Spurring INnovations for forest eCosystem sERvices in Europe

Project no. 773702

Start date of project: 1 January 2018

Duration of project: 48 months

H2020-RUR-05-2017 Novel public policies, business models and mechanisms for the sustainable supply of and payment for forest ecosystem services

D1.3

Analysis and relationships between Forest ecosystem Services supply and demand, and Innovative mechanisms across Europe

Due date of deliverable: **January 31th, 2020**

Actual submission date: **February 12th, 2020**

Organisation name of lead beneficiary for this deliverable: **University of Kassel**

Dissemination level: **PU**

Authors

Mario Torralba, Marko Lovrić, Giorgia Bottaro, Paola Gatto, Davide Pettenella, Georg Winkel and Tobias Plieninger.

Reference

Torralba, M., Lovrić, M., Bottaro G., Gatto, P., Pettenella, D., Winkel, G., Plieninger, T. (2020). DELIVERABLE 1.3 Analysis and relationships between Forest ecosystem Services supply and demand, and Innovative mechanisms across Europe. H2020 project no.773702 RUR-05-2017 European Commission, 76pp.

Executive summary

This deliverable summarizes the results from the analysis relating forest ecosystem services and innovative mechanism across Europe, undertaken in task 1.2, in WP1. This analysis was carried out through two separated Pan-European surveys, which make up the core of this document. In the first survey, forest owners and managers across Europe were asked to state current supply and demand of forest ecosystem services in their forests, and whether or not there has been any type innovation in their forest in the last decades. The results provide a detailed overview of the interplay between supply, demand and innovation in European forest for eleven forest ecosystem services, covering provisioning, regulating and cultural ecosystem services. In the second Pan-European survey, an especial emphasis was given to cultural ecosystem services. In particular, forest owners and managers across Europe were asked about current and potential supply of cultural ecosystem services in European forests, and about which are the mechanism that could be implemented to further promote them. This analysis identifies the different pathways and strategies to encourage a multifunctional use of the forest depending on the context-related characteristics of the social-ecological system in which the forest is located.

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Acronyms

CAP	Common Agricultural Policy
CES	Cultural Ecosystem Services
CORINE	Coordination of Information on the Environment Land Cover, also known as CLC
ES	Ecosystem Services
EU	European Union
FES	Forest Ecosystem Service
HCA	Hierarchical Cluster Analysis
IM	Innovative Mechanism
INNOFOREST	Smart information, Governance and Business Innovations for Sustainable Supply and Payment Mechanism for Forest Ecosystem Services
NUTS	Nomenclature des unités territoriales statistiques
NWFP	Non-Wood Forest Products
PCA	Principal Component Analysis
PES	Payment for Ecosystem Services
PPGIS	Public Participatory Geographic Information System
ROS	Experiential and recreational use
SINCERE	Spurring INnovations for forest eCosystem sERvices in Europe

1. Introduction

1.1. Background and objectives

European forests contribute in multiple ways to society's well-being (Miura et al., 2015, Bottaro et al., 2018). These direct and indirect contributions are commonly referred as Ecosystem Services (ES, MEA 2005). In forest, ES are supplied by ecosystems and flow to society, who benefits and satisfies specific demands for ES. As such, in this document we consider ES supply as the components of a provided ES based on biophysical properties, ecological functions and social properties in a particular area and over a given period (Burkhard et al., 2012). As for ES demand we consider it as the level of a given ES required or desired by human society (Wolff et al., 2015). The differences in quantity and quality that occur between supply and demand of a given ES are considered as ES mismatches (Geijzendorffer et al., 2015).

ES supply and demand do not distribute homogeneously through space and time (Rodríguez et al., 2006; Felipe-Lucia et al., 2014). Instead, their supply and demand vary depending on biophysical (e.g. climate, type of vegetation, etc.), cultural (e.g. lifestyle aspects) and economic (e.g. livelihoods) factors. Additionally, ES are inter-related in synergistic and trade-off interactions (Bennett et al., 2009). In forests, typically when planning and management focus on promotion of a particular forest ES (FES), it would have a direct effect on the capacity of ecosystems to supply other ES, which van be positive (synergy) or negative (trade-off). Meeting demand for FES in a sustainable way is currently a priority for forest policy-making. In this context, mapping their supply and demand has gained much attention as a decision making tool to make rational and grounded FES management decisions.

In optimal conditions, innovative mechanisms (IM) promoting FES would be located in areas where both societal demand for FES and the potential for additional provisioning of ecosystem services is the highest. It is necessary to consider that spatial targeting has been identified as the single-most important policy mechanism design issue (Wunder et al., 2018). Yet, it is currently unknown how FES supply and demand are spatially linked with IM across Europe.

To assess this gap and increase our knowledge on FES dynamics in European forests, the main objective of this deliverable will be to integrate FES supply and demand, covering all FES categories (provisioning, regulating and cultural), to assess potential FES mismatches. This analysis will be complemented with an assessment of current IMs across European forests, which will allow the identification of the factors that are enabling and hindering innovation in the context of European forests. Several assessments have identified that among FES, there is a considerable knowledge gap on cultural FES (Fagerholm et al. 2016). Therefore, in a specific section of the deliverable

we will focus in depth on cultural ES (CES). The objective will be to assess what is their current role in European forests, what are the existing perspectives and views around them, how compatible they are in relation to other FES, what is the potential for further CES supply, and what would be the policy mechanism necessary to do so.

1.2. Existing efforts mapping FES supply, demand and IM in Europe

In June 2018, within the context of SINCERE a workshop was organized aiming to compile existing available datasets and cartographic information in relation to FES supply and demand in Europe (Torralba and Plieninger 2018). This workshop was attended by different experts in mapping FES from the projects SINCERE and INNOFOREST. Along the workshop, a wide body of literature and case studies was collected, which set the conceptual framework for the assessments presented in this deliverable:

1. *FES supply*: in the context of European forests, probably the most complete cartographic effort has been carried out within the project INNOFOREST and collected in Primmer et al., (2018). In this work, available European datasets were collected to produce Pan-European maps supply for 10 FES at Tier 1 scale (Fig. 1): Biomass, Bioenergy, Soil stabilization, Water retention potential, Pollination potential, Habitat maintenance and protection, Soil organic content, Carbon storage, Experiential and recreational use, and Symbolic value. However, due to the nature and scale of available secondary data, some of the indicators might not be providing the most accurate picture on FES supply in Europe. Moreover, the outcomes for different FES are difficult to compare and integrate.

2. *FES demand*: mapping demand has increasingly gained attention in the past years. However, as Wolff et al. (2015) summarized in a systematic review, these particular field of knowledge is still in development. Currently, there are different understandings of what ES demand refers to, as well as which indicators and methods should be used to map and assess it in different contexts. In Europe, numerous efforts can be found at different scales for different ES (e.g. García-Nieto et al., 2013; Termansen et al., 2013). However, there is currently no available and comparable set of FES demand indicators, which can be used to assess with accuracy the majority FES, especially of regulating and cultural FES.

3. *Relation between ES supply and ES demand*: a growing number of studies have been carried out in the last years to assess the overlaps and mismatches between ES supply and demand (Wei et al., 2017). Most of these studies have been done at regional and local level (e.g. Burkhard et al., 2012; Baró et al., 2016; Egarter Vigl et al., 2017). At European level, four studies have assessed these

interactions for selected groups of ES: regulating ES (Stürck et al., 2015), pollination potential (Schulp et al., 2014; Breeze et al., 2014) and flood regulation (Stürck et al., 2015).

4. *Forest IMs in Europe*: within the project SINCERE, different efforts have been carried out to assess existing IMs. Bottaro et al. (2019) developed an analytical framework to assess innovations in European forests, and compiled and initial non-exhaustive inventory of IMs in European forests. Additionally, Wunder et al. (2019) collected worldwide evidence to synthesize best-practice design and implementation of PES and other IM for the context of European forests. In this deliverable, we complement these works with two recent literature reviews on innovation management (Van Lancker et al., 2016; Lovrić et al., 2019).

Despite this growing scientific knowledge, as a result of the mentioned workshop we identified the need to plan for further empirical work to compensate some of the caveats of existing available spatial datasets in relation to FES supply and to fill the gaps in relation to FES demand and existing IMs in European forests. To do so, we decided to perform a Pan-European survey, led and executed by SINCERE with punctual strategic collaboration of INNOFOREST.

In the next chapters, we will present the results from such Pan-European surveys. In Chapter 2, we will assess and integrate the collected information in relation to supply, demand and IMs in Europe. In Chapter 3, we will present the results from a second survey, which focuses on two specific elements that we early identified as particularly relevant and understudied: the role of cultural ecosystem services in European forests and the potential pathways and policy mechanisms to support them.

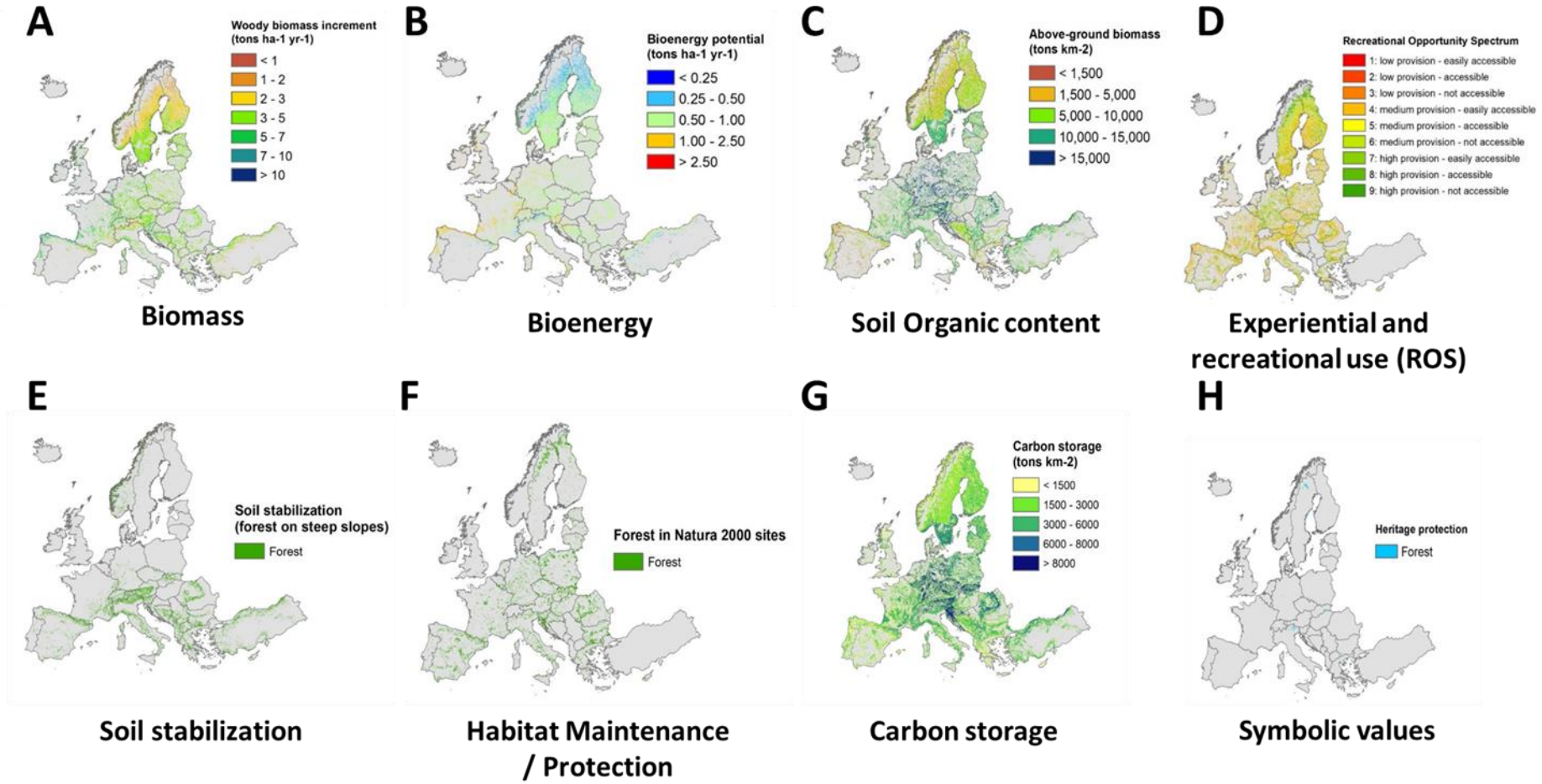

Figure 1. Pan-European maps of FES supply (see Primmer et al., 2018 for more details).

2. Mapping FES supply, demand and IM in European forests

2.1. Introduction

European forests provide multiple FES that go beyond timber provision (multiple NWFP, habitat provision, carbon sequestration, pollination, recreation, etc.). However, forest management models have commonly been designed for, although not exclusively, optimizing biomass production. In the last decades, and in parallel to a change is societal demands, multiple initiatives and efforts have emerged to promote alternative sustainable management models that satisfy the multiple and diverse society's needs in term of FES.

In this context, policy mechanisms like regulations and incentives are meant to play an important role meeting these FES demand. Within SINCERE, Wunder et al. (2019) distilled different lessons to be learnt from worldwide experiences for the design and implementation of FES and other related instruments in the context of Europe. Maybe among the most relevant lessons, would be the need of a careful spatial targeting that combines the implementation of multiple policy mechanisms, each targeting different actors/contexts (e.g. mixing tools like PES, protected areas or incentives and disincentives programs), with proper mechanisms in place to monitor and sanction non-compliance (Wunder et al., in review; Bösch, et al., 2019). In Europe, FES supply (specially regulating FES) is often perceived as a public responsibility, which should be financed through states' resources and regulatory power. This background in part explains the relative lower tradition and presence of PES-related strategies in European countries (Wunder et al., 2019). Therefore, given the growing demand for FES, it seems relatively clear that solutions would need to capitalize, either on an increased use of public funds, or by incentivizing private initiatives.

In an ideal situation and to adjust the spatial targeting, these mechanisms and initiatives promoting a specific FES would preferably focus on areas where for such FES, demand is strong while FES supply could be increased. However, the degree of overlapping between FES and existing IMs is unknown, as well as which social-ecological factors are driving its appearance and maintenance. The understanding of the dynamics of innovations would provide support for the identification of suitable areas and conditions for the implementation of such initiatives.

FES in Europe are co-produced by a combination of natural and human processes (Palomo et al., 2016). As such, to explore the dynamics between FES supply and demand, we find crucial to focus our attention on forest owners and managers as ultimate decision makers over which FES are supplied and in what intensity. How forest operators

perceive FES demand, in combination with their specific social-ecological context (biophysical, cultural and economic context, individual/group set of values, and views and perspectives), would play a central role determining management and thus, the flow of FES (Torralba et al., 2018a).

In this context, this chapter will explore at a European level how forest owners and managers perceive the relationships between FES supply, demand, and existing innovation efforts in the context of European forests.

2.2. Methods

To explore and map how forest owners perceive supply and demand of FES, and to explore the existence and the types of innovations in European forests, we carried out a Pan-European online survey.

The survey was translated to 19 languages, and targeted all types of forest operators with direct knowledge about current management of the forest (forest owners, managers, and responsible of certain segments of management). Respondents were recruited online through the networks and national chapters from three major forest owner and manager organizations: European State Forest Association (EUSTAFOR), Confederation of European Forest Owners (CEPF), and European Landowners Association (ELO). Furthermore, we distributed the survey through the contacts and channels of communication of SINCERE and INNOFOREST. The survey was tested through the SINCERE network in May-August 2019. Data collection started on the 19/09/2019 and ended on the 10/12/2019.

Prior to the survey (accessible at: https://app.maptionnaire.com/en/5199/), there was an introduction stressing the focus of the survey on the informant's personal views, a detailed explanation of the objectives of the survey, and a brief explanation of the main concepts used in the survey (e.g. FES). The survey was then structured in three main sections. After some initial questions to identify the respondents, the survey started with the first main section, in which the respondents had to describe their perceptions on supply and demand of multiple FES. Afterwards, respondents would identify in a map their forest's location. The background map was a Bing satellite image with overlaid Open Street Map objects. A minimum zoom level of 1:25,000 was enforced to ensure a precise identification of the forest location. Finally, in the third section, respondents were asked whether there had or had not been any innovation related to any FES in the last two decades in their forest. In case the answer was positive, the survey was redirected to a section that aimed to explore in depth what type of innovation occurred, and in which conditions it emerged.

Concerning the set of FES to be assessed by the survey, they were selected through a series of iterative deliberative discussions between SINCERE and INNOFOREST experts

on which a selection of the most relevant FES to forest owners in Europe was selected. The final selection included 11 FES covering provisioning, regulating and cultural FES. Among (1) *Provisioning FES*: Biomass (material), Biomass (energy), Wild products (e.g. mushrooms, berries) and Game (hunting); (2) *Regulating FES*: Provision of habitat for biodiversity, Air purification, Climate change mitigation, Watershed protection; (3) *Cultural FES*: Cultural emotional and spiritual values, Educational values, and Healthcare and outdoor activities. On top of the perceptions on their supply and demand, we asked respondents about the relative importance of each FES for their income and their perception of FES social demand evolution.

To assess innovation in European forests, we created a typology of innovations based on findings from the inventory of innovative mechanisms developed in SINCERE (Bottaro et al., 2019). The typology consists out of 10 FES innovation types. In relation to the factors that may support or impede the development of these innovations, we used the open-innovation concept, which can be defined as *"… a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology*" (Chesbrouh, 2003, p. 24). The main difference between open innovation concept and other perspectives on innovation is that the open-innovation concept emphasizes the importance of factors out of the innovating organization.

The external variables, such as access to capital or support from different stakeholder groups, are the focus of SINCERE, and are factors that policy actors can have an effect on. The starting points for defining of these innovation factors were factors defined in literature reviews implemented by Van Lancker et al. (2016) and Lovrić et al. (2019). The full set of factors identified in these works (which were broadly focused on technology and innovation management literature) was adapted to the context of European forests in an iterative process with experts from SINCERE and INNOFOREST. As a result, 15 factors were selected. In case any element was missed, the questionnaire also had the option for respondents to define their own factors that either supports or impedes the development of innovations.

Although the survey did not included sensitive information and all the responses were anonymized, the survey included some parts that some respondents might be reticent to answer. That would include for example the mapping of the forest they own or manage, or the questions related to the relative importance of each FES category on forest direct economic profits. In order to incentivize participation and maximize the number of responses, we decided not enforce that every part of the survey had to be answered in order for the survey to be valid. Instead, respondents could decide to skip the sections they did not find relevant or did not feel comfortable to answer. The implications of this decision are that for each specific objective of the survey we would

have a different number of respondents. Therefore, the analysis on FES supply and demand would include only those respondents that completed that section. For instance, the spatial analysis only would include those respondents that decided to map their forest, and so on. Those analyses that required the integration of different sections of the survey would include those respondents completing all the sections involved.

The section of the survey related to FES supply and demand, as well as the section related to existing innovations were explored through descriptive statistics, Chi-square analysis, independent samples' t-test and correlation analysis.

As for the spatial analysis, our approach was the identification of focus areas for each FES. Those would be areas where the demand is strong, and where supply could be increased. To do so, first, we selected those mapped forests that met the following conditions for each FES:

- Supply was Medium, Low or Very Low (<60%). These would select those areas where supply of a service, in the view of the respondents, had not reach its full potential and thus, FES supply could be increased.
- Demand was Medium, High or Very High (>40%). These would select those areas where there is a local demand for a particular FES.

The intersection of these two conditions was selected for each FES, highlighting those forests where potential efforts to support FES could take place. For each of the identified forests, we generated density surfaces from the point layers using quadratic Kernel function (Silverman 1986), a method widely applied to describe intensity and to visualise the spatial patterns of ecosystem service indicators mapped through PPGIS (Brown and Fagerholm 2015). The result was, for each FES, a FES focus map.

2.3. Results and discussion

2.3.1. Overall results

The total number of survey responses was 2597, a number that was reduced to 1707 (Fig. 2) after filtering out those survey answers that were either invalid (e.g. the respondent did not managed or owned a forest in Europe), incomplete (e.g. the respondent did not answer at least 50% of one of the survey sections) or illogical (e.g. the time used for the completion of the survey was below two minutes). Due to the design of the survey, not every respondent completed all parts of the survey but only those they found relevant (Fig. 3A). Therefore, each section of the survey had a different number of respondents. Every respondent completed the section related to FES supply and demand, while 1145 respondents provided the coordinates of their forest, and 932 respondents completed the section on innovation. A total of 889 respondents completed the whole survey.

