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ORIGINAL ARTICLE

Balancing Risks and Benefits: Stakeholder Perspective on Managing Non-Native Tree Species in the European Alpine Space

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Abstract
For centuries, non-native tree (NNT) species have been planted throughout Europe for ecosystem services including timber and urban greenery. Public interest in NNTs has recently increased due to their potential role in climate change adaptation as alternatives to vulnerable native forest tree species. However, opinions regarding the benefits and risks of European NNTs differ. Understanding stakeholder perceptions is crucial for guiding adaptive forest management, especially in sensitive ecosystems like the European Alpine Space. To assess awareness and perception, a structured questionnaire was administered to 456 respondents from six countries in the European Alpine Space. Most respondents were aware of the origin of native and NNT species in their area. NNTs and invasive-NNTs were primarily found in urban regions, with a perceived increase in their occurrence over the past 25 years. With some exceptions, such as *Pseudotsuga menziesii* (*Mirb*.) Franco, the most common NNTs were generally perceived as potentially invasive. The perception of the invasiveness of NNTs correlated with their perceived risks and benefits on ecosystem services. The respondents who were unconcerned about invasiveness believed NNTs had a positive impact on provisioning services like timber, while those concerned about invasiveness perceived their negative effects on regulating cultural ecosystem services such as native biodiversity and landscape aesthetics. Overall, most respondents were conservative, opposing the promotion of NNTs, even in biodiversity-poor areas. Most stakeholders also believe that NNT regulations should prioritize their sustainable use and management rather than focusing solely on an invasive-centric narrative.

Keywords Climate change adaptation · Ecosystem services · European Alpine Space · Invasiveness · Non-native trees · Perception

Extended author information available on the last page of the article

1 Introduction

Non-native tree (NNT) species have been integral to European ecosystems for centuries. Identified as the tree species whose post-glacial, natural geographical distribution range was outside of Europe, NNTs are also referred to as "non-indigenous", "alien", "introduced", "allochthonous", or "exotic" tree species, breeds, or hybrids whose presence is the result of anthropogenic intentional or unintentional introduction (Marinšek et al. 2022; Pötzelsberger et al. 2020a). Though NNTs already made their appearance in Europe after the discovery of the new world, they were first intentionally introduced in the European continent in the sixteenth century to provide ecosystem services such as timber, fiber, urban greenery, and ornamentation (Brundu and Richardson 2016; Brus et al. 2019; Castro-Díez et al. 2019; Brundu et al. 2020). Later, some NNTs became naturalized and exhibited invasiveness following their unintended escape and spread from the initial introduction areas (Dodet and Collet 2012; Chapman et al. 2016; Bartz and Kowarik 2019). Brus et al. (2019) estimated that around 4% of the forest cover in Europe, which roughly corresponds to 8.5 million ha, is currently covered by NNTs. This figure, however, does not account for the distribution of NNTs in urban and peri-urban areas. About 145 NNTs were documented by Brus et al. (2019) in Europe, mostly originating from North America, Asia, and Australia dominated by species such as *Robinia pseudoacacia* L., *Picea sitchensis* (Bong.) Carr., and *Pseudotsuga menziesii* (Mirb) Franco. While within the Interreg ALPTREES project (Lapin et al. 2020), 530 NNTs were identified including forests and urban areas of the European Alpine space (Marinšek et al. 2022).

The ecological and sociopolitical discourse on NNTs is polarized and can be summarized as "usage-centric" because of their positive effects as providers of multiple ecosystem services and "invasive-centric" due to negative effects on native biodiversity when they become invasive resulting from their undesired expansion and invasion (Castro-Díez et al. 2019; Pötzelsberger et al. 2020b; Pyšek 2020; Dimitrova et al. 2022; Marinšek et al. 2022). While NNTs are viewed as alternative tree species in sites where native species are vulnerable to climate change (Bolte et al.2009; Lindner et al. 2010; Chakraborty et al. 2016; Frischbier et al. 2019), their potential negative influence has been discussed (Campagnaro et al. 2018; Dueñas et al. 2018; Brundu et al. 2020; Wagner et al. 2021; Wohlgemuth et al. 2022).

For example, the North American conifer Douglas fir (*Pseudotsuga menziesii*) is being discussed as an alternative species in the European forest stands dominated by native *Picea abies* (L.) H. Karst. which is vulnerable to drought, storm damage, and insect attack (Klimo and Hager 2000; Roques et al. 2019; Spiecker et al. 2019). Recent studies however report that Douglas fir can be potentially invasive on poor, shallow, and dry sites or block fields (Tschopp et al. 2015; Bindewald and Michiels 2018). As such, the discussion on Douglas fir is controversial as it shows both risks and benefits depending on the site, although there is no evidence of its large-scale invasion in forests of Central Europe (Frei et al. 2022; Lange et al. 2022). The current debate on forestry-related assisted migration (forestry-AM) under climate change has also further propelled the discussion on the role of NNTs in adaptation strategies (Pedlar et al. 2012; Hajjar et al. 2014; Aitken and Bemmels 2016; Peterson St-Laurent et al. 2018). Hence, the use of NNTs for assisted species migration has been strongly discussed primarily from the view of invasiveness and its effects on native biodiversity (Peterson St-Laurent et al. 2018; Hagerman and Kozak 2021; Kracke et al. 2021).

