

Global guidelines for the sustainable use of non-native trees to prevent tree invasions and mitigate their negative impacts

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Abstract

Sustainably managed non-native trees deliver economic and societal benefits with limited risk of spread to adjoining areas. However, some plantations have launched invasions that cause substantial damage to biodiversity and ecosystem services, while others pose substantial threats of causing such impacts. The challenge is to maximise the benefits of non-native trees, while minimising negative impacts and preserving future benefits and options.

A workshop was held in 2019 to develop global guidelines for the sustainable use of non-native trees, using the Council of Europe – Bern Convention Code of Conduct on Invasive Alien Trees as a starting point.

The global guidelines consist of eight recommendations: 1) Use native trees, or non-invasive non-native trees, in preference to invasive non-native trees; 2) Be aware of and comply with international, national, and regional regulations concerning non-native trees; 3) Be aware of the risk of invasion and consider global change trends; 4) Design and adopt tailored practices for plantation site selection and silvicultural management; 5) Promote and implement early detection and rapid response programmes; 6) Design and adopt tailored practices for invasive non-native tree control, habitat restoration, and for dealing with highly modified ecosystems; 7) Engage with stakeholders on the risks posed by invasive non-native trees, the impacts caused, and the options for management; and 8) Develop and support global networks, collaborative research, and information sharing on native and non-native trees.

The global guidelines are a first step towards building global consensus on the precautions that should be taken when introducing and planting non-native trees. They are voluntary and are intended to complement statutory requirements under international and national legislation. The application of the global guidelines and the achievement of their goals will help to conserve forest biodiversity, ensure sustainable forestry, and contribute to the achievement of several Sustainable Development Goals of the United Nations linked with forest biodiversity.

Keywords

Biological invasions, code of conduct, environmental policy and legislation, invasion science, stakeholder engagement, stakeholder participation, sustainable forestry, tree invasions

Introduction

Non-native trees (hereafter NNTs) and sustainably managed plantation forests of NNTs provide a wide range of forest goods and services and help to reduce the pressure on natural forests (FAO 2010a, b). Because of their often greater hardiness, faster growth rates, and resistance to climate change, pathogens, and pests compared to native species (Bolte et al. 2009; Seidl et al. 2017), the standardisation of silviculture techniques (e.g., nurseries, seedling establishment, and thinning), and industrial processes for their products (e.g., timber and pulp), certain NNTs are favoured over native species in tree planting programmes (Wang et al. 2013; Papaioannou et al. 2016; Brus et al. 2019; Vítková et al. 2020). As a result, NNTs make up 44 percent of plantation forests globally (approximately 58 million ha) (FAO 2020). The prevalence of NNT forestry plantings varies significantly between regions. For example, plantation forests in North and Central America mostly comprise native species whereas those in South America consist almost entirely of NNTs (FAO 2020).

This large extent of NNTs is, in part, due to the rapid decrease in the extent of natural forests. Many on-going large-scale planting initiatives, sometimes with NNTs, aim to compensate for the loss of natural forests. Some examples of drivers of this loss are the reduction of natural forests caused by human activities in tropical regions of Brazil (Seymour and Harris 2019; Klug et al. 2020), in Chile (Braun et al. 2017), and in cold regions of Russia (e.g., Trunov 2017), and the loss of conifer forests in North America and Europe due to recent bark-beetle outbreaks (Morris et al. 2017; Hlásny et al. 2019). The expansion of NNT plantations has been highlighted as a major land use/cover change worldwide, leading both to deforestation and loss of agricultural land (Hua et al. 2016; Benra et al. 2019), although this varies by country and depends on underlying policies and economic situations (Pirard et al. 2017).

NNTs also represent a significant component of urban forests and are widely planted in urban greening projects worldwide (Bauduceau et al. 2015; Sjöman et al. 2016; Castro-Díez et al. 2019; Escobedo et al. 2019). The continuous growth in urban populations creates demands and opportunities for urban forests to deliver ecosystem services critical to human wellbeing and biodiversity (dos Santos et al. 2010; Potgieter et al. 2017; Endreny 2018; Riley et al. 2018; Kowarik et al. 2019). NNTs are often promoted in cities because of their aesthetic value, easy and well-known requirements for maintenance, higher growth rate than native species, and the reliability of achieving greening and the associated ecosystem and social services (Dickie et al. 2014; Potgieter et al. 2017).

Botanic gardens and arboreta, all hosting a large variety of NNTs, are increasingly recognised as key components of global plant conservation efforts through their living collections of endangered species, long-term archiving of seeds, taxonomic training, and public outreach (Hulme 2011). Yet, an increasing body of evidence highlights the role of botanic gardens in facilitating plant invasions worldwide (Hanspach et al. 2008; Hulme 2011, 2015; van Kleunen et al. 2018), albeit at a much smaller scale than through commercial horticulture and forestry practices. A number of botanic gardens now apply stringent measures to prevent the spread of invasive species and to promote the use of native species in ecological restoration efforts, but most do not (Hulme 2015).

A major change in the planting of trees has emerged recently, as massive tree-planting campaigns using NNTs are beginning to gain momentum globally as an assumed silver bullet to mitigate the impacts of climate change and for other purposes such as poverty alleviation (Table 1). In response to climate change, trees, regardless of their biogeographical status (native or non-native), are being presented as a general panacea (Bastin et al. 2019). However, emerging research suggests that trees might not help offset carbon emissions as much as some would expect (e.g., Popkin 2019), and plantations in inappropriate sites can have disastrous consequences for sustainable development, biodiversity conservation, and ecosystem functioning (Bond 2016; Bond et al. 2019; Temperton et al. 2019), and even may lead to a loss of soil organic carbon (Jackson et al. 2002). Silveira et al. (2020) highlighted the myth that tree planting is always good for biodiversity and ecosystem services and that the use of trees in the restoration of tropical and subtropical old-growth grassy biomes is misguided. The notion that the presence of trees indicates good ecosystem health is a driver of tree planting initiatives (Table 1) in many parts of the world (Richardson et al. 2014). In many cases, increased tree cover is clearly at odds with objectives of biodiversity conservation and the sustained delivery of ecosystem services (e.g., Jackson et al. 2005).

Although sustainably managed NNTs can and do deliver economic and societal benefits with limited risk of escape and spread from planting sites into adjoining areas in many contexts, some widely used NNTs are invasive or have high potential to become invasive, sometimes causing substantial damage to biodiversity and related ecosystem services and functioning (Richardson 1998; Richardson et al. 2000; Richardson and Rejmánek 2011; Castro-Díez et al. 2019). Many of the traits that are desired in NNTs are the same as those that have been recognised as promoting invasiveness (e.g., fast growth rate, high seed production, and high seedling survival) (Pyšek and Richardson 2007). The number of NNTs that are being reported as spreading and causing negative effects on biodiversity and ecosystem services is increasing rapidly globally (Rejmánek and Richardson 2013; Krumm and Vítková 2016).

Invasive NNTs (INNNTs) can be important ecosystem engineers, i.e. they “directly or indirectly modulate the availability of resources to other species by causing physical state changes by biotic or abiotic materials” (Jones et al. 1994; Mitchell et al. 2007; Ayanu et al. 2015). They can also cause regime shifts in invaded ecosystems (altered states of ecosystem structure and function that are difficult or impossible to reverse), alter the identity of dominant species and therefore change dynamics on all levels, lead-

ing to impacts that ripple across trophic levels such as in the case of ecosystems invaded by *Acacia cyclops*, *A. longifolia*, and *A. saligna* (Gaertner et al. 2014; Souza-Alonso et al. 2017) or by *Tamarix* sp.pl. affecting the flood and sediment regime (Zavaleta 2000). INNTs can also radically change fire regimes by increasing fuel availability and flammability (Paritsis et al. 2018; Davis et al. 2019), which can have disastrous effects on ecosystems and people (e.g., in Chile, Portugal, South Africa, and Spain). The impacts of such invasions are particularly notable in naturally treeless ecosystems (Jäger et al. 2007; Rundel et al. 2014). Moreover, the spread of INNTs are among the invasions with the greatest impacts on ecosystem services such as water provision (Richardson 1998; Le Maitre et al. 2002; van Wilgen and Richardson 2012; Richardson et al. 2014).

As for many other groups of non-native species, perceptions regarding NNTs differ across interest groups, sometimes creating conflicts around their use and management (Starfinger et al. 2003; van Wilgen and Richardson 2014; Woodford et al. 2016; Vítková et al. 2017). For example, among some of the most widely planted genera such as *Acacia* s.l., *Eucalyptus* s.l., and *Pinus* there are many invasive species that have severe impacts on biodiversity and ecosystem services (Richardson 2011; Richardson and Rejmánek 2011; Cazetta and Zenni 2020). *Prosopis* species were introduced by NGOs and government organisations to countries like Kenya in the 1970s and 1980s to provide wood and animal fodder, and to stabilise soils in degraded ecosystems (Swallow and Mwangi 2008; Maundu et al. 2009). There is continuing advocacy for the utilisation of these NNTs (Choge et al. 2007), despite clear evidence that these species have devastating effects on human livelihoods and biodiversity (e.g., Mbaabu et al. 2019; Linders et al. 2019). Kenya is, as far as we know, the only country that has enshrined in its constitution the goal of achieving a particular level of national tree cover (10%). According to the corresponding National Strategy, the achievement of this goal will require the planting of NNTs, including INNTs which are among the worst invasive species worldwide. This is particularly troublesome in the case of *Prosopis juliflora*: while the area covered by this notoriously INNT is included in Kenya's estimates of current tree cover, the country has recently also launched a National *Prosopis* Strategy which aims to bring the invasion of this species under control in order to protect Kenya's nature, people, and the economy (<http://www.environment.go.ke/>).

