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REVIEW

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Scientists' warning to humanity on tree extinctions

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[Correction added on 12 September 2022, after first online publication: Global Tree Assessment Contributors has been added to the Author Contributions section.]

Societal Impact Statement

Trees play vital roles in many of the world's ecosystems while providing many benefits to people. New evidence indicates that a third of tree species are threatened with extinction, representing a tree extinction crisis. Here we demonstrate how tree species extinction will lead to the loss of many other plants and animals and significantly alter the world's ecosystems. We also show how tree extinction will negatively affect billions of people through loss of livelihoods and benefits. We highlight a series of urgent actions needed to avert an ecological, cultural and socio-economic catastrophe caused by widespread extinction of tree species.

Summary

Trees are of exceptional ecological importance, playing a major functional role in the world's ecosystems, while also supporting many other plants, animals and fungi. Many tree species are also of direct value to people, providing a wide range of socio-economic benefits. Loss of tree diversity could lead to abrupt declines in biodiversity, ecosystem functions and services and ultimately ecosystem collapse. Here we provide an overview of the current knowledge regarding the number of tree species that are threatened with extinction, and the threats that affect them, based on results of the Global Tree Assessment. This evidence suggests that a third of the world's tree species are currently threatened with extinction, which represents a major ecological crisis. We then examine the potential implications of tree extinctions, in terms of the functioning of the biosphere and impacts on human well-being. Large-scale extinction of tree species will lead to major biodiversity losses in other species groups and substantially alter the cycling of carbon, water and nutrients in the world's ecosystems. Tree extinction will also undermine the livelihoods of the billions of people who currently depend on trees and the benefits they provide. This warning to humanity aims to raise awareness of the tree extinction crisis, which is a major environmental issue that requires urgent global attention. We also identify some priority actions that need to be taken to reduce the extinction risk of tree species and to avert the ecological and socio-economic catastrophe that will result from large-scale extinction of tree species.

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conservation action, ecological implications, economic implication, extinction, Global Tree Assessment, tree conservation

1 | INTRODUCTION

The concept of a 'World Scientists Warning to Humanity' dates back to 1992, when more than 1700 scientists, including most living Nobel laureates, called on humankind to halt environmental destruction and make fundamental changes to the relationship between humans and the natural world, in order to avoid 'vast human misery' (Kendall, 1992). This call was renewed 25 years later, when more than 15,000 scientists signed a second warning, which highlighted the fact that most environmental trends had significantly worsened since 1992. This highlighted intensifying climate change, deforestation and agricultural production as particularly concerning issues (Ripple et al., 2017). This statement suggested a range of steps that humanity could take to transition to sustainability, including halting the conversion of forests, increasing the protection of habitats through establishment of protected areas, restoring plant communities (and especially forest landscapes) at large scales and developing adequate policy instruments to remedy the exploitation and trade of threatened species, among others (Ripple et al., 2017).

This 'second warning to humanity' has subsequently spawned a series of further articles on a similar overall theme but focusing on specific environmental issues. Examples include scientist warnings to humanity on microorganisms and climate change (Cavicchioli et al., 2019), insect extinctions (P. Cardoso et al., 2020), the freshwater biodiversity crisis (Albert et al., 2021), the degradation of large lakes (Jenny et al., 2020), the illegal or unsustainable wildlife trade (P. Cardoso et al., 2021), endangered food webs (Heleno et al., 2020), invasive alien species (Pyšek et al., 2020) and the climate emergency (Ripple et al., 2020). The breadth of these different themes highlights the multidimensional nature of the global biodiversity crisis, but the list is hardly exhaustive. Major declines are occurring in many different species groups, including birds, mammals and amphibians, while abrupt large-scale changes are being observed in the entire biological systems, including coral reefs, arctic tundra, temperate grasslands and coastal ecosystems (IPBES, 2019a; Newton, 2021a; Turner et al., 2020). These changes are being driven by a range of anthropogenic factors, including land/sea use change, direct exploitation, climate change, pollution and introduction of invasive alien species (IPBES, 2019a).

Each of these different warnings to humanity provides further evidence of the depth and magnitude of the ecological changes that are currently taking place. One of the common threads running through this literature is the identification of widespread lack of awareness regarding the extent of these changes, both among politicians and other decision-makers, as well as the wider public. While many of these publications suggest potential policy and management responses to biodiversity loss, for example, by addressing novel disturbance regimes (Leverkus et al., 2021), progress towards implementing these proposals has been limited to date.

Here we build on this literature by presenting a 'warning to humanity' focusing on extinction of tree species. We are a group of conservation scientists who are deeply concerned about the decline of tree species worldwide and the potential impacts that this might have on humanity. As the defining component of forest ecosystems, trees play a major role in the dynamics of the global biosphere, providing habitat for at least half of the world's known terrestrial plant and animal species (FAO & UNEP, 2020). Forests also provide a range of ecosystem services, including storage of about 50% of the world's terrestrial carbon stocks and provision of around three quarters of the world's accessible freshwater (Shvidenko et al., 2005). Despite these high values, global forest area has declined by around 40% in the past 300 years, and 25 countries have lost their forest cover entirely (Shvidenko et al., 2005). At the same time, many remaining forest areas have been highly degraded by unsustainable land use practices such as illegal extraction of timber.

In this paper, we provide a brief overview of current knowledge regarding the number of tree species that are threatened with extinction and the threats that affect them. We then examine what the potential implications are of tree extinctions, both in terms of the functioning of the biosphere and in terms of human well-being. We also suggest some urgent actions that need to be taken to reduce the extinction risk of tree species and to mitigate these potential impacts. Our assessment is based on recent progress in assessing the extinction risks to tree species—the Global Tree Assessment (GTA), which for the first time enables us to provide a comprehensive overview of the current status of this important component of global biodiversity (BGCI, 2021). Our aim in providing this warning to humanity is to raise awareness of tree conservation as a major environmental issue that requires urgent attention. Our suggestions should be viewed as complementary to the other warnings that have recently been given; all dimensions of the global biodiversity crisis need to be addressed if a transition to sustainability is to be achieved (Ripple et al., 2017).

2 | HOW MANY TREE SPECIES ARE THERE?

In 2015, we identified the need for a GTA to be conducted, to provide a comprehensive overview of the conservation status of tree species throughout the world (Newton et al., 2015). At that point, there was great uncertainty about the number of tree species that might exist, as no systematic attempt had been made to collate a comprehensive list; initial suggestions were that there might be as many as 100,000 species (Oldfield et al., 1998). A first step of the GTA was therefore to compile a database of published, accepted names of tree species with their native country distribution. Compilation of taxonomic monographs and databases, regional floras and herbarium specimens

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enabled a global database of tree species to be constructed, named GlobalTreeSearch (Beech, Rivers, et al., 2017). As a result, we now know that there are approximately 58,000 described and validly published tree species worldwide (BGCI, 2022a).

