Annals of Forest Science (2021) 78: 60
https://doi.org/10.1007/s13595-021-01044-5

RESEARCH PAPER

Multi-actor perspectives on afforestation and reforestation strategies in Central Europe under climate change

Reneema Hazarika[1] · Andreas Bolte[2] · Dagmar Bednarova[3] · Debojyoti Chakraborty[1] · Julian Gaviria[4] · Monika Kanzian[5] · Jan Kowalczyk[6] · Magdalena Lackner[7] · Milan Lstibůrek[8] · Roman Longauer[3] · Lazlo Nagy[9] · Ivana Tomášková[8] · Silvio Schueler[1]

Received: 14 September 2020 / Accepted: 10 February 2021 / Published online: 5 July 2021

Abstract

• ***Key message*** **Understanding forest genetic diversity and national legislation on trade and utilization of forest reproductive material (FRM) are key aspects for management and adapting forests to climate change. Despite concerns about the negative effects of climate change on forests, awareness of the role of genetic diversity in climate change adaptation is limited.**

• ***Context*** Adaptive forest management strategies such as afforestation and reforestation depend on the selection of appropriate FRM and their knowledge among the relevant stakeholders.

• ***Aims*** To analyze the perceptions among the forest, conservation, and nursery managers of six Central European countries on awareness of genetic diversity and practical and legislative issues of afforestation and reforestation in climate change.

• ***Methods*** A survey was conducted with structured questionnaires.

• ***Results*** Around 80% of the respondents believe in climate change. Local FRM is preferred for reforestation. Although 80% of the conservation and forest managers perceive the importance of forest genetic diversity, almost half of them feel unaware of it. The majority of respondents believe that national and European legislation on seed transfer is not adapted to climate change.

• ***Conclusion*** Inadequacy in the awareness of genetic diversity and policies on FRM is likely to influence forest adaptation to climate change in Europe.

Keywords Afforestation-reforestation · Climate change · Perception · Forest reproductive material · Genetic diversity

1 Introduction

Climate change has long-lasting implications on forest ecosystems demanding urgent adaptation and mitigation action by governments and civil societies across the globe (Osberghaus et al. 2012; IPCC 2018). Effects of climate change on European forests may include changes in productivity (Reyer et al. 2014), intensifying disturbance and drought events (Allen et al. 2010; Seidl et al. 2017), changing carbon budgets (Jandl et al. 2019), and altered species compositions with significant changes of the economic value of forests (Hanewinkel et al. 2013).

Among a variety of different management options, afforestation and reforestation can contribute significantly to both mitigation and forest adaptation (Nilsson and Schopfhauser 1995; Reyer et al. 2014; IPCC 2018; Spathelf et al. 2018). Afforestation programs have been widely claimed as nature-based

Handling Editor: Marta Benito Garzon

This paper is part of the Topical Collection on *Assisted Migration and Forest Seed Transfer*

Contribution of the co-authors RH: Analyzed the survey data and wrote the manuscript;
DC: Supported in statistical analysis;
AB, DB, JG, MK, JK, M Lackner, M Lstibůrek, RL, LN, and IT: Supported in survey dissemination; and
SS: Conceived the study, helped in data analysis, and edited the manuscript.

✉ Reneema Hazarika
reneema.hazarika@bfw.gv.at

Extended author information available on the last page of the article

solutions to remove carbon from the atmosphere (Griscom et al. 2017; IPCC 2018; Bastin et al. 2019) although their efficacy is controversial from a scientific point of view (Grainger et al. 2019; Lewis et al. 2019; Popkin 2019). Forest transformation and reforestation programs aiming to maintain the provision of ecosystem services in the future may include change in species composition, new tree species mixtures, non-native tree species, and selecting adapted forest reproductive materials (Bolte et al. 2009; Keenan 2015; Andersson et al. 2017; Luyssaert et al. 2018).

Since the implementation of the EU directive on trade and utilization of forest reproductive material (FRM) (European Council Directive 1999/105/EC), afforestation and reforestation activities mainly implied native tree species and local seed provenances following the principle of "local is best" (MCPFE 1993). However, because climate change is predicted to occur much faster than the natural ability of tree species to adapt and to migrate (Savolainen et al. 2007; Aitken et al. 2008), the link between the respective site climate and local adaptations is at risk of being disrupted (Aitken and Whitlock 2013; Hamann and Aitken 2013; Keenan 2015; Polechová and Barton 2015). To overcome the increasing risk of maladaptation of forest trees (Bradley St Clair et al. 2007; Frank et al. 2017), assisted migration and assisted gene flow were suggested as reliable adaptive management measures (Aitken and Whitlock 2013; Benito-Garzón and Fernández-Manjarrés 2015; Sáenz-Romero et al. 2016; Peterson St-Laurent et al. 2018; Messier et al. 2019). While assisted migration aims at facilitating the colonization of forest tree species into new habitats with a suitable climate, assisted gene flow aims at the managed translocation of preadapted seeds and seedlings within the current species range to facilitate rapid adaptation to climate change and improve the long-term prospects of trees and its related communities. A further management measure often discussed in Europe is the planting and utilization of non-native tree species, which are better adapted to the expected climate conditions (Klimo et al. 2000; Bolte et al. 2009; Lindner et al. 2010; Temperli et al. 2012; Chakraborty et al. 2015; Jandl et al. 2019), because within some regions, the natural tree species and tree genetic diversity in Europe have already been seriously reduced due to the legacies of prehistoric glaciations (Latham & Ricklefts 1993; Malcolm et al. 2002; Svenning 2003; Tollefsrud et al. 2008), while other regions are high in forest biodiversity (e.g., Petit et al. 2003). Besides the need for empirical scientific evidence, the implementation of assisted migration also depends on national and international policies for forest seed transfer as well as on the perception and willingness of the involved actors and businesses. In Europe, trade and utilization of forest reproductive materials (FRMs) of most tree species involve elaborate national and international legal frameworks such as the European Council Directive 1999/105/EC (European Commission 2000) and its derived national legislations as well as the "Scheme for the Control of Forest Reproductive Material Moving in International Trade" of the Organization for Economic Cooperation and Development (OECD 2012). These regulations were mostly designed under the "local is best" paradigm, when conservation of regional forest genetic resources was the major objective at that time and climate change was not considered such an urgent issue. The scope of the Directive is limited to 47 species and artificial hybrids important for forestry purposes (listed in Annex-1 of the directive). The Council Directive on the marketing of FRM is harmonized with the "OECD Scheme for the Certification of Forest Reproductive Material Moving in International Trade." Generally, a supplier needs an official license for trading material for forestry purposes. In certain countries of Central Europe like Czechia, there are restrictions related to the marketing of FRM, based on the protection of valuable local genetic resources.

Existing legislations influence a wide range of actors from different branches of forest restoration and conservation, such as forest managers, forest-nursery managers, and conservation managers. Therefore, understanding the perceptions of the involved practitioners and decision-makers on issues such as climate change and its effects on forest ecosystems, the awareness of genetic diversity, and the current legislation on FRM is crucial.

Generally, adapting forests to climate change is a challenging task and requires concordance between the understandings and desires of the stakeholder. This requires harmony between sociopolitical aspects such as legislation and the management aspects of adaptation such as silviculture, choice of species, and land-use planning. The stakeholder perceptions on the expected effects of climate change and their willingness to implement changes influence forestry management, design, and policies (Arbuckle et al. 2013; Lenart and Jones 2014). Perception studies in forestry usually focus on issues such as management for risk reduction, effects of climate change, and its likely economic outcomes (Hajjar et al. 2014; Halofsky et al. 2018; Jalonen et al. 2018; Laakkonen et al. 2018; Sousa-Silva et al. 2018). However, studies focusing on the management as well as legislative issues related to trade and utilization of forest reproductive materials (FRM) are rare in Europe (Jensen et al. 2019). In a recent study, Vinceti et al. (2020) examined the perceptions of forest owners and managers of 15 European countries and found that the respondents prefer FRMs from local sources over foreign planting materials and are aware of the potential benefits of using genetic diversity as an adaptive management strategy. Their study also reported that more efforts are needed in understanding the perception of multiple actors to develop advisory for adapting forests to climate change.

We aim at understanding the perceptions of forest managers, conservation managers, and nursery managers with regards to (a) the effects of climate change, (b) current practices in selecting FRM, and (c) the importance of genetic diversity and the influence of legislation on utilizing FRM under climate change. These perceptions were collected via surveys conducted in six Central European countries considering the various national languages of the respondents.

2 Materials and methods

2.1 Survey design

Structured questionnaires (Bryman 2012) were used to collect primary data from the six central European countries: Austria, Germany, Czechia, Hungary, Poland, and Slovakia (Hazarika et al. 2020). These central European Countries have similarities in their forest tree species composition, have a long tradition of forest restoration, and have a comparable legal framework to control trade and utilization of FRMs. Three questionnaires (Tables 6, 7, 8 in Appendix) were designed, one for each of the three groups of respondents namely forest managers, conservation managers, and nursery managers. Forest managers are those working for the preservation and protection of forests and woodlands. They are responsible for the management of areas used for timber production, public recreation, and natural preservation. The conservation managers are considered as those managing the national parks and protected areas. Here, nursery managers are those who manage forest nurseries. Based on these criteria, the respondents identified their role as either a conservation manager, forest manager, or nursery manager and selected the respective questionnaire to respond.

This survey was launched online for 4 months from May 2017 until August 2017. As practitioners in all six countries mainly communicate in their local language, all three questionnaires were translated from English into the five local languages of the partner countries, i.e., German (for both Austria and Germany), Hungarian, Czech, Polish, and Slovakian. In total, the conservation managers were asked 12 questions; the forest managers, 14 questions; and 10 questions to the nursery managers (Tables 6, 7, 8 in Appendix). These questions were grouped into three categories: (1) perceptions on the effects of climate change on forests and their forest-related businesses, (2) current practice of the use of FRM for afforestation and reforestation, and (3) perceptions on the importance of genetic diversity and the adaptation of current national and European legislations on FRM in climate change (Table 1, Table 9 in the Appendix). Most questions were common across the three groups of respondents, while some questions were specific to each group (Table 9 in the Appendix).

In addition to online access, for a wider dispersal of the survey, the questionnaires were also disseminated through email lists, social media platforms, targeting organizations, and forest SMEs, involved in the forest management, forest nursery, and forest conservation, triggering an exponential non-discriminative snowball sampling (Goodman 1961) also known as chain referral sampling. The questions were mainly multiple choice, and the participants had the option of choosing one or more relevant options to certain questions

Table 1 Question asked to analyze (i) the perceptions on the effects of climate change on forests, (ii) current practice of reforestation/afforestation, and (iii) perceptions on the importance of genetic diversity

Perceptions of climate change
1. Do you expect changes of your conservation area due to climate change?
2. If yes, will it have any influence on the conservation objectives?
3. If yes, what changes are you expecting?
Current practice of reforestation/afforestation for promoting stability of forest ecosystem under climate change
1. Do you consider planting and reforestation activities to improve forest ecosystem services, in particular, to increase forest stability in climate change?
2. If yes, how do you select forest reproductive material?
3. Do you take national regions of provenance into account when selecting the planting material?
4. Have you ever used planting material in the area from other regions outside your country?
5. If yes, why?
6. How many plants are you selling per year?
Perceptions of genetic diversity and adaptation of national and regional policies on FRM in climate change
1. Do you consider genetic diversity of forest trees to be important?
2. Do you consider forest genetic diversity in your management plans?
3. Do you feel you are well-informed about forest genetic diversity?
4. Do you think the national legislation on seed transfer is well-adapted in times of climate change?
5. Do you think the European legislation on seed transfer is well-adapted in times of climate change?

Table 2 Details of the participants in the local survey along with the basic data on forest ownership

Countries	Respondents			
	Forest managers (FM)	Conservation managers (CM)	Nursery managers (NM)	Total
Austria	107	12	19	138
Czechia	22	5	10	37
Germany	119	7	8	134
Hungary	19	1	31	51
Poland	192	17	166	375
Slovakia	50	7	23	80
Total	510	49	257	815

or also to "not respond" to certain questions according to their convenience. To avoid exclusion of participants with limited access and competencies in online surveys, forms were also sent by post and received back as hand-filled forms or via email, particularly in Austria, Hungary, and Poland. Data received on hand-filled forms and via email were processed into the official online survey system.