The challenge is to maximise the socio-economic benefits and opportunities of NNTs, while minimising risks and negative impacts on the environment or compromising future benefits and land uses (Richardson 2011; Brundu and Richardson 2016). Addressing this challenge requires collaborations between governments, non-governmental organisations, environmental managers, forestry and horticultural industries, and other parties to develop and promote tailored policies, coordinate existing legislation tools, ensure capacity building, promote the preferential use of native trees, ensure the responsible introduction and sustainable use of NNTs globally, and to identify and share best-management practices to deal with INNTs. Such measures are essential to mitigate and reduce the negative impacts from unregulated and poorly informed use and dissemination of NNTs. To increase the awareness of issues associated with the use of NNTs and the potential risks, this paper proposes a set of

Table 1. Examples of massive tree planting campaigns.

Name of the initiative	Geographical scope	Aim of the initiative, tree species considered	Web site / Reference
The Great Green Wall initiative (African Union)	Africa (the Sahel)	Restore degraded land, sequester carbon and create green jobs by 2030 to reduce desertification; no indication for species used.	http://www.unccd.int/actions/great-green-wall-initiative (Bond et al. 2019) http://time.com/5669033/great-green-wall-africa
The Trillion Trees campaign (NGO)	Global	Plant and protect one trillion trees to mitigate climate change and promote prosperity by 2050; native tree species are preferred, but planting NNTs is considered when there is a clear socio-economic, ecological, or climatic reason.	http://www.trilliontrees.org/home (Cernansky 2018)
Tree Nation (NGO)	Global	Citizens and companies can compensate CO ₂ emissions by supporting tree planting projects worldwide; trees are being chosen of a list of 300 species, but without further information if native trees are preferred over NNTs.	http://tree-nation.com
Plant for the Planet (NGO)	Global	Platform enables to support tree planting projects worldwide with the goal to plant 1.000 billion trees; no indication for species used.	http://www.plant-for-the-planet.org/en/home http://www.unenvironment.org/news-and-stories/press-release/planting-trees-has-never-been-easier
The Bonn Challenge (launched by German Government)	Global	Restore 150 million hectares of deforested and degraded land by 2020 and 350 million hectares by 2030 worldwide; no indication for species used.	http://www.bonnchallenge.org
The “Seed Bombing” initiative (Thai Government)	Thailand	Reforestation programme in Thailand throwing “seed bombs” from planes; only native species are considered.	http://thelondonpost.net/tree-seeds-tree-seeds-bombing-thailand
The Billion Tree Tsunami Afforestation Project (BTTAP) (Khyber Pakhtunkhwa Government)	Pakistan	The BTTAP in Pakistan’s northern Khyber Pakhtunkhwa province was launched in 2015. It has surpassed its target by restoring and planting trees in 350,000 hectares of degraded forest landscapes; no indication for species used.	http://ejatlas.org/conflict/billion-tree-tsunami-afforestation-project (Nazir et al. 2019)
The Billion Trees campaign (NGO)	Global	Afforestation campaign with the goal to plant a billion trees across the planet to mitigate climate change; no indication for species used.	http://www.nature.org/en-us/get-involved/how-to-help/plant-a-billion http://www.unenvironment.org/resources/publication/plant-planet-billion-tree-campaign
The One Billion Trees Programme (New Zealand Government)	New Zealand	Afforestation and reforestation programme with the aim to plant one billion trees to diversify existing land uses across New Zealand and to improve socio-economic performance; planting native species is encouraged to improve biodiversity.	http://www.mpi.govt.nz/funding-and-programmes/forestry/one-billion-trees-programme/about-the-one-billion-trees-programme/
The Three-North Shelter Forest Program (Chinese Government)	China	More than 66 billion trees were planted since 1978 to stop expansion of arid regions; NNTs and native species have been used so far, but native vegetation will be preferred in future.	http://www.nature.com/articles/d41586-019-02789-w http://news.bbc.co.uk/2/hi/world/monitoring/media_reports/1199218.stm (Ge et al. 2020)
The 300,000 Trees in Nicosia initiative (Cyprus Government)	Cyprus	Afforestation programme with the aim to plant about 50,000 trees to combat climate change and protect biodiversity; planting indigenous species, such as endemic and rare varieties, is encouraged.	http://www.themayor.eu/fr/nicosia-launches-large-scale-tree-planting-campaign
The 60 Million Trees initiative (Madagascar Government)	Madagascar	Reforestation project with the aim to plant 60 Million trees across 40,000 hectares; endemic and agroforestry species, including NNTs and INNTs, are being used to balance economic and ecological interests.	http://www.ecowatch.com/madagascar-tree-planting-2644879937.html
The 50 Million For Our Forests campaign (NGO)	USA	Reforestation campaign with the aim to plant about 50 million trees to combat forest loss due to natural disturbances; only native trees are being used.	http://www.nationalforests.org/get-involved/tree-planting-programs
The 73 Million Trees in the Amazon initiative (NGO)	Brazil	Reforestation programme with the aim to plant 73 million trees in the Amazon rainforest to combat forest loss; only native tree species are being used.	http://www.smithsonianmag.com/smart-news/brazil-begins-effort-plant-73-million-trees-amazon-180967086/
The 350 million trees in 12 hours Guinness record (Ethiopia Government)	Ethiopia	Afforestation project with the aim to plant 4 billion trees to combat deforestation and climate change effects; 350 million trees were planted in 12 hours setting a new world record; no indication for species used.	http://albertonrecord.co.za/221373/afforestation-project-ethiopia-recently-resulted-350-million-trees-planted-one-day/

Name of the initiative	Geographical scope	Aim of the initiative, tree species considered	Web site / Reference
Conversion of Cropland to Forest Program (also called Grain for Green) (Chinese government)	China	Tree-planting enterprise (since 1999) that pays farmers to plant trees on their land and provides degraded land to rural families to restore; native and NNTs are being used.	http://forestsnews.cifor.org/52964/grain-for-green-how-china-is-swapping-farmland-for-forest?fnl=en http://www.cifor.org/publications/pdf_files/articles/APutzell1601.pdf (TheOneEartheditorial team 2020)
Millennium show forest (Chinese government)	China (new city "Xiongang New Area")	Massive urban afforestation project to construct a close-to-natural urban forest with the aim to minimise invasive species impacts; prioritisation of local species and seedlings.	(Li et al. 2020)
Eden Reforestation Programme (NGO)	Global	Reforestation project with the aim to reduce poverty and restore forests by hiring local villagers to plant trees; no indication for species used.	http://edenprojects.org
WeForest Making Earth Cooler (NGO)	Global	Forest and landscape restoration programme with the aim to mitigate climate change, conserve biodiversity, and reduce poverty of local communities; no indication for species used.	http://weforest.org
OneTreePlanted (NGO)	Global	Reforestation programme to protect biodiversity, restore degraded soils, improve climate, and reduce poverty; no indication for species used.	http://onetreepanted.org
60 Million trees (60 Milioni di Alberi)	Italy	Planting one tree for each Italian citizen to fight climate change. It is recommended the use of native or non-native non-invasive trees.	http://www.alberitalia.it

Global Guidelines for the use of Non-Native Trees (GG-NNTs). These GG-NNTs were developed, discussed, and elaborated at a workshop in Prague, Czech Republic, in September 2019 that was attended by many of the co-authors of this paper. The guidelines and supporting text were further developed in consultation with a large number of researchers and other interested and affected parties in the fields of arboriculture, forestry, nature conservation, and invasion science. In compiling the working team, consideration was given to geographic and gender balance and diversity of age and expertise. However, we recognize that certain areas, especially in low and lower-middle income countries, are underrepresented and should be considered in future efforts.

Global Guidelines for the use of Non-Native Trees (GG-NNTs)

The GG-NNTs set out in this paper are addressed to all relevant stakeholders (including policy makers, the forestry and agroforestry industries, national forest authorities, certification bodies, environmental organisations, organisations and individuals involved in urban greening, landscape architecture, climate change mitigation, and all other endeavours that rely on the planting and management of trees). The GG-NNTs aim to reduce the risk of introduction of new INNNTs and the negative impacts that might originate from their unregulated and/or unscrupulous use. To do so, these guidelines aim to enlist the co-operation of all relevant stakeholders to identify both robust scientific knowledge and technical knowledge and experience regarding the use and management of NNTs. Containment of NNTs to areas set aside for their cultivation or use must become an integral part of silviculture. Managers and planners need

to consider the species and the environmental context and therefore should develop a stratified approach to take into account regional and habitat-specific management (van Wilgen and Richardson 2012; Pergl et al. 2016; Sádlo et al. 2017; Campagnaro et al. 2018).

The eight recommendations (Rec.) in the GG-NNTs are clustered according to three overarching goals (Fig. 1): (1) preventing the introduction of INNNTs; (2) preventing and mitigating the risk of escape of NNTs from plantation sites to adjoining areas; and (3) mitigating the negative impacts of INNNTs. They are not an exhaustive list of recommendations, but rather provide the first step towards building a global consensus on the precautions that should be taken when introducing and planting NNTs, particularly over large areas. The GG-NNTs are voluntary, and are intended to complement and guide statutory requirements under international or national legislation. Private forestry enterprises, local authorities, arboreta, and public forest managers might wish to publicise their adherence to the GG-NNTs through adopting a symbol or logo indicating this commitment (Fig. 2). The GG-NNTs could be incorporated in national or regional strategic documents or plans dealing with non-native species.