Although identification of this number represents a significant step forward, clearly this represents an underestimate, as an unknown number of species still await discovery and description. Estimation of the total number of tree species that might exist has attracted interest from a number of researchers, especially in species-rich areas such as the Amazon (i.e. Cazzolla Gatti et al., 2022; Hubbell et al., 2008; Qian et al., 2018; Slik et al., 2015; Ter Steege et al., 2020). Such estimates are typically produced using statistical extrapolation procedures applied to forest inventory and distribution data, an approach that is subject to a number of potential biases and uncertainties. This is illustrated by the debate concerning the number of tree species in the Amazon. Hubbell et al. (2008) estimated that there might be around 11,000 species in Amazonia. Conversely in 2013, Ter Steege et al. (2013) suggested that around 16,000 tree species should occur in Amazonia based on data from 1170 forest plots across the region. This figure was contested by D. Cardoso et al. (2017), who provided a much lower value of 6727 tree species based on taxonomically verified checklists. Since then, there has been progress in describing new species and increasing the number of forest inventory plots and in the development of statistical approaches for analysing inventory data. These were employed by Ter Steege et al. (2020) to produce a revised estimate of over 15,000 tree species for the Amazon.

The uncertainties and challenges associated with producing accurate estimates of tree species richness for the Amazon also apply at the global scale and indeed to groups of species other than trees (Scheffers et al., 2012). Recently, Cazzolla Gatti et al. (2022) have estimated the total number of tree species worldwide, again using statistical extrapolation from forest inventory plots, using a database of more than 100,000 such plots distributed worldwide. Results suggested that there may be ~73,000 tree species globally, which suggests that thousands of species remain to be discovered and described. These authors suggest that around 40% of undiscovered tree species are located in South America, especially in the Amazon basin and the eastern Andes. Many of these are likely to be rare, with low population density and limited spatial distribution (Cazzolla Gatti et al., 2022) and are therefore likely to be threatened. Although these analyses are subject to the same uncertainties identified by D. Cardoso et al. (2017) for the Amazon and may represent an overestimate of the number of tree species still to be discovered, they nonetheless highlight the urgent need for further field campaigns and taxonomic research to produce a comprehensive list of the world's tree species.

3 | HOW MANY TREE SPECIES ARE THREATENED?

The first major assessment of the conservation status of tree species was undertaken in the 1990s, culminating in the World List of Threatened Trees (Oldfield et al., 1998). This applied the IUCN Red List categories and criteria (version 2.3) (IUCN, 1994) to over 10,000 tree species, of which 8753 were found to be globally threatened. Subsequently, a series of themed assessments were conducted in different groups of tree species, focusing on different geographic areas, forest types or taxonomic groups (e.g. Baldwin et al., 2018; Barstow et al., 2018; Bartholomew et al., 2021; Beech, Barstow, et al., 2017; Carrero et al., 2020; Crowley et al., 2020; Gibbs et al., 2011; Kozlowski et al., 2018; Marinho & Beech, 2019; Rivers et al., 2016; Shaw et al., 2014). Results from 10 of these assessments were summarised by Newton and Oldfield (2008), who observed that the proportion of taxa that were categorised as threatened varied markedly between groups assessed, with values ranging from 8% to 90%, with an overall mean of 42%. However, these authors noted the poor state of knowledge of most tree species in relation to conservation status. This led to development of the GTA (Newton et al., 2015), which aims to provide a comprehensive conservation assessment of all of the world's tree species.

The GTA has developed an extensive global network of organisations and individuals, which has involved over 500 tree experts across at least 68 countries. The network is coordinated by Botanic Gardens Conservation International (BGCI), working in partnership with the IUCN Species Survival Commission Global Tree Specialist Group (SSC GTSG). Recognising that nearly 58% of all tree species are single country endemics (Beech, Rivers, et al., 2017), we identified key countries (and regions) with high levels of unassessed species (i.e. Brazil, Madagascar, etc.), where we have created partnerships and built capacity with national partners. Partnerships have also been developed for specific plant families that are rich in trees (i.e. Annonaceae, Dipterocarpaceae, Sapindaceae). The assessment is being conducted using the IUCN Red List Categories and Criteria (v 3.1) (IUCN, 2001). The GTA is an ongoing and continuous process, incorporating newly described tree species and conservation assessments as they become available.

Based on results of the GTA obtained to date, including all published and submitted conservation assessments of trees, 17,510 (29.9%) tree species are considered threatened with extinction (BGCI, 2021). In addition, there are 142 tree species recorded as Extinct or Extinct in the Wild. Conversely, 41.5% of species are not considered to be at high risk of extinction (Least Concern). A further 13.2% of tree species are recorded as Data Deficient; many of these are only known from small, relatively unexplored areas. If all Data Deficient species are threatened, the percentage of tree species threatened with extinction could be as high as 51.3%.

However, the picture is not uniform across the globe; there are clear differences between countries and regions in terms of the numbers of threatened tree species. For example, most threatened trees occur in the tropics, with 7047 species recorded in the Neotropics and 3819 and 3644 threatened trees recorded in Indo-Malaya and the Afrotropics, respectively (BGCI, 2021). In addition, there are clear differences between forest types; for example, boreal and temperate forests have a lower percentage of threatened trees than subtropical and tropical forests (Table 1). This in part reflects the fact that tropical

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TABLE 1 The percentage threatened tree species (Vulnerable, Endangered and Critically Endangered) on the International Union for the Conservation of Nature (IUCN) Red List in each forest type (IUCN, 2022)

Forest type	Percentage threatened tree species
Boreal/subarctic/subantarctic	9.1
Temperate	23
Subtropical/tropical dry	39
Subtropical/tropical moist lowland	30
Subtropical/tropical mangrove vegetation above high tide level	19
Subtropical/tropical swamp	31
Subtropical/tropical moist montane	41

Note: Forest types are those defined according to the IUCN habitat classification scheme.

regions have more tree species that occur at low abundance and/or with restricted geographical distributions. Within the tropics and subtropics, montane and dry forest habitats have a higher percentage of tree species that are threatened than moist lowland forests (Table 1).

4 | WHY ARE TREES THREATENED?

The main threat to tree species across the word is habitat loss owing to the spread of agriculture, which affects 29% of species, followed by logging and other forms of wood harvesting (27%), livestock farming (14%) and urban development (13%) (BGCI, 2021). Other threats affecting large numbers of tree species include changes in fire regimes, energy production and mining and presence of invasive species. Although climate change currently affects only 4% of tree species that have been assessed, this threat is likely to intensify in future, with trees of coastal, dryland and montane ecosystems being the most vulnerable (Garavito, Newton, Golicher, & Oldfield, 2015; Garavito, Newton, & Oldfield, 2015). Climate change can also interact with other threats, such as fire and the spread of pests and diseases, to intensify their impact (BCGI, 2021; Newton, 2021b).

