Land Use Policy 134 (2023) 106935

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Probabilistic typology of private forest owners: A tool to target the development of new market for ecosystem services

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ARTICLE INFO

Keywords:
Clustering
Forest owner typologies
Individual need vs social demand
Gaussian mixture model
Nonindustrial private forest landowners (NIPF)
Payment for environmental services (PES)

ABSTRACT

Understanding how and why private forest owners manage their forests is the basis for efficient policy, and improperly targeting forest owners can lead to inefficiencies. Furthermore, new markets for ecosystem services have been proposed as a way to diversity private forest owner revenues and move forest management in a more sustainable direction. Based on a survey of 220 French private forest owners, we perform a cluster analysis to identify distinct groups of forest owners according to their stated behaviors. Owners were clustered based on their rating of statements derived from existing profiles as well as their rating of the importance of new markets and social recognition. We then test if our owner classifications are sufficient predictors of the valuation of a set of ecosystem services, explicitly comparing an individual's stated need for ecosystem services to their perceived social demand. Our results confirm previously reported forest owner typologies of European forest owners, and show that these typologies can meaningfully explain variation in ecosystem service demand. This is important as the preservation and production of ecosystem services are increasingly important components of forest management and policy.

1. Introduction

Understanding how and why private forest owners manage their forests is the basis for an efficient policy, particularly in the face of climate change and future social demand. Indeed, forest resources can be mobilized to pursue a variety of economic and non-economic purposes (Garcia et al., 2018; Masiero et al., 2019; Zhang and Stenger, 2015), and improperly targeting forest owners can lead to inefficiencies in forest policy (Malovrh et al., 2015). Take, for example, the implementation of a payments for ecosystem or environmental services (PES) scheme. Using financial incentives to encourage forest owner enrollment and compliance can be effective if forest owners are purely utilitarian and profit maximizing (Persson and Alpízar, 2013). However, if forest owners respond rather to social demand for environmental services, then including them in the program will result in a negative selection bias as they already provide what society demands (Engel et al., 2008; Persson and Alpízar, 2013). Indeed, the presence of forest owners with intrinsic motivations to provide socially demanded environmental services may not only lead to self-selection bias but also crowding out, as intrinsic motivations for providing environmental services may be crowded out by payments (Engel et al., 2008; Karsenty et al., 2017; Rode et al., 2015).

In this study, we characterize private forest owners according to their stated individual demand for ecosystem services, and their perceptions of society's demand for the same set of ecosystem services. Forests provide a wide range of services recognized by forest owners to benefit individuals and society. These include, for example, provisioning of timber, firewood, and harvest of other non-timber products, water protection, carbon storage, and recreational activities such as hiking, cycling, or fishing (Gatto et al., 2019). Some of these provide income (e.g., timber) or direct utility like hunting on owned land, while others can be considered as positive externalities that influence the utility of society in general (e.g., clean air and water or climate mitigation). Furthermore, the ecosystem service framework provides a multidimensional perspective of forestry that aligns with French forest policy, where the preservation and production of ecosystem services are important components of forest management (Ambroise et al., 2022). This includes habitat protection schemes proposed to owners with forests in Natura2000 zones, though uptake has been relatively limited (Hily et al., 2015).

New market mechanisms have been proposed to promote the provisioning of ecosystem services by users of forests or forest products

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https://doi.org/10.1016/j.landusepol.2023.106935
Received 27 October 2022; Received in revised form 2 October 2023; Accepted 3 October 2023
Available online 12 October 2023
0264-8377/

(consumers or firms). This includes joint forest owner-firm forest restoration projects (Martel et al., 2015), the development of a certification system for carbon storage projects (Grimault and Foucherot, 2019; Vallauri et al., 2021), i.e. the label Bas-Carbone, implementation of the Forest Stewardship Council's Ecosystem Services Procedure (Forest Stewardship Council, 2021), which facilitates payment for ecosystem services, or the organization of crowdfunding forest restoration projects by intermediary firms like Reforest'Action.[1] For the buyers of forest ecosystem services or intermediary firms, it is important to understand the sellers to better target individuals for new business opportunities or more sustainable management policies (Miina et al., 2023; Muttilainen and Vilko, 2022; Rouleau et al., 2016).

The goals of this study are first to relate owner- and property-specific characteristics to forest owner stated demand for a set of eight ecosystem services, as well as (separately) their perceived social demand for those services; second, to compare the associated variables of individual stated demand and perceived social demand – a practice that has seldom been done in the literature (Mann et al., 2022); and finally, to test whether independently classifying forest owners by their stated management practices contributes additional explanatory information to their demand. To accomplish the last, we perform a cluster analysis to identify distinct groups of forest owners (Deuffic et al., 2018; Favada et al., 2009; Ficko and Boncina, 2013; Hill and Lewicki, 2006; Kuuluvainen et al., 2014; Scrucca et al., 2016; Sotirov et al., 2015), and incorporate forest owner cluster as an explanatory variable in our analysis. Specifically, we apply the forest owner typologies or "meta-profiles" of Deuffic et al. (2018) and Sotirov et al. (2015), which are grounded in the field of political science to study the different factors that may alter forest owner behavior. In particular, Deuffic et al. (2018) is quite broad, encompassing twenty case studies across ten countries. Forest owner typology has long been used to sort behaviors and assess the diverse set of values and beliefs held by forest owners (Boon et al., 2004; Ficko and Boncina, 2013; Ficko et al., 2019; Ingemarson et al., 2006; Karppinen, 1998; Ross-Davis and Broussard, 2007; Sotirov et al., 2019; Sotirov et al., 2015; Urquhart and Courtney, 2011). However, how much (if any) of this information contributes to our understanding of how forest owners value ecosystem services remains an open question. We hypothesize that forest owner typologies can capture unobservable heterogeneities not identified by standard socio-demographic variables, and explain meaningful variation in private forest owners' stated demand (and perceived demand by society) for ecosystem services.

In the following section we describe our data collection and the statistical methods applied to the analyse the data. We then briefly present the results of the cluster analysis and characterize stated individual demand and perceived social demand for forest ecosystem services. The paper concludes with a discussion of the results and their applications for forest policy.

2. Methods

2.1. Study area

Our study was conducted in the Grand-Est region of France, which represents 12% of the forested area in the country (1.9 million ha). The region is the second largest with respect to harvested timber volume, with 7 million m^3 harvested in 2016 (DRAAF Grand-Est, 2018). Therein, the wood industry employs a total of 45,810 individuals and 11,420 companies, generating 2.7 billion euros added across all sectors in 2015 (Batto and Eichwald, 2019). Private forest owners hold 44% of the forested area in the Grand-Est (DRAAF Grand-Est, 2018), which is mainly composed of broadleaves (oak, common hornbeam, common beech), except in the Vosges mountains where coniferous tree species are common.

[1] www.reforestaction.com.

2.2. Survey design and implementation

The data are from a Web-based survey targeting private forest owners. The questionnaire was developed in collaboration with local stakeholders, in particular members of the French private forest extension service, the Centre Régional de la Propriété Forestière (CRPF). All property owners in our sample were private forest owners whose properties were located in the Grand-Est, though their residence may be outside the Grand-Est. Each belonged to the "Merlin" database, a CRPF database that registers owners with a sustainable management document. These include the Regulated Management Plan (*Règlement Type de Gestion* or RTG) and the Simple Management Plan (*Plan Simple de Gestion* or PSG). The RTG is a tool corresponding to the Code of Good Silviculture Practices (*Le Code des Bonne Pratiques Syvicoles* or CBPS), which is a technical forest management guide whose certification targets forest owners with less than 25 ha and involves a voluntary engagement of 10 years with some fiscal advantages. The RTG applies only to forests that are part of a cooperative or are managed by a forest expert. The PSG is a forest management plan and is mandatory for forests larger than 25 ha.

