=Gabriele+Basilico+catalogo&espv=2&biw=1366&bih=667&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwi_qp3k-PLLAhUGhQ8KHWD9B1kQsAQIGw&dpr=1#tbm=isch&q=Ferdinando+Scianna+catalogo)

[https://www.google.it/search?q=Gabriele+Basilico+catalogo&espv=2&biw=1366&bih=667&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwi_qp3k-](https://www.google.it/search?q=Gabriele+Basilico+catalogo&espv=2&biw=1366&bih=667&tbm=isch&tbo=u&source=univ&sa=X&ved=0ahUKEwi_qp3k-PLLAhUGhQ8KHWD9B1kQsAQIGw&dpr=1#tbm=isch&q=Ferdinando+Scianna+catalogo)

[PLLAhUGhQ8KHWD9B1kQsAQIGw&dpr=1#tbm=isch&q=Ferdinando+Scianna+catalogo](http://www.michelevettorazzi.it/0_trees.html)

http://www.michelevettorazzi.it/0_trees.html

Data for Portugal were obtained from the following websites:

<http://olhares.sapo.pt/>

<http://cinclusvouzela.com/galeria>

http://www.ciencia20.up.pt/index.php?option=com_ciencia20galleries&view=system1&level1=13&level2=15&level3=59&Itemid=223

<https://nationalgeographic.sapo.pt/a-sua-foto?limitstart=0>

<http://wildlifeportugal.pt/>

<http://fotografiaportugal.pt/>

Data for South Africa were obtained from the following websites:

<https://www.ormsdirect.co.za/blog>

<https://www.countrylife.co.za>

<http://www.smithsonianmag.com/photocontest/tags/cape-town/>

www.getaway.co.za/photo/

<http://www.medioclubsouthafrica.com/>

Data for Spain were obtained from the following websites:

www.miradanatural.es

www.fotonatura.org/galerias/flora

<https://fotografiaperfecta.wordpress.com/2012/12/28/77-fotografos-de-naturaleza-que-deberias-conocer/>

<http://www.agefotostock.com/age/es/Photographers.aspx>

http://migaleria-afona.org/#/tematicas/paisajes/p_20

<http://www.fonamad.org/galerias/>

5. SCIENTIFIC INTEREST

This CES was considered by evaluating the amount of scientific publication on NNTs and NTs for each country.

NUMBER OF SCIENTIFIC PUBLICATIONS

Rationale: scientific knowledge about a given tree species can be communicated by means of scientific publications. The number of scientific publications produced in each country therefore indicates the amount of interest.

Methods: a bibliometric search was carried out for two lists – one list of NNT species, and one list of NT species – for each country. The number of published scientific records for each list was evaluated using the search engine *Scopus* (<https://www.scopus.com/home.uri>). The search key words used in *Scopus* were the scientific name of each tree species, separated by the boolean operator “OR”. For example, for a list constituted by the tree species *Pinus pinaster* and *Eucalyptus globulus*, our search string was (“*Pinus pinaster*” OR “*Eucalyptus globulus*”). For each country, we limited the territorial context of the search, by filtering the *Scopus* search to each country (search field = Country). We further limited the search to the following document types: Articles OR Review OR Letter OR Book chapter. We considered all records retrieved by the search prior to the year 2016.

ECOSYSTEM DISSERVICE: POLLEN ALLERGENICITY

The ecosystem disservice comprised information on the potential for pollen allergenicity provided by NNTs and NTs.

Rationale: the allergenic potential of a given tree reduces the benefit of human–nature interactions. People may avoid areas dominated by tree species that produce allergenic pollen compounds.

Methods: in each country searching was carried out for one list of NNT species and another list of NT species. The potential for pollen allergenicity of each species was checked using the database Allergome (available at: <http://www.allergome.org>). All searches were finalized in February 2017. From the NNT and NT lists, we counted the number of allergenic NNT and NT species in Allergome.

For South Africa, however, we used a subset of species due to the large number of NTs and NNTs. For NNTs we used all the trees listed in the National Environmental Management: Biodiversity Act (NEM:BA) regulations. For NTs we took a subset of the 1700 native tree species. We randomly selected 200 species that included at least one species from each genus. Additional searches were conducted in Berman (2013), Potter (2010), and Pollenlibrary (at: <http://www.pollenlibrary.com/>).

AREAS COVERED BY NON-NATIVE AND NATIVE TREES IN EACH COUNTRY/REGION

This information concerns the area covered by NNT and NT tree species in each country or region within countries. The areas are used for calculating effect sizes of NNTs on the cultural ecosystem services: monumental tree species, websites of tourism information, nature routes and artistic nature photographs. Below we indicate the main sources of information considered for each country.

Specific information for each country:

Argentina: data on the area covered by NTs was obtained from the Primer Inventario Nacional de Bosques Nativos (at: <http://www.ambienteforestalnoa.org.ar/userfiles/nodo/informenacionalpinbn.pdf>).

For NNT cover, data were obtained from Primer Inventario Nacional de Bosques Nativos. Informe Regional Andino Patagónico (at: [http://leydebosques.org.ar/zips/bosquesargentinos/Inventario%20Nacional%20de%20Bosques%201998_2005%20Andino%20Patag%C3%B3nico%20\(SAyDS\).pdf](http://leydebosques.org.ar/zips/bosquesargentinos/Inventario%20Nacional%20de%20Bosques%201998_2005%20Andino%20Patag%C3%B3nico%20(SAyDS).pdf)).

Australia: NT and NNT areas were obtained from Australia's State of the Forests Report (2013) Criterion 1: Conservation of biological diversity written and compiled by the Australian Government Department of Agriculture (at http://www.agriculture.gov.au/abares/forestsaustralia/Documents/criterion1_web.pdf). The cover area for each species was not available, so the available information was categorized as follows: total native forest, total industrial plantation (non-native (softwood plantation), native (hardwood plantation)), and other forests (unknown or mixed forests (mostly non-native forests)). Native forests include varying growth stages: regeneration, regrowth, mature and senescent, and uneven-aged forests. Forests were also categorized into eight broad forest types based on the dominant genus: *Acacia*, *Callitris*, *Casuarina*, *Eucalypt* (further divided into 11 subtypes according to height and cover class), Mangrove, Melaleuca, Rainforest, and Other comprised of less-common native forest types. 'Total industrial plantation' includes farm forestry and environmental plantings which may include a mixture of both NTs and NNTs. As stated in the report: "Industrial plantations, reported through the National Plantation Inventory, comprise 1.03 million hectares of softwood species (mostly exotic pines), 0.98 million hectares of hardwood species (mostly eucalypts), and 0.01 million hectares of plantations for which the species is unrecorded or where there is more than one species." 'Other forests' are small areas of forests dominated by introduced (exotic) species established without human intervention (that is, not planted), and these are also classified in this category. Land area units were calculated in hectares per state/territory.

Austria: data were obtained from Austrian forest inventory data collected between 2007 and 2009 (available at: www.waldinventur.at). For the area calculation, growing stock (in Vfm = Festmeter = stacked cubic meter) of two groups: NT species and NNT species (represented by Eastern white pine, Douglas-fir, black-locust, and hybrid-poplar) were used to calculate their presence (in %). Finally, the % of both groups and the total forest area without any legal protection regime, e.g. Natura 2000, national protected areas (in ha) were used to estimate the total coverage of NS and NNS in Austrian forests in ha.

