**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)**

**Terms and definitions – Acronyms**

NNT(s): Non-native tree(s)

INNT(s): Invasive non-native tree(s)

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

AFR100: African Forest Landscape Restoration Initiative

CABI: Centre for Agriculture and Bioscience International

CBD: Convention on Biological Diversity

COMIFAC: Commission des Forêts d’Afrique Centrale

COP: Conference of the Parties

CPM: Commission on Phytosanitary Measures

DSS: Decision Support System

EDRR: Early Detection and Rapid Response

EICAT: Environmental Impact Classiﬁcation for Alien Taxa

ENFIN: European National Forest Inventory Network

EPPO: European and Mediterranean Plant Protection Organization

EU: European Union

FAO: Food and Agriculture Organization of the United Nations

FRA: Global Forest Resources Assessment (FAO FRA)

FSC: Forest Stewardship Council

GG-NNT: Global Guidelines on Non-native Trees

IPPC: International Plant Protection Convention

IPSN: International Plant Sentinel Network

ISPM(s): International Standards for Phytosanitary Measures

IUCN: International Union for Conservation of Nature

NGOs: Non-Governmental Organizations

NPPOs: National Plant Protection Organisations

OFAC: Observatoire des Forêts d’Afrique Centrale

PEFC: Programme for the Endorsement of Forest Certification schemes

PEOLG: Pan European Operational Level Guidelines

PIER: Pacific Island Ecosystems at Risk

PRA: Pest Risk Analysis

REDD+: Reducing Emissions from Deforestations and Forest Degradation in Developing Countries

SBSTTA: Subsidiary Body on Scientific, Technical and Technological Advice (CBD SBSTTA)

SFM: Sustainable forest management

SRC: Short Rotation Coppice

SRF: Short Rotation Forestry

UF/IFAS: University of Florida/Institute of Food and Agricultural Sciences

UN SDGs: United Nations Sustainable Development Goals

UN: United Nations

UNCED: United Nations Conference on Environment and Development

UNFCC: United Nations Framework Convention on Climate Change

USDA APHIS: United States Department of Agriculture – Animal and Plant Health Inspection Service

**Invasion debt**

According to Rouget et al. (2016) invasion debt has four main components: (1) the number of species not yet introduced but that will be introduced in future given current levels of introduction/propagule pressure; (2) the number of introduced species that are not currently established but that will establish in future; (3) the area that will become invaded in future if invasions are not managed; and (4) the increase in the severity of impacts if no mitigation methods are implemented. These authors suggest that invasion debt is a valuable metric for reporting on the threats attributable to biological invasions. Invasion debt must be factored into strategic plans for managing global change, and that it provides a counter-factual argument against which to measure the success of a management or policy intervention (and as with other studies it tends to highlight the value of proactive management). However, given the uncertainty associated with biological invasions, further work is required to quantify the different components of invasion debt.

**Non-Native Tree (NNT)**

(Synonyms: alien, allochthonous, exotic, introduced, non-indigenous tree)

In the GG-NNTs, 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 tree (NNT) has exclusively a biogeographical meaning, i.e. it refers to a tree species, subspecies, lower taxon, or genotype, introduced to regions outside its past or present natural distribution, and includes any part, seeds, or propagules of such taxon that might survive and subsequently reproduce. As such, the term alien tree carries no connotation (negative or positive) relating to the risk of the species affecting biodiversity. The concept is not related to political limits but rather to geographical, abiotic or biotic barriers that limit species’ distribution. In this sense, NNTs include species that are native to restricted regions in a country and are translocated by humans to other regions in the same country or even state where they are not native. Importantly, an NNT species is “introduced outside its natural past or present distribution” deliberately or accidentally by human activity. The definition takes into consideration the Recommendation No. 142 (2009) of the Standing Committee (Convention on the Conservation of European Wildlife and Natural Habitats), adopted on 26 November 2009, interpreting the CBD definition of “invasive alien species” to take into account climate change, “recommends Contracting Parties to the Convention and invites Observer States to: 1. interpret the term “alien species” for the purpose of the implementation of the European Strategy on Invasive Alien Species as not including native species naturally extending their range in response to climate change”. As a result, also past mass migratory events in forest tree populations, postglacial recolonization routes and similar events are not considered herewith in the definition of NNT species. We focus on NNTs deliberately or accidentally introduced by human activity outside their natural past or present distribution, where “past” refers to the definition of “neophytes” (i.e. introduced after the 1,500) as used in the CBD context and defined by Pyšek et al. (2004).

**Invasive Non-Native Tree (INNT)**

Only a subset of all the NNTs species are, or may become after some time, INNTs (*sensu* COP 6 Decision VI/23 “Alien species that threaten ecosystems, habitats or species”). In accordance with the CBD definition, and for the purposes of these GG-NNTs, an invasive non-native tree (INNT) is herewith defined as an NNT species whose introduction and/or spread threatens or adversely impacts biodiversity and related ecosystem services, or causes ecosystem disservices (Vaz et al. 2017). INNTs are thus a subset of the (naturalised) NNTs. However, we also take into consideration that negative impacts on the economy and on public health might occur (Bacher et al. 2018).

**Introduced tree (FAO)**

The 2010 FAO Global Forest Resources Assessments used the term “introduced species” which is defined as a species, subspecies or lower taxon, occurring outside its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could occupy without direct or indirect introduction or care by humans) (FAO 2010). The FAO 2015 Global Forest Resources Assessment (FRA), defines an introduced species as a species, subspecies or lower taxon, occurring outside its natural range (past or present) and dispersal potential, i.e. outside the range it occupies naturally or could occupy without direct or indirect introduction or care by humans. In FAO FRA 2015 the term introduced is considered equivalent to non-native (FAO 2016).