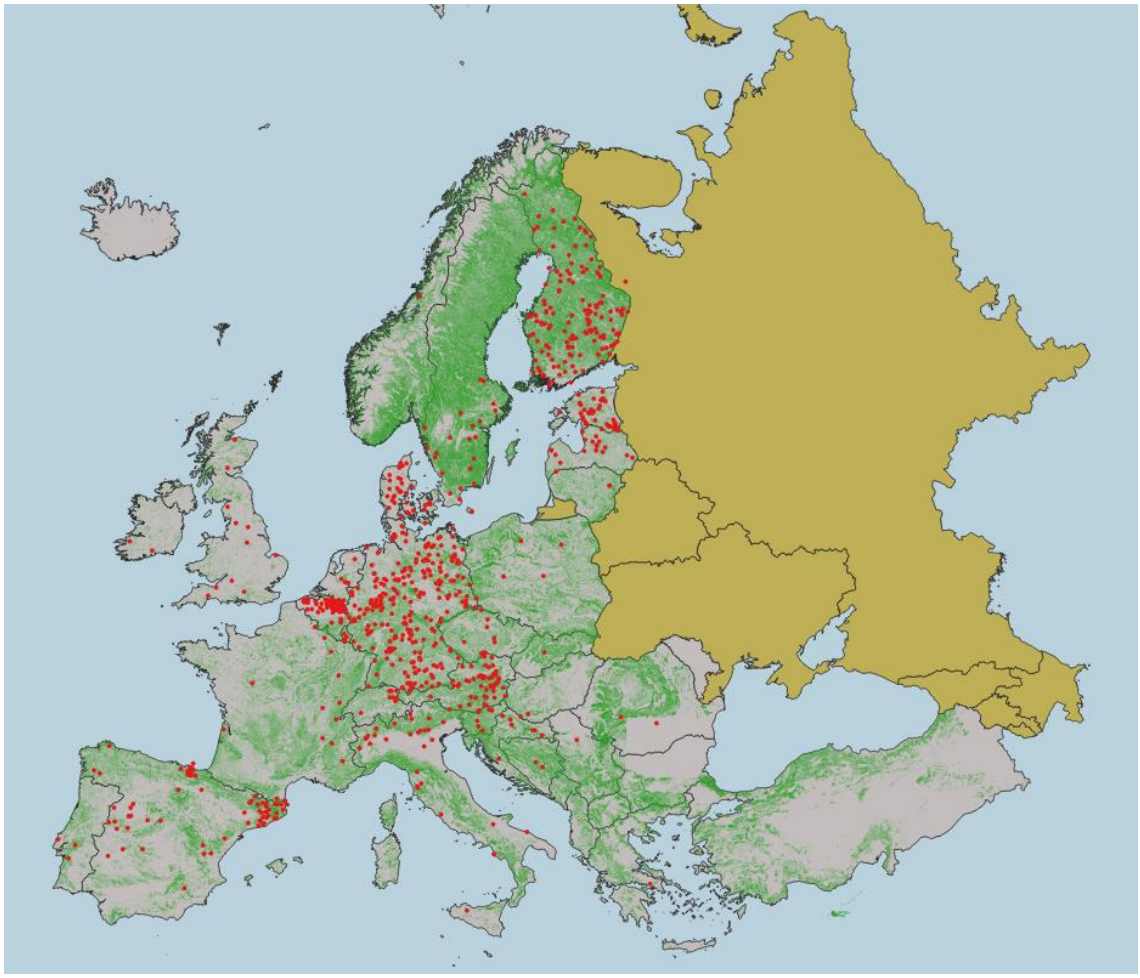

Figure 2. Mapped responses to the survey. Background: forest is Europe (Source: CORINE: Codes 311, 312 and 313)

In relation to the types of forest ownership represented in the survey (Fig. 3B), the sample mirrored the heterogeneous landscape of forest ownership type and property size of the European forests (Hirsch and Schmizhüsen 2010). Most of the forests were private and owned or managed by individuals/families (75.5%), followed by public forests managed by local governments (9.8%), private forests belonging to a business entity (5%), private forests belonging to a private institution (e.g. church, foundation, 3.5%), public forests managed by regional governments (3.2%), and public forests managed by national governments (2.1%). In relation to the size of the forests (Fig. 3C), approximately one third of respondents were smallholders (33.9%), while the rest of the size classes were relatively balanced (7-17%).

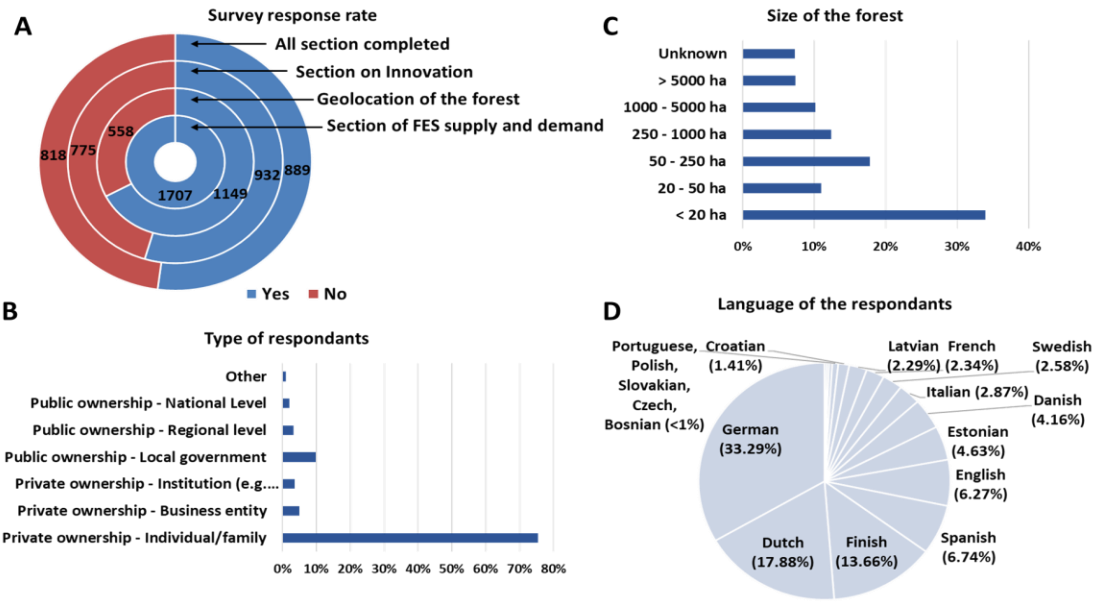

Figure 3. Characteristics of the respondents. **A**: Survey response rate - Number of respondents of each part of the three parts of the survey. **B**: Type of forests owned or managed by the respondents. **C**: Size of the forest. **D**: Language of choice in which the survey was completed.

To assess where each of the forest represented in the survey was located has been challenging since not all respondents decided to use the mapping tool to locate their forest. For the whole dataset, we can make an approximation by looking to the chosen language in which the survey was answered (Fig. 3D). However, this information is not detailed enough and cannot discriminate among countries sharing the same language. Another problem assigning the country is that some people might have decided to complete the survey in a language that is not their native one (which might for example provide an over-representation of English-answered surveys). The only precise information we can provide is based on those respondents that provided the coordinates of the forest they owned/managed. Based on that information (Fig. 4B), the best-represented forest in the survey are located in Germany (27.16%), followed by Belgium (19.29%), Finland (15.22%), and Spain (6.92%).

This asymmetric representation of European forests in the mapping assessment should be considered when interpreting the results, as there are important geographical gaps for most Eastern Europe and Mediterranean, as well as France, Ireland, Norway and the UK. To avoid further bias, we decided to carry on the spatial analysis integration of FES supply, demand, and IMs only in those areas with a strong representation (Fig. 4A). In this way, our interpretation of the spatial analysis results is focused on three main areas: Baltic (Including all the countries surrounding the Baltic Sea), Central Europe (ranging from the North of Italy to Denmark and from Belgium to the Czech Republic), and the Iberian Peninsula (focusing specially in the North). Anyhow, we want to emphasize,

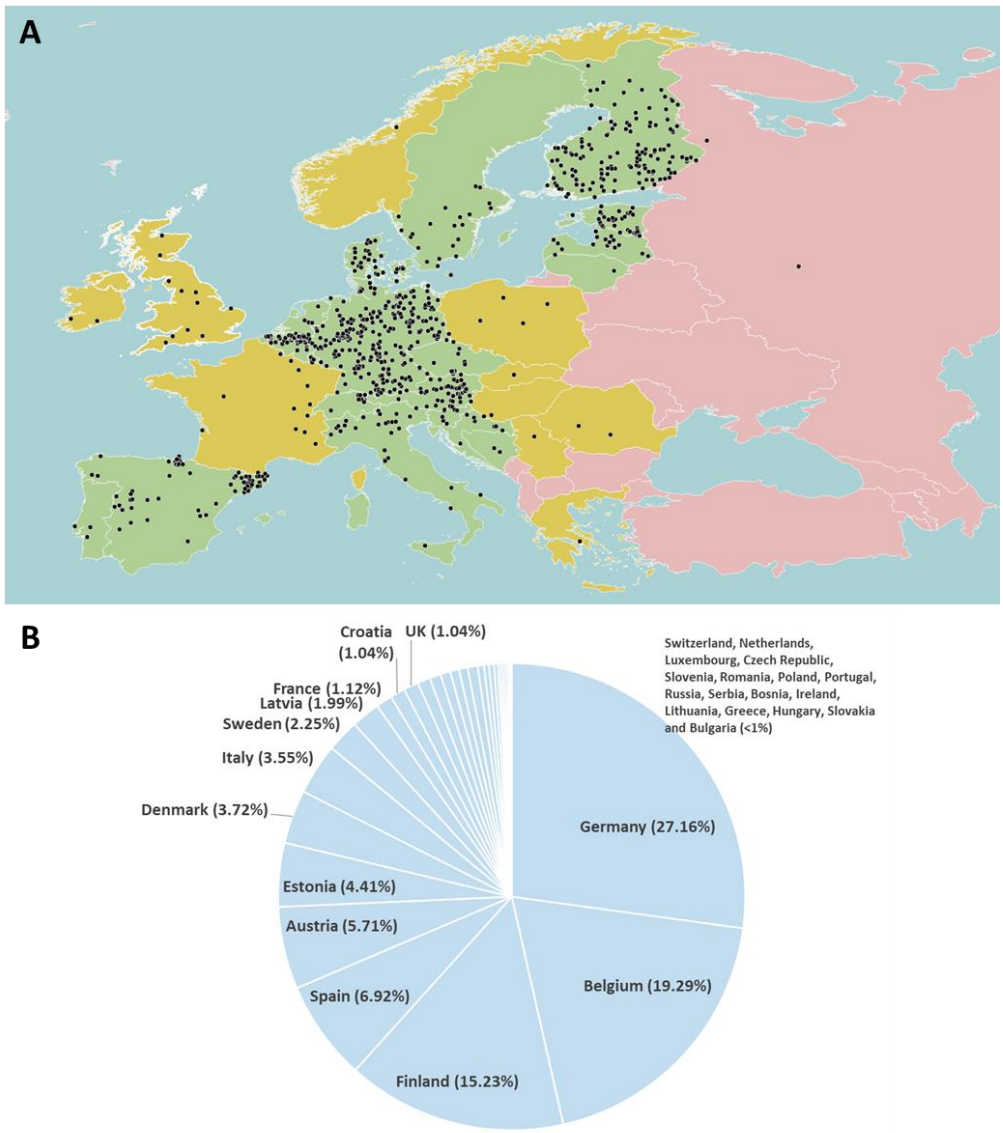

Figure 4. A: Distribution of mapped responses in Europe. Background map: Green: areas included in the spatial analysis; Yellow: areas excluded from the spatial analysis; Red: areas with no valid responses). **B:** Proportion of mapped forest by country

especially in relation to the spatial integration and the focus maps, that these maps are not exhaustive enough and that aim to provide a general overview and highlight the potential of these analysis. Results are strongly influenced by the asymmetric representation of our sample, which makes that some areas are overdimensioned (e.g. Belgium and Cataluña), while others are underdimensioned (e.g. Lithuania). As we stressed in our introduction (and in the next chapters), spatial focus and targeting should always be done with detailed and well-represented primary data at a local/regional level.

2.3.2. Supply and demand of FES in Europe

As expected, the results from asking to European forest owners how (from their perspective) is the supply and demand of different types of FES are very heterogeneous (Table 1; Figure 5A). For each of the FES categories – provisioning, regulating and cultural - the average supply and demand vary greatly, both within each individual FES, and among FES.

Overall, the analysis shows that FES supply in Europe is high, while the demand for FES is similarly on the rise. For each of the FES categories, supply and demand do not strongly differ in their average values. The main message from this initial general result is that from the perspective of European forest owners, forest in Europe contribute intensely and in multiple ways to society's wellbeing, which in return demand these multiple FES from the European forests.

Regulating FES is the category that is supplied and demanded more prominently, with approximately 75% of forest owners perceiving that the contribution of their forests to the regulation and maintenance of ecosystems is high or very high. Although the average values for supply and demand are very diverse (SD are rather high), this is also the only FES category where supply is perceived as higher than demand.

As for Provisioning and Cultural FES, results for both supply and demand are similarly Medium-High (Fig. 5A). However, when looking in detail, there are interesting differences among provisioning and cultural FES (Figure 5B). In Europe, a large proportion of actively managed forests are designed to profit to a large extent from provisioning FES. However, our results show that there is a general perception that management for provisioning FES could be further intensified to maximize its supply. This view is aligned with the perceptions related to regulating FES, which as mentioned above are relatively high (regulating and provisioning FES often establish trade-off interactions). Therefore, most forest owners in Europe perceive supply of provisioning FES as Medium or high, but far from its maximum potential. In contrast, the situation for cultural FES seems relatively context-dependant, with no general perception of its supply as high or low (as can be seen in table 1 and Fig. 5A, its SD is higher than for other FES categories). Cultural FES are inherently subjective, and emerge from the context-dependant relationships between individuals/groups and their surrounding ecosystem (Pascual et al., 2017). It seems therefore logical that the perceptions greatly vary for this FES category.

Table 1. Perception of Supply and Demand of FES in Europe

FES Category	Average (±SD)	Very low (%)	Low (%)	Medium (%)	High (%)	Very high (%)
Provisioning FES Supply	52.59 ± 25.90	14.69	15.70	26.42	28.50	14.69
Provisioning FES Demand	53.55 ± 25.81	13.27	15.75	27.84	27.59	15.56
Regulating FES Supply	71.52 ± 25.44	6.65	6.41	12.21	30.23	44.50
Regulating FES Demand	64.03 ± 28.78	10.84	11.41	15.53	25.98	36.25
Cultural FES Supply	51.92 ± 29.75	18.69	18.57	18.88	22.43	21.43
Cultural FES Demand	55.13 ± 29.33	17.13	14.29	19.11	25.99	23.48

We performed a correlation analysis comparing how each individual FES is related to the others considering them supply and demand (Table 2a and 2b). The results of this analysis show that synergetic interactions are perceived as dominating in comparison to trade-offs. As suggested in Figure 5A by the similar values between FES categories' supply and demand, the correlation analysis shows that they are commonly strongly associated for each individual FES.

Interestingly, correlation between supply and demand of regulating FES is the one with the weaker positive associations. This would indicate some mismatch between the perceptions of supply and demand for regulating FES. Our interpretation is that, while European forest owners perceive that their management strongly contributes to FES like climate change mitigation, purification of air quality, erosion control and provision of habitat for biodiversity; they often don't perceived the social demand of these services equally. This mismatch is particularly interesting as regulating FES are the ones that generate more synergies among each other (they are often jointly supplied). This pattern is particularly strong for watershed protection against processes like soil loss and erosion, which is the FES that generates more positive interactions (seems to be the most compatible FES in relation to the rest), which demand is positively related with all regulating and cultural FES.

From a policy perspective, this potential mismatch between regulating FES supply and demand is particularly relevant in relation to payments for ecosystem services (PES). In particular concerning spatial targeting and PES implementation. One of the conclusions in SINCERE (Wunder et al., 2019), was that PES should target those areas where at the same time supply of a given FES could be enhanced, while social demand is high. In the case of regulating FES, we often observe the opposite, namely that the supply is perceived as higher than demand. This does not mean that regulating FES like climate change mitigation or control of erosion should not be a priority in European forest policies. What it implies is that PES design will need to be carefully carried out to maximize its chances of success (Martin Persson and Alpízar 2013; Wunder et al., 2018). Moreover, our data suggest that supply of regulating FES in several areas in Europe, forest owners do not perceive that these environmental services are economically reattributed (Fig. 7) or socially recognized (Fig. 6). These clear mismatches could have negative outcomes, as forest owners might change their management to adjust the

perceived "higher" supply to the "lower" social demand, with negative consequences for regulating FES provision. Therefore, we would suggest to treat this situation with policy-mix strategies that complement carefully spatially targeted PES schemes with alternative and complementing measures and instruments to ensure and enhance regulating FES supply (Barton et al., 2017).

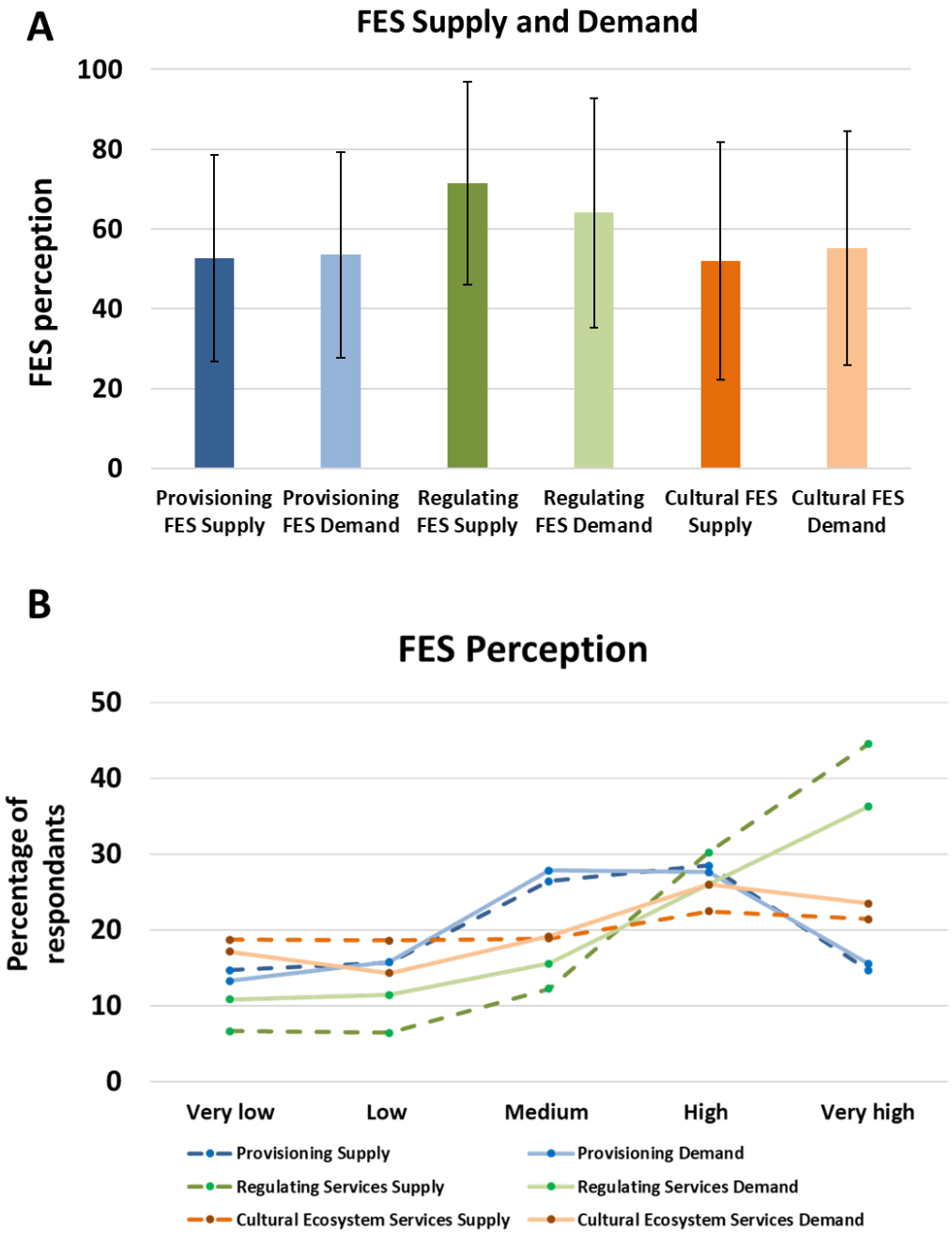

Figure 5. A: Average supply and demand for each FES category. Error bars represent standard deviation. **B:** Percentages of respondents perceiving Supply and Demand of FES as Very low, Low, Medium, High, or Very High