2.2 Statistical analysis

The results from the survey were first assessed through exploratory analyses. For a more comprehensive understanding of the views and perceptions, multiple correspondence analysis (MCA) was used to understand patterns or associations, if any, in the perceptions between countries and among respondent groups. MCA is analogous to principal component analysis for quantitative variables and aims at reducing the dimensions in the qualitative data to detect associations, patterns, and relations and has been used in studies for understanding perceptions on climate change (Ali et al. 2018; Brunette et al. 2018). The result of the MCA was depicted as MCA biplot, which shows the grouping, if any, within and between individuals and variable categories. MCA analysis was done with the statistical software R (R Core Team 2016) using the package- "*factoextra*" (Kassambara and Mundt 2017) to implement and visualize the results of MCA. The significance in the MCA analysis was tested with a Wilks test.

3 Results

In total, 815 participants from six Central European countries (Austria, Germany, Poland, Czechia, Slovakia, and Hungary) had responded to this survey (Table 2). The number of survey participants varied between the three groups of respondents and between the countries, with forest managers showing the highest and conservation managers the lowest number of responses (Table 2).

3.1 Perceptions of the likely effects of climate change

Although on average, across countries (83% of conservation managers, 87% of forest managers, and 85% of nursery managers) perceived that climate change is likely to influence their operational area and businesses (Table 3), there are some variations between the countries. It was observed that between 93 and 100% of the respondents among all three managers in Austria, Germany, and Hungary expected changes in their managed land and businesses, due to global warming, whereas, in Poland, Czechia, and Slovakia, this percentage ranged only between 40 and 88% of the respondents (Table 3).

On average, 26% of the conservation managers believed that their management objectives will be affected by climate change, whereas, among the forest managers, 62% believed that their management objectives will require adjustment (Fig. 1, Tables 10 and 11 in Appendix). Moreover, between 40 and 80% of the forest managers expect that management objectives will be more difficult to reach, while among the conservation managers, less than 40% expect such negative consequences (Fig. 1, Tables 10 and 11 in Appendix).

Furthermore, the nursery managers were asked more specifically about the expected effects of climate change on their operational areas (Fig. 2; Table 12 in the Appendix). With decreasing order of relevance, nursery managers from all countries expect (1) increasing demand for other tree species with a change from conifers to broadleaved trees; (2) increasing demand for other provenances with higher resistance to climate extremes or new pest/diseases; and (3) increasing demand for non-native tree species. The perception of the

Table 3 Differences in perception of the conservation managers (CM), forest managers (FM), and nursery managers (NM) on the effects of climate change on their respective operational areas and businesses. *n* = number of respondents for that specific question (total number of respondents may vary for each question as every participant might/might not respond to every question)

Group	*n*	Responses (% of yes)						
		Austria	Czechia	Germany	Hungary	Poland	Slovakia	Mean
Do you expect changes in your conservation area, forest area or nursery business due to climate change?								
CM	49	100	40	100	100	88	71	83
FM	510	95	82	93	100	69	84	87
NM	257	95	70	100	97	69	78	85

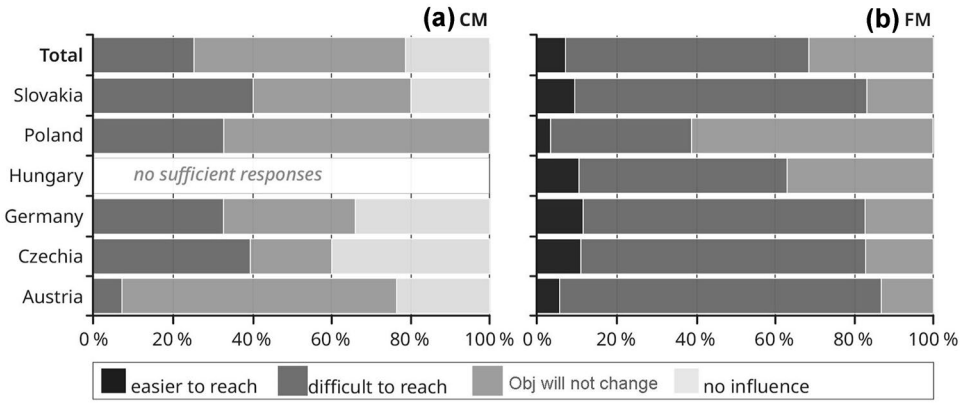

Fig. 1 The expected effect of climate change on conservation and forest management objectives as expressed by (**a**) conservation managers (CM), (**b**) forest managers (FM), and (**c**) nursery managers (NM). Total (**a** and **b**) refers to a combined response of all CM and FM across countries

nature of expected changes for nursery managers also varied among countries. In Austria and Germany, increasing demand for non-native tree species such as a Douglas fir and Red oak was observed as the highest-ranked perception (Fig. 2). Nursery managers in Poland and Hungary rather expect higher demand for more resistant provenances, and in Slovakia, they were found to be more inclined towards a higher demand for provenances from outside the country. Only a few among this group of respondents were found to expect a decreasing demand for FRM (Table 12 in the Appendix).

3.2 Current practices for selecting FRM for afforestation-reforestation

Among the forest managers, between 63% (Hungary) and 97% (Germany) of respondents (on average 88%) consider planting and reforestation an option to improve forest ecosystem services and forest stability in climate change (Table 11 in the Appendix). Among the conservation managers, planting activities were considered by 70% on average to 100% (Hungary, Czechia) (Table 10 in the Appendix).

When selecting FRM for afforestation/reforestation, 68% of conservation and 92% of forest managers, across countries, prefer to use FRM from their own or nearby registered seed stand or even buy it from the closest nursery (Fig. 3). Planting materials utilized in afforestation/reforestation are usually obtained by considering national provenance regions (Table 4). The survey revealed that on average, 80% of the conservation and 99% of the forest managers take national provenance regions into account while selecting FRM for reforestation (Table 4). The share of conservation and forest managers using FRM originating from regions outside of their respective country (non-national) is low with an average of 13% in both groups (Table 4). However, this share might increase slightly as 15% of conservation managers and 25% of forest managers would be willing to use non-national FRM. Interestingly among nursery managers, who typically provide FRM to forest and conservation managers, the use of FRM from outside the country is 39% on average across all countries (Table 4). The response of nursery managers varied widely among countries with 84% and 88% of them in Austria and Germany that already uses FRM from other European countries, while only between 9 and 29% in the other countries used non-local FRM. The lowest 9% observed from Poland, and 29% from Hungary, and Slovakia and Czechia falls in between (Table 12 in the Appendix). The main reason given for using non-local FRM by conservation, forest, and nursery managers was the unavailability of domestic FRMs (Fig. 4). So, in Poland, Slovakia, and

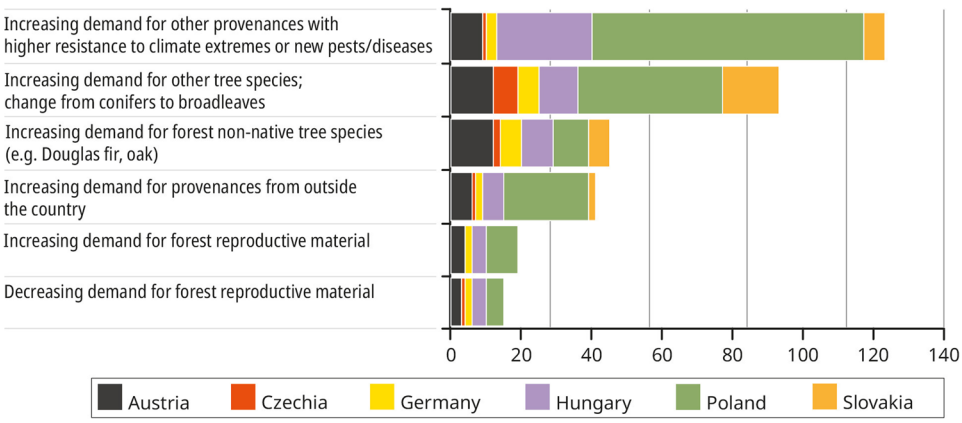

Fig. 2 Expected changes in climate warming on the demand of various forest reproductive materials as expressed by nursery managers

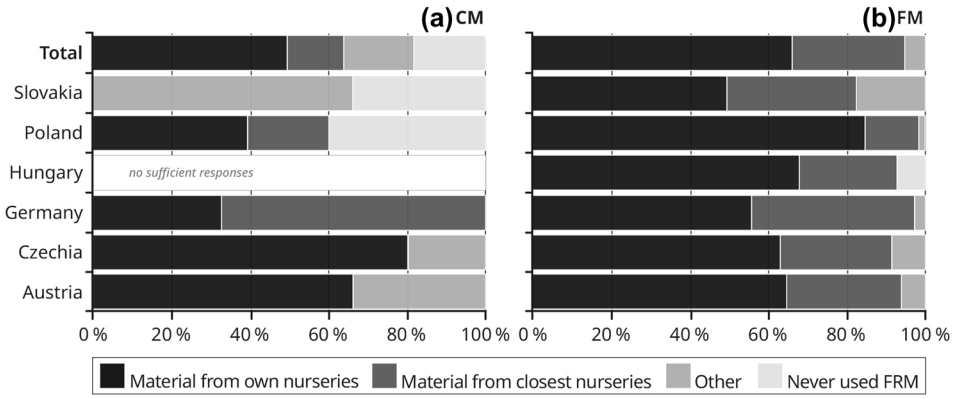

Fig. 3 Current practices of a selection of FRM by (**a**) conservation managers(CM) and (**b**) forest managers (FM). The total represents the combined response across countries

Czechia, for 58–100% of respondents, the main reason for the utilization of other non-local European seed sources was the unavailability of domestic seeds/seedling and a lesser reason cited as the availability of better genetic material, as we saw from 33% respondents from Poland (Fig. 4). Also in Austria and Germany, the unavailability of seeds and seedlings was stated as the main cause (38% and 45%), while better genetic material (27%) and better adaptation to expected climate conditions (23 and 18%) were also considered respectively (Fig. 4).

MCA was carried out to identify trends in the perceptions of nursery managers on the likely effect of climate change and their interest and motivations in FRM of foreign origin. Taking into consideration the size of their nurseries in terms of the number of plants sold per year, this analysis revealed that the motivation of nurseries to deploy FRM of foreign origin was the most important variable explaining around 55% of the total variation of Dim 1 and Dim 2 combined (Fig. 9 in the Appendix). Larger nurseries, which sell 2–10 million or more than 10 million seedlings per year, are the ones who deal with seedlings of foreign origin because of the scarcity of local seedlings (Fig. 5). Also, these nurseries have a stronger perception of the effect of climate change on their business. Nurseries that are relatively smaller in size (selling 0.1–0.5 million seedlings per year) either do not use foreign FRM or are unaware of it. Also, small nurseries are rather unaware of the effects of climate change on their businesses (Fig. 5).

The conservation and forest managers were asked about the importance of four management measures (Fig. 6). For concise reporting, here, we have combined the responses under "important" and "very important" together. Therefore, around 48% of conservation and 82% of forest managers believed that planting adapted provenances fit for climate change is important/very important (Fig. 6a). In total, 91% of conservation and 93% of forest managers believed that the use of domestic seed sources is either an important or a very important management activity (Fig. 6c). Keeping the current tree composition was perceived as a slightly less important management activity among both the conservation and forest manager groups because only 57% and 65% of them respectively considered it important/very important (Fig. 6b). Minimizing the anthropogenic influence in their areas was mainly considered important/very important for conservation managers (77%) but to a lesser degree for forest managers (65%) (Fig. 6d).

3.3 Perceptions of genetic diversity and implications of national and regional policies on trade and utilization of FRM

The majority of respondents of conservation and forest managers across all six countries believe forest genetic diversity to be important (Fig. 7). Also, 76% of conservation managers and 83% of forest managers consider genetic diversity in their management plan. However, in contrast to the positive perception of genetic diversity, almost half (on average 49% and 56% among conservation and forest managers respectively) among the same set of respondents says that they were not well-informed about forest genetic diversity (Fig. 7).

The MCA combining the perception of genetic diversity and the effects of climate change revealed two groups (i) those who feel well-informed about genetic diversity, do not expect the negative effects of climate change, and do not consider the importance of genetic diversity in their management plans; and (ii) those who consider the negative effects of climate change and account for genetic diversity in their management plan but also responded that their level of awareness about genetic diversity is not adequate (Fig. 8). In this analysis, the importance of genetic diversity and its use in management plans were the most influential variables explaining about 95% of the total variation in the response of forest and conservation managers on the subject of genetic diversity and climate change (Fig. 10 in the Appendix). The responses did not differ significantly between the countries, but among the managers, as demonstrated by a Wilks test (p-value: manager 0.00008; country 0.1181).