The GG-NNTs aim to implement and expand the geographical context of most of the principles and recommendations of the European Code of Conduct for Invasive Alien Trees as endorsed by The Standing Committee to the Convention on the Conservation of European Wildlife and Natural Habitats, acting under the terms of article 14 of the Bern Convention, on the 8th of December 2017 (Rec. No. 193/2017). The Bern Convention has endorsed two other Codes that included overlapping principles addressing NNTs used as ornamental species, i.e. the Code of Conduct on Horticulture and Invasive Alien Plants published by the Council of Europe (Heywood and Brunel 2011) or kept in botanic garden and arboreta (European Code of Conduct for Botanic Gardens on Invasive Alien Species, Heywood and Sharrock 2013). Therefore, in proposing the GG-NNTs we mainly focus on NNTs used in forestry, in other types of large-scale plantings, restoration projects, and in urban forestry.

Terminology and structure of the GG-NNTs and their recommendations

In the context of the present GG-NNTs, and in accordance with the Convention on Biological Diversity (CBD) principles and definitions (Decision V/8 of the Conference of the Parties to the CBD), the term non-native trees (NNTs) has exclusively a biogeographical meaning, i.e. it refers to tree species, subspecies, lower taxa, or genotypes, introduced through human activity outside their past or present natural distributions, and includes any part, seeds or propagules of such taxa that might survive and subsequently reproduce. As such, the term NNTs carries no *a priori* connotation (negative or positive) relating to risks to biodiversity (or to the economy or public health). For a detailed discussion of the terms used in these GG-NNTs and how they relate to those used internationally see Annex 1, Glossary/Acronyms.



Figure 1. Main goals and recommendations of the Global Guidelines for the use of Non-Native Trees (GG-NNTs) in relation to the Sustainable Development Goals of the United Nations (UN SDGs).

In the context of the GG-NNTs, the terms alien, allochthonous, non-native, non-indigenous, exotic, and introduced are considered synonymous. These synonyms are all used in international and national legislation and in various technical documents, although with different frequency and with sometimes subtle differences in the meaning they convey. Therefore, for consistency, we use the term NNTs in accordance with the CBD definition, and for the purposes of the GG-NNTs, the term invasive non-native trees (or INNTs) is herewith defined as a NNTs whose introduction and/or spread threatens or adversely impacts biodiversity and related ecosystem services, or causes ecosystem disservices (Vaz et al. 2017), recognising that negative impacts on the economy and on public health might occur as well (Bacher et al. 2018).



Figure 2. Private forestry enterprises, local authorities, arboreta and public forest managers might wish to publicise their adherence to the GG-NNTs through adopting a symbol or logo indicating this commitment.

Recommendation 1: Use native trees, or non-invasive non-native trees, in preference to invasive non-native trees

Native tree species should be preferred over NNTs, and consideration should be given to the precise provenance of seeds and germplasm. If native tree species are not suitable, the consequent recommendation is to evaluate the use of NNTs with low invasion risk.

Within a country or region, native tree species rather than NNTs, should be used, in planning and establishing large-scale plantings, afforestation or reforestation projects, planted forest, and agroforestry (Douglas et al. 2014; Peltzer et al. 2015) wherever possible. This approach is particularly important in massive and global projects such as the Trillion Trees campaign, the African Green Wall initiative (Goffner et al. 2019), the China’s Grain-for-Green Program (Hua et al. 2016), and the Bonn Challenge (Temperton et al. 2019) (Table 1).

Multiple organisations have suggested, under certain conditions, the promotion of native trees over NNTs, including, for example, FAO (FAO 2006; FAO 2010 – Principle 9 – “if native trees are equal to or better than introduced species for the intended purpose”) and UNFCCC (Aarrestad et al. 2014). FSC certification comprises 10 principles and 70 criteria that cover environmental, social, and economic aspects of forest management. The FSC standard uses the CBD definition of alien species and criterion 10.3 (Principle 10 “Implementation of Management Activities”) states that “The Organisation shall only use alien species when knowledge and/or experience have

shown that any invasive impacts can be controlled and effective mitigation measures are in place”. Before introducing NNTs, FSC certification requires the presence of a management plan and scientific evaluations (Indicator 10.3.1), a stakeholder consultation and the use of effective mitigation measures to avoid the spread of NNTs outside the management unit area (Indicator 10.3.2), and the cooperation with competent authorities/bodies (Indicator 10.3.3).

PEFC certification system sets international Sustainable Forest Management benchmarks (see PEFC ST 1003:2018, Sustainable Forest Management – Requirements); within the framework provided by these benchmarks (11 criteria and 48 guidelines), national stakeholders develop their own national standards with the open participation of interested parties in a consensus-driven decision making process. All 54 recognised national standards require that origins of native species that are well-adapted to site conditions shall be preferred for reforestation and afforestation. Only those NNT species, provenances or varieties shall be used whose impacts on the ecosystem and on the genetic integrity of native species and local provenances have been scientifically evaluated, and if negative impacts can be avoided or minimised (Stupak et al. 2011). PEFC national standards recognise as guidance for avoidance of non-native invasive species CBD Guiding Principles for the Prevention, Introduction, and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species.

Native tree species exhibit multiple local adaptations to the climate of their habitat, guaranteeing optimal growth and survival under stable environmental conditions (Aitken et al. 2008). For example, in the hot arid North African desert belt, the conservation of stands of the native *Vachellia tortilis* subsp. *raddiana* and augmentative restoration plantings of seeds or seedlings may promote invasion resistance through establishment of shade to limit the invasion of *Prosopis glandulosa* (Abbas et al. 2019). The seedlings of *V. tortilis* subsp. *raddiana* are able to implement important shifts in key functional traits in response to altering abiotic stress conditions, behaving as a stress-tolerant species that is well-adapted to the habitat it occupies in the hot arid deserts of North Africa.

With global change, the link between climate and local adaptation may be disrupted, leading to local provenances of native tree species no longer providing the required ecosystem services (Alfaro et al. 2014; Podrázský et al. 2020). Different provenances of tree species with wide natural distribution ranges are adapted to different conditions. Thus, a possible match for a planting site in terms of vitality and productivity should first be sought among provenances of already present native tree species, drawing from the vast network of provenance trials and models built upon them. In a second step, provenances of other native species that are predicted to be better adapted to the planting site should be considered. Only if both alternatives have been exhausted, should NNTs be considered for planting to sustain the required ecosystem services (Bolte et al. 2009; Allen et al. 2010; Brus et al. 2018; Frischbier et al. 2019). According to Climate-Smart Forestry (CSF), an emerging branch of sustainable forest management, one option to further resilience and adaptability of native forest diversity is to improve

connectivity and migration corridors of key species and forest structures to sustain the availability of seed sources, as well as genetic variation (Bowditch et al. 2020).

When native tree species cannot be used, it is necessary to evaluate the use of NNTs with an expected low risk of invasiveness. Standard weed risk assessment tools can be successful at distinguishing between INNNTs and non-invasive NNTs; see Gordon et al. (2012), and Ziller et al. (2019) for *Eucalyptus*, and McGregor et al. (2012) for pines. New data and information on the biology and ecology of species may result in a change of the risk assessment and evaluation outcomes. However, the use of weed risk assessment tools might not be familiar to practitioners and risk assessment and management approaches should be carefully communicated among relevant stakeholders (Stokes et al. 2006). Lorentz and Minogue (2015) remarked that trait selection during breeding is potentially a very effective containment approach for managing the risk of invasiveness in non-native *Eucalyptus* taxa. The likelihood of spread can be reduced by decreasing fecundity or by increasing the age to maturity, although the latter method may negatively influence productivity (Gordon et al. 2012). This strategy has been successfully implemented in other taxonomic groups, including a triploid *Leucaena* hybrid in Hawaii (Richardson 1998). Likewise, elimination of seed production is considered a feasible goal for *Eucalyptus* (Gordon et al. 2012), and elimination of fertile pollen production has been accomplished in the transgenic hybrid *E. grandis* × *E. urophylla* (AGEH427) (Hinchee et al. 2011). There have been some suggestions that polyploidy may be related with invasiveness of forestry species, as in the case of *Prosopis juliflora* (Kaur et al. 2012). Polyploids may have an advantage over their diploid progenitors in having higher growth vigour but are often sterile (Pandit et al. 2011). In the case of *Robinia pseudoacacia*, there are many cultigens that are generally less invasive than the typical form (Sádlo et al. 2017). For some species of Pinaceae, there is a good understanding of the invasiveness of the different species, with some species having low invasion risk (Rejmánek 1996; Carrillo-Gavilán and Vilà 2010; McGregor et al. 2012). This understanding has been used in some areas to promote plantations with fewer invasive species and to discourage the plantation of highly invasive species (Nuñez et al. 2017). However, a careful assessment and evaluation of risk and benefits is always necessary. For example, male individuals of non-native *Populus* clones suitable for fast growing bioenergy plantations might be recommended to prevent seed dispersal to natural areas, but it is important to locate the site so as to avoid the risk of hybridisation with native poplars. A similar recommendation was proposed for the planting of male plants of *Acer negundo* in urban areas to mitigate the risk of spread by samaras, although the production of allergenic pollen must be considered (Ribeiro et al. 2009).

Trees for urban environments are generally selected on the basis of pragmatic criteria, such as suitability for the site, pest resistance or tolerance, availability of stock, and the cultural and aesthetic preferences of local people (Spellerberg and Given 2008). Evidence from Northern and Central Europe shows that in some regions the catalogue of native tree species might be too limited to fulfil ecosystem services and resilience in harsh urban environments (Sjöman et al. 2016). Thus, it might be unrealistic to generally exclude NNTs from consideration for urban greening. Further work is required to

quantify the diverse benefits of native species in many contexts. Therefore, we recommend to (a) plant more native trees in urban areas; (b) avoid NNTs if they pose risks to biodiversity or ecosystem services; and (c) plant NNTs only if invasion risk in the surrounding areas is low or can be managed effectively.

At a country level, the recommendation of using native trees in preference of NNTs should be based on sound knowledge of the natural ranges and distribution of native tree species within the country and its regions, to limit translocations across biogeographical regions and safeguard biological integrity of Important Plant Areas (Mehravian et al. 2020), protected areas, and hot-spots of endemism for trees.