The different discourses on the positive and negative effects of NNTs in European forests have led to a wide range of legislative frameworks in Europe primarily addressing the invasive potential of NNTs (Pötzelsberger et al. 2020a). The EU Regulation No 1143/2014 is one such legislation that aims to prevent, minimize, and mitigate the adverse impacts of invasive alien species on biodiversity and ecosystem services (European Council 2014). Article 3 of this regulation defines invasive alien species (IAS) of Union concern and enlists them in article 4(3) if such species entail "adverse impact" which requires concerted action at the Union level. This regulation focuses solely on the management of IAS and not specifically on NNTs and their sustainable management (Lapin et al. 2020). Nevertheless, only a small proportion of the 4% NNTs established in the Alpine Space (Marinšek et al. 2022) were found to be actually or potentially invasive (ALPTREES NNT database 2022). Several studies have proposed guidelines for sustainable use, management (Brundu and Richardson 2016; Brundu et al. 2020), and risk assessment of NNTs (Bindewald et al. 2021), but these are legally non-binding. Lack of data and transnational communication, usage of various terminologies, differences in definition, and assessment methods are major challenges in developing a robust method for risk assessment (Kulhanek et al. 2011; Gallardo et al. 2016; Roy et al. 2018) for NNTs. Recently Dimitrova et al. (2022) concluded that limited, and likely biased knowledge about NNTs has prevented their sustainable use and management in Europe. One such knowledge gap identified by Dimitrova et al. (2022) is the lack of scientific evaluation of the awareness and perceptions of NNTs in Europe and the need for pan-European collaboration for their assessment of the risks and benefits of NNTs. A large number of scientific studies on perceptions exist for urban forests and their role in human well-being (Gerstenberg and Hofmann 2016), including ecosystem services urban greenery and parks (Collins et al. 2019; Schlaepfer et al. 2020), mixed forests (Grilli et al. 2016) and the suitability of forest tree species for multiple ecosystem services (Smaill et al. 2014). However, only a few studies evaluate the stakeholder's perceptions and their awareness of the risks and benefits of NNTs (Verbrugge et al. 2013; Vaz et al. 2021; Dimitrova et al. 2022).

Knowledge about stakeholder perceptions of forests and their management can help formulate policies on forest and climate adaptation under uncertain conditions (Peterson St-Laurent et al. 2018; Petit 2021). Environmental awareness and risk perception are also important information from stakeholders that can help select the best planning and management options in a multi-objective setting (Choon et al. 2019). Moreover, socio-demographic factors like gender, age, and personal characteristics like education, occupation, and job designation are proven to influence how different people perceive environmental and climate-related issues (Vaske et al. 2001; Hornsey et al. 2016; Beiser-McGrath and Huber 2018).

Mountain forests, which provide crucial ecosystem services and support the livelihood of millions of people, are particularly vulnerable to climate change-induced drought, insects, and pathogens (Brang et al. 2013; Härtl et al. 2016; Blattert et al. 2017). The European Alpine Space is such a mountainous ecosystem, covering an area of approximately 0.45 million km^2 and home to around 80 million inhabitants in seven countries that share geographical and environmental characteristics and challenges. With 40% of its land covered in forests (Dupire et al. 2020) the Alpine Space is one of Europe's most biodiverse regions with different ecosystems highly vulnerable to climate change (EEA 2020, Lapin et al. 2023).

Therefore, there is a need to evaluate the perceptions of multiple stakeholders such as the general public, scientists, conservation and forest managers, including policymakers, on the positive and negative impacts of NNTs on sensitive ecosystems (Shackleton et al.

2019; Dimitrova et al. 2022) such as the Alpine Space. With this study, we analyzed how various stakeholders (i) perceive NNTs and invasive-NNTs (ii) their awareness of the risks and benefits of NNTs on ecosystem services and (iii) evaluate the management of advantageous as well as potentially invasive-NNTs in the European Alpine Space, considering variances between countries.

2 Materials and methods

2.1 Study area

The stakeholder survey was conducted in five countries, Austria, Germany, France, Slovenia, and Italy (Fig. 1) which were participants in the Interreg Alpine Space project ALPTREES (Project no. 791, 2019–2022) under the Interreg-Alpine Space Programme. However, Switzerland was included in this study since the ALPTREES project had collaborations with external Swiss observers who were working actively on NNTs in the country.

2.2 Survey design

A structured questionnaire was designed to document the perception of the risks, benefits, use, and management of NNTs from the six countries of the European Alpine Space. The questionnaire focused on both forest and urban stakeholders within the Alpine Space. The questions were divided into four sections. Section 1 gathers socio-demographic information like age, education, and type of occupation of participants, Sect. 2 documents the stakeholder perceptions on the identification of NNT, as well as their origin and relevance, Sect. 3 focuses on the benefits and risks of NNT on ecosystem services, and Sect. 4 evaluates the understanding of forest management measures (for details please check Supplementary information A). The participants had the opportunity to choose one or more relevant options from the multiple-choice questions. A list of 30 tree species growing in the

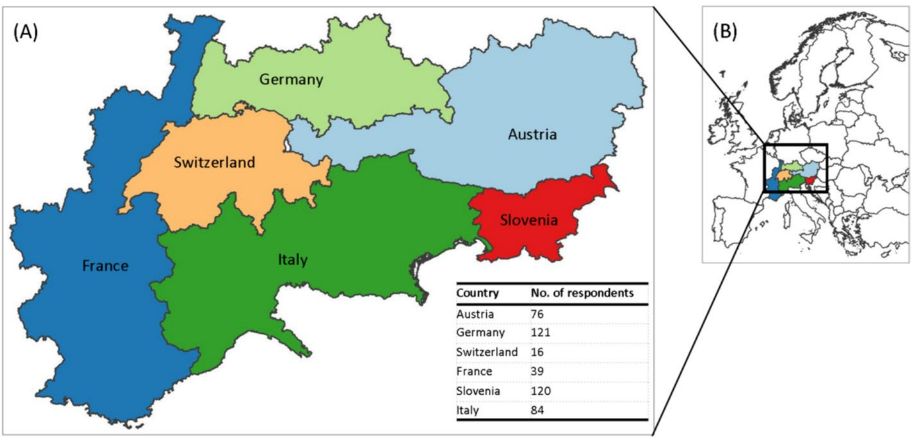

Fig. 1 Surveyed region in the European Alpine Space with the number of survey respondents from each country (**A**) and its location in Europe (**B**)

Alpine Space was provided with the questionnaire out of which 25 were NNTs. The five native tree species were included in this list along with the NNTs to assess the awareness of the participants regarding native and NNT species in their region (Table S1 in Supplementary Information B & Sect. 2.2 in Supplementary Information A).

A list of contacts of different stakeholders was prepared in consultation with the ALP-TREES project partners which included individuals, organizations, and businesses involved in forestry, forest management, nature conservation, public gardens, urban nurseries, urban landscape designers, and urban green spaces in the European Alpine Space. The questionnaire was designed as an online survey and was available from June to December 2020. The survey was translated into 5 European languages namely English, German, French, Slovenian, and Italian. In addition to online access, the questionnaire was also disseminated to targeted stakeholders through email lists for a wider dispersal of the survey and uploaded to various social media platforms triggering an exponential non-discriminative snowball sampling (Goodman 1961; Johnson 2014).