The questionnaire was administered with the Lime survey software on the INRAE survey platform. The questionnaire was first sent to a pilot sample of 100 people for testing. The invitation was then sent to the 784 remaining forest owners in our sample. The questionnaire was online from 23 April to 25 May 2020. After 27 days, a reminder was sent to all of the people on the initial mailing list, and 40 more owners responded afterward. On average, it took 26 minutes for respondents to complete the questionnaire. A total of 108 people started but did not finish the questionnaire. The number of completed questionnaires useable for our analyses was 220, giving us a response rate of 25%. This response rate is notably higher than previous surveys in France.[2] French forest owners are notoriously difficult to survey, with previous analyses reporting response rates of 3.5% in a postal survey Petucco et al. (2015) and 14% in Gadaud and Rambonilaza (2010). These low response rates are often attributed to the fact that many French forest owners own small properties and either do not engage in or engage in only limited forest management (Table S6, Supplemental Material C). However, we can also observe low response rates in Sweden, where typically forest owners possess larger properties. See, for example, response rates of 11.5% in surveys by Ouvrard et al. (2019) and Degnet et al. (2022).

2.3. Survey questions

The questionnaire included four sections. The first consisted of questions intended to identify forest owners' perceptions of their management practices based on their agreement with the forest owner typologies of Deuffic et al. (2018) (Table 1; Table S2, Supplemental Material C). We took the questions from Deuffic et al. (2018) and Sotirov et al. (2015) as inspiration when designing the questionnaire, intentionally using rather specific profile statements to emphasize the adhesion to or rejection of those statements. In addition, we also asked owners about their openness to new innovations and markets, and their desire for public recognition for their commitment to forest management. Respondents were asked to rate their agreement to each question on a 5-point Likert scale, ranging from strongly disagree to neutral to strongly agree.

Next, we asked forest owners to assess the demand for ecosystem services normally provided by French forests, both from their own

[2] We attribute our success to three factors. First, we took advantage of the Covid-19 confinement in France, sending the questionnaire during a lock-down when owners might have more time to answer. Second, we organized a lottery in partnership with a local forest equipment company to stimulate responses, i.e., 14 gift cards with a value between 25 and 200 euros. Finally, the invitation was issued via the CRPF, a channel of dissemination that the forest owners knew and trusted.

Table 1
Summary statistics of forest owner profile statements and ecosystem service demand.

Forest owner profile statement (response variable name)	*Mean (median)*	*St. Dev.*		
I am attentive to the expectations of the industry (*Industry*).	3.87 (4)	1.03		
The actions I could take in my forests will not make any significant difference in terms of outcomes (*No effect*).	2.66 (3)	1.38		
I am an independent producer of wood (fuel and/or timber) and I look after my forest in the same way as my predecessors (*Independent*).	3.24 (3)	1.4		
My role is to promote biodiversity or other amenities; wood production is only a secondary objective (*Biodiversity*).	3.1 (3)	1.41		
I want people to know about the work I do in the forest and/or my commitment (*Social recognition*).	3.84 (4)	1.13		
I am open to innovations and new markets (*New markets*).	4.34 (5)	0.84		
	Individual need		*Perceived social demand*	
Ecosystem service	*Mean (median)*	*St. Dev.*	*Mean (median)*	*St. Dev.*
Air and water purification	4.15 (5)	1.10	4.06 (4)	1.13
Beauty of the landscape	3.81 (4)	1.25	3.70 (4)	1.23
Climate change mitigation (e.g., carbon sequestration)	4.11 (5)	1.15	4.09 (4)	1.14
Cultural heritage	3.70 (4)	1.35	2.96 (3)	1.59
Gathering of non-timber forest products (berries, mushrooms, meat)	2.92 (3)	1.41	2.96 (3)	1.26
Providing habitat for wild plants and animals useful to us	3.92 (4)	1.17	3.71 (4)	1.24
Recreational activities	2.27 (2)	1.44	3.21 (3)	1.50
Timber production	4.18 (5)	1.11	3.61 (4)	1.17

perspective and what they believed that society demands. We used the classification of ecosystem services according to the Common International Classification of Ecosystem Services.[3] We selected eight ecosystem services based on initial consultations with stakeholders: the gathering of non-ligneous (non-timber forest) products, habitat for wild plants and animals useful to humans, climate change mitigation, air and water purification, cultural heritage, beauty of the landscape, recreational activities, and timber production. It has already been shown that forest owners' preferences for supplying ecosystem services depend on the service in question (Müller et al., 2020). In our case, we contrasted if forest owners assess their needs for ecosystem service provisioning differently than those perceived from society. More specifically, we asked forest owners, with reference to their own forest, to rate the need of each ecosystem service on a scale from 0 (no need) to 5 (an essential need). Similarly, forest owners were asked to rate society's demand for each ecosystem service from 0 (no demand) to 5 (a large demand).

Thirdly, forest owners were asked about their current management. This included if and who harvested timber on the property (family member, non-family/professional individual, logging operator), who is involved in making management decisions (solely the owner or if s/he is aided by a family member, non-family member/professional individual, expert, technician, logging contractor, or a cooperative), and if the property is certified as having a "code of good silviculture practices" (CBPS)[4] or Program for the Endorsement of Forest Certification (PEFC).

The final section identified the demographics and property-specific characteristics of forest owners, including owner age and gender, level of education, occupation, if the owner was the first forest owner in their family, how the property was acquired (purchased, inherited, or converted from agricultural land), and if the owner was involved in a forest network or program (such as Natura 2000, forest charter, or a rural development programs). In terms of forest-specific characteristics, we asked the size of the property, the number of plots, and the number of years owned.

For a detailed presentation of the survey in its entirety, see Josset et al. (2021). A translation of our questionnaire can be found in Supplemental Material A. Summary statistics for all survey variables can be found in Tables 1 and 2. Tables of their correlation coefficients can be found in Tables S3-S5 in Supplemental Material C. In an effort to be clear and transparent, note that our sample is likely to *not* be representative of the general Grand-Est population. For comparison, we present available

Table 2
Summary statistics of socio-demographic and property-specific variables.

Explanatory variable	Type	Frequency
Forest owner age*	categorical	
30–45 years		29
46–60 years		51
61–75 years		120
> 75 years		20
Education	categorical	
Less than a high school diploma		77
High school		23
Associate's or Bachelor's degree		33
Advanced degree		81
Employment[†]	categorical	
Employed		90
Retired		129
Size of the property	categorical	
0–4 ha		41
5–10 ha		32
11–25 ha		48
25–100 ha		61
> 100 ha		38
Number of plots owned	categorical	
1 plot		48
2 plots		27
3 plots		23
> 3 plots		122
Number of years owned	categorical	
< 5 years		22
5–9 years		66
10–20 years		38
> 20 years		94
Acquisition[þ]	binary	
Purchased		149
Purchased as part of a forestry group		18
Converted plantation		46
Inherited		132
By donation		23
Management plan in place	binary	180
Conservation or forest certification program	binary	119

* Age was originally coded with a "< 29 years" category. However, as we only had 1 observation, we merged this with the "30–45 years" category.
† A single individual reported to "never had worked". This observation was dropped from the analysis.
þ A forest owner may have acquired the forest in more than one way. Therefore, they were given the option to choose multiple answers to they acquired their forest.

3 https://cices.eu.