Recommendation 2: Be aware of and comply with international, national, and regional regulations concerning non-native trees

Those engaged in the introduction, breeding, and use of NNTs and in the planted forest sector in general need to be aware of and comply with their obligations under regulations and legislation to prevent the introduction of INNTs and to minimise conflicts with regulatory authorities.

There is a substantial corpus of legally binding and non-binding conventions, regulations, and agreements on invasive non-native species at international, national, and regional levels. The CBD and its Parties recognised that there is an urgent need to address the impact of invasive alien species, and have adopted guidance on prevention, introduction, and mitigation of impacts of alien species that threaten ecosystems, habitats or species, and have taken a number of relevant decisions on invasive alien species, and forest biodiversity (e.g., COP 9 Decision IX/5). The CBD, the UN Climate Change, and UN Desertification Conventions may act synergistically to reduce the negative impacts of INNTs, promoting integrated, coherent, and multi-disciplinary approaches to these related issues and guiding the national forest authorities.

These international conventions have direct and indirect impacts on the everyday work in the planted forest sector and in the use of NNTs. Indeed, international conventions addressing issues of invasive alien species have been ratified by many countries (Shine 2007; Ormsby and Brenton-Rule 2017) and a significant number of NNT species are banned or are subject to restrictions. At national (or subnational) level, many countries have legislation and/or regulations aimed at preventing possession, transport, trade or use of specific (invasive) NNTs (e.g., for Europe see Brundu et al. 2020; Pötzelberger et al. 2020).

The Regulation (EU) No. 1143/2014 has included in the “list of invasive alien species of [European] Union concern” a number of NNTs – *Acacia saligna*, *Ailanthus altissima*, *Prosopis juliflora*, and *Triadica sebifera* (syn. *Sapium sebiferum*) – totally banning any use of these species in the European Union. This is a very stringent ban, as invasive non-native species of concern in the European Union may not be intentionally: (a) brought into the territory of the Union, including transit under customs supervision; (b) kept, including in contained holding; (c) bred, including in contained

holding; (d) transported to, from or within the European Union, except for the transportation of species to facilities in the context of eradication; (e) placed on the market; (f) used or exchanged; (g) permitted to reproduce, grown or cultivated, including in contained holding; or (h) released into the environment.

An example of national-level regulation is that of Mesquite (*Prosopis juliflora*) in the Sudan. This species, native to Mexico, Central America, and northern South America, was introduced to the Sudan in 1917 from South Africa and Egypt and was planted in Khartoum for research purposes. The success of this species in tolerating drought and stabilising sand dunes led to it being introduced to more drought-prone areas. In the 1990s, *P. juliflora* was introduced as part of dune stabilisation programmes in the spate irrigation systems of the Gash and Tokar. However, soon after its introduction *P. juliflora* became invasive. Tens of thousands of hectares were invaded in these areas and a 1995 presidential decree pledged to eradicate the species from Sudan (Laxén 2007). Similarly, *Melaleuca quinquenervia* (a tree native to Australia and Malaysia) was introduced into Florida in 1906 as a potential commercial timber and was later widely sold as an ornamental tree. This species is now on the Federal Noxious Weed List (USDA 2012) because it has invaded all types of terrestrial and wetland habitats, including undisturbed pine flatwoods, sawgrass-dominated communities and cypress swamps, but also roadsides, pastures, and urban sites (Porazinska et al. 2007). For these examples, earlier pro-active regulations on the sale or use of these INNTs could have reduced rates of invasions and impacts.

Recommendation 3: Be aware of the risk of invasion and consider global change trends

Those engaged in the planted forest sector and otherwise in the introduction and use of NNTs need to be aware of the potential for NNTs to become invasive and/or have negative impacts, and to use such information to inform decisions about the selection of trees and the management of plantations. This awareness should be based on the best available knowledge, on experience from elsewhere, and on appropriate assessments of risk, taking into account the existence of time lags in NNTs species spread and impacts (i.e. the “invasion debt”, Essl et al. 2011; Rouget et al. 2016) and global change trends.

The fact that some NNTs have not yet spread from the sites where they were planted should not be taken as definitive evidence that spread and negative impacts will not occur in the future. Experience with the same NNTs in planted forests or gardens in other parts of the world, including areas where the species have long residence times (Richardson et al. 2015), should be evaluated to assess the extent of invasion debt since NNTs often have long lag-phases (up to 200–300 years or longer; see Kowarik 1995). There is strong evidence that INNTs can replicate invasive behaviour and impacts in environmentally similar conditions in different parts of the world (Essl et al. 2010).

INNTs included in legally-binding prohibited species or in advisory lists (such as the IUCN list of “100 of the world’s worst invasive species”, which includes, e.g., *Acacia mearnsii*, *Cinchona pubescens*, and *Leucaena leucocephala*) should not be used

in the countries or regions where they are listed, nor released in the environment, nor planted along transport networks, nor used for new planted forests. For example, all new plants (including trees) currently not in New Zealand are banned unless permitted (Hulme 2020). Each new NNT species or provenance planned to be introduced for the first time in a given country or to be planted over large scales which has not yet been evaluated, should be subject to a comprehensive risk analysis to consider opportunities, risks, and management options, with uncertainties explicitly recognised. Moreover, regions or countries should consider not planting NNTs if these taxa are restricted in neighbouring jurisdictions, as NNTs can easily spread across national borders making biosecurity a regional issue (Faulkner et al. 2020). For example, the list of the Israel's "least wanted alien ornamental plant species" includes numerous NNTs which may be relevant for various countries around the Mediterranean, experiencing Mediterranean, semiarid, and arid climates (Dufour-Dror et al. 2013).

More than 100 risk assessment and risk analysis schemes for plant species have been proposed (Křivánek and Pyšek 2006; Leung et al. 2012), and decision-support schemes have been developed specifically for trees or woody plants (Reichard and Hamilton 1997; Pheloung et al. 1999; Kumschick and Richardson 2013; Wilson et al. 2014). Although no global repository currently exists, the European and Mediterranean Plant Protection Organisation (EPPO) platform on pest risk analysis (PRA) contains more than 400 PRAs produced since the early 1990s, including a few for NNTs, and additional documents related to PRA activities. A number of Weed Risk Assessments for NNTs (e.g., *Vachellia nilotica* and *Ligustrum sinense*) are available on-line, e.g., the Noxious Weeds Program Risk Assessments of USDA APHIS (<https://www.aphis.usda.gov/aphis/>), the PIER (Pacific Island Ecosystems at Risk – Plant threats to Pacific ecosystems; <http://www.hear.org/pier/>), and the UF/IFAS Assessment of Non-native Plants in Florida's Natural Areas (<https://assessment.ifas.ufl.edu/>). The result of risk assessments conducted for NNTs in Brazil are available on the web page of the Horus Institute (<https://institutohorus.org.br/>).

It has been suggested that importers, breeders, and growers who are responsible for introducing potentially invasive non-native species should be responsible for damages to the environment (i.e. the "polluter pays" principle), rather than allowing the burden to be borne by tax payers or neighbouring private landowners (Richardson 1998; Hulme et al. 2008; Buddenhagen et al. 2009; Chimera et al. 2010; McCormick and Howard 2013; Lorentz and Minogue 2015). In addition, contingency plans (EPPO 2009) and effective rapid response measures in the event of escape of NNTs should be in place before the introduction takes place (Rec. 5).

Climate change could affect the dynamics of invasions of NNTs in many interacting ways, for example: (a) by causing modification in the ecosystems that potentially modify opportunities for establishment, naturalisation, and spread of both native trees and NNTs (e.g., Iverson et al. 2008; Bezeng et al. 2017; Fei et al. 2017; Aubin et al. 2018); (b) by favouring individual traits of particular NNTs (e.g., Kawaletz et al. 2013; Castro-Díez et al. 2014); and (c) by modifying introduction pathways, potentially promoting the increased use of certain NNTs (Lindenmayer et al. 2012; Frischbier et al. 2019), thereby challenging the recommendation to preferentially use native trees

(Rec. 1). Climate matching between native and non-native ranges of tree species is often crucial for the outcomes of introducing NNTs (Petitpierre et al. 2012); it is therefore important to incorporate climate change into risk-analysis models for an anticipatory evaluation of scenarios for invasiveness of NNTs. Risk maps that incorporate the effects of climate change should guide land and forest managers and stakeholders with longer-term planning. Land-use change (not only related to the establishment of plantings) is also an important driver of NNTs invasions. Abandonment of land can increase the potential for invasion of NNTs or lead to the establishment of plantations (Lugo 2004, 2015; Sitzia et al. 2012; Mullah et al. 2014; Bravo et al. 2019; Vaz et al. 2019).

Under climate change, outbreaks of pests on native trees might increase, giving a greater momentum to planting NNTs, but these NNTs are also susceptible if pest/pathogens are subsequently accidentally introduced. For example, there has been an alarming increase in impacts of bark beetle outbreaks in conifer forests in recent years in Austria, the Czech Republic, Germany, Slovakia, and in North America (Hlásny et al. 2019). Synchronised by extreme weather, recent bark beetle outbreaks have already reached a supranational scale. Outbreaks are likely to further increase in extent and severity in the future due to climate change (Hlásny et al. 2019). A study in France (Bertheau et al. 2009) supports the assertion that native phytophagous insects adapted rapidly to conifers introduced in Europe. Non-native conifers in France are now colonised by native bark beetles. For risk assessment of native bark beetle attacks on newly introduced conifers, tree taxonomic relatedness appears to be a good predictor of shifting probability and the simplest one to consider in forest management. Planting NNTs within stands of taxonomically unrelated species might therefore reduce the rate of bark beetle shifts into novel hosts (Bertheau et al. 2009). NNTs species are widely used in planted forests for their high productivity and performance compared to native trees. However, these advantages may be compromised by insects and microbial pathogens which were introduced accidentally or have adapted to new host trees (Branco et al. 2015; Wingfield et al. 2015).