Brazil: the area of NNTs included the area of commercially planted forests (at: <http://www.florestal.gov.br/snif/recursos-florestais/as-florestas-plantadas>) as a surrogate for total area covered by NNTs. Potentially missing data include areas planted with NNT orchards, for ornamentation, and non-commercial NNT plantations. For NTs, we used information from the National Forest Inventory (<http://www.iflorestal.sp.gov.br/>), together with the botanical atlas (<http://mapas.sosma.org.br/>), and additional governmental information (<http://www.ief.mg.gov.br/florestas>).

Czech Republic: data were obtained from the Annual Report on the State of Forests in 2014 (<http://www.uhul.cz/ke-stazeni/informace-o-lese/zelene-zpravy-mze>). Since not all data for NNT species were provided at the species level in this report, the area of NNTs was computed as the sum of areas of NNTs provided in Mlíkovský & Stýblo (2006).

Hawaii: no data on Hawaiian forest was available at the time of the search, therefore, Hawaiian data were derived from the monumental trees and artistic nature photographs data sources, resulting in respective covers of 22648.80 km² for NNTs and 5662.20 km² for NTs.

Israel: two data sources were considered for both NT and NNT species: (a) census data of the Keren Kayemeth Lelsrael Jewish National Fund (KKL-JNF), which is the organization that manages all forests in Israel (at: <http://www.kkl-jnf.org/about-kl-jnf/>); (b) the Report on Nature Status

2016

(http://www.hamaarag.org.il/sites/default/files/media/file/report/field_report_report_file/sn_r_web_2016.pdf).

Italy: data were obtained from the second Italian National Forest Inventory (INFC2005; Gasperini & Tabacchi, 2011), available at the Ministry of Agriculture and Forestry webpage (<http://www.sian.it/inventarioforestale/jsp/documentazione.jsp>). Data are provided at the species and province levels, as the basal area, in m² (sum of all section areas of trees at 1.30 m height, referred to a hectare). Within the “forest” category of INFC2005, the total number of NNTs (stems with diameter at breast height larger than 4.4 cm) represented 4.4% of the total number of trees with invasive NNT species representing 2.7%. The IFNC2005 only covers forest areas larger than 5000 m², so species present in small patches or narrow corridors (e.g. riparian forests) may not be included. However, for the basal area and volume of invasive NNTs, based on Rizzo & Gasparini (2011), the proportion was calculated as 1.9% and 1.8%, respectively, of the total basal area and volume of Italian forests.

New Zealand: data were obtained from the New Zealand Land Cover Database (LCDB) version 4.1 available at (<https://iris.scinfo.org.nz/layer/423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/>). Spatial data are provided as vector polygons for land cover by region in New Zealand, in hectares (ha) and include North Island, South Island and Stewart Island. The Chatham Islands are not included. Referring to the LCDB classification table (available from the above website), classes were grouped as: NT – Broadleaved Indigenous Hardwoods (class 54) and Indigenous Forest (class 69) and NNT – Forest Harvested (class 64), Deciduous Hardwoods (class 68) and Exotic Forest (class 71).

Portugal: data were obtained from COS2007 (at: <http://www.dgterritorio.pt/>). Spatial data are provided as a shapefile for the country, in hectares (ha). Since the land cover data is not always provided at the species level, we used a conservative approach in the sense that only classes dominated by NNT or NT land cover were considered. To assess the area covered by NT and NNT per region, the information from COS2007 was merged with the shapefile for the administrative regions from Eurostat (<http://ec.europa.eu/eurostat/web/gisco/geodata/reference-data/administrative-units-statistical-units>). The final values were compared to the values provided by the National Forest Inventory (ICNF, 2013a), and the obtained proportions of NNTs and NTs were validated.

South Africa: we used FAO (2010) (<http://www.fao.org/forest-resources-assessment/past-assessments/fra-2010/en/>) to determine the cover of NTs and NNTs. For NT cover we summed the cover for forest, woodland, thicket degraded forest and woodland and degraded thicket. For NNT cover we added forest plantation and improved grassland categories.

Spain: data were obtained from the 3rd National Forest Inventory (IFN3 1997-2007), available at the Ministry of Agriculture, Fishing, Food and the Environment webpage (<http://www.mapama.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/ifn3.aspx>). Data are provided at the species and province levels, in basal area in m² (sum of all section areas of trees at 1.30 m height, referred to a hectare). The IFN only covers large forest areas, so species present in small patches or narrow corridors (e.g. riparian forests) may not be included. Because of this, seven regions had an area with NNT = 0. To obtain information on these regions, we used another source (Beltrán *et al.*, 2013), that provided the cover area (in hectares) of NT and NNT forest types. This source allowed estimates for four out of the seven regions with zero-NNT-cover. We used the NNT/NT cover proportion of these four regions to calculate the NNT cover in IFN units. The remaining regions with zero values (Murcia, Baleares, and Valencia) were kept as zero, and were not considered in subsequent analysis.

Appendix S7. Description of data sources of predictors used to explain the variation of the effects of non-native trees on ecosystem services.

Biome

We selected biome as a predictor for all ecosystem service categories because previous knowledge suggests that large-scale bioclimatic variables affect plant performance and then may modulate non-native tree (NNT) species effects on ecosystem processes and properties (Castro-Díez *et al.*, 2014a). Biome categories were simplified to categories shown in Table S7.1. The assignment of case studies to each biome was made according to the information provided by the source documents [in the case of regulating ecosystem services (RES)] or based on expert knowledge by the authors [in the case of provisioning (PES) and cultural ecosystem services (CES)].

Table S7.1. Biomes used in our study.

Biomes
1 Tropical forest
2 Subtropical forest
3 Subtropical desert
4 Mediterranean
5 Temperate forest
6 Temperate grassland/desert
7 Boreal forest

The map of biomes shown in Fig. 1 of the main paper was simplified from the FAO Global Ecological Zones for illustrative purposes (given the low resolution). Assignment of case studies to biomes was not based on this map.

Native ecosystem type

Native ecosystem type was applied to explain variation of NNT effects on RES because we expect the type of native vegetation cover to affect the magnitude and even the direction of the NNT effects. For instance, the introduction of NNTs may contribute to erosion control if the native ecosystem lacks trees, but no effect if introduced in a site covered by native forests. We used the information provided by the articles from which we retrieved data to classify the native ecosystem type into the following categories:

1. (Semi)desert – very low vegetation cover
2. Grassland – vegetation cover dominated by grass
3. Shrubland – vegetation cover dominated by shrubs
4. Open forest – there is a tree layer, but its cover is lower than 50% (e.g. savanna, dehesa)
5. Forest – tree cover higher than 50%
6. Urban – includes urban parks and streets with trees

Stand type

Stand type was applied to explain variation of NNT effects on RES, and classified into:

1. Stands where NNTs were intentionally planted by people: mostly forest plantations and urban parks or streets.
2. Stands where NNT have established without further human action (i.e. naturalized).

We selected this predictor because it may affect NNT performance and therefore the magnitude of NNT effects on RES (regulating services). The term 'naturalized' implies that the NNTs have successfully passed the local environmental filters, being able to survive, reproduce, and establish self-supporting populations (Richardson *et al.*, 2000). By contrast, NNTs in plantations have just passed the local environmental filters, but may not be successful at reproducing, which may imply a lower potential to alter the native ecosystems and the services they provide.

The assignation of each case study to one of these two stand types was based on the description of the study site provided by the article from which the case study was retrieved.

N-fixation

N-fixation ability of the NNT was selected as a predictor of NNT effects on RES because previous knowledge indicates that N-fixing exotic plants have a large potential to alter the primary production, soil properties and nutrient cycles of the recipient ecosystem (Liao *et al.*, 2008; Vilà *et al.*, 2011; Castro-Díez *et al.*, 2014a).

NNT species were classified into N-fixers or not N-fixers according to their taxonomic family.

