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Research article

Navigating climate threats in forestry across five European regions: Stakeholder's adaptive management and policy strategies to resilience

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ABSTRACT

This study explores the perspectives and adaptive strategies of forest stakeholders across five regions of Europe, North to South—Finland, Lithuania, Romania, Serbia, and Greece—regarding climate change challenges in forestry. 129 stakeholders were surveyed, including forest owners, professionals, environmental NGOs, government representatives, and recreationists, who pointed at soil quality, biodiversity, carbon sequestration, and timber production as the main concerns. Regional threats varied, with storms and pests prevailing in Finland, illegal logging in Lithuania, Romania and Serbia, and fires and unsustainable grazing in Greece. Proposed solutions emphasise active forest management, stakeholder engagement and policy reforms. While Finland and Serbia are optimistic about future forest resilience, Lithuania and Romania are neutral. Greece shows mixed reactions, mainly due to concerns about the political will to implement effective forest policy. The study highlights nuanced regional responses to climate-related forest challenges and the need for region-specific approaches to forest management and policy, with broader implications for environmental governance strategies.

1. Introduction

Climate change causes continuing changes in weather patterns (Rummukainen, 2012; Seneviratne et al., 2021). Climate change leads to increasing temperatures, rising ocean levels, higher storm intensities, higher incidences of heavy rainfall, and modified winter conditions, including more snowfall or, in other areas, reduced precipitation. These changes potentially exacerbate negative impacts on forests, such as

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wildfires, pest infestations and droughts, affecting forest growth, productivity and provisioning of ecosystem services (Patacca et al., 2023). Hence, the effects of climate change on forestry are intricate and multifaceted (Kirilenko and Sedjo, 2007). However, international agreements, like the Kyoto and Paris agreements, have focused on mitigation, not adaptation to climate change. While IPCC's different assessment reports highlight the biophysical mitigation potential of forests and the necessity to adapt to climate change (IPCC, 2001; IPCC et al., 2007; IPCC et al., 2023), there are limited global guidelines for adaptation in forest management (Seppälä and Katila, 2009).

Climate change increases disturbances in European forests, such as deterioration due to wind-induced damage, outbreaks of bark beetles, wildfires and, in some areas, increased snow damage (Forest Europe, 2020; Romeiro et al., 2022). From 2018 to 2020, 4.74 million hectares of European forests were subject to natural disturbances, with a trend of increasing disturbance sizes and frequencies (Forzieri et al., 2021). At the European level, forest disturbances have been mainly caused by three agents: wind (46 % of the total damage), fire (25 %) and bark beetles (17 %) (Patacca et al., 2023). The importance of these disturbances varies across Europe.

Addressing the challenges of climate change requires adaptive forest management strategies. These may enhance the resilience of forest ecosystems or reduce the disturbance pressures. Adaptive forest management is a dynamic process incorporating monitoring, learning, and flexible decision-making to adjust management practices over time (Temperli et al., 2012; Lindner et al., 2014; Yousefpour et al., 2017). Adaptive forest management emphasises proactive measures such as promoting phylogenetic and structural diversity, enhancing natural regeneration, and implementing silvicultural practices that reduce vulnerability to disturbances (Sousa-Silva et al., 2018; Braunschweiger et al., 2024). Key strategies include maintaining mixed-species forests, fostering uneven-aged stands, and managing deadwood to support biodiversity and ecosystem services (European Environment Agency, 2024). By integrating scientific knowledge with practical management, adaptive strategies can mitigate adverse impacts and support the long-term sustainability of forest resources (Seidl et al., 2017). Therefore, local stakeholders' expertise is attaining greater recognition which is imperative in addressing sustainability and climate change issues (UNESCO, 2017; Gómez-Baggethun, 2021). According to Hallberg-Sramek et al., (2023), integrating local stakeholders' experience with scientific knowledge opens new prospects for enhancing sustainable forest management. Thus, forest stakeholders play a central role in adaptation processes, influencing the potential adaptability of forests through their actions and participation in decision-making processes, whether individually or collectively (Conde et al., 2005).

Regional and seasonal variations in windstorm occurrence across Europe are significant. Central and Eastern Europe are experiencing an increasing frequency of intense wind events (Donat et al., 2011). Thunderstorm-induced forest damage is expanding into previously less affected regions, such as Eastern Europe (Sulik and Kejna, 2020). Wind damage is most prevalent in Northern and Eastern Europe during autumn and winter (Ikonen et al., 2017; Petit et al., 2021), while strong seasonal winds like the Etesians primarily affect the Mediterranean in summer (Katopodis et al., 2021).

Bark beetles primarily infest Norway spruce, the predominant tree species in Northern and Central Europe (Schelhaas et al., 2018). The main drivers behind bark beetle outbreaks are windthrow, high temperatures, and drought conditions (Fernandez-Carrillo et al., 2020). Further, root-rot has yielded substantial economic losses across Europe, estimated at around 800 million euros annually (Woodward et al., 1998). In Finland, *Heterobasidion annosum s.l.* infections affect 15 %–20 % of Norway spruce trees, while in Latvia, the incidence ranges from 30 % to 39 % (Venäläinen et al., 2020; Klavina et al., 2021). Snow and ice storm damage occur recurrently in high-latitude regions of Northern Europe and mountainous areas in the rest of Europe (Suvanto et al., 2021). Heavy snow loads often break treetops and branches, increasing trees' vulnerability to further damage from insects and fungi (Nykänen et al., 1997). Freezing rain occurrence is typical in Central and Eastern Europe between November and February (Klopčič et al., 2020). In a particularly impactful instance, an extreme ice storm in 2014 devastated over 500 thousand hectares of forests in Northern Croatia and Slovenia. The aftermath of this event led to an unexpected consequence: Slovenia experienced its warmest summer on record in 2015, setting the stage for a historic bark beetle outbreak that impacted over 1.2 million cubic meters of timber (Nagel et al., 2017; de Groot et al., 2018). Wildfire emerges as substantial disturbances in many European countries, particularly affecting forests in the Mediterranean regions (Seidl et al., 2017; Forest Europe, 2020). In 2023, Greece experienced several large fires that significantly impacted forests, cultural heritage sites and infrastructures, resulting in 174,800 ha burned (EFFIS, 2024). Drought is one of the prominent climate-induced disturbances affecting European forests and is predicted to become more frequent and intense under climate change scenarios (State of Europe's Forests, 2020). Southern Europe has faced several consecutive years of drought, impacting forest growth and is the main reason behind increased tree mortality (Peters et al., 2021; Hartmann et al., 2022).

In the face of escalating climate change impacts, forest ecosystems across Europe are experiencing significant threats, affecting ecological stability and societal well-being. Understanding the perspectives of diverse forest stakeholders is essential. It can help pinpoint priority areas for implementing strategic actions that enhance forest resilience, incorporating local expertise to address the existing challenges and their growing complexity (Focacci et al., 2017). For example, by collective definition of critical concepts and terms (Fuller and Quine, 2015), identifying challenges and needed actions (see Bowditch et al., 2019), building forest scenarios (Haatanen et al., 2014), etc. Questionnaires are a valuable tool for gathering information about stakeholders' involvement in the forest sector and their engagement and role in participatory processes for decision-making (Kangas et al., 2010). In this line, Nijnik et al. (2010) analysed the attitudes of forestry stakeholders from several European countries towards multifunctional forests through questionnaires. They found that despite differences in stakeholders' perspectives, all groups emphasised the importance of regeneration for multiple purposes and enhancing forest ecosystems. At a broader scale, Rametsteiner et al. (2009) used existing literature and questionnaires to study stakeholders' perceptions about the meaning of forests, finding essential differences across topics and European countries, with forest protection and conservation being the most critically identified topics. The questionnaire study conducted by Sousa-Silva et al. (2018) established a connection between the perceptions of forest owners and managers and their responses to climate change adaptation. It underscored the importance of leveraging expert local knowledge to address information gaps in specific European regions and initiate essential measures for forest adaptation.

However, although several studies have examined stakeholder knowledge, a sufficient understanding of stakeholders' concerns regarding addressing forest threats and providing region-specific adaptation and mitigation strategies for forest resilience is still missing, especially from a cross-country regional comparison perspective. Thus, this study aims to investigate local and regional stakeholders' insights and resilience strategies in selected European countries, focusing on their perceptions of climate vulnerability and adaptive management approaches. The concerns of stakeholders are sometimes in contrast with scientific studies on climate vulnerability. By comparing stakeholders' concerns with scientific assessments of climate risks, we analyse adaptive management strategies and examine how natural and socio-economic conditions along the Eastern European gradient influence our findings. Given the regional differences in climate change impacts, we expect that local stakeholders' perceptions of forest threats, and their suggested management and policy solutions, will vary across regions, reflecting distinct climate-related challenges, governance structures and socio-economic context. Based on our expertise and knowledge of regional forestry dynamics, we assume that stakeholders in different regions will prioritize different threats and propose locally suitable adaptation actions. This study offers a novel perspective by linking experts' insights across several countries with climate-induced forest threats, providing management and policy recommendations that address regional challenges in forest resilience.

In this paper, we aim to 1) establish the key uses of forests according to local stakeholders, 2) identify the most vital ecosystem services, 3) determine the main threats facing these forests, and 4) analyse how forest management practices and policies address these threats. Additionally, we explore how today's forest management can contribute to the sustainability of future forest-based sectors, which will be identified during the study.

2. Methods of study

Study area. The five Living Labs (LLs) used here are North Karelia in Finland (1), Dzukija National Park (NP) in Southern Lithuania (2), Iedera in Romania (3), alluvial regions of Central Serbia (4), and Xeromero in Greece (5) (Table 1). According to the European Network of Living Labs (ENoLL et al., 2025), 'LLs' are defined as "user-centered, open innovation ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real-life communities and settings". However, Our five LLs geographically follow a North-to-South gradient (Fig. 1).

The study areas were also selected to represent various forest types, considering ecological, climatic and production perspectives. Romania features diverse mosaic forest landscapes, Serbia has riparian forests, Finland is known for boreal forests, and Lithuania and Greece have silvopastoral forests. These regions cover a broad North-South gradient of climatic zones in Europe. Another crucial reason is the diverse range of forest uses, from economic to non-economic. Finland prioritizes wood production, while Serbia and Romania place greater emphasis on protection and conservation forests (Forest Europe, 2020), highlighting the importance of non-wood forest products (Lovrić et al., 2020).

We will compare threats to forest use and challenges and identify potential management policies that local stakeholders have proposed to address climate change.

Stakeholders. We first identified relevant stakeholder groups. The stakeholder groups selected for our open questionnaire were selected based on choices made in previous studies (e.g. Reid et al., 2005; Haines-Young and Potschin, 2018) and our own experiences. We focused on stakeholder groups with extensive experience in forestry, either directly or indirectly. As a result, the stakeholder selection process was purposive, following a non-random expert sampling technique.

The study encompasses the perspectives of four distinct stakeholder groups. Group 1 represents forest owners; Group 2 consists of forestry professionals and contractors, forest and wood industries. Group 3 encompasses a range of stakeholders, such as environmental NGOs, government representatives or employees, and municipal representatives or employees. Lastly, Group 4's stakeholders are involved in recreational activities and the gathering of non-timber forest products. Stakeholders engaged in recreational activities were contacted as representatives of hiking and mountain biking clubs, hunting and sportfishing clubs, youth organisations, and individuals collecting non-timber forest products (such as mushrooms, berries, honey, chestnuts, and grazing). These stakeholder groups were explicitly selected for sampling.

Questionnaire Design and Data Collection. We developed a questionnaire to capture local stakeholder knowledge and inform future approaches to forest rehabilitation, restoration, and sustainable forest management. Participation in the questionnaire was based on free, prior, and informed consent.

In developing the questionnaire, the theoretical framework considers climate change as a driving factor that leads to perceived threats to forests. At the same time, policies, management approaches and predictions about future outlook are viewed as moderator variables. Therefore, we designed a questionnaire that aligns with the research objectives and aims to provide meaningful responses. The questionnaire incorporates both closed and open-ended format questions. Open-ended questions were chosen as the most suitable approach because they allow respondents to express their thoughts. We thought that multiple choice questions would limit respondents. To facilitate this, we did not restrict the length of the responses.

The questionnaire was uploaded to the EU survey system and translated into five languages—Finnish, Lithuanian, Romanian, Serbian, and Greek—using machine and manual translation. Each translation was reviewed and edited by the local partner in the living lab. Finally, a link was generated and shared. The survey was conducted from April 19 to July 30, 2023, yielding 137 responses. After removing 8 outliers and incomplete responses, a total of 129 valid samples were used for the analysis.

Analysis steps and methods. The questionnaire included two types of question formats: closed-ended questions (Q1-7) and open-ended questions (Q8-12). The closed-ended questions, which used Likert scale and multiple-choice questions, generated quantitative data on the respondents (e.g. age, education, experience and involvement in the forest sector), as well as their general views on the importance of various forest uses (e.g. wood production, carbon sequestration, recreation). The open-ended questions sought qualitative insights on conflicts between forest uses, identification of threats, the role of management and policies in addressing these threats, and perspectives on the future ability of forests to support the forest-based sector (Fig. 2).

This mixed-methods approach provided both quantitative and qualitative data. Quantitative data were analysed using R and IBM SPSS

Table 1
The main characteristics of the forest areas studied.

North Karelia (NK), Finland	Dzukija National Park, Lithuania	Iedera, Romania	Central Serbia, Serbia	Xeromero, Greece
NK is a province of Eastern Finland, with about 1.5 million ha of land covered by forests, (89 % of the total land area). 5 % of the forest area, including nationally iconic landscapes and high cultural heritage values, is protected. The forest comprises conifers, mainly Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*). Mixed pine-birch-spruce forests are also present.	Dzukija NP is situated in the southern part of Lithuania and covers 47.3 thousand ha. The area is heavily forested (83 %), mainly by Scots pine. It is rich in biodiversity and famous for its cultural heritage, clean environment and recreation. Forest use of wood and non-wood products is the primary source of income for local inhabitants.	Iedera is situated in South Romania and covers around 3800 ha. The area is covered with local broadleaved tree species, such as European beech, sessile oak, hornbeam and lime. Forest stands are naturally regenerated. Besides timber, forest yields valuable products like games, berries, mushrooms, medicinal plants, honey, seeds, and tannins.	The LL is situated in the Alluvial regions of Central Serbia, around the larger rivers (Kolubara, Morava, Mlava). These are highly diverse mixed forests with *Quercus robur*, *Populus alba*, *Fraxinus angustifolia*, etc., depending on the groundwater level. Oaks have been heavily harvested (also uncontrolled) and are rare nowadays. A large majority of forests are privately owned and not adequately managed.	Xeromero LL is an ancient agroforestry system that features valonia oak (*Quercus ithaburensis subs. macrolepis*). It stretches southwest of Lake Ozeros in the Ligovitsi—Manina area and is mainly formed by open and old-aged oak stands. This forest holds both historical and ecological significance.