**Sentinel plant, sentinel plantings**

The simplest definition of a sentinel plant is “a plant that is monitored for the presence of species that have the potential to cause damage” (Mansfield et al. 2019). The sentinel plant (or sentinel plantings) concept has been interpreted in several different ways, including the possibility of identifying NNTs with a potential risk of escaping from the planting sites and becoming invasive.

**Risk maps**

Risk maps are powerful visual communication tools to describe where invasive alien species might arrive, establish, spread, or cause harmful impacts. These maps inform strategic and tactical invasive non-native species management decisions, such as potential restrictions on international trade or the design of pest surveys and domestic quarantines. Diverse methods are available to create pest risk maps, and can potentially yield different depictions of risk for the same species (Kaplan et al. 2014).

**Planted Forest**

Forest predominantly composed of trees established through planting and/or deliberate seeding (FAO 2018). In this context forest means a land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use, predominantly means that the planted/seeded trees are expected to constitute more than 50 percent of the growing stock at maturity. It Includes coppice from trees that were originally planted or seeded (FAO 2018).

**Plantation Forest**

Planted Forest that is intensively managed and meet all the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing (FAO 2018). Specifically includes: short rotation plantation for wood, fibre and energy. It specifically excludes: forest planted for protection or ecosystem restoration. It specifically excludes: forest established through planting or seeding which at stand maturity resembles or will resemble naturally regenerating forest.

**Other Planted Forest**

Planted forest which is not classified as plantation forest (FAO 2018). Planted forests which are not intensively managed, and they may resemble natural forests at stand maturity. The purposes of other planted forests may include ecosystem restoration and the protection of soil and water value (FAO 2020).

**Urban forest**

A network or systems comprising all woodlands, groups of trees, and individual trees located in urban and peri-urban areas; it includes, therefore, forests, street trees, trees in parks and gardens, and trees in derelict corners. Urban forests are the backbone of the green infrastructure, bridging rural and urban areas and ameliorating a city’s environmental footprint (<http://www.fao.org/forestry/urbanforestry/87025/en/>). **Urban forestry** is generally defined as the art, science and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits trees provide society (Konijnendijk et al. 2006).

**Table 1S.** Non-native tree species in planted forests and for other uses: historical and recent pathways of introduction.