Gross Domestic Product and Human Development Index

Gross Domestic Product (GDP) and Human Development Index (HDI) were considered as predictors of NNT effects on CES, PES and EDS, since previous research has shown that the direction of impacts of non-native species on ecosystem services depends on the level of economic development of the location where those species occur (Vilà & Pujadas 2001; Krumm & Vítková, 2016; Hulme *et al.*, 2017). For instance, less-developed regions with lower economic income are more vulnerable to non-native species effects, whereas more developed regions tend to have a higher introduction of non-natives (Vilà & Pujadas, 2001).

GDP and HDI values were assigned to each country where the case study was located. GDP and HDI values were taken from the Human Development Report of 2015, from the United Nations Development Programme (http://hdr.undp.org/sites/default/files/hdr_2015_statistical_annex.pdf; accessed October, 2017). For Brazil, since each state was considered separately, GDP values were gathered from comparable national data (http://www.ibge.gov.br/english/estatistica/economia/pibmunicipios/2010/default_xls.shtm; accessed October, 2017); no HDI was available at the state level. Data for Hawaii was retrieved from national data (<https://data.hawaii.gov/>).

Population density, Proportion of rural population and Ecological Footprint

Population density, proportion of rural population and ecological footprint are widely recognized as indicators of human pressure on ecosystem resources, and hence ecosystem services (Ghosh & Traverse, 2005; OECD, 2013). Therefore, these were considered as predictors of NNT effects on ecosystem services. Whereas population density is recognized as a driver of ecological resource use, the ecological footprint expresses the effective human pressure on ecosystems. It is an indicator of direct human influence on terrestrial ecosystems based on human settlement (population density, built-up areas), accessibility (roads, railroads, navigable rivers, coastline), landscape transformation (land-use/land-cover) and electric power infrastructure (night-time lights).

Data on ecological footprint was gathered from the Footprint network (<http://www.footprintnetwork.org/>). Data on population statistics was gathered from national surveys, using the following sources (reference year: 2015):

Country	Source
Argentina	http://www.indec.gov.ar/nuevaweb/cuadros/novedades/gacetilla_01_09_11.pdf
Australia	http://www.abs.gov.au/
Austria	DEMOGRAPHISCHES JAHRBUCH H herausgegeben von STATI STIK AUSTRIA, 2015
Brazil (state level)	http://stat.abs.gov.au/
Czech Republic	https://www.czso.cz/csu/czso/czech-demographic-handbook-2015
Finland	http://vrk.fi/default.aspx?site=4&docid=85
Hawaii (USA)	https://data.hawaii.gov/Economic-Development/Table-1-09-DE-FACTO-POPULATION-BY-COUNTY-1990-TO-2/r7rd-74na/data
Italy	http://demo.istat.it/bil2015/index_e.html
Portugal	https://www.ine.pt/xportal/xmain?xpgid=ine_main&xpid=INE
South Africa	http://www.statssa.gov.za/publications/P0302/P03022013.pdf
Spain	http://www.ine.es/jaxi/Datos.htm?path=/t20/e244/avance/p01/l0/&file=01001.px&type=pcaxis
New Zealand	http://www.stats.govt.nz/browse_for_stats/population/estimates_and_projections/NationalPopulationEstimates_HOTPA30Jun15.aspx
Israel	http://cbs.gov.il/reader/newhodaot/search_topic_hodaot_eng.html?year=2013&topic=1

Spearman correlations among continuous predictors

The correlation values among the different continuous predictors considered to explain the variation of NNT effects on ecosystem services are shown in Table S7.2. Since these correlation coefficients were below 0.6, these predictors can be considered as uncorrelated (Quinn & Keough, 2002) and thus were used in subsequent analyses.

Table S7.2. Spearman correlation coefficients among quantitative socio-ecological predictors.

Spearman correlation	GDP	Population Density	Proportion of rural population	Human Development Index	Ecological Footprint
Gross Domestic Product (GDP)	1.00				
Population Density	−0.05	1.00			
Proportion of rural population	0.06	−0.01	1.00		
Human Development Index	−0.02	0.17	−0.21	1.00	
Ecological Footprint	−0.16	0.15	−0.42	0.44	1.00

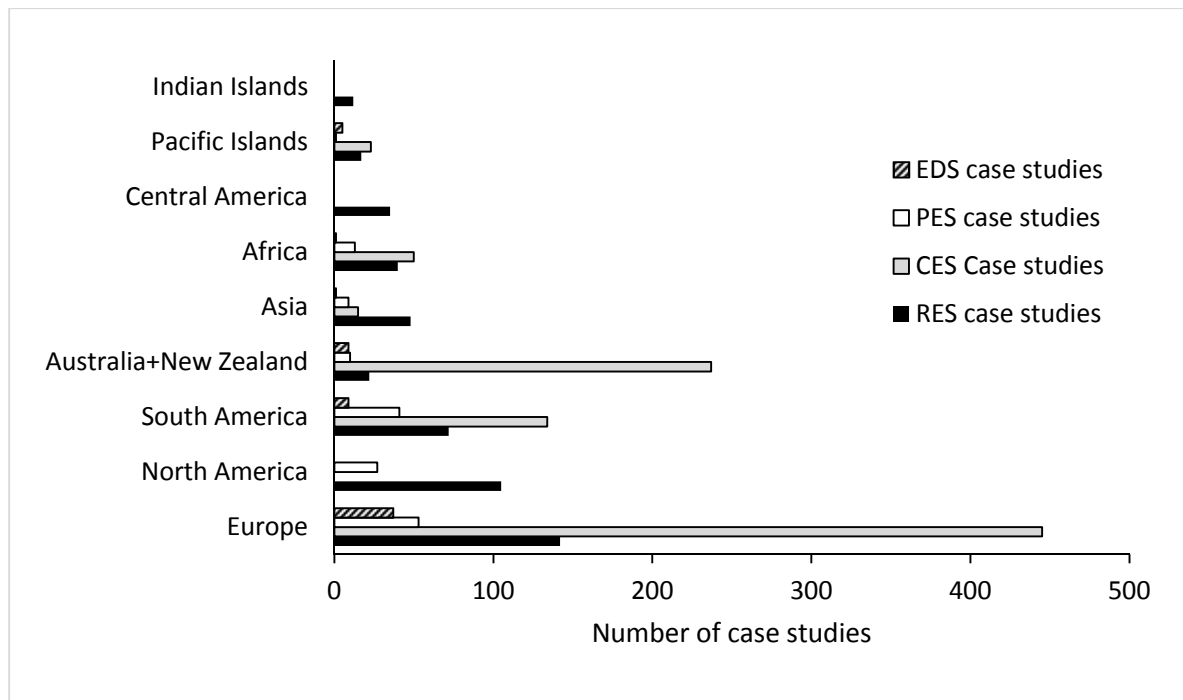


Fig. S1. Number of case studies on provisioning (PES), cultural (CES) and regulating (RES) ecosystem services, and an ecosystem disservice (EDS) per (sub)continent.