Table 2A. Pairwise correlations between FES Supply and FES Supply and Demand

	Supply											**Demand**									
	Biomass (material)	Biomass (Energy)	Game	Wild forest products	Watershed protection	Air quality regulation	C. Change mitigation	Habitat provision	Cultural values	Educational values	Outdoor recreation	Biomass (material)	Biomass (Energy)	Game	Wild forest products	Watershed protection	Air quality regulation	C. Change mitigation	Habitat provision	Cultural values	Educational values	Outdoor recreation
Biomass (material)	1	-	-	-	-	-	-	-	-	-	-	0.65	0.36	0.28	0.21	0.28	0.07	0.11	0.15	0.19	0.16	0.16
Biomass (Energy)	0.45	1	-	-	-	-	-	-	-	-	-	-	0.61	0.26	0.20	0.22	0.09	0.09	0.12	0.17	0.17	0.19
Game	0.45	0.32	1	-	-	-	-	-	-	-	-	-	-	0.55	0.27	0.23	0.03	0.06	0.12	0.13	0.16	0.15
Wild forest products	0.23	0.20	0.37	1	-	-	-	-	-	-	-	-	-	-	0.60	0.20	0.10	0.09	0.08	0.22	0.11	0.12
Watershed protection	0.35	0.25	0.35	0.33	1	-	-	-	-	-	-	-	-	-	-	0.53	0.16	0.13	0.15	0.24	0.26	0.31
Air quality regulation	0.24	0.23	0.23	0.22	0.54	1	-	-	-	-	-	-	-	-	-	-	0.42	0.24	0.20	0.27	0.22	0.31
Climate change mitigation	0.31	0.25	0.29	0.19	0.45	0.73	1	-	-	-	-	-	-	-	-	-	-	0.30	0.25	0.21	0.17	0.26
Habitat for plants and animals	0.18	0.20	0.29	0.12	0.43	0.54	0.62	1	-	-	-	-	-	-	-	-	-	-	0.30	0.20	0.23	0.31
Cultural, emotional and spiritual values	0.22	0.21	0.22	0.36	0.36	0.37	0.37	0.39	1	-	-	-	-	-	-	-	-	-	-	0.62	0.31	0.27
Educational values	0.22	0.27	0.22	0.22	0.38	0.31	0.27	0.31	0.39	1	-	-	-	-	-	-	-	-	-	-	0.61	0.40
Healthcare, sports and outdoor recreation	0.25	0.24	0.25	0.30	0.41	0.37	0.33	0.37	0.43	0.61	1	-	-	-	-	-	-	-	-	-	-	0.62

Table 2B: Pairwise correlations between FES Demand and FES Supply and Demand

	Supply											**Demand**										
	Biomass (material)	Biomass (Energy)	Game	Wild forest products	Watershed protection	Air quality regulation	C. Change mitigation	Habitat provision	Cultural values	Educational values	Outdoor recreation	Biomass (material)	Biomass (Energy)	Game	Wild forest products	Watershed protection	Air quality regulation	C. Change mitigation	Habitat provision	Cultural values	Educational values	Outdoor recreation
Biomass (material)	0.65	0.35	0.33	0.16	0.27	0.22	0.29	0.20	0.18	0.18	0.17	1	-	-	-	-	-	-	-	-	-	-
Biomass (Energy)	-	0.61	0.28	0.15	0.24	0.21	0.26	0.22	0.18	0.22	0.21	0.62	1	-	-	-	-	-	-	-	-	-
Game	-	-	0.55	0.24	0.24	0.14	0.19	0.19	0.18	0.14	0.16	0.39	0.42	1	-	-	-	-	-	-	-	-
Wild forest products	-	-	-	0.60	0.30	0.19	0.16	0.13	0.28	0.17	0.24	0.29	0.34	0.39	1	-	-	-	-	-	-	-
Watershed protection	-	-	-	-	0.53	0.28	0.24	0.24	0.20	0.25	0.22	0.36	0.36	0.32	0.42	1	-	-	-	-	-	-
Air quality regulation	-	-	-	-	-	0.42	0.26	0.19	0.18	0.12	0.17	0.24	0.26	0.19	0.30	0.59	1	-	-	-	-	-
Climate change mitigation	-	-	-	-	-	-	0.30	0.19	0.14	0.09	0.12	0.28	0.27	0.20	0.26	0.52	0.75	1	-	-	-	-
Habitat for plants and animals	-	-	-	-	-	-	-	0.30	0.15	0.18	0.17	0.27	0.28	0.22	0.25	0.46	0.59	0.64	1	-	-	-
Cultural, emotional and spiritual values	-	-	-	-	-	-	-	-	0.62	0.29	0.32	0.23	0.28	0.25	0.40	0.41	0.48	0.42	0.49	1	-	-
Educational values	-	-	-	-	-	-	-	-	-	0.61	0.39	0.24	0.29	0.20	0.30	0.45	0.42	0.35	0.44	0.55	1	-
Healthcare, sports and outdoor recreation	-	-	-	-	-	-	-	-	-	-	0.62	0.27	0.31	0.22	0.37	0.41	0.44	0.38	0.42	0.51	0.64	1

In relation to the way FES demand has evolved in the last decades, European forest owners generally perceive that society increasingly demand for FES (Fig. 6). Aligned with the previous results, regulating FES is the category that has experienced the higher rise in demand, followed by cultural FES, and provisioning FES in the last position. Again, our results point out how conventional intensive management models focus on single FES (e.g. biomass production) are relatively obsolete and perceived as not demanded by society. Instead, our results suggest that European forests are called nowadays to meet the demand of multiple FES that range from contributing to maintain ecological flows and biological conditions to satisfying material (biomass, wild products, etc.) and non-material (recreation, spiritual, cultural) demands. In other words, from the forest owners' perspective, society wants them not only to produce timber, but also wants them to contribute fighting climate change, as well as provide a space to relax in their spare time.

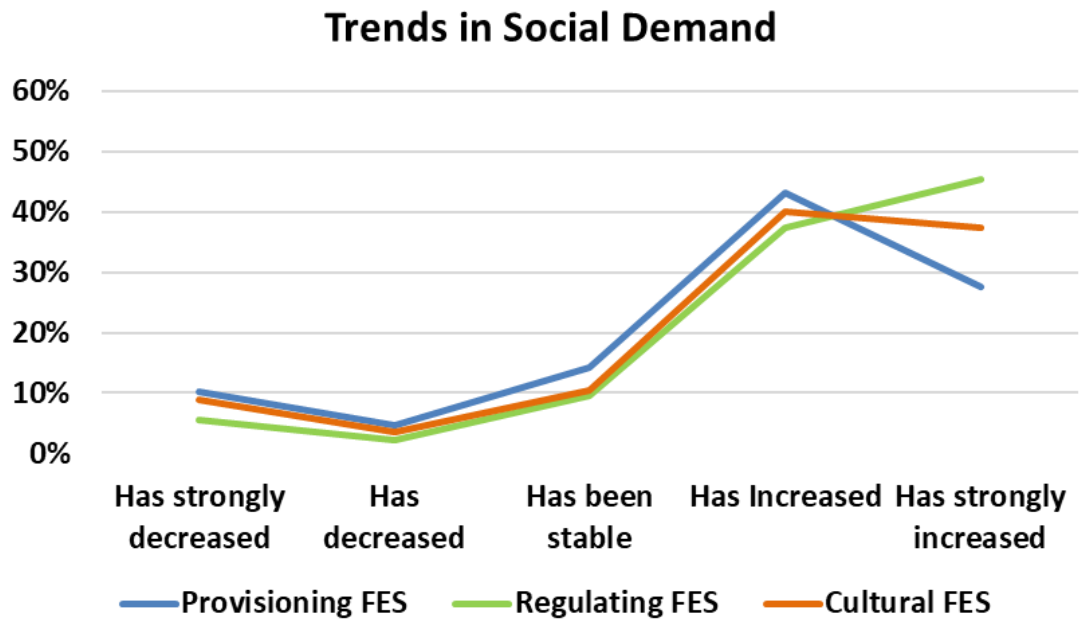

Figure 6. Evolution of societal demand for FES as perceived by European forest owners

This contrast with how much does each FES category contributes to the direct incomes of the forest owners. Despite the social demand (Fig. 6) and actual supply (Fig. 5) of regulating and cultural FES, their direct economic importance is almost non-existent for the majority of European forest owners (for the 86% in the case of regulating FES and for the 88% in the case of cultural FES, they contribute to less than 20% of respondents income; Fig. 7). As we saw in the beginning of the section, in many occasions, provisioning FES are not the most supplied FES (that would often be regulating FES), and in most cases it is the least demanded FES. As we will explore in the next section, this clear mismatch indicates the general lack of mainstreamed business models built around

regulating and cultural FES, something that contrast with the current importance of these FES for society. In view of these results, we emphasize the need to further explore what is motivating forest owners to provide such a diverse range of FES, especially as they generally do not perceive direct economic benefits from them. Land management decisions are guided by a balance of motivations, often rooted in a varied range of attitudes and values linked with the personal and social-ecological context (Follo et al., 2017; Torralba et al., 2018a). As such, recent studies point that sustainability plays a role as important as economic profit for an important part of the forest owners community in Europe (Feliciano et al., 2017). If this is the case, as is suggested by our results, we should increase our efforts to recognize these benefits, while promoting models, mechanisms and strategies that enhance these motivations towards multifunctionality.

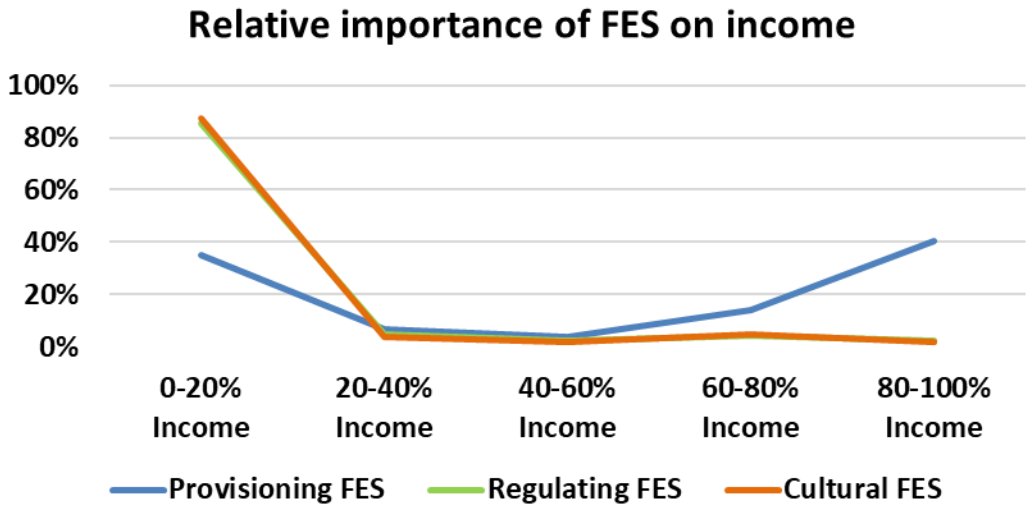

Figure 7. Relative income generated by each FES category. Regulating (green) and Cultural (red) FES are almost fully overlapping.

2.3.3. Provisioning Forest Ecosystem Services

The analysis shows that provisioning FES supply is of considerable importance for European landowners (Table 3). In the previous subsection, we already discussed the key role provisioning FES play in European management models as the main source of income for a large proportion of European forest owners. On the other hand, our analysis also shows that provisioning FES supply is far from reaching its current maximum potential, a self-made decision by forest owners that limits short-term revenue, probably oriented towards not compromising current and future supply of regulating and cultural FES. Scientific evidence shows that intensive forest management establishes trade-offs with regulating and cultural FES (Felipe-Lucia et al., 2018). From the demand side, our analysis suggests that forest material products are also rather demanded by society (Table 3), being the FES demand generally higher than FES supply.

Table 3. Perception of Supply and demand of provisioning FES in European forests

Provisioning FES	Average (±SD)	Very low (%)	Low (%)	Medium (%)	High (%)	Very high (%)
Biomass (Material) supply	59.91 ± 36.12	23.10	8.60	7.22	22.16	38.92
Biomass (Material) demand	59.15 ± 33.51	19.07	13.08	9.39	25.05	33.40
Biomass (Energy) supply	54.80 ± 33.58	22.64	14.27	8.05	28.60	26.44
Biomass (Energy) demand	57.12 ± 31.90	18.37	15.74	9.22	29.06	27.60
Game (Hunting) Supply	57.96 ± 35.43	23.80	8.75	6.24	27.86	33.36
Game (Hunting) Demand	50.91 ± 32.82	24.42	18.60	10.01	24.72	22.26
Wild products Supply	38.39 ± 35.06	44.08	13.65	5.55	21.00	15.72
Wild products Demand	47.03 ± 34.51	32.78	14.48	7.88	22.88	21.98
Provisioning Supply	52.59 ± 25.90	14.69	15.70	26.42	28.50	14.69
Provisioning Demand	53.55 ± 25.81	13.27	15.75	27.84	27.59	15.56

Looking at each provisioning FES individually, Biomass for material, Biomass for energy purposes and game (hunting), all have relatively similar values for supply and demand, while wild products (e.g. mushrooms, berries) are comparatively less relevant. Once again, these results of great heterogeneity highlight the importance of considering the local social-ecological context. Supply and demand of each provisioning FES changes depending on the economic, biophysical, socio-cultural local conditions of the forest and the social landscape in which is located.

Our integration analysis identified those areas where based on the perceived supply (Medium, or very low) and perceived demand (medium, high or very High) create the conditions where to focus IMs and policy mechanisms to focus. The results for Biomass production either for material or energy use are relatively similar (Fig. 8 and 9). It is for wild products harvesting where exist larger opportunities and where the difference between demand and supply is the highest (Table 3). As such, our analysis of focus areas for wild products provision, show that the surface for this FES is the largest compared to the rest of provisioning FES (Figure 10).

From a policy perspective, wild products harvesting shows a large potential in relation to IMs design and implementation, especially when it is considered its synergistic relation with several cultural FES as outdoor recreation or cultural identity. Nearly 25% of European households have reported to engage in collecting NWFP (Prokofieva et al., 2017). As such, wild products harvesting could potentially have a strategic role in

European forests in the future, and due to its potential, Europe can have a prominent position in the international NWFP market (Prokofieva et al., 2017).

Game is the provisioning FES where there is the largest difference between the perceptions of its current supply and demand. As such, our integration analysis shows the smallest focus area among all provisioning FES (Figure 11). As we will see in the next chapter of this deliverable (where we will largely discuss on CES and its relation to other FES), hunting places a relatively controversial role in forest management. On the one hand, game plays a key role in European forests, being of great economic importance and central for the cultural and sense of identity in many European rural communities (which explains its higher average supply; Díaz et al., 2008). However, it is an activity that due its nature, establishes strong trade-offs with other users of the forests that cannot simultaneously access and use them (which explains its lower average demand).

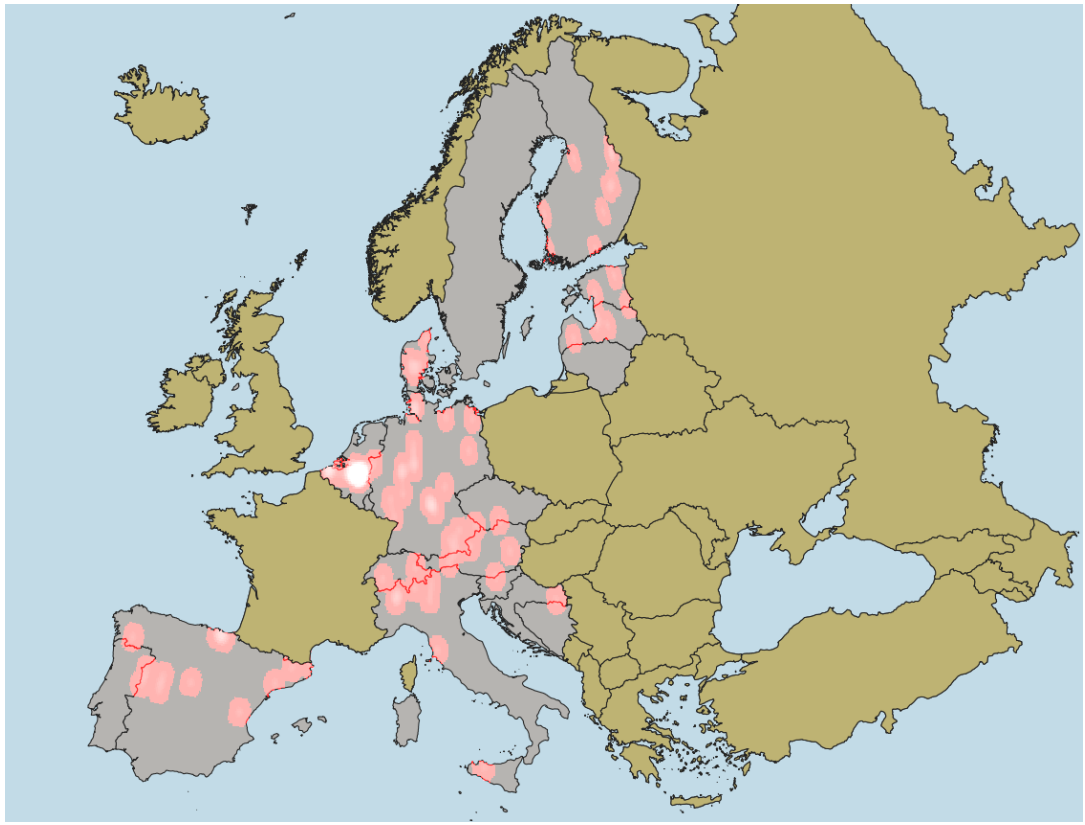

Figure 8. Focus areas for Biomass (Material) in European forests. (Supply < 60%; Demand > 40%)

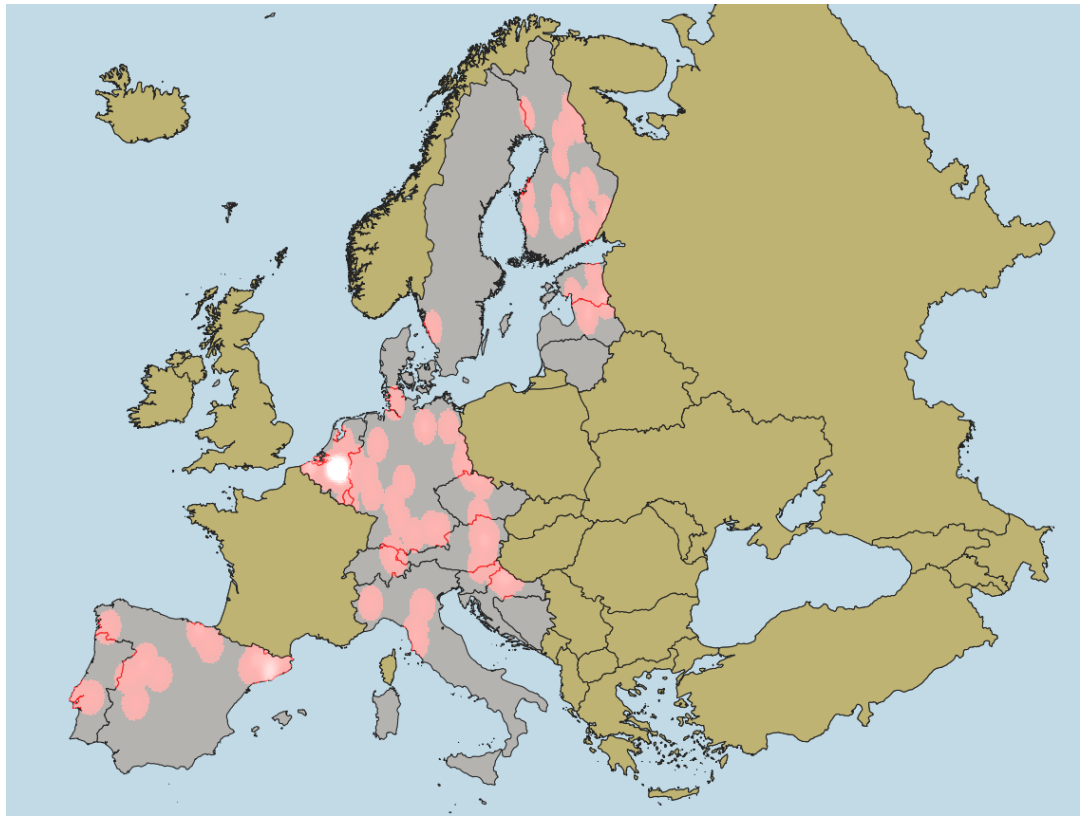

Figure 9. Focus areas for Biomass (Energy) in European forests. (Supply < 60%; Demand > 40%)