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| **Purpose of the plantation** and related **CBD Pathway for introduction** | **Species (examples)** | **Benefits & Risks** |
| Industrial Forestry[ESCAPE from confinement, Forestry (including afforestation or reforestation)] | (many)For example, especially *Pinus, Eucalyptus* and *Acacia* species in Brazil | Planted forests designed to provide multiple ecosystem services can reduce pressure on natural forests, and can even restore some ecological services provided by natural forests. |
| Forest trials[ESCAPE from confinement, Research and ex-situ breeding (in facilities)] | (many) | Provenance trials. The term provenance refers to the geographic source of seed or plant material or to the plants from such a source. It is generally true that tree species with a wide geographical distribution exhibit considerable provenance variation in anatomy, morphology and physiology. Provenance trials can be used to identify the most productive and best adapted seed sources for commercial or other uses. |
| Mitigating climate change (voluntary or legal commitments)[RELEASE in nature, Other intentional release] | (many) | Table 1 in the main text of the GG-NNTs, reports examples of massive tree planting campaigns. Well-planned tree-planting projects are an important component of global efforts to improve ecological and human well-being. But tree planting becomes problematic when it is promoted as a simple, single solution and overshadows other actions that have greater potential for addressing the drivers of specific environmental problems (Holl and Brancalion 2020). |
| Ornamental, landscaping & Urban Forest[ESCAPE from confinement, Ornamental purpose other than horticulture] | (many)*Cupressus lusitanica, Grevillea banksia, Grevillea robusta, Hovenia dulcis, Ligustrum* sp. pl., *Morus alba, Morus nigra, Pachira aquatica, Pittosporum undulatum, Terminalia catappa, Schefflera actinopylla* | Providing multiple ecosystem services not possible with native species. Tree plantings in private and public urban areas can reduce overheating, improve landscapes through their aesthetic value and reduce pollutants such as dust particles. However, there are risks to human health including allergenic potential from pollen. Trees in urban areas can also facilitate the introduction and establishment of non-native tree insects and pests (Branco et al. 2019). For example, *Ligustrum lucidum*, native to China, was transported to different countries worldwide since the eighteenth century as a garden and landscape ornamental tree and widely grown as hedging. Nowadays, it is considered as an INNT in several countries (Fernandez et al. 2020). |
| Botanic Gardens & Arboreta[ESCAPE from confinement, Botanical garden/zoo/aquaria (excluding domestic aquaria)] | (many) | Botanic Gardens and Arboreta can play an important role making aware citizens of which species are NNTs or INNTs. There is potential to join networks of sentinel planting sites and research global networks. However, tropical botanical gardens have played an important role in the distribution, naturalisation and spread of non-native plants worldwide (Dawson et al. 2008). Importantly, NNTs are often planted also in Zoological Gardens. |
| Translocations and Assisted Migration[RELEASE in nature, Other intentional release] | (many) | Assisted migration (AM), the translocation of species, populations, or genotypes into new regions projected to be more climatically favourable, is a high‐risk strategy for preventing climate‐induced extinction that raises logistical, ethical, and financial concerns (Simler et al. 2019). |
| Plantations on disturbed land[RELEASE in nature, Landscape/flora/fauna “improvement” in the wild] | *Acacia, Alnus, Betula, Eucalyptus, Pinus, Salix, Robinia, Leucaena leucocephala, Psidium guajava* | The use of NNTs species remains an acceptable option to restore areas degraded by mining activities if they fulfil a temporary successional role to colonize and ameliorate severely degraded sites and facilitate colonization and eventual dominance by native flora and do not spread outside the intervention site. |
| Habitat restoration, phytoremediation[RELEASE in nature, Landscape/flora/fauna “improvement” in the wild] | *Populus, Leucaena leucocephala, Psidium guajava, Eucalyptus* sp. pl. | NNTs can help restoration efforts of highly modified habitats, for example, by processing water contaminated with hazardous contaminant. In the short term this could benefit native species, as NNTs might positively transform a system making it more habitable. There is a risk that NNTs can establish and overtake native species by becoming more dominant. For example, *Robinia pseudoacacia* was introduced in the Loess Plateau (China) in the 1950s when the Chinese government launched large-scale tree planting campaigns to reforest denuded mountains in the Loess Plateau. Black locust was considered a promising tree for reforestation due to its fast growth and ability to fix atmospheric nitrogen and has become the pioneer tree in the Loess Plateau (Wang et al. 2012).  |
| Protection forest[RELEASE in nature, Landscape/flora/fauna “improvement” in the wild] | *Acacia* sp. pl.*, Robinia pseudoacacia, Ailanthus altissima* | The term protection forest is used inconsistently and sometimes misleadingly in various countries and regions. The forest of Robinia pseudoacacia in the Yellow River Delta (YRD) is the largest artificial ecological protection forest in China (Lu et al. 2020). *Ailanthus altissima* invades protection forests in southern Switzerland, where it shows a higher drought resistance than its main competitor *Castanea sativa*. Locally observed high frequencies of decay in *A. altissima* and *C. sativa* suggest that the analysed protection forests may have a limited ability to protect from rockfall (Knüsel et al. 2015). |
| Short-Rotation Forestry, Short-Rotation Coppice, Bioenergy[ESCAPE from confinement, Forestry (including afforestation or reforestation)] | Fast-growing poplars and willows. *Salix viminalis* in Europe and *S. eriocephala* in North America and Canada. *S. dasyclados*, *S. schwerinii*, *S. triandra*, *S. caprea*, *S. daphnoides* and *S. purpurea*, and many varieties are interspecific hybrids. *Acacia angustissima*, *Gliricidia sepium* and *Leucaena collinsii* in Zambia, *Eucalyptus* sp. pl. and hybrids (e.g., *Eucalyptus grandis* × *E. urophylla* and freeze-tolerant *Eucalyptus* clones), *Platanus occidentalis*, *Pinus taeda*, *Liquidambar styraciflua, Robinia pseudoacacia* | Two main drivers have pushed renewable energy production to the top of global agendas: climate change and energy security. At the regional scale, significant uncertainties exist and there is a major concern that extensive commercial production with invasive alien trees could have negative effects on biodiversity, in particular in areas of high nature-conservation value. On the contrary, integration of biomass species into agricultural landscapes could stimulate rural economy, thus counteracting to some extent negative impacts of farm abandonment or supporting restoration of degraded land, resulting in improved biodiversity values (e.g., K. Rédei and I. Veperdi 2009; Grünewald et al. 2009; Kaonga 2012).  |
| Agroforestry & afforestation of agricultural land[ESCAPE from confinement, Forestry (including afforestation or reforestation)] | *Artocarpus heterophyllus, Prosopis juliflora, Salix x rubens, Casuarina equisetifolia, Acacia* sp. pl. | Agroforestry is practiced in both tropical and temperate regions, for both wood and non-wood products, including food and fibre for improved food and nutritional security (Richardson 2011; Rosenstock et al. 2019; Tschora and Cherubini 2020) . The potential of agroforestry to contribute to sustainable development has been recognized in international policies, including the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD), justifying increased investment in its development (http://www.fao.org/forestry/agroforestry/en/). Problems arise when NNTs spread from sites of introduction and cultivation to invade areas where their presence is, for various reasons, deemed inappropriate. |
| Mediterranean planted forests and sand dune stabilisation | *Pinus* sp. pl., *Acacia* sp. pl. *Eucalyptus* sp. pl., *Robinia pseudoacacia, Casuarina equisetifolia* | NNTs in the Mediterranean basis region were once limited to land at risk from erosion, but these now cover large areas of pastoral land and even agricultural land, also as a result of the naturalisation and establishment of the introduced species. Restoration is challenging. |
| Preventing and combating desertification in arid zones[ESCAPE from confinement, Forestry (including afforestation or reforestation)][RELEASE in nature, Landscape/flora/fauna “improvement” in the wild] | (many) | Desertification affects millions of the most vulnerable people in Africa, where two thirds of the land cover consists of drylands and deserts many NNTs species have been deliberately introduced into many arid and semi-arid regions across the world aiming to combat desertification and provide resources - like fuelwood - to the rural communities. A number of these NNTs have become invasive, with negative impacts on other species as well as people. To this aim, e.g. *Acacia saligna* has been planted in North Africa for dune stabilization, wood production and livestock forage (Tiedeman and Johnson 1992). Tremendous efforts have been made since the 1960s to arrest desertification and for ecological restoration of the Thar desert in India. In this effort about 115 *Eucalyptus* species, 73 *Acacia* species and 170 other NNTs from various countries including Mexico, U.S.A., Latin America, former USSR, Africa, Israel, Arizona, Peru, Kenya, Australia, Chile, Sudan, Zimbabwe and the Middle East were introduced (Chauhan 2003). |
| Multi-purpose NNTs, cultural, religious or traditional uses, non-wood (forest) products[ESCAPE from confinement, Forestry (including afforestation or reforestation)][RELEASE in nature, Landscape/flora/fauna “improvement” in the wild] | *Acacia* sp. pl., *Eucalyptus* sp. pl., *Robinia pseudoacacia* | Many ‘multi-purpose’ trees have been transported around the world and several have subsequently become naturalised and invasive (Rejmánek and Richardson 2013). *Robinia pseudoacacia* has been widely used for various purposes such as ornamentation, timber (wood quality comparable to hardwood tropical trees), firewood, re-vegetation of dry land, soil stabilisation, fertilisation of poor soils and providing nectar for honey production (Grünewald et al. 2009; Vítková et al. 2020). |
| Breeding - Genetically improved and genetically modified alien trees[ESCAPE from confinement, Forestry (including afforestation or reforestation)] | (many) | Intensively managed, highly productive forestry incorporating the most advanced methods for tree breeding, including the application of genetic engineering, has tremendous potential for producing more wood on less land. However, the deployment of genetic engineering trees in plantation forests, both on native and NNTs is a controversial topic and concerns have been particularly expressed about potential harms to the environment (Häggman et al. 2013; Ruohonen-Lehto et al. 2016). |