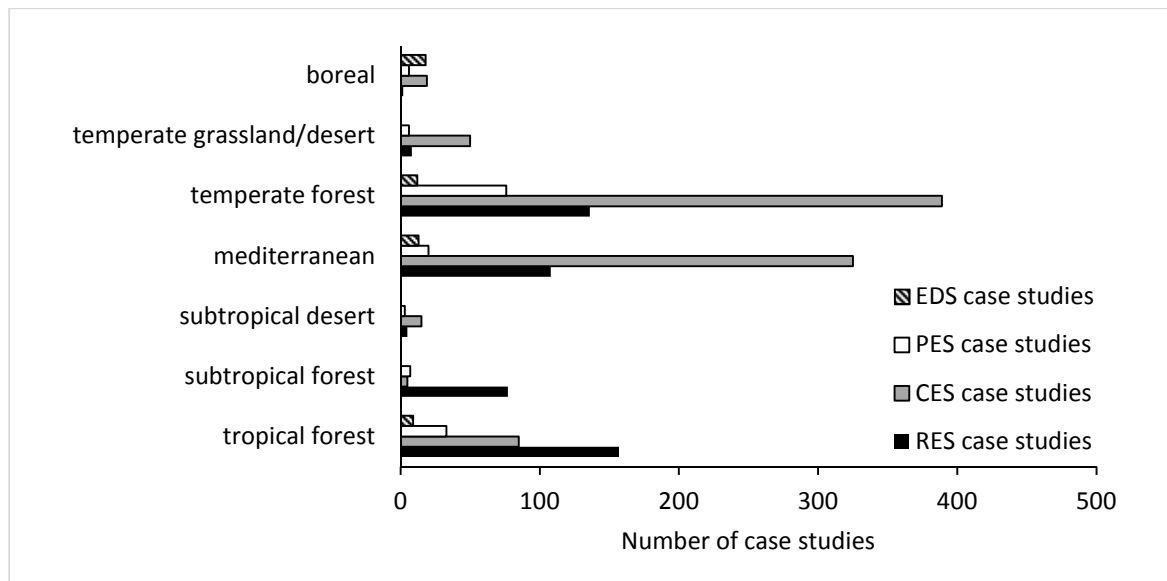


Fig. S2. Number of case studies on provisioning (PES), cultural (CES) and regulating (RES) ecosystem services, and an ecosystem disservice (EDS) per biome.

Table S1. Non-native tree species in the regulating ecosystem services (RES) data set. Species are ordered by decreasing number of case studies. Nomenclature follows The Plant List (at: <http://www.theplantlist.org/>; accessed 12th January 2018).

Species	No. case studies	Species	No. case studies	Species	No. case studies
<i>Ailanthus altissima</i> (Mill.) Swingle	22	<i>Abies procera</i> Rehder	3	<i>Artocarpus altilis</i> (Parkinson ex F.A.Zorn) Fosberg	1
<i>Pinus radiata</i> D.Don	21	<i>Acer negundo</i> L.	3	<i>Bauhinia picta</i> (Kunth) DC.	1
<i>Robinia pseudoacacia</i> L.	21	<i>Acer rubrum</i> L.	3	<i>Betula pendula</i> Roth	1
<i>Falcataria moluccana</i> (Miq.) Barneby & J.W.Grimes	20	<i>Acer saccharum</i> Marshall	3	<i>Betula</i> sp.	1
<i>Acacia saligna</i> (Labill.) Wendl.	17	<i>Betula alleghaniensis</i> Britton	3	<i>Bischofia javanica</i> Blume	1
<i>Eucalyptus globulus</i> Labill.	14	<i>Chamaecyparis pisifera</i> (Siebold & Zucc.) Endl.	3	<i>Catalpa speciosa</i> (Warder ex Barney) Warder ex Engelm.	1
<i>Acacia longifolia</i> (Andrews) Willd.	12	<i>Citharexylum caudatum</i> L.	3	<i>Cedrus libani</i> A.Rich.	1
<i>Ligustrum lucidum</i> W.T.Aiton	10	<i>Sphaeropteris cooperi</i> (F. Muell.) R.M. Tryon	3	<i>Eucalyptus microtheca</i> F.Muell.	1
<i>Elaeagnus angustifolia</i> L.	9	<i>Eucalyptus gunnii</i> Hook.f.	3	<i>Syzygium malaccense</i> (L.) Merr. & L.M.Perry	1
<i>Morella faya</i> (Aiton) Wilbur	9	<i>Eucalyptus tereticornis</i> Sm.	3	<i>Ficus benjamina</i> L.	1
<i>Pinus contorta</i> Douglas ex Loudon	9	<i>Eucalyptus urophylla</i> S.T.Blake	3	<i>Ficus elastica</i> Roxb. ex Hornem.	1
<i>Pseudotsuga menziesii</i> (Mirb.) Franco	9	<i>Gmelina arborea</i> Roxb.	3	<i>Ficus lyrata</i> Warb.	1
<i>Psidium cattleianum</i> Afzel. ex Sabine	9	<i>Larix kaempferi</i> (Lamb.) Carrière	3	<i>Frangula alnus</i> Mill.	1
<i>Casuarina equisetifolia</i> L.	8	<i>Miconia calvenscens</i> DC.	3	<i>Fraxinus chinensis</i> Roxb.	1
<i>Cupressus lusitanica</i> Mill.	8	<i>Morella cerifera</i> (L.) Small	3	<i>Gliricidia sepium</i> (Jacq.) Walp.	1
<i>Pinus elliottii</i> Engelm.	8	<i>Pinus oocarpa</i> Schiede	3	<i>Hibiscus</i> sp.	1

<i>Pinus patula</i> Schiede ex Schltdl. & Cham.	8	<i>Pinus peuce</i> Griseb.	3	<i>Leucaena greggii</i> S.Watson	1
<i>Pinus pinaster</i> Aiton	8	<i>Pipturus albidus</i> A.Gray ex H.Mann	3	<i>Leucaena pulverulenta</i> (Schltdl.) Benth.	1
<i>Tectona grandis</i> L.f.	8	<i>Schinus terebinthifolia</i> Raddi	3	<i>Magnolia grandiflora</i> L.	1
<i>Acacia mangium</i> Willd.	7	<i>Sequoiadendron giganteum</i> (Lindl.) J.Buchholz	3	<i>Malus sylvestris</i> (L.) Mill.	1
<i>Fraxinus uhdei</i> (Wenz.) Lingelsh.	7	<i>Thuja plicata</i> Donn ex D.Don	3	<i>Mangifera indica</i> L.	1
<i>Melaleuca quinquenervia</i> (Cav.) S.T.Blake	7	<i>Acacia mearnsii</i> De Wild.	2	<i>Olea europaea</i> L.	1
<i>Acacia auriculiformis</i> Benth.	6	<i>Cestrum nocturnum</i> L.	2	<i>Pentadesma butyracea</i> Sabine	1
<i>Acacia cyclops</i> G.Don	6	<i>Eucalyptus camaldulensis</i> Dehnh.	2	<i>Picea abies</i> (L.) H.Karst.	1
<i>Pinus ponderosa</i> ex C.Lawson	6	<i>Gleditsia triacanthos</i> L.	2	<i>Pinus tecunumanii</i> F.Schwerdtf. ex Eguiluz & J.P.Perry	1
<i>Ulmus pumila</i> L.	6	<i>Pinus caribaea</i> Morelet	2	<i>Populus nigra</i> L.	1
<i>Acacia dealbata</i> Link.	5	<i>Pinus halepensis</i> Mill.	2	<i>Prosopis glandulosa</i> Torr.	1
<i>Acer platanoides</i> L.	5	<i>Pinus sylvestris</i> L.	2	<i>Prunus cerasifera</i> Ehrh.	1
<i>Albizia procera</i> (Roxb.) Benth.	5	<i>Pinus taeda</i> L.	2	<i>Salix</i> sp.	1
<i>Eucalyptus nitens</i> (H.Deane & Maiden) Maiden	5	<i>Populus tremuloides</i> Michx.	2	<i>Schefflera actinophylla</i> (Endl.) Harms	1
<i>Leucaena leucocephala</i> (Lam.) de Wit	5	<i>Rhamnus cathartica</i> L.	2	<i>Senna spectabilis</i> (DC.) H.S.Irwin & Barneby	1
<i>Prunus serotina</i> Ehrh.	5	<i>Salix x fragilis</i> L.	2	<i>Spathodea campanulata</i> P.Beauv.	1
<i>Sapium sebiferum</i> (L.) Roxb.	5	<i>Schinus molle</i> L.	2	<i>Swietenia macrophylla</i> King	1
<i>Acacia holosericea</i> G.Don	4	<i>Sonneratia apetala</i> Buch.-Ham.	2	<i>Tamarix chinensis</i> Lour.	1
<i>Cinnamomum verum</i> J.Presl	4	<i>Styphnolobium japonicum</i> (L.) Schott	2	<i>Tamarix ramosissima</i> Ledeb.	1