4 *Le Code des Bonnes Pratiques Sylvicoles* (CBPS) is a technical forest management guide. Certification targets forest owners with less than 25 ha and involves a voluntary engagement of 10 years with some fiscal advantages.

regional and national forest owner statistics in Table S6 in Supplemental Material C. Our sample is characterized by retired male forest owners aged 61–75 years old with larger properties, who have owned their property for greater than twenty years, and engage in more active management than the general population in the region (Agreste, 2012). France, in general, contains a large number of forest owners with small properties – there are more than two million forest owners with less than one hectare of forest (Le Jeannic et al., 2015) – who possess few plots and have owned their property for a greater than an extended period of time (>20 years). Forest owners in the Grand-Est are characterized by an even older population than our sample, and almost four times as many owners with small properties. However, we do feel that our sample is a relevant demographic for French forest policy. We believe that this population more actively manages their forest than the average forest owner, and – as owners in the Merlin database have already had contact with the CRPF – engaging them presents an opportunity to increase the survey response rate and initiate follow-up discussions. Therefore, when interpreting our results, keep in mind that our study considers a small subsample of the population that, while not necessarily representative of the average private forest owner, actively manages their forest and may be more responsive to policy than the typical forest owner.

2.4. Statistical analysis

First, we grouped forest owners based on their agreement with the forest owner profiles defined by Deuffic et al. (2018) (Table 1; Table S2, Supplemental Material C). To do so, we performed a cluster analysis using a finite mixture model (Fraley and Raftery, 2002; Hill and Lewicki, 2006; Scrucca et al., 2016), which is based only on the degree of self-identification with the forest owner profile questions independent from the socio-economic data. It estimates the probability of individual forest owners belonging to one or more groups (e.g., "soft clustering" or the idea that forest owners can simultaneously below to more than one group). We assume that owners belong to the group that has the highest probability of membership.[5]

We tested a suite of possible formulations and number of clusters, using Bayesian Information Criteria (BIC) and integrated complete-data likelihood (ICL) criteria to choose the best-fit cluster distribution and number of clusters. For an illustration of the method to group forest owners, we would direct the reader to Ficko and Boncina (2013). The cluster analysis was conducted in R 3.6.1 using the '*mclust*' package. A detailed description of the cluster analysis can be found in Supplemental Material B.

We then characterized forest owners' individual stated demand for ecosystem services and their perception of society's demand (separately) by their demographic and forest-specific factors. That is, we tried to understand what socio-demographic and forest-specific characteristics explain the weight that forest owners place on their individual needs for ecosystem services and perceived needs by society. Additionally, we tested the hypothesis that the owner classifications proposed by Deuffic et al. (2018) and Sotirov et al. (2015) are meaningful predictors of individual and societal needs for ecosystem services. In theory, each forest owner cluster captures unobservable information about owner behavior that is at least partly exogenous to their socio-demographic and forest-specific characteristics. Therefore, it could be a useful tool for explaining variation in the need for ecosystem services (among other stated preferences).

[5] Soft clustering has an advantage over "hard clustering" in that we do not make the strict assumption that forest owners can only belong to a single group. However, by assuming that an owner belongs to the group with the highest probability of membership, our method of soft clustering essentially functions as a hard clustering method. Our approach will be particularly advantageous in future studies where one explicitly considers forest owner uncertainty to participation in each group, which is discussed in more detail in the Discussion.

Specifically, we estimated statistical models on two sets of dependent variables: an individual's stated need for one of our eight ecosystem services separately, and their perceived social demand for those services. Our independent variables were the same for all analyses, and included forest owner age, education, employment status, size of the property, number of plots owned, number of years owned, how the property was acquired, whether a management plan was in place, whether the property was enrolled in a conservation or forest certification program, and the forest owner cluster.

Responses to the ecosystem services questions are clearly ordered. That is, there is an intrinsic scaling or natural ordering of preferences within the responses (e.g., "not needed" is less than "moderately needed", which is less than "very needed"). To account for this natural ordering of the data, we estimated an ordered logistic model of the form,

$$\begin{aligned} \Pr(y_{ij}=1|X_i) &= \Pr(\varepsilon_i \le u_1 - \beta' X_i) \\ \Pr(y_{ij}=2|X_i) &= \Pr(\varepsilon_i \le u_2 - \beta' X_i) - \Pr(\varepsilon_i \le u_1 - \beta' X_i) \\ &\vdots \\ \Pr(y_{ij}=r|X_i) &= \Pr(\varepsilon_i \le u_r - \beta' X_i) - \Pr(\varepsilon_i \le u_{r-1} - \beta' X_i) \end{aligned} \quad (1)$$

where y_{ij} is the probability of a ranked response of $r = 1, 2, \ldots, 5$ for each individual i and ecosystem service j. Each respondent can be thought of as having some level of utility or opinion associated with each ecosystem service, with the reported ranking of the response increasing as the utility or strength of opinion gained increases past a certain threshold or cutoff (Greene and Hensher, 2010; Train, 2009). The vector β_k is a vector of regression coefficients to be estimated, X_{ik} is a matrix of our independent variables (socio-demographic and forest-specific characteristics, owner cluster), and ε_i is the error term. The thresholds or cutoffs u_r mark the transitions from one alternative to another and are estimated in the model.

In the context of forestry, ordered logit models have been used to study owner willingness to harvest (Aguilar et al., 2014; Gruchy et al., 2012), risk aversion (Andersson, 2012), the probability of enrollment in carbon sequestration programs (Dickinson et al., 2012), and reasons for owning forest (Shanafelt et al., 2022), among others. We would direct the reader to Cameron and Trivedi (2005), Train (2009), and Greene and Hensher (2010) for detailed discussions on this type of model. All models were estimated in R 3.6.2 using the method of maximum likelihood with the '*ordinal*' package.

3. Results

It is worth reiterating that, when interpreting our results, our sample is likely not representative of the general population of forest owners in the Grand-Est, nor all of France (see the Methods section for details). Our study represents a fairly small subset of all forest owners who, given their inclusion in the Merlin database, are likely active managers of their forests and more responsive to public policy than the typical French private forest owner.

3.1. Forest owner profiles and clustering

Profile statements that elicited the highest median scores were: "I am attentive to the expectations of the industry"; "I am open to innovations and new markets"; and "I want people to know about the work I do in my forest and/or my involvement". In contrast, people tended to disagree with the notion that their actions would not make significant differences in terms of outcomes. We find the greatest amount of variation between forest owner responses regarding the effects of owner behavior on outcomes, the independence of the forest owner as a wood producer, the priority of biodiversity and other amenities over wood production.

Our analysis identified five clusters according to Bayesian Information Criterion (BIC) and integrated complete-data likelihood (ICL) model-fit criteria. Specifically, the clustering algorithm selected a Gaussian finite mixture model with so-called VEI parameterization for the within-group covariance structure (diagonal distribution, variable volume, and equal shape) (Scrucca et al., 2016). A comparison of different model formulations (alternative covariance specifications) and numbers of clusters is presented in Fig. S1 (Supplemental Material C). Following Deuffic et al. (2018), we categorize each of our clusters as:

"Passives" (k_1). Like the name implies, passives do not think that their actions impact forest outcomes, nor do they see themselves as independent wood producers (though they do prioritize biodiversity and other amenities over wood production). In comparison to the full sample, they are less attentive to the expectations of the industry, and less interested in social recognition or access to new markets. (37 individuals)

"Environmentalists" (k_2). Environmentalists declare that biodiversity and other amenities are more important than wood production, and that their actions have an impact in terms of outcomes. However, they still ask for social recognition, follow the expectations of the industry, and are interested in new markets and innovations. (60 individuals)

"Optimizers" (k_3). Individuals here consider industry expectations and wood production as important, and consequently place the least importance to biodiversity and other amenities compared to the

Table 3
Order logit results for an individual's value for ecosystem services.