**Table 2S.** Main types of negative impacts of INNTs (after Richardson et al. 2000).

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| **Type** | **EICAT**[[1]](#footnote-1) **mechanism** | **Impact description & examples** |
| **Transformers** (ecosystem engineers) | (9), (10) & (11) Chemical, physical and/or structural impact on ecosystem | Transformer INNTs are invasive NNTs that reach very high densities and substantially increase biomass or change the type and arrangement of above-ground material (*sensu* Richardson et al. 2000).Invasive alien *Acacia* and *Pinus* species have rapidly transformed species-rich fynbos shrublands in South Africa, sand-dune vegetation in Portugal, and grasslands and savannas in South America into species-poor, forests or woodlands dominated by alien species and with markedly changed biodiversity and ecosystem functions. Examples include invasion of *Melaleuca quinquenervia* in Florida’s Everglades (Dray et al. 2006). Australian *Acacia* species (in Chile, Portugal, South Africa), *Cinchona pubescens* (Galapagos Islands) (Jäger et al. 2007), *Ligustrum robustum* var. *walkeri* (La Réunion Island), *Miconia calvescens* (Tahiti, Hawaii) (Meyer 1998; Burnett et al. 2007), *Mimosa pigra* (Northern Australia & Zambia) (Braithwaite et al. 1989; Lonsdale and Miller 1993), *Morella faya* (Azores, Hawaii) (Costa et al. 2012), *Pinus pinaster* (South Africa), *Robinia pseudoacacia* (temperate and sub-Mediterranean Europe, temperate Asia and South America, northern and southern Africa, Australia and New Zealand), and *Triadica sebifera* (North America) (Pile et al. 2017a; Pile et al. 2017b). |
| **Exploiters** | (1) Competition | Excessive users of resources. Prominent examples are *Tamarix* sp. pl.[[2]](#footnote-2) in North America (Stromberg et al. 2010) and *Acacia* species, notably *A. mearnsii*, in South Africa (Dye and Jarmain 2004; Crous et al. 2012) and in Sardinia (Italy). |
| **Donors of limiting resources** | (9) Chemical impact on ecosystem | Well-studied examples are *Morella faya* which doubles canopy nitrogen as it replaces native forest species in Hawaii (Asner et al. 2010), Australian *Acacia* species in South Africa and in the Mediterranean, and *Robinia pseudoacacia* (e.g., Sitzia et al. 2012; Cierjacks et al. 2013; Campagnaro et al. 2018; Vítková et al. 2020)). Due to symbiosis between *R, pseudoacacia* and nitrogen fixing bacteria, more available mineral forms of soil nitrogen accumulate in the A-horizon under favourable moisture regime. On the other hand, high soil nitrification can decrease the pH of topsoil, and potentially lead to higher leaching of ions. *Ailanthus altissima* increases the availability of mineral nitrogen under its canopy due to the large amounts of fast-decomposing litter that it produces (González-Muñoz et al. 2013; Castro-Díez et al. 2014; Medina-Villar et al. 2015). |
| **Fire promoters /suppressors** | (10) Physical impact on ecosystem | The best-studied example of an INNT that brings fire to a previously fire-free system is that of *Melaleuca quinquenervia* invasions of wetland habitats in Florida, USA (Turner et al. 1997; F. Allen Dray et al. 2006; Porazinska et al. 2007), where a massive increase in fuel load material leads to very intense fires. Examples of where alien tree and shrub invasions have suppressed fire frequency are *Mimosa pigra* in northern Australia and *Triadica sebifera* and *Schinus terebinthifolius* in North America (Stevens and Beckage 2009, 2010); in all cases alien tree invasions result in reduced horizontal continuity of fuel which reduces fire frequency and intensity (Brooks et al. 2004). |
| **Sand stabilizers** | (11) Structural impact on ecosystem | Australian *Acacia* species have been widely planted along coastal dunes in several parts of the world to stabilize sand movement (Kull et al. 2011). For example, many coastal dune ecosystems in Portugal are invaded by the leguminous tree *Acacia longifolia*. Long-term occupation by *Aacacia longifolia* significantly altered the soil properties with increased levels of organic C, total N and exchangeable cations resulting in higher microbial biomass, basal respiration, and b-glucosaminidase activity (Marchante et al. 2003; Marchante et al. 2008; Marchante et al. 2011). The replacement of drought tolerant native species by the water spending invader, *A. longifolia*, can have serious implications for ecosystem functioning, especially during the pro-longed drought periods predicted to occur in Portugal in the future (Rascher et al. 2011).During 19th century, first large-scale plantations of *Robinia pseudoacacia* were established in several European countries (e.g. Hungary, Romania, Austria, Slovakia, Poland) to fix unstable aeolian sands and mitigate the temperature extremes in the soil (Rédei et al. 2008; K. Rédei and I. Veperdi 2009; Nicolescu et al. 2018). At present, *Robinia* is a great threat for native open sandy grasslands with many rare species. Changes in light regime, microclimate and soil conditions after *Robinia* invasion cause extinction of many endangeredlight-demanding plants and invertebrates from dry and semi-dry grasslands (Sádlo et al. 2017; Vítková et al. 2020). |
| **Colonizers of intertidal mudflats /sediment stabilizers** | (11) Structural impact on ecosystem | In their native range, mangroves are ecosystem engineers, strongly modifying their environment and providing important ecosystem services, including shoreline protection, entrapment of heavy metals, sediment stabilization, litterfall subsidy, and nursery grounds (Siple and Donahue 2013). In their introduced range, these NNTs must be weighed against impacts on native ecosystems: In Hawai'i, alien mangroves create habitats dramatically distinct from the sandflats inhabited by the few native coastal macrophytes, transforming nearshore sandy habitat into heavily vegetated areas protected from oceanic erosion with low water velocity, high sedimentation rates, and anoxic sediments. Alien mangrove forests provide habitat for alien species, including burrowing predators, which can exert top-down effects on benthic communities (Siple and Donahue 2013).Plantation of fast-growing non-native mangrove species has been used as a tool for mangrove restoration/reforestation in several countries. However, the fast-growth ability can make recently introduced species invasive as they can possibly replace co-occurring native mangroves through expressing higher growth performance and phenotypic plasticity (Fazlioglu and Chen 2020).Red mangrove (*Rhizophora mangle*) was introduced to Hawai'i in 1902 to control runoff from upstream agriculture. Other species of alien mangrove have been introduced to Hawai'i, but *R. mangle* is the most successful, occupying coastal habitats throughout the main Hawaiian Islands, including estuarine fishpond sites developed for aquaculture by native Hawaiians as early as 1000 C.E. (Siple and Donahue 2013). |
| **Litter accumulators** | (10) Physical impact on ecosystem | The North American *Pinus strobus* invades both natural *P. sylvestris* forests and planted forests of the latter species in sandstone areas of the Czech Republic. *Pinus* *strobus* produces greater quantities of more slowly decomposing litter than its native congener which has a major effect on soil acidity. Under such conditions, *P. strobus* regenerates better than *P. sylvestris* which contributes to its success as an alien invader (Pyšek and Prach 2003). In Central Europe, many sandstone areas are protected for their unique environment, and large-scale regeneration.*Quercus rubra* in Europe can alter environmental conditions beneath its canopy, especially by decreasing light availability and litter decomposition rate. Such conditions also contribute to biotic homogenization of the understorey vegetation (Myczko et al. 2017; Dyderski et al. 2020; Chmura 2020). |
| **Hybridisers** | (3) Hybridisation | NNTs and INNTs can hybridise and introgress if the NNTs have close taxonomic relatives in the native flora (Klonner et al. 2017). This can be desirable for a better adaptation to changing climatic conditions and to meet human needs in the renewable material “wood”, while undesirable from a conservation point of view (Rhymer and Simberloff 1996; Smulders et al. 2008; Felton et al. 2013), especially if the native species are rare[[3]](#footnote-3) in number compared to planted individuals of the invasive alien tree. For example, *Populus nigra* is a major species for European riparian forests but its abundance has decreased over the decades due to human influences. For restoration of floodplain woodlands, the remaining black poplar stands may act as source population. A potential problem is that *P. nigra* and *Populus deltoides* have contributed to many interspecific hybrids, which have been planted in large numbers. As these *Populus x canadensis* clones have the possibility to intercross with wild *P. nigra* trees, their offspring could establish themselves along European rivers (Broeck et al. 2005; Smulders et al. 2008). |
| **Vectors** |  | When NNTs reach novel environments, they may act as vectors of pests, pathogens and typically arrive with hidden microbiomes. In general, most of these hitchhikers remain on their co-evolved hosts, some contribute to the invasiveness of their hosts, and a small number can undergo host shifts and move onto native hosts (Burgess et al. 2016). For example, a study from Santolamazza-Carbone et al. (2019) have shown that the spread of Australian fungal taxa and the establishment of novel interactions enhanced the mycorrhization of eucalypts in NW Spain. The Australian fungus *Descolea maculata* dominated the eucalypt fungal assemblage and also spread to the native host plants, in all the habitats, posing the risk of further co-invasion (Santolamazza-Carbone et al. 2019). The dispersion of Australian fungal propagules may be facilitating the spread of eucalypts along watercourses in semiarid regions increasing the water lost in Portugal (Díez 2005). |