<i>Eucalyptus grandis</i> W.Hill	4	<i>Syzygium jambos</i> (L.) Alston	2	<i>Terminalia catappa</i> L.	1
<i>Eucalyptus robusta</i> Sm.	4	<i>Tamarix aphylla</i> (L.) H.Karst.	2	<i>Albizia niopoides</i> (Benth.) Burkart	1
<i>Eucalyptus</i> sp.	4	<i>Acacia</i> sp.	1	<i>Elaeagnus umbellata</i> Thunb.	1
<i>Morus</i> sp.	4	<i>Acer pseudoplatanus</i> L.	1	<i>Enterolobium cyclocarpum</i> (Jacq.) Griseb.	1
<i>Quercus rubra</i> L.	4	<i>Alstonia macrophylla</i> Wall. ex G.Don	1	<i>Elaeis guineensis</i> Jacq.	3
<i>Abies cephalonica</i> Loudon	3	<i>Araucaria angustifolia</i> (Bertol.) Kuntze	1	<i>Hevea brasiliensis</i> (Willd. ex A.Juss.) Müll.Arg.	2
<i>Abies grandis</i> (Douglas ex D.Don) Lindl.	3	<i>Araucaria</i> sp.	1		

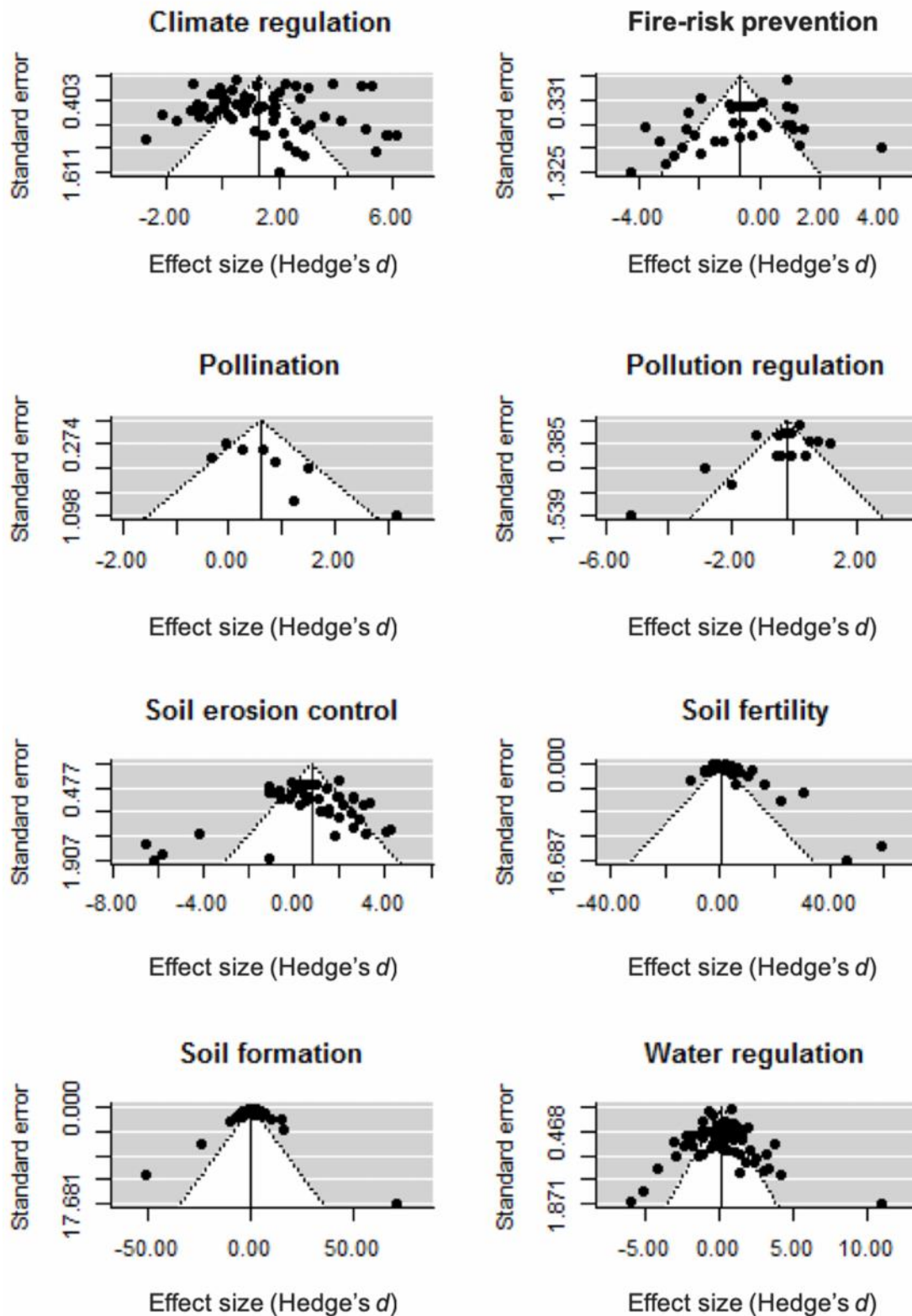


Fig. S3. Funnel plots for each meta-analysis on the effect of non-native trees on regulating ecosystem services (RES). Effect sizes are plotted on the x-axis and standard error of effect

sizes on the y -axis. In the absence of publication bias, funnel plots are expected to be symmetric, with larger dispersion of effect sizes for studies with small replication (i.e. with large standard error of effect size). Funnel asymmetry may be indicative of publication bias, i.e. small studies reporting small effects have less chance to be published than those reporting large effects, leading to missing values on one side of the funnel. Results of asymmetry tests are shown in Table S2.

Table S2. Analysis of publication bias in the meta-analyses exploring the effects of non-native tree species on regulating ecosystem services (RES). Results of Egger's test of funnel plot asymmetry (see Fig. S3). Egger's test performs a structured meta-analysis adding the standard error (SE) of effect sizes as a predictor. Q_M is the amount of heterogeneity explained by the model, for which significance is tested against a χ^2 -squared distribution with degrees of freedom = df . Q_E is the remaining heterogeneity not explained by the model. When SE was significant in the test without an additional predictor, the test was repeated for the model with the predictor that explained the most heterogeneity. If SE was still significant, a trim-and-fill procedure was applied to assess the impact of funnel asymmetry on the meta-analysis result. The trim-and-fill procedure estimates whether theoretical missing case studies are necessary to attain funnel symmetry. The number of missing studies and the side of the funnel where they are added are shown, as well as how this addition changes the mean effect size.