Table 4 Differences in perception of the conservation managers (CM), forest managers (FM), and nursery managers (NM) on the role of FRM and its current practice of utilization for reforestation. n = number of respondents for that specific question (total number of respondents may vary for each question as every participant might/might not respond to every question)

Respondents	n	Responses (% of yes)						
		Austria	Czechia	Germany	Hungary	Poland	Slovakia	Mean
Do you take national regions of provenance into account when selecting the planting material?								
CM	49	88	100	100	100	56	33	80
FM	447	98	100	97	100	100	98	99
Have you ever used planting material in this area from other regions outside your country?								
CM	49	33	0	29	0	0	14	13
FM	496	18	14	22	19	2	4	13
NM	257	84	10	88	29	9	13	39
Would you use planting material from other regions outside your country?								
CM	49	25	20	0	0	12	29	15
FM	503	24	23	43	26	13	24	25

Among forest and nursery managers, the two groups dealing mostly with FRM, 30% of forest managers and 45% of nursery managers consider their national seed legislation to be well-adapted to climate change, while 29% of forest and 27% of nursery managers do not agree to this (Table 5). In both groups, the share of uncertain respondents is high being 41% of forest and 28% of nursery managers (Table 5). Concerning European legislation on FRM, the number of uncertain respondents is even higher (71% of forest and 57% of nursery managers) and only small groups (9% of forest and 26% of nursery managers) believe European legislation to be well-prepared for climate change (Table 5).

4 Discussion

Afforestation and reforestation can transform vulnerable forests into diverse, productive, and climate-resilient mixed forests (Bolte et al. 2009; Reyer et al. 2015). Both afforestation and reforestation entail the active involvement of actors from forestry, conservation, and nursery business. This study examines the perception of these actors on adapted seed and seedling provision in climate change.

In this survey, the majority of respondents regardless of their country or role (as conservation, forest or nursery managers) had expressed concern that climate change is likely to affect their operations and businesses (Table 3). This has also been reported in several other studies based on perceptions of foresters towards the effects of climate change in central Europe (Yousefpour and Hanewinkel 2015), northern Europe (Blennow and Persson 2009), Mediterranean (Sousa-Silva et al. 2018), and Balkans (Gudurić et al. 2011; Živojinović and Wolfslehner 2015). In a survey among forest stakeholders in Sweden, France, Germany, and Italy, the respondents agreed to have experienced changes in the climate over time but were unsure about the nature and extent of the impacts of such changes in their forests (Keskitalo et al. 2015). A recent survey among forest owners and managers in 15 European countries by Vinceti et al. (2020) reported that the majority of the respondents expressed their concerns about pests and diseases, storms, and droughts to be the top-ranking threats to forests. They also found that FRMs from local sources are largely preferred over foreign planting materials. Although there is a general awareness about the potential benefits of using genetic diversity as an adaptive management strategy, more efforts are needed to include multiple actors and raising the level of awareness on genetic diversity to design management plans and advisory for adapting forests to climate change (Vinceti et al. 2020). These perception studies spanning across a decade were found to be a major stimulus for increased global awareness on climate change impacts among forestry and related stakeholders (Williamson et al. 2005; Ameztegui et al. 2018).

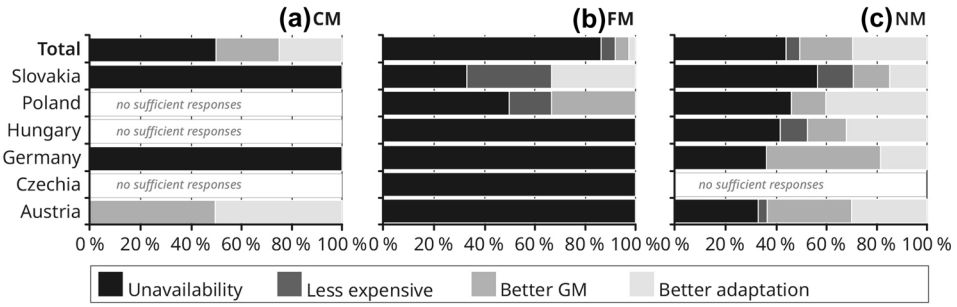

Fig. 4 Reasons for using non-local FRM for reforestation given by (**a**) conservation managers (CM), (**b**) forest managers (FM), and (**c**) nursery managers (NM)

Our study builds on these contemporary studies by including multiple actors such as forest managers, conservation managers, and nursery managers and analyzing the perceptions from a practical and sociopolitical standpoint.

It is notable that although 80% of the conservation and forest managers believed that climate change is likely to influence their conservation and management areas (Table 3), the perceptions on the nature of such effects of climate change vary between the countries (Fig. 1). Some conservation managers especially from Austria and Poland seemed to be cautious as they believe their conservation objectives are unlikely to change under climate change (Fig. 1a). Scientific evidence, however, indicates that conservation areas in altitudinally uniform countries of the Pannonian basin are vulnerable to climate change especially due to drought stress (Hannah et al. 2007; Araújo et al. 2011). Changes in conservation objectives are challenging and usually associated with tedious political processes (Hannah et al. 2007; Camacho et al. 2010; Hagerman et al. 2010; Barbour and Kueppers 2012). This may also have contributed to the perception of the conservation managers on the static nature of their conservation objectives. Another reason for such a perception of the conservation managers may arise from the belief that natural genetic processes will be sufficient to mitigate the effects of climate change (Fady et al. 2016). With more than 100,000 sites across 54 countries, Europe has more protected

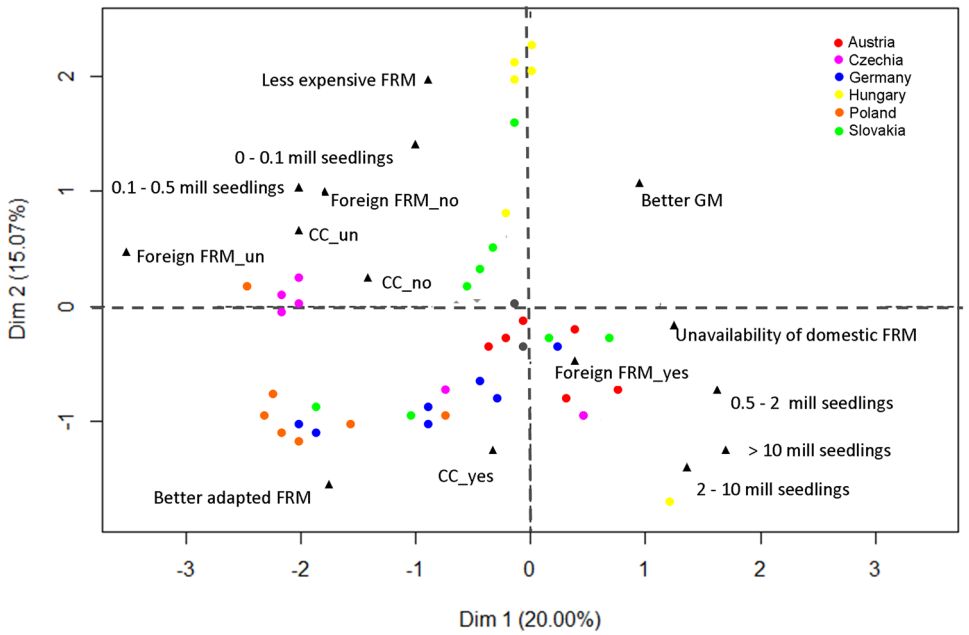

Fig. 5 MCA biplot showing the beliefs of NM on the expected effect of climate change on nursery business, the experience of nursery managers with non-domestic seeds and seedlings including the reasons for utilizing such seed sources in relation to the size of nurseries in terms of the number of plants sold. The two dimensions (Dims 1 & 2) explain around 35% of the variance in the responses analyzed. The coordinates of the variable categories are shown with black triangles, and the coordinates of the individuals of each country are marked with colors shown in the index. The questions included within this analysis are (i) do you believe that climate change will influence your business (cc_yes, cc_no, cc_un) ?, (ii) have you ever received seeds/seedlings from other European countries (Foreign FRM_yes, Foreign FRM_no, Foreign FRM_un)?, (iii) reason for receiving seeds/seedlings from other European countries (Unavailability of domestic FRM, less expensive FRM, better genetic material, better adapted FRM), (iv) how many plants are you selling per year? Suffixes _yes, _no, and _un refers to yes, no and uncertain respectively

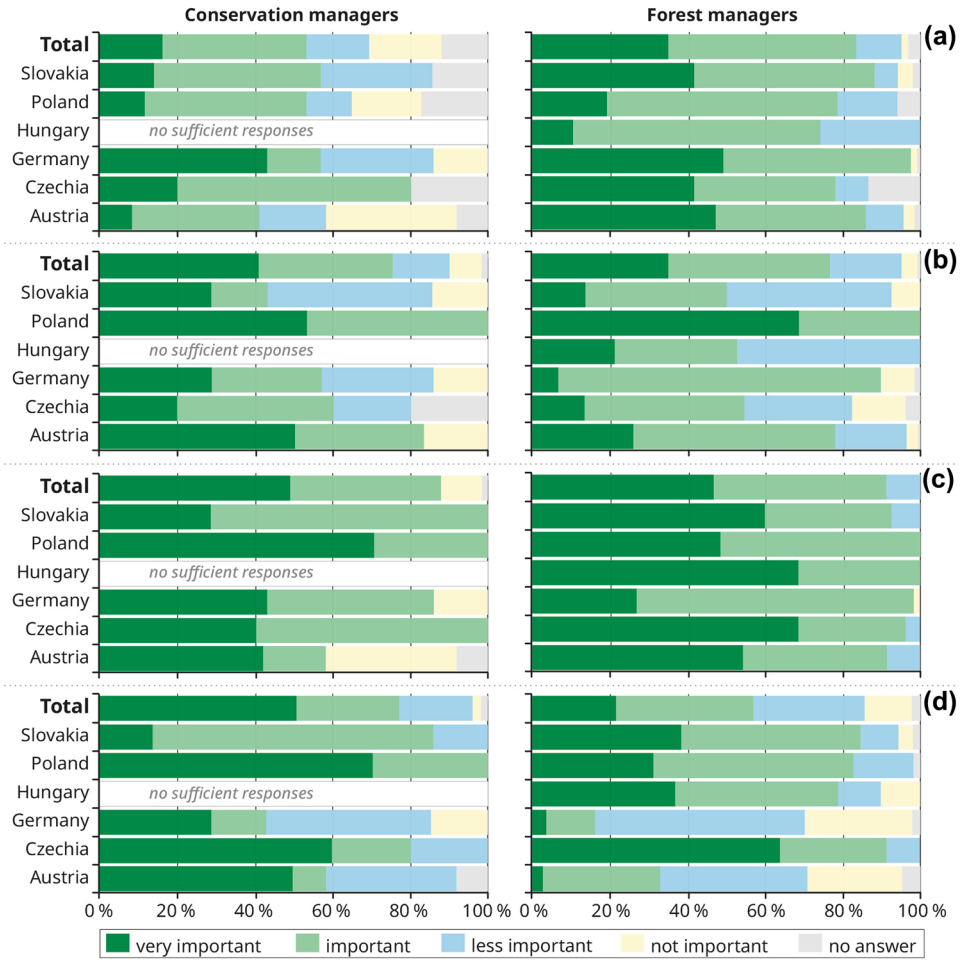

Fig. 6 Perceptions of conservation managers and forest managers on the importance of the management activities in their area. The activities include (**a**) plant tree provenances fit for climate change (also from other countries), (**b**) keep the tree composition of the area the same, (**c**) use of domestic seeds and plants, and (**d**) minimize anthropogenic influence in the area

