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REVIEW PAPER

Transnational strategy on the sustainable management and responsible use of non-native trees in the Alpine Space

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Abstract

Non-native tree species – defined as those species intentionally or unintentionally introduced by humans – have long been a part of the Alpine Space, providing numerous benefits, but also posing a potential threat to native biodiversity and related ecosystem services. Compared to the urban space where non-native trees comprise most tree species, the number of non-native trees in forests and plantations is relatively low. To evaluate potential risks and benefits of non-native trees in the Alpine Space, a transnational strategy for the responsible use and management of non-native trees is needed. The goals of the strategy are to tailor management practices for a sustainable and responsible use or admixture of non-native trees, to reduce the risks connected with the invasive potential of some non-native tree species, to help forests and urban areas to adapt to climate change, and to improve coordination and cooperation regarding best practices between different regions of the Alpine Space. A proposal was developed in a four-step process including expert-based assessment, stakeholder mapping, an extensive data review, and a public consultation. For implementing the strategy fully, strong collaboration among diverse stakeholders is anticipated and robust governance and an adequate long-term and fair funding scheme is needed.

Key words: adaptive forest management; non-native tree species; Alpine Space; biosecurity; green infrastructure

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1. Introduction

The Alpine Space (Balsiger 2016; Interreg Alpine Space 2022) spans across an extensive region (390,000 km^2) of seven European countries (Austria, France, Germany, Italy, Liechtenstein, Slovenia, and Switzerland), covering a mosaic of landscapes (Grêt-Regamey et al. 2008; Tattoni et al. 2017) (Fig. 1). Likewise, some of the most important European metropolitan areas with a total population of over 70 million are located in this region. Almost two thirds of the plants on the European continent are present in four biogeographic regions (Continental, Alpine, Mediterranean and Pannonian Region) crossing the Alpine Space (Sundseth 2006). The Alpine Space is one of the most responsive Hot-Spots for climate change and is among the richest areas in Europe in terms of biodiversity in many sensitive ecosystems (EEA 2020). It will likely face more severe consequences of both climate change and the biodiversity crisis than other parts of Europe, as climate warming is progressing at faster rates than the

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average warming of the northern hemisphere (Rebetez & Reinhard 2008; IPBES 2020). On the one hand, trees in urban, peri-urban and forest ecosystems are widely discussed and promoted as nature-based solutions for climate change mitigation in the Alpine Space (Lapin et al. 2020; Hazarika et al. 2022). On the other hand, trees increasingly face challenging growth conditions under climate change: inter alia droughts, high temperatures, floods, storms, wildfires, seasonal shifts in precipitation, and other extreme weather conditions are limiting the growth and vitality of native tree species and entire forests (Brang et al. 2013) in the Alpine Space. The future impacts of climate change therefore represent a major challenge for urban planners (Jenerette et al. 2016; Czaja et al. 2020) as well as forest and conservation managers. Against this background, management approaches to promote resilience are urgently needed to adapt ecosystems so that they are able to cope with disturbances and to become resilient to climate change.

The use of non-native trees (NNT), i.e. tree species, varieties or hybrids whose presence is the result of human activity (Krumm & Vítková 2016), are considered one important climate change mitigation strategy (Brang et al. 2016; Krumm & Vítková 2016; Rigling et al. 2016). In addition, NNT can enhance ecological and cultural ecosystem services, for example, they may provide habitats for native plant and animal species, reduce erosion and enhance fertility in soil, contribute to other protective functions of forests, or they can be grown as ornamental species in arboreta, parks and urban green spaces (Schilthuizen et al. 2016; Vaz et al. 2018; Bouget et al. 2021; Castro-Díez et al. 2021; Wohlgemuth et al. 2021).

In the last decades the number of NNT in planted forests has increased worldwide (Brus et al. 2019; Brundu et al. 2020). However, the number of NNT in forests and forest plantations of the Alpine Space remains relatively low. Based on earlier studies (Brus et al. 2019; Müller-Meißner & Bindewald 2021) an NNT knowledge hub was created collecting comprehensive information on NNT in the Alpine Space (BFW 2022). Although 526 NNT were identified in the Alpine Space for the year 2021, the majority (67%) are currently cultivated exclusively in urban forests and green city areas, where they are important components of the Green Infrastructure (NNT in urban areas cf. Marinšek et al. 2022a; in forests Marinšek et al. 2022b). Most of the reported NNT in the Alpine Space (90%) have their natural distribution range outside of Europe, especially in Asia and North America (Müller-Meißner & Bindewald 2021).