To avoid the exclusion of participants with limited access and competencies in online surveys, questionnaires were also sent by post and received back as hand-filled forms or via e-mail. Three hand-filled responses and two via email from Austria were manually processed into the official online survey system. Due to these different forms of dissemination, it was not possible to predetermine the sample size in advance. Due to the terms of confidentiality, the identity of the respondents has not been shared. For analysis, all the responses were translated into English.

2.3 Statistical analysis

The results from the survey were first assessed through exploratory analyses. The Kruskal-Wallis test was used to analyze if statistical differences exist between the mean ranks of the groups of respondents when answering a specific question. Combined responses to multiple questions were analyzed by Multiple Correspondence Analysis (MCA) to understand patterns or associations, if any among respondent groups. The questions analyzed in the MCA encompassed those that assessed survey participants' levels of concern regarding the impacts of the invasive NNTs, their opinions on the contribution of the specified NNTs to ecosystem services in their region, and their ability to accurately identify the origins of both native and NNTs in their region. Similar to Principal Component Analysis (PCA) for quantitative variables, MCA aims to reduce the dimensionality of qualitative data to detect associations, patterns, and relationships. MCA has been utilized in studies to understand perceptions of climate change (Ali et al. 2018; Brunette et al. 2018; Hazarika et al. 2021). The results of the MCA were depicted as MCA-biplot which shows the grouping, if any, within and between individuals and variable categories. In the questionnaire, we used the terms "urban" and "peri-urban". Peri-urban areas are defined as zones of transition from rural to urban land use. However, during the data analysis, it was unclear whether the responses were made in the context of urban or peri-urban habitats. Hence, for a comprehensive analysis, we summarized the responses to those questions as relevant for "urban" areas. The questions analyzed to examine the stakeholder's perception of risks and benefits for ecosystem services and the management of invasive-NNTs are listed in Table S3 in Supplementary Information B. All statistical analysis and figures were done with software R (R Core Team 2021) while R- package "factoextra" (Kassambara and Mundt 2017) was used to implement and visualize the results of the MCA.

3 Results

The survey was taken by (N = total) 456 respondents from the six Alpine Space countries (Fig. 1), out of which 300 were males, 153 were females, and 3 were identified as others. The number of respondents participating in the survey varied between the 6 countries, with Germany and Slovenia having the most responses with 121 and 120 respondents respectively, and only 16 responses were received from Switzerland. Most of the respondents across all countries were associated with forestry (55%) and nature conservation (20.4%) as their expertise or field of operation (Table S2 in Supplementary Information B).

3.1 Awareness of the origin and perception of the risks and benefits of NNTs

The respondents were familiar with the NNTs analyzed in this study. Around 90% of the NNTs were correctly identified by the respondents across the countries (Fig. 2). However, NNTs such as *Aesculus hippocastanum* L., *Juglans nigra* L., and *Platanus acerifolia* (Aiton) Willd., were identified as native species by 38%, 25%, and 15% of the respondents, respectively. Similarly, the origin of the native species was correctly identified by around 80% of the respondents across all the countries (Fig.S1 in Supplementary Information C). However, two native species, *Taxacus baccata.* L and *Ulmus glabra* Huds. were identified as NNT species by around 12% of the total respondents (Fig.S1). No significant difference *(Kruskal–Wallis, N = 456, p = 0.07)* was found between the countries in their ability to identify the origin of the native and NNT species (Fig.S2 in Supplementary Information C).

Within the study area, the most commonly reported NNTs by the respondents were *Robinia pseudoacacia* (*291 responses*), *Pseudotsuga menziesii* (*220 responses*), *Ailanthus altissima* (Mill.) Swingle (201 *responses*), *Quercus rubra* L. (99 *responses*), *Paulownia tomentosa* (Thunb.) Steud. (72 *responses*),and *Acer negundo* L. (72 *responses*) (Fig. 3 &. Fig.S3 in Supplementary Information C). No significant differences exist in the ranking of the abundance of the NNTs (*Kruskal–Wallis, N = 456, p = 0.088*), suggesting all the countries have reported similar NNTs as the most abundant ones. However, Italy was an exception where Douglas-fir (*Pseudotsuga menziesii*) was not among the first five NNTs, while it featured among the top five NNTs in the other 5 countries (Fig.S3). Also, most respondents (approximately. 90%) agree that invasive-NNTs occur in their area of operation (their area of residence or work) (Fig.S4 in Supplementary Information C).

Most often *Ailanthus altissima, Robinia pseudoacacia, Prunus serotina, Rhus typhina*, *and Acer negundo* (Fig. 3) were reported as invasive or potentially invasive-NNT species across these six Alpine Space countries (more details on individual countries in Fig.S5 in Supplementary Information C).

Around 85% of the total respondents agree that NNTs occur commonly in urban areas which are significantly higher (Kruskal–Wallis, N = 456, p = 0.000) than the total respondents who agree that NNTs occur commonly in forest areas (Fig. 4A). A significantly higher number (approx. 70%) of respondents (Kruskal–Wallis, N = 456, p = 0.001) believe that the occurrence of NNTs has increased in both urban and forest areas over the last 25 years (Fig.S6 in Supplementary Information C), compared to those who disagree. Moreover, a significantly higher proportion of respondents (Kruskal–Wallis, N = 456, p = 0.000) think that invasive-NNTs are of major occurrence in urban areas compared to forest areas and