Managed relocation or assisted migration has been proposed as an approach to mitigate climate change impacts on biodiversity by intentionally moving species to climatically suitable locations outside their natural range (Richardson et al. 2009). It has also been proposed as a means to maintain forest productivity, health, and ecosystem services under rapid climate change (e.g., Gray et al. 2011; Kreyling et al. 2011; Pedlar et al. 2012; Benito-Garzón and Fernández-Manjarrés 2015; Peterson St-Laurent et al. 2018). This practice has the potential to launch invasions and should be subjected to the same level of risk analysis as for any other type of NNT planting.

Recommendation 4: Design and adopt tailored practices for plantation site selection and silvicultural management

All stakeholders involved in the many activities related to NNTs use, from the nursery industry to the design of plantation, and from silvicultural management to timber har-

vest, should design and adopt tailored practices to ensure the sustainable use of NNTs and minimise the risk of the escape of NNTs. The nursery industry and public nurseries are key stakeholders (Table 2), as the sustainable supply of germplasm of planting material and its quality is crucial for any tree-based project, from afforestation to restoration and to urban forestry (Broadhurst et al. 2015; Whittet et al. 2016). Nurseries are key stakeholders also for sharing information on native and NNTs (Rec. 8). Commercial horticultural and forest nurseries can act as important hubs of non-native species dissemination to planting sites and urban forest sites. Many weeds and forest pests, both insects and pathogens, have also entered new lands via nursery stock (Liebhold et al. 2012) e.g., *Phytophthora* (Sims et al. 2019), and *Hymenoscyphus fraxineus* (Nielsen et al. 2017). Nurseries are one of the most important sources of unintentional introductions of non-native plants (Hulme et al. 2008). Best-practice methods relating to species and provenances of seed or clones (Karlman 2001), seedling production, weed, pest and disease control should be adopted (FAO 2011). Invasive non-native species and pests should be detected, identified, recorded, notified to competent authorities if mandatory or suggested by the local regulations, and eradicated where possible, before transfers and planting.

Table 2. Stakeholder groups and their expected involvement in the implementation and use of Global Guidelines for the use of Non-Native Trees (GG-NNTs). The classification of stakeholder groups is modified from Raum (2018) and Kleinschmit et al. (2018). Y = Involvement of the stakeholder group in a recommendation (R).

Stakeholder Group	Description	R1	R2	R3	R4	R5	R6	R7	R8
Regulators/Governors/ Public Administrators	National, regional and local governments involved in policy, law making, law enforcement, and incentives. National and regional environmental and forest authorities, public forest agencies, public forest nurseries, protected areas.	Y	Y	Y	Y	Y	Y	Y	Y
Commercial agro-forestry business & industry	Private businesses involved in timber production, harvesting, processing, transport, and trade; water companies; and energy suppliers. Includes confederations of industries.	Y	Y	Y	Y		Y		
Commercial nursery industry	Private businesses involved in tree collection, breeding, trade, etc. Turf and substrata industry.	Y	Y	Y	Y				Y
Forest certification organisations	Independent, non-profit organizations setting standards under which forests and companies are certified.	Y	Y	Y	Y			Y	
Professionals and their organisations or confederations	Individuals providing specialist advice and support, urban forest professionals, landscape architects.	Y	Y	Y	Y	Y	Y		
Academia, science and education	Broad group of individuals and organisations conducting research on biodiversity, forest ecosystems related issues, urban forestry, and providing education. National or international scientific associations such as IUFRO.	Y	Y	Y	Y	Y	Y	Y	Y
Botanic gardens and arboreta	Public or private institutions, including historical gardens where trees are grown for scientific study and display to the public. Confederations such as BGCI.		Y	Y		Y	Y	Y	Y
Private forest owners and their organisations or confederations	Broad groups of individuals and organisations responsible for plantations and woodland management.	Y	Y	Y	Y	Y	Y		
Local or indigenous communities	Local, tribal, and indigenous groups involved either formally or semi-formally in running or managing local woodlands.	Y	Y	Y		Y			
Individuals	Individuals (local) who use (the nearby) woodland or urban forest for numerous purposes, e.g. recreational activities, collection or non-wood forest products, as bee-keepers, hunters, agriculture and grazing.			Y					
General public	Citizen and consumers and their organisations, non-directly using the plantations or the urban forests.			Y					
Media and social media	Media professionals and their organisations, private individuals and organisations, broadcasting and social media platforms.	Y		Y		Y		Y	

Standard biosecurity protocols (Sharma et al. 2014) and phytosanitary measures should be followed and applied, such as the International Standards for Phytosanitary Measures (ISPMs) which are standards adopted by the Commission on Phytosanitary Measures (CPM), which is the governing body of the International Plant Protection Convention (IPPC) (Ormsby and Brenton-Rule 2017). Scouting principles such as those used in integrated pest management are relevant; these require growers to follow a standardised sampling plan to scout large numbers of NNTs efficiently, focussing on key NNT species and vectors that are most susceptible to important pests. Any nursery growing or maintaining ornamental and forest NNTs should have an invasive non-native species and pest control program to prevent the growth of non-native species and NNTs outside sites demarcated for cultivation and around growing areas. Similarly, accidental dispersal of NNT propagules, e.g., through the movement of soil, growing media, equipment, machinery, water, should be avoided. Correct labelling of the nursery material (species and provenances) using scientific names is essential. It is also good practice to use double labels for all seed lots – one label fixed outside the bag, the other inside (Schmidt 2007).

Standards, guidelines, criteria, and indicators for sustainable forest management (SFM) have been developed by intergovernmental processes, international organisations, certification schemes (e.g., Forest Stewardship Council, FSC, and Programme for the Endorsement of Forest Certification schemes, PEFC) (Masiero et al. 2015) and national governments. These recommendations, which apply to all forests including planted forests, have resulted in forestry being recognised as a sustainable form of land-use essential to combatting climate change by storing carbon and preventing deforestation. Activity was increased considerably after the Statement of Principles for the Sustainable Management of Forests was adopted in 1992 at the Earth Summit in Rio in response to global concerns about deforestation and the unsustainable exploitation of natural forests (Stupak et al. 2011). At the European level, the 46 signatories of the Ministerial Conference on the Protection of Forests in Europe agreed on a definition of sustainable forest management in a Ministerial Process dating from 1990 and have developed and refined a set of criteria and indicators. These criteria are regularly updated and adapted to new challenges (<https://foresteurope.org/>).

Best-management practices include criteria such as that biodiversity issues must be considered in the design of planted forests (Conference of the Parties COP 11 Decision XI/19, 8–19 October 2012, Hyderabad, India). For example, the shape of planted forests comprising NNTs should minimise edges at right angles to prevailing winds during the seed-release season. The establishment of representative natural forest should be encouraged within planted forests and, where possible, natural forests should be restored on appropriate sites (Secretariat of the Convention on Biological Diversity 2009). Plantings of NNTs should be avoided near protected areas or endangered habitats. Because the seeds or other propagules of many INNNTs are dispersed in water, consideration must be given to the proximity of planting sites to streams and rivers. Suitable practices for planted forest and urban forestry should also include all available methods to limit the spread of pathogens and pests within planted forests and

from infested sites to native forest and other ecosystems (e.g., Engelmark et al. 2001; FAO 2011).

Land managers and owners of planted forests should be informed of forestry activities that favour or limit the spread of NNTs outside plantations (Sitzia et al. 2016). For example, coppicing is known to encourage the spread by *Ailanthus altissima* and *Robinia pseudoacacia*. In South Tyrol, Northern Italy, Radtke et al. (2013) concluded that the currently applied coppice management, involving repeated clearcuttings every 20–30 years, favours the spread of both NNTs. They proposed adaptation of the system to avoid further spread. Vítková et al. (2017) confirmed that, in the absence of forestry interventions, the abundance of *R. pseudoacacia* would decrease during succession in European forests with highly competitive and shade-tolerant trees. However, nearly all lowland forests in Central Europe are managed, which means that these findings are of little value for forestry management in this region unless management plans are totally overhauled. In fact, the limited pool of native woody species, the lack of serious natural enemies, and a dense cover of grasses and sedges can suppress forest succession and favour the development of *R. pseudoacacia* monodominant stands. A stratified approach, combining both tolerance in some areas and strict control at sites of high conservation value, provides the best option for achieving a sustainable coexistence of *R. pseudoacacia* with people and nature (Motta et al. 2009; Vítková et al. 2017, 2020; Sádlo et al. 2017).

The New Zealand guidelines for the use of the Decision Support System (DSS) “Calculating Wilding Spread Risk from New Plantings” (Paul and SCION 2015) are intended to guide individual landowners, consultants, and planners in carrying out initial assessments of wilding spread risk for new afforestation projects. The assessment applies a DSS known as the Wilding Spread Risk Calculator to assess wilding spread risk in a transparent, consistent and repeatable manner using the step-by-step description and examples.