While using NNT has potential benefits, their generalised large-scale cultivation can nevertheless entail risks for biodiversity, ecosystem functioning and carbon budget (Felton et al. 2013; Wohlgemuth et al. 2021). For example, NNT may threaten native species and habitats when spreading from cultivated to (semi-)natural sites, they may give rise to introgression by hybridization with native tree species or promote outbreaks of (new) pests and pathogens (Bolte et al. 2009), especially when they have congeneric native species in the Alpine Space (Brunet et al. 2013).

The major drivers for the use of NNT in managed forests are the economic, social and ecological benefits associated with their often better growth performance and pest/disease resistance compared to native tree spe-

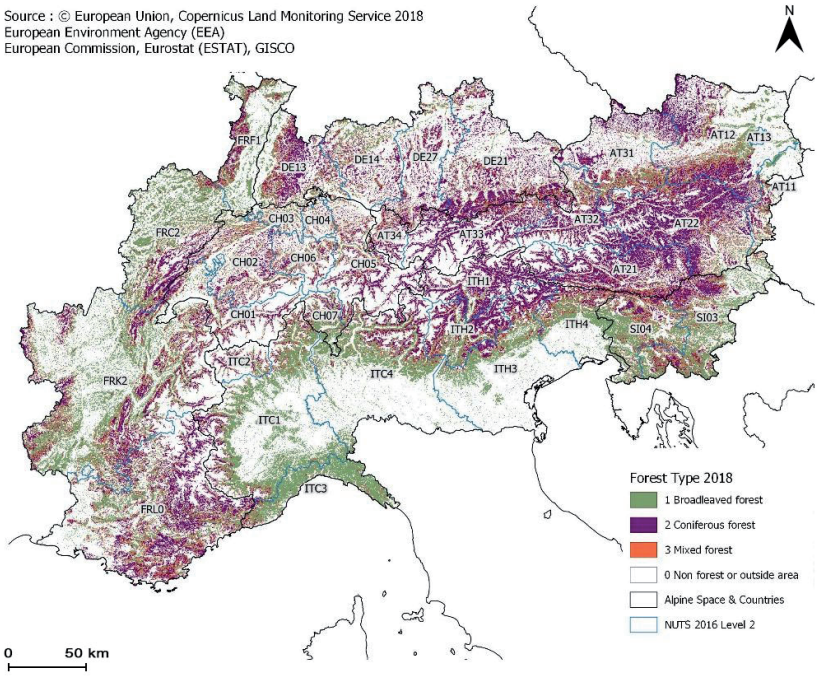

Fig. 1. Map of forest cover types (broadleaved, coniferous, and mixed forest) in the Alpine Space according to the third level of the European Union's Nomenclature of Territorial Units for Statistics.

cies, particularly when considering the impacts of climate change (Hanewinkel & Knook 2016; Thurm et al. 2018; Pötzelsberger et al. 2020b). Yet, some NNT are regarded as or are legally classified as invasive (Regulation (EU) No 1143/2014), meaning they pose potential or real risks to native biodiversity, ecosystem functioning or socio-economy, including human health (Haysom & Murphy 2004; Richardson & Rejmánek 2011; Pötzelsberger et al. 2020a; Suanno et al. 2021). Mitigating the risks of invasive tree species has therefore become a major global challenge for the protection of biodiversity and ecosystem services.

There is a controversy on the continued use of some NNT in the forests of the Alpine Space as well as on the selection of species in urban areas, highlighting the need for a careful and consistent assessment of risks and benefits (Weber & Gut 2004; Lapin et al. 2021) involving relevant stakeholders (i.e. decision makers ad various administrative levels; foresters and land managers; managers of natural areas; conservation actors and related non-governmental organisations (NGOs); forest industry, especially small and medium-sized enterprises (SMEs) and regional users and processors of timber or non-timber forest products; the general public in the Alpine Space). The objective of this discussion paper is to provide a methodological framework for such a strategy and outline goals and recommendations for the management of non-native trees in the Alpine Space.