The relative importance of different threats to tree species varies between geographic regions (Table 2). For example, in northern temperate zones (Europe, North America and North Asia), the main threats to tree species are invasive species, pests and diseases, whereas in tropical regions, the main threats are loss of habitat to agriculture (including livestock husbandry) and biological resource use (i.e. logging). Urban and industrial development is a major threat in six different geographic regions, whereas natural system modification, which includes changes to fire regime as well as reforestation, is an important threat in Oceania, Europe and Sub-Saharan Africa (Table 2). It is also important to note that threats often interact with each other, rather than acting independently. For example, fires may be used to expand the area of agricultural land, which may lead to increased colonisation of nonnative species and development of infrastructure such as roads can open forest areas to other human activities such as logging and livestock husbandry, as well as hunting of wildlife (Quintana et al., 2022).

5 | WHAT ARE THE IMPLICATIONS OF TREE EXTINCTIONS?

The extinction of tree species has profound implications for ecological and economic systems, and both human livelihoods and cultures. We consider each of these aspects below.

5.1 | Ecological implications

Tree species provide multiple direct and indirect benefits to people, including food, fodder, timber, firewood, fibre, pulp, medicines and clean water (see Figure 1). Provision of these benefits depends on a range of ecological processes and functions, which are typically considered at the scale of ecosystems (Fisher et al., 2008). As the dominant component of forest ecosystems, trees make a significant contribution to regulatory processes at the scale of the entire Earth system, such as climate regulation (via carbon uptake), soil formation and stabilisation, as well as cycling of nutrients and water (Pan et al., 2013; Shvidenko et al., 2005). Forest degradation, and associated loss of tree species, will undermine such processes and will likely reduce the ability of forests to tolerate climate change and other disturbance factors, such as fire, pests, pathogens and invasive species (Brockerhoff et al., 2017).

The world's forests provide fundamental protection of soil and water resources. More than a quarter of global forest area is managed specifically for provision of these resources (Miura et al., 2015). Key services relating to soil that are provided by trees and forests include protection against erosion from rain, wind and coastal waves; reduction of downstream sedimentation; increased soil strength; preservation of soil structure; maintenance of biological activity in the soil on which soil fertility depends; and reduced risks of shallow landslides (Miura et al., 2015). Trees and forest ecosystems also play a crucial role in the provision of fresh water, owing to their major contribution to the hydrological cycle (FAO, 2013). Forests influence the amount of water available by regulating surface and groundwater flows, maintain high water quality through filtration and reduce water-related risks such as floods and droughts. They also help to prevent desertification and salinisation (FAO, 2013; Miura et al., 2015).

Trees and forest ecosystems have a major influence on the global carbon cycle, accounting for about 75% of terrestrial gross primary production and 80% of Earth's total terrestrial plant biomass; they collectively contain more carbon than is stored in the atmosphere (Pan et al., 2013). Natural forests store more carbon than plantations, and they continue to store carbon over timescales of centuries. Protection of natural forests therefore needs to be a central component of approaches to mitigation of climate change (Waring et al., 2020). Furthermore, ecological features of natural forests that increase their

TABLE 2 The percentage of tree species affected by different threats, for each geographic region

	Development	Agriculture	Energy production and mining	Transportation	Biological resource use	Human intrusions and disturbance	Natural system modifications	Invasive species and diseases	Pollution	Geological events	Climate change and severe weather	Other options
Caribbean Islands (1555)	10.9	27.1	3.4	2.6	26.2	2.8	8.7	14.1	0.5	0.8	17.1	0.3
East Asia (2546)	9.7	18.1	0.5	1.6	19.4	0.7	2.8	2.6	0.6	0.5	2.2	0.6
Europe (459)	16.8	29.6	2.0	4.1	25.5	3.9	32.7	33.6	3.7	3.5	12.0	3.7
Mesoamerica (4763)	13.6	35.0	3.7	1.7	24.2	1.8	9.4	1.8	0.3	0.4	8.1	0.5
North Africa (164)	22.0	32.9	1.2	3.7	25.0	3.7	18.3	20.1	4.3	1.2	18.9	1.8
North America (1083)	8.1	16.5	1.3	0.8	9.7	2.7	14.8	33.9	1.3	5.4	18.1	0.8
North Asia (226)	12.4	19.9	1.8	1.8	23.9	2.2	11.9	19.9	2.7	0.4	8.8	3.1
Oceania (5391)	9.2	24.7	8.5	1.7	15.7	0.8	12.7	9.0	0.2	0.1	4.1	0.4
South America (10491)	14.8	30.9	11.6	4z`.7	18.4	1.5	7.8	1.4	1.5	0.1	3.3	0.2
South and SE Asia (6978)	21.6	42.1	3.9	3.3	33.2	1.9	6.1	1.1	0.2	1.1	3.6	0.7
Sub-Saharan Africa (7073)	13.6	59.5	20.7	1.8	59.9	1.6	30.1	4.0	0.4	0.0	2.2	0.6
West and Central Asia (639)	10.0	23.9	0.8	1.3	28.0	1.9	8.3	10.3	1.3	0.3	8.8	1.3

Note: The top three threats in each region are colour-coded red, orange and yellow respectively. Total number of trees per geographic region is given in brackets (IUCN, 2022).

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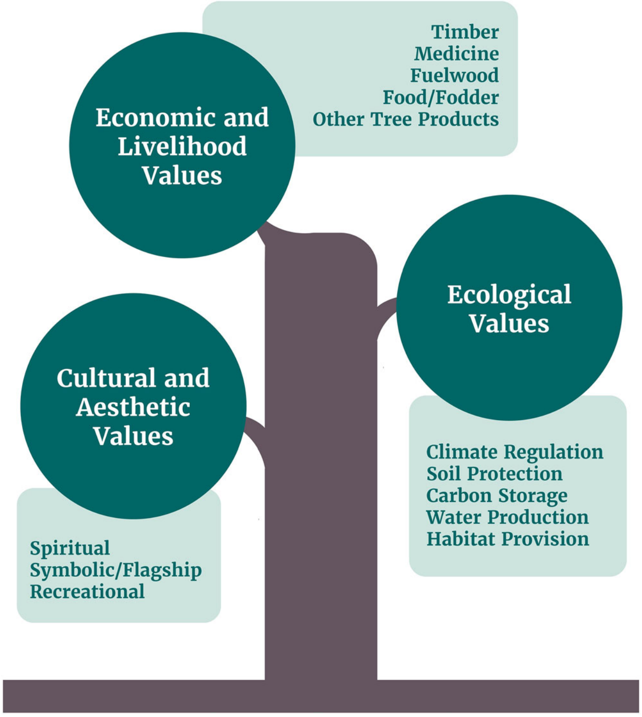