Calviño-Cancela and Rubido-Bará (2013) suggested the establishment of a safety belt around *Eucalyptus* plantations in Spain to reduce the spread of eucalypts from plantations. This measure requires the elimination of all newly recruited individuals in this safety belt (e.g., a 15-m wide belt could reduce the probability of *Eucalyptus* spread by more than 95%) before they start producing seeds, thereby hindering the advance of the front line of invasion. For this purpose, Calviño-Cancela and Rubido-Bará (2013) recommended managing operations at 1–2-year intervals, so that saplings can be removed (uprooted), thus preventing resprouting. Their recommendations apply to situations without fire. Fire stimulates regeneration (Gill 1997; Calviño-Cancela et al. 2018) and could increase dispersal distances, which means that additional measures would probably be needed to control *Eucalyptus* spread after fires. According to Nereu et al. (2019), keeping dense competing vegetation is probably the most cost-effective option to minimise unwanted *E. globulus* recruitment and maximise seedling mortality inside and around plantations. In Portugal, *Eucalyptus* wildlings are more abundant in plantations in moist aspects, coppiced, with older tree stems and corresponding to intermediate site growth indexes (Águas et al. 2017). Silva et al. (2016) undertook an

experiment in six regions in Brazil, under different climatic/ecological conditions, with five pure species (*E. camaldulensis*, *E. pellita*, *E. grandis*, *E. urophylla*, and *E. saligna*) and three hybrids. Factors such as competition with other plant species and seedlings predation drastically limited *Eucalyptus* establishment suggesting low ecological adaptation as an invasive species.

Tailored management practices should be followed in the case of planted forests with NNTs for bioenergy production (Short Rotation Forestry SRF, Short Rotation Coppice SRC): choosing new planting sites; mitigating negative impacts on biodiversity (Weih 2008; Framstad et al. 2009; Vanbeveren and Ceulemans 2019); preventing spread into surrounding habitats e.g., using buffer zones (Crosti et al. 2016); protecting hydrology (Christen and Dalgaard 2013); conserving landscape values; and planning for the restoration of the site after the cultivation cycle (Hardcastle et al. 2006; Neary 2013; Caplat et al. 2014). For example, experience with *Eucalyptus* plantations under intensive short-rotation regimes in China (Zhou et al. 2020) suggests that, in the long term, the intensively managed monospecific plantations under short-rotations should be progressively converted into mixed plantations with short-, medium- and long-term rotations. This strategy could be accomplished by interplanting with high-value native tree species such as *Castanopsis hystrix*, *Dalbergia odorifera*, and *Parashorea chinensis*.

Finally, it is very important to design and adopt good practices for harvesting and transport of timber and other forest products or materials, to mitigate the unintentional spread of reproductive material of NNTs by harvest and transport of timber, to reduce the spread of seeds of other weeds, pathogens, and pests inside and outside the plantations. A key requirement of best practice in this regard is to keep forestry machinery out of water bodies and riparian margins. Machinery needs to be cleaned and checked regularly where the transfer of propagules of NNTs species is an identified risk. Although the role of such dispersal has only been studied in a few cases (e.g., Kaplan et al. 2014) it is probably a major factor in invasions of NNTs in many situations. Appropriate water and sediment controls need to be installed to reduce runoff directly into waterways to reduce opportunities for the spread of propagules of NNTs.

Forest personnel and city council staff responsible for working with urban trees should be trained to recognise and report unusual pests and symptoms of diseased or infested trees, to report escape events, and to carry out practices that reduce the risk of pest, NNTs and other non-native species or propagules moving to other locations (Rec. 6). Personnel should wear outer layers of clothing and footwear that are not “seed friendly” (*sensu* USDA 2012) to minimise the risk of spreading INNTs and other invasive non-native species propagules accidentally.

Forest roads (usually built with the primary aims of supporting forest management and harvesting), fire-control ditches, and road and railways networks should be periodically monitored to prevent the escape of NNTs, especially during harvesting or other silvicultural operations that can promote the accidental spread of propagules (Nereu et al. 2019; Chmura 2020). Transport of timber, and other forest products of materials, removing trees or coppice, arboricultural work in urban forestry and mechanisation movement are also responsible for unintentional transport of NNT propagules and other (non-native) species, such as invertebrates, pathogens, and pests.

Recommendation 5: Promote and implement early detection and rapid response programmes

It is very important to regularly monitor plantings for the spread of NNTs and to act rapidly to control spread so that invasions can be managed before they become widespread and costly to control. Early detection and initiation of management to promptly remove INNTs can make the difference between being able to prevent invasions and having to either spend substantial resources controlling widespread invasions or accept or mitigate against whatever negative impacts they have (Nuñez et al. 2017). Proactive measures to reduce the chances of NNT and INNT spread and for dealing with problems at an early stage must be included in standard silvicultural practices, large-scale plantation plans, and urban forestry policies, such as the design of buffer zones around NNT plantations where the potential spread can be monitored more accurately.

The relatively long initial lag phase between introduction and naturalisation/invasion (Kowarik 1995), relative long life span and age of maturity, and slow dynamics observed in many INNTs, compared to other non-native invasive plant species (e.g., aquatic invasive non-native plants), offers opportunities to control the INNTs while escaped populations are still small (Finnoff et al. 2007; Dodet and Collet 2012). Developing “alarm lists” or “alert lists” of possible new invasive NNTs can also enable more rapid reaction (Richardson 2011; Faulkner et al. 2014) as can horizon scanning exercises (e.g., Roy et al. 2014).

Any NNTs detected outside cultivation areas – especially NNTs recognized elsewhere as invasive and/or if occurring in areas of high conservation value – should be georeferenced, reported, and controlled or contained. All records and sightings will help to determine the extent of the INNT problem in a given area and facilitate a rapid response where necessary. They can also help to better understand species distribution, habitat suitability, and thus support better management. Such data should ideally be collected and quality-controlled by a (national / state) coordination centre, so that it can directly inform policy and management. Owing to the huge number of species observations that can be collected by non-professional scientists, citizen science has great potential to contribute to data collection, scientific knowledge on invasive non-native species, and to support early detection for NNTs outside cultivation areas. The recent adoption of information and communications technology in citizen science (e.g., web or mobile application-based interfaces for citizen training and data generation) has led to a massive surge in popularity, mainly due to reduced geographic barriers to citizen participation (Adriaens 2015; Johnson et al. 2020).

A rapid response capacity implies the availability of skilled personnel, contingency plans (where responsibilities are clearly determined), and technical guidelines for controlling invasive NNTs. Guidelines exist for many NNTs (e.g., PM-9 for *Ailanthus altissima*, EPPO 2020) but they need to be incorporated into a unified framework and databases (Rec. 8). It should be stressed that controlling small foci of escaped NNTs, generally saplings, does not require heavy equipment and costly investments. In most cases control can be easily achieved either by cut-stump, drill-fill or hack and squirt techniques that do not require sophisticated tools. In addition, controlling a limited number of NNTs

with direct application methods, i.e. without spraying, enables using very small quantities of herbicides. The recent development of new herbicides with high ecotoxicological profiles gives the opportunity to perform INNTs control with a maximum effectiveness and a minimum risk for the environment (Dufour-Dror and Yaacoby 2019).

Establishing a new sentinel garden or joining a network of sentinel sites is an important tool for supporting early detection and early warning strategies. This approach provides the unique opportunity to monitor NNTs in sentinel site networks (Kenis et al. 2018) both for their susceptibility to pathogens and pests, and for their ability to naturalise and to escape from cultivation. Other areas that worth monitoring as they are likely to act as sources of propagules and sites of entry for new invasions are urban areas, areas of human habitation outside large towns where gardens have been established (Alston and Richardson 2006; McLean et al. 2017), experimental plantings, arboreta or botanical gardens containing NNTs (Dawson et al. 2008), networks of non-native monumental trees. They can also be included in sentinel networks (Roques et al. 2015).

Kenis et al. (2018) and Visser et al. (2014) believe that sentinel site networks as described above could help to: (1) identify emerging trends in NNT invasions; (2) provide valuable mapping for particular NNTs; (3) monitor changes in NNT abundance and distribution over time; (4) help ensure legislative compliance of land managers and plantation owners; and (5) track management efforts over time. The International Plant Sentinel Network (IPSN; <https://www.plantsentinel.org/>), was developed to facilitate collaboration amongst institutes around the world, with a focus on linking botanic gardens and arboreta, National Plant Protection Organisations (NPPOs), and plant health scientists, focusing on pests and pathogen, but it might also help in monitoring NNTs.

Efficient monitoring activities require carefully planning, large and permanent funding and skilled personnel, but important contributions can be done even with limited resources. For example, Visser et al. (2014) showed that Google Earth can be used to establish a global sentinel site network for NNT invasions, because imagery is continuously being updated, is free to access and is low-tech. The ease of accessing Google Earth, potentially linked with projects in platforms such as iNaturalist (<https://www.inaturalist.org/>), means that effective monitoring of networks of sentinel sites could be achieved as part of citizen science initiatives. Google Street View has been used to detect eucalypt wildlings along roads in Portugal (Deus et al. 2016).

Recommendation 6: Design and adopt tailored practices for invasive non-native tree control, habitat restoration, and for dealing with highly modified ecosystems

If an INNT species has been introduced and started to spread beyond a planting site, early detection and rapid response is crucial to prevent its establishment. The preferred response is to eradicate the INNTs as soon as possible (UNEP/CBD/COP VI/23, principle 13). If eradication is not feasible, containment, and long-term control measures should be implemented. It is often not clear how INNTs can be successfully managed,

but there are examples from Australia and South Africa where integrated management approaches are applied, including chemical, physical, biological (Hill et al. 2020), and cultural control (Richardson et al. 2015; van Wilgen et al. 2020). As with other invasive non-native species, a clear definition of the management goals and a spatially coordinated management strategy are key for successful management of INNNTs.

It is necessary to develop and adopt species-specific and site-specific guidelines for the restoration of sites previously occupied by INNNTs or by planted forests of NNTs, to minimise or reverse disturbances caused by the previous land use or INNNTs. In fact, recent international commitments have paved the way for the implementation of large-scale ecological restoration programs in the upcoming decades (<https://www.decade-onrestoration.org/>), such as the Initiative 20x20 in Latin America and the Caribbean (<https://initiative20x20.org/>) that seeks to restore 20 million hectares of degraded land by 2020, the AFR100 African Forest Landscape Restoration Initiative (afr100.org) that aims to bring 100 million hectares of degraded land under restoration by 2030 (Chazdon et al. 2017), and the Atlantic Forest Restoration Pact, which aims at restoring 15 million hectares in the Brazilian Atlantic Forest until 2050 (Pinto et al. 2014).