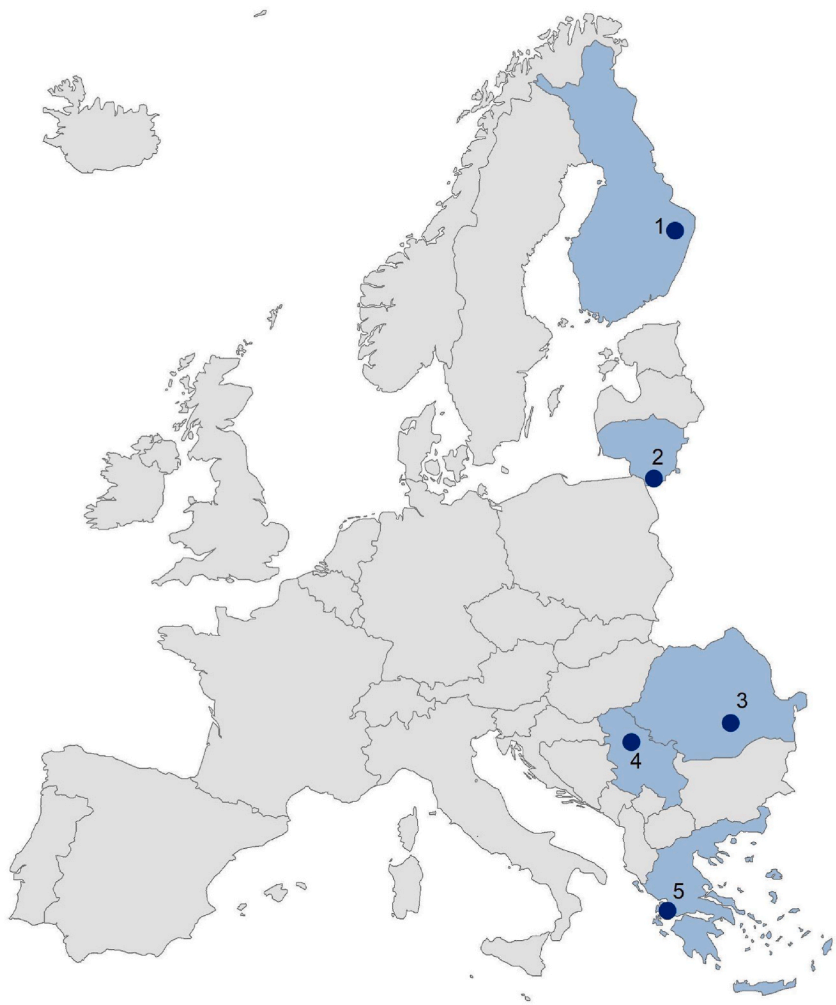

Fig. 1. Location of the study area: 1) North Karelia, Finland; 2) Dzukija National Park, Lithuania; 3) Iedera, Romania; 4) Central Serbia, Serbia; and 5) Xeromero, Greece.

Statistics (version 27.0), while qualitative text data were analysed using R and Atlas.ti23 software.

For the quantitative analysis, cross-tabulation was used to calculate percentages. A Sankey diagram was employed to represent the respondents' profiles visually. To determine the three most important forest uses, responses were analysed by professional groups. The data was reshaped into a 'long' format using the 'pivot_longer' function in R, where each 'Forest_use' value occupies its own row. The 'Use number' column indicates which of the three uses it corresponds to. Finally, any rows with 'NA' values were filtered out.

To identify forest threats in the LLs, we first organised and coded the original data. This involves standardising similar words or terms mentioned in various ways into a single term (Table 2). For qualitative text analysis, tokenisation was performed, followed by the creation of a Document-Feature Matrix (DFM) using the 'corpus' function. Preprocessing steps included stemming, converting text to lowercase, and removing stop word. Once the DFM for each 'LL' is generated, word cloud plots are created using the 'quanteda.textplots' package in R (Benoit et al., 2018).

The identification of forest management and policy suggestions provided by respondents of the corresponding LL was executed through network analysis. In this approach, words are represented as nodes connected by lines or edges. A threshold for node connections between 2 and 5 was considered. This implies that any node in the network with a degree (or number of connections) less than 2–5 connections are removed. The degree of a node refers to the total number of edges connected to it. This threshold value is somewhat arbitrary and can be adjusted. The significance of a node in the network is determined by its degree, with more connections indicating higher centrality and influence within the network.

In our network analysis, text preprocessing converted the text to lowercase and eliminated numbers, punctuation (except underscores), as well as stop words and non-informative words. We created a Document-Term Matrix (DTM) and computed term frequency (TF) by summing term counts across documents. Using TF values, we generated a co-occurrence matrix and created plots based on this matrix. During the graph plotting, we applied a threshold for node degree, identified key nodes, and removed the filtered nodes from the graph. Node centrality was calculated using the degree centrality measure and a data frame was sorted by centrality in descending order. To visualize the network graph and customize the plot according to our preferences, we utilized the 'ggraph' R package (Pedersen, 2024). In the network plot, the font size of text labels corresponds to the significance of the nodes; larger font sizes indicate greater importance, while smaller font sizes suggest less importance. Consequently, smaller labels represent less important nodes and can be disregarded by readers.

To assess whether future forests will support today's forest-based sectors, we carefully analysed each response to capture their perspectives on the future of forests. After reviewing the responses multiple times, we were able to clearly categorise which respondents had a

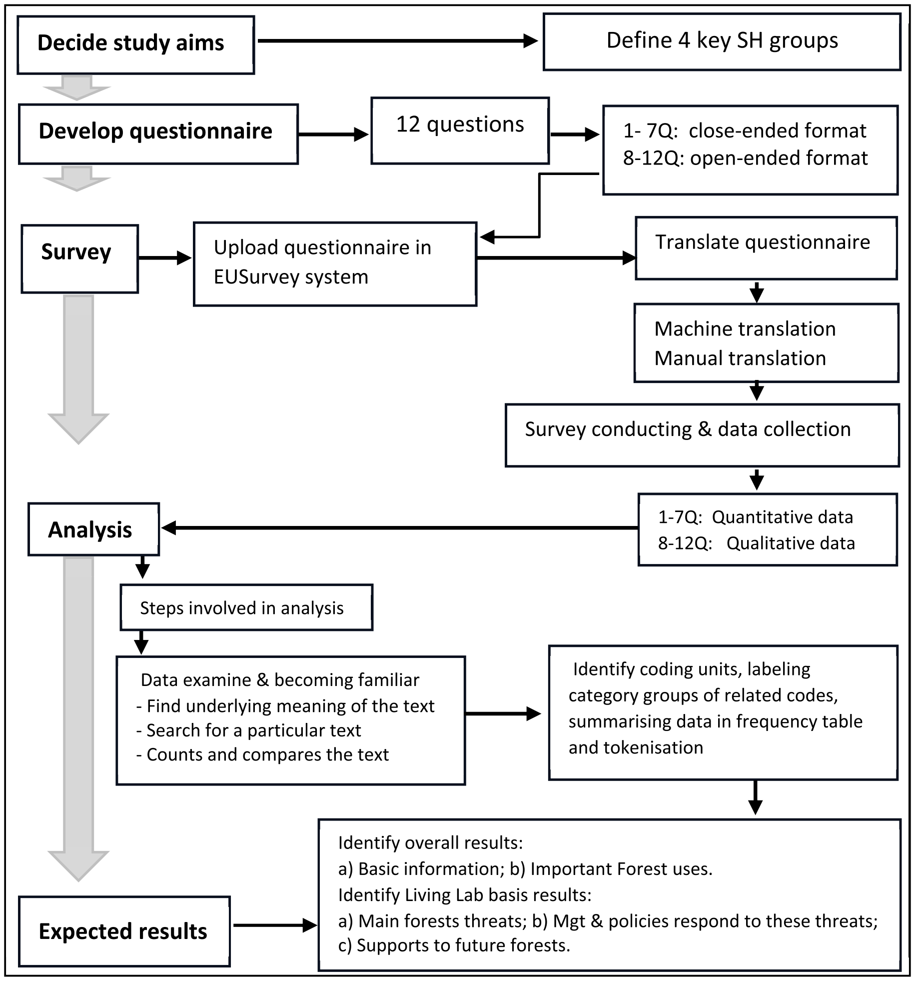

Fig. 2. Methodological framework of the study
EUSurvey system= EU online survey managemnet system; Mgt = Management; Q = Question; SH = Stakeholder.

Table 2
Specific terms used by respondents in the questionnaire and consequent coding.

Coding	Terms used by respondents
land_use_change	change_land_use, wild_land_fills, wind_turbines, wind_turbines and solar_plant_installations
decay_fir	fir_trees_damage, death_fir_forests, decay_fir_trees, drying_fir_trees
fires	forest_fire
illegal_logging	illegal_logging, unplanned_logging, incorrect_cutting, intensive_logging, cutting_down_forests, uncontrolled_logging
l_Mgt (lack of management)	poor_forest_management, traditional_management
overregulation	Regulations_EU, overregulation
pests[a]	activation of insects, attacks_ibis_coniferous, bark_beetle_typographus, bark_beetle_eating, bark_beetles, forest_diseases, fungi_parasites, insects phytopathological_entomological diseases, phytopathological_entomological_agents, insect_damage, pests, European Spruce bark_beetle/s, forest_pest/s, pest/s and disease outbreaks
snow	snow_damage
storms	storm_damage, thunder_storm, wind_damage, windbreaks
unsustain_grazing	overgrazing_undergrazing, indiscriminate grazing, overgrazing

[a] Pests = forest diseases + forest insects.

positive, negative, or neutral view on the future of forest-based sectors. Therefore, we calculated respondent's sentiment scores by using the AFINN lexicon, which assigns a numeric sentiment score to each text. Specific keywords and the underlying meaning of the respondents' answers guided this assessment. Subsequently, we calculated region-wise average sentiment scores to reveal geographic differences in perceptions. The sentiment distribution score provides a detailed understanding whether a text expresses a more positive or negative sentiment. We generated a sentiment aggregation score plot for each LL, applying thresholds to the sentiment scores. To interpret sentiment strength, we categorised the responses into three groups: 'Yes' responses were considered Positive reactions (scores above 1), 'No Opinion' were deemed Neutral (scores between −1 and 1), and responses with 'No' were considered Negative reactions (scores below −1).

In addition to the packages mentioned before, our entire analysis involved several other R packages, including caret (Kuhn, 2021), dplyr (Wickham et al., 2020), e1071 (Meyer et al., 2019), ggplot2 (Wickham, 2016), ggsankey (Sjöberg, 2018), igraph (Csardi and Nepusz, 2006), irlba (Baglama and Reichel, 2005), networkD3 (Allaire et al., 2017), randomForest (Liaw and Wiener, 2002), syuzhet (Jockers, 2015), tidyverse (Wickham et al., 2019), tidyr (Wickham et al., 2024) and tm (Feinerer and Hornik, 2018).

Methodological considerations. In our study, the distribution of sample sizes by group, regional and male-female proportion, was uneven across all regions. Since the data collection process was conducted by the Living Lab teams, it was beyond our control. However, it reflects age and gender distributions of active stakeholders. Similar issues were also encountered by Ranacher et al. (2017) and Roitsch et al. (2023) in their online questionnaire distribution, and in obtaining balanced sample sizes. In reality, achieving a perfectly balanced sample size is challenging, with some of these differences being representative of the current situation in the European forest sector (Follo et al., 2016; Ludvig et al., 2024). We suppose the gender imbalance is reasonable for our study, as our study did not focus on any male-female comparative analysis. Further, as we followed purposive sampling techniques, the unbalanced sample size in LL basis is fine, given that we are dealing with a large volume of textual data. The coding and execution of the analysis are complex. However, we have made every effort and taken possible measures to address this issue.

3. Results

3.1. Characteristics of stakeholders

3.1.1. Respondents' background information

The total sample consists of 129 respondents from five regions: North Karelia (24 respondents 19 %), Dzukija NP (35 respondents 27 %), Iedera (32 respondents 25 %), Central Serbia (20 respondents 15 %), and Xeromero (18 respondents (14 %). Out of the total sample, 93 respondents (72 %) are male, while 36 (28 %) are female. When examining the gender distribution by location, North Karelia has 8.5 % female respondents and 10.1 % males, in Dzukija_NP females 4.7 % and males 22.5 %. Iedera shows a lower female representation at 1.6 % females and 23.3 % males. In Central Serbia, females contribute 4.7 % and males 10.9 %. Notably, Xeromero is the only location where females surpass males, with 8.5 % females compared to 5.4 % males (Fig. 3).

The age distribution of the respondents was as follows the 18–25 age group comprised of 9 respondents (7 %), the 26–35 age group 23 respondents (18 %), the 36–46 age group 35 respondents (27 %), the 46–65 age group 51 respondents (40 %), and the 65+ age group involves 11 respondents (8 %). Regarding professional experience, 25 respondents (20 %) have less than 5 years of experience, 11 respondents (9 %) 6–10 years of experience, 20 respondents (15 %) 11–15 years, and 72 respondents (56 %) have 15 or more years of experience. In terms of educational qualifications, the majority hold University degrees (MSc) or Polytechnic (up to BSc and equivalent) qualifications, with 72 and 34 respondents, respectively. In general, most of the respondents are well-educated, middle-aged and highly experienced.

3.1.2. Professional groups and important forest uses

In the preliminary phase of stakeholder identification, the results revealed diverse groups among the respondents. These included respondents engaged in recreation-related associations, such as hiking, mountain biking (7 %), hunting or sportfishing clubs (1.6 %), individuals involved in the collection of non-timber forest products (e.g., mushrooms, berries, honey, chestnuts, grazing, etc.) (1.6 %). The participant distribution also encompassed government representatives or employees (16.3 %), environmental NGOs (1.6 %), forestry professionals and forest contractors (36.4 %), forest owners (13.2 %), and forest and wood industries, including contractors (3.9 %). Additionally, there were respondents affiliated with municipality representatives or employees (2.3 %) and youth organisations (0.80 %). The remaining respondents reflected combinations of two or more interest groups. Notably, forestry professionals and forest contractors constituted a significant category, accounting for the largest share of the total.

After classifying the stakeholders into four distinct groups, the distribution is as follows: Group 1, forest owners, constitutes approximately 13 %; Group 2, encompassing forestry professionals, contractors, and forest and wood industries, comprises the majority at 41 %; Group 3, which includes environmental NGOs, government representatives or employees, and municipal representatives or employees, represents a substantial 20 % and lastly, Group 4, consisting of respondents involved in recreational activities, accounts for about 12 % (Fig. 4a). Respondents identifying as being part of several groups account for about 14 % of the total. Besides, it is also worthy to add that among the total respondents of each LL, Group 1 dominates in North_Karelia (66.7 %), Group 2 dominates in Dzukija_NP (74.3 %) and Iedera (50 %) LLs and Group 3 dominates in Central_Serbia (40 %) and Xeromero (72.2 %).