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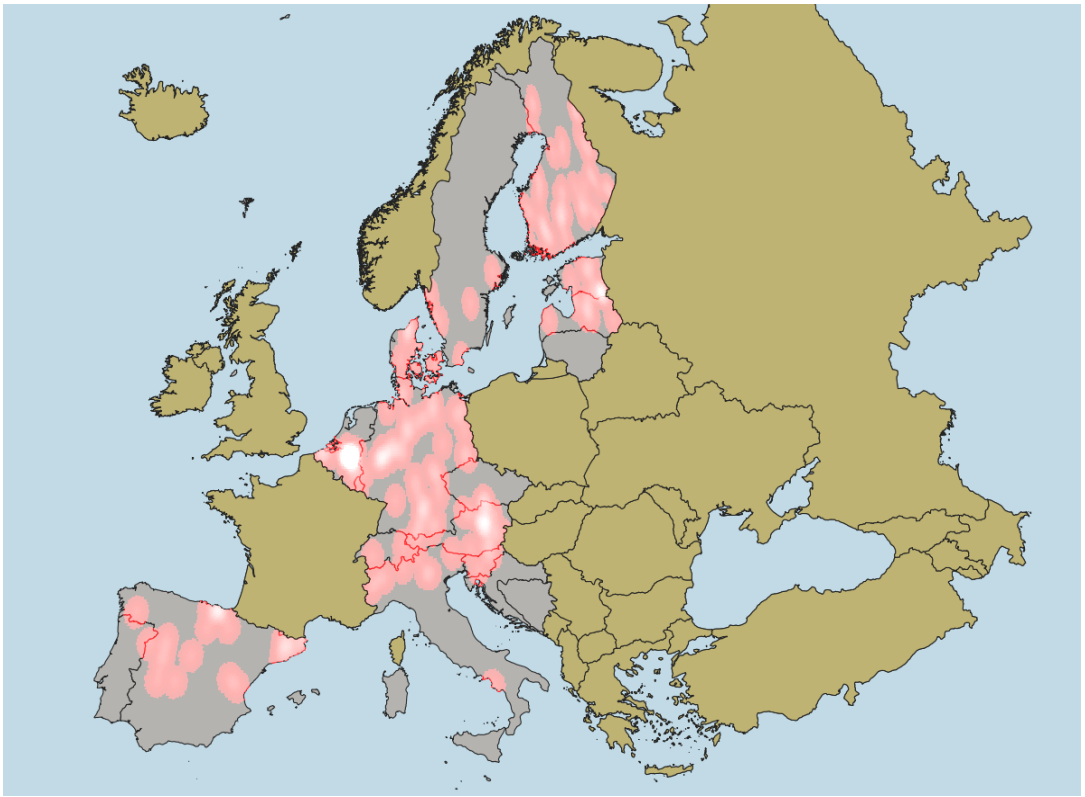


Figure 10. Focus areas for Wild Product harvesting in European forests (Supply < 60%; Demand > 40%)

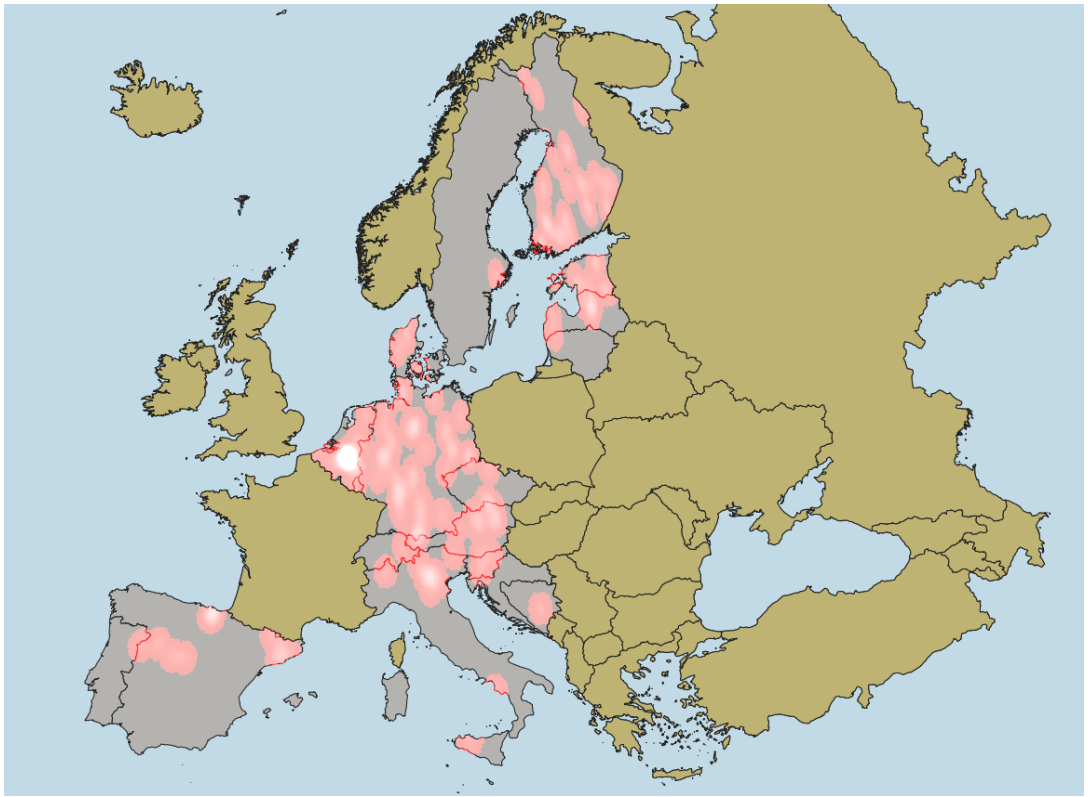


Figure 11. Focus areas for Game (Hunting) in European forests. (Supply < 60%; Demand > 40%)

2.3.4. Regulating Forest Ecosystem Services

Our results show that regulating FES is the category that is perceived to have the highest supply and demand in European forests. All regulating FES excepting watershed protection are perceived as highly or very highly supplied and demanded in European forests. Furthermore, as mentioned in section 3.2, regulating FES is the only category where forest owners perceive there is a surplus in ES provision, that is, the supply of the services is larger than its demand. If this is the case, based on our global review on PES and enabling factors, to maximize success it would be important to select carefully the areas to be targeted (Wunder et al., 2019). That is especially relevant as for most regulating FES, by inherent reasons, supply and demand must meet at a local/regional level (providing and consuming units of FES are not very distant; García-Nieto et al., 2013; Wei et al., 2017). Triangulation of data is also relevant to refine the spatial targeting. Regulating FES are probably the most challenging FES category to perceive, so the data coming from participatory methods (like the results coming from this assessment) should always be checked and verified empirically (Willemen et al., 2015).

Furthermore, in the current situation, where stated attitudes towards regulating FES supply are positive, policies should focus in maintaining current trends, for example by providing recognition (not necessarily economic compensation) to those areas where supply is high. Currently, regulating FES do not represent a significant share of the direct profit made in European forests and current supply seems to be driven for the most part by non-direct economic motivations or non-economic values. The strategies to engage those forest owners currently not inclined towards regulating FES supply could imply, either the creation and implementation of public-financed PES (similar to the Common Agricultural Policy), or the creation of user-financed PES.

Looking individually to each of the regulating FES, Habitat for biodiversity is the FES for which there is a larger gap between demand and supply, and therefore the FES that would has less priority from European forest owners' perspective (Fig. 12). As we mentioned in the introduction of this chapter, these gap between supply and demand must be, to a certain extent, understood as inherent in the European context, where supply of key FES (such as biodiversity protection) is perceived as a public responsibility, to be addressed through structures such as National Parks or the NATURA 200 network. Something similar probably occurs for FES like climate change mitigation (Fig. 13) and air quality regulation (Fig. 14). Our integrative analysis suggests that watershed protection would be the regulating FES with the largest focus area (Fig. 15). In table 4, we can see how the supply of this FES is still far from reaching its maximum potential. Interestingly, our results also show that social demand for watershed protection is not particularly high in forest, especially given the key role forest play in soil retention (Maes et al., 2011).

Table 4. Perception of Supply and demand of regulating FES in European forests

Regulating FES	Average (±SD)	Very low (%)	Low (%)	Medium (%)	High (%)	Very high (%)
Watershed Protection Supply	58.11 ± 36.22	25.035	7.972	6.853	25.035	35.105
Watershed Protection Demand	55.22 ± 31.17	25.434	11.849	7.170	24.830	30.717
Air Quality Regulation Supply	73.79 ± 30.31	11.577	4.261	4.048	27.557	52.557
Air Quality Regulation Demand	65.22 ± 35.06	19.404	8.556	4.736	22.536	44.767
Climate Change Mitigation Supply	78.86 ± 26.89	7.374	3.722	4.066	24.466	60.372
Climate Change Mitigation Demand	69.24 ± 33.26	14.974	8.181	5.478	21.914	49.452
Habitat for Biodiversity Supply	81.10 ± 22.76	4.139	3.672	4.139	26.636	61.415
Habitat for Biodiversity Demand	69.96 ± 29.62	10.554	9.668	6.347	28.339	45.092
Regulating Services Supply	71.52 ± 25.44	6.651	6.409	12.213	30.230	44.498
Regulating Services Demand	64.03 ± 28.78	10.837	11.407	15.526	25.982	36.248

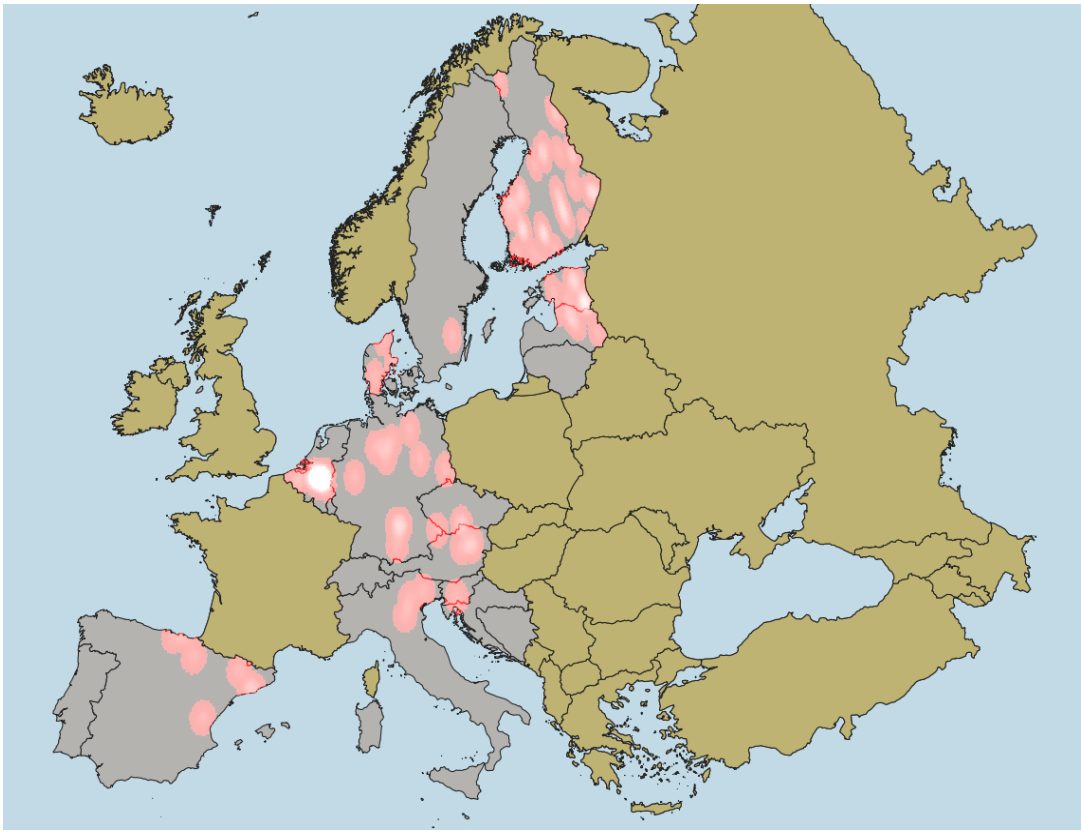


Figure 12. Focus areas for Habitat for biodiversity in European forests (Supply < 60%; Demand > 40%)

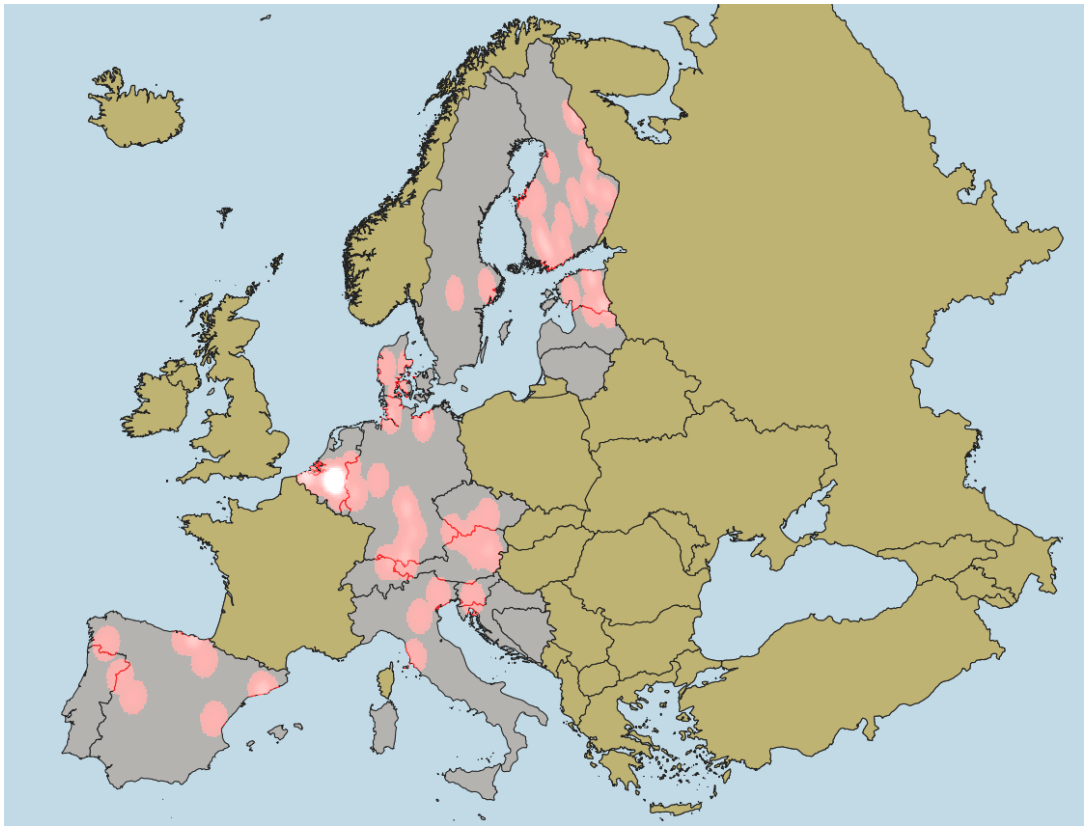


Figure 13. Focus areas for Climate change mitigation in European forests (Supply < 60%; Demand > 40%)

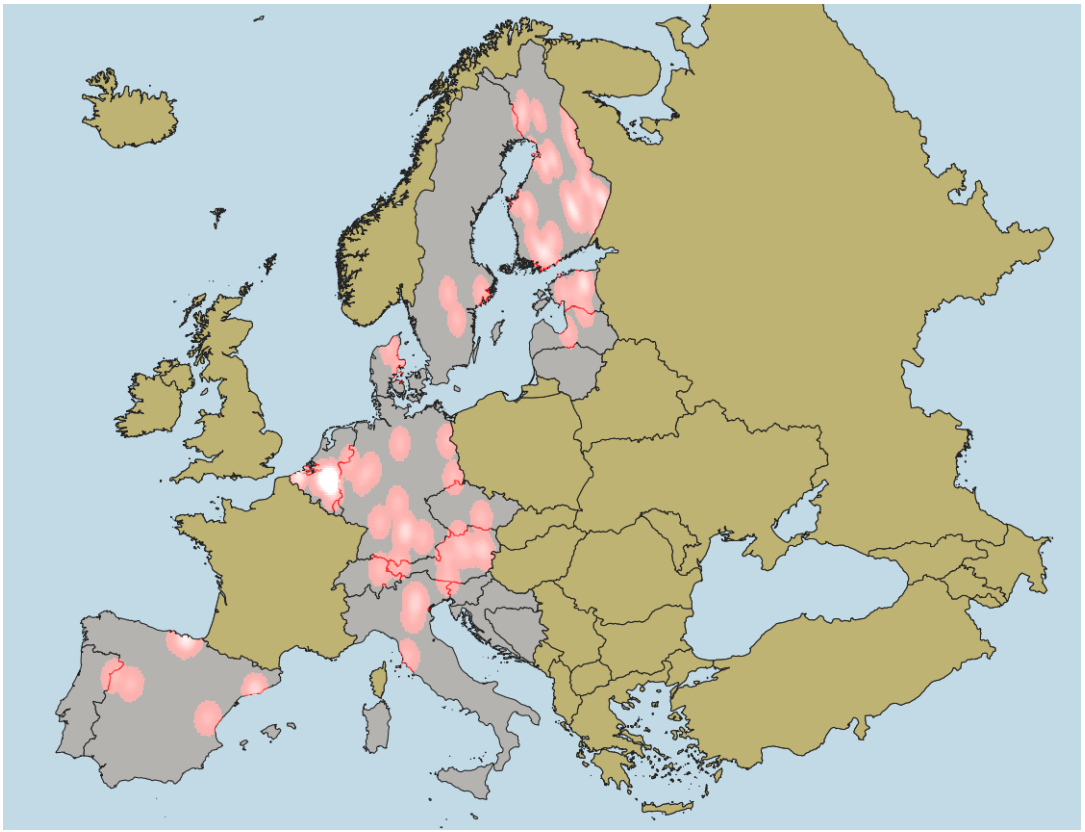


Figure 14. Focus areas for Air quality regulation in European forests (Supply < 60%; Demand > 40%)

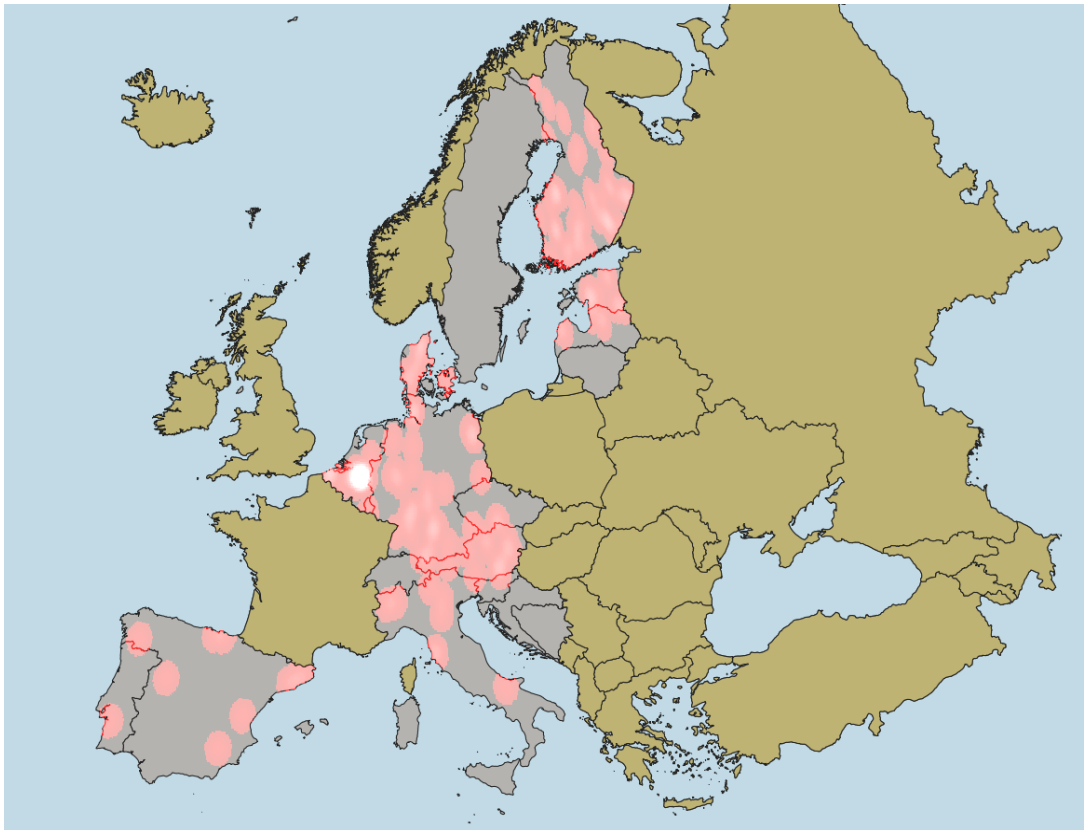


Figure 15. Focus areas for Watershed protection in European forests (Supply < 60%; Demand > 40%)

2.3.5. Cultural Forest Ecosystem services

Our assessment for cultural FES shows once again a heterogeneous landscape. Although supply and demand is perceived mostly as Medium or High (Table 5), and the trends show that its demand is on the rise (Fig. 6), the views over Cultural FES are much divided. How people access, perceive, use and experience forest is to a very large extent dependant on personal/group context and its relation to the ecosystems (Chan et al., 2012a). The specific characteristics of the forest and its surroundings, such as its accessibility or the degree of multifunctionality at a landscape level, play a fundamental role in how much forest is experienced and used and how it is perceived (Plieninger et al., 2017; Fagerholm et al., 2019). Similarly as for regulating FES, where supply and demand are usually met at a local level, promotion of CES in European forests should take into account the need to refine the spatial targeting to those areas where the conditions are optimal for CES. These inter-relations between forest and its users are rather complex, and we will explore them in more depth in the next chapter of this deliverable.