2. The methodological framework

The proposal for a transnational strategy was developed in a four-step process (Fig. 2):

First, an expert-based preselection of relevant NNTs in the Alpine Space was conducted, subsequently a policy brief was formulated, disseminated and a quantitative survey was conducted in a pre-trial (Hazarika 2021) for relevant target groups (Lapin et al. 2020). After that, a streamlining process for developing the strategy was designed accompanied by seven regional stakeholder workshops where stakeholders from the sectors of forest science, forest management and wood processing, tree-nursery, nature conservation and urban, peri-urban and rural planning were involved in their respective local languages at multiple stages of the project. During this

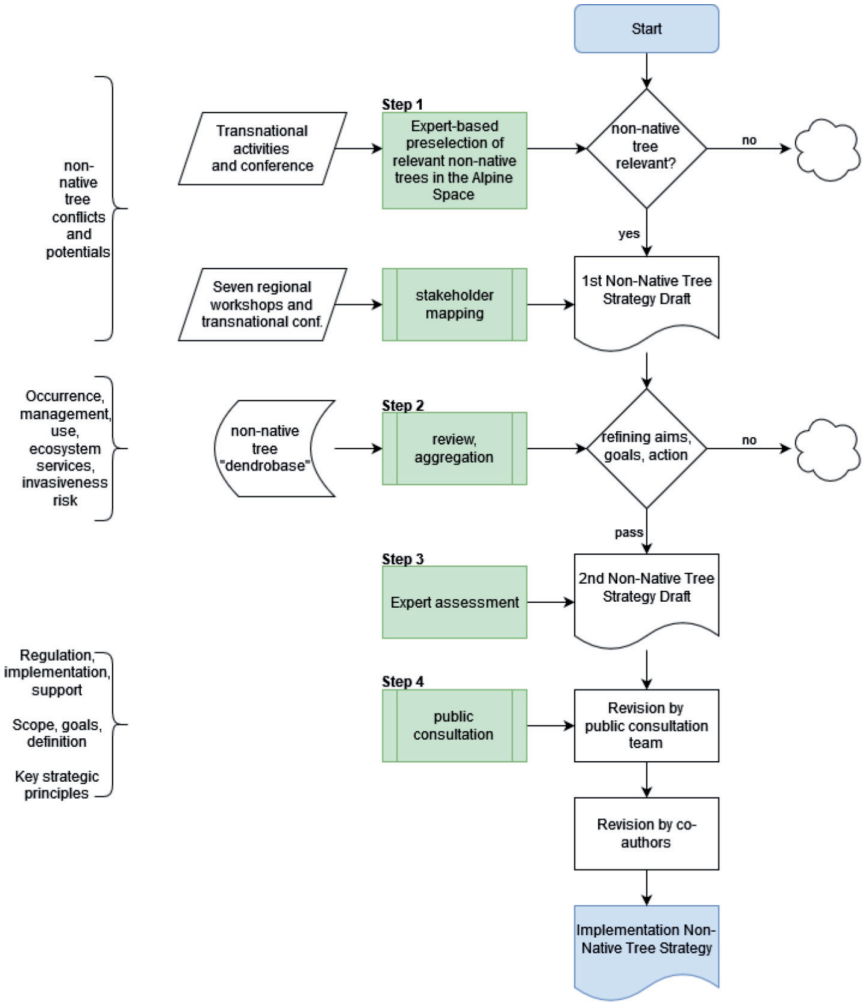

Fig. 2. Major steps and activities regarding implementation of the transnational non-native tree strategy.

process an extensive stakeholder mapping was carried out and a draft document on a transnational strategy for NNT and policy implementation was formulated with the first draft being concluded at a transnational conference. Stakeholders and activities were documented per activity in public outreach actions (where individual stakeholder background could not be attributed and categorized with sufficient certainty, e.g. social media, public events) and by participation of stakeholders in more specific actions (e.g. workshop attendance lists, expert surveys, EU Survey) (total: n = 599, cf. Fig. 3). Existing conflicts concerning NNT species were identified in collaboration with NGOs, international organisations and public authorities from the conservation and forestry sectors during these activities (Hazarika 2021; Hazarika et al. 2022).

Second, data on the occurrence, management, use, and ecosystem services of the pre-selected NNT were gathered to provide an overview of the status-quo in forests and urban areas. This step included the collection of species-specific information on the ecology, growth, and potential risks of existing NNT in the Alpine Space as well as an overview of the current policy approaches. Information was structured and stored in a relational database and published online (BFW 2022).