Restoration objectives have been broadly classified into overarching strategies, such as rehabilitation, reconstruction, reclamation, and replacement (see Stanturf et al. 2014). Native tree species can grow in the understory of planted forests of NNTs. However, not all planted forests of NNTs develop species-rich understories; some remain NNT monocultures. Low light intensity below the canopy, distance to seed sources, inhospitability to seed dispersers, altered soil and litter conditions affecting seed germination or seedling growth, intensive root competition with the planted NNTs, other forms of plant-soil interactions, plantation design, or periodic disturbances by organisms or any external factor are likely causes of the lack of native species diversity in NNT planted forests that require careful consideration (Lugo 1997). Thus, human-mediated restoration is likely necessary after the presence of NNTs. One option is the continuous change of the plantation by reducing the abundance of NNTs and simultaneous replanting with native species.

Sádlo et al. (2017) proposed a stratified approach to the management of eight types of *Robinia pseudoacacia* stands growing in Europe, based on decisions that reflect the local context. Specific guidelines for restoration of sites previously occupied by planted forests of *R. pseudoacacia* have been produced in the Piedmont region of Italy and in China (Zhang et al. 2018). Sturges and Atkinson (1993) suggested management strategies for the restoration of near-natural sand dune habitats following the clearfelling of *Pinus* planted forests in Britain, and Brown et al. (2015) proposed approaches for restoring areas previously planted with non-native conifers on ancient woodland sites. Szitár et al. (2014) assessed the recovery of open and closed grasslands over five years after the removal of planted forests of non-native pine species through burning in an inland sand dune system in Hungary. Arévalo and Fernández-Palacios (2005) proposed the continuous elimination of the non-native *P. radiata* and augmentation with the native *P. canariensis* on Tenerife, Canary Islands (Spain). Hughes and Richards (2003) and Moss and Monstadt (2008) proposed management guidelines for the restoration

of floodplain forests in Europe. Detailed guidelines are available for the restoration of South African fynbos vegetation following the clearing of NNTs (Holmes et al. 2000, 2005, 2008; Hirsch et al. 2020; Holmes et al. 2020a, b).

The Atlantic Forest in the Brazil biodiversity hotspot is being threatened by its replacement for *Eucalyptus* plantations (Joly et al. 2014). In many regions, small remnants of Atlantic Forest currently persist in a matrix of *Eucalyptus* plantations (Tavares et al. 2019). Restoration plantations in this biome must be established with nursery-grown seedlings of high genetic diversity (Sujii et al. 2017). Inbreeding depression in trees may lead to reduced tree population viability in forest restoration areas. This issue may play an even more relevant role in restoration plantations in the tropics because most tree species are pollinated by animals, and their maximum flight distances are not considered when distributing seedlings in the field (Sujii et al. 2017).

Active restoration of ecosystems degraded by INNNTs to pre-invasion or pre-degradation conditions is impractical in some situations for logistical or financial reasons. In such cases, options for managing such ecosystems sustainably to optimise biodiversity and considerations relating to key ecosystem services should be explored, and guidelines should be formulated for integration into regional management plans (e.g., Schwartz et al. 2012). Management interventions involving inexpensive measures to encourage spontaneous succession following the removal of NNTs or other degrading disturbances are removed or reduced (“passive restoration”) have been successful in many regions (see Holmes et al. 2020b for a review). Engagement with all stakeholders is crucial in restoration and control programmes pertaining to NNTs (Rec. 7).

Recommendation 7: Engage with stakeholders on the risks posed by invasive non-native trees, the impacts caused, and the options for management

Stakeholder engagement and public participation are key in the management of risks posed by NNTs and INNNTs. The crucial role of stakeholder engagement is increasingly recognized globally, but engagement still implemented mostly in a top-down fashion (Shackleton et al. 2019); much more attention is needed to co-design, co-create and co-implement research and management. Social learning and feedback to stakeholders also need to be promoted, and multidisciplinary collaboration and partnerships are also highly beneficial (Rec. 8).

Forest and forestry issues have become more complex in recent decades. The many uses of forests, of NNTs, and the related types of land uses, now benefit a wider stratum of people than ever before, and is subject to a large range of social and environmental demands. An example of one possible classification of the major stakeholder groups involved in forest and forestry issue, and which are differentially affected by the GG-NNTs, is reported in Table 2. It is a general classification, to be applied only to the GG-NNTs, and cannot substitute national and local analysis of the forest and forestry systems and dedicated stakeholder’s maps for local implementations of the GG-NNTs.

It is always important to consider that many NNTs, planted for production or for other purposes, have strong direct positive economic impacts on the local and national

economies of many countries, including poverty alleviation, but often lead to sharp conflicts of interest when the NNT species become invasive, and have negative impacts on the ecosystem (Dodet and Collet 2012; van Wilgen and Richardson 2012; Dickie et al. 2014; Sladonja et al. 2015). Such conflicts can be reinforced if risk assessment methods are not transparent or do not give adequate consideration to the context-dependence of impacts (Bartz and Kowarik 2019).

Besides land managers, forest owners, and local or indigenous communities, engagement with the general public is very important for issues related to NNTs, from their use in gardening and landscaping to forests and forestry. The active and informed participation of communities and stakeholders affected by planted forest management decisions is critical to the credibility and acceptance of management processes. Public awareness-raising and communication activities play critical roles in informing and educating the public (Andreu et al. 2009; Marchante et al. 2011; Schreck Reis et al. 2013), thereby allowing them to participate more effectively in decision-making and in the management of NNTs and INNNTs (Dechoum et al. 2019). Public support for eradication, management or control efforts directed at INNNTs must be sought through carefully planned, long-term ongoing outreach initiatives involving, among other things, meetings with stakeholders, local village leadership, employment of villagers from areas adjacent to invasions, and the effective use of media outlets (Novoa et al. 2018).

An increasing number of tourists are interested not only in experiencing unique natural and cultural environments and landscapes but also learning more about them. Forest-based tours are an ideal opportunity to share information about different types of forest environments, native and NNT species, restoration actions, wildlife and landscapes, how they function, and how they came to be. Visitors are also likely to be interested in the lifestyles, cultures, and social and political histories of local communities living near forest areas and making use of local tree species. Citizen science projects such as online apps for collecting data on distribution and impacts of INNNTs (Groom et al. 2017, 2019) should be utilized. Wider engagement and education regarding impacts can be through online sources or field guides (Rotherham and Lambert 2012; Veenvliet et al. 2019).

Since 1992, the UNCED Statement of Forest Principles (Galizzi and Sands 2004) states that the provision of timely, reliable, and accurate information on forests and forest ecosystems is essential for public understanding and informed decision-making and should be ensured (principle 2, letter c). Similarly, the CBD COP 6 Decision VI/23 “Alien species that threaten ecosystems, habitats or species”, within its Guiding Principle no. 8 stresses the importance of the process of the exchange of information on invasive alien species.

In formulating legislation on NNTs and INNNTs a further application of the participatory approach from regulators, governors, and the public administration in general is envisaged. The aim of participatory forestry is to ensure that all stakeholders are included in all aspects of forest management, decision-making and policy formulation (FAO 2010a). It is often remarked that the public is more likely to comply with regulations that they have actively participated in creating (Sudirman et al. 2004). However, there is diverse criticism regarding the ability to successfully design participatory forest

policy processes (Kleinschmit et al. 2018). For example, in Ghana, it has been suggested that involving the public can be disruptive, costly, time consuming, and inefficient, because they are "unable to participate effectively" (Mohammed 2013). On the contrary, many publications identify key factors for successful participation (Kleinschmit et al. 2018), dedicated novel tools, such as the Participatory Technology Assessment (Griessler 2012), Co-Design (Blomkamp 2018), or show how participatory tools in forest policy, legislation making and forest management (e.g., in Tanzania; Magessa et al. 2020) can also help in achieving a number of UN Sustainable Development Goals (<https://sdgs.un.org/>).

Participatory forestry in the context of NNTs should include professionals from the invasion science sector, as scientific knowledge and evidence are usually conceived outside of policy systems and legislation corpus, and then brokered or disseminated into the policy process, with varying degrees of success (Cairney and Oliver 2017; Pineo et al. 2020).

Recommendation 8: Develop and support global networks, collaborative research and information sharing on native and non-native trees

Global networks, collaborative research, and information sharing are crucial for supporting the implementation of the recommendations of the GG-NNTs and for achieving their goals. Thus, this final recommendation is cross-cutting and relevant to all the other recommendations.

For example, the preferential use of native trees has to be supported by large-scale efforts for the conservation and evaluation of forest genetic resources (Sigaud 2000), from dedicated research in forest tree breeding and improvement, particularly in developing countries. These collaborations and research programmes are essential for the adaptation and the evolutionary processes of trees and forests, for improving their resilience and productivity, and for providing suitable materials and information to the nursery sector on native and NNTs. To date, forest trees are underrepresented among available plant genome sequences (Holliday et al. 2017).

Another important field, and a critical aspect of collaborative research in the management of NNTs and INNNTs, is the need for defining and identifying NNT species, since species are the unit tied to regulatory policies and management (Hamelin and Roe 2020). However, a large number of NNTs are used, including thousands of cultigens (hybrids, clones, etc.); for many NNTs, further studies on biosystematics, phylogenetics, taxonomy, nomenclature, and biogeography (e.g., an accurate delineation of native, neonative *sensu* Essl et al. (2019), non-invasive, and invasive geographic ranges) are vital to reproducibility, documentation, and prediction. Lack of concern for nomenclature can undermine science and management of NNTs, and it can lead to serious mistakes. Furthermore, the CBD has long recognised that taxonomy is crucial for the implementation and monitoring of the CBD itself (Global Taxonomy Initiative, Decision IV/1).