Table 5. Perception of Supply and demand of cultural FES in European forests

Cultural FES	Average (±SD)	Very low (%)	Low (%)	Medium (%)	High (%)	Very high (%)
Cultural, emotional and spiritual values Supply	59.73 ± 35.12	22.44	9.88	6.35	24.75	36.58
Cultural, emotional and spiritual values Demand	51.96 ± 34.37	25.67	17.22	7.11	24.33	25.67
Educational values Supply	38.74 ± 35.23	44.59	13.68	5.48	19.59	16.67
Educational values Demand	46.98 ± 33.62	29.36	18.34	8.21	24.38	19.71
Healthcare and outdoor activities Supply	55.77 ± 36.17	26.74	10.49	5.90	23.96	32.92
Healthcare and outdoor activities Demand	64.31 ± 33.17	16.84	10.09	5.77	26.48	40.82
Cultural Ecosystem Services Supply	51.92 ± 29.75	18.69	18.57	18.88	22.43	21.43
Cultural Ecosystem Services Demand	55.13 ± 29.33	17.13	14.29	19.11	25.99	23.48

The results of our integration analysis for each of the Cultural FES assessed shows similar context-related patterns. In general, focus areas for CES are large. These is likely the consequence of a general lack of mainstreamed models and frameworks focused

primarily on cultural, Emotional and spiritual values; or on Educational values, together with the high demand for these services (Fig. 16 and Fig. 17). For these same reasons, Healthcare and outdoor recreation show the smallest focus area among CES. Our interpretation is that, for inherent reasons, recreation is the Cultural FES that is easier to monitor and capitalize. It is therefore the CES for which more initiatives and models already exist (Fig.18).

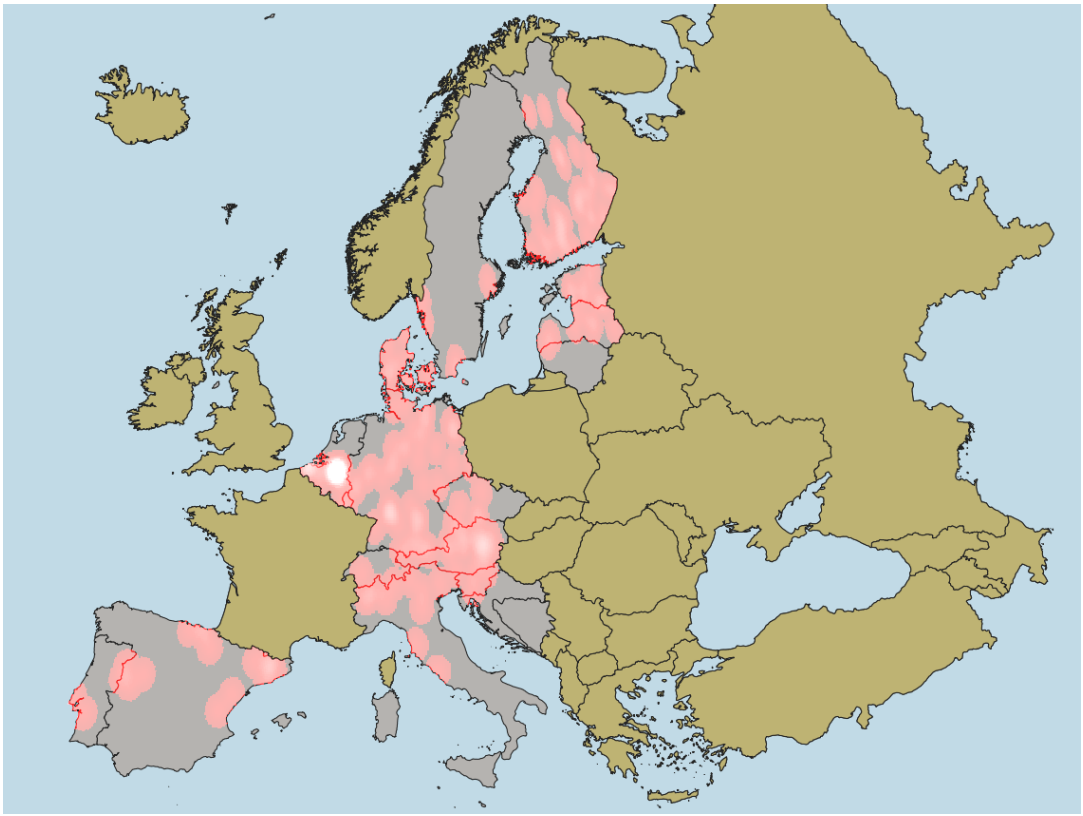


Figure 16. Focus areas for Cultural, emotional and spiritual values in European forests (Supply < 60%; Demand > 40%)

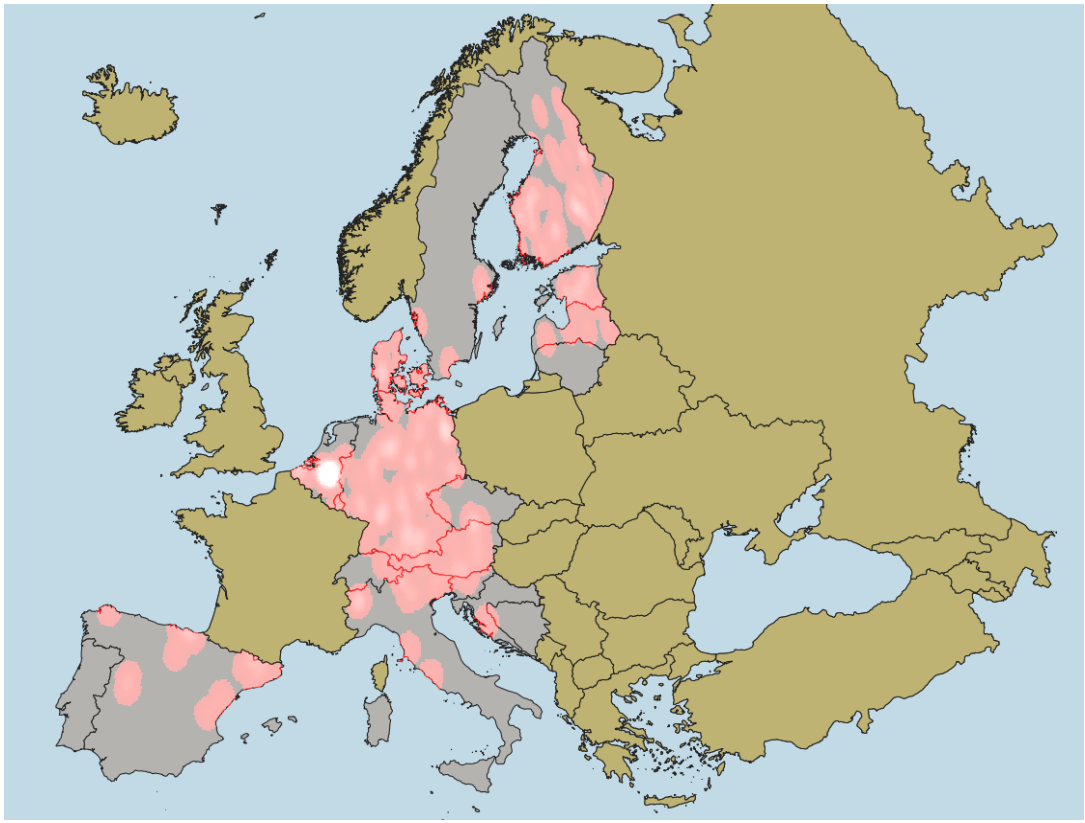


Figure 17. Focus areas for educational values in European forests (Supply < 60%; Demand > 40%)

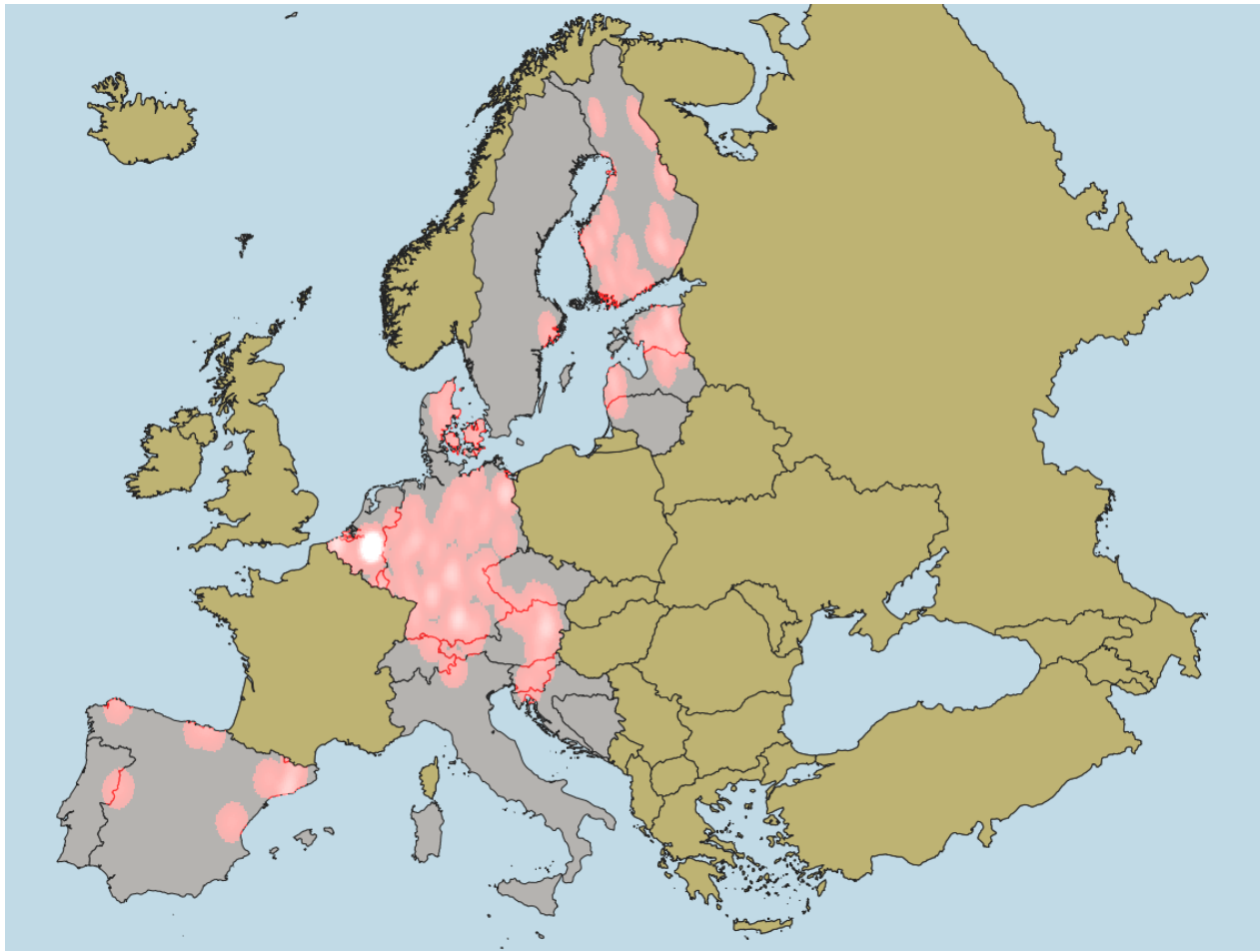


Figure 18. Focus areas for Healthcare and outdoor activities in European forests (Supply < 60%; Demand > 40%)

2.3.6. Innovations

From the 1149 respondents that completed the section dealing with innovations in European forests, 411 indicated the presence of some kind of innovation in their forest in relation to at least one FES in the last two decades (35.7% of the respondents; Fig. 19A). Our assessment shows that a total of 1081 innovations have been developed. In average, the number of innovations implemented in the last two decades has been above one (average = 1.13 ± 2.3). These innovations have been very diverse and dealt with many different dimensions of forest planning and management (Fig. 19B). The most common innovations were related to biomass production, either by modifying or adapting management to improve production (60.8%) or by incorporating a new technological advance (49%). With less frequency, innovations focused on non-provisioning FES, either by modifying/adapting management (38.2%), or by incorporating new FES (33.3%). In approximately a quarter of the cases, innovation had to do with new trans-sectoral contracts (28.5%), new users of the forest products and services (28.2%) and new ways to generate value from them (26.5%) or to promote them (24.8%). The least frequent innovations were directly related to non-provisioning FES - the creation of transboundary cooperation (11.7%) and the incorporation of new technology not related to biomass production (9.7%).

We asked respondents to state which of these developed innovations were, from their perspective, the most innovative and the most economically important (Fig. 20). New technology for biomass production is overall the most economically important innovation type. Although the same descending trend in frequency can be seen in relation to economic and innovative importance, there are notable exceptions: New ways to generate value from ecosystem services are not as innovative as we would have expected, while the opposite can be stated for innovations focused on new ecosystem services. It seems clear that innovations related to provisioning FES, mainly focused on biomass production, have been the most important economically, while they are not perceived comparably so innovative. On the other hand, innovations of non-biomass production are comparatively perceived as fresher but less economically important. Once again, these results indicate the gap between the current demand and interest in multiple FES and the lack of business models and market alternatives to make them financially relevant.

This results confirm what has been assessed in previous European efforts looking at innovations (Lovrić et al., 2019) and helps contextualizing our previous result and interpretations on the relative importance of different FES on income in European forests (Fig. 7).

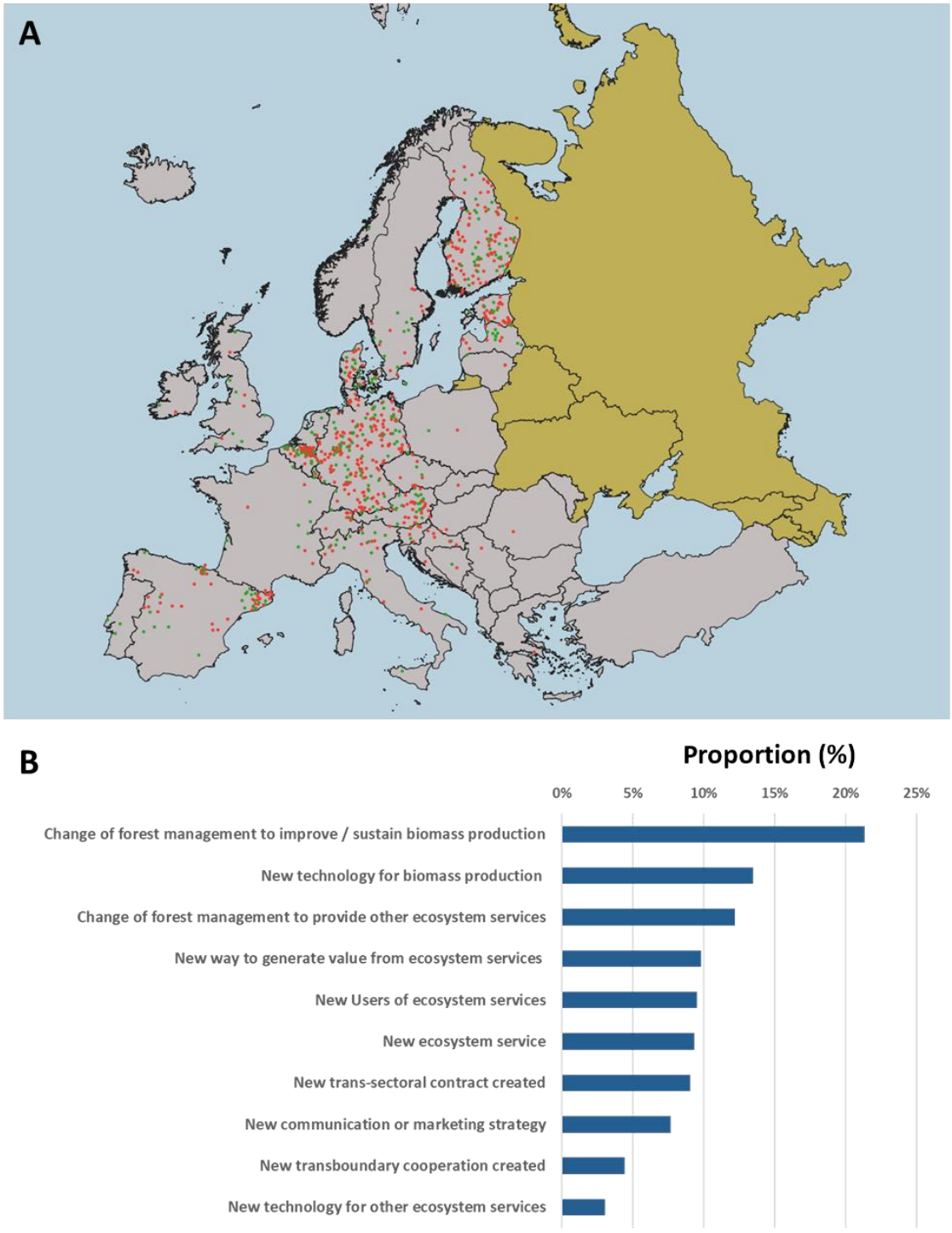


Figure 19. A: Map of innovations in Europe. *Green*: all areas where there has been an innovation in the last two decades related to at least one FES; *Red*: areas where there has not been an innovation in the last decades related to at least one FES. **B**: Types of Innovations in European forests

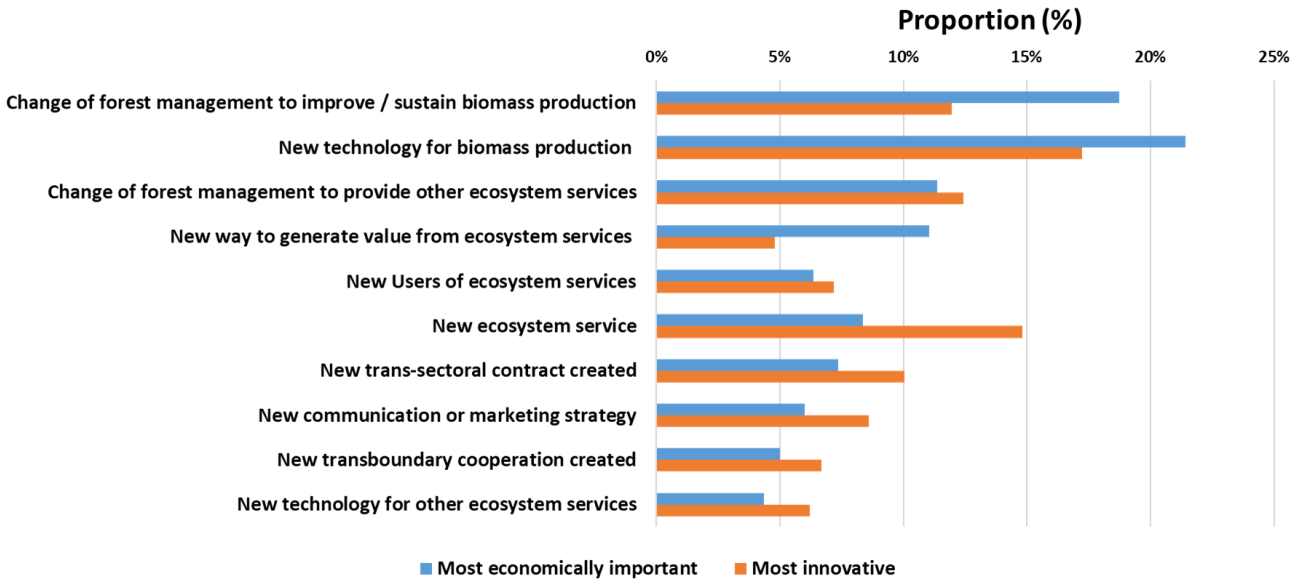


Figure 20. Share of most economically important and most innovative innovations by type

In relation to the factors enabling and undermining innovation in European forests (Fig. 21), the most innovation-supporting factors were individual leadership and organizational culture, followed by strong private sector and available knowledge. The most hindering factor is the low profitability of a FES before implementation of the IM, pointing to the fact that in this FES context innovations tend to occur out of opportunity and not out of necessity (Van Lancker et al., 2016). These results are in line with the lessons learnt from our global review on PES and IMs (Wunder et al., 2019) and our initial hypothesis: innovation occurs in localized areas, with stable and optimal economic and socio-cultural conditions related to stability, local private support, and where the intermediate agencies are perceived as legitimate and supportive. Interestingly, Climate Change and High profitability before the innovation somewhat support the development of most economically important innovations, but at the same time impede to implement those actions perceived as the most innovative ones.