Third, a consortium of scientists and managers working in the Alpine Space conducted an expert-based assessment of the collated information and developed the second draft of the Strategy.

Fourth, a public consultation was conducted from the 1st of September 2021 to the 15th of October 2021 via the EU online survey management system (EU Survey). Relevant stakeholders of the Alpine Space were invited to participate in the public consultation of the strategy document. We implemented the responses (n = 40; included in Fig. 3) in development of the strategy. Subsequently, the consortium of scientists and managers responded to the comments gathered systematically in the public consultation and provided the final version of the Strategy.

3. Objectives of the transnational strategy

The overall objective of the proposed transnational strategy is to improve knowledge-based decision-making and communication on the responsible use and management of NNT in the Alpine Space. The responsible use of NNT implies that the potential risks for biodiversity and related ecosystem services as well as cultural resources of forests and urban areas are minimised, while the potential benefits, including climate adaptation and mitigation, are maximised. The strategy aims to help relevant stakeholders to streamline their governance strategies and to enable all citizens to participate actively in the development and implementation of transnational science based policies on NNT. The strategy will improve coordination and promote the establishment of a roadmap for the implementation of specific, achievable, and targeted actions facilitated by a broad collaboration and an agreed implementation plan. This strategy is underpinned by three key principles:

1. *Knowledge is freely sought and shared:* access to the latest scientific results and technical experiences on ecology, site-specific invasive potential, impact on human health, usage value, and management of NNT based on the principle of findability, accessibility, interoperability and reusability (FAIR; Collins

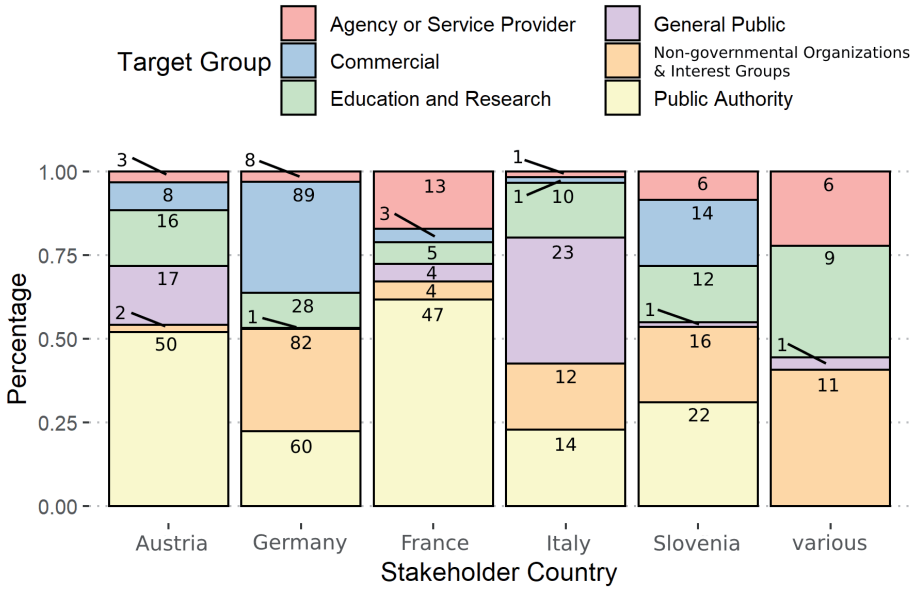

Fig. 3. Stakeholders involved in activities conducted by the Alpine Space Countries [n = 599]. Target groups involve the number of stakeholders involved except for "General Public" where the number of outreach activities was counted (numbers added within the respective bars; various: other countries).

et al. 2018) is the foundation for information-based decision making.

2. *Legislation, ownership, and individual rights are respected:* any action should be based on the knowledge of the legislative frameworks underlying regulation of introduction, use and management of NNT. The framework is linked to duties and rights of public and private ownership of forests or green infrastructure. While the legal implications are to be accepted, implementation of the strategic goals shall be supported by an open dialogue and mutual respect for individual decision-making.
3. *Communication and decisions are evidence-based:* any regulative decision related to the use and management of NNT should be evidence-based and follow the analysis of quantitative data to ensure reliability and transparency. Clear communication helps sharing scientific studies and results of risk assessments with relevant stakeholders (as mentioned above).