	Ecosystem service							
Explanatory variable	CAW	CLIM	CUL	HAB	LAND	NTFP	REC	TIM
Owner age								
46 to 60 years | ≤ 45 years	-0.85	-0.54	-0.35	-1.21	-0.68	-0.85	-0.02	-0.08
61 to 75 years | ≤ 45 years	-0.23	-0.27	0.08	-0.62	0.10	-0.51	0.09	0.07
> 75 years | ≤ 45 years	-0.21	-0.17	0.80	-1.57	0.23	-0.72	-0.09	0.32
Education								
High school | < high school	1.09	1.16	0.02	0.76	0.85	0.70	-0.23	-0.92
University degree | < high school	-0.41	-0.36	-0.07	-0.01	-0.41	-0.90	0.41	0.02
Advanced degree | < high school	-0.15	0.28	-0.37	-0.56	-0.34	-0.19	0.10	0.24
Retired | Employed	-1.08	-0.47	-0.69	-0.66	-1.40	-0.89	0.20	-0.02
Forest size								
5 to 10 ha | < 5 ha	0.71	0.07	-0.65	0.43	-0.42	0.57	-1.26	-1.93
11 to 25 ha | < 5 ha	0.77	0.68	0.01	0.59	0.51	1.01	-0.12	-0.66
26 to 100 ha | < 5 ha	0.12	0.28	-0.07	0.40	0.54	0.50	-0.67	-0.58
> 100 ha | < 5 ha	0.78	1.09	-0.37	0.61	0.24	1.00	-0.96	-1.38
Number of plots								
2 plots | 1 plot	0.24	0.24	-0.07	0.18	0.22	0.60	-0.33	-1.08
3 plots | 1 plot	1.15	0.62	0.19	0.72	0.84	0.19	0.82	-0.60
> 3 plots | 1 plot	-0.67	-0.49	-0.54	-0.16	-0.70	0.18	-0.29	-0.28
Years owned								
5 to 9 years | < 5 years	0.26	0.43	1.18	0.38	0.30	-0.09	-0.08	1.59
10 to 20 years | < 5 years	0.36	0.78	0.95	0.72	0.64	-0.43	-0.49	1.25
> 20 years | < 5 years	0.82	0.73	1.56	0.70	0.59	0.20	-0.38	1.80
Acquisition type								
Purchase	-0.27	-0.52	-0.49	-0.68	-0.14	0.03	0.30	-0.52
Group purchase	-0.08	-0.29	-0.33	0.29	-0.16	-0.40	0.08	-0.59
Donation	0.20	-0.03	0.06	0.24	-0.60	-0.46	-0.32	-0.73
Conversion from agriculture	0.64	-0.33	-0.06	-0.04	0.51	0.20	-0.55	0.09
Inherited	0.34	-0.18	0.61	-0.37	0.65	0.10	-0.19	-0.91
Management plan	0.03	-0.47	0.03	-0.40	-0.01	-0.02	-0.19	-0.09
Certification	0.01	0.52	-0.42	0.22	-0.16	0.08	-0.19	0.62
Forest owner clusters								
Passives | Traditionalists	-1.60	-1.89	-0.95	-0.92	-0.05	-0.62	-0.48	-2.56
Environmentalists | Traditionalists	-1.01	-1.21	-0.42	-0.25	0.07	-0.71	0.33	-0.72
Optimizers | Traditionalists	-1.01	-0.58	-0.87	-0.17	-0.59	-1.10	-0.26	0.24
Satisfiers | Traditionalists	-1.79	-1.72	-0.92	-1.16	-0.41	-0.70	0.11	-1.49
Threshold coefficients								
0|1	-7.14	-6.57	-4.68	-6.37	-5.64	-4.25	-3.15	-7.13
1|2	-5.48	-5.85	-3.29	-5.37	-3.75	-2.79	-1.92	-6.55
2|3	-3.91	-3.82	-2.36	-4.19	-2.55	-1.55	-0.70	-4.68
3|4	-2.80	-2.81	-1.26	-2.78	-1.38	-0.27	0.61	-3.06
4|5	-1.35	-1.54	-0.05	-1.28	0.05	0.86	1.50	-1.65

The reference level for factor variables is given by the "|" symbol. Ecosystem services are air and water purification ("CAW"), climate regulation mitigation ("CLIM"), cultural heritage ("CUL"), habitat ("HAB"), landscape beauty ("LAND"), non-timber forest products ("NTFP"), recreation ("REC"), and timber ("TIM"). Statistically-significant variables at the ten percent level are highlighted in blue (if positively associated), red (if negatively associated), and grey (constants or intercepts).

average. While they do not see themselves as an independent or traditional wood producer, they are the most optimistic in terms of the impact of their management on outcomes. Optimizers seek greater social recognition than the mean, and are interested in new markets. (27 individuals)

"Traditionalists" (k_4). Traditionalists place the most emphasis on their predecessor's practices compared to the sample mean, while valuing social recognition. (31 individuals)

"Satisfiers" (k_5). Forest owners in this category are less interested in new markets than the sample average, see themselves as independent, and do not ask for social recognition at the same level as other clusters. Additionally, they are less convinced that their forest management has an impact on the state of the forest. (66 individuals)

A visual representation of the clusters can be found in Fig. S2 in Supplemental Material C. Table S7 gives the contributions of each axis in the clustering algorithm. Table S8 in Supplemental Material C presents the means and standard deviations of the forest owner profile questions by cluster. Overall, the results of our cluster analysis overlap with what we would expect from the correlations between the forest owner profile statements (Table S4, Supplemental Material C).

Our cluster analysis is in general agreement with the forest owner profiles found by Deuffic et al. (2018). While they identified four clusters

Table 4
Order logit results for the perceived social demand for ecosystem services.