**Table 3S.** Major international initiatives and legislation pertaining to invasive alien species and INNTs. Many international instruments refer to invasive alien species that have undesired environmental or economic impacts. These range from legally binding treaties to non-binding technical guidelines focussing on particular species or pathways. The main international regulations concerning invasive alien species are given in the following with specific reference to INNTs and planted forests. The information here provided is intended to provide support to the recommendation 2 of the GG-NNTs: be aware of and comply with international, national and regional regulations concerning non-native trees.

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| **The Convention on Biological Diversity (1992-1993)** | CBD requires Parties “as far as possible and as appropriate (to) prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species” under the provision of Article 8(h). |
| CBD: Conference of the Parties (COP) & Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA). | The Convention made numerous decisions with respect to alien species, many of which are directly relevant to the management of (invasive) alien tree species. In particular, the COP 11 Decision XI/19[[4]](#footnote-4) states that “when designing, implementing and monitoring afforestation, reforestation and forest restoration activities for climate change mitigation, consider conservation of biodiversity and ecosystem services through, for example: (i) Converting only land of low biodiversity value or ecosystems largely composed of non-native species, and preferably degraded ecosystems; (ii) Prioritizing, whenever feasible, local and acclimated native tree species when selecting species for planting; (iii) Avoiding invasive alien species; (iv) Preventing net reduction of carbon stocks in all organic carbon pools; (v) Strategically locating afforestation activities within the landscape to enhance connectivity and increase the provision of ecosystem services within forest areas”. |
| Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests ('**Forest Principles**') | The ‘Forest Principles' were adopted in Rio in 1992 (Rosendal 1995). The Non-Legally Binding Instrument on All Types of Forests ('NLBI'), was adopted by the United Nations General Assembly in 2007, after three intense years of negotiations According to principle 6 (a), “all types of forests play an important role in meeting energy requirements through the provision of a renewable source of bio-energy, particularly in developing countries, and the demands for fuelwood for household and industrial needs should be met through sustainable forest management, afforestation and reforestation. To this end, the potential contribution of plantations of both indigenous and introduced species for the provision of both fuel and industrial wood should be recognized”. |
| **The United Nations Framework Convention on Climate Change (UNFCCC) (1992-1993) & COPs** | (Kyoto Protocol, Paris Agreement, The Boon Challenge). The Bonn Challenge is a practical means of realizing many existing international commitments, including the CBD Aichi Target 15, the UNFCCC REDD+ goal, and the Rio+20 land degradation neutrality goal. |
| **The United Nations Convention to Combat Desertification (UNCCD) (1994) & COPs** | **Land Degradation Neutrality** (LDN) represents a paradigm shift in land management policies and practices. As a voluntary and flexible process, the United Nations Convention to Combat Desertification (UNCCD) Parties recognized LDN as “a strong vehicle for driving implementation of the UNCCD”, with the adoption of various decisions (Decision 3/COP.12). The protection of natural habitat and the sustainable land management promoted by LDN can enhance the resilience of ecosystems and thus reduce their vulnerability to invasion and harm from invasive alien species. Restoration activities for LDN may directly target invasive alien species for removal (UNCCD, 2019[[5]](#footnote-5)). |
| **The Council of Europe and the Bern Convention** | The Council of Europe[[6]](#footnote-6) promotes actions (without any regulatory mandate), to avoid the intentional introduction and spread of alien species, to prevent accidental introductions and to build an information system on invasive alien species (IAS). In 1984, the Committee of Ministers of the Council of Europe adopted a recommendation to that effect. Also, the Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats), the main Council of Europe treaty in the field of biodiversity conservation, requires its Contracting Parties “to strictly control the introduction of non-native species[[7]](#footnote-7)”.In 2003, the Bern Convention adopted the European Strategy on Invasive Alien Species (Genovesi and Shine 2004), aimed at providing precise guidance to European governments on IAS issues. Many Recommendations on IAS have been adopted by the Standing Committee since 1997[[8]](#footnote-8). |
| **The International Plant Protection Convention** (FAO/IPPC) (1950) | The International Plant Protection Convention (IPPC), which has existed since the 1950s, aims to prevent the introduction and spread of plant pests. National plant protection services and the governing body of the IPPC, the Interim Commission on Phytosanitary Measures (ICPM), recognized that the aim of the CBD to prevent the introduction of alien species corresponds in large measure to the aim of the IPPC. Since 1999, the ICPM has been actively engaged in clarifying its role in regard to invasive alien species that are plant pests. In 2001, it determined that such species should be considered quarantine pests and should be subjected to measures according to IPPC provisions. The ICPM also decided that IPPC standards should be reviewed to ensure that they adequately address environmental risks of plant pests. In 2003, the ICPM adopted supplements to two of the international standards for phytosanitary measures (namely Glossary of phytosanitary terms and Pest risk analysis for quarantine pests). These supplements elaborated on environmental considerations. To avoid conflicting developments within the IPPC and the CBD regarding invasive alien species and plant pests (Lopian 2005; Brunel et al. 2009). |