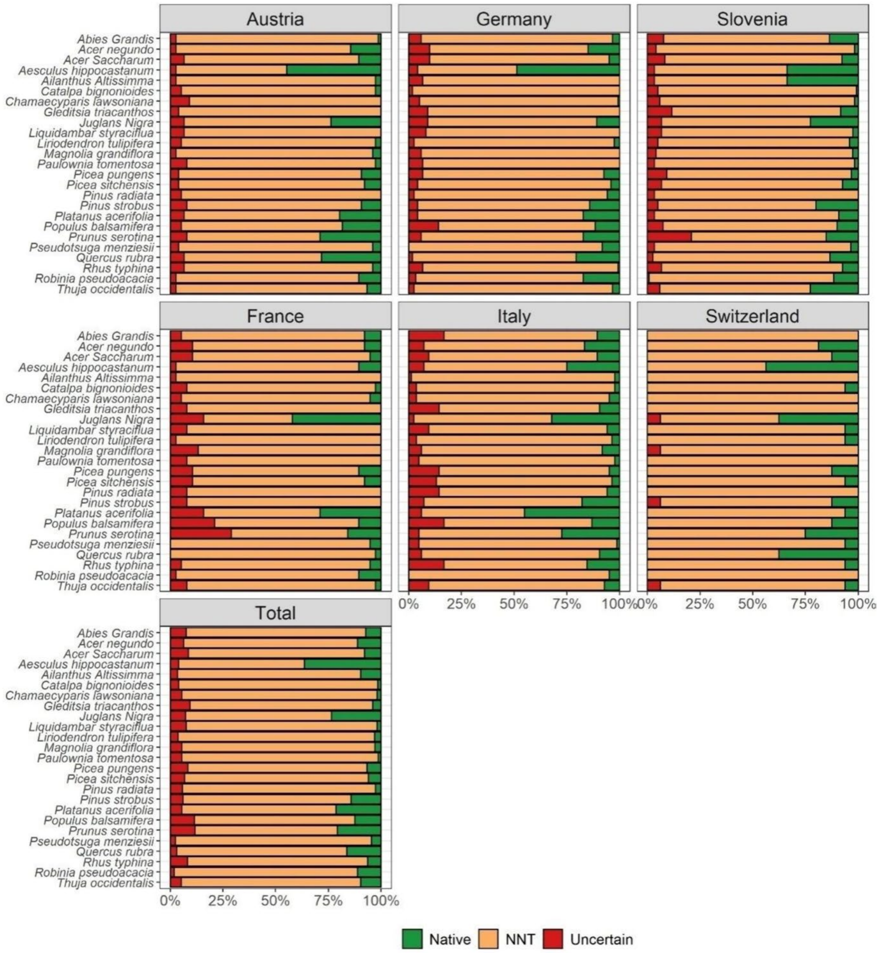

Fig. 2 Knowledge of the respondents about the origin of the 25 NNTs found in the six European Alpine space countries. Total refers to the combined responses of the six countries

that their proportion in both the forest and urban areas have been increasing in the last 25 years (Fig. 4B, & Fig.S6).

3.2 Effects of NNTs on Ecosystem Services

Approximately 50% of the total (*n* = *456*) respondents think that the risks and benefits of NNTs depend on the site conditions and the respective management goals (Fig.S7 in Supplementary Information C). Only 5–10% of the respondents feel NNTs are generally beneficial, and around 5–10% of the respondents across all 6 countries feel that NNTs must be eliminated. There are differences among the countries as well, as around 50% in Italy and 40% in Slovenia think that NNTs pose risks (Fig.S7). Among the respondents, the Swiss and Italian respondents tend to be highly concerned about the invasiveness of NNTs (Fig.

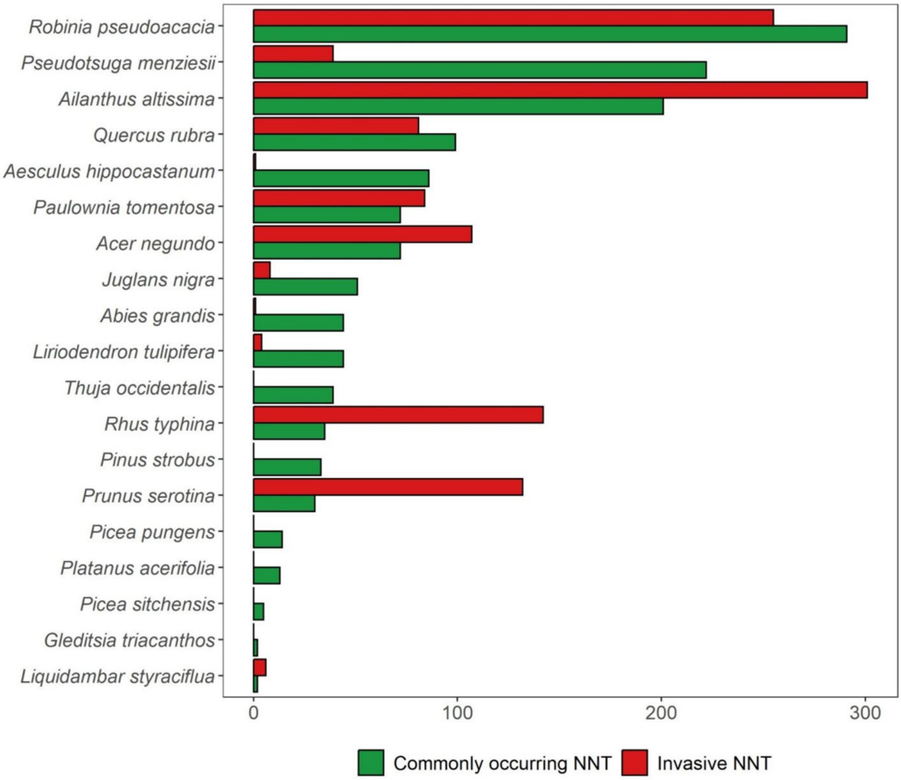

Fig. 3 Most commonly reported NNTs and most reported invasive-NNTs by the respondents. (For detailed responses by each country see Fig.S3 & S5 in Supplementary Information C)

S8 in Supplementary Information C). However, for both the risks and benefits of NNTs as well as concern for invasiveness, no statistically significant difference was observed between the respondents of the countries *(Kruskal–Wallis, N = 456, p = 0.712)*.

The respondents were asked about their opinion on the likely contribution (positive, depends, or negative) on 17 important ecosystem services provided by the NNTs (Fig.S9 in Supplementary Information C). Perceptions of the respondents vary according to countries and type of ecosystem services. However, respondents across all countries believe that NNTs will have a significantly higher positive influence on provisioning and supporting ecosystem services such as timber and bioenergy (*Kruskal–Wallis, N = 456, p = 0.000*). While a significantly higher negative influence was perceived on regulating and cultural services such as biodiversity maintenance, landscape aesthetics, and cultural heritage (*Kruskal–Wallis*, *N = 456, p = 0.004)* (Fig. 5, Fig.S9 & Fig.S10 in Supplementary Information C) except for 50% positive perceptions for air quality and noise attenuation under regulating ecosystem services (Fig. 5).

