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Private Forest Owner Typology Based on Post-Disturbance Behaviour in Slovenia

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Abstract: In recent years, Europe has experienced an unexpectedly high frequency of natural disturbances. Private forest owners (PFOs), who manage a significant proportion of European forests and have diverse objectives and approaches to forest management, play a crucial role in salvage logging. The aim of this study was to (i) categorise PFOs based on their forest management objectives, experience with regular forest management, and responses to natural disturbances, and (ii) propose policy implications for particular PFO groups to improve salvage logging operations and meet legal requirements. A survey was conducted among a random sample of PFOs whose forests were affected by natural disturbances (n = 547). The survey data were analysed using K-means cluster analysis, and three groups of PFOs were identified. The outsourcing-oriented managers (32%) responded most strongly to natural disturbances, with 96.0% carrying out salvage logging. This highly co-operative group often relies on forest contractors and demonstrates the highest commitment to performing forest management activities among the three groups. The self-reliant managers (42%) also responded strongly (92.6% carried out salvage logging) and are characterised by a strong preference for performing the work themselves. The group of less active managers (26%) included the highest proportion of PFOs who did not conduct salvage logging (19.0%) and those with no previous forest management experience (12.0%). Despite these differences, common policy instruments based on smart regulation principles are proposed to promote efficient salvage logging. The results may contribute to the holistic transformation of forest policy and management in response to the current challenges posed by large-scale natural disturbances.

Keywords: natural disturbances; salvage logging; private forest owners' behaviour responses; smart regulation principles; forest policy recommendations

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1. Introduction

Climate change and related natural disturbances have a profound impact on forests, leading to changes in forest structure, composition, and ecosystem dynamics [1]. A significant increase in forest disturbances was observed in 34 European countries between 1950 and 2019 [2], with the average volume of disturbed and salvaged timber amounting to around 44 million m^3 of wood per year. Wind was the most frequent disturbance agent, accounting for 46% of total damage, followed by fire (24%) and pest infestations (17%) [2]. In addition, in 2022, a record number of forest fires burned around 900,000 hectares of land

in Europe [3]. The increasing frequency and severity of natural disturbances pose major challenges for European forest ecosystems [4–6]. A common response to damaged forests is salvage logging, which is crucial for maintaining the economic value of the damaged wood and preventing insect outbreaks [7,8]. In recent years, the extent of salvage logging has increased significantly in Europe [9,10], particularly in Central Europe. An analysis of data from 17 European Union (EU) Member States [11], which together account for 76% of the total forest area of the EU-27, shows that the volume of salvage logging increased by 138% in 2018 compared to 2014, from 44.5 million m^3 to 106 million m^3. The share of salvage logging in the total harvest rose from 10.7% to 22.8% during this period. However, there are considerable differences between individual countries: in the Czech Republic, salvage logging accounted for as much as 90% of total logging in 2018, while in Sweden the share was only 3% [11]. This influx of damaged timber can lead to severe economic losses for PFOs due to declining timber quality and oversupply on the market [11–13].

In response to these challenges, the EU has adopted several strategies (e.g., the EU Strategy on Adaptation to Climate Change, the New EU Forest Strategy for 2030, the European Green Deal), policies and laws (e.g., the Nature Restoration law, the European Climate Law), and measures aimed at strengthening the resilience of forests and mitigating the impact of such events. Prior to the implementation of current EU forest strategies and national forest laws, forest policy in many EU countries was primarily focused on timber production and economic returns [14,15]. However, recent natural disturbances have shown the limits of implementing these policy goals, especially in countries where private forest ownership prevails. Therefore, at the EU and national level, policy goals have moved towards more proactive and resilient forest governance. A key focus is now on climate-resilient forest management [16], which aims to enhance forest health in the face of rising temperatures, changing hydrological conditions, storms, fires, and pest outbreaks. This approach integrates climate considerations into daily forest management through a long-term, adaptive framework designed to address uncertainty and dynamic environmental conditions [16,17].

One such approach is closer-to-nature forest management, which is promoted as a climate-resilient strategy in the New EU Forest Strategy for 2030 [18]. It emphasises natural processes in forest development and promotes structurally diverse and complex forest ecosystems that are more resilient to climatic stress. In 2023, the European Commission published guidelines on closer-to-nature forest management aimed at striking a balance between ecosystem services, biodiversity conservation, and climate resilience. The new EU Nature Restoration Law [19] aims to restore ecosystems, including forests, by addressing the effects of disturbances and strengthening resilience. The Proposal for a Regulation on Forest Monitoring proposed by the European Commission aims to create a comprehensive knowledge base on forests [20]. This initiative facilitates the collection and exchange of comparable forest data through Earth observation technologies and ground measurements, creating a robust system for monitoring and understanding the impacts of natural disturbances on forest ecosystems. By improving data availability and accuracy, this framework supports the early detection and risk assessment of disturbances, allowing policymakers and forest managers to implement timely and targeted interventions. As part of its broader efforts to address the increasing challenges posed by natural disturbances to forest ecosystems, the EU also recognises the crucial role of private forest owners (PFOs) in building forest resilience and ensuring sustainable management.

In the context of this study, we define PFOs as individuals, families, and associations that own forest land not belonging to the state, municipality, or other public institutions. Specifically, we refer to non-industrial PFOs, those whose primary activity is not industrial-scale forestry, but who generally own forests for personal, recreational, ecological, or

small-scale economic purposes. Ownership must be formally recognised, typically through a land register or an official document confirming the owner's legal rights to the forest. PFOs usually have the right to utilise, manage, and economically benefit from forest resources (e.g., timber and non-timber forest products), within the framework of national laws [21,22].

In the EU, 60.7% of forests are privately owned [21]. Understanding how and why PFOs manage their forests is fundamental for effective policy implementation, particularly in the context of increasing climate change impacts and the need for efficient post-disturbance forest management. Previous studies have indicated growing heterogeneity among PFOs over time (e.g., [23–25]). In addition, PFOs represent a diverse group in terms of their forest management goals, objectives, and their conceptualisation of forest management and responses to climate change impacts [26,27].

Typologies of PFOs based on cluster analysis are a widely used method for understanding differences between these heterogeneous groups [22,28–30]. Reviewing the literature, Ekström et al. [31] summarise that typologies provide insight into different decision domains of PFOs, including preferences of forest management styles, forest ownership objectives, and links between ownership objectives and policy preferences. As highlighted by Ficko et al. [32], typologies delineate subcategories of PFOs, allowing for a deeper understanding of forest ownership dynamics and how these influence private forest management [32,33]. To further deepen this understanding, Sotirov et al. [34] introduced behavioural models and linked them to meta-profiles of PFOs that help explain how their values and approaches interact with broader structural factors.

Slovenia is one of the EU countries with the highest proportion of forest cover and has been severely affected by large-scale natural disturbances in recent decades, including ice storms, bark beetle outbreaks, and windthrow [35–37]. The country's forests are predominantly temperate mixed forests, dominated by beech and spruce. Beech forests make up about 70% of the forest area. The forests are relatively well preserved, with a high proportion of mature stands (over 70%), reflecting close-to-nature forest management of the last 70 years [36,37].