Ecosystem services or forest uses prioritised by respondents by

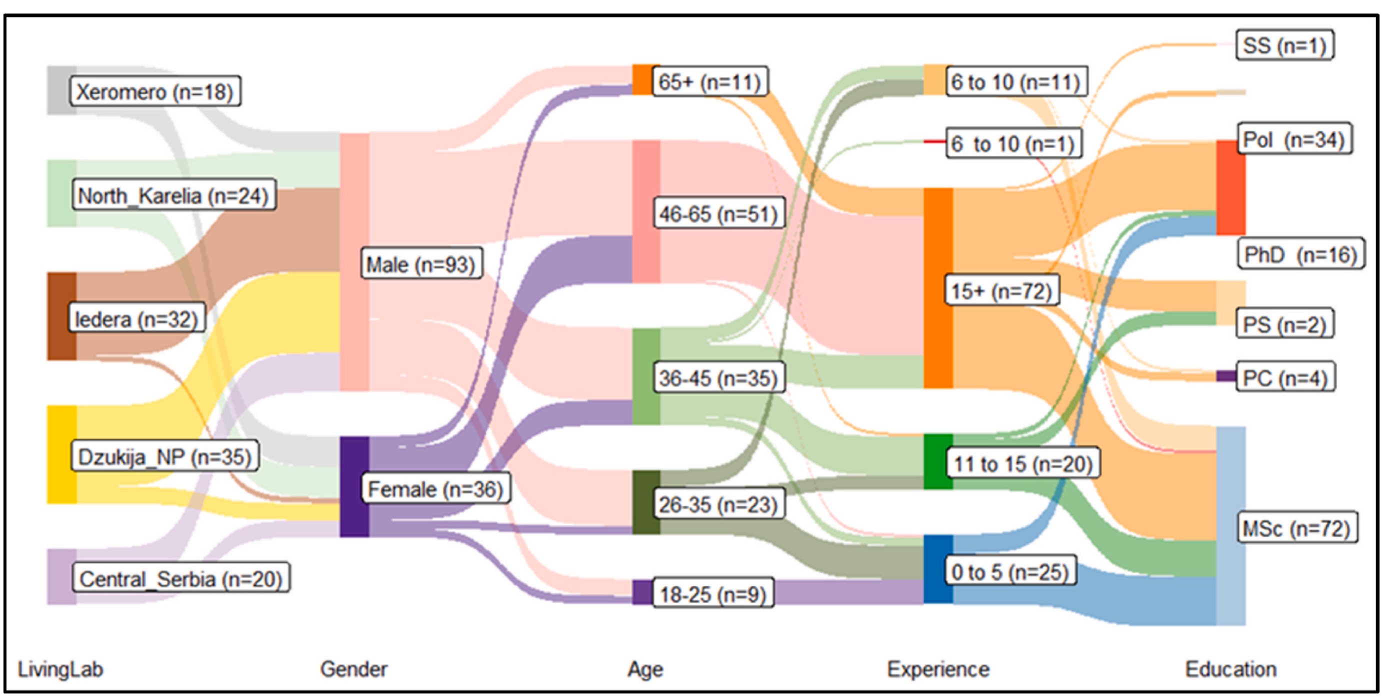

Fig. 3. Respondents' background information
MSc = University (MSc); PC = Professional certificate; PhD = PhD and equivalent; Pol = Polytechnic (up to BSc and equivalent); PS = Primary school, SS = Secondary school.

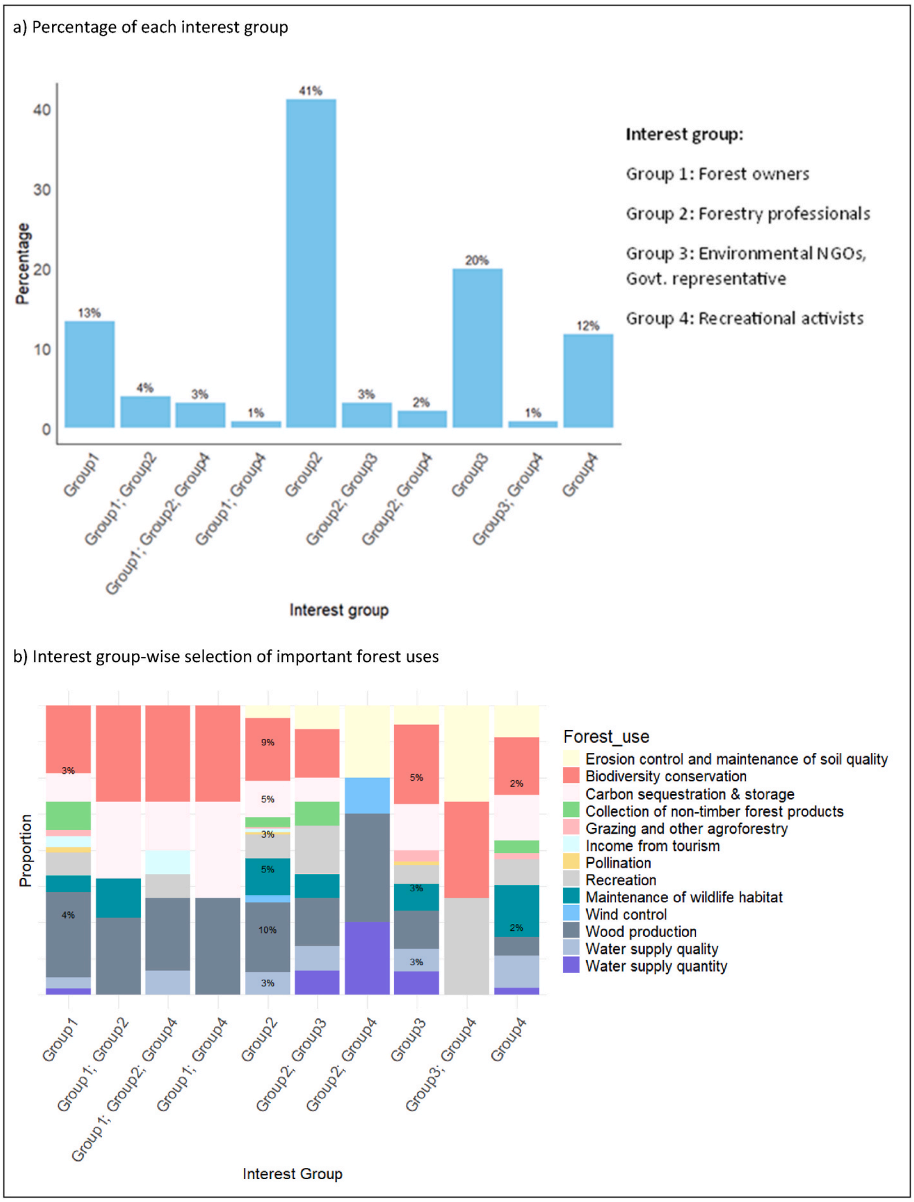

Fig. 4. Important Forest uses according to different interest groups.

interest groups are shown in Fig. 4b. The majority of respondents identified wood production (≈21 %), carbon sequestration and control (≈14 %), and biodiversity management (≈15 %) as the most important forest uses. Thus, in total, approximately 56 % of respondents across all regions believe that maintenance of soil quality, biodiversity management, carbon sequestration and wood production are the most important forest uses for society's future. Furthermore, the majority (≈57 %) considered that there were no conflicts between forest uses. The remaining respondents largely expressed no opinion on conflicts.

However, after observing all the LLs, it is found that stakeholders prefer biodiversity conservation and wood production as the key uses. Biodiversity conservation is recommended by 7.59 % in Dzukija_NP, 4.45 % in Central_Serbia and North_Karelia, 3.40 % in Xeromero and Iedera. Additionally, with the exception of Xeromero, wood production is recommended by 6.28 % in Iedera, 6.02 % in Dzukija_NP, 5.76 % in North_Karelia and 2.09 % in Central_Serbia. Furthermore, carbon sequestration and storage, water supply quality and wind control are selected by the remaining majority of respondents from the various LLs.

3.2. Living labs based results

3.2.1. Perceived main threats

Respondents were asked to briefly describe their respective regions' primary threats to forests. The results revealed that storms, pests, an overabundance of moose population, rising temperatures, and droughts are the major threats to the North Karelia LL's forest (Fig. 5a). Some respondents in the region mention that climate-induced threats, namely storms, snow damage and droughts have contributed to increased pest outbreaks, particularly bark beetles. In Noth Karelia, this issue is severe, especially near the Finish-Russian border area.

In Dzukija (South Lithuania) the major threats identified by respondents were pests, fire, illegal logging, climate change impact, reduction of groundwater levels and decay of the Norway spruce (Fig. 5b). Many respondents reported that the region's forests face significant challenges, especially rapid mature forest decline, delayed implementation of forest health measures, neglect of invasive species, unsustainable logging practices, and bureaucratic hurdles hindering swift responses. These challenges contribute to loss of habitats and rare species, as well as a growing disconnection between the forest

Fig. 5. Main identified forests threats in the Living Labs

changes_trees_types =changes in the types of trees growing in forests; changes_wood_production_conditions = changes in the conditions for wood production; decisions_government_cheap_r = decisions made by the government to attain cheap ratings; disappearance_gam = disappearance of game; illegal_act = illegal activities; illegal_log = illegal logging; increasing_continuous_cultivation = increasing continuous cultivation; insufficient_care_young_forests = insufficient care of young forests; l_mgt = lack of management; land_use_change = land use change; ngos = environmental non-government organisations; non-intervent = non-intervention; overregul = overregulations; public's_wrong_attitude_forests = public's wrong attitude towards forests; pest/pests = pests; soil_eros = soil erosion; too_efficient_felling_trees = too efficient felling of trees; unsustain_graz = unsustainable grazing; waste_pollut = waste pollution; uncoordinated_development_protected areas = uncoordinated development of protected areas.

Larger font size signifies the number of mentions or occurrences of each term; readers may overlook smaller, less significant labels.

management and its potential for social services. Moreover, as expressed by a respondent, climate change leads to the proliferation of pests and diseases, shifts in tree species, and altered wood production conditions due to milder winters are the major threats to their forests. Furthermore, a lack of coordination and fair compensation for forest owners, bureaucratic challenges, and excessive control prevail according to the respondents. Additionally, restrictions on privately managed commercial forest management and an uncontrolled rise in deer populations occur as hunting quotas are inadequately managed.

In Iedera (South Romania), the main forest threats identified were illegal logging, illegal activities, pests, droughts, fire, and the decline of game populations. Some respondents also believe that there are no significant forest threats in the LL area (Fig. 5c). According to the majority, the degradation of wood quality is primarily due to illegal or unauthorized tree extraction and unsustainable forestry practices. Furthermore, some respondents noted that excessive restrictive protection measures can lead to negative outcomes by preventing sustainable forest activities. Despite natural regeneration processes, the ongoing unauthorized logging by the local people puts pressure on their forest resources.

In alluvial regions of Central Serbia, the major perceived threats to forest are illegal logging, land use changes, impacts on water and soil, fires, and the reduction of groundwater levels (Fig. 5d). The conversion of forested areas into construction or agricultural land is highlighted as a significant threat. Therefore, climate change has also contributed to the physiological weakening of forests, rendering them susceptible to diseases and to extreme climatic events. Furthermore, temperature variations worsen these adverse effects. Lastly, the respondent underscores the negative impact of political and non-governmental populism on the forestry profession, stating that these influences can result in political and social actions that compromise professional independence and pose a risk to forest conservation. Another respondent stated that uncontrolled logging in the private sector, exacerbated by climate change and forest diseases, is a major threat to forests in the region. According to the majority of the respondents, unregulated construction and urbanization are posing significant risks, along with the persistent threat of forest fires. Furthermore, as noted by some respondents, forest pollution is also a major concern for them, extending beyond municipal waste to include packaging from artificial fertilizers, chemical preparations, and the improper disposal of various waste by workers in the forests.

The analysis of the questionnaire responses from Xeromero (Greece), reveals that the major forest threats are fire, unsustainable grazing, land use change, illegal logging, rising temperatures, anthropogenic activities, etc. (Fig. 5e). According to some respondents, the main threats to forests also include climate-induced die-offs, resulting from prolonged droughts periods along with elevated temperatures which particularly affect fir and pine forests. One respondent from the LL said that there are three major threats of the region. Those are firstly, elevated forest fire risks, secondly, biological threats (attacks from insects, fungi, and parasites), and thirdly, challenges related to grazing practices (encompassing both overgrazing and the abandonment of grazing activities). Another respondent pointed to the misuse of forests as a key issue (including illegal activities such as unauthorized access in the forest, setting fires, and camping), as well as legal activities (such as mountain running races and sports) contributing to increased pressure on the forest ecosystem.

As a summary, the results from different LLs reveal that pests, illegal logging, fire, storms, droughts, climate, and land use changes are the predominant threats across the majority of the LLs (Fig. 5f). Notably, environmental, social, and political issues influence these regional forests from North Karelia to Xeromero. From an ecological perspective, pests are the major threats in North Karelia, while fire is one of the mentioned threats for Dzukija, Iedera, and Central Serbia and becoming particularly critical in Xeromero. Environmentally, while rising temperatures and droughts are less significant in the North Karelia region, these factors are more severe in the other regions, exacerbated by the groundwater crisis. Considering the social perspective, the central concerns of illegal logging, illegal activities, and bureaucracy are significantly higher in the central to southern LLs, but are notably absent in North Karelia LL. These findings underscore the diverse and region-specific nature of forest threats, necessitating tailored adaptation approaches and conservation strategies to effectively address the unique challenges in each region.

3.2.2. Forest management response to regional forest threats

We used network analysis to analyse how forest management should respond to climate change (question 10).

For North Karelia (Fig. 6a), responses were centered around two clusters. We interpreted that the first cluster focused on silvicultural responses with keywords like 'trees', 'mixed', and 'species'. The second cluster was mixed, although it contained many governance-related keywords, such as 'removal_subsidies', 'taxation', and 'obligation'.

This suggests that respondents from North Karelia emphasise proactive sustainable forest management. They often referred to good forest management as including active management, game management, the obligation to care for the forest, monitoring and controlling pests. This involves activities like growing a diverse range of tree species, establishing protection zones for valuable biotopes, creating ecological corridors, and keeping decaying wood in forests for diversity. Some underscored the necessity for more research to foster the development of more resilient trees through strategic thinning. Others emphasised the

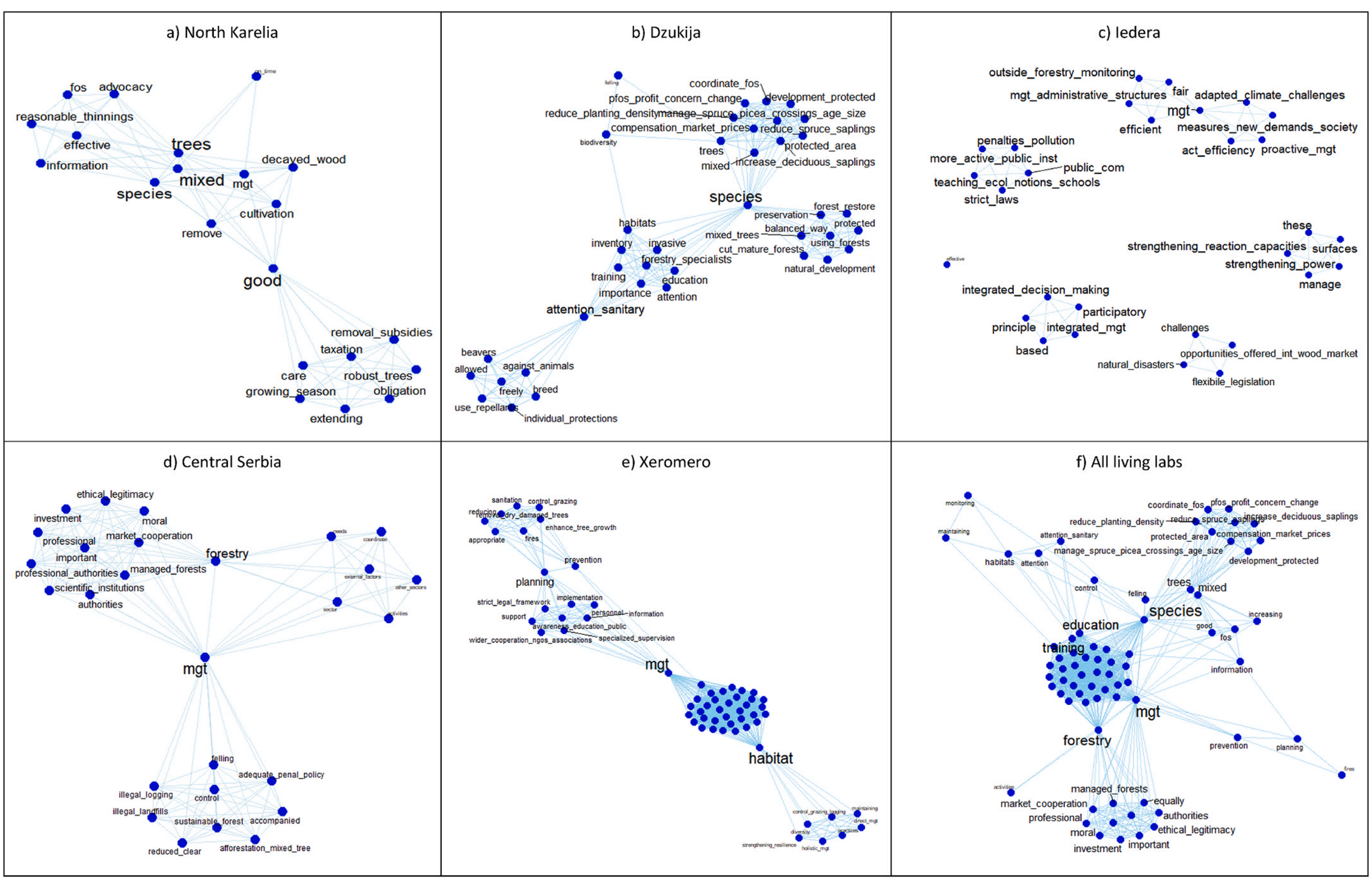

Fig. 6. Forest management suggestion by the respondent of the selected Living Labs.
fos = forest owners; mgt = management. Font size signifies the number of mentions or occurrences of each term; readers may overlook smaller, less significant labels.

need for well-timed forest management incorporating mixed stands and thinning, enhancing mixed tree density, removal of subsidies and imposing taxes on some areas if necessary, investing for pest controlling, and providing effective information and advocacy to forest owners.