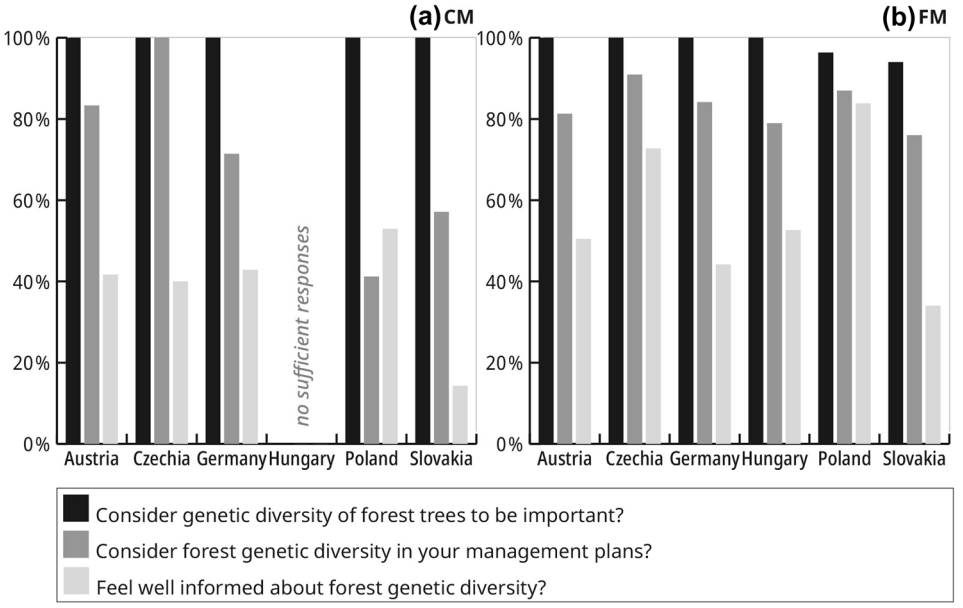

Fig. 7 The response of (**a**) conservation managers (CM) and (**b**) forest managers (FM) on (i) the importance of genetic diversity of forest trees, (ii) if they consider forest genetic diversity in their management plans, and (iii) their perceived level of knowledge about forest genetic diversity

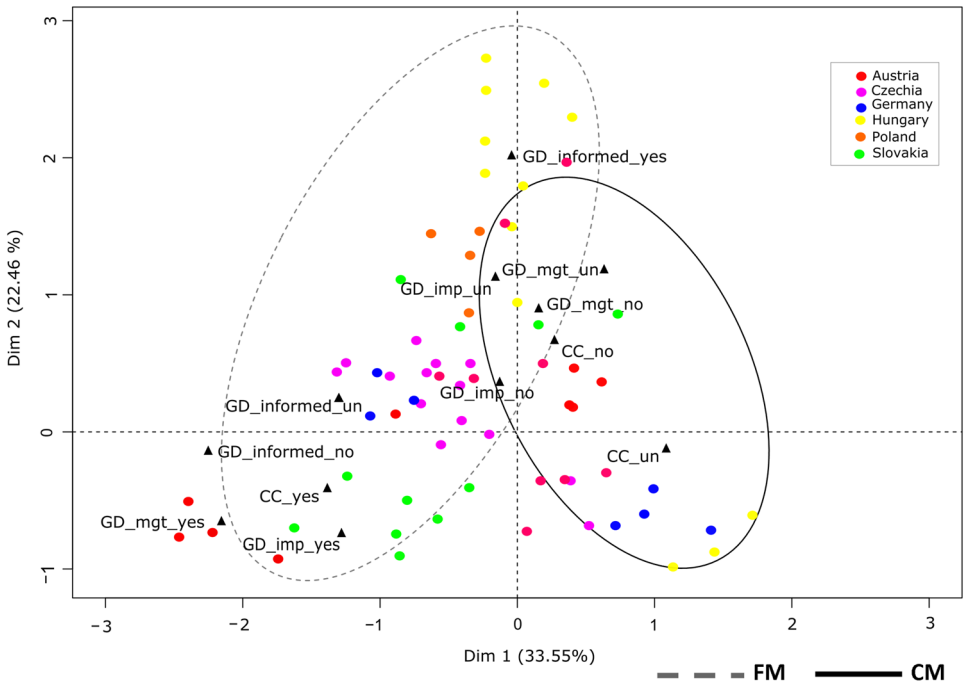

Fig. 8 MCA biplot depicting the beliefs of forest managers (FM) and conservation managers (CM) on the expected effects of climate change on their operational areas together with their believes on the importance of genetic diversity and perceived level of knowledge. The two dimensions (Dims 1 & 2) explain around 56% of the variance in the responses analyzed. Coordinates of variable categories are shown with black triangles and coordinates of the individuals of each country are marked with colors shown in the index. The analyzed questions were the following: Do you expect changes in your forest area due to climate change? (CC_yes,CC_no, _CC_un); Do you consider the genetic diversity of forest trees to be important? (GD_imp_yes, GD_imp_no, GD_imp_un); Do you consider forest genetic diversity in your management plans? (GD_mgt_yes, GD_mgt_no, GD_mgt_un); and Do you feel you are well-informed about forest genetic diversity? (GD_informed_yes, GD_informed_no, GD_informed_un). The groups were defined by 95% confidence ellipse that plot confidence ellipses around group mean points

areas than any other region in the world with both national and transnational conservation areas such as nationally designated areas and NATURA 2000 sites (Araújo et al. 2011; European Commission 2014). However, the efficacy of such conservation areas to fulfill their objectives under climate change has come under intense debate (Araújo et al. 2011) because of various reasons such as disharmony in national and transnational policies, conservative attitude of policy-makers citing lack of proof, and uncertainty of the climate change impacts (Camacho et al. 2010; Geyer et al. 2017).

A majority of forest managers believed not only that climate change would change their management objectives but also that these objectives would be more difficult to achieve (Fig. 1b). This may be due to reasons, such as uncertainty of the impact of climate change, tradeoffs between forest management and desired ecosystem services (Lindner et al. 2010; Briner et al. 2013; Blennow et al. 2014), and many others.

Again, the indicators used to describe the nature of climate change impacts were different for the nursery

Table 5 Differences in perception of the forest managers (FM) and nursery managers (NM) on the role of national and European legislation on seed transfer for selecting FRM for afforestation under climate change. *n* = number of respondents for that specific question (total number of respondents may vary for each question as every participant might/might-not respond to every question)

Respondents	*n*	Responses (% of yes)						
		Austria	Czechia	Germany	Hungary	Poland	Slovakia	Mean
Do you think the national legislation on seed transfer is well-adapted in times of climate change?								
FM	510	28	18	34	16	36	48	30
NM	253	39	70	75	20	31	35	45
Do you think the European legislation on seed transfer is well-adapted in times of climate change?								
FM	498	9	5	14	5	11	10	9
NM	257	37	30	38	16	10	22	26

managers (Fig. 2). This set of indicators was specifically aimed to describe the possible aspects of forest nursery operations and businesses. The responses of the nursery managers reflected the perceived rise in demand for broad-leaved species and adapted provenances in response to climate change. Such responses by the nursery managers were expected because in Central Europe, there has been a steady trend in forest management to reduce the share of secondary conifer forest with species such as Norway spruce (Klimo et al. 2000; Hanewinkel et al. 2013) and use of adapted planting material (Bolte et al. 2009; Jensen et al. 2019).

The current practice of utilizing FRM for reforestation by both forest and conservation managers were mainly focused on the selection of local planting material (Fig. 3a, b). The conservation and forest managers attribute the occasional use of planting materials of foreign origin to the unavailability of domestic material (Fig. 4). The nursery managers, however, also considered better adaptation when trading FRM of foreign origin (Fig. 4c). This is because cross border trade and utilization of FRM in European countries are regulated by the European Council Directive 1999/105/EC (European Commission 2000) and the "Scheme for the Control of Forest Reproductive Material Moving in International Trade" (OECD 2012). An expert survey conducted in 2017 (SUSTREE 2017), within six countries of Central Europe, revealed that the deployment and transfer of FRM within and between them differ due to varying national legislations. For example, in Austria, Hungary, and Germany, the use of FRM from outside the country but originating within Europe is allowed without restrictions, whereas in Poland, Czechia, and Slovakia, the introduction of foreign FRM is subjected to significant restrictions. Poland allows free transfer of FRM up to 100 km from its official border. In other cases, permission from the Ministry and other administrative intervention is required. Slovakia allows the use of FRM from neighboring countries such as Poland, Hungary, Czechia, and Austria. In Czechia, the import of FRM from outside the country for afforestation is restricted. This restriction is relaxed to a certain extent in the case of tree species such as Douglas fir and Grand fir from the USA and Canada (Konnert et al. 2015).

Local planting materials are commonly selected, and in some cases, it is the only option allowed under national and regional law (MCPFE 1993, Jensen et al. 2019; Vinceti et al. 2020). The argument behind the preferential use of local planting material is embedded in the paradigm of "local is best" which assumes tree populations are locally adapted to their place of occurrence thereby using local seed sources to reduce chances of maladaptation (Aitken and Bemmels 2016). However, under climate change, the paradigm of local being the best has been criticized (Jones 2013; Chakraborty et al. 2015). For many temperate tree species, it was observed that trees are not optimally adapted to their place of occurrence. In many cases, populations gain fitness when moved to a few degrees warmer than their origin indicating an adaptation lag (Wang et al. 2010; Leites et al. 2012; Rehfeldt et al. 2014; Chakraborty et al. 2015, Fréjaville et al. 2019). Broadhurst et al. (2008) emphasize that utilizing local seed sources alone might lead to poor quality restoration especially in the context of wider geographical scales. Therefore, the focus should be more on increasing the genetic diversity of the seed source to maximize adaptive potential in climate change. Hajjar and Kozak (2015) conducted a survey among the public in British Colombia and Alberta in Canada, where they found that 60% of the respondents supported reforestation with non-local seed for climate change adaptation and that increasing awareness of the reforestation process increased the likelihood of acceptance of the strategy. In our survey, we found that larger nurseries, selling more than 2–10 million seedlings per year, are the ones who deal with FRM of foreign origin (Fig. 5). The smaller nurseries mostly rely on local material and deal with seedlings of foreign origin mainly in case of scarcity of local seedlings (Fig. 5).

The preference for using local FRM may also be related to the level of awareness about genetic diversity and regulations that limit the utilization of FRMs of foreign origin. The survey revealed that despite perceiving the importance of genetic diversity in forest trees, the majority of the respondents feel that they are not adequately aware of genetic diversity (Fig. 7) and how it might contribute to forest adaptation to climate change. Vinceti et al. (2020) also reported the need for further awareness on the importance of genetic diversity in adapting forests to climate change. Again, this lack of awareness and knowledge is reflected in the response to the question on the adaptation of national and European legislation on FRM to climate change. The survey also reveals that the majority of respondents either do not agree or are uncertain whether the national and European seed transfer legislations are adapted to climate change (Table 5). Recent research by Jensen et al. (2019) also reported this general lack of awareness among foresters of Europe except for certain north European countries such as Sweden. A survey conducted by Whittet et al. (2016) among UK nurseries found that they were conservative about using non-local FRM and mostly source seeds from warmer locations also known as predictive provenance. Therefore, it is evident that despite a large body of literature on the importance of genetic diversity, the level of awareness and its implementation on advisory for adaptive management are limited because of lack of training and rigid and outdated laws and regulations.

Certain limitations due to the initial design of the survey should be taken into consideration while adopting

the survey results into practice. These include some dissimilarity in the questions asked to the three groups of respondents, giving rise to difficulty in the comparative analysis of responses. We addressed this issue by focusing on the questions which were comparable across the three groups as far as practicable. Also, the survey represents more public forest managers (55%) compared to private forest managers (27%) which may underrepresent or overrepresent the respective stakeholders in a certain country. Besides, limitations such as the number of respondents and possible biases resulting from the experimental design and snowball sampling also should be considered. With this method of sampling, the surveyor has limited control in the circulation of the survey at some point in time. Kircherr and Charles (2018) identified an important bias in the snowball sampling method known as "cold call," where surveys are circulated surveys via email without personal follow-up. We have tried to avoid this "cold call" bias by following up with the email recipients as far as practicable. In spite of its limitations, this method enables us to gather a substantial number of responses in a short duration of time like our study of four months.