FIGURE 1 Tree species provide multiple direct and indirect values to people, including economic and livelyhood values, ecological values and cultural and aesthetic values

value for carbon storage, such as heterogeneity in tree size, and large carbon pools in dead wood, litter and soils are difficult to achieve in commercially managed plantations (Brockerhoff et al., 2017; Waring et al., 2020). This supports the importance of conserving natural populations of tree species, rather than focusing on extensive tree planting, in policies focusing on climate change mitigation (di Sacco et al., 2021). Demographic characteristics of tree populations have also been shown to have a major impact on patterns of carbon storage (Pugh et al., 2019). Old-growth forests are of particular importance in this context, playing a crucial role both in the storage and sequestration of atmospheric carbon. In a review of the available evidence, Luyssaert et al. (2008) found that the net carbon balance of forests between 15 and 800 years of age is usually positive, indicating that old-growth forests can continue to accumulate carbon even when most trees have reached maturity. Half of the remaining old growth forests are located in the boreal and temperate regions of the Northern Hemisphere. Luyssaert et al. (2008) estimated that these forests alone sequester at least 1.3 ± 0.5 GtC year^{-1}, which represents about 10% of global carbon storage. Old-growth forests can therefore accumulate carbon for centuries and store large quantities of it, but if these forests are disturbed, this carbon will be returned to the atmosphere and contribute to global heating.

Although the contribution that forest ecosystems make to the functioning of the global biosphere is well established, the potential impact of tree extinctions depends critically on the relationship between ecosystem processes and tree species richness or diversity. Understanding this relationship continues to be an active focus of research, reflecting the continuing uncertainty regarding the potential impacts of biodiversity loss on ecosystem function (Newton, 2021a). Whereas some researchers believe that there are causative relationships between diversity and ecosystem functioning, others have questioned this. Rather, the principal drivers of ecosystem properties may not be species diversity per se but the functional attributes or traits of the species present (Edwards et al., 2007; Wardle et al., 2000). In other words, species identity matters; the consequences of tree species loss for the functioning of ecosystems will depend on which species actually become extinct and what their functional roles are. Despite the uncertainties expressed in the scientific literature, there is general consensus that (i) the functional characteristics of species strongly influence ecosystem properties, (ii) the effects of species loss can differ among ecosystem properties and ecosystem types and (iii) some ecosystem properties are relatively insensitive to species loss because ecosystems may have multiple species that carry out similar functional roles (Cardinale et al., 2012; Hooper et al., 2005). This implies that some of those tree species that are rare or occur at low densities may contribute relatively little to ecosystem properties. However, evidence is accumulating that rare tree species can often make important contributions to ecosystem function (Dee et al., 2019). In addition, rare species may also be important in the future by providing resilience to new climates owing to their possession of rare traits (Baker et al., 2017).

Recent research has provided evidence suggesting that ecosystem function is related to species richness. In an assessment of field data obtained from 777,126 sample plots distributed throughout the world, Liang et al. (2016) reported that there is a positive and concave relationship between tree species richness and forest productivity. In other words, continued loss of tree species richness would result in an accelerating decline in forest productivity worldwide. Similar results have been obtained with global analysis of grasslands and accord with some theoretical predictions (Grace et al., 2016). On the basis of these analyses, loss of tree species could lead not only to a decline in forest productivity but also to a reduction in forest carbon absorption rate, which would in turn compromise the global forest carbon sink, thereby significantly increasing the risks associated with anthropogenic climate change (Liang et al., 2016). Working in Japan, Mori (2018) also found a positive relationship between tree species diversity and forest productivity. Here this relationship was attributed primarily to the dominance of high performance species at high diversity, regardless of the forest type. In less productive forest ecosystems, other processes (such as complementarity between species) increased productivity. This illustrates how the different functional roles of tree species, as well as their taxonomic identity, can influence ecosystem processes. Other regional studies have similarly found positive relationships between tree species richness and forest productivity or carbon storage, for example, in Spain and in the eastern United States (Bravo-Oviedo et al., 2021) and in southeast China (Liu et al., 2018). A positive relationship was also found in the global scale study described by Chisholm et al. (2013), although here the relationships were found to vary with scale, being more strongly positive at local scales. Diversity–carbon relationships in tropical

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forests have also found to be scale-dependent; Sullivan et al. (2017) found a weak positive relationship within 1 ha plots but either a weak or absent relationship at larger scales.

Researchers have also investigated the relationship between tree species richness and provision of ecosystem services or the benefits provided by ecosystems to people. Gamfeldt et al. (2013) provided an analysis of forest inventory plots throughout Sweden, which showed positive relationships between tree species richness and provision of multiple ecosystem services, including production of tree biomass, soil carbon storage, berry production and game production potential. Biomass production, for example, was found to be approximately 50% greater with five than with one tree species. Furthermore, no single tree species was able to provide all services. This highlights the need for forest management to consider multiple tree species to sustain the full range of benefits that are provided by forests to human society (Gamfeldt et al., 2013). In Borneo, Labrière et al. (2015) surveyed a range of different land use types in a mosaic of vegetation, including areas with swidden agriculture, rubber tapping and logging and found that tree species diversity and ecosystem service production were highest in natural forests. In southwestern Ethiopia, Shumi et al. (2021) found that the diversity of ecosystem services was positively related to the diversity of tree species present, a finding that was replicated by Himes et al. (2020) in the Pacific Northwest, USA. Similarly, Balvanera et al. (2014) summarised evidence indicating a positive relationship between the ecosystem service of timber production and tree species richness. Research undertaken by Albrich et al. (2018) in the Austrian Alps demonstrated a further aspect of this relationship: Tree species diversity had a positive effect on the stability of ecosystem service provision over time.

Together, this evidence indicates that loss of tree species will reduce the provision of multiple ecosystem services to people, which could result in negative impacts on human well-being and livelihoods. This may be true even if the tree species concerned are relatively rare, as many rare species often make a much greater contribution to provision of ecosystem services than their low abundance would suggest. Rare species can have unique function roles in ecosystems, and in some cases the provision of a service may be entirely dependent on presence of a rare species (Dee et al., 2019). For example, in a mixed Afromontane landscape in Ethiopia, Tekalign et al. (2017) found that rare tree species have distinct traits that provide specific services, which could not be compensated by the remaining common species. Similarly, charismatic threatened tree species such as the Giant Redwoods (*Sequoiadendron giganteum*) of California have high value for provision of aesthetic and recreational services; such trees can also have iconic or spiritual value to people. Rare trees can also be ecological keystone species with disproportionate roles in structuring communities, thereby indirectly contributing to services (Dee et al., 2019), as is the case with many palm species (Blach-Overgaard et al., 2015).