| **The European and Mediterranean Plant Protection Organisation (EPPO)** | In 2002 a Panel on Invasive Alien Species which was charged with identifying invasive plant species that may present a risk to the EPPO region (https://www.eppo.int/) and proposing measures to prevent their introduction and spread and recommendations on ways to eradicate, suppress and contain invasive alien species that have already been introduced. Available PRAs and PM/9 for non-native trees are available on the EPPO web site, as in the case of *Ailanthus altissima* (EPPO 2020). |
| **The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)** | CITES, which primarily addresses trade in endangered species, can prevent or better regulate the transfer of endangered species that may be invasive alien. It has three different levels of protection for species, reported as Appendices[[9]](#footnote-9). Although there are literally thousands of plant species protected under CITES, only a portion of these species are trees, and of the included tree species, only a relatively small portion of them are actually used as lumber. *Araucaria araucana*[[10]](#footnote-10) and *Dalbergia nigra*[[11]](#footnote-11) are included in Appendix I.  |
| **Forest Principles**, i.e. “Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests” | These principles should apply to all types of forests, both natural and planted, in all geographical regions and climatic zones and, importantly, principle 6 (a) states that “all types of forests play an important role in meeting energy requirements through the provision of a renewable source of bio-energy, and that the potential contribution of plantations of both indigenous and introduced species for the provision of both fuel and industrial wood should be recognized”. |
| **Amazon Cooperation Treaty Organization – (ACTO) (1978 - 1980 as ACT).** | The 2004-2012 Strategic PlanThe “Tarapoto Proposal” for the Amazon forest identified 12 criteria and 77 indicators that explain features of the region’s ecosystems and associated social and cultural factors. The criteria and indicators provide a framework for measuring Amazon Forest sustainability (Tarasofsky 1999).  |
| **Central American Forest Convention (1993)** | Several instruments (both political and legal) were approved at a regional level to complement the Tropical Forest Action Plan for Central America (PAF-CA). Of these, the most important and far-reaching is the 1993 Regional Convention for the Management and Conservation of Natural Forest Ecosystems and the Development of Forest Plantations (‘Central American Forest Convention’). (Tarasofsky 1999). |
| The **FOREST EUROPE**[[12]](#footnote-12) process (Ministerial Conferences on the Protection of Forests in Europe, MCPFE) (1990) | The first two set of guidelines, “General guidelines for sustainable forest management” and “General guidelines for conservation of biological diversity of forests in Europe” were developed in Helsinki in 1993 (Resolution H1 and H2 respectively). In the first part of the Resolution H1 “general guidelines”, principle 9 states that “*Native species and local provenances* should be preferred where appropriate. The use of species, provenances, varieties or ecotypes outside their natural range should be discouraged where their introduction would endanger important/valuable indigenous ecosystems, flora and fauna. *Introduced species* may be used when their potential negative impacts have been assessed and evaluated over sufficient time, and where they provide more benefits than do indigenous ones in terms of wood production and other functions. Whenever introduced species are used to replace local ecosystems, sufficient action should be taken at the same time to conserve native flora and fauna”. The “Pan-European Operational Guidelines for Sustainable Forest Management” endorsed at Lisbon Ministerial Conference in 1998, were further elaborated to translating international commitments to the level of forest management practices and planning. They are directly based on Resolutions H1 and H2, and follow the structure of the six pan-European criteria that were identified as the core elements of sustainable forest management. They are divided into/addressing “Forest Management Planning” and “Forest Management Practices”, focusing on basic ecological, economic and social requirements for sustainable forest management within each criterion. The Criterion no. 4 is titled “Maintenance, conservation and appropriate enhancement of biological diversity in forest ecosystems” and at 4.2 (b) states that “for reforestation and afforestation, origins of *native species and local provenances* that are well adapted to site conditions should be preferred, where appropriate. Only those *introduced species*, provenances or varieties should be used whose impacts on the ecosystem and on the genetic integrity of native species and local provenances have been evaluated, and if negative impacts can be avoided or minimised”. |
| FSC, PEFC | FSC certification was created in 1993 to “promote environmentally appropriate, socially beneficial, and economically viable management of the world’s forests” (Auld et al. 2008) (<https://ic.fsc.org/index.htm>). FSC certification[[13]](#footnote-13) comprises 10 principles and 70 criteria that cover environmental, social and economic aspects of forest management. The standard uses the CBD definition of alien species and criterion 10.3 (Principle 10 “Implementation of Management Activities”) states that “The Organization[[14]](#footnote-14) shall only use alien species[[15]](#footnote-15) when knowledge and/or experience have shown that any invasive impacts can be controlled and effective mitigation measures are in place”. PEFC certification system was founded in 1999 as an international umbrella organization providing independent assessment, endorsement and recognition of national forest certification systems. PEFC Council sets international Sustainable Forest Management Benchmarks Organization[[16]](#footnote-16); within the framework provided by these benchmarks (11 Criteria and 48 guidelines), national stakeholders develop their own national standards. PEFC national standards recognise as guidance for avoidance of invasive species CBD Guiding Principles for the Prevention, Introduction, and Mitigation of Impacts of Alien Species that Threaten Ecosystems, Habitats or Species. National standards require that origins of native species that are well-adapted to site conditions shall be preferred for reforestation and afforestation. Only those introduced 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. |