Respondents who have low or no concern about invasiveness tend to think that NNTs will have a positive influence on provisioning ecosystem services such as timber and bioenergy, while those who are highly concerned about invasiveness think that NNTs have a negative influence on regulating and cultural ecosystem services such as biodiversity,

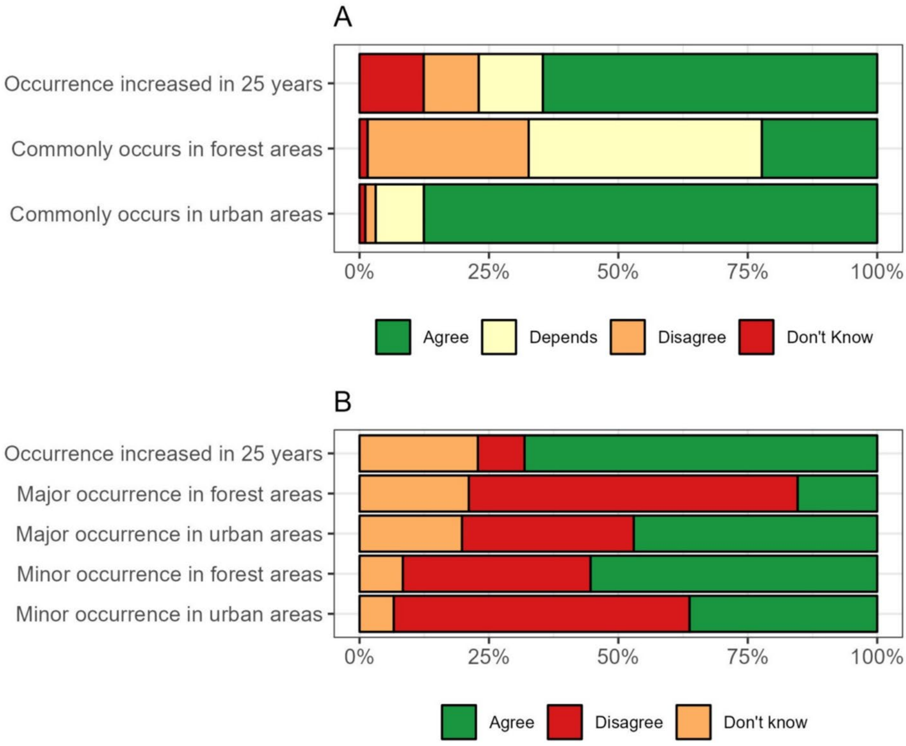

Fig. 4 Perception of the occurrence of NNTs (**A**) and invasive-NNTs (**B**) in forest, and urban areas, and their increase of occurrence in the last 25 years

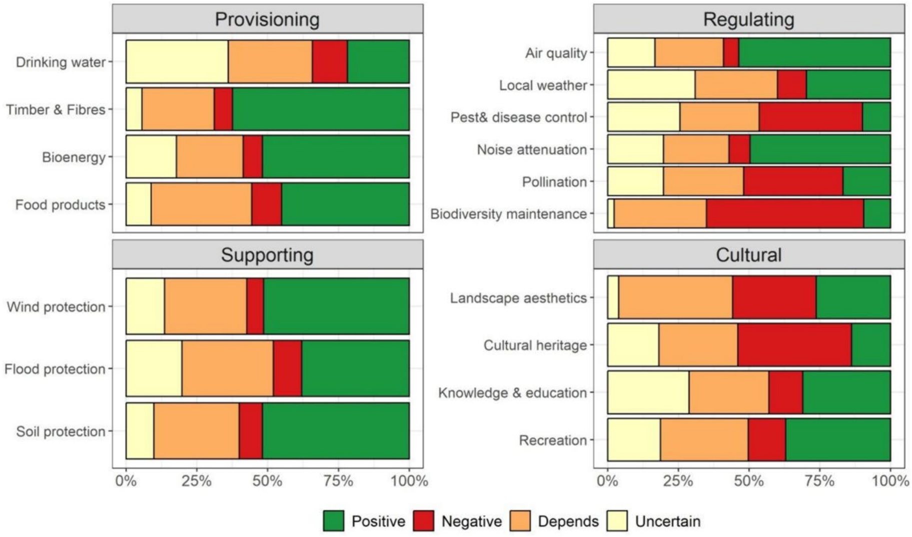

Fig. 5 Perceptions on the categories of effects (positive, negative, depending on site conditions, and uncertain) of NNTs on the four major groups of ecosystem services. See Fig S9 in Supplementary Information C for detailed responses by ecosystem services and countries

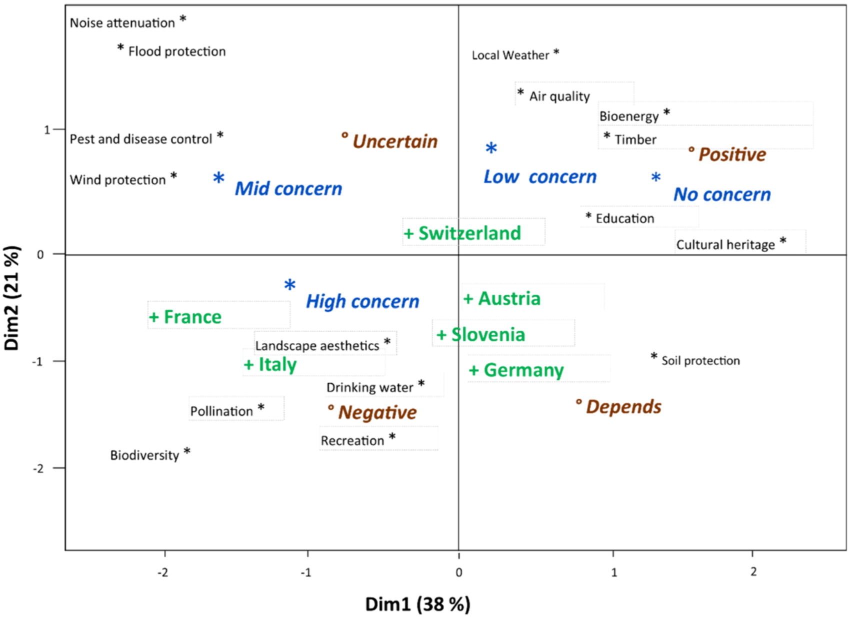

Fig. 6 MCA biplot depicting the perceptions of the respondents from the six countries (+) on the contribution of NNTs (°) on 17 ecosystem services (*); and their concerns regarding the invasiveness of the NNTs (*). The two dimensions (Dims 1 & 2) explain around 59% of the variance in the responses analyzed. The analyzed questions included in this MCA are the following i) what is the level of concern about the impacts of the five invasive trees you have chosen (from the list) found in your region? (high concern, medium concern, low concern, no concern, uncertain) and ii) what is your opinion on the contribution of the listed NNT species to the given 17 ecosystem services in your region? (positive, negative, depends, uncertain)

pollination, recreation, and landscape aesthetics (Fig. 6). No statistically significant groups in the countries were found (Fig. 6). The responses on the concern for the invasiveness of the NNTs and their contribution to different ecosystem services did not differ significantly between the six countries (Fig. 6).