Fast and reliable identification of NNTs and INNNTs is also a prerequisite of early detection and rapid response (Rec. 5). Global networks and collaborative research can

advance application of novel techniques, such as remote microscopy facilitating real-time identification of NNTs (Thompson et al. 2011). This task is achieved by using web-enabled video cameras mounted on microscopes, allowing live streaming of images to a web address. This web link can then be accessed by anybody (e.g., a specialist taxonomist for that NNT species) with access to the Internet. Direct communication between an expert and a specimen holder using remote microscopy equipment facilitates a very high level of interactivity (Thompson et al. 2011).

Global networks (Packer et al. 2017) are critical for the future of invasion science, and to ensure effective planning and management of NNTs to deal with, among other things: identifying global priorities for research and management agendas; coordinating data collection over space and time; assessing risks and emerging trends; understanding the complex influences of biogeography on mechanisms of invasion; predicting the future of invasion dynamics; and using the insights on all of the aforementioned issues to improve the efficiency and effectiveness of evidence-based management techniques.

The scientific community should support the improvement of standard and accepted methods to assess negative impacts of INNTs, establish priorities for intervention, and provide improved tools for comparing species (Bindewald et al. 2019), habitats and regions at the global level. In 2020 the IUCN adopted as a formal standard the Environmental Impact Classification for Alien Taxa (EICAT) methodology (Hawkins et al. 2015; IUCN 2020). Consideration should be given to assessing the impact of INNTs using EICAT. Results of such assessments should be shared using freely accessible platforms such as the IUCN Global Invasive Species Database. An important example of global network is the CONTAIN project, supported by a group of more than 20 researchers from four countries (Argentina, Brazil, Chile, and the UK) with diverse research focuses, such as invasion ecology of plants and animals, ecological restoration, economy, statistics, and social dimensions of invasions, which aims to design, and introduce to stakeholders a user-friendly decision making tool that will help to guide the long-term management of invasive species (Lambin et al. 2020).

Cavender and Donnelly (2019) called for greater involvement of botanical gardens and arboreta with urban forestry to improve sustainability of cities and human lives. These institutions have a significant public reach, maintain strong professional networks, and can make important contributions to addressing key priorities including protecting existing trees; improving tree selection, diversity, and age structure; and improving planning, standards, training, and management. Improving urban forests is one of the solutions to achieving several of the UN SDGs, such as making cities healthier and more liveable (Fig. 1). With the cooperation of practitioners involved in forest and urban forest management, best practice manuals for control or eradication for the most important INNT species can be prepared for different world regions and taxa.

Information on NNTs and INNTs and strategies for dealing with them is critical for the implementation of all the recommendations in the GG-NNTs. Science-based strategies to tackle biological invasions depend on recent, accurate, well-documented, standardised, and openly accessible information on non-native species (Hulme and Weser 2011; Groom et al. 2017). Information is becoming more easily accessible (e.g.,

IUCN Global Invasive Species Database, www.iucngisd.org, IUCN Global Register of Introduced and Invasive Species, <http://www.griis.org/>, and CABI Invasive Species Compendium, www.cabi.org/ISC). For INNTs of concern in the European Union, IUCN provided comprehensive information on costs and available methods of appropriate management actions. Such science-based reviews are also available from the EPPO website; an example is the PM/9 Standard on *Ailanthus altissima* (EPPO 2020). The European National Forest Inventory Network (ENFIN) is a facilitator for enhancing harmonisation and comparability of national data and the ancillary information required to monitor European forestry-related policies (Vidal et al. 2016). Similarly, the *Observatoire des Forêts d'Afrique Centrale* (OFAC) is an association of public and private bodies, researchers and NGOs whose goal is to help set up the convergence plan of *Commission des Forêts d'Afrique Centrale* (COMIFAC). It provides COMIFAC and country members a powerful steering and national or remote sensing data sharing platform to promote better governance and the sustainable management of forest ecosystems (Vidal et al. 2016).

However, there is the need to improve the quality and quantity of the available information, and support and use systems for information sharing. For example, the precise geographical distribution of plantations of NNTs is not available for many countries. Harmonised and quality-controlled data at the regional scale (e.g., for the European Union) are needed for robust assessments of responses of forest tree species to climate change (Serra-Diaz et al. 2018; Reyer et al. 2019; Ruiz-Benito et al. 2020).

Information sharing systems would greatly improve the ability of authorities to prevent the introduction and spread of INNTs (Katsanevakis et al. 2013; Tsiamis et al. 2016). Up-to-date and accurate data are also particularly relevant for “horizon scanning” initiatives, which are an essential component of invasive species management, to prioritise potential new invaders that are not yet naturalized in a region (Groom et al. 2015).

Global networks, collaborative research, and information sharing are also crucial to adequately design and promote forest and forestry biosecurity training programmes, in building and developing capacity. In fact, the effective management of NNTs and INNTs, from prevention to early detection and rapid response, from habitat restoration to stakeholder engagement, requires a breadth of expertise from field to laboratory, and specialised knowledge and skills that can only be developed over time. The capacity and awareness of landowners, forestry officials, nursery personnel, and other stakeholders are crucial for effective implementation of the recommendations of the GG-NNTs, as is their hands-on experience to help design training programmes or adjust and improve existing guidelines.

A number of universities offer graduate and postgraduate certification and diplomas on plant biosecurity. Skill development includes, for example, knowledge of the legislative frameworks underlying the regulation of transboundary movement of potentially invasive non-native species, the identification and analysis of pathways and vectors, writing risk assessments for new species (pre-border and post-border), developing incursion response plans, biodiversity management plans, and research proposals, as well as gaining advanced science communication skills. Other important topics include training on pest and pathogen risks to forestry (Marzano et al. 2017), and the

use of plant protection products. A single full curriculum dedicated to biosecurity for NNTs is not yet available; there is thus scope for collaborative research aimed at implementing and sharing online training for everyone who might be interested.

Conclusions

A large and growing number of NNTs are invasive in their new ranges and have diverse negative impacts on biodiversity and ecosystem functioning, as well as on Nature's Contribution to People (Díaz et al. 2018). The GG-NNTs call for the preferential use of native trees whenever possible, aims to raise awareness and contribute to reducing the further introduction and spread of new INNTs and further dissemination of known invaders. Where the use of NNTs is unavoidable, the GG-NNTs call for the application of best practices to guide NNT cultivation to minimise the risk of escape from areas set aside for plantings and to ensure that measures are in place to control wildings in the early stage of the invasion process. The application of the GG-NNTs and the achievement of their goals will help to conserve forest biodiversity, ensure sustainable forestry, and contribute to the achievement of a number of Sustainable Development Goals linked with forest biodiversity.

The GG-NNTs outlined in this paper are general; they need to be modified for implementation in different national, regional, and local-scale contexts, in consultation and with full engagement of all relevant stakeholders. Different groups of stakeholders have different fundamental and unreplaceable roles in formulating workable management strategies. For example, in the stakeholder group that includes regulators, governors, and public administration, key expectations are to: make pledges to mobilise resources; build and develop capacity; mainstream the GG-NNTs into national and sub-national policies, regulations, strategies and plans, to prevent NNTs invasions and ecosystem degradation; and to support collaborative scientific research and delivering of technical solutions for the sustainable management of plantations of native trees and NNTs.

The GG-NNTs offer general recommendation on NNTs and provide a basic framework and suggestions on tools for planning and implementing sustainable use of NNTs in nationally appropriate and scientifically sound practices that account for national and sub-national needs. It is important to bear in mind that national circumstances vary considerably in terms of biophysical conditions (e.g., NNT species, forest types, and forest and forestry utilization practices), institutional and legal frameworks, economic challenges and possibilities, management, and use, among other factors. Therefore, no "one-size-fits-all" approach can be applied in the implementation of the GG-NNTs. Instead, various technical and organisational options must be combined to achieve efficient implementation of the guidelines.

Global networks, collaborative research, and information sharing are crucial for supporting the implementation of the recommendations of the GG-NNTs and for achieving their goals. This is the main cross-cutting recommendation. However, other recommendations or parts of them are somewhat cross-cutting and relevant to the whole set of GG-NNTs, such as the need to consider global change trends and to en-

gage with all relevant stakeholders. In fact, tree species, provenance, and site selection, plantation management, evaluation of risks and benefits in the use on NNTs, restoration, and conservation activities are all expected to be strongly influenced by changes in climate and land use.

Finally, in the implementation phase, intersectoral collaboration within the country or within regions should be promoted. Sectors such as agriculture, environmental protection, biodiversity conservation, ecotourism development, and other social fields will be interested in the process of local implementation and in the results of applying the GG-NNTs to the country scale. This involvement may lead not only to greater value at the national level, but also to greater understanding, acceptance of and support for the guidelines. Ideally, the goals of the GG-NNTs should be embedded in national strategies on biodiversity and invasive non-native species. Forest certification schemes are important instruments for mainstreaming the recommendations in the GG-NNTs.

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Supplementary material I

Global guidelines for the sustainable use of non-native trees to prevent tree invasions and mitigate their negative impacts (GG-NNTs) Background information (Annex to the GG-NNTs)

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Data type: additional materials

Explanation note: Terms and definitions, Acronyms, and additional Tables: Non-native tree species in planted forests and for other uses: historical and recent pathways of introduction; Main types of negative impacts of INNTs (after Richardson et al. 2000); Major international initiatives and legislation pertaining to invasive alien species and INNTs.

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