4. Goals and recommendations

Goal 1 – Achieving a sustainable use of non-native trees

On the one hand, NNT can support sustainable development of the Alpine Space, in particular when regarded through the framework of "The UN Sustainable Development Goals (SDGs)" targets 13, 15, and 17. Many NNT are valued for their provision of ecosystem services in urban areas and for increasing the option for climate change adaptation and carbon sequestration in areas of the Alpine Space's forest where native trees, on certain sites and in certain regions, are already at risk. Conversely, invasive NNT can severely detract from nature conservation goals, economic activities, livelihoods, food security, and human health and well-being, and thus bear the risk of undermining progress towards achieving 10 of the 17 SDGs.

This goal implies that sustainable management of NNT follows several steps, including identification of suitable NNT and the risks associated with them, developing a regionally produced supply of reproductive plant material for the forest and the horticultural sector, as well as their long-term maintenance. Therefore, increased and in particular site-specific research is urgently needed to investigate characteristic responses of NNT to climate change, including risks and benefits in different regions across the Alpine Space.

Recommendations:

i. Promote or prefer native tree species whenever possible.
ii. Evaluate potential benefits and risks of each NNT in the Alpine Space with respect to ecosystem services (e.g. protective forests) and disservices. Evaluation results will be documented in the NNT knowledge hub
iii. Promote and facilitate discussions and information sharing between relevant stakeholders (as mentioned above).
iv. Support collection, breeding, propagation and local production of forest and horticultural plant material for diverse NNT and native species.
v. Evaluate NNT in urban environments that pose no risk to human health, whose spread can be controlled with minimal effort, and whose inclusion diversifies the portfolio for tree species selection.
vi. Evaluate the use of those NNT in forests that currently pose no risk (of becoming invasive) in the area of interest, or where any risks can be easily mitigated or eliminated by sustainable management measures.

Goal 2 – Reduce the risk of escape and other threats

Invasive NNT threaten the protection, conservation and ecological connectivity of Alpine Space ecosystems as well as the sustainability of their services. The risk of a NNT becoming invasive can be defined as the likelihood and magnitude of negative impacts associated with its introduction, establishment, and spread (FAO & IPPC 2019). More specifically, the risk reflects the possibility that a given NNT will outcompete native species, hybridise with native congeneric species, change ecosystem functions, introduce or facilitate the establishment of new pathogens and pests, and cause allergies or other negative impacts to humans or human activities. Whether a NNT escapes from the planting site and becomes invasive depends not solely on tree species specific characteristics and ecological behaviour, but also on local site conditions and silvicultural management practices, invasion pathways (Hulme 2015), as well as plantation size and density (Křivánek et al. 2006). Potential invasiveness of a given NNT can significantly vary between regions and ecosystems of the Alpine Space and can change over time. A comprehensive breeding strategy is required to mitigate these risks and increase the resilience and diversity of planted forests (Messier et al. 2022). Streamlining and sharing of potentially available information about planting trials, arboretums, common gardens and urban trees will enhance informed use of NNT (Fady & Rihm 2022).

Anticipation of the risks posed by NNT is an important goal of the strategy. This can be achieved by creating, sharing and updating knowledge on the risks and management options of NNT with the various stakeholders from the Alpine Space, while also considering knowledge and expertise from external territories. In order to be able to assess the risks associated with the use of NNT, regional data is needed on their extent and distribution, regeneration dynamics, dispersal distances, potential impacts in different ecosystem types, experiences with removal and eradication efforts, as well as the information on the cost-efficiency of risk management and habitat restoration measures (Bindewald et al. 2021). Regardless of the positive or negative influences of NNT, the preparation of any measures must be based

on knowledge about their site-specific performance and behaviour. Rigorous monitoring of NNT in forests and respective inventories, but also regional, process-based solutions in the respective Alpine Space countries (e.g., Marinšek et al. 2022a), as well as harmonisation and dissemination of information obtained through regional and international projects will be very helpful for achieving this goal.