In Slovenia, forest management is regulated by the Forest Act [38], which promotes sustainable, closer-to-nature and multifunctional forest management, regardless of ownership [39]. Forest policy was historically rooted in the principles of sustainable yield while ensuring public interest. After joining the EU in 2004, Slovenia gradually adapted its forest policy to EU standards. This included a shift towards biodiversity conservation and adaptation to climate-driven disturbances. Despite this, Slovenia's long history of PFO engagement in forest management makes it an ideal setting for exploring how typologies can explain behavioural and management responses to forest disturbances. PFOs in Slovenia are legally required to conduct salvage logging and remove damaged trees following natural disturbances in a timely manner (Article 29 in ref. [38]). PFOs usually receive an official notification from the Slovenia Forest Service when salvage logging is required. Non-compliance may lead to administrative measures or fines. In practise, however, compliance is influenced by various behavioural and structural factors. Many PFOs are older, have fragmented or inaccessible properties, or lack the resources or knowledge to organise timely salvage logging. And although the law clearly defines responsibilities, actual enforcement often depends on local conditions and the ability of forest professionals to work with PFOs [35].

Between 2014 and 2019, salvage logging accounted for more than 50% of total logging in Slovenia, reflecting the magnitude of these disturbances. In 2023, salvage logging accounted for 42% of total logging, amounting to 1.82 million cubic metres of timber [36]. Given that 77% of Slovenia's forests are privately owned and represent a typical European

private ownership structure [40], implementing effective post-disturbance forest management practices presents unique challenges. This context provides a valuable case study for examining PFO behaviour in response to natural disturbances.

In contrast to previous studies that have largely focused on PFO typologies in the context of regular forest management, classifying PFOs primarily based on their forest management objectives and approaches, there is a notable gap in understanding how these behavioural typologies influence responses to large-scale natural disturbances. This study contributes to the literature by providing a more comprehensive framework for understanding and incorporating the responses of PFOs to natural disturbances. The main aim of this study was to (i) classify PFOs based on their forest management objectives, experience with regular forest management, and responses to natural disturbances, and (ii) propose policy implications, based on smart regulation principles [41–43], targeting individual PFO groups in order to increase the share of completed salvage logging after natural disturbances and enable a faster response in line with legal requirements. Compared to regular management, disturbances force PFOs to react quickly, often demanding a substantial commitment of their resources. However, their behavioural responses are often shaped by their regular forest management approaches and decisions [26,44]. Therefore, our study builds on the behavioural theory underlying PFO decisions and motivations in managing their forests. This theoretical foundation enables us to identify different types of PFOs and propose more effective policy instruments for salvaging damaged forests based on their behavioural patterns. Understanding PFO post-disturbance behaviour and subsequent management responses can provide forest policy decision-makers with important insights for developing and adapting instruments to improve private forest management. Accordingly, this study addresses the following research question: How do different types of PFOs respond to natural disturbances and how are these responses shaped by their regular forest management behaviour? We hypothesise that PFOs can be meaningfully categorised into groups based on their management objectives and behavioural patterns, which in turn influence the likelihood and effectiveness of salvage logging operations.

2. Analytical Framework: Typologies and PFO Behavioural Response to Natural Disturbances

PFOs have always played an important role in supplying the forest industry with timber and in providing society with various ecosystem services and goods. As a result, numerous studies have attempted to describe PFO profiles, behaviours, and management responses, often with the intention of aligning forest policy instruments more effectively with their practices and needs. PFO management approaches and decision-making rationales are shaped by both individual behaviour (agent-based factors) and behavioural responses to external influences from policy, market, and public pressures (structural factors), while also accounting for ecological and bio-physical conditions [23,32]. In this study, post-disturbance behaviour refers to the actions and decision-making processes of PFOs after a natural disturbance, which includes the PFOs response to a disturbance.

Sotirov et al. [34] developed a framework to analyse three primary behavioural models of PFOs: homo economicus, homo sociologicus, and homo psychologicus, each representing different forest management approaches. The homo economicus model assumes that individuals act to maximize their material self-interest. PFOs make decisions aiming to optimize economic utility. Policy and market changes influence their behaviour primarily through financial incentives or disincentives, such as subsidies, taxes, or market demand shifts. The homo sociologicus model emphasizes the role of social norms, institutions, and traditions in shaping behaviour. Individuals conform to societal expectations and rules to maintain legitimacy and avoid exclusion. The homo psychologicus model highlights the

impact of perception, beliefs, and mental models on decision-making. PFOs interpret policy and market changes through the lens of their pre-existing values and knowledge. They adopt or resist management practices based on whether they align with their core beliefs. Building on these insights, various types of PFOs have been identified. For example, Deuffic et al. [45] identified five types of private and public forest owners across 10 European countries. According to Ficko et al. [32], PFOs generally fall into two to six profiles, with a wide range of labels used to describe their diverse management behaviours (124 labels were found). Matilainen and Lähdesmäki [24] were the first to explore diversity within the so-called "passive" PFO group and subdivided them into distinct subgroups. Their study found that more than one third of respondents were not passive at all. The second largest group was completely passive in terms of forestry activities, neither conducting nor planning any timber harvesting or management. The third group was passive in terms of timber sales but remained active in other forest management activities.

Theoretical frameworks and typologies that explain PFO behavioural responses offer valuable perspectives for understanding how different PFOs perceive and respond to natural disturbances in their forest management practices. As Stare et al. [46] note, a range of factors influence PFO decision-making after natural disturbances, resulting in two main post-disturbance strategies: implementing salvage logging or deciding to refrain from intervention altogether. Among those who opt for salvage logging, two further management strategies can be distinguished. The first is clearing, where all trees, both damaged and surviving, are removed. The second is salvaging, in which only damaged trees are removed, while some surviving and even dead trees are left standing [47,48]. PFOs behavioural responses to natural disturbances are shaped by a combination of socio-demographic characteristics, forest ownership characteristics, previous management experience, and market conditions. According to Stare et al. [46], two factors have the greatest influence on the implementation of salvage logging: previous experience with forest management and cooperation with forest service providers. PFOs who adopt more passive management strategies (do not conduct nor plan any timber harvesting or management) may allow for natural recovery, either for environmental reasons [8,49–51] or due to other motivations, including agent-based or structural factors [52].

Based on typologies, some studies have also aimed to propose appropriate combinations of policy instruments tailored to specific PFO types in order to increase policy effectiveness and implementation. These policy recommendations draw on various theoretical and analytical frameworks, including smart regulation principles [53], the persona method [28], or the Theory of Planned Behaviour [49].

3. Materials and Methods

3.1. Questionnaire Design and Data Collection

A stratified random sample of households across Slovenia was surveyed in March and April 2022. The questionnaire was designed to collect information on PFOs' socio-demographic characteristics (gender, age, occupation, education, size of place of residence), forest ownership structure (forest property size and the extent of damage to their forest property), current forest management practices (past management activities related to timber harvesting in the five years prior to the survey, use of forestry contractors), and forest management objectives, as well their responses to large-scale natural disturbances (whether they carried out salvage logging and cooperated with other PFOs in salvage logging). To ensure clarity and precision, the questionnaire was pre-tested and revised. The sample was drawn randomly within a stratified gross sample covering all households in Slovenia, with representativeness ensured by quotas based on age, region, and settlement type. Only households that reported owning forest were included in the analytical sample.