Responses on Dzukija (Fig. 6b) clustered into four distinct clusters. The first cluster emphasised silviculture (e.g. 'reduce_planting density', 'increase_deciduous_seedlings') with elements of forest economy (e.g. 'compensation_market_price'). The second cluster addressed forest conservation (e.g. 'protected'), while the third cluster addressed human resources and knowledge for forest management (e.g. 'education'). The last cluster emphasised forest wildlife management (e.g. 'against_animals', 'beavers').

Key recommendations from them were promotion of mixed tree species, the preservation of protection and eradication of invasive species for forest management. Other recommendations included reducing spruce saplings or planting, lower planting densities, and increase the restoration of deciduous saplings. As for alternative tree species, respondents deemed larch and beech as essential. Adjusting the final cutting age, the recommendation was to apply diameter-based cutting methods, especially for spruce trees. Again, in terms of management techniques, suggestions included timely thinning, monitoring, and abandoning monocultures, along with employing less intensive logging techniques. Concerns were also given to the forest sanitation, and suggestions provided from greater control measures, imposing fines, and conducting timely salvage logging along with avoiding tree cutting in slope areas (to prevent erosion). These practices involved the thorough removal of remaining roots after forestry operations and the implementation of preventive measures. Many respondents underscored the importance of highly qualified professionals and specialists, emphasizing the necessity of their training and education. Another frequently mentioned aspect was the coordination within the Forest Owners' Society.

Also, Iedera had four clusters (Fig. 6c). The first cluster addressed the changing demands of society (e.g., 'mgt_administrative_structures') and general management concepts (e.g., 'proactive_mgt'. The second cluster addressed regulations (e.g. 'penalties'), and the third small cluster the adaptive capacity (e.g. 'strengthening_reaction_capacities'). The fourth last cluster was mixed with an emphasis on the opportunities forests provide to local communities (e.g., 'participatory' or 'integrated_decision_making').

According to some respondents from Iedera, the forest management control mechanism should be simpler but more effective. Some suggested flexible legislation, while others emphasised the need for a stable and coherent economic legislative environment. Respondents from Iedera emphasised the importance of informing the general public about forestry rules. They also advocated integrated management based on participatory principles and integrated decision-making. Another suggestion was that public institutions should be more active in communicating with the public. Additionally, some respondents suggested that ecological concepts should be taught at a middle high school level, and forestry subjects should be mandatory. Others suggested finding ways to attract young people to the forestry sector.

Central Serbia also had four clusters (Fig. 6d). The uppermost cluster focused on silvicultural measures (e.g. 'control_grazing', 'enhance_tree_growth'). The second cluster, which was very close to the first, addressed societal issues, especially cooperation and legislation (e.g. 'support', 'strict_legal_framework'. The third cluster is linked to habitats and management, and the last cluster looked at management for resilience (e.g. 'resilience', 'control_grazing_logging').

Respondents form the LL suggested afforestation with mixed tree species, and identify measures for reducing and controlling clear-cutting and illegal logging. Some emphasised forests at all levels (at the strategic, tactical, and operational levels) should be managed by the professional authorities with a high degree of morality and ethical legitimacy. The importance of forestry professionals with a broad multifaceted experience of forestry. Thus, respondents from Central Serbia reckon that forest management should consider all external factors that influence the forestry sector and coordinate its activities with other sectors. Furthermore, fostering collaboration between the economy (direct forest management mechanisms) and scientific/educational institutions (faculties, institutes) is considered to be vital to effective forest management.

Xeromero had three clusters (Fig. 6e). The central elements that connect to the nodes are 'mgt' (management), and 'habitat'. The central 'mgt' node also connects with various other nodes that linked with the wider scientific cooperations among the forest stakeholders, growing public awareness and tightening the legal framework (e.g. 'scientific', 'wider cooperation among ngos associations', 'awareness of public education', 'strict legal framework' and more). The 'planning' node is suggesting different management approaches (e.g. 'prevention', 'fires', 'control grazing', 'removal of dry damaged trees', 'strengthening resilience', and 'direct and holistic management' and so forth).

However, the respondents of LL emphasised that the goal of forest management should be to increase resilience of the ecosystem, with a particular focus on preventing forest fires. Another respondent suggested that a strategic approach should be utilized by the forest management to address the aforementioned threats. This entails putting specific measures to protect endangered species and ecosystems, constructing and maintaining forest paths, creating an institutional framework for management, fostering collaboration with relevant agencies, and increasing awareness among the public entities. Lastly, ensuring smooth cooperation, training between the EU country levels during firefighting seasons is also necessary to tackle the emergency situation.

A network analysis for all sites joined resulted in three clusters (Fig. 6f). The uppermost cluster deals with silviculture with a mixture of economic (e.g. 'profit_concern_change') and silvicultural concerns (e.g. ' reduce_planting_density'). The cluster is highly connected to tree species selection ('species'). The second cluster is dense and focuses on management, education, and training. The third cluster addresses societal issues with keywords like 'ethical_legitamicy' and economic questions like 'investment'.

3.2.3. *Forest policies response to the regional forest threats*

Text based network analysis was used to understand how forest policy should address threats (Question 11). In North Karelia, policy suggestions from respondents primarily converged into a single prominent cluster, which expanded in three key directions (Fig. 7a). Therefore, the highest connectivity based central nodes include advice, management (mgt), subsidies, and 'Kemera'. The "Kemera subsidies" are silvicultural subsidies enacted by the Temporary Act of the Financing of Sustainable Forestry (34/2015) to support the private forest owners for more sustainable and effective forest management (FINLEX). These subsidies covered various activities including early care of seedling stands, young forest management, construction and improvement of forest roads, corrective fertilization and peatland forest management, agri-environmental support agreements, biodiversity management in forests, and controlled burning. The Kemera subsidy program expired at the end of 2023 and was replaced by the Forestry Incentive System, referred to as Metka (Metsäkeskus, 2024). Further, the central node 'subsidies' is connected with other major nodes, i.e., mgt, advice, and Kemera (top-directed connections).

The edges of these nodes focus on the management of moose hunting permits, climate change adaptation through legal amendments, the modernization of forest management associations, timely clearing and thinning advice, and the encouragement of forest owners to actively manage their forests. It is worth adding that there is a substantial number of respondents in the LL that emphaised the significance of providing "Kemera" subsidies to forest owners.

The left side of the cluster proposes government support for forest owners, subsidies for thinning and initial care of plantations, enhanced information accessibility and increased inspections. According to a respondent, emphasizing support for the management of young forests is

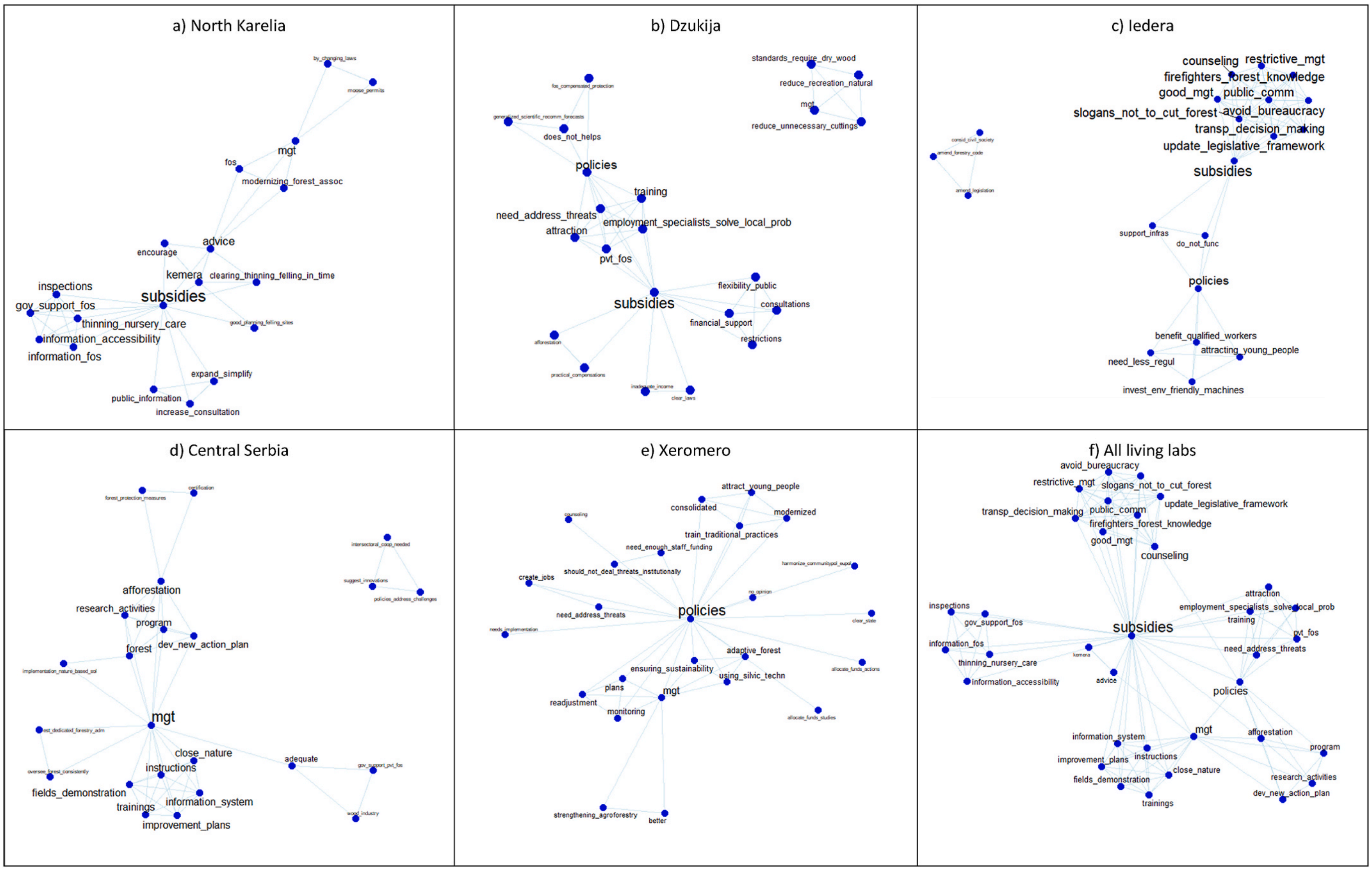

Fig. 7. Forest Policy suggestion by the respondent of the selected Living Labs.
fos = forest owners; mgt = management. Font size signifies the number of mentions or occurrences of each term; readers may overlook smaller, less significant labels.

crucial to establish well-growing forests. A second cluster suggests that it is important to simplify and expand the subsidy system- It also mentions the need for better information and involvement of the local communities to facilitate adaptation. Besides these central clusters, some points suggest the establishment of mixed tree plantations. The respondents of the area argued that by mitigating browsing damage, these mixed plantations would not only improve forest resilience but also play a vital role in climate change adaptation.

In Dzukija the network analysis reveals three clusters. In the largest cluster the most connected nodes are subsidies and policies (Fig. 7b). The central node, 'policies', anchor the largest cluster at the top. According to some respondents, the current policy fails to effectively address threats. They argue that defining forests only as trees and other vegetation in the forest law, without recognizing forests as an ecosystem rich in biodiversity, hinders progress toward climate adaptation. In addition, some respondents suggest that the forest policy of their region needs to specifically address threats. They propose managing these forest threats requires generalized scientific recommendations and forecasts—answering questions like, 'What should we grow?' Others emphasise the necessity of providing training and implementing an attractive policy to encourage climate-resilient actions.

The core node 'subsidies' is linked to detailed clarification of unclear laws, financial support to the forest owners who have restrictions and inadequate income (i.e. restrictions, inadequate_income, financial_support), consultations, afforestation, and practical compensation etc. Some respondents of LL suppose that subsidies should be provided to the private forest owners. Like the respondents of the other LLs, they also suppose that the subsidy providing and accepting system should be clear, flexible, more liberalized, and less bureaucratized to facilitate the forest management framework. Respondents also focus on the importance of attracting forestry specialists to address local forest problems.

Another separate cluster proposes to address management-related issues, such as dead wood management, reduce unnecessary cuttings, and reduce recreational activities in the protected natural environment.

The policy network plot of Iedera LL is divided into two main clusters. The first cluster features subsidies and policies as two pivotal connecting nodes, and the other cluster is centered around legislation (Fig. 7c). The LL respondents suggestion considering subsidies suggested to reduce bureaucracy, to ensure transparency in decision-making, to advocate for both restrictive and effective management, emphasise public communication (public_comm), to update the legislative framework, to promote slogans that advocate to not cutting the forest, to integrate firefighting forest knowledge, to support infrastructure, and to avoid subsidies for specific functions (do_not_func).

The policy-related cluster comprises elements such as attracting young people, advocating for reduced regulation, benefiting qualified workers, and investing in environmentally friendly machines. According to the respondents, forest owners are consistently disadvantaged compared to agricultural landowners. Therefore, counseling is imperative in the forestry field, necessitating public communication to attract young people to forestry, given the current low workforce levels and high average age in the industry. According to some other respondents, for the high-performance in forestry sector policy involvement for investing in Subsidy is essential. The significant nodes of the legislation cluster are related to the suggestion of amendment of different legislations, and consideration of civil society in policy updating. According to the respondents, the legislative framework needs updating to be less regulated, so amendments to the forestry code are crucial to mitigate and adapt to climate change.