NNTs have been introduced for a wide range of uses in the European Alpine Space. The respondents of the survey were given 6 options to choose from and which NNT (in the list of 25) they thought might be useful. For example, *Robinia pseudoacacia* was perceived to be widely used (Fig. 7) for protection against natural disturbances (20%), agroforestry (12%), forestry (22%), climate change (cc)-adaptation (14%), land improvement (17%), and urban greening (15%). *Quercus rubra* was believed to be used for forestry (39%), climate change(cc)-adaptation (15%), and urban greening (23%). *Peudotsuga menzeisii* covers all aspects but more of forestry (57%) and cc-adaptation (22%). *Ailanthus altissima* was perceived to be useful for protection against natural disturbances (39%) and urban greening (28%).

3.3 Management of the risks and benefits of NNTs

The respondents' awareness of the possible management interventions to control invasive-NNTs varies from a "low awareness" in biocontrol (25%), herbicide (30%) and

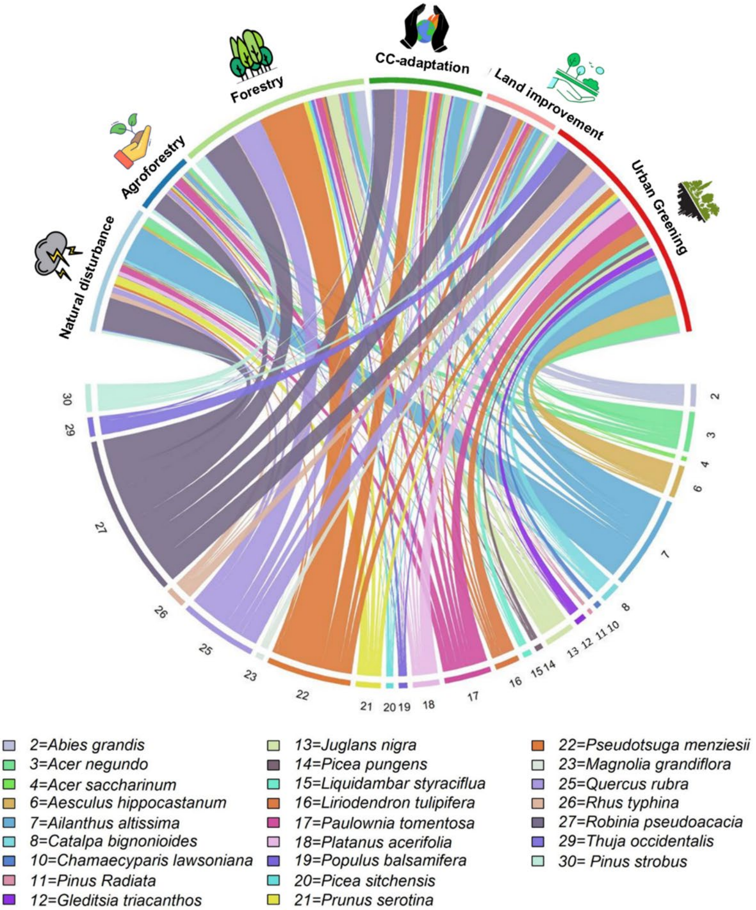

Fig. 7 Perceptions on the 6 given reasons (in the top axis) that make NNT species (numbered in the bottom axis), useful in the European Alpine Space. The numbers refer to the NNTs listed in Table S1 in Supplementary Information B. It should be noted that among the list of 30 species, 5 are native, and therefore not included here and only the 25 NNTs are shown in this figure

buffer zone management (35%), while a “high awareness” found in measures such as monitoring (85%), girdling (65%) and cutting (75%), (Fig. 8). Interestingly, a significantly higher number of respondents (75%) are aware of management measures to control invasive-NNTs compared to those who are aware of national and EU legislation and policies on the management of NNTs and invasive-NNTs (*Kruskal–Wallis, N*=*456, p*=*0.000*) (Fig.S11 in Supplementary Information C). No significant difference in opinion between the countries was found (*Kruskal–Wallis, N*=*456, p*=*0.675*).

A significantly higher proportion (75%) of total respondents think that controlling and managing invasive-NNTs is in the hands of private owners compared to conservation authorities and municipalities (Fig. S12 in Supplementary Information C). The majority of the respondents also think that invasive-NNTs should not be cultivated at all (even in biodiversity-poor areas), and if existing NNTs are invasive, they should be eliminated (Fig.S12).

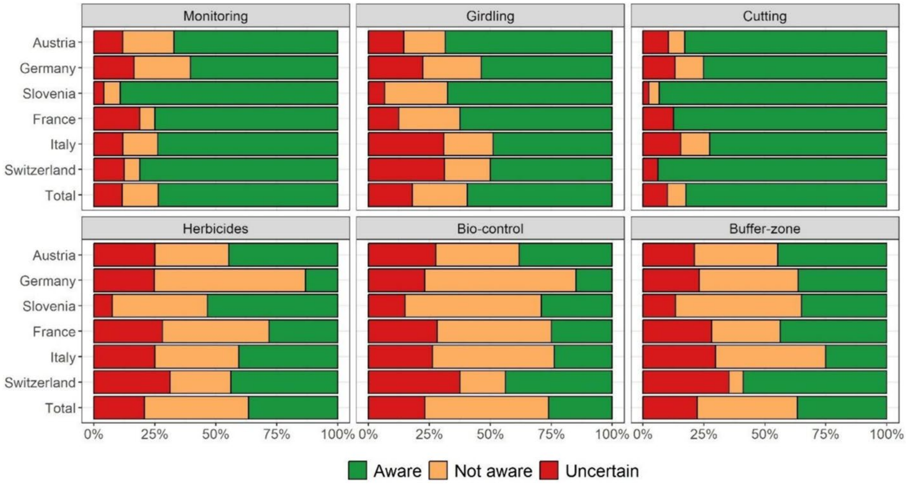

Fig. 8 Response to the awareness of management measures to control invasive-NNTs

4 Discussion

The occurrence of NNTs has been on the rise in both forests and urban ecosystems over the past few decades, contributing to a divisive attitude toward their risks and benefits. In this study, the perception of the risks and benefits of NNTs and their role in providing ecosystem services were analyzed among multiple stakeholder groups in different countries in the European Alpine Space to provide insights into their sustainable management and use.