	Ecosystem service							
Explanatory variable	CAW	CLIM	CUL	HAB	LAND	NTFP	REC	TIM
Owner age								
46 to 60 years | ≤ 45 years	−0.87	−0.33	−0.47	−1.06	−0.59	−1.21	−0.81	0.08
61 to 75 years | ≤ 45 years	−0.02	−0.15	0.10	−0.56	0.10	−0.76	0.08	−0.44
> 75 years | ≤ 45 years	−0.20	0.32	0.52	−1.38	−0.24	−1.11	−0.72	−0.18
Education								
High school | < high school	0.43	0.50	0.22	0.75	0.84	0.64	−0.54	−0.43
University degree | < high school	−0.26	−0.21	−0.27	−0.04	−0.04	−0.13	0.54	−0.51
Advanced degree | < high school	0.09	0.19	−0.28	−0.28	0.33	−0.01	0.41	0.09
Retired | Employed	−0.91	−0.55	−0.55	−0.57	−0.87	−0.55	−1.12	0.71
Forest size								
5 to 10 ha | < 5 ha	1.17	1.10	−0.65	0.72	0.01	0.35	0.39	−0.80
11 to 25 ha | < 5 ha	0.82	0.79	−0.19	0.59	0.44	0.67	0.35	−0.81
26 to 100 ha | < 5 ha	0.23	0.46	−0.10	0.31	0.68	0.53	0.65	−0.48
> 100 ha | < 5 ha	1.13	1.13	−0.32	0.69	0.47	0.39	−0.03	−0.93
Number of plots								
2 plots | 1 plot	−0.52	−0.40	0.17	−0.52	−0.50	−0.69	−0.62	−0.17
3 plots | 1 plot	−0.01	−0.04	0.36	0.07	0.10	−0.48	1.14	−0.13
> 3 plots | 1 plot	−0.36	−0.27	0.02	−0.26	−0.44	−0.54	−0.24	−0.08
Years owned								
5 to 9 years | < 5 years	−0.51	0.16	0.02	−0.01	−0.40	−0.72	0.01	0.39
10 to 20 years | < 5 years	0.27	0.23	0.00	0.15	0.43	−0.76	0.11	−0.15
> 20 years | < 5 years	−0.01	0.23	0.34	0.32	0.11	−0.26	−0.07	0.35
Acquisition type								
Purchase	0.01	−0.34	−0.06	0.09	−0.29	0.12	0.08	0.05
Group purchase	−0.05	−0.16	−0.36	0.34	0.21	0.63	−0.33	0.88
Donation	−0.60	−0.22	−0.07	−0.11	−0.81	−0.71	−0.28	−0.41
Conversion from agriculture	0.96	0.21	0.25	0.16	0.81	0.64	0.88	0.06
Inherited	0.77	0.22	0.58	0.09	0.90	0.57	0.49	−0.56
Management plan	0.45	0.73	0.29	0.53	0.48	0.43	0.49	−0.11
Certification	0.57	0.28	−0.61	0.04	−0.04	−0.08	0.12	−0.27
Forest owner clusters								
Passives | Traditionalists	−1.03	−1.33	−0.13	−0.55	−0.19	−0.16	−0.51	−0.53
Environmentalists |Traditionalists	−0.52	−0.82	−0.38	−0.16	−0.67	−0.44	0.27	−0.31
Optimizers | Traditionalists	−0.78	−0.71	−0.54	−1.11	−0.98	−0.76	0.32	−0.12
Satisfiers | Traditionalists	−0.89	−1.73	−0.49	−1.03	−0.78	−0.38	−0.28	−0.70
Threshold coefficients								
0|1	−5.60	−4.64	−3.46	−5.51	−4.74	−5.05	−2.90	−6.12
1|2	−3.77	−3.62	−1.85	−3.55	−3.46	−3.20	−1.68	−4.35
2|3	−2.28	−2.81	−1.08	−2.47	−1.88	−1.79	−0.81	−3.14
3|4	−1.12	−1.41	−0.18	−1.07	−0.74	−0.34	0.55	−1.58
4|5	0.30	0.02	0.77	0.16	0.91	1.18	1.63	−0.17

The reference level for factor variables is given by the "|" symbol. Ecosystem services are air and water purification ("CAW"), climate regulation mitigation ("CLIM"), cultural heritage ("CUL"), habitat ("HAB"), landscape beauty ("LAND"), non-timber forest products ("NTFP"), recreation ("REC"), and timber ("TIM"). Statistically-significant variables at the ten percent level are highlighted in blue (if positively associated), red (if negatively associated), and grey (constants or intercepts).

(excluding their 'multifunctionality' group), our 'satisfiers' group corresponds to a sub-profile of their 'traditionalists' cluster, confirming that it is indeed possible to reproduce the profiles of Sotirov et al. (2015) and Deuffic et al. (2018) for France.

3.2. Attitude toward ecosystem services

Tables 3 and 4 present the estimation results of the ordered logit models, assessing whether an individual's cluster can explain an individual's value for an ecosystem service (or their perceived perception of society's demand), controlling for socio-demographic and forest-specific factors, and forest owner clusters. Tables of the raw results including the standard deviations and p-values can be found in Supplemental Material C. For the cluster factor variables, we use the "Traditionalist" cluster as the reference base. Recall that we define a variable as statistically-significant at the ten percent level.

We find general agreement between an individual's value for ecosystem services and their perceived demand by society. That is, if a variable is statistically significant in both data sets, it has the same sign for that association. For example, compared to its baseline, forest owner age is negatively associated with clean air and water (CAW) from an individual's perspective and from the perceived perspective of society. However, with the exception of property acquisition, we find noticeably more statistically-significant associations with an individual's ecosystem service value dataset.

Specifically, we find that forest owner age is negatively associated with clean air and water (CAW), habitat (HAB), and non-timber forest products (NTFP) for both individuals and society, and negatively associated with recreation (REC) by society only. (It was not statistically-significant for individual demand for recreation.) For an individual's values, education is positively associated with climate regulation (CLIM) and landscape beauty (LAND), and negatively associated with HAB, NTFP, and timber production (TIM). Education was positively associated with perceived social valuation for LAND. Relative to being employed, retirement is negatively associated with an individual's value for CAW, LAND, and NTFP, and society's perceived demand for CAW, LAND, and REC.

For the individual, forest property size is positively associated with CLIM and NTFP, and negatively associated with REC and TIM. In contrast, for society, it is positively associated with CAW and CLIM, and negatively associated with TIM. The number of plots is negatively associated with LAND and TIM for the individual, and positively associated with REC for perceived societal demand. What is particularly interesting is that we see a quantitative break in the value of CAW for the individual. That is, owning three plots is negatively associated with CAW, but owning greater than three plots is positively associated. The number of years owned is positively associated with an individual's demand for cultural heritage (CUL) and TIM. It is not associated with any ecosystem service values for society.

Acquisition via purchase is negatively associated with an individual's value of HAB, and inheriting a property is positively associated with CUL and LAND and negatively associated with TIM. In terms of statistical significance, property acquisition well explains the perceived social demand for ecosystem services. Purchasing as a group is positively associated with TIM. By donation is negatively associated with LAND. Converting the property from agriculture is positively associated with CAW, LAND, NTFP, and REC. Finally, inheriting the property is positively associated with CAW, CUL, LAND, and NTFP, and negatively associated with TIM. Having a management plan in place or a forest certification showed no statistically-significant relationships with any individual's value for ecosystem services, except for a positive association between forest certification and TIM. However, for the perceived social demand, a management plan was positively associated with CLIM, and forest certification was positively associated with CAW and negatively associated with CUL.

Notably, our forest owner clusters are often statistically significant explanatory variables of both an individual's value and the perceived social demand for an ecosystem service. That is, they meaningfully contribute to explaining the variance in the data more than an analysis with just the socio-demographic variables alone (otherwise they would not be significant at all). Indeed, repeating the analysis without the clusters and evaluating model fit via pseudo log-likelihood and AIC criteria (which penalize extra parameters) confirms this claim. Compared to the baseline "Traditionalist" cluster, the "Passive" cluster is negatively associated with an individual's value for CAW, CLIM, CUL, HAB, and TIM; the "Environmentalists" cluster is negatively associated with CAW and CLIM; the "Optimizers" is negatively associated with NTFP; and the "Satisfiers" cluster is negatively associated with CAW, CLIM, CUL, HAB, and TIM. In terms of perceived social demand, the "Passives" cluster is negatively associated with CAW and CLIM; the "Optimizers" cluster is negatively associated with HAB and LAND; and the "Satisfiers" cluster is negatively associated with CAW, CLIM, HAB, and LAND. By calculating the marginal effects of our estimates, we can compare the magnitudes the associations of each cluster. The marginal effects for the clusters are presented in Table 5. What is particularly interesting is that all of the forest owner clusters – which again are based on statements of behavior – report lower demand for ecosystem services, individually and from society, than the traditionalist group. Similarly, differences in the magnitudes of the marginal effects, between clusters as well as individual demand versus societal, lead to interesting policy implications which will be discussed in the next section.