5 Conclusions

There is no doubt that awareness of climate change is growing rapidly, and practitioners in forestry, nature conservation, and nurseries are aware of the impacts of these changes on their forests and related businesses. The outcome of our survey also highlights this trend that the understanding of the likely effects of climate change is consistently high across all the countries and all three groups of managers with only limited variation. It was also found that trade and utilization of FRM so far are guided by the national provenance regions, and the use of foreign materials is not a broadly accepted adaptation strategy requirement yet. Issues of genetic diversity in forest trees are perceived as important but discrepancies and knowledge gaps are evident. It has been observed that the forest practitioners are keen on including genetic diversity in their management plans but admitted lacking the understanding of these scientific and technical mechanisms. Most importantly this study reveals that there are critical uncertainties in the awareness of existing national-level and European-level policies and their likely effects in trade and utilization of FRM for afforestation in Europe. Nevertheless, it generates valuable insights on the understanding of climate change and the associated transnational issues of trade and utilization of FRM to grow adaptive forests under climate change.

Appendix

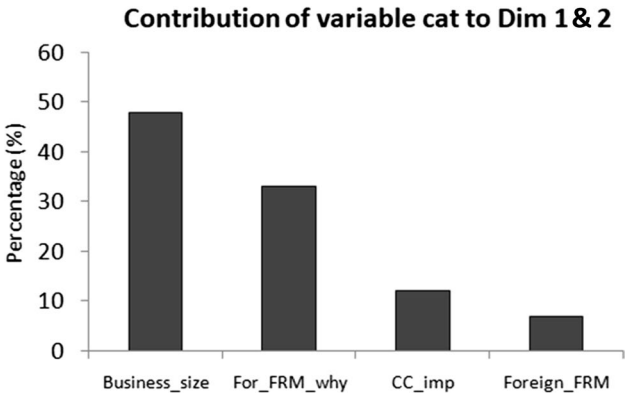

Fig. 9 Contribution of the variable categories on the total variance explained by Dims 1 and 2 in Fig. 5. For_FRM why = on the likely effect of climate change, why NM are interested in buying FRM of foreign origin; Business_size = size of the nurseries in terms of the number of plants sold in millions; Foreign_FRM = whether the NM receive FRM from other European countries; and CC_imp = whether the NM feels that climate change will adversely affect their business

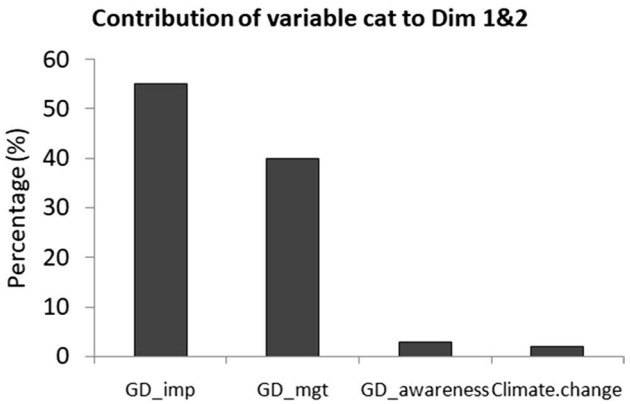

Fig. 10 Contribution of the variable categories on the total variance explained by Dims 1 and 2 in Fig. 8

Table 6 Questionnaire for Conservation manager (CM)

SUSTREE Survey – Conservation managers

Preliminary info

Name of organization/ company/ entity/ park: _____

Country: _____

* The data will be processed anonymously. Multiple answers are possible.

1) Do you consider genetic diversity of forest trees to be important?
   - (a) Yes
   - (b) No
   - (c) I don't know

2) Do you consider forest genetic diversity in your management plans?
   - (a) Yes
   - (b) No
   - (c) I don't know

3) Do you feel you are well informed about forest genetic diversity?
   - (a) Yes
   - (b) No
   - (c) I don't know

4) Do you expect changes of your conservation area due to climate change?
   - (a) Yes
   - (b) No
   - (c) I don't know

4.1) If YES, will it have any influence on the conservation objectives?

(a) Will be easier to reach
(b) Will be more difficult to reach
(c) Conservation objectives will not change
(d) Will not have any influence on the conservation objectives

5) Do you consider climate change in you management planning?
   - (a) Yes
   - (b) No
   - (c) I don't know

6) Do you consider planting and afforestation /reforestation activities in order to improve forest ecosystem services, in particular to increase forest stability in climate change?
   - (a) Yes
   - (b) No
   - (c) I don't know

If YES, ...

6.1) How do you select the forest reproductive material (FRM)?
   - (a) I use material of our own forests (seeds, seedlings, ...)
   - (b) I use material from the closest nursery
   - (c) Other: _____
   - (d) I have never used FRM

6.2) Do you take national regions of provenance into account when selecting the planting material?
   - (a) Yes
   - (b) No
   - (c) I don't know about regions of provenance
   - (d) I have never used FRM in the area

6.3) Have you ever used planting material in the area from other regions outside your country?
   - (a) Yes
   - (b) No

6.3.1) If YES, why?

(a) Unavailability of domestic seeds/seedlings

Table 6 (continued)

(b) Less expensive reproductive material
(c) Better genetic material (i.e. better growth, stem form etc.)
(d) Better adaptation to expected climate conditions

6.4) Would you use planting material from other regions outside your country?
- (a) Yes
- (b) No

7) Have you ever received subsidies for planting activities?
- (a) Yes
- (b) No
- (c) I have never used FRM

8) Please rank the following aspects regarding the importance for the conservation activities in the area :

	(a) Very Important	(b) Important	(c) Less important	(d) Not important	(e) No answer
[1] Plant tree provenances fit for climate change (also from other countries)					
[2] Keep the tree composition of the area the same					
[3] Use of domestic seeds and plants					
[4] Minimize anthropogenic influence in the area					

9) How big is the conservation area of your organization? _____ ha

10) Please specify the category of the conservation area (IUCN categories):
- (a) Ia— Strict Nature Reserve
- (b) Ib — Wilderness Area
- (c) II — National Park
- (d) III — Natural Monument or Natural Feature
- (e) IV — Habitat management area / Species Management Area
- (f) V — Protected Landscape / Protected Seascape
- (g) VI — Protected Area with sustainable use of natural resources (Managed Resource Protected Area)
- (h) Other:_____

11) Please specify roughly the tree composition of your forest:
- Conifers _____ %
  (a.1) (____ % planted (a.2) ____ % natural regeneration)
- Broadleaves _____ %
  (b.1) (____ % planted (b.2) ____ % natural regeneration)
- Mixed stands _____ %
  (c.1) (____ % planted (c.2) ____ % natural regeneration)

12) Comments/ Remarks/ Further explanations to question Nr ___

Table 7 Questionnaire for Forest managers (FM)

SUSTREE Survey – Forest managers

Preliminary info

Name of organization/ company/ entity: _____

Country: _____

* The data will be processed anonymously. Multiple answers are possible.

1) Do you consider genetic diversity of forest trees to be important?
   - (a) Yes
   - (b) No
   - (c) I don't know

2) Do you consider forest genetic diversity in your management plans?
   - (a) Yes
   - (b) No
   - (c) I don't know

3) Do you feel you are well informed about forest genetic diversity?
   - (a) Yes
   - (b) No
   - (c) I don't know

4) Do you consider climate change in you management planning?
   - (a) Yes
   - (b) No
   - (c) I don't know

5) Do you expect changes in your forest area due to climate change?
   - (a) Yes
   - (b) No
   - (c) I don't know

5.1) If YES, will it have any influence on the management objectives?

(a) Will be easier to reach
(b) Will be more difficult to reach
(c) Management objectives will not change
(d) Will not have any influence on management objective

Table 7 (continued)

6) Do you consider planting and afforestation / reforestation activities in order to improve forest ecosystem services, in particular to increase forest stability in climate change?

- (a) Yes
- (b) No
- (c) I don't know

If YES, ...

6.1) How do you select forest reproductive material (FRM)?

- (a) I use material of our own forests (seeds, seedlings, ...)
- (b) I use material from the closest nursery
- (c) Other: _____
- (d) I have never used FRM in the area

6.2) Do you take national regions of provenance into account when selecting the planting material?

- (a) Yes
- (b) No
- (c) I don't know about regions of provenance
- (d) I have never used FRM in the area

6.3) Have you ever used planting material in this area from other regions outside your country?

- (a) Yes
- (b) No
- (c) I don't know

6.3.1) If YES, why?

(a) Unavailability of domestic seeds/seedlings
(b) Less expensive reproductive material
(c) Better genetic material (i.e. better growth, stem form etc.)
(d) Better adaptation to expected climate conditions

6.4) Would you use planting material from other regions outside your country?

- (a) Yes
- (b) No
- (c) I don't know

7) Have you ever received subsidies for planting activities?

- (a) Yes
- (b) No
- (c) I have never used FRM

Table 7 (continued)

8) Please rank the following aspects regarding the importance for the management activities in the area

	(a) Very Important	(b) Important	(c) Less important	(d) Not important	(e) No answer
[1] Plant tree provenances fit for climate change (also from other countries)					
[2] Keep the tree composition of the area the same					
[3] Use of domestic seeds and plants					
[4] Minimize anthropogenic influence in the area					

9) Do you think the national legislation on seed transfer is well adapted in times of climate change?

- (a) Yes
- (b) No
- (c) I don't know

10) Do you think the European legislation on seed transfer is well adapted in times of climate change?

- (a) Yes
- (b) No
- (c) I don't know

11) How big is the forest area of your organization? _____ ha

13) Please specify the ownership of the forest:

- (a) Private
- (b) Public
- (c) Other, please specify:_____

14) Please specify roughly the tree composition of your forest:

- Conifers _____ %

  (a.1) (____ % planted (a.2) ____ % natural regeneration)

- Broadleaves _____ %

  (b.1) (____ % planted (b.2) ____ % natural regeneration)

- Mixed stands _____ %

  (c.1) (____ % planted (c.2) ____ % natural regeneration)

15) Comments/ Remarks/ Further explanations to question Nr ___

Table 8 Questionnaire for Nurseries (NM)

SUSTREE Survey - Forest nurseries

Preliminary info

Name of organization/ company: _____

Country: _____

* The data will be processed anonymously. Multiple answers are possible.

1) Do you believe that climate change will have an influence on your business?
   - (a) Yes
   - (b) No
   - (c) I don't know

1.1 If yes, what changes are you expecting?
   - (a) Increasing demand for other tree species; change from conifers to broadleaves
   - (b) Increasing demand for forest reproductive material
   - (c) Decreasing demand for forest reproductive material
   - (d) Increasing demand for non-native tree species (e.g. Douglas fir, red oak)
   - (e) Increasing demand for other provenances with higher resistance to climate extremes or new pests/diseases
   - (f) Increasing demand for provenances from outside the country
   - (g) Others:_____

2) Have you ever received seeds/seedlings from other European countries?
   a) Yes
   b) No

2.1 If Yes, because of ...
   (a) Unavailability of domestic seeds/seedlings
   (b) Less expensive reproductive material
   (c) Better genetic material (i.e. better growth, stem form etc.)
   (d) Better adaptation to expected climate conditions

3) Are you interested in buying forests seeds/ seedlings from other European countries?

a) Yes
b) No

3.1 If Yes, because of ...
   (a) Unavailability of domestic seeds/seedlings
   (b) Less expensive reproductive material
   (c) Better genetic material (i.e. better growth, stem form etc.)
   (d) Better adaptation to expected climate conditions

Table 8 (continued)

4) Do you think you will increasingly sell reproductive material to foreign clients?
   - (a) Yes
   - (b) No
   - (c) I don't know

5) Do you think the national legislation on seed transfer is well adapted in times of climate change?
   - (a) Yes
   - (b) No
   - (c) I don't know

6) Do you think the European legislation on seed transfer is well adapted in times of climate change?
   - (a) Yes
   - (b) No
   - (c) I don't know

7) How many plants are you selling per year?
   - (a) 0 – 100 000
   - (b) 100 000 – 500 000
   - (c) 500 000 – 2 millions
   - (d) 2 – 10 millions
   - (e) More than 10 millions
   - (f) I don't know/ No answer

8) Please specify the percentage of trees sold annually:
   - (a) Conifers _____ %
   - (b) Broadleaves _____ %

9) The SUSTREE project aims at developing an online information system on forest reproductive material across Central Europe. This information will help users (forest companies, seed trading companies, nurseries, etc.) to inform themselves about reproductive material outside their country and might potentially facilitate trans-national trade and adaptation to changing climate conditions. Are you interested in listing your company as a potential trans-national provider of forest seeds/seedlings in this online information service?
   - (a) **Yes**

     Contact details for online tool

     Name: _____

     Name of company: _____

     Address:

     Street _____

     ZIP Code, City_____

     Country_____
   - (b) **No**

10) Comments/ Remarks/ Further explanations to question Nr ___

Table 9 The questions analyzed to test (1) perceptions on climate change, (2) reforestation and afforestation for promoting stability of forest ecosystem under climate change, and (3) perceptions on genetic diversity and implications of national and regional policies on trade and utilization of FRM

Perceptions on climate change			Reforestation and afforestation (A/R) for promoting stability of forest ecosystem under climate change			Perceptions on genetic diversity and implications of national and regional policies on trade and utilization of FRM		
CM	FM	Nurseries	CM	FM	Nurseries	CM	FM	Nurseries
4. Do you expect changes of your conservation area due to climate change?	5. Do you expect changes in your forest area due to climate change?	1. Do you believe that climate change will have an influence on your business?	6. Do you consider planting and A/R activities in order to improve forest ecosystem services, in particular to increase forest stability in climate change?	6. Do you consider planting and A/R activities in order to improve forest ecosystem services, in particular to increase forest stability in climate change?	-	1. Do you consider genetic diversity of forest trees to be important?	1. Do you consider genetic diversity of forest trees to be important?	
4.1 If yes, will it have any influence on the conservation objectives?	5.1 If yes, will it have any influence on the management objectives?	1.1 If yes, what changes are you expecting?	6.1 If yes, how do you select forest reproductive material?	6.1 If yes, how do you select forest reproductive material?		2. Do you consider forest genetic diversity in your management plans?	2. Do you consider forest genetic diversity in your management plans?	
			6.2 Do you take national regions of provenance into account when selecting the planting material?	6.2 Do you take national regions of provenance into account when selecting the planting material?		3. Do you feel you are well-informed about forest genetic diversity?	3. Do you feel you are well-informed about forest genetic diversity?	
			6.3 Have you ever used planting material in the area from other regions outside your country?	6.3 Have you ever used planting material in the area from other regions outside your country?	2. Have you ever used planting material in the area from other regions outside your country?		9. Do you think the national legislation on seed transfer is well-adapted in times of climate change?	5. Do you think the national legislation on seed transfer is well-adapted in times of climate change?
			6.3.1 If yes, why?	6.3.1 If yes, why?	If yes why?		10. Do you think the European legislation on seed transfer is well-adapted in times of climate change?	6. Do you think the European legislation on seed transfer is well-adapted in times of climate change?
					How many plants are you selling per year?			

Table 10 Responses of CM. All figures in percentage of the total responses for the respective question (n)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
1	Do you consider genetic diversity of forest trees to be important?	Yes	100	100	100	100	100	100
	$n=49$	No	0	0	0	0	0	0
		Uncertain	0	0	0	0	0	0
2	Do you consider forest genetic diversity in your management plans?	Yes	83	100	71	100	41	57
	$n=49$	No	17	0	14	0	29	43
		Uncertain	0	0	14	0	29	0
3	Do you feel you are well-informed about forest genetic diversity?	Yes	42	40	43	100	53	14
	$n=49$	No	42	60	43	0	41	43
		Uncertain	17	0	14	0	6	43
4	Do you expect changes of your conservation area due to climate change?	Yes	100	40	100	100	88	71
	$n=49$	No	0	40	0	0	12	14
		Uncertain	0	20	0	0	0	14
4.1	If yes, will it have any influence on the conservation objectives?	Will be easier to reach?	0	0	0	0	0	0
	$n=49$	Will be more difficult to reach?	8	40	29	0	29	29
		Conservation objectives will not change	67	20	29	0	59	29
		Will not have any influence on the conservation objectives	25	40	29	100	0	14
		No answer	0	0	14	0	12	29
5	Do you consider climate change in your management planning	Yes	67	60	71	0	35	43
	$n=49$	No	33	40	29	100	41	57
		Uncertain	0	0	0	0	24	0
6	Do you consider planting and afforestation/reforestation activities in order to improve forest ecosystem services, in particular to increase forest stability in climate change?	Yes	50	100	43	100	65	57
	$n=49$	No	50	0	57	0	29	43
		Uncertain	0	0	0	0	6	0
6.1	If yes, how do you select forest reproductive material?	I use material of our own forests (seeds, seedlings…)	67	80	33	100	40	0
		I use material from the closest nursery	0	0	67	0	20	0
		Other	33	20	0	0	0	67
		I have never used FRM in the area	0	0	0	0	40	33
6.2	Do you take national regions of provenance into account when selecting the planting material?	Yes	88	100	100	100	56	33
		No	0	0	0	0	6	0
		Don't know	0	0	0	0	0	17
		Never used FRM	13	0	0	0	38	50
6.3	Have you ever used planting material in the area from other regions outside your country?	Yes	33	0	29	0	0	14
		No	67	100	71	100	100	86

Table 10 (continued)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
6.3.1	If yes, why?	Unavailability of domestic seeds/ seedlings	0		100			100
		Less expensive reproductive material	0	0	0	0	0	0
		Better genetic material (i.e., better growth, stem form)	50		0			0
		Better adaption to expected climate conditions	50		0			0
6.4	Would you use planting material from other regions outside your country?	Yes	25	20	0	0	12	29
		No	75	80	100	100	88	71
7	Have you ever received subsidies for planting activities?	Yes	30	40	29	100	41	0
	$n=49$	No	40	40	29	0	29	43
		Never used FRM	30	20	43	0	29	57
8	Please rank the following aspects regarding the importance for the conservation activities in the area:							
	$n=49$							
	[1] Plant tree provenances fit for climate change (also from other countries)	Very important	8	20	43	0	12	14
		Important	33	60	14	0	41	43
		Less important	17	0	29	0	12	29
		Not important	33	0	14	100	18	0
		No answer	8	20	0	0	18	14
	[2] Keep the tree composition of the area the same	Very important	50	20	29	0	53	29
		Important	33	40	29	0	47	14
		Less important	0	20	29	100	0	43
		Not important	17	0	14	0	0	14
		No answer	0	20	0	0	0	0
	[3] Use of domestic seeds and plants	Very important	42	40	43	0	71	29
		Important	17	60	43	100	29	71
		Less important	33	0	14	0	0	0
		Not important	8	0	0	0	0	0
		No answer	0	0	0	0	0	0
	[4] Minimize anthropogenic influence in the area	Very important	50	60	29	100	71	14
		Important	8	20	14	0	29	71
		Less important	33	20	43	0	0	14
		Not important	0	0	14	0	0	0
		No answer	8	0	0	0	0	0
9	How big is the conservation area of your organization in ha	Not answered						
	$n=49$							
10	Please specify the category of the conservation area (IUCN categories):	Strict nature reserve	10	0	0	0	0	0
	$n=45$	Wilderness area	20	0	17	0	0	0
		National park	40	60	33	0	63	43
		National monument or natural feature	0	0	0	0	0	14

Table 10 (continued)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
		Habitat management area/species management area	10	0	0	0	25	0
		Protected landscape/protected seascape	0	40	0	0	0	43
		Protected area with sustainable use of natural resources (managed resource protected area)	0	0	0	0	6	0
		Other:	20	0	50	0	6	0
		NA = no response						

Table 11 Responses of FM. All figures in percentage of the total responses for the respective question (n)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
1	Do you consider genetic diversity of forest trees to be important?	Yes	100	100	100	100	96	94
	$n = 510$	No	0	0	0	0	1	2
		Uncertain	0	0	0	0	3	4
2	Do you consider forest genetic diversity in your management plans?	Yes	81	91	84	79	87	76
	$n = 510$	No	12	9	10	11	11	18
		Uncertain	7	0	6	11	2	6
3	Do you feel you are well-informed about forest genetic diversity?	Yes	50	73	44	53	84	34
	$n = 510$	No	41	14	38	32	7	54
		Uncertain	8	14	18	16	9	12
4	Do you consider climate change in your management planning?	Yes	91	64	92	84	38	88
	$n = 508$	No	8	14	4	16	48	8
		Uncertain	2	23	4	0	14	4
5	Do you expect changes in your forest area due to climate change?	Yes	95	82	93	100	69	85
	$n = 510$	No	4	5	3	0	9	6
		Uncertain	1	14	4	0	22	9
5.1	If yes, will it have any influence on the management objectives?	(a) Will be easier to reach	6	11	12	11	4	9
	$n = 433$	(b) Will be more difficult to reach	81	72	72	53	36	74
		(c) Management objectives will change	13	17	16	37	61	16
		(d) No influence	0	0	0	0	0	0
6	Do you consider planting and afforestation/reforestation activities in order to improve forest ecosystem services, in particular to increase forest stability in climate change?	Yes	95	95	97	63	84	96
	$n = 507$	No	5	5	3	21	4	0
		Uncertain	0	0	0	16	12	4

Table 11 (continued)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
6.1	If yes, how do you select FRM?	(a) I use material of our own forests (seeds, seedlings…)	63	62	54	67	84	48
	$n=507$	(b) I use material from the closest nursery	30	29	43	25	14	33
		(c) Other	7	10	3	0	2	19
		(d) I have never used FRM in the area	0	0	0	8	0	0
6.2	If yes, do you take national regions of provenance into account when selecting the planting material?	(a) Yes	98	100	97	100	100	98
		(b) No	2	0	3	0	0	2
	$n=447$	(c) Uncertain	0	0	0	0	0	0
		(d) Never used FRM	0	0	0	0	0	0
6.3	Have you ever used planting material in this area from other regions outside your country?	(a) Yes	18	14	22	19	2	4
	$n=495$	(b) No	75	86	75	75	97	96
		(c) Uncertain	7	0	3	6	1	0
6.3.1	If yes, why?	Unavailability of domestic seeds/ seedlings	56	33	43	100	43	33
		Less expensive reproductive material	6	0	7	0	14	33
		Better genetic material (i.e., better growth, stem form)	17	33	21	0	29	0
		Better adaption to expected climate conditions	22	33	29	0	14	33
6.4	Would you use planting material from other regions outside your country?	Yes	24	23	43	26	13	24
	$n=503$	No	64	64	41	53	55	73
		Uncertain	12	14	17	21	32	2
7	Have you ever received subsidies for planting activities?	Yes	27	95	77	89	67	58
	$n=489$	No	72	5	23	11	33	42
		Uncertain	1	0	0	0	0	0
8	Please rank the following aspects regarding the importance for the management activities in the area:							
	$n=507$							
8.1	Plant tree provenances fit for climate change (also from other countries)	(a) Very important	47	41	49	11	19	42
	$n=506$	(b) Important	39	36	40	63	59	46
		(c) Less important	9	9	8	26	15	6
		(d) Not important	3	0	2	0	1	4
		(e) No answer	2	14	1	0	6	2
8.2	Keep the tree composition of the area the same	(a) Very important	26	14	7	21	68	14
	$n=507$	(b) Important	51	41	49	32	31	36
		(c) Less important	19	27	34	47	0	42
		(d) Not important	3	14	9	0	0	8
		(e) No answer	1	5	2	0	1	0

Table 11 (continued)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
8.3	Use of domestic seeds and plants	(a) Very important	54	68	27	68	48	60
	$n=509$	(b) Important	36	27	57	32	46	32
		(c) Less important	9	5	14	0	6	8
		(d) Not important	0	0	2	0	0	0
		(e) No answer	0	0	1	0	1	0
8.4	Minimize anthropogenic influence in the area	(a) Very important	3	64	3	37	31	38
	$n=506$	(b) Important	30	27	13	42	52	46
		(c) Less important	38	9	54	11	16	10
		(d) Not important	25	0	28	11	0	4
		(e) No answer	5	0	3	0	2	2
9	Do you think the national legislation on seed transfer is well-adapted in times of climate change?	Yes	28	18	34	16	36	48
	$n=501$	No	26	41	31	26	19	30
		Uncertain	45	41	35	58	45	22
10	Do you think the European legislation on seed transfer is well-adapted in times of climate change?	Yes	9	5	14	5	11	10
	$n=498$	No	27	9	19	37	8	22
		Uncertain	64	86	66	58	81	68
11	How big is the forest area of your organization (ha)?	Not answered						
12	Please specify the ownership of the forest:	(a) Public	29	50	62	61	3	2
	$n=496$	(b) Private	67	45	21	33	83	20
		(c) Both	1	0	15	0	4	0
		(d) Other	3	5	3	6	10	78