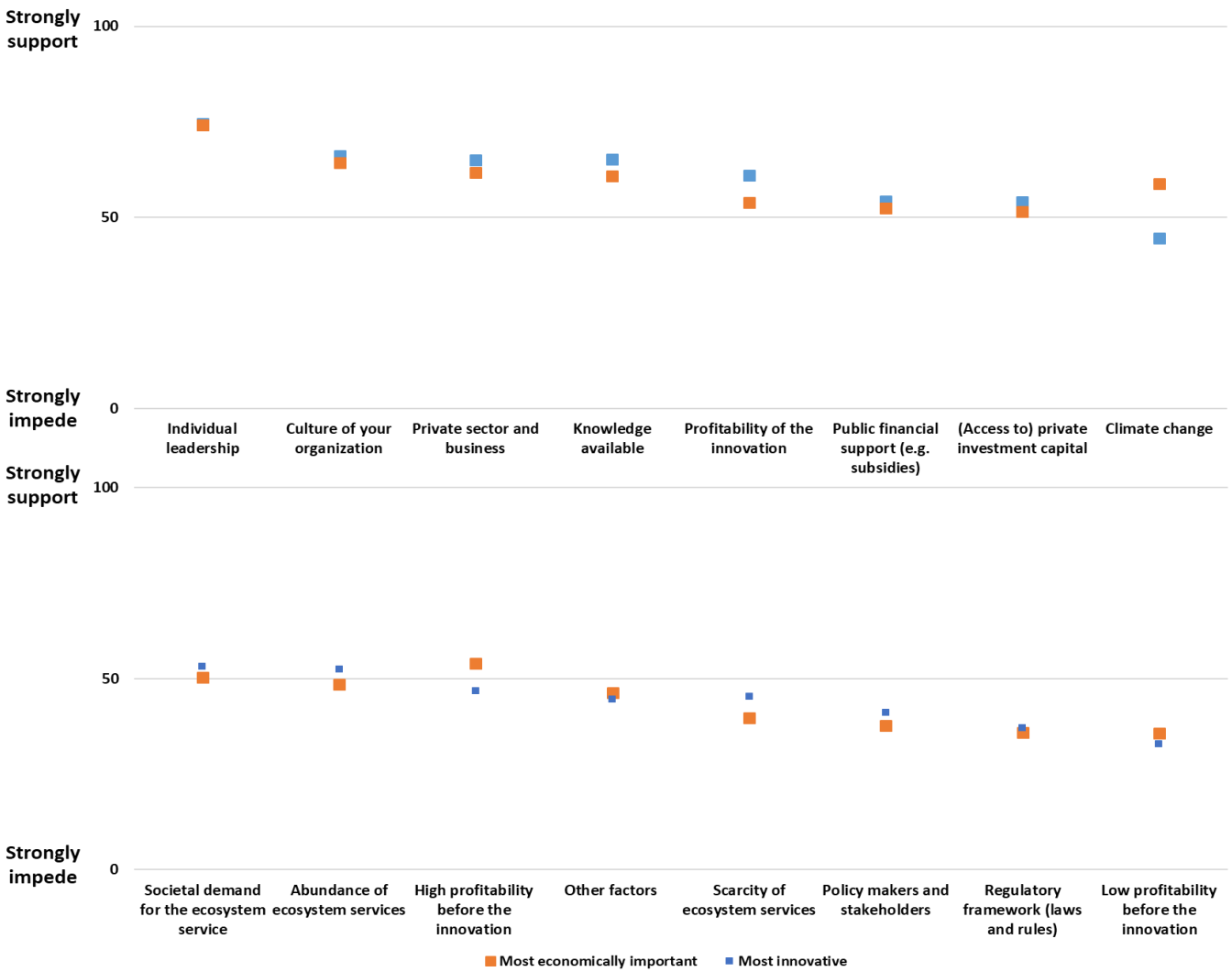


Figure 21. Enabling and hindering factors on development of most economic and relevant innovations in European forests

Our analysis showed that there were no significant geographic differences in relation to innovations ($\chi 2$ (df=1, N=1690) = 5.04 p = 0.02). Once again, our results suggest the importance of the specific social-ecological context when considering FES supply, demand, and innovation (see table S1 in Appendix 1 for more details). In line with this result, we have observed significant differences depending on the type of respondent. Our results suggest that individual/family private forest owners are less prone to innovate than public forest owners (at all institutional scales) and private forest managers from institutions or business entities. Our analysis are in line with previous studies that show how factors related to land tenure are a decisive factors influencing land management (Joshi and Arano 2009; Urquhart et al., 2012; Torralba et al., 2018b).

We have also compared the two sub-samples (with / without innovations) in relation to supply and demand of individual forest ecosystem services. This comparisson would tell as whether supply and demand of FES happen or not in areas where there has been some innovation.

Our results clearly show that both supply and demand for FES is higher in areas where some innovation has happened (See Tables S2 and S3 in Appendix 1 for more details). This is true for all individuals FES supply and demand questionnaire items. These differences are statistically significant ($p \leq 0.05$) for all of the FES supply and demand questionnaire items except for the supply and demand of air quality regulation (where the difference between two sub-samples for its supply is 2.7 and for demand is 4.7). Interestingly innovation was particularly helpful for those services that usually do not have an established or consolidated business models (cultural FES). These results reinforce the relevance of projects like SINCERE that aim to build on context-specific local initiatives and to promote models that can be generalized and adapted to other contexts.

2.3.7. Conclusions

- Supply and demand of FES are perceived as rather high and synergistic. However, forest owners only benefit from provisioning services. Regulating and cultural FES seems to be on the rise, but there is a clear need of innovative mechanisms implementation.
- Supply and demand vary greatly depending on the local context. It seems therefore necessary to refine the spatial target prior any intervention to boost supply of any FES.
- Supply of FES seems to be enhanced by innovation. However, this innovation is perceived to be constrained by policy makers, stakeholders and regulatory frameworks. This reinforces the importance of approaches that build on landscape-based context-related initiatives to promote innovation models that can be adapted, tested and then exported.

3. Mapping Cultural Ecosystem Services in European Forests

This chapter of the document moves forward from all FES to focus specifically on Cultural FES. As has been explored in the previous chapters, CES are called to play an important role in European forests. While there is currently no thorough assessment focused on them, our analysis shows that their demand is on the rise (Fig. 6), while their current importance in livelihoods is low (Fig. 7), and the potential for innovations on them are particularly fruitful (Tables S2 and S3 in Appendix 1).

Therefore, in the next pages we will focus on current and potential CES supply in European forests. Furthermore, we will assess how compatible CES are, and what specific policies and mechanisms could be implemented to further foster them.

This is a pre-print version of the following paper, still in submission phase:

Torralba, M., Lovrić, M., Budniok, M.A., Mulier, A.S., Winkel, G., Roux, J.L., Plieninger; T. (Submitted). Examining the relevance of cultural ecosystem services in forest management in Europe.

3.1. Introduction

Forest provide multiple ecosystem services such as timber, carbon sequestration, hydrological regulation and recreation (MEA 2005). A strong focus on one single service, for example on timber production, typically tends to generate trade-offs with other ecosystem services and generate a negative impact on some of them, like reducing biodiversity levels (Duncker et al., 2012). In contrast, a management that enhances the multifunctionality of the forest (e.g. by promoting the structural heterogeneity and increasing accessibility of forests) tends to create synergies and promote multiple ecosystem services simultaneously at the cost of reducing timber production from its potential maximum production (Felipe-Lucia et al., 2018).

Forest owners and managers play a key role in the supply of forest ecosystem services (FES) as they are the main decision makers regarding forest planning and management. Their management decisions are largely rooted on personal values and perspectives, which go beyond economic profit and combine several other aspects like their personal preferences, past experiences, cultural identities and social norms (Hugosson and Ingemarson 2004; Urquhart et al., 2012; Maier and Winkel 2017).

Management models focused on enhancing multiple societal functions in order to promote sustainable forest management have been developed in Europe since the early 20th century (Pistorius et al., 2012). However, in the last decades the model of managing for multifunctional forests has re-emerged as a paradigm in consequence of, among

others, accelerated environmental degradation, increasing social demand for multiple FES, and the development of landscape approaches and theoretical frameworks such as the ecosystem services concept (Bieling 2004; Plieninger et al., 2015; Borrass et al., 2017).

While the need to provide multiple forest ecosystem services or functions is frequently underlined in forest policy documents in Europe, like in the EU forest strategy (EC 2011), there is a continuous debate in how far such political ambitions are translated into instruments that promote forest management for multiple services (Winkel and Sotirov 2016; Borrass et al., 2017). This holds particularly true for cultural ecosystem services (CES – the non-material benefits society obtained from ecosystems), which are largely absent from scholarly assessments, practical support, and policy mechanisms. While FES have been integrated in forest related policies (such as the EU Biodiversity Strategy, EU Forest Strategy, Common Agricultural Policy and the Green Infrastructure Strategy), only very few references are made to CES, and this is usually in the context of tourism and recreation. There are several reasons for the lack of policy support mechanisms on an EU level regarding CES. Firstly, competency in the various policy sectors are differently shared and distributed between the EU and Member States. Forestry is responsability of the member states but other important associated sectors, like water, are shared between EU and the states (Schleyer et al., 2015). Determining which governance level has the responsibility to develop policies on CES in forests is not an easy task, especially regarding CES such as recreational fishing. Secondly, CES are mostly referred to in an environmental context, which fuels the power asymmetries between economic oriented policy stakeholders and environmental oriented policy stakeholders (Schleyer et al., 2015; Bouwma et al., 2018).

The reasons for the absence of CES from policies does also relate to theoretical, practical and methodological challenges intrinsic to CES quantification, valuation and integration in long-term management plans (Chan et al., 2012b; Satz et al., 2013). CES are inherently pluralistic (they mean something different for different groups of people), interdependent (they inextricably influence each other), and in many cases lacking a proper framework for a monetary economic translation. CES have recently been framed close to relational values, being intimately linked to regulating and provisioning ES and emerging from the context-related interactions between the individual and/or the group, and the ecosystem (Chan et al., 2016; Arias-Arévalo et al., 2017).

Demand for CES is strongly on the rise in Europe as a direct consequence of processes like urbanization, changes in lifestyle and increase of environmental awareness, both from landowners and managers, and from the general public (Kanowski and Williams 2009; Satz et al., 2013; Cáceres et al., 2015; Wolff et al., 2015). This creates an opportunity to increase political support and societal appreciation of forests, while opening the window for innovation in the promotion and use of CES in forests. On the

other hand, sophisticated promotion for the cultural ecosystem services of forests can also generate conflicts in relation to the use of the forest when these innovation processes leave key groups behind (Tyrväinen et al., 2017). Currently, very little is known about the uses and management of CES in privately owned forests of Europe beyond some local and regional-level studies (i.e. Urquhart et al., 2012; Hendee and Flint 2014). Similarly, there are few public support program that target promotion of CES in forests, and these are focused on those services that are easy to assess and consider under market-based instruments such as recreation or aesthetic appreciation (Satz et al., 2013; Cooper et al., 2016).

In this context, we performed a Europe-wide survey of forest landowners with the following objectives:

1 - To assess CES supply in European forests and evaluate forest owners' willingness towards further CES supply.
2 - To assess synergies and tradeoffs as perceived by forest owners and managers in relation to CES supply.
3- To identify different groups of forest owners in relation to their attitudes toward CES.
4- To uncover the barriers and limitations that hinder CES use and to identify potential pathways to solve them.

3.2. Methods

3.2.1. Survey design and distribution

Our survey included 16 questions that explored diverse factors related to forest management and to CES use. The survey considered which CES are supplied by the forest (by assessing which activities providing non-material benefits usually take place in the property) and which CES could potentially be further supplied, given the appropriate incentive. Our understanding of CES was inclusive, considering a plurality of values that are associated with the relationships between individuals/groups and the ecosystem (Pascual et al., 2017). Thus, we covered a broad range of non-material benefits associated with forest activities, including e.g. beekeeping, which is directly associated with pollination, but is additionally related to non-material benefits such as cultural identity, spirituality or recreation (Hill et al., 2019).

The survey was available in 20 languages (Bulgarian, Croatian, Czech, Dutch, English, Estonian, Finnish, French, German, Hungarian, Italian, Latvian, Lithuanian, Polish, Portuguese, Romanian, Slovak, Slovenian, Spanish, and Swedish), and was distributed through different landowners associations working at EU level: the European Landowners' Organisation (ELO), Copa-Cogeca, the Confederation of European Forest

Owners (CEPF), the European Federation for Hunting and Conservation (FACE), the International Council for Game and Wildlife Conservation (CIC), and the European Historic Houses Association (EHHA). The survey was distributed online between November 2017 and February 2018 by email and social media via national contact points, targeting all members of those organizations and covering nature managers, farmers, foresters and heritage owners.

The number of survey responses received was 1322. However, responses of participants not owning or managing forest in Europe were not included in the analysis, which led to a reduction of the sample. Eventually, 1186 questionnaires were included in the analysis, including many properties that combined forests with other land uses (grasslands, croplands, water bodies, etc.). Table 6 shows the main variables analysed and the corresponding questions in the survey questions.

Table 6. List of variables analysed and their original version in the survey

Variables analysed	Original questions in the surv	Categories
1. Current CES supply on the forest 2. Potential supply that could be (further) promoted if there were incentives	1. Which of these activities currently take place on the land/site(s) you manage? 2. Could the site/area that you manage deliver more activities if you received additional incentives?	Farming Beekeeping Gathering fruits and other natural products Dog walking Horse riding Hunting/game management Enjoyable landscape/aesthetic experiences Provision of area for accommodation Nature-/ bird watching / photography Sporting/exercise activities Recreational fisheries management Historical/cultural sites Spiritual enrichment Artistic activities Research/science Outdoor learning/education
3. Existing facilities and infrastructure that promote CES supply	3. What infrastructure is in place in your land/site(s)?	Presence of access roads Presence of trails and paths Presence of toilets Presence of parking facilities Presence of walkways/bridges Presence of signage Designated area for accommodation
4. Supporting management actions for CES supply	4. What types of actions do you put in place to support CES on your land/site(s)?	Road/trail maintenance Additional garbage disposals Control of invasive species Outdoor learning programs Adaptation of management practices Habitat management
5. Degree of integration of CES supply in forest management	5. To what extent are CES integrated in the long-term planning of the land/site(s), which you manage?	(Don't know / Not at all / Slightly / Significantly)

6. Costs and barriers for further CES supply implementation	6. Do any particular activities represent an obstacle/challenge to the land/site(s), which you manage? 7. Are there any costs linked to the delivery/support of CES on your land/site(s)?	Open answer - Responses were analyzed and categorized as the following: - Related to waste disposal management. - Related to modifications in land use and management. - Related to maintenance of infrastructures. - Related to users of the land. Related to regulations, administrative and bureaucratic processes.
7. Policy support for further CES promotion	8. Do you think public authorities could help land owners/managers to deliver/support more? – *Open answer*	Open answer – Responses were analysed and categorized as the following: - Programs for infrastructure development/ implementation in private forests. - Public political support and recognition. - Improvement of public facilities. - Increase of public awareness and promotion of ES. - Reduction bureaucracy and control over forest owners. - Education and training programs. - Change in regulations. - Direct economic support.
8 Habitats present on the property	9. Please describe the types of habitats/features present on the land which you manage	Coastal areas Wetlands Water bodies i.e. rivers, lakes Arable land Grazed land

3.2.2. Statistical analysis

To assess whether CES in European forests do associate together or not, we performed two Principal Component Analysis (PCA). One PCA was done for the current CES uses, and one for the potential CES uses in case of additional incentives. Presence/absence of all the categories in Table 6 were included as dependent variables. These analyses allowed us to see which uses can enter into conflict with each other and which ones tend to co-occur.

We then performed a Hierarchical Cluster Analysis (HCA) to identify whether there are different groups of landowners in relation to their management and attitudes towards FES using the explicative factors (eigenvalue > 1) from the two PCAs (5 factors from the PCA on current use of CES and the 2 factors extracted from the PCA on potential future CES use) as clustering variables. To build the clusters we used the Euclidean distance and Ward linkage method. To characterize and assess the differences between the different groups of landowners identified in the cluster analysis we performed Kruskal-Wallis tests. The different groups of forest landowners and managers were included as dependent variables, while the total number of CES currently and potentially used in the property, the types and amount of facilities, the supporting management actions, the level of integration of CES in management, and the diversity of habitats were included as independent variables. All statistical analysis were made using the software XlSTAT (Addinsoft 2009).

3.2.3. Qualitative analysis

A qualitative approach was used to assess the costs and barriers for further CES supply, and the demands for policy support for further CES supply. Inductive coding was used to establish different categories for the two open questions. Coding was split between the two first authors in two separate coding rounds. The process led, through a series of deliberative discussions, to the establishment of five categories of costs and barriers, and eight types of measures of policy support for further CES promotion (Table 6). Qualitative data was also used to augment and aid in the interpretation of the ordination analysis, nuance the typology of forest owners and managers, and outline the potential strategies to engage each type of forest owner.

3.3. Results

3.3.1. Current state of CES in European forests

The analysis of the dataset shows that forests across Europe are used for a wide range of CES (Mean ± SD: 5.8 ± 3.3). The most frequently used CES is hunting, but there are seven other CES that appear as well in more than 40% of the answers. These are research activities, wild products harvesting, farming, outdoor recreation, and sports (Fig. 22).

When asked which further CES (that are not currently present) could be supported by forest management if they were incentivized, the results show that forest owners and managers are rather open to further CES supply (Mean ± SD: 4.6 ± 4.4). All the suggested CES in the survey were positively considered by at least 15% of the respondents. This would indicate a high interest and a fertile ground for policies and mechanisms that promote CES supply (Fig. 22).

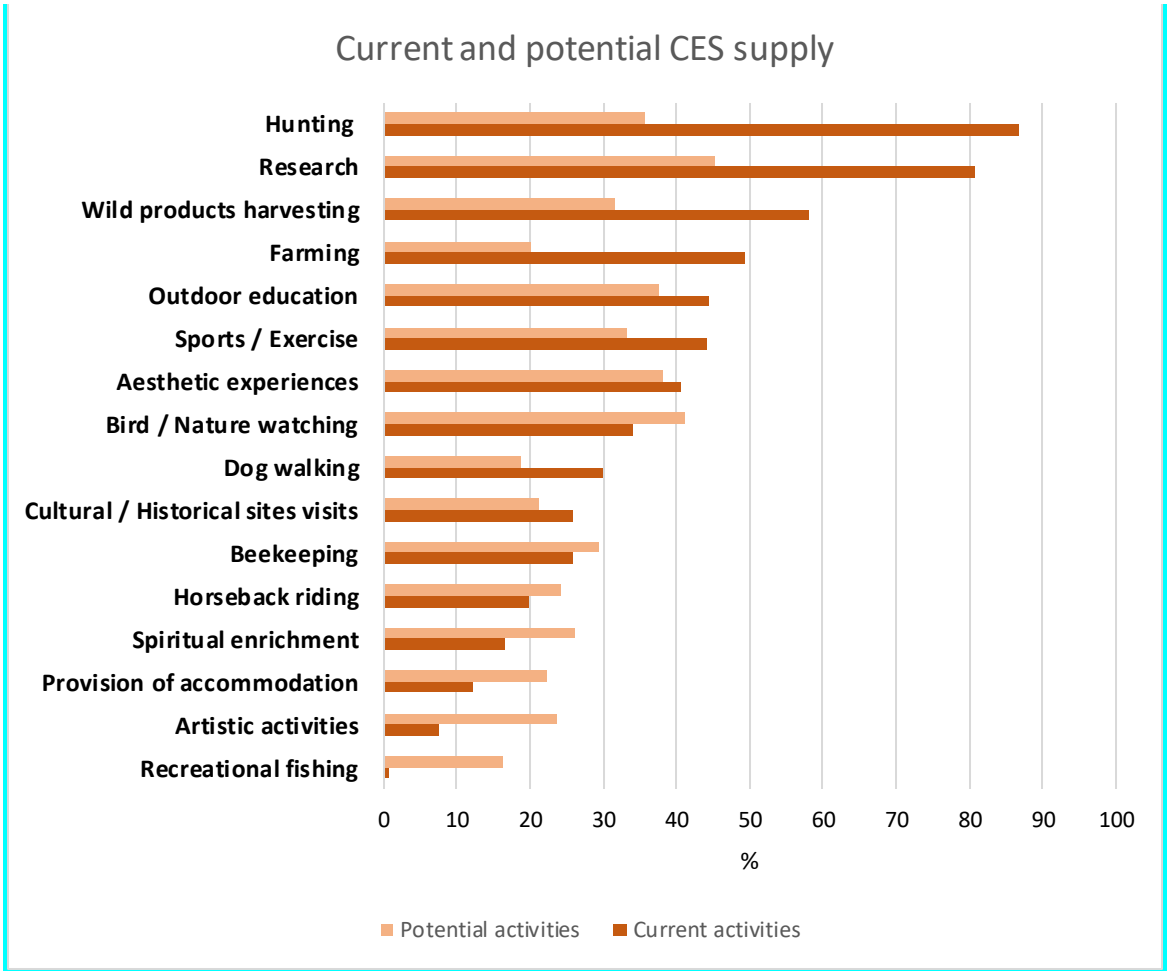


Figure 22. Percentage of respondents indicating the presence of different activities and the potential for future implementation

Around 40% of the respondents stated that CES are integrated to some extent in their management plans (Fig. 23). In addition, a rather high number of management actions were carried out, the most common one being the maintenance of trails and paths within the forest (Fig. 23).