4. Discussion

Overall, we found that fewer variables were statistically significant in the analysis of perceived demand by society than the individual, suggesting that the demand from society does not depend on the forest owner but is more of an objective, exogenous factor on which forest owners largely agree on. That being said, we did find overlap between an individual's value of ecosystem services and those that they perceived to be demanded by society. We could interpret this trend as an indicator that, for our sample, forest owners are not so different from the general population in how they value ecosystem services provided by forests. Another interpretation is that respondents are justifying themselves by answering that society has the same demand as themselves. The latter interpretation is supported by the fact that effects of cluster membership are similar between forest owners' stated needs and their perceived demands by society. Indeed, statistically-significant correlations between an individual's value for ecosystem services and their perceived social demand are all positive (Table S5, Supplemental Material C). In a recent study, Mann et al. (2022) surveyed forest owners across Europe about their individual supply of ecosystem services and perceived demand for those services by society. They found a similar positive correlation between stated supply and perceived demand. It could be fruitful to ask if forest owners believe that their management for ecosystem services meets their perceived social demand for it, explicitly comparing stated supply with observed forest management practices.

In terms of the factors explaining how forest owners assess ecosystem services, our findings regarding an individual's value and perceived social value for ecosystem services are consistent with the overall literature (Amacher et al., 2003; Beach et al., 2005; Silver et al., 2015). Rather than walk through each variable point-by-point, we find that it is more efficient to highlight some of the key findings. We find that the way forest is acquired is important for owner perceptions of ecosystem services. If a forest is purchased, owners were less concerned about providing habitats; if inherited, cultural heritage and landscape beauty were important while timber was less important. This is in line with a recent study by Shanafelt et al. (2022), who showed that how a forest property was acquired mattered in determining private family forest owners' reasons for owning. They speculated that landowners who purchased property did so to acquire their property for specific reasons or values, which is in contrast to those who are given land as inheritance

Table 5
Marginal effects of forest owner clusters for ecosystem services.

	Ecosystem service							
Explanatory variable	**CAW**	**CLIM**	**CUL**	**HAB**	**LAND**	**NTFP**	**REC**	**TIM**
Individual's need for services								
Passives | Traditionalists	-0.098	-0.129	-0.048	-0.045				-0.191
Environmentalists | Traditionalists	-0.053	-0.071						
Optimizers | Traditionalists						-0.006		
Satisfiers | Traditionalists	-0.115	-0.114	-0.047	-0.062				-0.089
Perceived social demand								
Passives | Traditionalists	-0.061	-0.081						
Environmentalists | Traditionalists								
Optimizers | Traditionalists				-0.043	-0.038			
Satisfiers | Traditionalists	-0.051	-0.111		-0.039	-0.028			

We present only statistically-significant variables at the ten percent level. The reference level for factor variables is given by the "|" symbol. Ecosystem services are air and water purification ("CAW"), climate regulation mitigation ("CLIM"), cultural heritage ("CUL"), habitat ("HAB"), landscape beauty ("LAND"), non-timber forest products ("NTFP"), recreation ("REC"), and timber ("TIM")

or as a gift, who may be more indifferent to specific types of benefits. If the forest was owned for a long period of time, provision of timber was considered important. This may be linked to the long-time horizons of forest investment, though see Bolkesjø et al. (2007) and Kuuluvainen et al. (2014), who find no statistically-significant effect of ownership length on timber supply. Effects of education level were mixed. While we found that having a high school degree relative to no degree increased the value of provision of climate and landscape services all else equal, we found that owners with an advanced degree valued less the provision of wildlife habitat. This is a surprising result, as most studies show that concerns for biodiversity increase with education level (Mitani and Lindhjem, 2015). For example, Shanafelt et al. (2022) found that the importance of the protection of nature or biodiversity as a reason for owning a forest increases with education level.

We then showed that the forest owner cluster can be a meaningful explanatory variable for their demand for ecosystem services and their perceived demand by society. Many studies have classified forest owners based on their stated management behaviors (see below, for detailed examples), but we have gone a step further and illustrated that these classifications contain useful information not captured in socio-demographic data. Calculating the marginal effects allows us to compare the magnitudes of the associations of our clusters for each ecosystem service, which leads to some interesting interpretations for policy decisions. For example, compared to the "Traditionalist" group, members of the "Satisfiers" group are about two times less likely to demand clean air and water than those in the "Environmentalist" group. When providing a subsidy scheme or a PES contract with the objective to increase water or air quality, owner cluster may be an important factor in determining the likelihood of a forest owner buying into the scheme or contract and the payment demanded by the owner. Therefore, knowledge about different forest owner types and their distribution among the population serves to anticipate the impact of different policy measures. A logical next step would be to test explicitly whether the clusters can predict stated or real management behaviors. If the Sotirov et al. (2015) and Deuffic et al. (2018) profile questions - which are more qualitative self-identifier questions - can predict forest owner behavior, then they could become a powerful tool for researchers and policy makers. It may also be relevant to develop information campaigns targeting specific owner clusters. However, this will require, for example, in-depth interviews with owners from different clusters, which can reveal perceived possibilities and barriers for participating in new markets for ecosystem services (Muttilainen and Vilko, 2022).

By using the forest owner profiles defined by Sotirov et al. (2015) and Deuffic et al. (2018) to classify private forest owners in northeastern France, we successfully applied their approach to a new demographic. Other studies in the forestry literature tend to base their classifications of forest owners on management behaviors (Eggers et al., 2014; Favada et al., 2009; Ficko et al., 2019; Ingemarson et al., 2006; Kuuluvainen et al., 1996), categorizing individuals into "industrial" or "non-industrial" groups based on their harvesting practices (clear cut or mixed stand, single or multi-species plantations, etc.) (Newman and Wear, 1993). The Deuffic et al. (2018) approach has an advantage in that it does not require personal information or information regarding management decisions. It would be interesting to be able to relate an individual's cluster to owner-specific or forest-specific variables. Cluster analysis using the expectation-maximization (EM) algorithm is not limited to the forest owner profile questions (Dempster et al., 1977; Fraley and Raftery, 2002; Scrucca et al., 2016), and could incorporate other owner- and property-specific information gathered in the survey. However, doing so will increase the dimensionality of the cluster analysis, making its estimation and the resulting interpretation of the clusters difficult. We leave this for future work.

The clustering algorithm performs a method of "soft clustering", meaning that individuals are assigned a probability of being in each cluster rather than a firm this-or-that assignment (Dempster et al., 1977; Fraley and Raftery, 2002; Scrucca et al., 2016). We take a forest owner's cluster as the one having the highest probability. However, the model also reports the level of uncertainty of this grouping. According to self-categorization theory (Benjamin et al., 2010; Haslam et al., 2012), we would expect forest owners with a high level of uncertainty to be less attached to the norms and beliefs related to their assigned profiles. It has been shown that self-identity is an important factor when an agent is making an economic decision in general (Akerlof and Kranton, 2000), a decision related to pro-social attitudes (Bénabou and Tirole, 2006), or when implementing agri-environmental management (van Dijk et al., 2016). It would be interesting to focus on this uncertainty and relate it to forest owners' values for ecosystem services and the probability of engaging in certain management behaviors. Further investigation is warranted.