Table 12 Responses of NM. All figures in percentage of the total responses for the respective question (*n*)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
1	Do you believe that climate change will have an influence on your business?	Yes	95	70	100	97	69	78
	n = 257	No	5	20	0	0	18	13
		Uncertain	0	10	0	3	13	9
1.1	If yes, what changes are you expecting?	1. Increasing demand for other tree species; change from conifers to broadleaves	26	54	27	18	24	50
		2. Increasing demand for forest reproductive material	13	8	9	10	14	6
		3. Decreasing demand for forest reproductive material	6	8	9	7	3	0
		4. Increasing demand for forest non-native tree species (e.g., Douglas fir, oak)	26	15	27	15	6	19
		5. Increasing demand for other provenances with higher resistance to climate extremes or new pests/diseases	19	8	14	44	45	19
		6. Increasing demand for provenances from outside the country	9	0	9	7	5	0
		7. Others	2	8	5	0	3	6
2	Have you ever received seeds/seedlings from other European countries?	Yes	84	10	88	29	9	13
	n = 257	No	16	90	13	71	91	87
2.1	If yes, because of…	1. Unavailability of domestic seeds/seedlings	38	100	45	89	58	100
		2. Less expensive reproductive material	12	0	9	11	8	0
		3. Better genetic material (i.e. better growth, stem form)	27	0	27	0	33	0
		4. Better adaption to expected climate conditions	23	0	18	0	0	0
3	Are you interested in buying forest seeds/seedlings from other European countries?	Yes	79	0	63	32	10	23
	n = 256	No	21	100	38	68	90	77
3.1	If yes, because of…	1. Unavailability of domestic seeds/seedlings	33		36	42	47	57
		2. Less expensive reproductive material	4		0	11	0	14
		3. Better genetic material (i.e., better growth, stem form)	33		45	16	13	14
		4. Better adaption to expected climate conditions	30		18	32	40	14

Table 12 (continued)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
4	Do you think you will increasingly sell reproductive material to foreign clients?	Yes	26	0	13	13	26	0
	$n=256$	No	42	80	88	43	26	57
		Uncertain	32	20	0	43	48	43
5	Do you think the national legislation on seed transfer is well-adapted in times of climate change?	Yes	39	70	75	20	31	35
	$n=253$	No	22	10	25	40	27	35
		Uncertain	39	20	0	40	41	30
6	Do you think the European legislation on seed transfer is well-adapted in times of climate change?	Yes	37	30	38	16	10	24
	$n=257$	No	21	10	0	39	18	14
		Uncertain	42	60	63	45	72	62
7	How many plants are you selling per year?	1. 0–100 000	11	20	13	42	40	48
		2. 100,000–500 000	28	0	13	42	26	30
		3. 500,000–2 millions	22	70	38	13	26	17
		4. 2–10 millions	33	10	13	0	5	0
		5. More than 10 millions	0	0	25	0	0	4
		6. I don't know/no answer	6	0	0	3	3	0
8	Please specify the percent of trees sold annually	(a) Conifers	Not answered	Not answered	Not answered	Not answered	Not answered	Not answered
		(b) Broadleaved	Not answered	Not answered	Not answered	Not answered	Not answered	Not answered

Table 12 (continued)

Q. no	Question	Answer	Responses					
			Austria	Czechia	Germany	Hungary	Poland	Slovakia
9	The SUSTREE project aims at developing an online information system on forest reproductive material across Central Europe. This information will help users (forest companies, seed trading companies, nurseries, etc.) to inform themselves about reproductive material outside their country and might potentially facilitate transnational trade and adaptation to changing climate conditions. Are you interested in listing your company as potential transnational provider of forest seeds/seedlings in this online information service?	Yes	42	0	25	71	39	61
		No	42	80	75	26	57	39
		Uncertain	16	20	0	3	4	0
	$n = 186$							

Acknowledgements We are grateful to the entire SUSTREE team in the 6 Central European countries for their immense support in the data collection. We would like to especially mention the names of Rafael Buchacher, Johann Hauer, and Gerald Schnabel (BFW, Vienna); Marek Rzońca (IBL, Poland); Jan Stejskal, Jaroslav Čepl (CULS, Czechia); Lea Henning (TI, German); and Ervin Rasztovits (Hungary) for their contribution in the survey dissemination and compilation of the data. Finally, we extend our sincere gratitude to all the foresters, conservation managers, and nurseries who have provided their valuable inputs and participation in our study.

Funding The study was funded by Interreg-CE project SUSTREE "Conservation and sustainable utilization of forest tree diversity in climate change." Interreg CE-Project No: CE614.

Data availability The datasets generated and/or analyzed during the current study are available in the Zenodo repository, https://doi.org/10.5281/zenodo.4319854.

Declarations

Ethics approval We declare that we have followed the rules of good scientific practice. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

References

Aitken SN, Bemmels JB (2016) Time to get moving: assisted gene flow of forest trees. Evol Appl. https://doi.org/10.1111/eva.12293

Aitken SN, Whitlock MC (2013) Assisted gene flow to facilitate local adaptation to climate change. Annu Rev Ecol Evol Syst 44:367–388. https://doi.org/10.1146/annurev-ecolsys-110512-135747

Aitken SN, Yeaman S, Holliday JA et al (2008) Adaptation, migration or extirpation: climate change outcomes for tree populations. Evol Appl 1:95–111. https://doi.org/10.1111/j.1752-4571.2007.00013.x

Ali F, Dissanayake D, Bell M, Farrow M (2018) Investigating car users' attitudes to climate change using multiple correspondence analysis. J Transp Geogr 72:237–247. https://doi.org/10.1016/j.jtrangeo.2018.09.007

Allen CD, Macalady AK, Chenchouni H et al (2010) A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For Ecol Manage 259:660–684. https://doi.org/10.1016/j.foreco.2009.09.001

Ameztegui A, Solarik KA, Parkins JR et al (2018) Perceptions of climate change across the Canadian forest sector: the key factors of institutional and geographical environment. PLoS One. https://doi.org/10.1371/journal.pone.0197689

Andersson E, Keskitalo ECH, Lawrence A (2017) Adaptation to climate change in forestry: a perspective on forest ownership and adaptation responses. Forests. https://doi.org/10.3390/f8120493

Araújo MB, Alagador D, Cabeza M et al (2011) Climate change threatens European conservation areas. Ecol Lett 14:484–492. https://doi.org/10.1111/j.1461-0248.2011.01610.x

Arbuckle JG, Prokopy LS, Haigh T et al (2013) Climate change beliefs, concerns, and attitudes toward adaptation and mitigation among farmers in the Midwestern United States. Clim Change. https://doi.org/10.1007/s10584-013-0707-6

Barbour E, Kueppers LM (2012) Conservation and management of ecological systems in a changing California. Clim Chang 111:135–163. https://doi.org/10.1007/s10584-011-0246-y

Bastin JF, Finegold Y, Garcia C et al (2019) The global tree restoration potential. Science 365(6448):76–79. https://doi.org/10.1126/science.aax0848

Benito-Garzón M, Fernández-Manjarrés JF (2015) Testing scenarios for assisted migration of forest trees in Europe. New For 46:979–994. https://doi.org/10.1007/s11056-015-9481-9

Blennow K, Persson E, Lindner M et al (2014) Forest owner motivations and attitudes towards supplying biomass for energy in Europe. Biomass Bioenerg 67:223–230. https://doi.org/10.1016/j.biombioe.2014.05.002

Blennow K, Persson J (2009) Climate change: motivation for taking measure to adapt. Glob Environ Chang 19:100–104. https://doi.org/10.1016/j.gloenvcha.2008.10.003

Bolte A, Ammer C, Löf M et al (2009) Adaptive forest management in central Europe: climate change impacts, strategies and integrative concept. Scand J For Res 24:473–482. https://doi.org/10.1080/02827580903418224

Bradley St Clair J, Howe GT, St Clair JB, Howe GT (2007) Genetic maladaptation of coastal Douglas-fir seedlings to future climates. Glob Chang Biol 13:1441–1454. https://doi.org/10.1111/j.1365-2486.2007.01385.x

Briner S, Huber R, Bebi P et al (2013) Trade-offs between ecosystem services in a mountain region. Ecol Soc. https://doi.org/10.5751/ES-05576-180335

Broadhurst LM, Lowe A, Coates DJ et al (2008) Seed supply for broadscale restoration: maximizing evolutionary potential. Evol Appl. https://doi.org/10.1111/j.1752-4571.2008.00045.x

Brunette M, Bourke R, Hanewinkel M (2018) Yousefpour R (2018) Adaptation to climate change in forestry: a multiple correspondence analysis (MCA). Forests 9(1):20. https://doi.org/10.3390/f9010020

Bryman A (2012) Social research methods Bryman. OXFORD Univ Press. https://doi.org/10.1017/CBO9781107415324.004

Camacho AE, Doremus H, McLachlan JS, Minteer BA (2010) Reassessing conservation goals in a changing climate. Issues In Science and Technology, Summer 2010, UC Irvine School of Law Research Paper No. 2012–48, Available at SSRN: https://ssrn.com/abstract=2065576

Chakraborty D, Wang T, Andre K et al (2015) Selecting populations for non-analogous climate conditions using universal response functions: the case of Douglas-Fir in Central Europe. PLoS One 10:e0136357. https://doi.org/10.1371/journal.pone.0136357

European Commission (2000) Council Directive 1999/105/EC of 22 December 1999 on the marketing of forest reproductive material. Available at: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31999L0105

European Commission (2014) Natura 2000 network. In: Nature&Biodiversity. Available at : https://ec.europa.eu/environment/nature/natura2000/index_en.htm

Fady B, Cottrell J, Ackzell L et al (2016) Forests and global change: what can genetics contribute to the major forest management and policy challenges of the twenty-first century? Reg Environ Chang 16(927):939. https://doi.org/10.1007/s10113-015-0843-9

Fréjaville T, Vizcaíno-Palomar N, Fady B, Kremmer A, Benito Garzón M (2019) Range margin populations show high climate adaptation lags in European trees. Glob Change Biol.https://doi.org/10.1111/gcb.14881

Frank A, Howe GT, Sperisen C et al (2017) Risk of genetic maladaptation due to climate change in three major European tree species. Glob Chang Biol. https://doi.org/10.1111/gcb.13802

Geyer J, Kreft S, Jeltsch F, Ibisch PL (2017) Assessing climate change-robustness of protected area management plans - the case of Germany. PLoS One. https://doi.org/10.1371/journal.pone.0185972

Goodman LA (1961) Snowball sampling. Ann Math Stat 32:148–170. https://doi.org/10.1214/aoms/1177705148

Grainger A, Iverson LR, Marland GH, Prasad A (2019) Comment on "The global tree restoration potential." Science 366(6463):eaay8334. https://doi.org/10.1126/science.aay8334

Griscom BW, Adams J, Ellis PW et al (2017) Natural climate solutions. Proc Natl Acad Sci U S A. https://doi.org/10.1073/pnas.1710465114

Gudurić I, Tomićević J, Konijnendijk CC (2011) A comparative perspective of urban forestry in Belgrade, Serbia and Freiburg, Germany. Urban For Urban Green 10:335–342. https://doi.org/10.1016/j.ufug.2011.08.002

Hagerman S, Dowlatabadi H, Satterfield T, McDaniels T (2010) Expert views on biodiversity conservation in an era of climate change. Glob Environ Chang 20:192–207. https://doi.org/10.1016/j.gloenvcha.2009.10.005

Hajjar R, Kozak RA (2015) Exploring public perceptions of forest adaptation strategies in Western Canada: implications for policy-makers. For Policy Econ. https://doi.org/10.1016/j.forpol.2015.08.004

Hajjar R, McGuigan E, Moshofsky M, Kozak RA (2014) Opinions on strategies for forest adaptation to future climate conditions in western Canada: surveys of the general public and leaders of forest-dependent communities. Can J For Res. https://doi.org/10.1139/cjfr-2014-0142

Halofsky JE, Andrews-Key SA, Edwards JE et al (2018) Adapting forest management to climate change: the state of science and applications in Canada and the United States. For Ecol Manage. https://doi.org/10.1016/j.foreco.2018.02.037

Hamann A, Aitken SN (2013) Conservation planning under climate change: accounting for adaptive potential and migration capacity in species distribution models. Divers Distrib 19:268–280. https://doi.org/10.1111/j.1472-4642.2012.00945.x

Hanewinkel M, Cullmann DA, Schelhaas M-JJ et al (2013) Climate change may cause severe loss in the economic value of European forest land. Nat Clim Chang 3:203–207. https://doi.org/10.1038/nclimate1687