Ecosystem service	Predictor	Q_M (df)	Q_E (df)	SE Slope (SE)	Trim-and-fill estimated number of missing case studies	Funnel side	Old mean effect size	New mean effect size
Climate regulation ($N = 76$)	SE	4.3* (1)	3059*** (74)	1.49 * (0.72)	0	Left	1.283 ***	1.283 ***
	Biome, SE	79*** (6)	2112*** (69)	2.01 ** (0.70)				
Fire-risk prevention ($N = 40$)	SE	4.2* (1)	205*** (38)	-1.75 * (0.85)	-	-	-	-
	Ecosystem type, SE	17** (4)	201*** (36)	-0.22 ns (1.24)				
Pollination ($N = 8$)	SE	9.3** (1)	8.01 ns (6)	3.10*** (1.01)	3	Left	0.606 ns	0.255 ns
Pollution regulation ($N =$	SE	9.2**	78***	-2.56**	0	Right	-0.235ns	-0.235 ns

17)		(1)	(15)	(0.84)				
Soil erosion control (<i>N</i> = 51)	SE	1.1 ns (1)	213*** (49)	−0.65 ns (0.63)	−	−	−	−
Soil fertility (<i>N</i> = 117)	SE	56*** (1)	1664*** (115)	2.89*** (0.38)	0	Left	0.631**	0.631**
	N-fixation, SE	69*** (3)	1249*** (114)	2.77*** (0.38)				
Soil formation (<i>N</i> = 145)	SE	2.7 ns (1)	1020*** (143)	0.64 ns (0.39)	−	−	−	−
Water regulation (<i>N</i> = 75)	SE	1.5 ns (1)	722*** (73)	0.71 ns (0.58)	−	−	−	−

Table S3. Comparison of meta-analysis models constructed to assess the grand mean effect sizes (and its 95% confidence intervals, CI) of non-native tree (NNT) species on regulating ecosystem services (RES). For each RES up to four models were constructed: a random-effect model (REMA), which allows for random variation of effect sizes across case studies (identified by 'id'), and up to three multi-level models (MLMAs), accounting for three potential sources of non-independence across case studies: Reference (i.e. publication), NNT species and country. In these three models case study is nested within the random factor. For REMA, three measures of heterogeneity of effect sizes across case studies are reported: Q_T , whose significance is tested against a chi²-squared distribution with degrees of freedom = df), T^2 , which is an estimate of the between-case studies variance (standard error in parentheses), and I^2 which is the proportion of the between-case studies variance that cannot be attributed to sampling error. For MLMA, I^2 was partitioned into the variance explained by the two random factors included in the model. The Akaike information criterion corrected for small samples (AIC_c) allows model comparison: when any of the more complex models (MLMA) has a value two points lower than that of the simplest model (REMA), it is considered to improve the simplest model.

RES	Model	Random factors	Mean effect size Signif/ permutest ¹ (SE)	95% CI	Q_T (df)	T^2 (SE)	I^2	I^2 Random factor (number of levels)	I^2 Residual (number of levels)	AIC_c
Climate regulation ($N = 76$)	REMA	id	1.283 *** /** (0.223)	0.846/1.721	3077*** (75)	3.370 (0.614)	97.67%	–	–	319.73
	MLMA	Reference, id(Reference)	1.028*** (0.257)	0.524/1.533	–	–	–	47.74% (45)	49.79% (76)	306.77
	MLMA	NNT, id(NNT)	1.303*** (0.252)	0.808/1.798	–	–	–	44.58% (54)	53.20% (76)	320.92
	MLMA	Country, id(Country)	1.097*** (0.294)	0.521/1.673	–	–	–	16.51% (21)	81.22% (76)	319.89
Fire-risk prevention ($N = 40$)	REMA	id	–0.641 **/** (0.229)	–1.091/–0.191	412*** (39)	1.660 (0.471)	90.87%	–	–	149.04
	MLMA	Reference, id(Reference)	–0.871* (0.377)	–1.610/–0.131	–	–	–	70.26% (18)	23.25%	144.95

	MLMA	NNT, id(NNT)	−0.528* (0.235)	−0.989/−0.067	−	−	−	90.63% (36)	>0.001%	145.38
	MLMA	Country, Id(Country)	−0.855** (0.314)	−1.471/−0.240	−	−	−	24.38% (13)	67.06%	149.76
Pollination (N = 8)	REMA	id	0.606 ns (0.213)	0.072/1.141	18.76** (7)	0.343 (0.305)	64.71%	−	−	25.90
Pollution regulation (N = 17)	REMA	id	−0.235 ns (0.224)	−0.674/0.204	92.13*** (16)	0.636 (0.292)	89.96%	−	−	56.04
Soil erosion control (N = 51)	REMA	id	0.757 ***/** (0.221)	0.324/1.190	213*** (50)	1.846 (0.484)	83.97%	−	−	212.07
	MLMA	Reference, id(Reference)	0.995*** (0.282)	0.443/1.548	213*** (50)	−	−	51.29% (22)	30.34% (51)	205.76
	MLMA	NNT, id(NNT)	0.798*** (0.226)	0.356/1.241	213*** (50)	−	−	9.49% (38)	74.41% (51)	213.98
	MLMA	Country, Id(Country)	0.951** (0.316)	0.331/1.572	213*** (50)	−	−	44.00% (15)	38.72% (51)	203.38
Soil fertility (N = 117)	REMA	id	0.631 **/** (0.237)	0.166/1.095	1745*** (116)	5.698 (0.843)	97.01%	−	−	635.82
	MLMA	Reference, id(Reference)	0.830** (0.294)	0.253/1.407	1745*** (116)	−	−	55.15% (76)	42.15% (117)	633.89
	MLMA	NNT, id(NNT)	0.500 ns (0.328)	−0.148/1.140	1745*** (116)	−	−	71.46% (57)	25.76% (117)	616.97
	MLMA	Country, Id(Country)	0.359 ns (0.311)	−0.249/0.968	1745*** (116)	−	−	9.90% (21)	87.08% (117)	631.68
Soil formation (N = 145)	REMA	id	0.500 **/** (0.172)	0.162/0.838	1027***	3.717 (0.498)	93.53%	−	−	721.17
	MLMA	Reference, id(Reference)	0.698* (0.305)	0.101/1.295	1027***	−	−	79.77% (73)	16.30% (145)	690.07

	MLMA	NNT, id(NNT)	0.481* (0.194)	0.100/0.861	1027***	–	–	21.62% (79)	71.71% (145)	714.03
	MLMA	Country, Id(Country)	0.358 ns (0.263)	–0.157/0.872	1027***	–	–	17.37% (26)	76.29% (145)	712.09
Water regulation (N = 75)	REMA	id	0.213 ns/ns (0.182)	–0.143/0.569	738*** (74)	2.014 (0.401)	94.98%	–	–	306.14
	MLMA	Reference, id(Reference)	0.320 ns (0.271)	–0.211/0.851	738*** (74)	–	–	79.08% (42)	17.28% (75)	292.29
	MLMA	NNT, id(NNT)	0.218 ns (0.184)	–0.143/0.579	738*** (74)	–	–	9.10% (60)	85.88% (75)	308.19
	MLMA	Country, Id(Country)	0.143 ns (0.263)	–0.373/0.659	738*** (74)	–	–	21.92% (18)	73.55% (75)	307.39

¹ Significance of effect sizes under REMA were assessed both by a parametric (first significance) and by a non-parametric “permutest” (second significance).

Table S4. Heterogeneity (QM) of effect sizes of non-native tree (NNT) species on regulating ecosystem services (RES) across case studies explained by four qualitative predictors under random-effects structured meta-analysis. Predictors: biome, native ecosystem type, stand type and N-fixation ability of the NNT. The number of case studies (*N*) is shown for each RES. The degrees of freedom (*df*) are shown in parentheses below each Q_M value. Categories of predictors are shown in Table 3 of the main paper. Categories with less than three case studies were removed from analyses. Pollution regulation and pollination heterogeneities were not analysed due to the low number of case studies. Significance was calculated by the non-parametric “permutest”: ns, $P > 0.05$; *, $0.05 \geq P > 0.01$; **, $0.01 \geq P > 0.001$.