A total of 1515 households that were familiar with their property and had basic knowledge of forest management participated in the survey. The respondent was the person who owned or managed the forest.

For this study, only those PFOs whose forests had been affected by natural disturbances within the past ten years were included in the cluster analysis (n = 547). PFOs that had not been affected by natural disturbances were excluded to ensure that behavioural responses analysed in the study were directly relevant and comparable in the context of post-disturbance forest management. The number reflects only fully completed questionnaires, as cases with missing data were excluded to meet the requirements of K-means clustering, which requires complete datasets. A total of 65.5% of respondents affected by natural disturbances were included in the cluster analysis.

3.2. Cluster Analysis

Cluster analysis was carried out using IBM SPSS Statistics 29.0 [54]. Cluster analysis is a statistical method used to explore data and identify homogenous groups within a dataset. Twelve variables (listed in Table 1) were used as the basis of the typology selected based on theoretical relevance and relevant literature to capture a comprehensive profile of PFOs. Prior to conducting the cluster analysis, the variables were analysed for correlations, and no strong correlations were found among them. The K-means method was used to categorise the dataset into distinct groups or clusters based on similarities among the responses [32].

Table 1. Variables used as a basis for the K-means method.

Variables	Categories
Past management activity	1—Without experience 2—With experience
Hiring forestry contractors	1—No (without experience) 2—Yes (with experience)
PFO performance of salvage logging	1—Yes, in accordance with the salvage logging deadlines determined by the Slovenia Forest Service 2—Yes, but after the salvage logging deadlines determined by the Slovenia Forest Service 3—I did not perform the salvage logging
Cooperation of PFOs in salvage logging	1—Yes 2—No
Forests are a place of rest or recreation.	PFO agreement with the statements that define the management objectives and motives of their forest 1—I do not agree at all 2—I do not agree 3—I neither agree nor disagree 4—I agree 5—I completely agree
Forests are important for mitigating climate change.	
Forests are important for the preservation of biodiversity.	
Forests are sources of wood and other forest products for personal consumption.	
Forests are an important source of income through wood and other forest products.	
Forests are an investment for the future, serving as a financial reserve.	
Forests are spaces for the management of natural and cultural heritage.	
Forests are intended for tourist activities.	

To determine the optimal number of clusters for K-means clustering, we used a combination of methods to validate the solution. First, a two-step clustering procedure automatically suggested three clusters based on statistical criteria. This result was further supported by hierarchical clustering, where the dendrogram also indicated a three-cluster structure. Finally, the elbow method confirmed that the three-cluster solution was the most interpretable model with a balanced distribution of respondents across the clusters.

Once the clusters were formed, we used appropriate methods to test whether there were statistically significant differences between the identified groups across all the variables considered. For categorical variables (gender, occupation, education, size of place of residence, past management activity, use of forestry contractors, PFO performance of salvage logging, and cooperation of PFOs in salvage logging), the Chi-square test was used to analyse associations (statistical relationships) between clusters and categorical characteristics. This test determines whether the observed distributions of a given categorical variable differ significantly between groups. For continuous variables (forest property size, age, and all forest management objectives), either ANOVA or Welch's ANOVA was used to compare means and determine whether the mean values of the variables differed significantly between clusters. Post-hoc tests were then carried out for variables that showed significant differences between cluster groups. The choice of post hoc test depended on the type of initial analysis performed: Tukey's HSD and Bonferroni corrections were used for the standard ANOVA, while the Games–Howell test was used for Welch's ANOVA. For categorical variables, Fisher's exact test was used where appropriate; otherwise, Chi-square tests were performed to compare specific groups on a given variable.

3.3. Framework for Policy Instrument Development

The conceptual framework applied in this study establishes the links between PFO typologies, their behavioural and management responses to natural disturbances, and the development of policy instruments aimed at improving salvage logging operations based on smart regulation principles. This framework contributes to the holistic transformation of forest policy and management (Figure 1). This framework helps predict and explain patterns in the behavioural responses of PFOs and facilitates the development of targeted policy instruments that promote both salvage logging and climate-smart forest management.

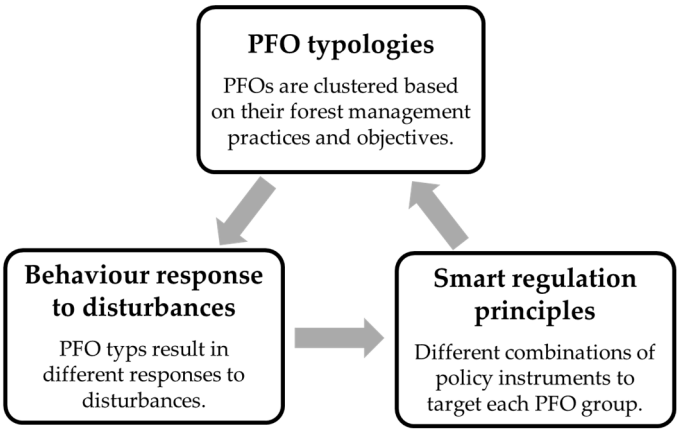


Figure 1. Conceptual framework of the study illustrating the interplay between PFO groups, their behavioural responses to disturbances, and smart regulation principles.

Smart regulation principles emphasise the use of a mix of regulatory, economic, and informational instruments, favouring a more collaborative and market-based approach over traditional top-down regulatory instruments. According to Van Gossum et al. [43], smart regulation principles are as follows: (1) avoid perverse effects of other policies, (2) prefer policy mixes incorporating a broad range of instruments, (3) prefer policy mixes incorporating a broad range of institutions, (4) develop or use new policy instruments when traditional instruments fail, (5) invoke motivational and informative instruments, (6) prefer less interventionist measures, (7) ascend a dynamic instrumental pyramid to

the extent necessary to achieve policy goals, and (8) maximise opportunities for win–win outcomes.