In Central Serbia, most of the suggestions were centered around management and afforestation. Regarding management (mgt), the suggestions included field demonstrations, improving the management of training systems, enhancing management practices close to nature, optimizing information system management, overseeing improvement plans, issuing clear instructions, providing government support for the management of forestry operations, ensuring adequate management of the wood industry, establishing a dedicated administrative system, overseeing forest management, and supervising the implementation of nature-based solutions. Respondents emphasised the need to set specific goals for areas requiring reforestation, recommending the use of acacia, Canadian poplars, or conifers for the reforestation process (Fig. 7d).

Some respondents emphasised the importance of forest management for protection, afforestation, research activities, and the development of a new action plan and program. Consequently, their suggestion was to establish a management system that closely aligns with nature. Regarding afforestation, the recommended strategy was the implementation of an afforestation program. Another small cluster of suggestions focused on developing policies to address threats, promoting intersectoral cooperation, and proposing innovative solutions. Some respondents believed that while forest policies address challenges and suggest innovations, there is a need for increased intersectoral cooperation.

However, the central nodes with the highest significance in the Xeromero graph are 'policies' and 'mgt' (Fig. 7e). Several policy suggestions include adaptive forest management by adjusting goals for sustainability, incorporating silvicultural techniques, modernizing policies, attracting young people, and training in traditional practices. According to some perspectives, policies should address threats, while others propose that policies should not only deal with threats institutionally but also require proper supervision of all the decided actions. Some respondents recommended that policies should be developed in a way that provides enough funding opportunities for forest management. Others suggest developing policies that create job opportunities. Some emphasise improving the management plan linked to policies by readjusting, implementing more programs for better management, or enhancing monitoring. They also propose strengthening the agroforestry sector to involve people and foster respect for the natural environment.

Finally, exploring each LL, with the exception of Xeromero LL, there is a collective emphasis on the necessity for subsidies (Fig. 7f). In this line, many respondents from those regions have suggested providing subsidies in sectors associated with the decision not to cut down forests. Suggestions include subsidies for afforestation, improved plans that align with nature, and initiatives addressing forest threats, which are deemed crucial for their respective regions, including the Xeromero LL.

Therefore, except for Dzukija, the primary suggestions from other LLs are mostly related to forest management. These suggestions involve providing advice to forest owners and are connected to policy adoption and decision-making. According to them, to avoid bureaucracy and restrictions in the legislative frameworks, it is essential to adopt a good management system. They also believe that improved policy measures, such as counseling, public communicating, and ensuring the involvement of firefighters with forest knowledge are crucial, especially for the southern, southeastern, and central regions.

3.3. The future forests supporting today's forest-based sectors

Will future forests be able to support today's forest-based sectors (Question 12)- in response to the question, a box plot was executed to illustrate the distribution of the sentiment scores across different LLs. The height of the box plot represents the variability of sentiment scores. For example, North Karelia has the taller boxplot, indicating a wider range of sentiment scores of the LL compared to others. Whether the median horizontal line within each box represents the central tendency of sentiment scores for each LL.

In North Karelia, the median sentiment score is nearer to the upper edge of the box which indicates a more positive sentiment compared to others. Likewise, the median sentiment score in the upper middle edge of the box plot of Central Serbia also suggests a more positive sentiment for the lab compared to others. Further, a more negative sentiment distribution is exhibited in Dzukija and Iedera LLs. As for Xeromero, the median line position indicates a sentiment that is relatively neutral compared to other labs.

Outliers, represented by dots in the box plots, represent extreme or unusual sentiment scores. Numerous positive outliers in Iedera and Xeromero indicate very positive reactions in specific cases. On the other hand, outliers on both the positive and negative sides may suggest polarized extreme reactions, for Dzukija (Fig. 8a).

Thus, the results of sentiment aggregation study reveal that North Karelia and Central Serbia have the most positive reactions compared to other LLs (Fig. 8b). Despite this overall positive outlook, some respondents from North Karelia LL express their concerns about the comprehension of decreasing their future yields and wood supply. However, they stress that renewable raw materials will continue to find new applications, serving as both raw materials and in energy production. These respondents draw attention to the untapped potential of natural products, urging consideration of their value. Nevertheless, they maintain a strong belief that Finland's nature and forests will remain highly esteemed worldwide.

Dzukija and Iedera are characterized by the highest neutral reactions, while Xeromero exhibits an equal distribution of neutral and negative reactions in comparison to its positive reactions. Moreover, some respondents from Dzukija believe that future forests have the potential to be supported by today's forest-based sectors, contingent on the continuous expansion of the forest resource, which might be protected by legal regulations. For further assistance to the forest industries, it is necessary to increase the annual harvesting rate that should align with market demands. According to the respondents, this approach would not only enhance forest conditions but also contribute to the well-being of the people. They suggested that in this situation, the proportion of protection zones in comparison to production areas should be considered here, incorporating the cultivation of wood crops.

Conversely, respondents from Central Serbia express challenges of using forests due to its oversized wood industry capacities and expansion of the log exporting, and due to these harvesting pressures, the non-timber forest products are at risk. Inadequate climate change prediction and adaptation measures also pose significant risks for future forest management. In Xeromero, some respondents' express disappointment and believe it is unlikely that future forests will be able to support today's forest-based sectors. According to them, due to the absence of political will to implement an effective forestry policy for the development of forest areas. Additionally, another respondent suggests that proactive initiatives are necessary to enable future forests to support various sectors. Such initiatives are long-term planning, adopting new practices, addressing current and future challenges like climate change, extreme weather events, and evolving societal needs, etc.

Overall, the comparison of responses among the living labs (Table 3) revealed a wide range of views, with respondents reflecting on the peculiarities of each region and the perceived threats affecting their forests. Concerns are similarly distributed according to the identified threats, and the recommended solutions range from management-focused practices to solutions targeted to the existent administrative and legal systems.

4. Discussion

This study analyses forest stakeholders' perspectives on forest use, the main threats affecting their forests, and the conflicts that arise from these challenges. Additionally, the study also explores suggestions of stakeholders' about forest management and the role of policies in enhancing forest resilience, considering regional differences in adaptation strategies.

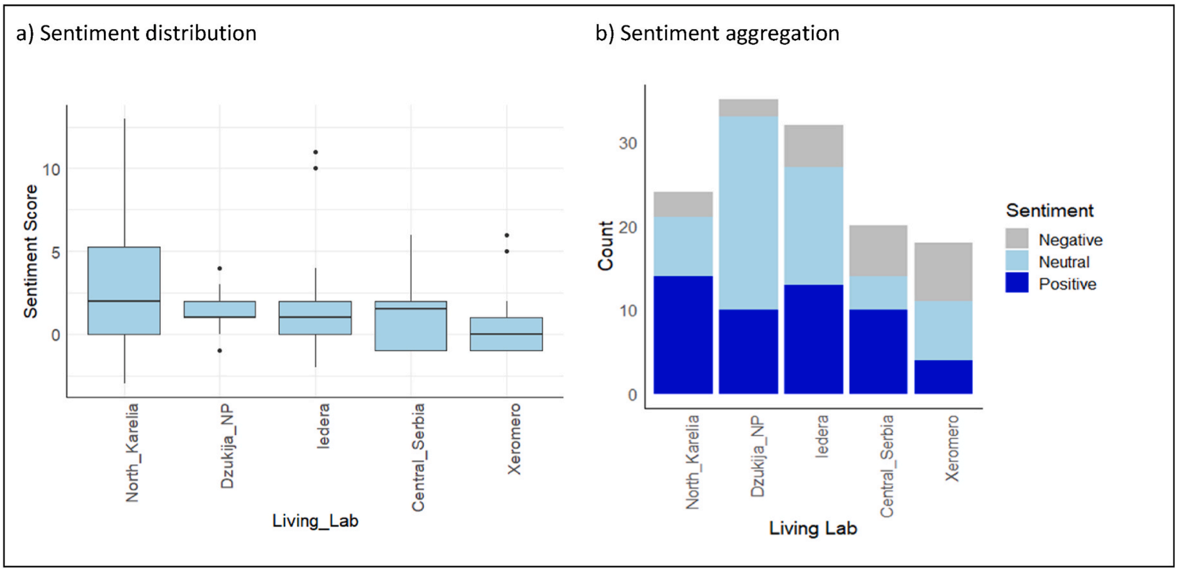

Fig. 8. Respondents' sentiment distribution (a) and aggregation (b) of different Living Labs.

Table 3
Cross-living labs comparison of respondents' main views.

Living Lab	Main perceived threats	Suggested forest management responses	Recommendations for policies to respond to forest threats	Future's forests ability to support the forest-based sector
North Karelia	Storms, pests, moose population, rising temperatures	Tree mixtures, species diversity, taxation, removal of subsidies, proactive management.	Subsidies (Kemera), advice and management.	Wide range of sentiment scores, leaning towards positive reactions
Dzukija	Pests, fire, illegal logging, climate change	Tree mixtures, preserve protected species, eradicate invasive species, cultivation of species resilient to climate change.	Subsidies, integrate forest threats into current policies, scientific recommendations and forecasts, provide training.	Mostly neutral reactions
Iedera	Illegal logging, illegal activities, pests, droughts, fire	Effective and proactive management, better information and communication, participatory decision-making, early forestry education, monitoring, etc.	Subsides, legislation, less bureaucracy, transparency in decision-making, restrictive and effective management, public communication, updated legislation, etc.	Mostly neutral reactions
Central Serbia	Illegal logging, land use changes, impacts on water and soil, fires	Investments, ethical legitimacy, expertise, sustainable management, tree mixtures, strict laws, control illegal logging, intersectoral coordination.	Supervised close to nature management, government support for the management of forestry operations, afforestation program, intersectoral cooperation.	More positive reactions
Xeromero	Fire, unsustainable grazing, land use change, illegal logging	Cooperation and collaboration, increase ecosystems resilience, strict laws, prevention measures.	Adaptive forest management, sustainability goals, enhance monitoring.	Relatively neutral reactions, leaning towards negative

Across Europe, our study revealed common and diverging themes on forest and climate change. We were surprised that forest governance was a dominant concern. The lack of expert knowledge was considered as an obstacle to adaptation in all sites except North Karelia. For governance, especially questions of subsidies and bureaucracy were mentioned. In several sites, the network analysis also indicates that stakeholders do not feel that they are heard. This agrees with Abrams et al. (2021) who attested that forest management in the American Midwest during a major bark beetle outbreak was limited by low capacity to change forest management. Hartebrodt and Schmitt (2016) suggested for Germany that state forest managers were rather traditional and oriented towards the goals of the government. This happened at the expense of stakeholder orientation and innovation. We think that this is seen in the desire for better participation in most of the sites.

Another theme was on silvicultural measures to improve adaptation of forests. Since the forests were located on a large geographical gradient, threats to forests and stakeholder opinions differ. The study by Nikinmaa et al. (2024) evidences a mismatch on forest management measures to promote forest resilience between the perceptions of forest professionals and those addressed in the scientific literature. Despite this mismatch, the study highlights the significance of integrating the diverse stakeholders' views. Similarly, de la Vega-Leinert et al. (2008) observed through dialogues with stakeholders a need to reconnect scientific frameworks with practical management to improve ecosystem vulnerability assessments and adaptation to global change. In the Northern sites, silvicultural recommendations focused on the diversification of forest management. Especially, spruce forests were perceived as needing to be replaced with mixed forests. Also, better forest sanitation was considered to be important. In the South fire management was of concern. As we will show in the discussion of individual sites, these observations are in line with scientific ideas on adaptation. Therefore, we would tend to disagree with the conclusions of Nikinmaa et al. (2024).

According to the stakeholders, the North Karelia LL faces threats from storms, pests, as well as from drought and rising temperatures. The findings align well with the research of Venäläinen et al. (2020), which emphasised similar challenges posed by climate change to forests and forestry in northern Finland. The challenges include windstorms, heavy snow loads, drought, forest fires, and significant biotic threats from insect pests and tree pathogens. In the experience of some of our respondents, pest issues in North Karelia, especially in the Finnish Russian border areas are severe. Some regions have a history of recurring outbreaks of the European spruce bark beetle (*Ips typographus* L.). According to Veteli et al. (2006), needle damage in Russian forests was found to be eight times higher than Finnish forests due to folivorous insects. So this suggests that with changing climate conditions, the lack of management in the Russian forests could be a reason for bark beetle activity there (Martikainen et al., 1996; Veteli et al., 2006) and spread to the Russian-Finnish border side. More recently, Pulgarin Diaz et al. (2024) reported a higher concentration of damage by spruce bark beetles near the Russian border in South-Eastern Finland.

In contrast, Dzukija grapples with its unique set of threats, including pests, in combination with fire risk, droughts and man-made threats such as illegal logging, which further exacerbate the region's challenges. Dzukija is a fire-prone heavily forested area, with numerous fire events spanning from 1742 to 2019 (Manton et al., 2022). The study also identified a notable shift after 1950, with fire intervals rising in dry forest and falling in peatland forests as a result of both human and natural factors. Concerns about illegal logging in the region are in line with existing research (Bouriaud, 2005) indicating significant increases during the early 2000s in the volume of illegally harvested wood in private forests and a latter decrease (Lazdinis et al., 2009), with reports acknowledging the difficulties finding up-to-date information on the topic and advocating for more transparency (Ottisch et al., 2007). Nevertheless, more recent statistics evidence a significant decrease in volume illegally fell in the country between 2014 and 2021 (State Forest Service, 2022).

Expanding on this, the major threats to the forests in Iedera and Central Serbia include droughts, fires, illegal logging, illegal activities, and reduction of groundwater levels. Notably, these threats are more acute in these LLs. The identification of threats by forest stakeholders in these regions coincides with their distribution according to climate change model projections across Europe (see Bouriaud et al., 2015). In a later study by FAO and UNECE (2021) in Romania, stakeholders also indicated wind damage, biotic pests, and illegal logging as key degradation concerns. According to the same study, in 2017, insects affected 37,680 ha, severe weather impacted 199,610 ha, and fires damaged 2460 ha of forest land. Illegal logging is a key issue in Serbia, where it is usual to make false claims about the species, volumes, values or origin of harvested wood (Glavonjic et al., 2005). In 2003, it was estimated that about $300,000 worth of wood was illegally harvested from state owned forests, while around $2.4 million was illegally harvested from private forests (Jovanović and Milanović, 2017).

Further, respondents cited illegal logging, unsustainable grazing, land use changes, fires, and rising temperatures as the main problems in Xeromero, Greece. Similar problems were highlighted in the review by Koulelis et al. (2023), which also pointed out important knowledge gaps, especially with regard to local climate patterns, water cycles, and how well forest management techniques enhance resilience. Xeromero stakeholders also suggested focusing on the long-term ecological impacts of fires, developing stakeholder integration in fire prevention, enhancing efforts in biodiversity conservation and protection, and insect population monitoring. Despite some advancements in fire control, Rüttinger et al. (2021) emphasised that illicit logging and fires remain hazards to forests in Southeastern Europe. Limited collaboration by the authorities is still a problem. Furthermore, rising temperatures, altered rainfall patterns, flooding, and more frequent droughts are all consequences of climate change that exacerbate security concerns related to illegal logging (Rüttinger et al., 2021).