Loss of tree species could also impact negatively on populations of other organisms. Forests contain around 80% of amphibian species, 75% of bird species and 68% of the world's mammal species, including iconic mammals such as the jaguar of Latin America, the bears of North America, the gorillas of Central Africa, the lemurs of Madagascar, the panda bears of China and the koalas of Australia (FAO and UNEP, 2020). The vast majority of the world's invertebrate species, perhaps as many as 10 million species, are also found in forests. The same is likely true for other mega-diverse groups, such as soil bacteria, fungi, nematodes, protists and mites, which together with forest-dependent pollinators and saproxylic beetles play crucial roles in the functioning of forest ecosystems (FAO & UNEP, 2020). Positive relationships have been observed between tree species richness and the diversity of many other species groups, including soil microbes (Wu et al., 2019), ectomycorrhizal fungi (Tedersoo et al., 2014), arthropods (Basset et al., 2012), birds and butterflies (Schulze et al., 2004) and epiphytic bryophyte and lichen species (Király et al., 2013). Loss of tree species would impact negatively on these organisms, while also reducing forest heterogeneity and structural complexity, which support the diversity of other groups such as vascular epiphytes (Wagner & Zotz, 2020). Evidence suggests that the abundance of forest-dependent species is declining globally, with a 53% decline in an index of forest-specialist species observed between 1970 and 2014 (Green et al., 2019).

Each individual tree is a member of multiple ecological networks, composed of the species with which the tree interacts through ecological processes including competition, mutualism and predation. If a tree species is lost from a particular ecological community, those species linked with the tree through these ecological networks could also be extirpated. In this way, the loss of species becomes amplified and self-reinforcing as more and more linked species are also extirpated, leading to an extinction cascade (Bascompte & Stouffer, 2009). Such cascades are often characterised by thresholds, leading to the rapid collapse of whole networks (Lever et al., 2014). In this way, as multiple ecological networks unravel at an ever increasing rate, extinction cascades can result in the collapse of an entire ecosystem (Newton, 2021a). Risks of extinction cascades are highest when autotrophs such as trees are removed from an ecological community and when the species richness of such a functional group is reduced (Borrvall et al., 2000). As a tree species declines in abundance, many ecological interactions with other species may be lost before the tree species itself disappears, indicating that ecosystem function and services may decline at a faster rate than species extinctions (Vanbergen et al., 2017). This process can lead to the 'empty forest' syndrome, where a forest ecosystem is devoid of species such as large mammals that were formerly linked to trees through ecological networks (Redford, 1992). Extinction cascades from trees to animals can also amplify the negative impacts of climate change on biodiversity (Schleuning et al., 2016).

All trees can be considered as ecosystem engineers, providing a food resource, shelter, refuge and microclimate for many other species and their associated interactions. This is illustrated by the many insect species that depend on trees for a range of resources, including a substrate for nests and webs, fibre as an important material for nest building, shading providing protection from direct sunlight and high temperatures and camouflage against predators (Kehoe et al., 2021). Loss of these resources through deforestation

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and logging will lead both to the loss of insect species and their interactions with trees (Kehoe et al., 2021); pollinators and other mutualists are at particularly high risk of such co-extinction (Dunn et al., 2009). Consequently, the loss of trees and the resulting extinction cascades are significant factors in the declines of insect abundance and diversity, which have recently been observed in many ecosystems (Kehoe et al., 2021). Loss of tree species can also lead to the decline of epiphytic communities such as lichens (Jönsson & Thor, 2012).

Some tree species can also be considered as 'foundation species' in forested ecosystems, where a single species can define much of the structure of and function of a community. Many temperate and boreal forests, for example, are dominated by a small number of tree species. Ellison et al. (2005) show that the loss of such species, which can occur even though they are relatively abundant and widespread, leads to profound ecological impacts. Examples of such impacts include changes in the local environment on which other species depend; disruption of fundamental ecosystem processes, including decomposition rates, nutrient fluxes, carbon sequestration and energy flow; and profound changes in the dynamics of associated aquatic ecosystems. Examples of the loss of foundation species from North American forests described by Ellison et al. (2005) include the decline of eastern hemlock (*Tsuga canadensis*) as the result of an introduced insect and salvage logging; the loss of whitebark pine (*Pinus albicaulis*) resulting from a nonnative pathogen, a native insect and alteration of fire regimes; and the widespread removal of American chestnut (*Castanea dentata*) by an introduced pathogen. The impact of these diseases provides a 'natural experiment' to help us understand what happens when a specific species is removed from an ecosystem, including cases where the species removed were previously dominant tree species.

Collapse of forest ecosystems can be caused by a variety of different mechanisms in addition to extinction cascades. Often, collapse is associated with interactions between multiple anthropogenic pressures. For example, Lindenmayer and Sato (2018) describe the collapse of Mountain Ash (*Eucalyptus regnans*) forests in southeastern Australia, which was characterised by the rapid decline of keystone ecosystem structures and associated biodiversity and ecological processes; this was attributed to interactions between fire, logging and climate change. Interactive impacts of multiple stressors on forests have recently caused large-scale dieback of forest stands in many parts of the world. Allen et al. (2010) identify 88 examples of such forest mortality since 1970, including the severe loss of Atlas cedar (*Cedrus atlantica*) from Morocco to Algeria, mortality of *Pinus tabuliformis* across 0.5 million ha in east-central China, death of >1 million ha of multiple spruce species in Alaska, >10 million ha of *Pinus contorta* in British Columbia and >1 million ha of *Pinus edulis* in the southwestern U.S.A. (Allen et al., 2010). Similarly, Peng et al. (2011) reported that tree mortality rates in boreal forests in Canada increased by an overall average of 4.7% year^{-1} from 1963 to 2008, because of regional droughts.

Owing to such processes, and especially the interaction between climate change and other pressures, McDowell and Allen (2015) suggest that this century will witness 'massive disruption' of forest ecosystems, resulting in substantial reorganisation of their structure, composition and carbon storage. Recent evidence suggests that such disruption is already taking place in the Amazon (Boulton et al., 2022; Brienen et al., 2015; Giannini et al., 2020; Pessôa et al., 2020), as well as many other important centres of tree diversity. This is further illustrated by the results of the IUCN Red List of Ecosystems (https://www.iucnrle.org/), which currently lists one forest ecosystem that has entirely collapsed (Central Ayeyarwady palm savanna), and 80 that are Critically Endangered and are therefore at high risk of collapse. More than a third (29) of these are found in China (Chen et al., 2020).

5.2 | Economic implications

In addition to the implications of tree extinctions on ecological systems, there are also substantial economic implications of such losses. Several estimates are available for the total economic value of the world's forests. FAO (2018) provided a figure of labour income derived from forests of more than US$580 billion per year, supporting more than 45 million jobs worldwide, with up to 60 million people being involved informally in the forest sector. Most of these people are located in Asia and Africa (FAO, 2020). However, this figure is likely to be an underestimate, as it overlooks the linkages between the forest sector and the wider economy. By attempting to take account of these wider effects, Li et al. (2019) provided a revised estimate of US$1.3 trillion contributed by the world's forests to the global economy each year. Even this higher value is likely to be an underestimate, as it does not capture many other values of forests (e.g. provision of ecosystem services to support agriculture and nature tourism and recreation related to forests) (Miller et al., 2020). Despite being underestimates, these values are orders of magnitudes larger than the cost of effectively conserving all terrestrial ecosystems at the global scale (US$76.1 billion per year; McCarthy et al., 2012), highlighting the importance of conserving tree species richness (Liang et al., 2016).