4. Results

4.1. Basic Information on Private Forest Owners

The sample represents PFOs whose forests were damaged by large-scale natural disturbances (e.g., forest fire, ice storms, windstorms, drought, bark beetle outbreaks) in the last ten years (2012–2021). The basic characteristics of the PFOs are presented in Table 2. The results show that the sample consists predominantly of male PFOs (60.1%). The average age of respondents is 53.6 years. Education levels are relatively evenly distributed, with 48.2% holding a bachelor's degree or higher and the remainder having completed high school or less. The majority are actively employed (55.9%), although the percentages of economically active and inactive individuals are relatively balanced. The average forest property size owned by respondents is 9.1 ha, with a median of 3.0 ha. Small forest properties (up to 5 ha) are the most common, comprising 58.7% of the sample. Regarding place of residence, 57.8% live in areas with fewer than 3000 inhabitants, 23.6% in areas with 3000–10,000 inhabitants, and 18.6% in areas with more than 10,000 inhabitants. On average, 24% of each PFO's total forest area was reported as damaged. The smallest reported damaged area was less than 1% of total forest area, and as many as 14.4% of PFOs reported that their entire forest area (100%) was damaged by large-scale natural disturbance. Additionally, 86% of PFOs reported that up to 50% their forest area had been affected. More than 80% of PFOs also carried out salvage logging within the mandatory deadlines, while 10.2% did so after the deadlines. However, 9.3% of PFOs did not carry out any salvage logging. PFOs exhibit varying levels of cooperation in salvage logging after natural disturbances. While 40.0% reported working with others (cooperation with other PFOs, forestry contractors, neighbourhood assistance, or a cooperative), 60.0% preferred to work independently or with the help of family members. Among those who did cooperate, most collaborated with forestry service providers, while a smaller proportion relied on neighbouring PFOs or other PFOs for assistance.

Table 2. Three groups of PFOs performing salvage logging after large-scale natural disturbances, compared to total sample characteristics.

		Total Sample	Group Outsourcing-Oriented Managers	Group Self-Reliant Managers	Group Less Active Managers	*p*-Value
Number of units		547	175	230	142	
Share (%)			32.0	42.0	26.0	
Basic characteristics of PFOs within groups						
Forest property size (ha)	Mean	9.1	13.9	7.0	6.9	0.011 *,1
	Std. deviation	19.7	27.5	15.5	12.6	
Gender (%)	Male	60.1	62.3	56.1	64.1	0.242 2
	Female	39.9	37.7	43.9	35.9	
Age (years)	Mean	53.6	55.9	52.9	51.7	0.018 *,1
	Std. Deviation	13.8	13.8	13.6	13.7	
Occupation (%)	Work inactive (housewife, student, unemployed, retired)	43.6	44.8	43.0	43.0	0.991 2
	Work active (employed, self-employed)	55.9	54.6	56.5	56.3	
	Insured as farmer	0.5	0.6	0.4	0.7	
Education (%)	Elementary school or less	3.5	3.5	4.8	1.4	0.010 *,2
	High school	48.3	37.4	53.9	52.8	
	Bachelor's education or more	48.2	59.2	41.2	45.8	
Size of place of residence (%)	<3000 inhabitants	57.8	46.3	63.3	62.0	0.003 *,2
	3000–10,000	23.6	27.4	21.3	22.5	
	>10,000 inhabitants	18.6	26.3	14.8	15.5	

Table 2. *Cont.*

		Total Sample	Group Outsourcing-Oriented Managers	Group Self-Reliant Managers	Group Less Active Managers	*p*-Value
Variables used as a basis for the typology						
Past management activity (%)	Without experience With experience	7.3 92.7	2.9 97.1	7.8 92.2	12.0 88.0	0.587 [2]
Hiring forestry contractors (%)	No Yes	61.1 38.9	7.4 92.6	87.0 13.0	85.2 14.8	<0.001 *,[2]
PFO performance of salvage logging (%)	Yes (within the deadlines) Yes (after deadlines) Do not perform	80.4 10.2 9.3	83.4 12.6 4.0	84.8 7.8 7.4	69.7 11.3 19.0	<0.001 *,[2]
Cooperation of PFOs in salvage logging (%)	Yes No, alone or with family help	40.0 60.0	94.3 5.7	10.9 89.1	20.4 79.6	<0.001 *,[2]
Forests are a place of rest or recreation.		4.0	4.1	4.3	3.6	0.010 *,[3]
Forests are important for mitigating climate change.		4.7	4.8	4.9	4.0	<0.010 *,[1]
Forests are important for the preservation of biodiversity.		4.6	4.7	4.9	3.9	<0.010 *,[1]
Forests are sources of wood and other forest products for personal consumption.		4.1	3.6	4.6	3.9	<0.010 *,[1]
Forests are an important source of income through wood and other forest products.		2.6	2.7	2.7	2.4	0.024 *,[1]
Forests are an investment for the future, serving as a financial reserve.		3.6	3.6	3.9	3.3	<0.010 *,[1]
Forests are spaces for the management of natural and cultural heritage.		4.4	4.5	4.8	3.8	<0.010 *,[1]
Forests are intended for tourist activities.		1.5	1.4	1.4	1.6	0.062 [3]

* $p < 0.05$; [1] Welch's test; [2] Pearson Chi-square test; [3] ANOVA test.

4.2. Cluster Analysis Results

Three groups of PFOs were identified in this study. These groups were named based on whether and how they carried out salvage logging (by hiring a service provider or by performing the work themselves) (Table 2). They are further described in terms of their basic socio-demographic characteristics, forest management experience, and forest management objectives. Despite their differences, all three groups considered mitigating climate change and preserving biodiversity to be the most important forest management objectives. Forest management objectives for each of the identified groups of PFOs are also graphically presented in boxplots (Appendix A, Figure A1).

Outsourcing-oriented managers represent 32.0% of the sample and are characterised by higher levels of education and larger average forest properties compared to the other clusters. These PFOs demonstrate a high behavioural responsiveness to natural disturbances, with 96.0% having completed salvage logging. However, they also have the highest proportion of salvage logging completed after the deadline (12.6%). This is not surprising, as this highly cooperative group frequently relies on forestry contractors for salvage logging and exhibits the highest level of forest management engagement among the clusters. In addition, this group has the highest average age among the clusters. What further distinguishes this cluster compared to others is that it has the highest proportion of owners living in settlements with more than 3000 inhabitants, with 53.7% falling into this category, including 26.3% who live in settlements with over 10,000 inhabitants. For this group, the most important forest management objective and motive was climate change mitigation.

The largest share of respondents (42.0%) belongs to the group of self-reliant managers. Compared to the outsourcing-oriented managers, this group is younger on average (52.9 years) and has the highest proportion of PFOs with only a primary school education among the three groups. Like outsourcing-oriented managers, these PFOs show a high behavioural response to natural disturbances, with 84.8% completing operations within the prescribed timeframe, and an additional 7.8% doing so after the deadline. This group is characterised

by a strong preference for carrying out forestry work themselves or with the help of family members, rarely hiring service providers. In contrast to the outsourcing-oriented managers, the PFOs in this group tend to live in smaller settlements. In total, 63.3% live in communities with fewer than 3000 inhabitants and only 14.8% in settlements with more than 10,000 inhabitants. Like the outsourcing-oriented managers, the self-reliant managers also ranked climate change mitigation as the most important objective of forest management, closely followed by biodiversity preservation and natural and cultural heritage management.

The smallest share of respondents belongs to the group of less active managers (26.0%), who tend to be the least active in forest management. Compared to the other two groups, this group includes the largest share of PFOs with no prior experience in forest management (12.0%), although this difference is not statistically significant. Additionally, this group consists of the largest percentage of PFOs who did not perform salvage logging after a natural disturbance (19.0%) and the smallest proportion who performed it within the required deadlines (69.7%). The less active managers have the smallest average forest property size (6.9 ha), although the difference is minimal compared to the self-reliant managers. With an average age of 51.7 years, they are also the youngest group of PFOs. Among the three groups, they have the lowest proportion of PFOs with only primary education (1.4%). The majority of them (62%) live in settlements with fewer than 3000 inhabitants. Their main forest management objective is also to mitigate climate change. However, what sets them apart from the other clusters is that they report significantly lower average values in terms of forest management objectives and motives compared to others.