Expanding on this research, a number of ecological and environmental factors contribute to the serious threats facing forests in Northern Europe, particularly North Karelia. In the Baltic, Eastern and Southeastern European regions (Dzukija, Iedera, and Central Serbia), the challenges are more intertwined. The stakeholder opinions underscore the varying nature of forest threats across different European regions, emphasizing the importance of considering multiple dimensions in forest management. Threats faced by regional forests are closely linked to their ecological, environmental, social, political, and geographical contexts. Therefore, management and policy recommendations must be designed to address these specific conditions. The network analysis underscores the importance of adaptation strategies to the unique circumstances of each region. In many living labs issues of training and governance were emphasised. By integrating knowledge from stakeholders at various levels, we can enhance climate change adaptation through sustainable forest management and explore new forms of forest governance (Locatelli et al., 2010).

To address forest threats, North Karelia emphasises climate smart forest management, including proactive measures like, pest control, increasing share of mixed species forest and timely thinning, underlining the need for effective forest management beyond basic legal requirements (Peltola et al., 2022). The ongoing discussions surrounding these management issues within Finnish forestry over several decades signify a deep-rooted awareness of the challenges and the necessity for proactive measures. This is reflected in the LL respondents' perceptions about how forest policies can respond to forest threats. For example, respondents suggested an increase in the number of moose hunting permits as a means to address forest threats. This suggestion and findings of the study are supported by several studies. For example, Heikkilä et al. (2003), Nikula et al. (2008) and Bergqvist et al. (2014) suggested that moose population control can be used to prevent browsing damage in young pine and birch stands, instead of planting other, less preferred by moose, species that might be vulnerable to insect attacks (i.e. spruce). Stakeholders from Dzukija suggest better coordinating forest owners, addressing private forest concerns, and implementing diverse plantation strategies which include species preservation, promotion of mixed tree species, eradication of invasive species, resilience cultivation, and lighter logging techniques. In Iedera, the emphasis is on improving communication, enforcing strict construction laws, imposing pollution penalties, and promoting ecological education. Central Serbia prioritizes selecting skilled personnel, promoting ethical forest management, and implementing silvicultural methods to reduce clear-cutting and illegal logging. Xeromero focuses on enhancing ecosystem resilience through fire prevention, climate change mitigation, protection of endangered species, and fostering seamless cooperation during fire-fighting seasons. Similarities across these regions include a shared emphasis on forest management practices such as timely interventions, monitoring, and promoting diverse tree species, as well as a collective concern for ecological education and public awareness. Many of these measures and their spatial distribution align with existing research analyzing adaptation strategies to climate change. For instance, Keskitalo (2011) reviewed adaptation strategies in expert reports at the European country level, observing that several countries advocated for timing of operations (e. g., Finland, Austria and Greece) and promoting tree diversity as forest management adaptation measures (such as Greece). Similarly, Kolström et al. (2011) collected potential adaptation options for forestry in Europe from the existing scientific literature, most of which are in line with those mentioned by the LLs stakeholders.

Dissimilarities among the regions are evident in their specific emphases, North Karelia highlights active and future forest management, Iedera emphasises communication and law enforcement, Dzukija focuses on forest stand diversification strategies, and Xeromero prioritizes resilience and emergency response. Dzukija and Central Serbia delve into the technical aspects of silvicultural control and management, while Central Serbia and Iedera prioritize human capacity enhancement. In contrast, Xeromero emphasises strategic elements, including scientific approaches, wider cooperation, strict legal frameworks, prevention measures, and efforts to strengthen resilience. Additionally, variations in the scope of suggestions emerge, with some locations addressing threats broadly (North Karelia, Xeromero) and others concentrating on technical measures (Iedera, Dzukija, Central Serbia).

In North Karelia, according to the respondents, forest policies should prioritize state subsidies, government support, and streamlined subsidy systems, emphasizing improved accessibility to information. Currently, forest policy in Finland regulating forest management and use is mainly stipulated in the Forest Act (FINLEX, Forest Act 1093/1996), which establishes the measures to be followed and minimum management requirements to ensure the sustainable use of Finnish forests. Additionally, certification schemes are broadly adopted in Finland, with about 90 % of the forests being certified by PEFC according to the Finnish Forest Centre (Metsäkeskus, Online). In relation to threats such as insects and other damages, the Forest Damages Prevention Act (FINLEX, Forest Damages Prevention Act 1087/2013) aims to keep a good health status and limit damages to Finnish forests by establishing certain obligations for forest owners. However, according to the respondents' suggestions and opinions in response to the replacement of Kemera subsidies (Temporary Act of the Financing of Sustainable Forestry 34/2015), the new Incentive System Metka should provide more substantial subsidies and be more accessible to forest owners. Concerning improved accessibility to information, Yousefpour and Hanewinkel (2015) and Brunette et al. (2020) identified that lack of proper information was hindering forestry professionals' adaptation decisions in central Europe.

Dzukija advocates for broader forest recognition, flexible subsidies, and addressing management issues. In Lithuania, the Forest law (I-671/1994) institutes forest zoning, regulates state and private forests, and provides a strict baseline for forestry practices (Lietuvos Respublikos miškų įstatymas I-671/1994). The legislation issued by the Ministry of Environment specifically regulating Forest felling (D1-690/2010), Forest restoration (D1-199/2008) and Forest sanitary protection (D1-204/2007) (Miško sanitarinės apsaugos taisyklės D1-204/2007; Miško atkūrimo ir įveisimo nuostatai D1-199/2008; Miško kirtimo taisyklės D1-690/2010). Forest policy is based on centralization, more severe management restrictions and command-and-control principles (Brukas et al., 2013; Makrickienė et al., 2019). It still lacks freedom of decision, adaptive management and increased environmental consideration (Brukas, 2014). The ambitions to improve forest governance and finding consensus on the future directions were mainly associated with a National Forest Agreement on Forests (2021–2022). However, after a long and exhausting stakeholder discussion process, the agreement was not reached, increasing the gap between forest use and biodiversity conservation.

Iedera recommends reducing bureaucracy, attracting youth to forestry, and updating legislative frameworks. In Romania, the legal system for the forest sector is based on the Forest Code which has been recently changed as the Law no. 331/2024 (Romanian Parliament, 2025). The forest code provides the general framework for the sustainable management of Romanian forests, detailing aspects related to forest administration, management and planning, biodiversity conservation, forest protection, logging, research and education in forestry, forest accessibility, etc. The subsequent legislation impacting the forest sector comprises more than 200 Governmental Decisions and Ministerial Orders, creating one of the most restrictive regulatory frameworks in Europe (Scriban et al., 2019; Nichiforel et al., 2020). In 2022, the National Forest Strategy 2030 was approved, setting the grounds for a new legal framework, as well as updated technical norms for forest management (Romanian Government, 2022). In December 2024, the new Forest Code was approved, strengthening e.g. the penalties for document falsification leading to illegal logging. Abrudan et al. (2009) and Marinchescu et al. (2014) evaluated current issues and common expectations of forest managers, agreeing with our findings on the problems caused by illegal logging and the inadequacy of existing legislation (such as the loopholes found by Albulescu et al., 2022 in the forestry legislation).

Central Serbia focuses on forest management, afforestation, and intersectoral cooperation. In Serbia, the Forest law (FAOLEX Database, 5/2010, amended in 12/2018) regulates the use and management of forests, their protection and conservation. Rogelja and Shannon (2017) mentioned the role and limitations for actors to influence forest policy in the country (specifically in relation to anti-corruption measures). This is conveyed by the suggestion of improving intersectoral cooperation and by the importance given to ethical legitimacy by the respondents in the Serbian LL. The policy analysis by Milutinović (2024) points in the same direction, highlighting the need for multi-sectoral initiatives to address climate change impacts. On the topic of afforestation, the Serbian State provides subsidies for afforestation purposes, although linear trends in total afforested area are negative for the period 2002–2021 (Ćirković et al., 2022).

Xeromero suggests adjusting sustainability goals, modernizing policies, attracting youth, providing funding opportunities, and addressing threats for proper supervision. In Greece, forest policy commenced by the creation of the Forest Service in 1830, however, systematic forest management was not implemented until the end of the Ottoman conquest. In 1923 the first National Parks were created while the “Golden Era” of forest management began by 1957 and, since then, there have been increasing law amendments and measures to protect this valuable natural resource i.e., law 3208/2003 on the protection and regulation of rights over forests. More recently, law 5106 of 2024 considers the impacts of climate change on forests and other systems, and establishes the necessary arrangements to address them. Additionally, the law 5069 of 2023 and related ministerial decisions regulate the utilisation of forest biomass in Greek forests (FAOLEX Database, 2025), especially regarding bioenergy purposes. In line with our findings, in the questionnaire study by Tsioras (2010) forestry workers and experts expressed the need for better guidance and training, as well as incentives and subsidies to promote the forest operations sector in Greece. Landowners responding to the questionnaire study by Kassioumis et al., (2004) agreed that forest policies should prioritize the regulation of subsidies and the contribution of forestry to environmental and societal objectives rather than production objectives. These results emphasise some of the same key policy aspects and suggestions mentioned by our respondents.

In summary, subsidies for afforestation, nature-aligned improvement plans, and effective forest management practices are highlighted as crucial across all regions except Dzukija. In Iedera's policy suggestions, subsidies are seen as necessary for those forest owners who are engaging in limited economic activities due to their forest conservation efforts. So, subsidies for the preservation of values remain more theoretical than practical there and, in such situations, compensating forest owners is essential.

Thus, similarities are also observed in response to questions about supporting future forests through today's forest-based sectors. The most similar positive outlooks are observed in North Karelia and Central Serbia, with similarities in neutral reactions observed in Iedera and Dzukija, while interestingly Xeromero reflects a mix of neutral and negative sentiments. A similar pattern, following a North-South gradient in perceptions about the impacts of climate change was observed in the questionnaire study by Roitsch et al. (2023). The study revealed that northern European countries (including Finland) had more balanced perceptions on the topic, whereas respondents from southern countries were more skeptical about the effects of climate change on forests. In our study, these perceptions are reflected in stakeholders' views on what types of measures to adopt (whether active forest management or policy and governance related) in order to respond to forest threats and ensure forest adaptation capacity.

However, addressing forest threats remains a common priority across all regions, with a consensus on the importance of timely interventions, ongoing monitoring, and the promotion of diverse tree species. While North Karelia and Xeromero adopt a broad approach to addressing threats, Iedera, Dzukija, and Central Serbia place more emphasis on specific actions and technical aspects in their forest management strategies. Considering all LLs, pests and damages emerge as primary concerns on a global scale. Moreover, governance challenges are apparent across various regions, notably with a significant focus on combating illegal logging in Romania and Serbia. In spite of increasingly negative climatic impacts, governance issues topped the agenda of those LLs, especially in relation to illegal logging. Existent research aligns with these results, pointing to the importance of governance questions in forest management and their role in Central-Eastern European countries (Bouriaud et al., 2013; Nichiforel et al., 2018, 2020). In Serbia and other Balkan countries, governance approaches have been mentioned as a key factor influencing illegal logging (Radosavljevic et al., 2024). Governance issues like administrative requirements and financial support for forestry were mentioned in all living labs. In Lithuania, illegal logging was also a concern for the respondents, which is in line with existing research (Bouriaud, 2005). The role of natural disturbances followed our expectations, with biotic disturbances topping the agenda in the North while fire was more important in Southern Europe. Conversely, in North Karelia, Finland, governance issues receive comparatively less attention. Stakeholders in the North favor solutions rooted in silviculture and species management, whereas in the South, societal management approaches are more prominently emphasised.

5. Conclusion

Synthesizing the above discussions, it is evident that effective governance mechanisms are essential for combating illegal activities and promoting sustainable management practices. Bridging the communication gap between foresters and the public, while fostering collaboration among stakeholders, including NGOs and local communities, is crucial for achieving meaningful progress. Additionally, as evidenced by the comparative analysis of illegal cutting issues across different LLs, understanding regional disparities is crucial for formulating targeted solutions to resolve this issue by taking necessary steps to promote sustainable forestry practices globally. Improving the administration of illegal logging areas, enforcement of laws and increasing the reporting of fraudulent timber data could enhance illegal logging control.

In conclusion, we can assert that regional strategies for forest adaptation should be favoured by policymakers, accounting for the differing forest threats, management approaches and perceptions found across the LL. Stakeholders advocate for region-specific solutions like mixed-species planting, pest control, and climate-smart forestry for North Karelia; forest management coordination, fire prevention for Dzukija; improved communication, law enforcement, skilled personnel, and ecological education for Idera and Central Serbia. These issues should be addressed by decision-makers to enhance forest management and resilience of these regions. In future research, we should focus on experimental studies on region-specific adaptive strategies that could help to manage and improve resilience of our forests in sustainable ways, while addressing the impacts of climate change.

In general, effective forestry management of these regions should prioritize the consideration of diverse socio-economic, environmental, and governance factors. By embracing a multifaceted approach and fostering inclusive decision-making processes, we can address regional forest threats, build resilient forests, and adapt to climate change, leading towards a more sustainable future for both our forests and communities.

CRediT authorship contribution statement

Tahamina Khanam: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Marina Peris-Llopis:** Writing – review & editing, Writing – original draft. **Mari Selkimäki:** Writing – review & editing. **Gediminas Brazaitis:** Writing – review & editing, Resources. **Blas Mola-Yudego:** Writing – review & editing. **Henrik Hartmann:** Writing – review & editing. **Alexandru Lucian Curtu:** Writing – review & editing, Resources. **Aureliu-Florin Hălălișan:** Writing – review & editing. **Žaklina Marjanovic:** Writing – review & editing, Resources. **Leena Leskinen:** Writing – review & editing, Resources. **Anastasia Pantera:** Writing – review & editing, Resources. **Marc Djahangard:** Writing – review & editing. **Rasoul Yousefpour:** Writing – review & editing. **Gailene Brazaityte:** Writing – review & editing. **Lana Kukobat:** Writing – review & editing. **Goran Trivan:** Writing – review & editing. **Zhun Mao:** Writing – review & editing. **Jo Van Brusselen:** Writing – review & editing. **Frank Berninger:** Writing – review & editing, Supervision, Project administration, Methodology, Conceptualization.

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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2025.125903.

Data availability

The data that has been used is confidential.

References

Abrams, J., Huber-Stearns, H., Steen-Adams, M., et al., 2021. Adaptive governance in a complex social-ecological context: emergent responses to a native forest insect outbreak. Sustain. Sci. 16, 53–68. https://doi-org.ezproxy.uef.fi:2443/10.1007/s11625-020-00843-5.

Abrudan, I.V., Marinescu, V., Ionescu, O., Ioras, F., Horodnic, S.A., Sestras, R.E., 2009. Developments in the Romanian forestry and its linkages with other sectors. Not. Bot. Horti Agrobot. Cluj-Napoca 37 (2), 14–21. https://doi.org/10.15835/nbha3723468.

Albulescu, A.C., Manton, M., Larion, D., Angelstam, P., 2022. The winding road towards sustainable forest management in Romania, 1989–2022: a case study of post-communist social–ecological transition. Land 11 (8), 1198. https://doi.org/10.3390/land11081198.

Allaire, J.J., Gandrud, C., Russell, K., Yetman, C.J., 2017. networkD3: D3 JavaScript network graphs from R. R package version 0.4. https://christophergandrud.github.io/networkD3/.