Attempts have also been made to estimate the total value of ecosystem services provided by forests to people. Costanza et al. (2014) suggested that the total value of these services to be approximately US$ 16 trillion per year, with forest ecosystems being of particularly high value for climate regulation, genetic resources, recreation and habitat for other species. These analyses were partly based on previous research by de Groot et al. (2012), who identified mean total values of ecosystem services for different biomes based on a literature review. Mean values for tropical forest were Int $ 5264 ha^{-1} year^{-1} (±6526 SD), for temperate forest Int $ 3013 ha^{-1} year^{-1} (± 5437 SD) and for woodlands Int $ 1588 ha^{-1} year^{-1} (±317 SD) (de Groot et al., 2012). An important finding from this analysis was the fact that most of the value of ecosystem services lies outside the market and is best considered as a form of nontradable public benefit. The continued degradation and overexploitation of ecosystems is therefore likely to impact significantly on the livelihoods of the poor and those of future generations (de Groot et al., 2012).

Timber is one of the world's most valuable natural commodities. The value of the global timber trade has more than doubled over the past 20 years, reaching US$153 billion in 2018; wood pulp accounts for a further US$ 63 billion annually (Raza et al., 2020). Timber consumption continues to rise, particularly in low- and middle-income countries and is forecast to triple over the next 30 years, driven by factors such as increasing urbanisation. The revenue from illegal logging and forest crime greatly exceeds other forms of illegal trade in wildlife with an annual value of US$51–152 billion, representing up to 50% of the total global timber trade (Interpol, 2019; Nelleman et al., 2014). Over 1500 tree species are recorded as traded internationally for timber (Mark et al., 2014). However, this is likely to be an underestimate, as much of the timber trade is undocumented at species level, and many more timber species are utilised and traded at local or national scales. In the case of tropical hardwoods, approximately 300 million m^3 of timber is harvested annually, equivalent to an estimated 100 million trees (Jenkins et al., 2018) and affecting at least 20% of humid tropical forests (Asner et al., 2009). In many tropical countries, illegal logging accounts for 50%–90% of all timber harvested (Interpol, 2019).

Of the tree species included in the IUCN Red List of Threatened Species (IUCN, 2022), 4022 have 'construction and structural' use recorded; and of these, 36% (1440 species) are recorded as threatened with extinction (IUCN, 2022). Many commercial timbers, especially tropical species, are sourced from natural forests; consequently, commercial logging often has had a negative impact on natural populations of tree species in many parts of the world. Notable examples of tree species threatened by timber harvesting include Mahogany (*Swietenia macrophylla*), which previously supported a multibillion dollar industry in Brazil (Grogan et al., 2002); rosewoods (*Dalbergia* spp.); and dipterocarps (Dipterocarpaceae), a large family of tropical tree species that are often forest dominants. Over US$3.5 billion worth of dipterocarp timber is exported each year from the island of Borneo alone, where 99 out of 162 endemic species are threatened with extinction (Bartholomew et al., 2021).

Many tree species are also the source of nontimber products, in which global trade is estimated to be more than US$88 billion annually (Chamberlain et al., 2020). These products include foods (e.g. fruit and nuts), ornamentals, medicinal and aromatic plants. In developing countries, wood fuel (fuelwood and charcoal) is a particularly important product derived from trees, both for household use and for sale. Some 880 million people are estimated to spend time collecting fuelwood or producing charcoal (Jin et al., 2017). More than 40 million people are engaged in commercial fuelwood and charcoal activities, often to supply towns and cities. In Africa 90% of wood consumed is used for wood fuel and charcoal, with an official charcoal production of 30.6 million tons in 2012, worth approximately US$9.2–24.5 billion annually. With current trends in urbanisation and the projected population increase of another 1.1 billion people in Sub-Saharan Africa by 2050, the demand for charcoal is expected to at least triple in the next 30 years (Nelleman et al., 2014). The widespread harvesting of wood for fuel places significant pressure on tree species. For example in Madagascar, 244 tree species are recorded as used for fuel, and nearly half of them (117) are recorded as threatened (Beech et al., 2021; BGCI, 2021).

Medicine extracted from tree species is fundamental to the well-being of millions of people. An estimated 10% of all trees (nearly 6000 tree species) have medicinal or aromatic use whether in mainstream modern medicine or traditional uses. The global reported trade in plants for medicinal purposes was valued at over US$3 billion in 2015 (Jenkins et al., 2018). Some medicinal tree species are of immense value in international trade. For example, Agarwood trees (from the genera *Aquilaria* and *Gonystylus*) produce a highly valuable resin used in perfumes, incense and medicines. This is one of the most valuable raw materials in the world, worth up to US$100,000 per kilogramme and with a global trade valued at US$32 billion (Ash, 2020). Overharvesting of the resin has led to more than 20 species being categorised as threatened by the IUCN Red List, including the main source of Agarwood, *Aquilaria malaccensis*. Another economically important medicinal tree is the African Cherry (*Prunus africana*), the bark of which is traded internationally to cure malaria, fever, kidney disease, urinary tract infections and prostate disorders. International trade was estimated to exceed US$200 million annually in the late 1990s (Bodeker et al., 2014). Overharvesting for the international market has meant this species is threatened throughout its range in central and southern Africa.

5.3 | Implications for human livelihoods

Worldwide, more than 1.6 billion people live within 5 km of a forest, a figure that includes approximately 250 million (40%) of the world's most extreme poor (Miller et al., 2020; Newton et al., 2020). Many of these people depend on products and services provided by trees to support their livelihoods. The 60 million indigenous people who live in forest areas are especially dependent on trees and the condition of forest ecosystems (SCBD, 2010). Trees can contribute to meeting energy, health, housing, income and nutritional needs, as well as non-material aspects of livelihoods such as community relations, culture and spirituality (Miller et al., 2020). For example, in India, more than a quarter of the population (i.e. 275 million people) are dependent on forest resources for subsistence and income generation (Milne, 2006). Tree products can provide 20%–25% of household income, an amount that is approximately equivalent to that derived from agriculture (Angelsen et al., 2014; Miller et al., 2020). Trees located outside forests often also make a significant contribution to rural livelihoods, for example, through their inclusion in different agroforestry systems (Miller et al., 2020; Waldron et al., 2017).

Trees can contribute to improving food security by providing affordable and often highly nutritious food. While products harvested from trees rarely provide a complete diet, they can make a significant contribution to calorific intake, especially at times of low agricultural production; they are also an important source of essential micronutrients in the form of nutrient-dense fruits, vegetables and

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nuts (Vinceti et al., 2013). Wild edible fruits obtained from trees are often perceived by consumers as being healthy, nutritious and linked to cultural identity, and increasingly, they are becoming the source of high-value food products that are sold to high-income consumers in both national and international markets (Chamberlain et al., 2020). Approximately 53% of the fruit available for consumption globally is produced by trees (Powell et al., 2013).