The responses received in this survey were disproportionate across countries, gender, and occupation (Table S2 in Supplementary Information B). This skewness in the responses due to the higher number of participants from Germany and Slovenia and respondents being mostly males from the field of forestry and conservation is likely to influence the findings of the study. Moreover, the timeline of this survey i.e. 2020 was within the global pandemic, which may have impacted the number of participants and outreach of the survey.

Around 90% of the respondents correctly identified the origins of native and NNT species (Fig. 2 and Fig.S2 in Supplementary Information C), indicating that they were aware of the major native forest tree species as well as the NNTs introduced in their area of operation (work/residence). Some widely occurring NNTs such as *Aesculus hippocastanum*, *Juglans nigra*, and *Platanus acerifolia* were identified as native species. This confusion may be attributed to the fact that these species have been widely planted in urban areas of the EU for timber production and urban greenery since the beginning of the seventeenth century (Nicolescu et al. 2020) and are therefore, mistaken as native. Several of the commonly reported NNTs in the survey such as *Ailanthus altissima, Robinia pseudoacacia, Prunus serotina, Rhus typhina,* and *Acer negundo* have also been documented to be the most prevalent NNTs in Europe by recent studies (Brus et al. 2019; Wohlgemuth et al. 2022; Simčič et al. 2022). And apart from Rhus typhina which is a black-listed invasive-NNT in Switzerland (FOEN 2022), the other four NNTs are black-listed and controlled in Europe (Brundu & Richardson 2016). Except for Italy, *Pseudotsuga menziesii* ranks among the top five NNTs i.e. most frequently reported across the other five countries in the survey. This may be because although *Pseudotsuga menziesii* is the second most extensive non-native conifer species in Europe (Nicolescu et al. 2023), it covers only 0.19% of the total forest area in Italy, compared to 2% to 2.6% in Germany and France respectively (Mercurio & Minotta 2000; La Marca et al. 2016; Riedel et al. 2017; Hasenauer et al. 2017; Spiecker et al. 2019).

Most respondents feel that NNTs, irrespective of whether they were perceived as invasive or not, occur more commonly in urban areas than in forests and that their occurrence has increased in the last 25 years (Fig. 4). This increase in the occurrence of both invasive and non-invasive-NNTs in the last 25 years has also been reported by national and regional studies (Seebens et al. 2015; Berg et al. 2016; Campagnaro et al. 2022). In this context, a strong perception was observed that urbanization promotes the spread of invasive-NNTs. Many studies on invasive species in Europe show that landscapes such as agricultural land, urban parks, and other disturbed sites are the most vulnerable areas to such invasions (Chytrý et al. 2009; Gaertner et al. 2017; Bartz and Kowarik 2019; Borden and Flory 2021). In contrast, broad-leaved and mixed forests, have remained relatively uninvaded (Chytrý et al. 2009; Santana-Marques et al. 2020) with exceptions of species like *Robinia pseudoacacia* and *Quercus rubra* which were found to invade also broadleaved forests (Benesperi et al. 2012; Vítková et al. 2017; Chmura 2020). However, it has been reported that scientific evidence linking urbanization to invasive species is often based on niche models developed with presence-only data which are heavily biased toward urban ecosystems (Gippet et al. 2022).

The potential invasiveness of widely occurring NNTs is concerning because they are used in a wide variety of applications, including forest management, agroforestry, climate change adaptation, urban greening, and land improvement (Fig. 7) and therefore, a large-scale invasion can be difficult to manage. For example, the negative influence of *Robinia pseudoacacia* (Black locust) has been widely reported in the Central European landscape (Vítková et al. 2017). This fast-growing and drought-resistant species has a long-standing history for its use in afforestation and economic value as timber and for apiculture (Quinkenstein and Jochheim 2016; Vítková et al. 2017). Well-managed forests of *Robinia pseudoacacia* provide high-quality honey (Farkas et al. 2007), but as a highly invasive species in open habitats, *Robinia pseudoacacia* is considered to threaten native biodiversity, causing the extinction of many endangered light-demanding plants (Vítková et al. 2017). However, some of the other widespread NNT species such as *Pseudotsuga menziesii, Juglans nigra, Aesculus hippocastanum,* and *Abies grandis* were not reported to be invasive. This perception might be also related to decades of practical experience in utilizing NNTs for ecosystem services. *Pseudotsuga menziesii* has been planted for its timber quality and resistance to pests and disturbance and is often prescribed as an alternative to the native *Picea abies* under climate change (Spiecker et al. 2019; Klimo and Hager 2000; Chakraborty et al. 2016; Roques et al. 2019). Therefore, both empirical studies (Klimo and Hager 2000; Issac-Renton et al. 2014; Roques et al. 2019) and stakeholders of our study view *Pseudotsuga menziesii* as a safe species to be used in assisted species migration in Europe. Another explanation is that the NNTs which can be usually easily controlled are not considered invasive by forest managers (Vor et al. 2015). In line with this, a recent study indicated that although more than 70% of the managers of protected areas believe that climate change and invasive species are highly relevant for conservation management, they see a high probability that these threats could be mitigated through stakeholder coordination (Mattsson & Vacik 2018). Additionally, NNTs such as *Abies grandis, Thuja occidentalis, Aesculus hippocastanum*, *Pinus strobus*, *Pinus pungens* that were not reported by the respondents as invasive are also those with limited potential for natural regeneration (Vor et al. 2015). However, these same NNTs are found to have a wide range of uses such as construction material, the paper industry, and medicinal use (Naser et al. 2005, Uprety 2013, Radu 2017, Karatoprak 2019, Dziedziński 2021) and have been positively viewed as potential candidates for assisted species migration in Europe (Frýdl et al.2018). Most of the respondents believe that the risks and benefits of NNTs (Fig.S7) depend on different factors, such as site conditions and management goals. For example, *Paulownia tomentosa*, which originates from China, and was introduced in Europe in 1834 as an ornamental tree (Essl 2007), is valued for its fast growth, quality wood, as well as the potential for the energy, and pulp industry (Dubova et al. 2019; Jakubowski 2022). But the species has been designated as (potentially) invasive in several countries of central Europe and in the Alpine Space because of the uncontrolled regeneration and presumed negative interaction with the native biodiversity range, especially in unmanaged and degraded urban ecosystems (Essl 2007; Bork et al. 2015; Wagner et al. 2021).