Baglama, J., Reichel, L., 2005. Augmented implicitly restarted Lanczos bidiagonalization methods. SIAM J. Sci. Comput. 27 (1), 19–42. https://doi.org/10.1137/04060593X.

Benoit, K., Watanabe, K., Wang, H., Nulty, P., Obeng, A., Müller, S., Khor, W., 2018. Quanteda: an R package for the quantitative analysis of textual data. J. Open Source Softw. 3 (30), 774. https://doi.org/10.21105/joss.00774.

Bergqvist, G., Bergström, R., Wallgren, M., 2014. Recent browsing damage by moose on Scots pine, birch and aspen in young commercial forests – effects of forage availability, moose population density and site productivity. Silva Fenn. 48, 10.14214/sf.1077.article1077org/10.14214/sf.1077.

Bouriaud, L., 2005. Causes of illegal logging in central and eastern Europe. Small-scale Forest Economics, Management and Policy 4, 269–291. https://doi.org/10.1007/s11842-005-0017-6.

Bouriaud, L., Nichiforel, L., Weiss, G., Bajraktari, A., Curovic, M., Dobsinska, Z., et al., 2013. Governance of private forests in Eastern and Central Europe: an analysis of forest harvesting and management rights. Ann. For. Res. 56 (1), 199–215. https://doi.org/10.15287/afr.2013.54.

Bouriaud, L., Marzano, M., Lexer, M., Nichiforel, L., Reyer, C., Temperli, C., et al., 2015. Institutional factors and opportunities for adapting European forest management to climate change. Reg. Environ. Change 15, 1595–1609. https://doi.org/10.1007/s10113-015-0852-8.

Bowditch, E.A., McMorran, R., Bryce, R., Smith, M., 2019. Perception and partnership: developing forest resilience on private estates. For. Pol. Econ. 99, 110–122. https://doi.org/10.1016/j.forpol.2017.12.004.

Braunschweiger, D., Ohmura, T., Schweier, J., Olschewski, R., Schulz, T., 2024. Preferences for proactive and reactive climate-adaptive forest management and the role of public financial support. For. Pol. Econ. 169, 103348. https://doi.org/10.1016/j.forpol.2024.103348.

Brukas, V., 2014. New world, old ideas—a narrative of the Lithuanian forestry transition. J. Environ. Pol. Plann. 17 (4), 495–515. https://doi.org/10.1080/1523908X.2014.993023.

Brukas, V., Felton, A., Lindbladh, M., Sallnäs, O., 2013. Linking forest management, policy and biodiversity indicators–A comparison of Lithuania and Southern Sweden. For. Ecol. Manag. 291, 181–189. https://doi.org/10.1016/j.foreco.2012.11.034.

Brunette, M., Hanewinkel, M., Yousefpour, R., 2020. Risk aversion hinders forestry professionals to adapt to climate change. Clim. Change 162 (4), 2157–2180. https://doi.org/10.1007/s10584-020-02751-0.

Ćirković, M.T., Brašanac, B.L., Hadrović, S., Eremija, S., Stajić, S., Đorđević, I., Rakonjac, L., 2022. Afforestation in the republic of Serbia: scope and trends from 2002 to 2021. Sustainable Forestry: Collection 85–86, 127–136. https://doi.org/10.5937/SustFor2285127C.

Conde, C., Lonsdale, K., Nyong, A., Aguilar, I., 2005. Engaging stakeholders in the adaptation process. Adaptation policy frameworks for climate change: Developing strategies, policies and measures 49–60. Retrieved from. https://www.preventionweb.net/files/7995_APF.pdf#page=52.

Csardi, G., Nepusz, T., 2006. The igraph software package for complex network research. InterJournal, Complex Systems 1695 (5), 1–9.

de Groot, M., Ogris, N., Kobler, A., 2018. The effects of a large-scale ice storm event on the drivers of bark beetle outbreaks and associated management practices. For. Ecol. Manag. 408, 195–201. https://doi.org/10.1016/j.foreco.2017.10.035.

de la Vega-Leinert, A.C., Schröter, D., Leemans, R., Fritsch, U., Pluimers, J., 2008. A stakeholder dialogue on European vulnerability. Reg. Environ. Change 8, 109–124. https://doi.org/10.1007/s10113-008-0047-7.

Donat, M.G., Renggli, D., Wild, S., Alexander, L.V., Leckebusch, G.C., Ulbrich, U., 2011. Reanalysis suggests long-term upward trends in European storminess since 1871. Geophys. Res. Lett. 38 (14). https://doi.org/10.1029/2011GL047995.

EFFIS, 2024. European forest fire information system. Area burned by wildfires in Greece from 2009 to 2023 (in hectares). https://effis.jrc.ec.europa.eu/apps/effis.statistics/estimates. (Accessed 5 February 2024).

ENoLL, 2025. Living Lab origins, developments and future perspectives. In: Schuurman, D., DeLosRios-White, M.I., Desole, M. (Eds.), Published by the European Network of Living Labs (ENoLL), 2025. https://doi.org/10.5281/zenodo.14764597. Licensed under CC BY-NC 4.0.

FAO (Food and Agricultural Organization of the United Nations) and UNECE (United Nations Economic Commission for Europe), 2021. Forest landscape restoration in eastern and south-East Europe: background study for the ministerial roundtable on forest landscape restoration and the bonn challenge. Retrieved from. https://unece.org/sites/default/files/2021-07/2106522E_WEB.pdf.

European Environment Agency, 2024. Climate-resilient forest management. Retrieved from https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/climate-resilient-forest-management. (Accessed 20 February 2025).

FAOLEX Database, 2025. Country profiles - Greece. Retrieved from. https://www.fao.org/faolex/country-profiles/general-profile/en/?iso3=GRC.

FAOLEX Database, Forest Law 12/2018. Serbia. Retrieved from. https://www.fao.org/faolex/country-profiles/general-profile/en/?iso3=SRB.

Feinerer, I., Hornik, K., 2018. Tm: text mining package. Retrieved from. https://CRAN.R-project.org/package=tm.

Fernandez-Carrillo, A., Patočka, Z., Dobrovolný, L., Franco-Nieto, A., Revilla-Romero, B., 2020. Monitoring bark beetle forest damage in Central Europe. A remote sensing approach validated with field data. Remote Sens. 12, 3634. https://doi.org/10.3390/rs12213634.

FINLEX. Laki metsätuhojen torjunnasta (Forest Damages Prevention Act) 1087/2013. Retrieved from https://www.finlex.fi/en/laki/kaannokset/2013/en20131087.pdf.

FINLEX. Metsälaki (Forest Act) 1093/1996. Retrieved from https://www.finlex.fi/en/laki/kaannokset/1996/en19961093_20140567.pdf.

FINLEX, Temporary act of the financing of sustainable forestry 34/2015. Act passed in Helsinki 23.1 Retrieved from https://www.finlex.fi/fi/laki/alkup/2015/20150034.

Focacci, M., Ferretti, F., De Meo, I., Paletto, A., Costantini, G., 2017. Integrating stakeholders' preferences in participatory forest planning: a pairwise comparison approach from Southern Italy. Int. For. Rev. 19 (4), 413–422. https://doi.org/10.1505/146554822272347.

Follo, G., Lidestav, G., Ludvig, A., Vilkriste, L., Hujala, T., Karppinen, H., et al., 2016. Gender in European forest ownership and management: reflections on women as "New forest owners". Scand. J. For. Res. 32 (2), 174–184. https://doi.org/10.1080/02827581.2016.1195866.

Forest Europe, 2020. State of Europe's forests 2020. https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf.

Forzieri, G., Girardello, M., Ceccherini, G., Spinoni, J., Feyen, L., Hartmann, H., et al., 2021. Emergent vulnerability to climate-driven disturbances in European forests. Nat. Commun. 12, 1081. https://doi.org/10.1038/s41467-021-21399-7.

Fuller, L., Quine, C.P., 2015. Resilience and tree health: a basis for implementation in sustainable forest management. Forestry: Int. J. Financ. Res. 89, 7–19. https://doi.org/10.1093/forestry/cpv046.

Glavonjic, B., Jovic, D., Kankaras, R., Vasiljevic, A., 2005. Forest and Forest Products Country Profile: Serbia and Montenegro, vol. 40. UN, Geneva. Timber and Forest Discussion Papers.

Gómez-Baggethun, E., 2021. Is there a future for indigenous and local knowledge? J. Peasant Stud. 49 (6), 1139–1157. https://doi.org/10.1080/03066150.2021.1926994.

Haatanen, A., den Herder, M., Leskinen, P., Lindner, M., Kurttila, M., Salminen, O., 2014. Stakeholder engagement in scenario development process–bioenergy production and biodiversity conservation in eastern Finland. J. Environ. Manag. 135, 45–53. https://doi.org/10.1016/j.jenvman.2014.01.009.

Haines-Young, R., Potschin, M.B., 2018. Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure.

Hallberg-Sramek, I., Nordström, E.M., Priebe, J., Reimerson, E., Mårald, E., Nordin, A., 2023. Combining scientific and local knowledge improves evaluating future scenarios of forest ecosystem services. Ecosyst. Serv. 60, 101512. https://doi.org/10.1016/j.ecoser.2023.101512.

Hartebrodt, C., Schmitt, J., 2016. Readiness of forest officers for adaptations in nForest management planning. Acta Silvatica Lignaria Hung. 12, 75–88. https://doi.org/10.1515/aslh-2016-0007.

Hartmann, H., Bastos, A., Das, A.J., Esquivel-Muelbert, A., Hammond, W.M., Martínez-Vilalta, J., McDowell, N.G., Powers, J.S., Pugh, T.A.M., Ruthrof, K.X., Allen, C.D., 2022. Climate change risks to global Forest health: emergence of unexpected events of elevated tree mortality worldwide. Annu. Rev. Plant Biol. 73 (1), 673–702. https://doi.org/10.1146/annurev-arplant-102820-012804.

Heikkilä, R., Hokkanen, P., Kooiman, M., Ayguney, N., Bassoulet, C., 2003. The impact of moose browsing on tree species composition in Finland. Alces 39, 203–213.

Ikonen, V.-P., Kilpeläinen, A., Zubizarreta-Gerendiain, A., Strandman, H., Asikainen, A., Venäläinen, A., Kaurola, J., Kangas, J., Peltola, H., 2017. Regional risk of wind damage in boreal forest under changing management and climate projections. Can. J. For. Res. 47, 1632–1645. https://doi.org/10.1139/cjfr-2017-0183.

IPCC (Intergovernmental Panel on Climate Change), 2001. CLIMATE CHANGE 2001 impacts, adaptation, and vulnerability. Contribution of working group II to the third assessment report of the intergovernmental panel on climate change. Retrieved from. https://www.ipcc.ch/site/assets/uploads/2018/03/WGII_TAR_full_report-2.pdf.

IPCC (Intergovernmental Panel on Climate Change), 2007. In: Parry, M.L., Canziani, O. F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 976pp. Retrieved from. https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf.

IPCC (Intergovernmental Panel on Climate Change), 2023. Summary for policymakers. In: Lee, H., Romero, J. (Eds.), Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team. IPCC, Geneva, Switzerland, pp. 1–34. https://doi.org/10.59327/IPCC/AR6-9789291691647.001.

Jockers, M.L., 2015. Syuzhet: extract sentiment and plot arcs from text. Retrieved from. https://github.com/mjockers/syuzhet.

Jovanović, M.M., Milanović, M.M., 2017. Remote Sensing and Forest Conservation: Challenges of Illegal Logging in Kursumlija Municipality (Serbia). Forest Ecology and Conservation, pp. 99–118. https://doi.org/10.5772/67666.

Kangas, A., Saarinen, N., Saarikoski, H., Leskinen, L.A., Hujala, T., Tikkanen, J., 2010. Stakeholder perspectives about proper participation for regional forest programmes in Finland. For. Pol. Econ. 12 (3), 213–222. https://doi.org/10.1016/j.forpol.2009.10.006.

Kassioumis, K., Papageorgiou, K., Christodoulou, A., Blioumis, V., Stamou, N., Karameris, A., 2004. Rural development by afforestation in predominantly agricultural areas: issues and challenges from two areas in Greece. For. Pol. Econ. 6 (5), 483–496. https://doi.org/10.1016/S1389-9341(02)00079-5.

Katopodis, T., Markantonis, I., Vlachogiannis, D., Politi, N., 2021. Assessing climate change impacts on wind characteristics in Greece through high resolution regional climate modelling. Renew. Energy 179, 427–444. https://doi.org/10.1016/j.renene.2021.07.061.

Keskitalo, E.C.H., 2011. How can forest management adapt to climate change? Possibilities in different forestry systems. Forests 2 (1), 415–430. https://doi.org/10.3390/f2010415.

Kirilenko, A.P., Sedjo, R.A., 2007. Climate change impacts on forestry. Proc. Natl. Acad. Sci. 104 (50), 19697–19702. https://doi.org/10.1073/pnas.0701424104.

Klavina, D., Bruna, L., Zaluma, A., Burnevica, N., Polmanis, K., Gaitnieks, T., Piri, T., 2021. Infection and spread of root rot caused by Heterobasidion parviporum in Picea abies stands after thinning: case studies on former pasture and meadow lands. Environ. Sci. Proc. 3, 2. https://doi.org/10.3390/IECF2020-07950.

Klopčič, M., Poljanec, A., Dolinar, M., Kastelec, D., Bončina, A., 2020. Ice-storm damage to trees in mixed Central European forests: damage patterns, predictors and susceptibility of tree species. Forestry: Int. J. Financ. Res. 93 (3), 430–443. https://doi.org/10.1093/forestry/cpz068.

Kolström, M., Lindner, M., Vilén, T., Maroschek, M., Seidl, R., Lexer, M.J., et al., 2011. Reviewing the science and implementation of climate change adaptation measures in European forestry. Forests 2, 961–982. https://doi.org/10.3390/f2040961.

Koulelis, P.P., Proutsos, N., Solomou, A.D., Avramidou, E.V., Malliarou, E., Athanasiou, M., et al., 2023. Effects of climate change on Greek forests: a review. Atmosphere 14 (7), 1155. https://doi.org/10.3390/atmos14071155.

Kuhn, M., 2021. Caret: classification and regression training. Retrieved from. https://CRAN.R-project.org/package=caret.

Lazdinis, M., Carver, A.D., Lazdinis, I., Paulikas, V.K., 2009. From union to union: forest governance in a post-soviet political system. Environ. Sci. Pol. 12 (3), 309–320. https://doi.org/10.1016/j.envsci.2008.12.004.

Liaw, A., Wiener, M., 2002. Classification and regression by randomForest. R. News 2, 18–22.

Lietuvos Respublikos miškų įstatymas (Forest Law of the Republic of Lithuania) Nr. I-671, 1994. Retrieved from. https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.6036/asr.