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1. EICAT, Environmental Impact Classification of Alien Taxa, see Hawkins et al. (2015), and https://www.iucn.org/theme/species/our-work/invasive-species/eicat [↑](#footnote-ref-1)
2. Tamarisk taxa (*Tamarix ramosissima*, *T. chinensis* and their hybrids) were introduced to the United States from Asia in the late 1800s for the control of soil erosion and landscaping purposes. They are now the third most prevalent alien tree riparian taxon in the western United States (Friedman et al. 2005). [↑](#footnote-ref-2)
3. E.g. *Abies nebrodensis*, or Sicilian fir, is an endemic species of Sicily (Italy), growing on the Madonie mountain range at 1700–1900 m above sea level. It is a highly-endangered species, comprising a single relict population of approximately 30 adult trees spread over an area of 150 ha (Sánchez-Robles et al. 2014; Pasta et al. 2020). [↑](#footnote-ref-3)
4. COP 11 Decision XI/19, Hyderabad, India, 8-19 October 2012 - “Biodiversity and climate change related issues: advice on the application of relevant safeguards for biodiversity with regard to policy approaches and positive incentives on issues relating to reducing emissions from deforestation and forest degradation in developing countries; and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries”. *Cf.* also Secretariat of the Convention on Biological Diversity (2002) (<https://www.cbd.int/doc/publications/cbd-ts-07.pdf>). The section on “unsustainable forest management” reports case studies on *Leucaena leucocephala, Miconia calvescens, Spathodea campanulata* and *Cordia alliodora* impacts. [↑](#footnote-ref-4)
5. Global Mechanism of the UNCCD and CBD. 2019. Land Degradation Neutrality for Biodiversity Conservation: How healthy land safeguards nature. Technical Report. Bonn, Germany. [↑](#footnote-ref-5)
6. The Council of Europe includes 47 member states, 28 of which are members of the European Union. (http://www.coe.int/en/web/portal/home). [↑](#footnote-ref-6)
7. In Article 11, paragraph 2.b of the Convention, each Contracting Party undertakes to strictly control the introduction of non-native species. [↑](#footnote-ref-7)
8. Recommendation No. 57 (1997) on the Introduction of Organisms belonging to Non-Native Species into the Environment; Recommendation No. 91 (2002) on Invasive Alien Species that threaten biological diversity in Islands and geographically and evolutionary isolated ecosystems; Recommendation No. 77 (1999) on the eradication of non-native terrestrial vertebrates; Recommendation No. 99 (2003) on the European Strategy on Invasive Alien Species, which recommends that Contracting Parties: draw up and implement national strategies on invasive alien species taking into account the European Strategy on Invasive Alien Species. And co-operate, as appropriate, with other Contracting Parties and Observer States in prevention, mitigation and eradication or containment of alien species; Recommendation No. 134 (2008) of the Standing Committee, adopted on 27 November 2008, on the European Code of Conduct on Horticulture and Invasive Alien Plants; Recommendation No 141 (2009) of the Standing Committee, adopted on 26 November 2009, on potentially invasive alien plants being used as biofuel crops.