	Biome (<i>df</i>)	Ecosystem type (<i>df</i>)	Stand type (<i>df</i>)	N-fixation (<i>df</i>)
Climate regulation (<i>N</i> = 76)	65.62** (5)	34.40 ns (3)	34.00 ns (2)	33.37 ns (2)
Fire-risk prevention (<i>N</i> = 40)	12.53 ns (3)	17.43* (3)	14.84ns (2)	9.31 ns (2)
Soil erosion control (<i>N</i> = 51)	30.08** (4)	18.54 ns (4)	11.49 ns (2)	21.51** (2)
Soil fertility (<i>N</i> = 117)	10.05 ns (4)	11.44 ns (4)	15.52** (2)	16.53** (2)
Soil formation (<i>N</i> = 145)	15.98* (4)	9.16 ns (4)	16.21** (2)	17.28** (2)
Water regulation (<i>N</i> = 75)	3.87 ns (4)	5.60 ns (4)	1.49 ns (2)	13.98** (2)

Table S5. Results of the linear models relating the effect size of non-native tree species on timber provision to five socio-economic and demographic predictors. The slope of each predictor and its standard error are shown, along with the value of the *t*-test and the associated *P*-value testing whether the slope differs from zero. Significant values ($P < 0.05$) are highlighted in bold.

	Slope	Standard error	<i>t</i> -value	<i>P</i> -value
Nominal Gross Domestic Product (US dollars)	-3.08E-08	2.02E-07	-0.153	0.880
Human Development Index	3.877	1.964	1.974	0.057
Population Density (km ²)	0.003	0.002	1.567	0.123
Proportion Rural Population	-0.043	0.014	-3.168	0.002
Ecological Footprint	-0.053	0.136	-0.393	0.697

Table S6. Comparison of meta-analysis models constructed to assess the grand mean effect size (and its 95% confidence intervals, CI) of non-native tree (NNT) species on cultural ecosystem services (CES) and on the disservice (EDS) pollen allergenicity. For each CES and EDS two models were constructed: a random-effect model (REMA), which allows for random variation of effect sizes across case studies, identified by 'id'), and a multi-level model (MLMA), which included country and id nested within country as random factors. For REMA three measures of heterogeneity of effect sizes across case studies are reported: Q_T , whose significance is tested against a χ^2 -squared distribution with degrees of freedom = df), T^2 , which is an estimate of the between-case studies variance (standard error in parentheses), and I^2 which is the proportion of the between-case studies variance that cannot be attributed to sampling error. For MLMA, I^2 was partitioned into the variance explained by the two random factors included in the model. The Akaike Information Criterion corrected for small samples (AIC_c) allows model comparison: when any of the more complex models (MLMA) has a value two points lower than that of the simplest model (REMA), it is considered to improve the simplest model.

CES/EDS	Model	Random factors	Mean effect size Signif/ permutest ¹ (SE)	95% CI	Q_T (df)	T^2 (SE)	I^2	I^2 Random factor (num. of levels)	I^2 Residual (num. of levels)	AIC_c
Aesthetics (plant dealers) ($N = 164$)	REMA	id	0.387 *** / ** (0.107)	0.177/0.598	2190*** (163)	1.638 (0.263)	92.56%	–	–	592.55
	MLMA	Country, id(Country)	0.943*** (0.280)	0.394/1.492	2190*** (163)	–	–	67.61% (22)	26.40% (164)	477.55
Aesthetics (urban parks) ($N = 148$)	REMA	id	0.579**/** (0.097)	0.389/0.768	1993*** (147)	1.060 (0.361)	92.62%	–	–	531.30
	MLMA	Country, id(Country)	1.254*** (0.245)	0.775/1.734	1993*** (147)	–	–	83.39% (30)	11.98% (148)	388.58
Recreation- ecotourism (nature routes) ($N = 356$)	REMA	id	–0.589 ***/** (0.085)	–0.755/–0.423	664*** (355)	1.025 (0.187)	46.53%	–	–	1250.26
	MLMA	Country, id(Country)	–0.015 ns (0.334)	–0.669/0.640	664*** (355)	–	–	32.13% (10)	23.80% (356)	1197.11
Recreation- ecotourism	REMA	id	0.732**/** (0.126)	0.485/0.979	354*** (110)	1.089 (0.241)	68.99%	–	–	387.64

(tourism webs) (<i>N</i> = 111)	MLMA	Country, id(Country)	0.605* (0.286)	0.045/1.166	354*** (110)	–	–	52.50% (16)	18.12% (111)	331.63
Cultural heritage (<i>N</i> = 63)	REMA	id	1.454***/** (0.150)	1.160/1.748	463***	0.841 (0.394)	86.62%	–	–	203.31
	MLMA	Country, id(Country)	1.295*** (0.227)	0.850/1.739	463***	–	–	42.29% (16)	44.93% (63)	199.65
Inspiration (<i>N</i> = 84)	REMA	id	0.094 ns/ns (0.182)	–0.216/0.405	135*** (83)	0.677 (0.292)	38.71%	–	–	294.68
	MLMA	Country, id(Country)	0.324 ns (0.309)	–0.281/0.930	135*** (83)	–	–	25.41% (9)	25.10% (84)	288.80
Scientific interest (<i>N</i> = 12)	REMA	id	–1.731 ***/* (0.428)	–2.570/– 0.892	3367*** (11)	2.178 (1.522)	99.67%	–	–	67.51
Pollen allergenicity (<i>N</i> = 62)	REMA	id	0.093 ns/ns (0.197)	–0.293/0.480	662***	2.109 (0.492)	90.79%	–	–	237.06
	MLMA	Country, id(Country)	0.587 ns (0.365)	–0.129/1.302	662***	–	–	86.39% (20)	5.65% (62)	168.57

¹ Significance of effect sizes under REMA were assessed both by a parametric (first significance) and by a non-parametric “permutest” (second significance).

Table S7. Structured meta-analysis assessing the contribution of predictors to explaining the heterogeneity of non-native tree (NNT) species effect sizes on cultural ecosystem services and on the disservice pollen allergenicity. We report the heterogeneity (Q_M) explained by each predictor and its significance based on a chi-squared distribution (degrees of freedom for biome = number of categories; for numerical predictors $df = 1$). Regression slopes and significance are shown in parentheses for the continuous predictors with a significant Q_M ($P < 0.05$). Statistical significance: ns, $P > 0.05$; *, $0.05 \geq P > 0.01$; **, $0.01 \geq P > 0.001$.

Predictors	Aesthetics	Recreation and ecotourism			Cultural heritage	Inspiration	Scientific interest	Ecosystem disservice
	Catalogues ornamental plant dealers	Tree inventories of urban parks	Official tourism websites	Nature routes	Official lists of monumental trees	Artistic nature photographs	Scientific interest	Pollen allergenicity
<i>Geographical context</i>								
Biome	96.83**	165.45**	90.29**	65.05*	91.28 ns	14.49 ns	40.44 ns	80.95**
<i>Socio-economic development</i>								
Nominal Gross Domestic Product x 10^{-5}	15.93** (0.06**)	54.90** (0.09**)	9.43** (0.05**)	4.42* (-0.04*)	0.05 ns	2.51 ns	2.96 ns	16.87** (0.13**)
Human Development Index	7.59** (-4.38*)	13.59** (-4.24**)	4.67* (-3.01*)	26.38** (-7.75**)	3.67 ns	4.59 ns	1.84 ns	3.11 ns
<i>Demography</i>								
Population Density per $\text{km}^2 \times 10^{-2}$	45.86** (-0.68**)	112.14** (-1.39**)	23.59** (0.71**)	16.89** (0.57**)	11.10** (-0.50**)	0.40 ns	0.00 ns	3.43 ns
Proportion of Rural Population	25.05** (-0.05**)	67.91** (-0.07**)	29.89** (0.046**)	23.24** (0.04**)	0.07 ns	2.14 ns	0.01 ns	4.07* (-0.05*)
<i>Human disturbance</i>								

Ecological Footprint	1.66 ns	2.42 ns	42.64** (-0.31**)	10.13** (-0.10**)	0.71 ns	11.42** (-0.18**)	0.07 ns	3.19 ns
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Table S8. Effect size of non-native tree species on cultural ecosystem services (CES) and on one disservice (pollen allergenicity), separated by biome. **The** values in parentheses indicate the 95% confidence interval of the effect size. Only CES significantly affected by biome are shown.