One of the main limitations for the uptake of further CES supply is the absence of proper facilities. We inquired about which facilities were present (Fig. 23). The most common facilities were roads that give access to the property, followed by marked trails and paths within the property. Many properties combined forests with patches of grasslands or croplands, and to a lesser extent with different types of water bodies (Fig. 23).

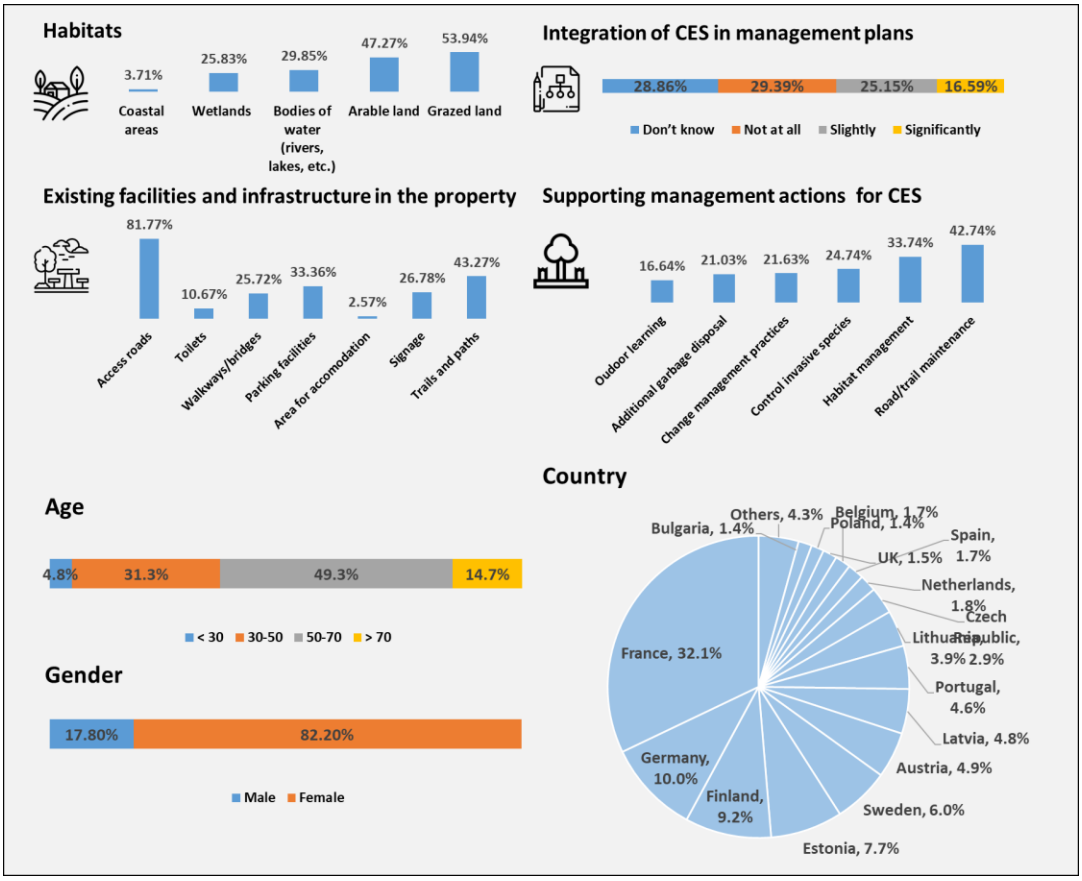


Figure 23. Descriptive statistics of the respondents, their land, and management practices

The respondents identified a large series of barriers for further fostering of CES. The content of those answers was analysed and grouped into different types of costs and obstacles. The different types of costs were: those related to the maintenance of facilities (Freq=237), those related to administrative and bureaucratic processes (Freq=129), and those related to waste disposal (Freq=92). In relation to the obstacles, the main types identified were those related to the control of the users of the land (Freq=374) and those related to the management of the land (Freq=362).

In relation to the potential supporting mechanisms that would incentivize CES, respondents once more identified several potential measures. These were analysed and grouped into different categories: economic/financial direct or indirect support (Freq=168), change in the planning and management regulations (Freq=112), education and training support (Freq=55), relief in the bureaucratic and administrative processes (Freq=48), increase of the public awareness and support of FES (Freq=47), political support and public recognition (Freq=39), and support for facilities implementation (Freq=33).

3.3.2. Synergies and trade-offs between CES uses

The PCA allowed the identification of five factors that show co-variability in CES supply (Table 7). We selected the first five factors for the interpretation based on the eigenvalues (selecting those factors with eigenvalue > 1). For each factor, positive or negative values would indicate how each CES relate to each other, while higher or lower absolute values would indicate the relative importance of each CES in that factor. Based on these criteria, these five factors represent:

1- *Multiple CES supply* (Table 7 - F1): This factor shows many positive associations, discriminating those forests with multiple CES uses from those forests with few or no CES use. CES positively related to this factor include sports, dog walking, bird/nature watching, aesthetic experiences and outdoor education.
2- *Focus on hunting* (Table 7 - F2). This factor discriminates those forests where hunting plays an important role from those where hunting does not take place. Hunting shows negative associations with CES like aesthetic experiences, outdoor recreation and horseback riding.
3- *Focus on farming* (Table 7 - F3). This factor indicates the role of farming in forests. Farming shows a strong negative association with recreational fishing.
4- *Focus on accommodation* (Table 7 - F4): This factor indicates the relevance of providing area for accommodation in forests. It shows a positive association with artistic activities and a weak negative association with outdoor education and aesthetic experiences.
5- *Focus on recreational fishing* (Table 7 - F5): This factor indicates the role of recreational fishing in forests. This CES shows a positive association to horseback riding and a negative association to research activities.

Table 7. Factor loadings derived from the PCA for current CES supply. For each variable, values in bold correspond to the factor for which the squared cosine is the largest

	F1 – Diverse CES uses	F2 - Focus on hunting	F3 - Focus on farming	F4 – Focus on accommodation	F5 - Focus on Fishing
Farming	0.253	0.368	**0.487**	-0.130	0.313
Beekeeping	0.309	0.123	0.346	0.254	-0.272
Hunting	0.250	**0.548**	0.215	-0.043	-0.268
Recreational fishing	0.044	0.118	-0.701	0.040	**0.509**
Wild products harvesting	0.476	0.332	0.147	-0.234	-0.223
Provision of accommodation	0.464	-0.161	-0.110	**0.558**	-0.121
Sports / Exercise	**0.662**	0.201	0.002	-0.034	-0.076
Dog walking	**0.640**	0.254	-0.228	0.021	0.122
Horseback riding	0.477	0.384	-0.096	0.102	0.483
Bird / Nature watching	**0.637**	-0.145	0.046	-0.127	0.094
Aesthetic experiences	**0.751**	-0.420	0.082	-0.367	0.006
Artistic activities	0.541	-0.117	-0.121	0.501	-0.060
Spiritual enrichment	0.530	-0.135	-0.274	0.036	-0.063
Cultural / Historical sites	0.610	-0.097	0.287	0.244	0.059
Outdoor education	**0.768**	-0.392	0.058	-0.349	0.013
Research	0.217	0.313	0.015	-0.180	-0.417
Eigenvalue	4.292	1.344	1.173	1.080	1.014
Cumulative %	26.825	35.223	42.554	49.303	55.644

To assess the willingness towards future CES supply we performed a PCA with all the potential CES as explanatory variables. Based on the factors' eigenvalues, we selected two factors for interpretation (Table 8). Based on the values of the factor loadings, these two factors represent:

1- *Interest in future diverse CES supply* (Table 8 – F1): this factor shows many positive associations, discriminating those forests where owners would be willing to facilitate multiple CES from those forests with few or no potential CES supply.
2- *Interest in future hunting* (Table 8 – F2): this factor discriminates those forests where hunting could take place in the future from those forests where hunting would not take place. Hunting shows negative associations with the majority of other potential CES.

Table 8. Factor loadings derived from the PCA for potential CES supply. For each variable, values in bold correspond to the factor for which the squared cosine is the largest

	F1 – Interest in future diverse CES supply	**F2 – Interest in future hunting**
Farming	0.535	0.303
Beekeeping	0.583	0.273
Hunting	0.519	**0.641**
Recreational fishing	0.551	0.131
Wild products harvesting	**0.645**	0.339
Provision of accommodation	0.562	-0.286
Sports / Exercise	**0.690**	-0.036
Dog walking	**0.678**	0.142
Horseback riding	**0.645**	0.153
Bird/Nature watching	**0.679**	-0.068
Aesthetic experiences	**0.678**	-0.111
Artistic activities	**0.670**	-0.438
Spiritual enrichment	**0.650**	-0.379
Cultural / Historical sites	0.596	-0.340
Outdoor education	**0.668**	-0.247
Research	**0.551**	0.136
Eigenvalue	6.182	1.384
Cumulative %	38.640	47.288

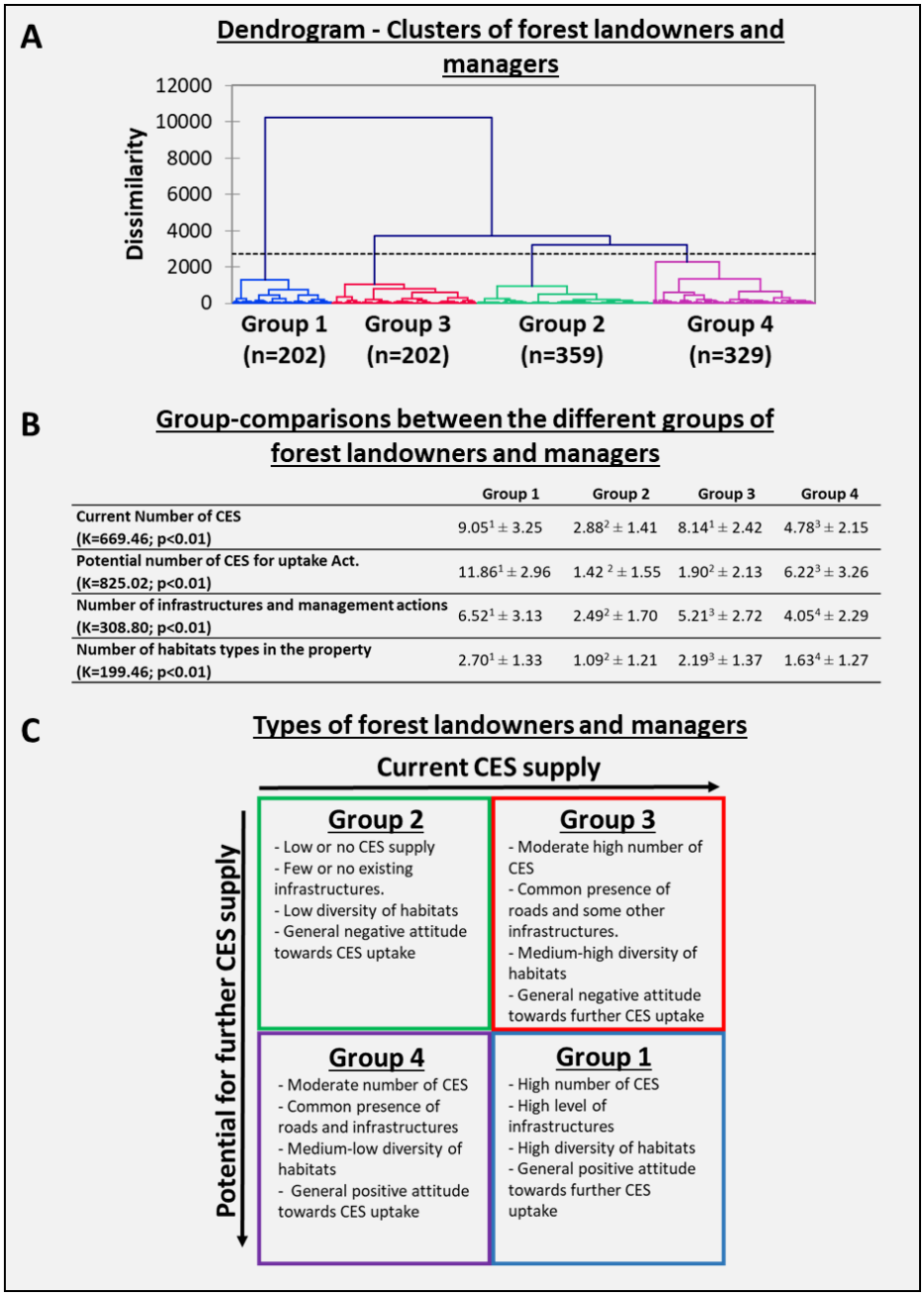
3.3.3. Grouping and characterizing forest owners and managers

The HCA based on the factor loadings from the explanatory factors from the PCAs on current and future CES supply classified forest owners and managers into four main groups (Fig. 24A). Kruskal-Wallis tests showed that these groups of forest owners significantly differ in the total number of CES used in the forests they own/manage, willingness towards future CES uses, the amount and types of infrastructures and management actions in place supporting CES and the number of different habitats present (Fig. 24B). Factors such as age of the respondents or country of origin had no influence.

Based on these results we classified European forest owners and managers in four different groups (Fig. 24C):

- *Group 1*: those owning or managing forests with multiple CES, where further CES supply could potentially take place in the future.
- *Group 2*: opposed to the first group, they own or manage forests with little or no CES supply, and are not open to further CES supply.

- *Group 3*: those that similarly to group 1 manage forests with multiple CES but are not open to further CES supply in future.
- *Group 4*: those that manage forests with little or no current CES supply, but are open to CES supply in the future.



	Group 1	Group 2	Group 3	Group 4
Current Number of CES (K=669.46; p<0.01)	$9.05^{1} \pm 3.25$	$2.88^{2} \pm 1.41$	$8.14^{1} \pm 2.42$	$4.78^{3} \pm 2.15$
Potential number of CES for uptake Act. (K=825.02; p<0.01)	$11.86^{1} \pm 2.96$	$1.42^{2} \pm 1.55$	$1.90^{2} \pm 2.13$	$6.22^{3} \pm 3.26$
Number of infrastructures and management actions (K=308.80; p<0.01)	$6.52^{1} \pm 3.13$	$2.49^{2} \pm 1.70$	$5.21^{3} \pm 2.72$	$4.05^{4} \pm 2.29$
Number of habitats types in the property (K=199.46; p<0.01)	$2.70^{1} \pm 1.33$	$1.09^{2} \pm 1.21$	$2.19^{3} \pm 1.37$	$1.63^{4} \pm 1.27$

Figure 24. Types of forest owners and managers. **A:** dendrogram grouping forest owners and managers in four main groups based on the CES taking place and the CES that could be further implemented. **B:** group-comparisons (kruskal-wallis tests) between the different groups of forest landowners and managers. For each variable, groups with significant different mean ($p<0.05$) have a different superscripted number. **C:** characterization of the four groups of forest landowners and managers

3.4. Discussion

3.4.1. Current state of CES supply in European forests

Our survey shows a rather heterogeneous picture in relation to CES in European forests, with a wide range of CES being harnessed in European forests, but also in relation to the facilities in place and management actions to support CES supply. European forests provide a high diversity of CES, with seven CES being supplied in more than 40% of the cases (hunting, wild products harvesting, research, farming, outdoor education, sports/exercise and aesthetic experiences). Especially abundant are those CES that either (1) besides their intrinsic and relational values, yield some material benefits and/or potential direct economic revenues. Among these CES, hunting stands out, but also wild products harvesting, beekeeping or farming (although farming likely takes place within the property out of the forest). (2) The second type of CES are those that comprehend important values in supporting local actors' personal attachment and cultural identity with the forests, and represent a relevant source for recreation, while adding complementary economic benefits. Our study also highlights the important role that forests are taking as place for recreation, while showing the increasing importance of forest for knowledge production (education and research).

However, if the picture of current CES supply is rather comprehensive, our data show that there is considerable space for further potential implementation given the appropriate incentives and conditions. That is especially relevant for those CES where willingness for future implementation exceeds their current supply. These are bird/nature watching, beekeeping, horseback riding, spiritual enrichment, provision of area for accommodation, artistic activities and recreational fishing. Most of these CES have in common that they require either making the forest more accessible to new users (bird/nature watching, spiritual enrichment) or specific knowledge that is not necessarily related to forestry activity (beekeeping, horseback riding, recreational fishing).

3.4.2. Synergies and trade-offs between CES

Our analysis allows us to discriminate forest owners and managers into two basic groups, those managing forests in which multiple CES are supplied and those where use is limited to a few or no CES supply (Fig. 24). We could therefore infer that CES supply tends to create positive associations among each other and co-occur. These results are consistent with other studies that show that CES are the ES category that generate more synergistic associations (Howe et al., 2014; Andersson et al., 2015). These synergistic dynamics of CES could be capitalized on, as potential policy instruments could target several FES at the same time while focusing on a limited number. Single policies that target one or few CES, have a high potential to additionally and simultaneously promote multiple non-material benefits from European forests.

Not all CES are fully complementary though we identified diverse trade-offs between CES that could enter into conflict with each other. While there is a bundle of CES that is jointly supplied (bird/nature watching, aesthetic appreciation, artistic activities, spiritual enrichment, and outdoor recreation), this bundle often enters in conflict with hunting, recreational fishing, farming or the provision of holiday homes. These all have in common that they are CES that limit access of the general public to some part of the land, which use is restricted permanently or temporarily for a single use of a small group of actors. These trade-off patterns were evident in the survey with multiple responses making a direct reference to the existing conflict between hunting and other CES, for example "*To me, because of the great movement of humans and animals (dogs), hunting and gamekeeping is totally impossible in many localities*" (forest owner from Czech Republic, male, 25-30 years). Another clear example was "*Mushroom picking, jogging, orienteering, biking, horse-back riding can enter into conflict with the hunting activities taking place on the estate. They also generally reduce the level of tranquillity of wild game in the forest and can even cause them to increase the damage done to certain forestry infrastructure (i.e. forest fencing)*" (forest owner from UK, male, 51-60 years).

Our analysis of the open questions in our survey suggest that this conflict is not exclusive to those CES that limit free access to the forest, but is often extended to those FES that sometimes require similar exclusion of part of the land (i.e. timber production, biodiversity conservation). This is consistent with findings from previous studies (Joshi and Arano 2009, Hendee and Flint 2014), indicating that forest owners and managers implementing an active management of the forest, focusing on timber extraction, have similar conflicts with some CES. In our survey, this position was clearly stated in some answers, like for example: "*High visitor numbers, illegal parking, environmental pollution, impossible to correctly protect the working area - people are increasingly ignoring the barriers, an increasingly varied use without asking and without consent (horse riding, cycling geocaching, motor biking, model airplanes, drones, mass snowshoeing events (tourist events etc.)*" (Forest owner from Austria, male, 41-50 years). These trade-offs indicate firstly, the need of transparent assessments on synergies and trade-offs among forest uses in Europe, as not everything can be done at the same time (Tyrväinen et al., 2017). Secondly, in order to promote CES uses, planning strategies should not only focus on forest operators, but also on the broader society and the way they engage with forests, especially in relation to recreation. Institutions have a large role to play in generating spaces and strategies that increase a common stewardship of the landscape (Peçanha Enqvist et al., 2018), which allow a multifunctional management of the forests that satisfies the needs and motivations of the different types of users and beneficiaries of the forest.

3.4.3. Different forest owners would require different engagement strategies

We identified four clearly differentiated groups in relation to their CES supply (Fig. 24). These groups also differ in how diverse are the habitats within the property they own or manage in addition to forest, and how integrated CES are in their forest management. Their views on CES are likely not casual. As has been identified in previous studies, what forest operators decide relates to multiple individual motivations, often shared in communities, of diverse nature (Hugosson and Ingemarson 2004; Bieling 2004; Steg et al., 2011; Sorice et al., 2014). Motivations driving management are related to context, such as lifestyle and socio-economic aspects (Joshi and Arano 2009; Howley 2013; Torralba et al., 2018a).