Lindner, M., Fitzgerald, J.B., Zimmermann, N.E., Reyer, C., Delzon, S., Van Der Maaten, E., Schelhaas, M.-J., Lasch, P., Eggers, J., Van Der Maaten-Theunissen, M., Suckow, F., Psomas, A., Poulter, B., Hanewinkel, M., 2014. Climate change and European forests: what do we know, what are the uncertainties, and what are the implications for forest management? J. Environ. Manag. 146, 69–83. https://doi.org/10.1016/j.jenvman.2014.07.030.
Locatelli, B., Brockhaus, M., Buck, A., Thompson, I., 2010. Forests and Adaptation to Climate Change: Challenges and Opportunities. IUFRO, pp. 21–42.
Lovrić, M., Da Re, R., Vidale, E., Prokofieva, I., Wong, J., Pettenella, D., et al., 2020. Non-wood forest products in Europe–A quantitative overview. For. Pol. Econ. 116, 102175. https://doi.org/10.1016/j.forpol.2020.102175.
Ludvig, A., Öllerer, B., Aubram, T., 2024. Connecting gender balance, crisis resistance and innovativeness in the forestry sector: women in leadership and management. Environ. Sci. Pol. 161, 103890. https://doi.org/10.1016/j.envsci.2024.103890.
Makrickiene, E., Brukas, V., Brodrechtova, Y., Mozgeris, G., Sedmák, R., Šálka, J., 2019. From command-and-control to good forest governance: a critical interpretive analysis of Lithuania and Slovakia. For. Pol. Econ. 109, 102124. https://doi.org/10.1016/j.forpol.2019.102024.
Manton, M., Ruffner, C., Kibirkštis, G., Brazaitis, G., Marozas, V., Pukienė, R., et al., 2022. Fire occurrence in hemi-boreal forests: exploring natural and cultural Scots pine fire regimes using dendrochronology in Lithuania. Land 11, 260. https://doi.org/10.3390/land11020260.
Marinchescu, M., Halalisan, A.F., Bogdan, P.O.P.A., Abrudan, I.V., 2014. Forest administration in Romania: frequent problems and expectations. Not. Bot. Horti Agrobot. Cluj-Napoca 42 (2), 588–595. https://doi.org/10.15835/nbha4229738.
Martikainen, P., Siitonen, J., Kaila, L., Punttila, P., 1996. Intensity of forest management and bark beetles in non-epidemic conditions: a comparison between Finnish and Russian Karelia. https://doi.org/10.1111/j.1439-0418.1996.tb01603.x.
Metsäkeskus, Online. Forest certification. https://www.metsakeskus.fi/en/forest-use-and-ownership/rights-and-obligations/forest-certification. (Accessed 26 February 2025).
Metsäkeskus, 2024. Metka-tuki metsänhoitoon. https://www.metsakeskus.fi/fi/metsatalouden-tuet/metka-tuet. (Accessed 6 February 2024).
Meyer, D., Dimitriadou, E., Hornik, K., Weingessel, A., Leisch, F., 2019. e1071: Misc Functions of the Department of Statistics. Probability Theory Group (Formerly: E1071), TU Wien. Retrieved from. https://CRAN.R-project.org/package=e1071.
Milutinović, S., 2024. Policy framework evaluation of climate change adaptation in the republic of Serbia. Teme-Časopis za Društvene Nauke 48 (3), 761–775. https://doi.org/10.22190/TEME240401043M.
Miško atkūrimo ir įveisimo nuostatai (The Rules on Forest restoration and afforestation) Nr D1-199, 2008. Retrieved from. https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.318353/asr.
Miško kirtimo taisyklės (Forest Felling Regulations) Nr. D1-690, 2010. Retrieved from. https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.364764/asr.
Miško sanitarinės apsaugos taisyklės (Forest Sanitary Protection Regulations Nr. D1-204, 2007. Retrieved from. https://e-seimas.lrs.lt/portal/legalAct/lt/TAD/TAIS.295781/SNriwDYMAD.
Nagel, T.A., Mikac, S., Dolinar, M., Klopcic, M., Keren, S., Svoboda, M., et al., 2017. The natural disturbance regime in forests of the Dinaric Mountains: a synthesis of evidence. For. Ecol. Manag. 388, 29–42. https://doi.org/10.1016/j.foreco.2016.07.047.
Nichiforel, L., Keary, K., Deuffic, P., Weiss, G., Thorsen, B.J., Winkel, G., et al., 2018. How private are Europe's private forests? A comparative property rights analysis. Land Use Policy 76, 535–552. https://doi.org/10.1016/j.landusepol.2018.02.034.
Nichiforel, L., Deuffic, P., Thorsen, B.J., Weiss, G., Hujala, T., Keary, K., et al., 2020. Two decades of forest-related legislation changes in European countries analysed from a property rights perspective. For. Pol. Econ. 115, 102146. https://doi.org/10.1016/j.forpol.2020.102146.
Nijnik, M., Nijnik, A., Lundin, L., Staszewski, T., Postolache, C., 2010. A study of stakeholders' perspectives on multi-functional forests in Europe. For. Trees Livelihoods 19, 341–358. https://doi.org/10.1080/14728028.2010.9752677.
Nikinmaa, L., de Koning, J.H., Derks, J., Grabska-Szwagrzyk, E., Konczal, A.A., Lindner, M., et al., 2024. The priorities in managing forest disturbances to enhance forest resilience: a comparison of a literature analysis and perceptions of forest professionals. For. Pol. Econ. 158, 103119. https://doi.org/10.1016/j.forpol.2023.103119.
Nikula, A., Hallikainen, V., Jalkanen, R., Hyppönen, M., Mäkitalo, K., 2008. Modelling the factors predisposing Scots pine to moose damage in artificially regenerated sapling stands in Finnish Lapland. Silva Fenn. 42 (4), 587–603. https://doi.org/10.14214/sf.235.
Nykänen, M.-L., Peltola, H., Quine, C., Kellomäki, S., Broadgate, M., 1997. Factors affecting snow damage of trees with particular reference to European conditions. Silva Fenn. 31, 193–213.
Patacca, M., Lindner, M., Lucas-Borja, M.E., Cordonnier, T., Fidej, G., Gardiner, B., Hauf, Y., Jasinevičius, G., Labonne, S., Linkevičius, E., Mahnken, M., 2023. Significant increase in natural disturbance impacts on European forests since 1950. Glob. Change Biol. 29, 1359–1376. https://doi.org/10.1111/gcb.16531.
Pedersen, T.L., 2024. Ggraph: an implementation of grammar of graphics for graphs and networks. Retrieved from. https://CRAN.R-project.org/package=ggraph.
Peltola, H., Heinonen, T., Kangas, J., Venäläinen, A., Seppälä, J., Hetemäki, L., 2022. Climate-smart forestry case study: Finland. In: Hetemäki, L., Kangas, J., Peltola, H. (Eds.), Forest Bioeconomy and Climate Change, Managing Forest Ecosystems, vol. 42. Springer, Cham. https://doi.org/10.1007/978-3-030-99206-4_11.
Peters, J.M.R., López, R., Nolf, M., Hutley, L.B., Wardlaw, T., Cernusak, L.A., Choat, B., 2021. Living on the edge: a continental-scale assessment of forest vulnerability to drought. Glob. Change Biol. 27, 3620–3641. https://doi.org/10.1111/gcb.15641.
Pulgarin Diaz, J.A., Melin, M., Ylioja, T., Lyytikäinen-Saarenmaa, P., Peltola, H., Tikkanen, O.P., 2024. Relationship between stand and landscape attributes and Ips typographus salvage loggings in Finland. https://doi.org/10.14214/sf.23069.
Radosavljevic, M., Rogelja, T., Masiero, M., Comic, D., Glavonjic, B., Pettenella, D., 2024. Institutional and actor-oriented factors influencing timber legality in selected Western Balkan countries: multiple case study of Croatia, Montenegro, Serbia, Slovenia, and the Republic of Srpska (Bosnia and Herzegovina). Montenegro, Serbia, Slovenia, and the Republic of Srpska (Bosnia and Herzegovina). https://doi.org/10.1016/j.forpol.2024.103261.
Rametsteiner, E., Eichler, L., Berg, J., Aggestam, F., Binda Zane, E., Plumet, C., Rademaekers, R., 2009. Shaping forest communication in the European Union: public perceptions of forests and forestry. ECORYS Final Report. Retrieved from https://agriculture.ec.europa.eu/document/download/e87c7f09-a97e-4690-9215-041497bf4df2_en?filename=ext-study-forest-comm-finalreport_2009_en.pdf.
Ranacher, L., Lähtinen, K., Järvinen, E., Toppinen, A., 2017. Perceptions of the general public on forest sector responsibility: a survey related to ecosystem services and forest sector business impacts in four European countries. For. Pol. Econ. 78, 180–189. https://doi.org/10.1016/j.forpol.2017.01.016.
Reid, W.V., Mooney, H.A., Cropper A. et al. 2005. MEA (Millennium Ecosystem Assessment). Ecosystems and Human Well-being: Synthesis Report. Island Press. Retrieved from https://www.millenniumassessment.org/documents/document.356.aspx.pdf.
Rogelja, T., Shannon, M.A., 2017. Structural power in Serbian anti-corruption forest policy network. For. Pol. Econ. 82, 52–60. https://doi.org/10.1016/j.forpol.2017.05.008.
Roitsch, D., Abruscato, S., Lovrić, M., Lindner, M., Orazio, C., Winkel, G., 2023. Close-to-nature forestry and intensive forestry–Two response patterns of forestry professionals towards climate change adaptation. For. Pol. Econ. 154, 103035. https://doi.org/10.1016/j.forpol.2023.103035.
Romanian Government, 2022. Governmental Decision No. 1227/2022 Regarding the Approval of the National Forest Strategy 2030.
Romanian parliament, 2025. The forest code (law no. 331/2024). Retrieved from. https://legislatie.just.ro/Public/DetaliiDocumentAfis/293218.
Romeiro, J.M.N., Eid, T., Antón-Fernández, C., Kangas, A., Trømborg, E., 2022. Natural disturbances risks in European Boreal and Temperate forests and their links to climate change–A review of modelling approaches. For. Ecol. Manag. 509, 120071. https://doi.org/10.1016/j.foreco.2022.120071.
Rummukainen, M., 2012. Changes in climate and weather extremes in the 21st century. Wiley Interdisciplinary Reviews: Clim. Change 3, 115–129. https://doi.org/10.1002/wcc.160.
Rüttinger, L., von Ackern, P., Gordon, N., Foong, A., 2021. Regional Assessment for South-Eastern Europe: Security Implications of Climate Change. Organization for Security and Co-operation in Europe (OSCE). Retrieved from. https://www.osce.org/files/f/documents/a/a/484148.pdf.
Schelhaas, M.J., Fridman, J., Hengeveld, G.M., Henttonen, H.M., Lehtonen, A., Kies, U., et al., 2018. Actual European forest management by region, tree species and owner based on 714,000 re-measured trees in national forest inventories. PLoS One 13, e0207151. https://doi.org/10.1371/journal.pone.0207151.
Scriban, R.E., Nichiforel, L., Bouriaud, L.G., Barnoaiea, I., Cosofret, V.C., Barbu, C.O., 2019. Governance of the forest restitution process in Romania: an application of the DPSIR model. For. Pol. Econ. 99, 59–67. https://doi.org/10.1016/j.forpol.2017.10.018.
Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., et al., 2017. Forest disturbances under climate change. Nat. Clim. Change 7, 395–402. https://doi.org/10.1038/nclimate3303.
Seneviratne, S.I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S.M., Wehner, M., Zhou, B., 2021. Weather and climate extreme events in a changing climate. In: Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R., Zhou, B. (Eds.), Climate Change 2021: the Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1513–1766. https://doi.org/10.1017/9781009157896.013.
Seppälä, R., Buck, A., Katila, P., 2009. Adaptation of forests and people to climate change. A global assessment report. IUFRO World Series 22, 224. https://www.cbd.int/doc/meetings/for/wscb-fbdcc-01/other/wscb-fbdcc-01-oth-04-en.pdf.
Sjöberg, D., 2018. Ggsankey: create Sankey diagrams with ggplot2. Retrieved from. https://github.com/davidsjoberg/ggsankey.
Sousa-Silva, R., Verbist, B., Lomba, Â., Valent, P., Suškevičs, M., Picard, O., et al., 2018. Adapting forest management to climate change in Europe: linking perceptions to adaptive responses. For. Pol. Econ. 90, 22–30. https://doi.org/10.1016/j.forpol.2018.01.004.
State Forest Service, 2022. Lithuanian statistical yearbook of forestry. Ministry of Environment. Retrieved from. https://amvmt.lrv.lt/public/canonical/1739857706/1714/Misku%20ukio%20statistika%202022%20(6%20sk).pdf
Sulik, S., Kejna, M., 2020. The origin and course of severe thunderstorm outbreaks in Poland on 10 and 11 August. Bull. Geogr. Phys. Geogr. 18, 25–39. https://doi.org/10.2478/bgeo-2020-0003.
Suvanto, S., Lehtonen, A., Nevalainen, S., Lehtonen, I., Viiri, H., Strandström, M., Peltoniemi, M., 2021. Mapping the probability of forest snow disturbances in Finland. PLoS One 16, e0254876. https://doi.org/10.1371/journal.pone.0254876.

Temperli, C., Bugmann, H., Elkin, C., 2012. Adaptive management for competing forest goods and services under climate change. Ecol. Appl. 22 (8), 2065–2077. https://doi.org/10.1890/12-0210.1.

Tsioras, P.A., 2010. Perspectives of the forest workers in Greece. iFor. Biogeosci. For. 3 (5), 118. https://doi.org/10.3832/ifor0547-003.

UNESCO, 2017. Local Knowledge, Global Goals. UNESCO, Paris, p. 48. Retrieved from. https://unesdoc.unesco.org/ark:/48223/pf0000259599.

Venäläinen, A., Lehtonen, I., Laapas, M., Ruosteenoja, K., Tikkanen, O.P., Viiri, H., Ikonen, V.P., Peltola, H., 2020. Climate change induces multiple risks to boreal forests and forestry in Finland: a literature review. Glob. Change Biol. 26 (8), 4178–4196. https://doi.org/10.1111/gcb.15183.

Veteli, T.O., Koricheva, J., Niemelä, P., Kellomäki, S., 2006. Effects of forest management on the abundance of insect pests on Scots pine. For. Ecol. Manag. 231 (1–3), 214–217. https://doi.org/10.1016/j.foreco.2006.05.048.

Wickham, H., 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag, New York.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L.D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T.L., Miller, E., Bache, S.M., Müller, K., Ooms, J., Robinson, D., Seidel, D.P., Spinu, V., Takahashi, K., Vaughan, D., Wilke, C., Woo, K., Yutani, H., 2019. Welcome to the tidyverse. J. Open Source Softw. 4 (43), 1686. https://doi.org/10.21105/joss.01686.

Wickham, H., François, R., Henry, L., Müller, K, 2020. Dplyr: a grammar of data manipulation. Retrieved from. https://CRAN.R-project.org/package=dplyr.

Wickham, H., Vaughan, D., Girlich, M., Ushey, K., 2024. Tidyr: tidy messy data. Retrieved from. https://cran.r-project.org/web/packages/tidyr/index.html.

Woodward, S., Stenlid, J., Karjalainen, R., Huttermann, A., 1998. Heterobasidion Annosum: Biology, Ecology, Impact and Control. CAB International, Oxon, p. 589. ISBN 0 85199 275 7.

Yousefpour, R., Hanewinkel, M., 2015. Forestry professionals' perceptions of climate change, impacts and adaptation strategies for forests in south-west Germany. Clim. Change 130 (2), 273–286. https://doi.org/10.1007/s10584-015-1330-5.

Yousefpour, R., Temperli, C., Jacobsen, J.B., Thorsen, B.J., Meilby, H., Lexer, M.J., et al., 2017. A framework for modeling adaptive forest management and decision making under climate change. Ecol. Soc. 22 (4). https://www.jstor.org/stable/26799027.