In general, the respondents believe that NNTs are likely to have a positive influence on provisioning and supporting ecosystem services such as timber and bioenergy, while they see a negative influence on regulating and cultural services such as biodiversity maintenance, landscape aesthetics, and cultural heritage (Fig. 5, Fig. S10). The respondents who perceive the positive effects of NNTs on provisioning ecosystem services are usually not so concerned about their invasiveness. This viewpoint may come from stakeholders who are primarily concerned with the production of timber and biomass from a small number of non-invasive NNTs. The respondents who are highly concerned about invasiveness also think that NNTs will have a negative influence on regulating and cultural ecosystem services such as biodiversity, pollination, recreation, and landscape aesthetics (Fig. 8). This perception was observed mainly in the respondents from countries like Italy and France who showed more concern about invasiveness compared to other countries (Fig S5). This view was perceived by countries such as Italy and Switzerland who showed more concern about invasiveness compared to other countries (Fig S5). Particularly in Italy, the reason for such a perception could be its high diversity of native trees compared to the other Alpine countries (Brus et al. 2012; Campagnaro et al. 2022) which triggers a higher concern for invasiveness on native ecosystems. Therefore, recent studies recommend that these differences in the perception of the risks and benefits of NNTs should be carefully evaluated when promoting NNTs for assisted species migration (Frýdl et al. 2018; Hagerman and Kozak 2021; Kracke et al. 2021).

Further, some respondents also believe that invasive-NNTs should not be cultivated at all, even in biodiversity-poor areas, and that NNTs should be eliminated if they are invasive (Fig S12 in Supplementary Information C). Sallmannshofer et al. (2023) also reported the concerns of forest managers about the spread of invasive-NNTs and their intentions to adapt their management to such challenges. Stevenson et al. (2023) observed that effective management strategies for invasive-NNTs are key to avoiding a biodiversity crisis. In this survey, according to the respondents monitoring, girdling and cutting were the common measures to control the spread of invasive-NNTs while measures such as biocontrol (use of living organisms such as insects or fungal pathogens), use of herbicides and buffer zones around protected habitats were comparatively less common (Fig. 6). This was also found by recent reviews on the management of invasive species where the control of invasive-NNTs is largely based on physical and non-chemical measures (Brundu and Richardson 2016; Weidlich et al. 2020; Sun et al. 2023). Since most respondents stated their expertise in the fields of forestry and nature conservation (Table S2), it is expected that they are aware of management strategies to control invasive-NNTs.

When it comes to policy awareness, it is interesting that among the same respondents, only 25% of them were found to be aware of national and EU legislation and policies on the management of NNTs and invasive-NNTs (Fig S11). This lack of awareness of policies on NNTs was identified as a major hurdle in the sustainable use of NNTs in Europe (Dimitrova et al 2022). The EU Forest legislative framework on NNTs focuses only on invasiveness and eradication as the final action leading to skepticism about their benefits and sustainable use. Individual countries across Europe have their specific guidelines and recommendations to deal with NNTs and some of them also include management measures for economically viable NNTs (Pötzelsberger et al. 2020a). Moreover, the shifting face of forest management and conservation under climate change is adding more complexity to decision-making (Winkel and Jump 2014) for NNTs. A recent study by Stevenson et al. (2023) on invasive non-native species has concluded that the knowledge gap in the science-policy interface can challenge the overall management of invasive species and the conservation of native biodiversity.

Around 70% of the total respondents think that controlling and managing invasive-NNTs is the responsibility of private owners compared to conservation authorities and municipalities (Fig S12). With this system of growing private ownership of forests in Europe (Lawrence et al. 2020) mainly in countries like Germany and Austria, it is no surprise that the onus of managing and controlling invasive-NNTs falls on the private forest owners. Approximately one-third of Europe is covered by forest (Forest Europe 2020) and 40% of these forests are owned and managed by private owners or families (Lähdesmäki and Matilainen 2013; Dobsinska et al. 2013). Therefore, managing and controlling invasive NNTs imposes high economic costs on private owners which is likely to have negative consequences on the forest-based industries (Fischer & Charnley 2012).

5 Conclusion

The survey offers information on how stakeholders in the European Alpine Space perceive the risks and benefits of NNTs and thus provides insight into planning future forest management in the region. Although NNTs provide a wide range of ecosystem services, the stakeholders across countries are more attuned to the invasion risks compared to their benefits. As such, the survey highlights both "usage-centric" and "invasive-centric" views on NNTs exists. We recommend that tradeoffs between the perception of invasiveness and the potential benefits of NNTs should also be considered when considering NNTs for assisted species migration. This calls for the urgent need for transnational cooperation for sharing knowledge and lessons learned on both the risks and benefits of NNTs. The perception that both the number of NNTs and invasive-NNTs have increased in the last 25 years also needs to be investigated for better decision-making. The need for capacity building among stakeholders is shown by the respondents' higher level of awareness of management strategies to control invasive-NNTs and their lower level of awareness of national and EU policies on NNTs. This also highlights that legislation and guidelines on NNTs that currently focus only on their invasiveness should transition to a more holistic inclusion of risk control and sustainable use and management. The forest owners of Alpine Space already have a rich tradition in sustainable forest management. Therefore, their knowledge, combined with research findings, such as this study, along with a comprehensive assessment of risks and benefits can support adaptive forest management in climate change. The results of this study should be interpreted with the potential source of uncertainties and limitations such as the focus on the European Alpine Space and the non-inclusion of policymakers among the stakeholders.

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Data availability Due to the terms of confidentiality, regarding identity of the respondents, data on the responses of the participants cannot be shared. This is due to the terms of confidentiality agreed upon before the survey was conducted and can be found in section C of Supplementary information (A).

Declarations

Conflict of interest The authors declare no competing interests.

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