Recommendations:

i. Use of the Site-Specific Risk Assessment (Bindewald et al. 2021) which can be defined as a structured assessment of risks posed by NNT species, distinguishing between location, habitat or ecosystem type.
ii. Do not introduce and promote new tree species in the Alpine Space until a pre-entry risk assessment has been performed.
iii. Clearly communicate the results of the Site-Specific Risk Assessment with policymakers, practitioners, and public users.
iv. Promote tree diversity in planting sites, including the genetic breeding of native tree species, and those NNT of which the knowledge and/or experience of have shown that all risks can be controlled, and effective mitigation measures are in place.
v. Explore new methods to improve the rapid and species-specific response for identifying and potentially eradicating high-risk NNT.
vi. Develop general and species-specific management plans to ensure a coordinated multilateral approach across sectors and the general public.
vii. Improve data availability on NNT occurrence and their growth characteristics. Through continuous monitoring, for example by explicit inclusion in national or regional forest inventories.

Goal 3 – Improve resilience of forest and urban trees to climate change

The goal is to improve adaptation to climate change by increasing tree species richness – both at inter- and intra-specific diversity level. Where reasonable, climate adaptation and mitigation strategies may include NNT with low risk of invasiveness in regional species portfolios to increase the resilience in both urban and forest areas. Particularly when selecting NNT for urban areas, better knowledge is required for choosing optimal provenances or genotypes adapted to anticipated climate conditions.

However, to strengthen the resilience of green infrastructure to climate change, three approaches are important, which may be applied simultaneously: The first approach involves utilising new provenances and genotypes of the same native species (assisted gene flow); the second approach employs the translocation at a regional level of additional native tree species and species mixtures better adapted to climate change (Chakraborty et al. 2019). If the first and second approaches do not seem sufficient to support the resilience to climate change, NNT may be planted to sustain important ecosystem services such as protection from avalanches, rockfall and erosion, timber production, long-term preservation of habitats, and carbon storage (Castro-Díez et al. 2019). Depending on the site-specific assessment of the expected positive and negative impacts of NNT, all three approaches may be applied in parallel or sequentially.

Recommendations:

i. NNT that pose a low invasion risk can be integrated in mixed-species stands and their regeneration carefully monitored.
ii. Consider multiple criteria for the selection of suitable NNT for planting in urban areas, wherein the selection should be limited to those species that are climate-adapted, drought tolerant, non-invasive, and aesthetically attractive, and pose no threat to human health.
iii. Re-evaluate recommendations for site-specific suitability of NNT, integrating assessed changes of their risks and benefits according to the latest research on the predicted range of future climatic conditions.
iv. Facilitate the testing and transfer of tree species native in regions of south-eastern Europe to central and northern parts of Europe.

Goal 4 – Improve cooperation, capacity building, and expertise sharing

Research and training activities in the Alpine Space have been inconsistent to date, especially in the area of NNT (Hasenauer et al. 2017) with a general problem of matching data from different domains (Karam et al. 2020; Musvuugwa et al. 2021). This places the Alpine Space at a disadvantage in terms of dealing with climate change and being in a position to influence policy at EU level. The goal is to fill the gap in the lack of coordinated NNT management of stakeholders across different regions, countries, and the potential for improving engagement and communication amongst stakeholders with a coordinated biogeographical approach (Miu et al. 2020) to the management of NNT in forests and urban areas. The development of sustainable funding mechanisms for cross-sectoral cooperation and partnerships will lead to increased research and innovation, accessible to all stakeholders in the Alpine Space.

Recommendations:

i. Ensure cross-sector cooperation and exchange of expertise in the field of forestry, horticulture and ornamentals.
ii. Enable cross-border trade and utilisation of forest reproductive materials, with full accordance to regulations of the Organisation for Economic Co-operation and Development considering potential threats of pests and diseases for NNT and availability of resilient forest reproductive material (van Loo & Dobrowolska 2019).

iii. Develop and maintain networks to provide and exchange information on the distribution, management and examples of the use of NNT to ensure the free and user-friendly access to comprehensive information on them.
iv. Invest in transnational research activities to identify suitable tree species and their long-term management requirements, and assess the adaptation potential of native and NNT in the Alpine Space.
v. Coordinate the establishment of training initiatives to ensure that stakeholders are equipped with the appropriate skills and knowledge to conduct a risk assessment.