The variables used to form the clusters proved to be statistically significant in most cases. Only two variables (out of 12) proved not significant: "management activity in the past" ($p = 0.587$) and "forests are intended for tourist activities" ($p = 0.062$) as a management objective. Post hoc tests conducted for the statistically significant variables (Appendix B, Tables A1 and A2) revealed significant differences between outsourcing-oriented managers and self-reliant managers in forest property size, education, size of place of residence, use of forestry contractors, cooperation of PFOs in salvage logging, and several forest management objectives: "forests are a place of rest or recreation", "forests are important in mitigating climate change", "forests as important for biodiversity conservation", "forests are a source of wood and other products for personal consumption", and "forests are spaces for natural and cultural heritage". When comparing outsourcing-oriented managers with less active managers, significant differences were found in all variables (Appendix B, Table A1) and across almost all forest management objectives, except for "forests are an important source of income through wood and other forest products" (Appendix B, Table A2). Fewer statistically significant differences were found between self-reliant managers and less active managers. Only two variables differed significantly: PFO performance of salvage logging and cooperation of PFOs in salvage logging. However, in terms of forest management objectives, significant differences were found across all categories.

4.3. Policy Instruments Developed for Different PFO Types

Building on the work of Stare et al. [55,56], who previously developed a mix of instruments to support the holistic redesign of forest policy and improve the effectiveness of salvage logging after natural disturbances, this study further refines and applies a combination of general and group-specific policy instruments tailored to the three identified PFO types (Figure 2). Rather than relying solely on strict regulatory enforcement, the approach adopted here integrates the principles of smart regulation by aligning interventions with the behavioural characteristics of each PFO group. General instruments are designed to

apply to all PFOs, while group-specific instruments are adapted to address the different motivational and management patterns observed within each group.

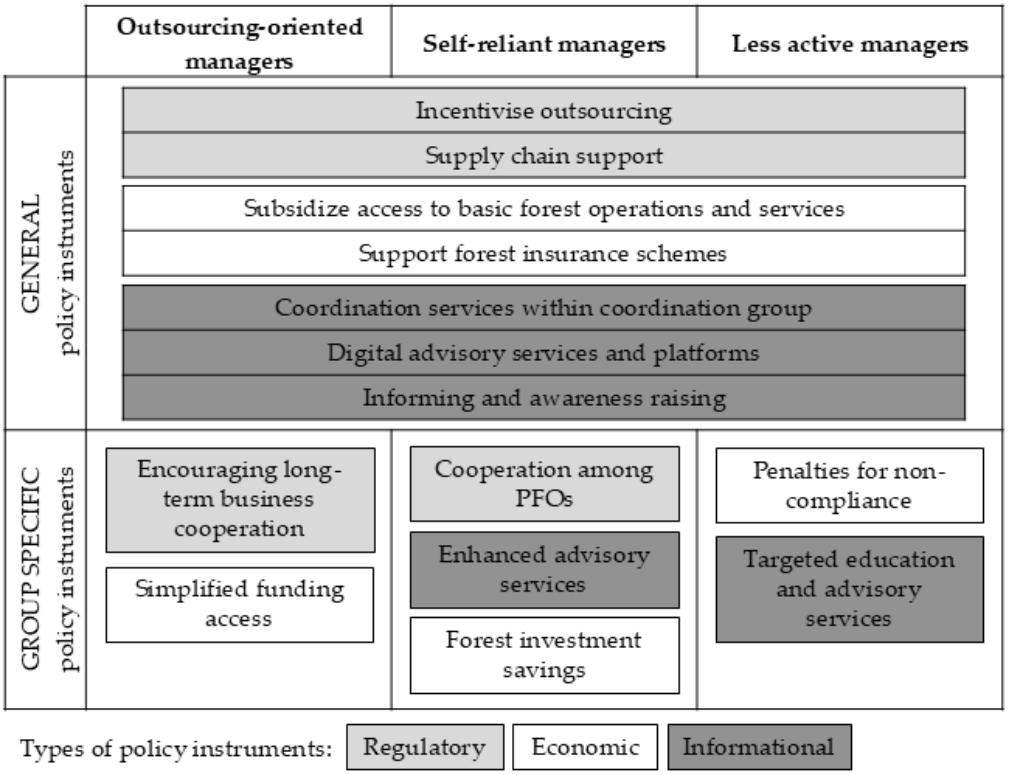


Figure 2. Application of policy instruments by integrating smart regulation principles in relation to three identified PFO types.

5. Discussion

5.1. Typology Based on Post-Disturbance Behaviour

This study builds on the well-established approach of clustering PFOs to capture the diversity of behavioural responses to salvage logging following natural disturbances. It identifies three distinct and relatively equally represented PFO groups: outsourcing-oriented managers, self-reliant managers, and less active managers, highlighting the pronounced heterogeneity among PFOs in their salvage logging responses.

A key difference between this typology and the identified groups and those in previous studies (e.g., review of PFO profiles [25]) is that none of the identified groups prioritise timber production as an important source of income as a forest management objective. Instead, all three groups prioritise environmental aspects, particularly the role of forests in mitigating climate change and preserving biodiversity. This is not surprising, as PFOs' personal experience with natural disturbances likely shapes their objectives, value orientations, and perceptions of the importance of various forest management strategies for climate change adaptation. Tiebel et al. [30] similarly note that most PFOs prioritise biodiversity conservation over resource use or income generation. This shift in forest management priorities can be attributed to the influence of natural disturbances, which have increased the awareness and importance of ecological values among PFOs, shifting their focus away from traditional economic objectives [57,58].

Another notable difference from previous typologies is that no passive or inactive PFO group was found, contrary to the findings in earlier studies (e.g., [34,45,59]), although there is a small percentage of less active PFOs within each group. Matilainen and Lähdesmäki [24] even reported an increasing proportion of passive or absent PFOs. The absence of a passive

group in this study could be attributed to the impact of natural disturbances, which may compel PFOs to become more actively involved in forest management. This pattern aligns with findings from other studies [48,58] which also found that disturbances have mobilized PFOs into more active engagement in post-disturbance forest management. In Slovenia, restoration is even prescribed in the Forest Act [38], which mandates that damaged forests be salvaged or restored within a specified deadline, with coercive measures applied if this is not met. This regulatory framework may explain why no passive PFO group was found.