Though our sample of forest owners cannot be considered as representative for all forest owners in France, we believe that our results show for a relevant population of forest owners an openness to new markets and a consciousness about their role as suppliers of other services than timber. Thus, there is potential for governments and intermediary firms to develop new markets mechanisms for forest ecosystem services. We also found variation across forest owner types in their consideration of different ecosystem services. This is a finding that should be considered both by government agencies developing PES schemes and by companies acting as intermediaries between forest owners and beneficiaries (e.g., companies funding forest projects as part of their corporate environmental responsibility activities). For example, it may be advantageous to provide a bouquet of measures and forest projects from which forest owners can choose according to their preferences. The rather diverse population of new intermediary companies developed in France over the last decade may already reflect this. However, our study only considers the supply side, i.e., forest owners. While there is a relatively large literature on the demand for forest ecosystem services by the general population (see Frings et al., 2023 for examples), there is less information on the perspectives of companies on new markets for forest ecosystem services. This should be addressed in future research and could help forest owner associations to better guide their members in developing new markets for ecosystem services.

Funding

This work was supported by the NOBEL project “Novel business models and mechanisms for the sustainable supply of and payment for forest ecosystem services”, under the umbrella program ERA-NET Cofund ForestValue (Horizon 2020 research and innovation program grant agreement No. 773324/ANR-19-SUM2-0001-04). The UMR BETA was supported by a grant overseen by the French National Research Agency (ANR) as part of the “Investissements d’Avenir” program (ANR-11-LABX- 0002-01, Laboratory of Excellence ARBRE).

CRediT authorship contribution statement

Clement Josset: conceptualization, formal analysis, investigation, methodology, software, visualization, writing – original draft; **David W. Shanafelt:** formal analysis, methodology, software, visualization, writing – review and editing; **Jens Abildtrup:** conceptualization, investigation, supervision, writing – original draft, writing – review and editing; **Anne Stenger:** conceptualization, writing – review and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgements

We would like to thank two anonymous reviewers for their time and energy in improving our manuscript.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.landusepol.2023.106935.

References

Agreste, 2012. Enquête sur la structure de la forêt privée en 2012. In: Forêt, M. d. l. A. d. l. A. e. d. l., (Ed.).
Aguilar, F.X., Daniel, M., Cai, Z., 2014. Family-forest owners’ willingness to harvest sawlogs and woody biomass: The effect of price on social availability. Agric. Resour. Econ. Rev. 43, 279–299.
Akerlof, G.A., Kranton, R.E., 2000. Economics and identity. Q. J. Econ. 115, 715–753.
Amacher, G.S., Conway, M.C., Sullivan, J., 2003. Economic analyses of nonindustrial forest landowners: Is there anything left to study? J. For. Econ. 9, 137–164.
Ambroise, L., Abildtrup, J., Puelzl, H., 2022. Policy Analysis of Forest Ecosystem Services in France: From the National to the Regional Level. Environmental Policy and Governance Online Early,.
Andersson, M., 2012. Assessing non-industrial private forest owners’ attitudes to risk: Do owner and property characteristics matter? J. For. Econ. 18, 3–13.
Batto, V., Eichwald, A., 2019. La filière forêt-bois: 3% des salariés de la région et une plus forte implantation à l'est. Institut National de la Statistique et des Etudes Economiques (INSEE) de Grand-Est, Strasbourg.
Beach, R.H., Pattanayak, S.K., Yang, J.-C., Murray, B.C., Abt, R.C., 2005. Econometric studies of non-industrial private forest management: A review and synthesis. For. Policy Econ. 7, 261–281.
Bénabou, R., Tirole, J., 2006. Incentives and prosocial behavior. Am. Econ. Rev. 96, 1652–1678.
Benjamin, D.J., Choi, J.J., Strickland, A.J., 2010. Social identity and preferences. Am. Econ. Rev. 100, 1918–1928.
Bolkesjø, T.F., Solberg, B., Wangen, K.R., 2007. Heterogeneity in nonindustrial private roundwood supply: Lessons from a large panel of forest owners. J. For. Econ. 13, 7–28.
Boon, T.E., Meilby, H., Thorsen, B.J., 2004. An empirically based typology of private forest owners in Denmark: Improving communication between authorities and owners. Scand. J. For. Res. 19, 45–55.
Cameron, A.C., Trivedi, P.K., 2005. Microeconometrics: Methods and Applications. Cambridge University Press,, Cambridge, United Kingdom.
Degnet, M.B., Hansson, H., Hoogstra-Klein, M.A., Roos, A., 2022. The role of personal values and personality traits in environmental concern of non-industrial private forest owners in Sweden. For. Policy Econ. 141, 102767.
Dempster, A.P., Laird, N.M., Rubin, D.B., 1977. Maximum likelihood from incomplete data via the *EM* algorithm. J. R. Stat. Soc. Ser. B Methodol. 39, 1–38.
Deuffic, P., Sotirov, M., Arts, B., 2018. "Your policy, my rationale". How individual and structural drivers influence European forest owners’ decisions. Land Use Policy 79, 1024–1038.
Dickinson, B.J., Stevens, T.H., Markowski-Lindsay, M., Kittredge, D.B., 2012. Estimated participation in U.S. carbon sequestration programs: A study of NIPF landowners in Massachusetts. J. For. Econ. 18, 36–46.
DRAAF Grand-Est, 2018. La récolte de bois et l'activité des scieries en 2016. Direction Régionale de l'Alimentation, de l'Agriculture et de la Forêt (DRAAF), Chalons-en-Champagne.
Eggers, J., Lamas, T., Lind, T., Ohman, K., 2014. Factors influencing the choice of management strategy among small-scale private forest owners in Sweden. Forests 5, 1695–1716.
Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: An overview of the issues. Ecol. Econ. 65, 663–674.
Forest Stewardship Council, 2021. Ecosystem Services Procedure: Impact Demonstration and Market tools. Forest Stewardship Council AC,, Bonn, Germany.
Favada, I.M., Karppinen, H., Kuuluvainen, J., Mikkola, J., Stavness, C., 2009. Effects of timber prices, ownership objectives, and owner characteristics on timber supply. For. Sci. 55, 512–523.
Ficko, A., Boncina, A., 2013. Probabilistic typology of management decision making in private forest properties. For. Policy Econ. 27, 34–43.
Ficko, A., Lidestav, G., Dhubhain, A.N., Karppinen, H., Zivojinovic, I., Westin, K., 2019. European private forest owner topologies: A review of methods and use. For. Policy Econ. 99, 21–31.
Fraley, C., Raftery, A.E., 2002. Model-based clustering, discriminant analysis, and density estimation. J. Am. Stat. Assoc. 97, 611–631.
Frings, O., Abildtrup, J., Montagné-Huck, C., Gorel, S., Stenger, A., 2023. Do individual PES buyers care about additionality and free-riding? A choice experiment. Ecol. Econ. 213, 107944.
Gadaud, J., Rambonilaza, M., 2010. Amenity values and payment schemes for free recreation services from non-industrial private forest properties: A French case study. J. For. Econ. 16, 1–15.
Garcia, S., Abildtrup, J., Stenger, A., 2018. How does economic research contribute to the management of forest ecosystem services? Ann. For. Sci. 75, 53.
Gatto, P., Defrancesco, E., Mozzato, D., Pettenella, D., 2019. Are non-industrial private forest owners willing to deliver regulation ecosystem services? Insights from an alpine case. Eur. J. For. Res. 138, 639–651.
Greene, W.H., Hensher, D.A., 2010. Modeling Ordered Choices: A Primer. Cambridge University Press,, New York.
Grimault, J., Foucherot, C., 2019. Du projet Vocal au label Bas-Carbone: La certification de projets carbone en forêt française. European Union,.
Gruchy, S.R., Grebner, D.L., Munn, I.A., Joshi, O., Hussain, A., 2012. An assessment of nonindustrial private forest landowner willingness to harvest woody biomass in support of bioenergy production in Mississippi: A contingent rating approach. For. Policy Econ. 15, 140–145.
Haslam, S.A., Reicher, S.D., Reynolds, K.J., 2012. Identity, influence, and change: Rediscovering John Turner’s vision for social psychology. Br. J. Soc. Psychol. 51, 201–218.
Hill, T., Lewicki, P., 2006. Statistics: Methods and Applications: A Comprehensive Reference for Science, Industry, and Data Mining. StatSoft,, Tulsa, Oklahoma.
Hily, E., Garcia, S., Stenger, A., Tu, G., 2015. Assessing the cost-effectiveness of a biodiversity conservation policy: A bio-econometric analysis of Natura 2000 contracts in forest. Ecol. Econ. 119, 197–208.
Ingemarson, F., Lindhagen, A., Eriksson, L., 2006. A typology of small-scale private forest owners in Sweden. Scand. J. For. Res. 21, 249–259.
Josset, C., Abildtrup, J., Stenger, A., 2021. Enquête auprès des propriétaires forestiers privés dans le GrandEst: Comment valoriser les biens et les services fournis par sa forêt? Rapport NOBEL. Bureau d'Economie Théorétique et Appliquée (BETA). Nancy,, France.
Karppinen, H., 1998. Values and objectives of non-industrial private forest owners in Finland. Silva Fenn. 32.
Karsenty, A., Aubert, S., Brimont, L., Dutilly, C., Desbureaux, S., Ezzine de Blas, D., Le Velly, G., 2017. The economic and legal sides of additionality in payments for environmental services. Environ. Policy Gov. 27, 422–435.
Kuuluvainen, J., Karppinen, H., Ovaskainen, V., 1996. Landowner objectives and nonindustrial private timber supply. For. Sci. 42, 300–309.
Kuuluvainen, J., Karppinen, H., Hanninen, H., Uusivuori, J., 2014. Effects of gender and length of land tenure on timber supply in Finland. J. For. Econ. 20, 363–379.
Le Jeannic, F., Thivolle-Cazat, A., Guinard, L., 2015. La Forêt privée française en France métropolitaine: Structure, propriétaires et potentiel de production. Agreste Les. Doss. 30.