Loss of tree species can exacerbate local poverty by reducing forest productivity and the provision of ecosystem goods and services (Liang et al., 2016). As the livelihoods of the rural poor are often strongly dependent on products derived from trees, decline of tree populations resulting from factors such as deforestation or overharvesting can result in a decline in living standards. This can lead to well-documented 'poverty traps', in which environmental degradation causes poverty to persist (Barrett et al., 2011). Close linkages between human well-being and tree resources also create the possibility of abrupt decline or collapse occurring simultaneously in both social and ecological systems (Barrett et al., 2011). Effective conservation of trees can reduce such risks to human livelihoods and can help people to avoid increased impoverishment. This can be achieved through the role of trees in furnishing food, fodder, fuel and other products when alternatives are not available, providing a form of 'safety net' to livelihoods (Marshall et al., 2006). This is especially important to the rural poor because they often do not have access to other forms of insurance, and they often rely on other livelihood activities that are vulnerable to external shocks such as drought (Noack et al., 2019).

Conversely, investment in tree resources through approaches such as forest protection, sustainable use and domestication can provide potential routes out of poverty (Marshall et al., 2006). This can be achieved directly through the sale of tree products and indirectly by enhancing soil fertility, water regulation and the provision of other ecosystem services that support food production and other livelihood requirements (Miller et al., 2020). For example in Mexico and Bolivia, Marshall et al. (2006) showed that nontimber forest products can provide cash income in subsistence communities where families may have no other cash-generating opportunities. Accumulation of cash savings, through the commercialisation of tree products, can provide a vital 'stepping stone' to a nonpoor life. This process can be supported by appropriate policy interventions, such as enhancing community organisation and provision of technical know how and organisational skills to ensure sustainable resource management and harvesting (Marshall et al., 2006; Newton, 2008). Furthermore, conservation of tree species can help maintain options for supporting human well-being and poverty alleviation in the future.

5.4 | Cultural implications

As well as having direct use values, trees play important cultural, spiritual, aesthetic, inspirational and recreational roles in many societies (Rival, 1998). This is illustrated by the fact that trees feature in the folklore, myths, tales and legends of most human cultures; trees also contribute to people's sense of place and their cultural connection with a specific location. They provide culture-specific artefacts, influence spiritual beliefs and strengthen community identities (Axelsson et al., 2021). Trees are symbolically and spiritually important in most of the world's major religious traditions (Shvidenko et al., 2005), as illustrated by the role of *Ficus religiosa* in Buddhism. Many indigenous people depend on trees for cultural identity and heritage, kinship and knowledge integrity; trees may be linked with tribal identities, association with place, kinship ties, customs, social protocols, stories and songs (Brockerhoff et al., 2017). The cultural identity of a society may be profoundly linked to an individual tree species, as in the case of the Pewenche people of southern South America, whose livelihoods are traditionally dependent on the Endangered conifer *Araucaria araucana*; their tribal name is derived from this species (Herrmann, 2005). Examples such as this, where a species is irreplaceable to a culture or a people, can be considered as Cultural Keystone Species (CKS) (Axelsson et al., 2021). In such cases, if the species is lost, very high social or cultural impacts are likely to ensue. Extinction of a tree species might negatively affect not only subsistence or spirituality but also the transmission of Traditional Ecological Knowledge and the continuity of traditional practices relating to the species (Freitas et al., 2020).

Trees are also of high value to more modernised, secular societies, in terms of providing recreation, aesthetic value, tourism and spiritual solace (Shvidenko et al., 2005). Tourism and recreation can have significant monetary value; for example, in Denmark, recreational services of forests provide up to EUR15,000 ha^{-1} $year^{-1}$ (Zandersen & Termansen, 2012). In reflection of this, some countries, states or cities have protected heritage trees (sometimes referred to as 'historic', 'landmark' or 'significant' trees), which are designated because of their unique value in relation to their age, rarity, size or beauty, or their cultural, historical or ecological importance (FAO and UNEP, 2020). For example in Italy, more than 3000 'monumental trees' have been designated for specific protection since 2014 (FAO and UNEP, 2020). More than 80 countries have also nominated 'national trees', which can be viewed as tree species of particular cultural value at the national scale; examples include *Adansonia digitata* in Angola and Senegal and *Dalbergia melanoxylon* in Tanzania. Nonetheless, trees have received far less attention as a focus for conservation efforts than other groups of organisms such as mammals or birds. While 'charismatic mega-fauna' have long been the focus of conservation action, there is also a need to recognise tree species as 'charismatic mega-flora', which could similarly have a significant role as 'flagship' species to stimulate conservation awareness and action (Hall et al., 2011). They could also serve as an 'umbrella' species that help protect other species or other aspects of the natural environment that require conservation (Hall et al., 2011).

6 | SUGGESTED ACTIONS

We now know that at least 17,510 tree species are threatened with extinction, which represents nearly a third of the world's tree species.

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Over 100 tree species are already extinct in the wild, and many more will soon become extinct unless urgent action is taken, as human impacts on the biosphere continue to intensify. Currently, around 15.3 billion trees are being destroyed each year as a result of harvesting, deforestation, land use change and other forms of disturbance (Crowther et al., 2015). Trees are of immense importance to ecological systems and the global economy and to human livelihoods and culture throughout the world. Loss of tree species adversely affects human health and well-being from local to global scales and undermines the resilience of ecological systems on which human livelihoods depend. Extinction of tree species therefore represents a critical element of the global biodiversity crisis, which has not received sufficient attention in previous discourse (e.g. IPBES, 2019b). A strong and urgent response is required, both to prevent further tree species extinctions and to restore the damaged and degraded ecosystems of which they form a part. Such actions will simultaneously help to address both the global biodiversity crisis and the climate change emergency.

We endorse the call for actions in other 'warning to humanity' papers (Albert et al., 2021; P. Cardoso et al., 2020, 2021; Cavicchioli et al., 2019; Heleno et al., 2020; Jenny et al., 2020; Pyšek et al., 2020; Ripple et al., 2017, 2020) and support the suggestions that humanity can take to transition to sustainability, including the need to shift to a green economy and to address climate change. We also identify the following seven key actions needed to avoid the catastrophic implications for humanity that could result from the loss of tree species.

1. Recognise the importance of tree species

Tree species are essential elements of global biodiversity, comprising the key components of forest ecosystems. Yet trees are often not appreciated as individual species but are more often seen as interchangeable elements of a particular habitat, community or ecosystem. Monitoring of environmental trends focuses on assessing changes in forest cover or tree density (Crowther et al., 2015; FAO, 2020; IPBES, 2019b), while ignoring the vital role of individual tree species and changes in tree species richness. All tree species have unique functions and ecological roles, while providing essential habitat for distinct communities of other species. Prevention of the extinction of individual tree species is paramount, together with maintenance of tree species richness within ecological communities. Greater recognition and understanding of the specific importance of the roles of different tree species is needed from individuals, conservation organisations, governments and the international policy community, in order to mobilise and act to prevent the further extinction of tree species.