The outsourcing-oriented managers consist of well-educated PFOs with larger-than-average forest properties. This group has the highest proportion of owners living in cities with more than 10,000 inhabitants, classifying them as urban PFOs. They have the highest overall completion rate for salvage logging operations, with only 4.0% failing to complete salvage logging. However, compared to the other groups, they are more likely to carry out salvage logging operations after the deadline, which is also related to the high proportion of PFOs living in urban areas and thus further away from their forest holdings. Their reliance on cooperation and outsourcing forest operations enables them to salvage their forests effectively. Outsourcing gives them access to expertise and technology that they may not possess by themselves, improving the quality and precision of forest management operations. However, outsourcing can also delay salvage logging, as natural disturbances often increase the workload, leading to frequent shortages of forestry contractors [48]. Although this group does not engage in timber production primarily for profit, their motivation for carrying out salvage logging can be explained by the legal obligations in Slovenia, which oblige PFOs to remove damaged trees within a certain timeframe [38]. Furthermore, this group valued the use of timber for personal needs relatively highly, suggesting that practical motivations also play an important role in their decision to act.

When comparing this group with those identified in previous studies, similarities emerge with the optimisers or economically oriented PFOs. As noted by Deuffic et al. [45], this type often consists of large PFOs whose forest management is primarily profit-oriented, though they do not ignore environmental concerns. They are more inclined to cooperate and hire services for forest work. To compare this type of PFO with the behavioural models [34], it most closely resembles the homo economicus, reflecting decisions based on efficiency, cost-effectiveness, and outcomes, with overall high completion rates for salvage logging despite some delays. The use of external contractors to compensate for their geographical and operational distance from the forest indicates a strategic approach to resource management characteristic of “optimisers” or “maximisers” [34,45].

The self-reliant managers demonstrate that direct involvement in forest management, even without major external cooperation, is just as important as working with external service providers to carry out salvage logging. The main distinction between this group and the others is their strict adherence to salvage logging deadlines and their direct, practical involvement in forest operations. These PFOs rely on family members and are the most responsive when it comes to completing salvage logging on time. The active involvement of families helps preserve traditional knowledge on forest management. The self-reliant managers represent the largest group in the sample, probably because their profile reflects the typical structure of private forest ownership in Slovenia and much of Central Europe (e.g., [22,33]). This is also reflected in the fact that they have similar characteristics to the traditionally oriented PFOs commonly identified in PFO typologies. In addition, the legal obligation for salvage logging in Slovenia might encourage the active engagement of PFOs who already tend to take personal responsibility for their forests. Their reluctance to hire service providers may also be due to a desire for autonomy, a cultural preference and a perception that hiring contractors is not cost effective for smaller operations, as already noted by Feliciano et al. [33]. They found that some PFOs prefer to avoid outsourcing

in small-scale forestry operations. Deuffic et al. [45], for example, describe this group as characterised by small or medium-sized forest properties. The main source of income for part-time PFOs is not from forest product sales but from other occupations. Their main goal is timber production, not to maximise profit, but rather to meet household needs and cover additional expenses. In their study, Sotirov et al. [34] also refer to a similar group as traditionalists, describing them as owners engaged in low-intensity logging, close-to-nature forestry based on family tradition and local knowledge, and responding to irregular demand. This behavioural logic largely corresponds to homo sociologicus, as their decisions are shaped less by financial incentives and more by social expectations and habits. Their behaviour is based on social norms, traditions, and family values, which are often embedded in intergenerational routines and maintained by a sense of duty.

Less active managers could also be compared to the traditional group, as they rely mainly on family help to carry out salvage logging. They represent the smallest group (26%) and exhibit a less proactive approach to forest management. This group is characterised by the lowest levels of past management activity and the lowest performance of salvage logging within prescribed deadlines. However, past management experience does not differ significantly from the other groups. Notably, they rank the lowest in forest management objectives and motives, making them the least engaged group in this study. A similar observation was made by Eriksson and Fries [23], who found that an overall lower focus on production-related knowledge and value priorities, together with a weaker identification with other PFOs, was also associated with inactivity in forest management. However, they are not passive PFOs in the traditional sense, as found in previous studies (e.g., [25]), as there is only a relatively low percentage (19.0%) of unrealised salvage logging in this group. As Matilainen and Lähdesmäki [24] point out, passive PFOs may still be active in ways that are not fully captured by conventional research perspectives. This group is more difficult to categorise within the behavioural models, but may reflect a form of homo psychologicus [34], where personal perceptions and mental models limit or delay active participation. Their lower level of active engagement does not necessarily indicate a conscious rejection of forest management, but rather a selective response to external incentives, filtered through existing values and beliefs. They are, therefore, not traditionally passive but may show a form of "cognitive disengagement" that is not easily changed by conventional policy or market measures. While the behavioural models of Sotirov et al. [34] provide a valuable theoretical basis, their practical application in forest management research faces certain limitations, including static typologies and a lack of spatially explicit data.

5.2. Policy Instruments in Relation to PFO Types

The design of proposed policy instruments builds on the findings of an empirical study on PFOs in Slovenia, which analysed a wide range of potential solutions—legal, political, economic, social, and technological, to overcome barriers to salvage logging [56]. This study provided a solid basis for the identification of group-specific instruments, which were then translated into targeted policy recommendations to improve the effectiveness of salvage logging after natural disturbances. In addition, experience from other EU countries [10,60] shows that the proposed instruments are not only conceptually sound but also feasible in practise, provided they are adapted to the national context and supported by strong stakeholder involvement.

The general forest policy instruments combine regulatory, economic, and informational instruments to ensure a resilient and adaptable framework. Regulatory instruments include the promotion of outsourcing, which enables PFOs to access professional support for salvage logging, and targeted supply chain support to ensure that timber from these

operations is efficiently absorbed by the market to avoid oversupply [48,61]. The supply chain should also be supported by ensuring that forest wood markets can absorb wood from salvage logging to reduce the burden on individual PFOs [48]. According to the eighth principle of smart regulation [43], supporting salvage logging through improved market integration and sustainable practises creates benefits for both PFOs and the environment. By easing the economic burden while promoting ecological resilience, these instruments aim to provide solutions that serve multiple interests simultaneously. Economic instruments include subsidising access to basic forestry activities and services to reduce operational burden, while support for forest insurance schemes improves financial security in the face of climate-related risks [62]. The proposal to support forest insurance schemes encourages the use of new and innovative policy instruments that take into account the changing circumstances and different profiles of PFOs, in line with the fourth principle of smart regulation [43].

Informational instruments include coordination services within organised coordination groups to strengthen collective responses [48], while digital advisory platforms provide accessible, up-to-date guidance. Information and awareness-raising remain key to empowering PFOs through knowledge transfer [23]. In addition, knowledge transfer helps PFOs better understand closer-to-nature forest management and select appropriate forest management approaches for climate change adaptation, which aligns with the fifth principle of smart regulation [43]. This supports behavioural change without strong regulatory pressure and is consistent with motivational approaches.

However, to increase responsiveness of PFOs, it is crucial to complement general policy instruments with more targeted, group-specific ones. The policy should allow for escalation where needed. This flexible scaling, from general support to tailored interventions, is in line with the seventh principle of smart regulation, the concept of the dynamic pyramid [43]. Studies suggest that tailoring instruments to specific types of PFOs helps policies to better reflect their values and motivations [63]. This reinforces the view that a one-size-fits-all approach is not sufficient. Instead, forest policy needs to address the different management objectives and the different priorities of forest owners [64].