Cultural ecosystem services->	Aesthetics		Recreation and ecotourism		Disservice
Data sources ->	Catalogues of ornamental plant dealers	Tree inventories of urban parks	Official tourism websites	Nature routes	Pollen allergenicity
Tropical forest	1.49 (0.95, 2.03)	2.14 (1.76, 2.53)	0.05 (−0.55, 0.64)	−0.27 (−1.22, 0.67)	1.33 (0.74, 1.91)
Subtropical forest	–	–	0.11 (−1.03, 1.24)	−1.40 (−4.41, 1.60)	–
Subtropical desert	–	−1.21 (−2.86, 0.44)	−0.24 (−1.13, 0.66)	−0.74 (−1.85, 0.37)	–
Mediterranean	−0.37 (−0.68, −0.05)	−0.34 (−0.62, −0.06)	1.50 (1.18, 1.82)	−0.19 (−0.47, 0.08)	−0.36 (−0.77, 0.06)
Temperate forest	0.92 (0.61, 1.22)	0.66 (0.41, 0.91)	0.35 (−0.03, 0.73)	−0.81 (−1.03, −0.59)	0.46 (0.03, 0.90)
Temperate grass-land /desert	2.37 (1.39, 3.35)	1.18 (0.44, 1.91)	−0.48 (−2.19, 1.24)	−0.75 (−1.29, −0.21)	–
Boreal forest	−0.71 (−1.27, −0.14)	–	–	–	−1.62 (−2.06, −1.19)

Table S9. Pairwise Spearman correlation coefficients among the effects of non-native tree species on different regulating ecosystem services. In each pairwise correlation we used the set of NNT for which we have effect sizes on the two correlated ecosystem services (N indicates the number of species involved). Significant correlations are shown in bold ($P < 0.05$).

	Climate regulation	Fire-risk prevention	Pollution regulation	Soil erosion control	Soil fertility	Soil formation
Fire-risk prevention	-0.311 ($P = 0.195$; $N = 19$)					
Pollution regulation	0.400 ($P = 0.750$; $N = 4$)	0.500 ($P = 1.000$; $N = 3$)				
Soil erosion control	0.683 ($P < 0.001$; $N = 25$)	-0.686 ($P < 0.001$; $N = 27$)	-0.500 ($P = 1.000$; $N = 3$)			
Soil fertility	0.510 ($P = 0.003$; $N = 32$)	-0.160 ($P = 0.525$; $N = 18$)	0.100 ($P = 0.950$; $N = 5$)	0.455 ($P = 0.004$; $N = 21$)		
Soil formation	0.309 ($P = 0.080$; $N = 33$)	-0.212 ($P = 0.252$; $N = 31$)	0.300 ($P = 0.683$; $N = 5$)	0.301 ($P = 0.080$; $N = 35$)	0.576 ($P < 0.001$; $N = 42$)	
Water regulation	0.025 ($P = 0.891$; $N = 325$)	-0.672 ($P < 0.001$; $N = 30$)	1.000 ($P = 0.083$; $N = 4$)	0.625 ($P < 0.001$; $N = 30$)	0.674 ($P < 0.001$; $N = 30$)	0.406 ($P = 0.010$; $N = 40$)

Table S10. Pairwise Spearman correlation coefficients and their significance (p) among the effects of non-native tree species on provisioning and cultural ecosystem services, and the disservice pollen allergenicity. In each pairwise correlation we used the set of countries for which we have effect sizes on the two correlated ecosystem services (*N* indicates the number of countries involved). Significant correlations are shown in bold ($P < 0.05$).

	Timber provision	Uniqueness non-timber products	Aesthetics (plant dealers)	Aesthetics (urban parks)	Recreation-ecotourism (nature routes)	Recreation-ecotourism (tourism webs)	Cultural heritage	Inspiration	Scientific interest
Uniqueness non-timber products	−0.080 ($P = 0.840$; $N = 10$)								
Aesthetics (plant dealers)	−0.010 ($P = 0.960$; $N = 17$)	−0.550 ($P = 0.100$; $N = 10$)							
Aesthetics (urban parks)	−0.180 ($P = 0.360$; $N = 28$)	−0.520 ($P = 0.120$; $N = 10$)	0.890 ($p > 0.001$; $N = 17$)						
Recreation-ecotourism (nature routes)	0.090 ($P = 0.840$; $N = 8$)	0.040 ($P = 0.920$; $N = 10$)	−0.270 ($P = 0.450$; $N = 10$)	−0.250 ($P = 0.490$; $N = 10$)					
Recreation-ecotourism (tourism webs)	0.480 ($P = 0.080$; $N = 14$)	0.280 ($P = 0.460$; $N = 9$)	−0.160 ($P = 0.570$; $N = 15$)	−0.100 ($P = 0.710$; $N = 15$)	0.530 ($P = 0.150$; $N = 9$)				
Cultural heritage	0.050 ($P = 0.860$; $N = 13$)	−0.600 ($P = 0.100$; $N = 9$)	0.340 ($P = 0.210$; $N = 15$)	0.310 ($P = 0.260$; $N = 15$)	−0.400 ($P = 0.290$; $N = 9$)	0.420 ($P = 0.120$; $N = 13$)			
Inspiration	0.070 ($P = 0.910$; $N = 7$)	−0.430 ($P = 0.300$; $N = 8$)	0.100 ($P = 0.810$; $N = 9$)	−0.020 ($P = 0.980$; $N = 8$)	0.670 ($P = 0.080$; $N = 8$)	0.580 ($P = 0.110$; $N = 9$)	0.360 ($P = 0.390$; $N = 8$)		
Scientific interest	0.580 ($P = 0.110$; $N = 9$)	−0.150 ($P = 0.670$; $N = 11$)	0.460 ($P = 0.150$; $N = 11$)	0.510 ($P = 0.130$; $N = 10$)	0.200 ($P = 0.580$; $N = 10$)	0.000 ($P = 1.000$; $N = 9$)	0.080 ($P = 0.840$; $N = 9$)	−0.190 ($P = 0.660$; $N = 9$)	

Pollen allergenicity	0.350 (<i>P</i> = 0.180; <i>N</i> = 16)	-0.710 (<i>P</i> = 0.030 ; <i>N</i> = 10)	0.560 (<i>P</i> = 0.010 ; <i>N</i> = 19)	0.650 (<i>P</i> = 0.010 ; <i>N</i> = 17)	0.010 (<i>P</i> = 1.000; <i>N</i> = 10)	-0.120 (<i>P</i> = 0.650; <i>N</i> = 16)	0.200 (<i>P</i> = 0.450; <i>N</i> = 16)	0.100 (<i>P</i> = 0.810; <i>N</i> = 16)	0.580 (<i>P</i> = 0.060; <i>N</i> = 11)
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