Malovrh, Š.P., Nonić, D., Glavonjić, P., Nedeljković, J., Avdibegović, M., Krč, J., 2015. Private forest owner typologies in Slovenia and Serbia: Targeting private forest owner groups for policy implementation. Small Scale For. 14, 423–440.

Mann, C., Loft, L., Hernandez-Morcillo, M., Primmer, E., Bussola, F., Falco, E., Geneletti, D., Dobrowolska, E., Grossmann, C.M., Bottaro, G., Schleyer, C., Kluvankova, T., Garcia, G., Lovric, M., Torralba, M., Plieninger, T., Winkel, G., 2022. Governance innovations for forest ecosystem service provision - Insights from an EU-wide survey. Ecosyst. Serv. 132, 282–295.

Martel, S., Casset, L., Gleizes, O., 2015. Forêt et carbone: comprendre, agir, valoriser: Programme CARBOFOP 2013-2015. Institut pour le Développement Forestier,, Paris, France.

Masiero, M., Pettenella, D., Boscolo, M., Barua, S.K., Animon, I., Matta, J.R., 2019. Valuing forest ecosystem services: A training manual for planners and project developers. Food and Agriculture Organization,, Rome, Italy.

Miina, J., Muttilainen, H., Vornanen, J., Vanhanen, H., 2023. Supply chain actors' perspectives concerning the cultivation of specialty wood-decay mushrooms in Finland. Forests 14, 134.

Mitani, Y., Lindhjem, H., 2015. Forest owners ' participation in voluntary biodiversity conservation: What does it take to forego forestry for eternity? Land Econ. 91, 235–251.

Müller, A., Olschewski, R., Unterberger, C., Knoke, T., 2020. The valuation of forest ecosystem services as a tool for management planning - A choice experiment. J. Environ. Manag. 271, 111008.

Muttilainen, H., Vilko, J., 2022. Heterogenising forest value production - Drivers and barriers of entering the non-wood forest products sector. Current Research in Environmental. Sustainability 4, 100141.

Newman, D.H., Wear, D.N., 1993. Production economics of private forestry: A comparison of industrial and nonindustrial forest owners. Am. J. Agric. Econ. 75, 674–684.

Ouvrard, B., Abildtrup, J., Bostedt, G., Stenger, A., 2019. Determinants of forest owners attitudes towards wood ash recycling in Sweden - Can the nutrient cycle be closed? Ecol. Econ. 164, 106293.

Persson, U.M., Alpízar, F., 2013. Conditional cash transfers and payments for environmental services - A conceptual framework for explaining and judging differences in outcomes. World Dev. 43, 124–137.

Petucco, C., Abildtrup, J., Stenger, A., 2015. Influences of nonindustrial private forest landowners' management priorities on the timber harvest decision: A case study in France. J. For. Econ. 21, 152–166.

Rode, J., Gómez-Baggethun, E., Krause, T., 2015. Motivation crowding by economic incentives in conservation policy: A review of the empirical evidence. Ecol. Econ. 117, 270–282.

Ross-Davis, A., Broussard, S., 2007. A typology of family forest owners in North Central Indiana. North. J. Appl. For. 24, 282–289.

Rouleau, M.D., Lind-Riehl, J.F., Smith, M.N., Mayer, A.L., 2016. Failure to communicate: Inefficiencies in voluntary incentive programs for private forest owners in Michigan. Forests 7, 199.

Scrucca, L., Fop, M., Murphy, T.B., Raftery, A.E., 2016. mclust 5: Clustering, classification and density estimation using Gaussian finite mixture models. R. J. 8, 289–317.

Shanafelt, D.W., Caputo, J., Abildtrup, J., Butler, B.J., 2022. If a tree falls, why do people care? An analysis of private family forest owners' reasons for owning forest in the United States National Woodland Owner Survey. Small-scale. Forestry 22, 303–321.

Silver, E.J., Leahy, J.E., Weiskittel, A.R., Noblet, C.L., Kittredge, D.B., 2015. An evidence-based review of timber harvesting behavior among private woodland owners. J. For. 113, 490–499.

Sotirov, M., Sallnäs, O., Eriksson, L.O., 2019. Forest owner behavioral models, policy changes, and forest management: An agent-based framework for studying the provision of forest ecosystem goods and services at the landscape level. For. Policy Econ. 103, 79–89.

Sotirov, M., Deuffic, P., Zivojinovic, I., Lidestav, G., Feliciano, D., Hujala, T., Lawrence, A., Weiss, G., 2015. United in diversity? Typology, objectives and socio-economic characteristics of public and private forest owners in Europe. Mid-term Proceedings of the COST Action FP1201 FACESMAP, 25–36.

Train, K.E., 2009. Discrete Choice Methods with Simulation. Cambridge University Press,, New York.

Urquhart, J., Courtney, P., 2011. Seeing the owner behind the trees: A typology of small-scale private woodland owners in England. For. Policy Econ. 13, 535–544.

Vallauri, D., Ollivier, L., Laurans, Y., 2021. Payer les forestiers pour services rendus? Principes pour des projets contribuant au stockage du carbone et à la conservation de la biodiversité. WWF France,, Paris.

Van Dijk, W.F.A., Lokhorst, A.M., Berendse, F., de Snoo, G.R., 2016. Factors underlying farmers' intentions to perform unsubsidized agri-environmental measures. Land Use Policy 59, 207–216.

Zhang, D., Stenger, A., 2015. Value and valuation of forest ecosystem services. J. Environ. Econ. Policy 4, 129–140.