Outsourcing-oriented managers who prefer to hire forest services and are less involved in everyday forest management would benefit from policy instruments that facilitate long-term business arrangements such as forest leasing or management contracts. The legal framework should support outsourcing, especially for salvage logging after natural disturbances. As Riguelle et al. [61] emphasise, outsourcing and coordinated logistics are crucial for an efficient crisis response and avoiding saturation of the timber market. Similarly, Sanginés De Cárcer et al. [48] emphasise the need for policy support to ensure that timber from salvage logging operations is effectively integrated into the supply chain to reduce the burden on individual PFOs. In addition, simplified access to EU and national funding can support PFOs in covering the costs of hiring professional contractors for salvage logging and other necessary operations. Pons et al. [64] advocate for the integration of funding mechanisms with evidence-based guidelines, stressing that financial tools when combined with ecological planning can help PFOs adopt less damaging, professional salvage logging practices. This policy orientation, which uses regulatory and economic instruments to create a favourable operational environment for outsourcing forest management operations, is in line with the second and eighth principles of smart regulation [43] and is particularly important given the current lack of emphasis on promoting win–win outcomes for both PFOs and service providers.

In contrast, self-reliant managers actively manage their forests and value independence in decision-making. For this group, policy instruments should focus on promoting financial resilience, for example, through instruments such as forest long-term investment savings.

As Nikinmaa et al. [62] noted, economic instruments tailored to the motivation and capacity of different types of PFOs are crucial for supporting climate adaptation while preserving the autonomy of PFOs. Voluntary cooperation between PFOs could be beneficial for pooling resources for salvaging damaged forests. Ikonen et al. [65] show that cooperation between PFOs can increase interest in landscape-level management and facilitate coordinated action, provided there are common goals and trust. Access to digital tools and real-time advisory services can further support post-disturbance management efficiency. Procedural knowledge and PFO confidence are key drivers of proactive management behaviour [23]. Tools that provide real-time market data on timber prices, forest contractors, and sustainable practises that support closer-to-nature forest management could, therefore, enable more efficient responses to disturbances. By enabling cooperation and financial security, the policy instruments are in line with the first principle of smart regulation [43], respecting the independence of this group without undermining their proactive engagement. In line with the third and fifth principles of smart regulation, the use of investment savings, digital platforms and advisory networks represents non-coercive instruments that increase salvage logging capacity.

Finally, less active managers tend to be the least proactive and need stronger support. For them, targeted education and information campaigns are important to raise awareness of the responsibilities and benefits of forest ownership. As several studies emphasize, tailored communication increases knowledge, confidence, and engagement among PFOs [43,62,65]. Penalties or third-party intervention may be necessary to ensure timely action, especially after natural disturbances [48,61]. Starting with educating and escalating to penalties or third-party intervention when necessary is in line with the seventh principle of smart regulation [43] and reflects a graduated response that only increases in intensity when milder interventions fail. In addition, the policy instruments are in line with the fourth and fifth principles: if conventional instruments are ineffective for this group, stronger interventions and awareness-raising efforts are justified. Education efforts aim to shift attitudes and foster a sense of responsibility, which is essential for achieving long-term behavioural change.

5.3. Methodological Challenges and Future Research

Some limitations in the use of cluster analysis have already been recognised [32]. Typology formation methods affect typology outcomes, introducing a degree of subjectivity in their creation. It is essential to clearly communicate these methodological choices to ensure accurate interpretation of results. Using the same dataset of PFOs, different methods can highlight different aspects of PFO characteristics, as visualised in Ekström et al. [31]. Ficko et al. [32] have criticised the use of cluster analysis, a challenge we address by applying a method tailored for relatively rare classifications, specifically in the context of PFO behavioural responses after natural disturbances. While this approach differs from those commonly used in European studies on PFOs [45,59,66], this may limit the direct comparability of the results. In addition, we deliberately limited the selection of variables for data collection and subsequent analysis, following general research recommendations [32]. It is also important to acknowledge that passive PFOs and those with very small holdings (e.g., <1 ha), which often do not participate in forestry research, tend to be under-represented in such surveys. As a result, this silent segment of PFOs, who are often the least active and least involved in institutional structures, may remain invisible in typology-based analyses.

Typologies should help policy decision-makers to develop a deeper understanding of existing groups [20]. In research, forest policy instruments have been adapted to different groups of PFOs, as policies are among the most important factors influencing PFO decision-making [45]. Ficko et al. [32] raise an important question about whether typology studies

should provide specific policy recommendations for each type of PFO in order to be more useful. However, some existing studies suggest that policy decision-makers may be better served by focusing on designing or improving policy instruments that are compatible with a variety of ownership objectives and management approaches [63]. Nevertheless, an examination of the effectiveness of policy instruments as a means of pursuing and implementing a policy to salvage logging is certainly needed. This research approach could also serve as a basis for future research by investigating how PFOs relate to and identify with the proposed instruments. Furthermore, tracking the evolution of PFO clusters over time could provide insights into changing patterns of behaviour and support the ongoing adaptation of policy instruments to ensure their continued relevance and impact.

6. Conclusions

This study shows how typologies can improve our understanding of the behavioural responses of PFOs to natural disturbances. In contrast to previous studies that often focused on economic motives, our findings reveal a shift toward environmental forest management objectives such as biodiversity conservation and climate change mitigation. This shift may reflect both increased ecological awareness following natural disturbances and the influence of national regulations that prescribe timely salvage logging.

We identified three groups of PFOs: outsourcing-oriented, self-reliant, and less active managers. These groups illustrate the heterogeneity of PFOs and highlight their different management approaches after natural disturbances. The outsourcing-oriented managers rely on service providers for salvage logging and often experience delays due to a shortage of forestry contractors. Self-reliant managers take a hands-on approach, actively managing their forests and adhering to salvage logging deadlines. Less active managers, on the other hand, exhibit a lower level of management activity, making them the least involved compared to the other groups.

A flexible policy mix based on smart regulation principles is proposed, tailored to the different management approaches and characteristics of PFOs. General policy instruments combine regulatory, economic, and informational instruments. Customised policy instruments address the different needs of three groups of PFOs: outsourcing-oriented managers benefit from long term business cooperation and funding; self-reliant managers need support through cooperation incentives, investment savings, and advisory services; and less active managers need targeted education and, if necessary, penalties for non-compliance. Future research should examine how these clusters evolve over time and refine policy instruments to better align with the different objectives of PFOs to ensure more effective and sustainable forest management outcomes.

Author Contributions: Conceptualization, D.S., M.T. and Š.P.M.; methodology, D.S., M.T. and Š.P.M.; formal analysis, D.S. and Z.U.; data curation, D.S. and Š.Š.; writing—original draft preparation, D.S., Z.U., M.T., Š.Š., N.K. and Š.P.M.; writing—review and editing, D.S., Z.U., M.T., Š.Š., N.K. and Š.P.M.; funding acquisition, N.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Appendix A

The forest management objectives of all PFOs and each identified group of PFOs are illustrated using boxplots.