Recommendation No. 142 (2009) the Standing Committee, adopted on 26 November 2009, interpreting the CBD definition of invasive alien species to take into account climate change. It recommends Contracting Parties to the Convention and invites Observer States to: “interpret the term “alien species” for the purpose of the implementation of the European Strategy on Invasive Alien Species as not including native species naturally extending their range in response to climate change”; Recommendation No. 160 (2012) of the Standing Committee, adopted on 30 November 2012, on the European Code of Conduct for Botanic Gardens on Invasive Alien Species; Recommendation No. 179 (2015) of the Standing Committee - Strasbourg, 1 December - 4 December 2015, on action to promote and complement the implementation of EU Regulation 1143/2014 on invasive alien species. (http://www.coe.int/en/web/bern-convention/recommendations-on-ias). [↑](#footnote-ref-8)
9. Appendix I: This appendix represents species that are in the most danger and are considered to be threatened with extinction, and are consequently the most restricted in international trade. Appendix II: This appendix contains species that are at risk in the wild, but not necessarily threatened with extinction. Species in this appendix are closely regulated, but are typically not as restricted as Appendix I. Appendix III: This appendix contains species that a certain country (called a “party” within CITES), has voluntarily requested to be regulated in order to help preserve the species in question. Appendix III species regulation is only applicable for the specific party that has requested its inclusion, and is therefore much less restrictive than Appendix I or II. CITES is implemented in the EU through the Wildlife Trade Regulations. Currently these are Council Regulation 338/97/EC on the protection of species of wild fauna and flora by regulating trade therein (the Basic Regulation) and Commission Regulation 865/2006/EC laying down detailed rules concerning the implementation of Council Regulation 338/97/EC (the Implementing Regulation). Suspension regulations including 997/2010/EC (5 November 2010) and Regulation 359/2009/EC (30 April 2009) suspend the introduction into the Community of certain species from certain countries. [↑](#footnote-ref-9)
10. *Araucaria araucana* has been widely planted as a specimen tree in temperate areas all over the world, but there are virtually no planted forests. A small-scale plantation was established in southwest Scotland in 1916 (Williams and Winn 1977)). Endangered for IUCN, *Araucaria araucana* is listed on Appendix I of CITES which strictly regulates the trade in its timber and seeds (CITES 2020: http://www.iucnredlist.org/details/31355/0). [↑](#footnote-ref-10)
11. *Dalbergia nigra* (Vell.) Allemao ex Benth, known as the Brazilian rosewood or Jacaranda-da-Bahia, is a tree species endemic to the central Atlantic Forest in Brazil. This species produces a high-quality wood that is highly valued for the manufacture of musical instruments and fine furniture, thus resulting in its overcutting since the colonization of Brazil. *D. nigra* is a threatened tree that is in the “Endangered” category due to its over-exploration, the absence of replacement plantations and the deforestation of the Atlantic Forest - (IUCN). *D. nigra* is extremely rare in nature, and its international trade has been prohibited since the 1990s by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES 2008, Appendix I, II and III to the Convention on International Trade in Endangered Species of Wild Fauna and Flora. US Fish and Wildlife Service: Washington; Ribeiro et al. 2011; Taylor et al. 2012). Further information can be found in the Resolution Conf. 13.10 (Thirteenth meeting of the Conference of the Parties - http://www.cites.org/eng/res/13/13-10.php). [↑](#footnote-ref-11)
12. FOREST EUROPE has also developed, in cooperation with the Environment for Europe/Pan European Biological and Landscape Diversity Strategy, the “Pan-European Guidelines for Afforestation and Reforestation” with a special focus on the provisions of the UNFCCC. The Guidelines, agreed in 2008, recognize the role of sustainable forest management in climate change mitigations. They form a set of recommendations for voluntary use by national authorities and other bodies and stakeholders relevant to implement economically viable, environmentally sound and socially equitable afforestation and reforestation programmes and projects. In the section titled “Ecological Guidelines”, guideline 19 affirms that “native tree species, provenance and varieties or ecotypes that are well adapted to site conditions should be used for afforestation and reforestation where appropriate”; guideline 20 that “the need to consider adaptation to climate change should be taken into account when choosing species, provenances and varieties for afforestation and reforestation” and guideline 21 that “species, provenances, varieties or ecotypes outside their natural range should only be used where their introduction would not endanger important and/or valuable indigenous ecosystems, flora and fauna. Those that are likely to be invasive should be avoided using the CBD Guiding Principle for the Prevention, Introduction, and Mitigation of Impacts of Alien Species That Threaten Ecosystems, Habitats or Species”. In addition, guideline 22 states that “a precautionary approach should be taken to the use of genetically modified trees. Ecological socio-economic and cultural impacts, including long term effects should be analysed and a thorough, comprehensive and transparent risk assessment should be completed in accordance with the Cartagena Protocol on Biosafety. In this context, the potential impacts of genetically modified trees on native gene polls should be fully considered”. [↑](#footnote-ref-12)
13. FSC 2012. FSC Principles and Criteria for Forest Stewardship. Document reference code : FSC-STD-01-001 V5-0 EN. Approval date: 10 February 2012. Forest Stewardship Council. <https://ic.fsc.org/download.fsc-std-01-001-v5-0-revised-principles-and-criteria-for-forest-stewardship.a-1780.pdf> [Accessed May 2020]. [↑](#footnote-ref-13)
14. The person or entity holding or applying for certification and therefore responsible for demonstrating compliance with the requirements upon which FSC certification is based (Source: FSC 2020). [↑](#footnote-ref-14)
15. A species, subspecies or lower taxon, introduced outside its natural past or present distribution; includes any part, gametes, seeds, eggs, or propagules of such species that might survive and subsequently reproduce (Source: Convention on Biological Diversity (CBD), Invasive Alien Species Programme. Glossary of Terms as provided on CBD website) Source: FSC 2020. [↑](#footnote-ref-15)
16. PEFC ST 1003:2018 - PEFC Sustainable Forest Management benchmarks – Requirements. https://cdn.pefc.org/pefc.org/media/2019-01/b296ddcb-5f6b-42d8-bc98-5db98f62203e/6c7c212a-c37c-59ee-a2ca-b8c91c8beb93.pdf. [↑](#footnote-ref-16)