2. Conserve and restore natural tree populations

Two thirds of tree species are found in protected areas (BGCI, 2021). We call for the effective conservation of threatened tree species within the global protected area network by strengthening local knowledge of their status and distribution, improving the effectiveness of conservation management, monitoring populations of threatened species and where necessary increasing enforcement of controls on illegal or nonsustainable harvesting of threatened species. We also need to extend protected area coverage, to include those threatened tree species and species assemblages that are currently not adequately represented in protected areas. We call for the information about tree species to be factored in to conservation prioritisation and decision-making, for example, by strengthening existing Key Biodiversity Areas (KBAs) (Eken et al., 2004) and in the designation of new KBAs. Restoration of degraded forests should focus on restoring the species composition and richness of tree communities as well as associated ecological processes and ecosystem functions (Aerts & Honnay, 2011).

3. Address direct threats to tree species

Results of the GTA have provided insights into which factors are threatening individual tree species (Table 2; BGCI, 2021). Action needs to be taken to address each of the threats affecting the most threatened species, supported by legal measures where necessary. Recognising that habitat loss from agricultural expansion and associated land cover change is the principal threat to most tree species, steps need to be taken to ensure that trees are conserved within agricultural landscapes and that rates of land cover change are reduced. Recognising that many tree species are threatened by overexploitation, we advocate measures to ensure that management of natural forests is environmentally sustainable, whether for timber production, nonwood products or multiple uses. We also need a greater understanding of the impact of harvesting on the population dynamics of individual tree species, through improved inventory, monitoring, and research. Efforts are also needed to address illegal logging more vigorously and to strengthen legal compliance and verification. In areas affected by invasive species, or by spread of pests and diseases, we need improved early warning of these threats by monitoring and understanding their spread and impacts on tree species, while developing improved controls and management practices.

4. Prioritise conservation action for tree species

Currently, there are more threatened tree species listed on the IUCN Red List than the number of threatened mammals, birds, reptiles and amphibians combined, yet it is these species groups that are typically used as flagships for biodiversity conservation. We suggest that tree species can usefully be considered as 'charismatic mega-flora' and as conservation flagships. As resources are limited, we need to prioritise conservation action for the most threatened trees. Information from the GTA (BGCI, 2021, 2022b) including conservation status, distribution and conservation action can inform conservation planning, prioritisation and action at local, national and international scales. To date, conservation action has been undertaken for over 400 of the world's threatened tree species through the Global Trees Campaign (BGCI and FFI, 2021). However, the vast majority of threatened tree species are still lacking a conservation action plan or

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any practical conservation measures. These are now needed to ensure that no tree species is forgotten, with funding, attention and action directed to tree species and sites that are in greatest need of conservation.

5. Strengthen the role of trees in environmental and climate policy

Action in support of tree conservation needs to be mandated by policies and legislation from local to international scales. Those policies and mechanisms that are currently in place that affect populations of tree species, such as those relating to forestry, biodiversity conservation, land use and climate change, should include specific measures supporting conservation action for threatened tree species. International policies should be implemented and applied to tree species with much greater resolve and commitment. The UN Convention on Biological Diversity (CBD) should acknowledge and address the specific conservation needs of tree species, for example, by encouraging Parties to develop action plans for those species that are threatened. Data describing the conservation status of tree species should be integrated into biodiversity indicators for monitoring implementation success. The policies and mechanisms of the UN Framework Convention on Climate Change (UNFCCC) designed to reduce deforestation should be rigorously supported, with adequate provision of funding. We support the important pledge made at UNFCCC COP26 to halt and reverse deforestation and land degradation by 2030 and encourage all Parties to ensure that the pledge is achieved in practice. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) includes over 900 tree species in its Appendices, including species traded for timber, medicinal and aromatic products. Implementation needs to be urgently strengthened for tree species, with measures extended to include a wider range of species. We welcome The New York Declaration on Forests, a voluntary and nonbinding international declaration to take action to halt global deforestation, which specifically includes commitments from the private sector to eliminate deforestation from the supply chains of major agricultural commodities. We also support the UN Strategic Plan for Forests 2017–2030, which calls for forest law enforcement and governance to be enhanced, and for illegal logging and associated trade to be significantly reduced worldwide. We strongly encourage stakeholders in these policy processes to ensure that these commitments are met in full.

6. Strengthen the role of trees in sustainable development

Conservation of tree species is crucial to retaining future options to support human well-being. As noted by Miller et al. (2020), trees are critical to global efforts aimed at ending poverty; they play a crucial role in supporting the livelihoods of people in rural communities. The contribution of trees to supporting the well-being of hundreds of millions of people around the world, particularly those in rural areas, needs to be recognised. The value of trees to people needs to be reflected in policies and actions aimed at achieving poverty alleviation, such as the Sustainable Development Goals. Tree species need to be appreciated as valuable assets for the poor; these values are often overlooked. Policies that conserve and sustainably manage tree species need to be implemented, so that they can directly benefit the poor (Miller et al., 2020; Newton, 2008), and support sustainable development.

7. Act now for trees

None of these suggested actions can be achieved by individuals, conservation organisations, businesses or governments acting in isolation. In order to prevent a tree extinction crisis, we need to develop a much wider partnership, including local communities, government agencies, forestry organisations, business communities, conservation NGOs, botanic gardens, universities and all other stakeholders that depend on trees in a myriad of different ways.

We all need to take action for the world's tree species, both collectively and individually. As individuals, we need to encourage our representatives and decision-makers to take action to protect tree biodiversity. We also need to ensure that products derived from trees are sourced sustainably, especially when this involves harvesting from natural forest. We can achieve this through our consumption preferences and the demands we place on the businesses that provide goods for our consumption. We also need to limit our consumption of products that are destroying natural forests (e.g. some sources of soya, oil palm and tropical hardwoods). We each need to support practical conservation initiatives throughout the world that are helping to conserve tree species, and to protect and restore natural forests. When supporting tree planting schemes, we need to make sure we choose schemes that include planting of native species, and ideally threatened tree species.

Our message for humanity is to remember how trees enrich and support our lives, as they have throughout human history. Yet we need to acknowledge that these values are at risk if we fail to consider the impacts of our actions and to change our collective behaviour in relation to trees. Although there is still much to learn about the biology, ecology and wonder of trees, we know how to conserve them. We also know that now is the time to act.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

M.R., A.N. and S.O. planned and designed the review, conducted the review, analysed data and wrote the manuscript. Global Tree Assessment contributors significantly contributed to global tree red list assessments, reviewed the manuscript and provided translations.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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