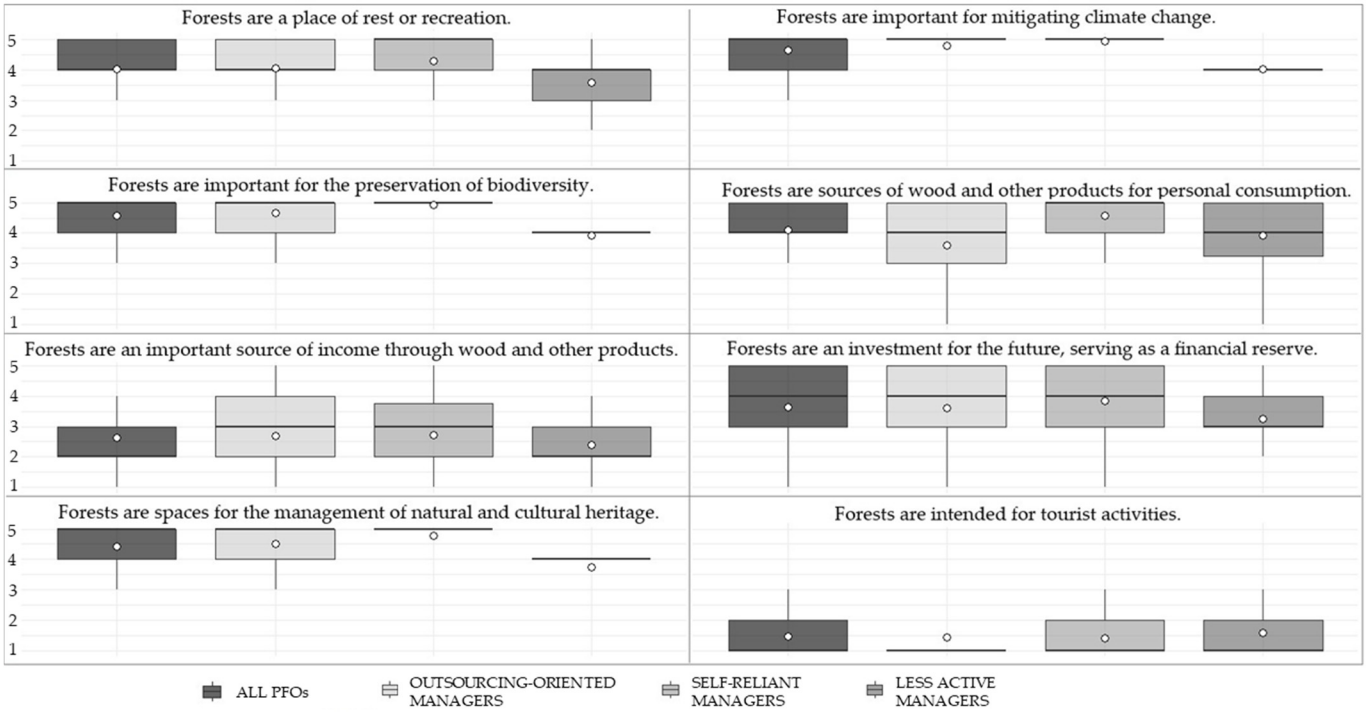


Figure A1. Graphical distribution of data in boxplots for forest management objectives for all PFOs and each of the identified groups of PFOs.

Appendix B

Results for the post hoc tests conducted for the statistically significant variables revealed which specific groups differed from each other.

Table A1. Significant differences in views of variables between groups of PFOs. Significant values (i.e., pointers where there is a significant difference in responses) are marked in bold.

Variables		Outsourcing-Oriented Managers	Self-Reliant Managers	Less Active Managers
Forest property size	Outsourcing-oriented managers		**0.013** *	**0.012** *
	Self-reliant managers	**0.013** *		0.996
	Less active managers	**0.012** *	0.996	
Age	Outsourcing-oriented managers		0.075	**0.020** *
	Self-reliant managers	0.075		0.697
	Less active managers	**0.020** *	0.697	

Table A1. *Cont.*

Variables		Outsourcing-Oriented Managers	Self-Reliant Managers	Less Active Managers
Education	Outsourcing-oriented managers		**0.005** *	**0.038** *
	Self-reliant managers	**0.005** *		0.291
	Less active managers	**0.038** *	0.291	
Size of place of residence	Outsourcing-oriented managers		**0.001** *	**0.013** *
	Self-reliant managers	**0.001** *		0.931
	Less active managers	**0.013** *	0.931	
Hiring forestry contractors	Outsourcing-oriented managers		**0.000** *	**0.000** *
	Self-reliant managers	**0.000** *		0.644
	Less active managers	**0.000** *	0.644	
PFO performance of salvage logging	Outsourcing-oriented managers		0.121	**<0.001** *
	Self-reliant managers	0.121		**0.001** *
	Less active managers	**<0.001** *	**0.001** *	
Cooperation of PFOs in salvage logging	Outsourcing-oriented managers		**<0.001** *	**<0.001** *
	Self-reliant managers	**<0.001** *		**0.015** *
	Less active managers	**<0.001** *	**0.015** *	

* The mean difference is significant at the 0.05 level.

Table A2. Significant differences in views of forest management objectives between groups of PFOs. Significant values (i.e., pointers where there is a significant difference in responses) are marked in bold.

Forest Management Objectives		Outsourcing-Oriented Managers	Self-Reliant Managers	Less Engaged Domestic Managers
Forests are a place of rest or recreation	Outsourcing-oriented managers		**0.048** *	**0.000** *
	Self-reliant managers	**0.048** *		**0.000** *
	Less active managers	**0.000** *	**0.000** *	
Forests are important for mitigating climate change	Outsourcing-oriented managers		**0.000** *	**0.000** *
	Self-reliant managers	**0.000** *		**0.000** *
	Less active managers	**0.000** *	**0.000** *	
Forests are important for the preservation of biodiversity	Outsourcing-oriented managers		**0.000** *	**0.000** *
	Self-reliant managers	**0.000** *		**0.000** *
	Less active managers	**0.000** *	**0.000** *	
Forests are sources of wood and other forest products for personal consumption	Outsourcing-oriented managers		**0.000** *	**0.019** *
	Self-reliant managers	**0.000** *		**0.000** *
	Less active managers	**0.019** *	**0.000** *	
Forests are an important source of income through wood and other forest products	Outsourcing-oriented managers		0.965	0.086
	Self-reliant managers	0.965		**0.030** *
	Less active managers	0.086	**0.030** *	
Forests are an investment for the future, serving as a financial reserve	Outsourcing-oriented managers		0.094	**0.010** *
	Self-reliant managers	0.094		**0.000** *
	Less active managers	**0.010** *	**0.000** *	
Forests are spaces for the management of natural and cultural heritage	Outsourcing-oriented managers		**0.000** *	**0.000** *
	Self-reliant managers	**0.000** *		**0.000** *
	Less active managers	**0.000** *	**0.000** *	

* The mean difference is significant at the 0.05 level.

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