Our data strongly suggests that CES supply is currently relevant for a significant proportion of European forest owners, but there are substantial differences among them. This current demand should be actively embodied into the European forest policy agenda to accommodate their different views. However, we should also thoroughly explore what are the consequences of CES supply, not only in relation to the trade-offs and synergies CES generate (among them and in relation to other FES), but also on how compatible CES are with different management models, and how could they be articulated with existing and potential viable business models. Our results hint some challenges in relation to CES use and an active management of the forest (i.e. for timber extraction), but these results are not thorough enough to comprehensively understand them.

Considering this complexity, there is no blueprint or single strategy to promote CES supply in European forests. European forests encompass a heterogeneous social-ecological landscape, where forests depart from very dissimilar situations in relation to current CES supply, and forest operators hold diverging motivations towards similar issues. These differences are not only transnational but exist at a local scale too. Therefore, policy makers should go beyond simplistic measures and offer a flexible policy framework. Such framework should take into account the local social-ecological context and be able to incorporate multiple instruments that satisfy the changing and mixed context-related needs of all those forest operators interested in CES in a given landscape.

In consequence, we propose that, in order to promote CES effectively, such policy framework could be based on four strategies, covering the diverse needs of the four main types of forest owners. Each strategy would need to be composed by locally agreed upon policy measures (Fig. 25):

- Those forest operators departing from a negative situation, both in relation to current and future CES supply, would require a strategy focused on stimulation, aiming to kick-start CES use in the forest. Some mechanisms that would fit into

this strategy would be for example, seeking contracts and PES/Compensation payments in contexts where societal demand for CES is high, or information programs highlighting the synergistic effects of CES with other forest ecosystem services. By providing economic incentives for CES, policy support would appeal to forest actors who initially are not interested in CES but are attracted to economic benefits and long-term sustainability (Bouwma et al., 2018).

- In cases where current CES supply is low but the general attitude towards future CES supply is positive, strategies facilitating management that promotes CES would be appropriate. This would involve policy instruments such as the establishment of training and educational programs, or by lightening bureaucracy requirements. Example of a demand for such strategies were made explicit in the survey, for example: *"They could help (the authorities) by making planning instruments available, in general cutting red tape, support with contractual nature conservation, working on concepts that go beyond the farm, information or educating target groups."* (landowner from cluster 4, male, 31-40 years, Austria).
- For those forests where current CES supply is high but would not like to engage in more, the strategy should focus on maintaining the current situation. Policy instruments should focus on increasing political support and promote public recognition. As it was stated in the questionnaire by a forest owner belonging to this typology: "*We have been maintained for generations without help from people. A little recognition and respect would be welcome*" (landowner from cluster 3, male, <30 years, France).
- Finally, there are cases of forest operators who, managing a forest with high current CES supply, would like to positively further engage. This group would be the most appropriate for innovation strategies, with financial incentives to start-up innovative management and business models, and where new regulations and scientific advances could be tested.

In that light, market-based approaches such as payment for ecosystem services might not always be the primary solution for promoting CES supply in forests, but can be important in specific situations. Rather, approaches that promote other articulated values beyond instrumental ones might be just what in some cases is needed. Our study demonstrates the need for a tighter social network where communication is stimulated and each of the actors present in the landscape feel heard and valued. This explicitly arose in the respondents' answers, with several calls for enhanced listening (i.e.: "*listen to owners foresters expectations…*", forest owner from France, male, 41-50 years), recognition (i.e.: "*Explain to the public how much time it takes to manage our nature. And how fast you can destroy it*", Swedish forest owner, male, 51-60 years) and dialogue (i.e.: "*It can only be consensual agreements after a frank dialogue. Everything is possible ... with respect for people, property and therefore natural ecosystems*", forest owner from France, male, 61-70 years).

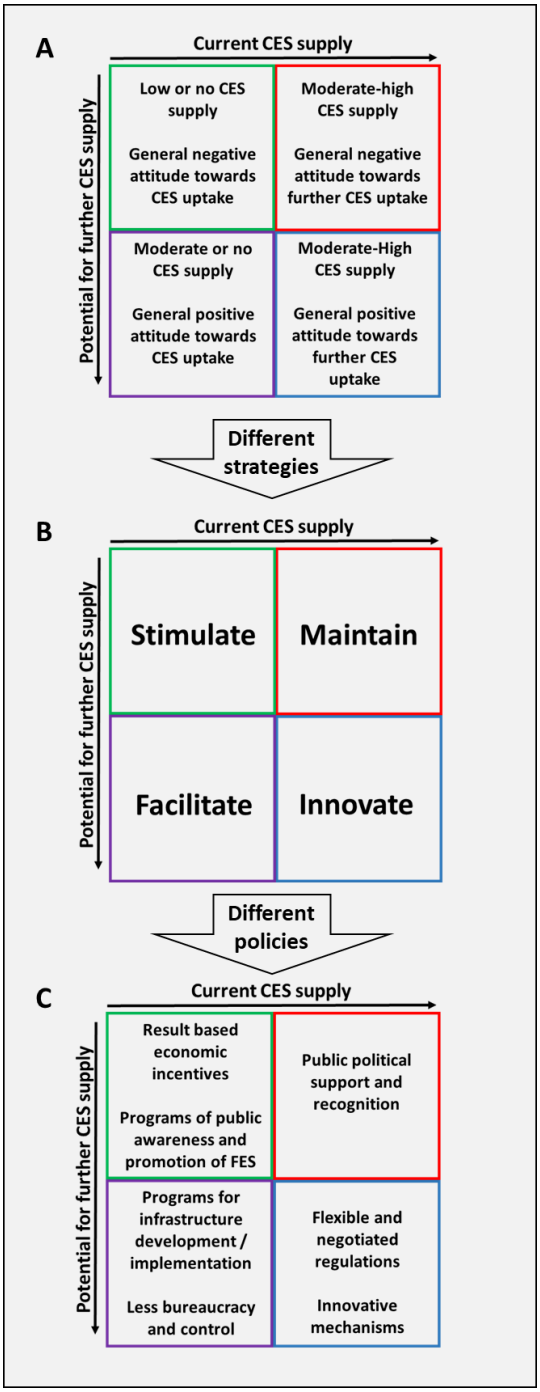


Figure 25. Different departing situations **(A)** would require different policy strategies **(B)** and policy mechanisms to promote CES supply in European forests **(C)**

3.4.4. Limitations of the study

This study provides a snapshot of the current state of CES supply in European forests. Naturally, results could be improved by increasing the number of respondents in some of those countries where participation was relatively low. Furthermore, our data might be biased towards those forest operators particularly engaged and interested in

promoting CES supply. In addition, some types of forest owners and managers might have been left out of the picture, especially those smallholders, who typically own a few hectares of forest but are not engaged in any management. The effect of those factors could have been elicited by including in our survey questions related to the property size, or to the economic benefits derived from each of the CES taking place in the property. Therefore, we must underline the exploratory nature of the analysis presented in this publication, and emphasize the need for further research looking into the above-mentioned factors. However, our results consistently cover a wide range of views on forest management despite these potential biases. This allows us to conclude that the identified four major groups of forest owners and managers are consistently present in Europe. Future efforts should refine our approach and look in more depth on the local and regional relevance and distribution of these groups, and on context-related factors determining forest owners and managers decisions.

3.4.5. Concluding remarks

This study provides a first exploration of the supply of CES in European forests. Our data strongly suggests that current and potential CES supply is relevant for a significant proportion of European forest owners, but there are substantial differences among them. This current demand should be actively embodied into the European forest policy agenda to accommodate their different views. However, we should also thoroughly explore what are the consequences of CES supply, not only in relation to the trade-offs and synergies CES generate (among them and in relation to other FES), but also on how compatible CES are with different management models, and how could they be articulated with existing and potential viable business models. Our results hint some challenges in relation to CES use and an active management of the forest (i.e. for timber extraction), but these results are not thorough enough to comprehensively understand them.

One major challenge would be to harmonize the general objective of promoting CES with the enormous diversity of local contexts. Given the (1) intrinsic heterogeneity of forests in Europe, with large gradients and stark contrasts in relation to landownership, property sizes, and contribution of forests outcomes in landowners' livelihoods; and (2) given the diverged social, economic and political trajectories that forest use had across Europe, the importance of considering local social-ecological contexts is crucial for having success in forests policies. Due to the multiplicity of actors playing a relevant role in CES uses in forests, it is highly recommendable to implement, on the one hand, multi-actor approaches that generate agreed upon and long-lasting solutions and, on the other hand, flexible policy frameworks that allow the use of multiple instruments and policies that satisfy heterogeneous needs.

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Appendix

Table S1. Chi-square test results for sub-samples with and without innovations - by country of respondents

DIFFERENCE IN OTHER VARIABLES	SIGNIFICANT DIFFERENCE ($p \leq 0.05$)		COUNT		SHARE	
			No innovation	Yes innovation	No innovation	Yes innovation
Public ownership by the State at national level	YES	$\chi2$ (df=1, N=1690) = 5.044, p = 0.025.	21	14	0.8%	1.7%
Public ownership by the State at sub-national (regional) level	YES	$\chi2$ (df=1, N=1690) = 3.854, p = 0.050.	35	19	1.4%	2.4%
Public ownership by local government (municipality or equivalent)	NO	$\chi2$ (df=1, N=1690) = 0.038, p = 0.845.	128	39	5.0%	4.8%
Private ownership by individual and family	YES	$\chi2$ (df=1, N=1690) = 16.842, p = 0.000.	1010	278	39.5%	34.4%
Private ownership by private business entity	YES	$\chi2$ (df=1, N=1690) = 4.733, p = 0.030.	57	29	2.2%	3.6%
Private ownership by private institution (e.g. church, foundation, etc.)	YES	$\chi2$ (df=1, N=1690) = 12.808, p = 0.000.	34	26	1.3%	3.2%
Owning and managing the forest	YES	$\chi2$ (df=1, N=1690) = 18.920, p = 0.000.	940	251	36.7%	31.1%
Owning the forest but not managing it	NO	$\chi2$ (df=1, N=1690) = 1.477, p = 0.224.	74	17	2.9%	2.1%
Managing the forest (but not owning it)	YES	$\chi2$ (df=1, N=1690) = 17.892, p = 0.000.	148	80	5.8%	9.9%
Responsible for certain segments of forest management (e.g. reforestation or sale of wood) but not owning it	YES	$\chi2$ (df=1, N=1690) = 7.119, p = 0.008.	113	54	4.4%	6.7%

Table S2. T-test for sub-samples with and without FES innovations, for supply and demand of FES

Group Statistics	INNOVATION	N	Mean	Std. Deviation	Std. Error Mean	DIFFERENCE in ES
Biomass wood for material use SUPPLY	Yes innovation	390	66.55	34.19	1.73	9.93
	No innovation	1203	56.62	37.36	1.08	
Biomass wood for material use is DEMAND	Yes innovation	360	64.47	32.39	1.71	9.12
	No innovation	1077	55.36	35.41	1.08	
Biomass wood for energy use SUPPLY	Yes innovation	376	58.11	33.14	1.71	6.33
	No innovation	1152	51.78	34.83	1.03	
Biomass wood for energy use DEMAND	Yes innovation	344	60.51	31.44	1.70	6.74
	No innovation	1022	53.78	33.84	1.06	
Game hunting SUPPLY	Yes innovation	359	60.95	36.31	1.92	5.31
	No innovation	1116	55.63	36.17	1.08	
Game hunting DEMAND	Yes innovation	338	56.54	33.69	1.83	9.75
	No innovation	1001	46.79	33.71	1.07	
Wild forest products SUPPLY	Yes innovation	351	40.60	35.93	1.92	4.70
	No innovation	1144	35.90	35.33	1.04	
Wild forest products DEMAND	Yes innovation	330	49.32	34.86	1.92	4.91
	No innovation	1003	44.41	35.42	1.12	
Provisioning SUPPLY	Yes innovation	405	55.75	27.31	1.36	6.53
	No innovation	1283	49.22	27.42	0.77	
Provisioning DEMAND	Yes innovation	392	57.31	26.73	1.35	7.53
	No innovation	1221	49.78	27.67	0.79	
Watershed protection SUPPLY	Yes innovation	349	64.03	34.89	1.87	8.78
	No innovation	1081	55.25	37.13	1.13	
Watershed protection DEMAND	Yes innovation	332	60.81	34.68	1.90	9.13
	No innovation	993	51.68	36.32	1.15	
Air quality regulation SUPPLY	Yes innovation	345	75.14	30.12	1.62	2.67

	No innovation	1063	72.47	31.68	0.97	
Air quality regulation DEMAND	Yes innovation	323	67.96	34.45	1.92	4.74
	No innovation	986	63.22	36.33	1.16	
Climate change mitigation SUPPLY	Yes innovation	364	81.65	24.26	1.27	4.26
	No innovation	1087	77.39	28.48	0.86	
Climate change mitigation DEMAND	Yes innovation	341	74.05	31.21	1.69	7.54
	No innovation	1028	66.50	35.03	1.09	
Habitat for plants and animals SUPPLY	Yes innovation	372	82.99	22.63	1.17	3.20
	No innovation	1126	79.79	24.14	0.72	
Living place for plants and animals DEMAND	Yes innovation	332	72.80	29.55	1.62	5.28
	No innovation	1023	67.51	31.62	0.99	
Regulating SUPPLY	Yes innovation	398	74.29	25.53	1.28	4.90
	No innovation	1256	69.39	27.21	0.77	
Regulating DEMAND	Yes innovation	382	67.22	28.81	1.47	5.93
	No innovation	1196	61.29	30.55	0.88	
Cultural emotional and spiritual values SUPPLY	Yes innovation	343	66.36	33.28	1.80	10.27
	No innovation	1043	56.09	36.66	1.14	
Cultural emotional and spiritual values DEMAND	Yes innovation	308	57.63	35.07	2.00	9.82
	No innovation	958	47.80	35.50	1.15	
Education eg basis for forest kindergartens schools SUPPLY	Yes innovation	346	47.50	35.95	1.93	13.16
	No innovation	1058	34.34	34.95	1.07	
Education eg basis for forest kindergartens DEMAND	Yes innovation	303	53.28	33.80	1.94	10.65
	No innovation	940	42.63	34.64	1.13	
Healthcare sports and outdoor recreation SUPPLY	Yes innovation	368	62.33	34.29	1.79	10.10
	No innovation	1072	52.23	37.41	1.14	
Healthcare sports and outdoor recreation DEMAND	Yes innovation	332	69.61	31.13	1.71	8.80
	No innovation	986	60.81	35.29	1.12	

Table S3. Detailed t-test for sub-samples with and without FES innovations, for supply and demand of FES

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower 95% CI	Lower 95% CI
Biomass wood for material use SUPPLY	Equal variances assumed	27.393	0	4.65	1591.00	0.00	9.93	2.13	5.74	14.11
	Equal variances not assumed			4.87	713.776	0	713.78	0.00	9.93	2.04
Biomass wood for material use is DEMAND	Equal variances assumed	23.142	0	4.32	1435.00	0.00	9.12	2.11	4.98	13.26
	Equal variances not assumed			4.51	667.632	0	667.63	0.00	9.12	2.02
Biomass wood for energy use SUPPLY	Equal variances assumed	10.003	0.002	3.10	1526.00	0.00	6.33	2.04	2.32	10.34
	Equal variances not assumed			3.17	665.811	0.002	665.81	0.00	6.33	1.99
Biomass wood for energy use DEMAND	Equal variances assumed	12.501	0	3.25	1364.00	0.00	6.74	2.07	2.67	10.81
	Equal variances not assumed			3.37	630.466	0.001	630.47	0.00	6.74	2.00
Game hunting SUPPLY	Equal variances assumed	0.803	0.37	2.42	1473.00	0.02	5.31	2.20	1.00	9.62
	Equal variances not assumed			2.41	603.371	0.016	603.37	0.02	5.31	2.20
Game hunting DEMAND	Equal variances assumed	1.213	0.271	4.60	1337.00	0.00	9.75	2.12	5.59	13.91
	Equal variances not assumed			4.60	581.071	0	581.07	0.00	9.75	2.12
Wild forest products SUPPLY	Equal variances assumed	1.211	0.271	2.17	1493.00	0.03	4.70	2.16	0.46	8.95
	Equal variances not assumed			2.15	573.071	0.032	573.07	0.03	4.70	2.18
Wild forest products DEMAND	Equal variances assumed	1.328	0.249	2.19	1331.00	0.03	4.91	2.24	0.51	9.30
	Equal variances not assumed			2.21	568.876	0.028	568.88	0.03	4.91	2.22
Provisioning SUPPLY	Equal variances assumed	0.193	0.661	4.18	1686.00	0.00	6.53	1.56	3.47	9.60
	Equal variances not assumed			4.19	680.389	0	680.39	0.00	6.53	1.56
Provisioning DEMAND	Equal variances assumed	2.242	0.135	4.72	1611.00	0.00	7.53	1.59	4.40	10.65
	Equal variances not assumed			4.81	680.421	0	680.42	0.00	7.53	1.57
Watershed protection SUPPLY	Equal variances assumed	18.237	0	3.89	1428.00	0.00	8.78	2.25	4.36	13.20
	Equal variances not assumed			4.02	622.171	0	622.17	0.00	8.78	2.18

Watershed protection DEMAND	Equal variances assumed	13.262	0	4.01	1323.00	0.00	9.13	2.28	4.67	13.60
	Equal variances not assumed			4.11	591.802	0	591.80	0.00	9.13	2.22
Air quality regulation SUPPLY	Equal variances assumed	1.838	0.175	1.38	1406.00	0.17	2.67	1.94	-1.14	6.47
	Equal variances not assumed			1.41	609.933	0.159	609.93	0.16	2.67	1.89
Air quality regulation DEMAND	Equal variances assumed	7.247	0.007	2.06	1307.00	0.04	4.74	2.30	0.22	9.25
	Equal variances not assumed			2.11	574.347	0.035	574.35	0.04	4.74	2.24
Climate change mitigation SUPPLY	Equal variances assumed	9.505	0.002	2.56	1449.00	0.01	4.26	1.66	0.99	7.52
	Equal variances not assumed			2.77	723.833	0.006	723.83	0.01	4.26	1.54
Climate change mitigation DEMAND	Equal variances assumed	18.62	0	3.54	1367.00	0.00	7.54	2.13	3.36	11.73
	Equal variances not assumed			3.75	646.203	0	646.20	0.00	7.54	2.01
Habitat for plants and animals SUPPLY	Equal variances assumed	1.566	0.211	2.25	1496.00	0.03	3.20	1.42	0.41	5.99
	Equal variances not assumed			2.32	671.124	0.02	671.12	0.02	3.20	1.38
Living place for plants and animals DEMAND	Equal variances assumed	4.062	0.044	2.69	1353.00	0.01	5.28	1.97	1.42	9.14
	Equal variances not assumed			2.78	596.019	0.006	596.02	0.01	5.28	1.90
Regulating SUPPLY	Equal variances assumed	3.672	0.055	3.18	1652.00	0.00	4.90	1.54	1.88	7.93
	Equal variances not assumed			3.28	705.357	0.001	705.36	0.00	4.90	1.49
Regulating DEMAND	Equal variances assumed	5.344	0.021	3.35	1576.00	0.00	5.93	1.77	2.46	9.41
	Equal variances not assumed			3.45	676.018	0.001	676.02	0.00	5.93	1.72
Cultural emotional and spiritual values SUPPLY	Equal variances assumed	25.65	0	4.60	1384.00	0.00	10.27	2.23	5.90	14.65
	Equal variances not assumed			4.83	636.2	0	636.20	0.00	10.27	2.13
Cultural emotional and spiritual values DEMAND	Equal variances assumed	2.884	0.09	4.24	1264.00	0.00	9.82	2.32	5.27	14.37
	Equal variances not assumed			4.26	524.244	0	524.24	0.00	9.82	2.30
Education eg basis for forest kindergartens schools SUPPLY	Equal variances assumed	2.931	0.087	6.04	1402.00	0.00	13.16	2.18	8.88	17.44
	Equal variances not assumed			5.95	573.328	0	573.33	0.00	13.16	2.21
Education eg basis for forest kindergartens DEMAND	Equal variances assumed	4.188	0.041	4.68	1241.00	0.00	10.65	2.27	6.19	15.12
	Equal variances not assumed			4.74	521.833	0	521.83	0.00	10.65	2.25
	Equal variances assumed	37.238	0	4.56	1438.00	0.00	10.10	2.21	5.75	14.44

Healthcare sports and outdoor recreationSUPPLY	Equal variances not assumed			4.76	688.619	0	688.62	0.00	10.10	2.12
Healthcare sports and outdoor recreationDEMAND	Equal variances assumed	26.195	0	4.04	1316.00	0.00	8.80	2.18	4.53	13.07
	Equal variances not assumed			4.30	639.111	0	639.11	0.00	8.80	2.05


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