Goal 5 – Increased communication, citizens' awareness and involvement

Citizens' awareness and involvement are important for the management and sustainable use of NNT. The goal is to give all citizens equal access to the latest information on NNT by overcoming languages, digital divide (Elena-Bucea et al. 2021), and age barriers. The transnational strategy emphasises that generalisations should be avoided when informing the public, and site-specific knowledge derived from risk assessments including the expected benefits of using non-native tree species and management options will be provided.

Recommendations:
i. When communicating with the public, always refer to species- and site-specific information to avoid generalisations and support the differentiation between invasive and non-invasive tree species and tree species whose risks are not yet known.
ii. Translate guidance and training material as well as policy documents and all relevant project results to local languages.
iii. Support appropriate education initiatives at all levels, including schools, universities and relevant stakeholders.

5. Strategy implementation

The implementation of this transnational strategy will require strong stakeholder partnerships, robust governance and an equitable funding model that is applicable to all stakeholders. A Strategy Implementation Plan has been prepared (Table 1) to address these issues and includes a set of actions in a time frame of 10 years. It provides further details about the actions necessary to achieve the goals set out in this document. Coordination, leadership, and adequate funding mechanisms will be required to implement and monitor the goals and recommendations of the strategy.

Table 1. Strategy Implementation Plan.

Stages	Action	Target Group	Indicators / Targets
Stage 1 [0 to 3 years]	Establishment of a transnational knowledge hub for non-native tree species	General public, higher education and research, public authority	An exchange platform for knowledge on non-native trees
	Coordination of partnerships that build capacity and capability	Sector agency, public authority, interest groups including non-governmental organisations, business support organisation	Number of network meetings and stakeholder events
	Development of a register for site-specific risk assessments and the distribution of non-native tree species in the Alpine Space	Public authority, interest groups including non-governmental organisations	Number of site-specific risk assessment developed
	Establishment of transnational leadership including relevant stakeholders of the forest and horticulture sector in the Alpine Space	Public authority	Board of consortium members from at least four Alpine Space countries
Stage 2 [3 to 8 years]	Update and review knowledge about pests and pathogens on non-native trees in the Alpine Space	Higher education and research, public authority (European and Mediterranean Plant Protection Organisation, National Plant Protection Organisations)	Number of full lists of pests and pathogens for non-native trees in the Alpine Space
	Update site-specific risk assessments	General public, higher education and research, public authority	Number of site-specific risk assessment updated
	Development & maintenance of networks for education & training	Education/training centre and school, higher education and research	Number of networks established
	Systematic and regular collection of data on non-native trees	Sector agency, public authority, interest groups including non-governmental organisations, business support organisation, higher education and research	Availability of data for the non-native trees of the Alpine Space
	Improvement of the knowledge on risks and use of non-native trees	(large) enterprise, small- and medium-sized enterprise , infrastructure and (public) service provider	Improvement of knowledge measured through dedicated questionnaires
	Training for forest owners and land managers for implementing non-native trees strategy after adequate risk assessment	Private forest owners and land managers working with forested areas	Implementation in national training schemes for forest management and conservation
Stage 3 [8 to 10 years]	Assessment of the outcomes of the strategy implementation	Public authority, higher education and research	Assessment report
	Adjustment of the strategy on non-native trees	Public authority, higher education and research, interest groups including non-governmental organisations	Public consultation on the adjustment of the strategy; adjustment plan

6. Conclusions

A wide range of stakeholders influence, either implicitly or explicitly, the tree species composition, the management and conservation of forest and urban green space. NNT have long been a part of the Alpine Space and many of them are valued for their numerous benefits. However, some species (e.g. *Paulownia tomentosa*, *Koelreuteria paniculata*, *Quercus rubra*) carry the risk of being or becoming invasive, threatening native biodiversity and associated ecosystem services, and causing potential human health issues. This strategy ensures that relevant stakeholders are aware of the benefits and risks of NNT as well as of their responsibilities for communication and management. In this way, the strategy can assist stakeholders in balancing benefits and disadvantages of using NNT.

To keep the risks from NNT use as low as possible and while strengthening the potential benefits of NNT in the Alpine Space, the transnational strategy is urgently needed to ensure sustainable and responsible use and cross-sectoral management. The strategy's intention is to reflect in transnational and European policies and allow an evaluation of site-specific trade-offs between promoting NNT which could potentially be better adapted to a future climate whilst protecting biodiversity, ecosystem services and cultural resources from possible negative impacts of some NNT in the Alpine Space.

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