Hannah L, Midgley G, Andelman S et al (2007) Protected area needs in a changing climate. Front Ecol Environ 5:131–138. https://doi.org/10.1890/1540-9295

Hazarika R, Bolte A, Bednarova D, Chakraborty D, Gaviria J, Kanzian M, …, Schueler S (2020) Dataset on survey of perspectives on afforestation and reforestation strategies in Central Europe under climate change. [dataset]. Zenodo.https://doi.org/10.5281/zenodo.4319854

IPCC (2018) Summary for policymakers. In: Global warming of 1.5°C. Intergov Panel Clim Chang. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/spm.html

Jalonen R, Valette M, Boshier D et al (2018) Forest and landscape restoration severely constrained by a lack of attention to the quantity and quality of tree seed: Insights from a global survey. Conserv Lett. https://doi.org/10.1111/conl.12424

Jandl R, Spathelf P, Bolte A, Prescott CE (2019) Forest adaptation to climate change—is non-management an option? Ann For Sci. https://doi.org/10.1007/s13595-019-0827-x

Jensen S, Konrad H, Geburek T (2019) Crossing borders – European forest reproductive material moving in trade. J Environ Manage 233:308–320. https://doi.org/10.1016/j.jenvman.2018.11.079

Jones TA (2013) When local isn't best. Evol Appl 6:1109–1118. https://doi.org/10.1111/eva.12090

Kassambara A, Mundt F (2017) Factoextra: extract and visualize the results of multivariate data analyses. Bug Reports, 1–76 .URL http//www.sthda.com/english/rpkgs/factoextra

Keenan RJ (2015) Climate change impacts and adaptation in forest management: a review. Ann For Sci 72:145–167

Keskitalo ECH, Legay M, Marchetti M et al (2015) The role of forestry in national climate change adaptation policy: cases from Sweden, Germany, France and Italy. Int For Rev. https://doi.org/10.1505/146554815814725068

Kirchherr J, Charles K (2018) Enhancing the sample diversity of snowball samples: recommendations from a research project on anti-dam movements in Southeast Asia. PLoS One 13(8):e0201710. https://doi.org/10.1371/journal.pone.0201710

Klimo E, Hager, Jirí Kulhavý (eds) (2000) Spruce monocultures in Central Europe – problems and prospects. Proceedings 33, European Forest Institute. ISBN: 952–9844–76-XISSN: 1237–8801

Konnert M, Fady B, Gömöry D, A'Hara S et al (2015) Use and transfer of forest reproductive material in Europe in the context of climate change. European Forest Genetic Resources Programme (EUFORGEN), Bioversity International, Rome, Italy. xvi and 75 p

Latham RE, Ricklefts RE (1993) Continental comparisons of temperate-zone tree species diversity. In: Ricklefs RE, Schluter D (eds) Species diversity in ecological communities: Historical and geographical perspectives. University of Chicago Press, Chicago, pp 294–317

Laakkonen A, Zimmerer R, Kähkönen T et al (2018) Forest owners' attitudes toward pro-climate and climate-responsive forest management. For Policy Econ. https://doi.org/10.1016/j.forpol.2017.11.001

Leites LP, Robinson AP, Rehfeldt GE et al (2012) Height-growth response to climatic changes differs among populations of Douglas-fir: a novel analysis of historic data. Ecol Appl 22:154–165. https://doi.org/10.1890/11-0150.1

Lenart M, Jones C (2014) Perceptions on climate change correlate with willingness to undertake some forestry adaptation and mitigation practices. J For. https://doi.org/10.5849/jof.13-051

Lewis SL, Wheeler CE, Mitchard ETA, Koch A (2019) Restoring natural forests is the best way to remove atmospheric carbon. Nature. https://doi.org/10.1038/d41586-019-01026-8

Lindner M, Maroschek M, Netherer S et al (2010) Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. For Ecol Manage 259:698–709. https://doi.org/10.1016/j.foreco.2009.09.023

Luyssaert S, Marie G, Valade A et al (2018) Trade-offs in using European forests to meet climate objectives. Nature. https://doi.org/10.1038/s41586-018-0577-1

Malcolm JR, Markham A, Neilson RP, Garaci M (2002) Estimated migration rates under scenarios of global climate change. J Biogeogr 29:835–849. https://doi.org/10.1046/j.1365-2699.2002.00702.x

MCPFE (1993) RESOLUTION H1 General guidelines for the sustainable management of forests in Europe. Second Minist Conf Prot For Eur 16–17 June 1993 1–5. https://doi.org/10.1007/s00266-004-0370-4

Messier C, Bauhus J, Doyon F et al (2019) The functional complex network approach to foster forest resilience to global changes. For Ecosyst. https://doi.org/10.1186/s40663-019-0166-2

Nilsson S, Schopfhauser W (1995) The carbon-sequestration potential of a global afforestation program. Clim Chang. https://doi.org/10.1007/BF01091928

OECD (2012) Forest Seed And Plant Scheme 2012 Rules and regulations OECD scheme for the certification of forest reproductive material. Available at: https://www.oecd.org/agriculture/forest/rules-regulations/

Osberghaus D, Finkel E, Pohl M (2012) Individual adaptation to climate change: the role of information and perceived risk. SSRN Electron J. https://doi.org/10.2139/ssrn.1674840

Peterson St-Laurent G, Hagerman S, Kozak R (2018) What risks matter? Public views about assisted migration and other climate-adaptive reforestation strategies. Clim Chang 151:573–587. https://doi.org/10.1007/s10584-018-2310-3

Petit RJ, Aguinagalde I, de Beaulieu JL, Bittkau C, Brewer S, Cheddadi R et al (2003) Glacial refugia: hotspots but not melting pots of genetic diversity. Science 300:1563–1565

Polechová J, Barton NH (2015) Limits to adaptation along environmental gradients. Proc Natl AcadSci U S A 112:6401–6406. https://doi.org/10.1073/pnas.1421515112

Popkin G (2019) How much can forests fight climate change? Nature . Available at: https://media.nature.com/original/magazine-assets/d41586-019-00122-z/d41586-019-00122-z.pdf

R Core Team (2016) R Core Team R. R A Lang. Environ. Stat. Comput. R Found. Stat. Comput. Vienna, Austria. URL http://www.R-project.org

Rehfeldt GE, Jaquish BC, Sáenz-Romero C et al (2014) Comparative genetic responses to climate in the varieties of Pinus ponderosa and Pseudotsugamenziesii: reforestation. For Ecol Manage 324:147–157. https://doi.org/10.1016/j.foreco.2014.02.040

Reyer C, Lasch-Born P, Suckow F et al (2014) Projections of regional changes in forest net primary productivity for different tree species in Europe driven by climate change and carbon dioxide. Ann For Sci 71:211–225. https://doi.org/10.1007/s13595-013-0306-8

Reyer CPO, Brouwers N, Rammig A et al (2015) Forest resilience and tipping points at different spatio-temporal scales: approaches and challenges. J Ecol. https://doi.org/10.1111/1365-2745.12337

Sáenz-Romero C, Lindig-Cisneros RA, Joyce DG et al (2016) Assisted migration of forest populations for adapting trees to climate change. Rev. Chapingo. Ser Cienc For Ambient 22:303–323

Savolainen O, Pyhäjärvi T, Knürr T (2007) Gene flow and local adaptation in trees. Annu Rev Ecol Evol Syst 38:595–619. https://doi.org/10.1146/annurev.ecolsys.38.091206.095646

Seidl R, Thom D, Kautz M et al (2017) Forest disturbances under climate change. Nat Clim Chang 7:395–402. https://doi.org/10.1038/nclimate3303

Sousa-Silva R, Verbist B, Lomba Â et al (2018) Adapting forest management to climate change in Europe: linking perceptions to adaptive responses. For Policy Econ 90:22–30. https://doi.org/10.1016/j.forpol.2018.01.004

Spathelf P, Stanturf J, Kleine M et al (2018) Adaptive measures: integrating adaptive forest management and forest landscape restoration. Ann For Sci 75:55. https://doi.org/10.1007/s13595-018-0736-4

SUSTREE (2017) Summary of the expert survey analysis. Report D.T1.1.2 of Interreg CE project SUSTREE, Conservation and sustainable utilization of forest tree diversity in Climate change (Project n° CE614). Available at Further T1 outputs and deliverables: https://www.interreg-central.eu/Content.Node/SUSTREE.html

Svenning J-C (2003) Deterministic Plio-Pleistocene extinctions in the European cool temperate tree flora. Ecol Lett 6:646–653

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

Tollefsrud MM, Kissling R, Gugerli F et al (2008) Genetic consequences of glacial survival and postglacial colonization in Norway spruce: combined analysis of mitochondrial DNA and fossil pollen. Mol Ecol 17:4134–4150. https://doi.org/10.1111/j.1365-294X.2008.03893.x

Vinceti B, Manica M, Lauridsen N et al (2020) Managing forest genetic resources as a strategy to adapt forests to climate change: perceptions of European forest owners and managers. Eur J Forest Res. https://doi.org/10.1007/s10342-020-01311-6

Wang T, O'Neill GA, Aitken SN (2010) Integrating environmental and genetic effects to predict responses of tree populations to climate. Ecol Appl 20:153–163. https://doi.org/10.1890/08-2257.1

Whittet R, Cottrell J, Cavers S et al (2016) Supplying trees in an era of environmental uncertainty: identifying challenges faced by the forest nursery sector in Great Britain. Land Use Policy. https://doi.org/10.1016/j.landusepol.2016.07.027

Williamson TB, Parkins JR, McFarlane BL (2005) Perceptions of climate change risk to forest ecosystems and forest-based communities. For Chron 81:710–716. https://doi.org/10.5558/tfc81710-5

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

Živojinović I, Wolfslehner B (2015) Perceptions of urban forestry stakeholders about climate change adaptation - a Q-method application in Serbia. Urban For Urban Green 14:1079–1087. https://doi.org/10.1016/j.ufug.2015.10.007

Authors and Affiliations

Reneema Hazarika[1] · Andreas Bolte[2] · Dagmar Bednarova[3] · Debojyoti Chakraborty[1] · Julian Gaviria[4] · Monika Kanzian[5] · Jan Kowalczyk[6] · Magdalena Lackner[7] · Milan Lstibůrek[8] · Roman Longauer[3] · Lazlo Nagy[9] · Ivana Tomášková[8] · Silvio Schueler[1]

Andreas Bolte
andreas.bolte@thuenen.de

Dagmar Bednarova
bednarova@nlcsk.org

Debojyoti Chakraborty
debojyoti.chakraborty@bfw.gv.at

Julian Gaviria
Julian.gaviria@anl.bayern.de

Monika Kanzian
monika.Kanzian@bundesforste.at

Jan Kowalczyk
j.kowalczyk@ibles.waw.pl

Magdalena Lackner
lackner@iufro.org

Milan Lstibůrek
lstiburek@fld.czu.cz

Roman Longauer
longauer@nlcsk.org

Lazlo Nagy
lnagy@erti.hu

Ivana Tomášková
tomaskova@fld.czu.cz

Silvio Schueler
silvio.schueler@bfw.gv.at

[1] Department of Silviculture and Forest Growth, Austrian Research Centre for Forests (BFW), Seckendorff-Gudent-Weg-8, 1130 Vienna, Austria

[2] Thünen-Institute of Forest Ecosystems (TI), Alfred-Möller-Straße 1, Haus 41/42, 16225 Eberswalde, Germany

[3] National Forest Centre (NLC), T. G. Masaryka 2175, Zvolen 960 01, Slovakia

[4] Bavarian Office for Forest Genetics (AWG), Forstamtsplatz-1, 83317 Teisendorf, Germany

[5] Austrian Federal Forests, Austria (ÖBF), Pummergasse 10-12, 3002 Pukersdorf, Austria

[6] Department of Silviculture and Genetics of Forest Trees, Forest Research Institute, (IBL), SekocinStary, 3 BraciLeśnej St., 05-090 Raszyn, Poland

[7] International Union of Forest Research Organizations (IUFRO), Marxergasse 2, 1030 Vienna, Austria

[8] Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague (CULS), Kamýcká 129, 165 21 Praha 6 - Suchdol, Czech Republic

[9] National Agricultural Research and Innovation Centre, Forest Research Institute (NAIK ERTI), Várkerület 30/A, 9600 Sárvár, Hungary