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Geographic Distribution of Global Economic Important Mahogany Complex: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author JAD performed the literature search and produced initial draft manuscript. Authors MA and AP proof read and reviewed the manuscript, while author AO developed the maps for the illustrations. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Mahogany is the collective international trade name for the high-value tropical and subtropical timber tree species of the family *Meliaceae.* Mahogany species are noted for their deep red-brown heartwood and are widely used in the construction, boat building, interior decoration (particularly paneling and floor tiles), and in the manufacture of furniture. Across their natural geographical distribution range, many rural communities depend for their livelihoods on the genetic resources of the species as they provide natural products and services. However, mahogany populations across their native range are threatened by deforestation, habitat fragmentation, excessive logging and genetic erosion. In addition, climate change may bring about a shift in the distributional range of the native species. To safeguard the rich diversity of mahogany requires a conscientious effort in policy formulation and the enforcement of existing laws in regard to the management and conservation of the species. In addition, it is imperative that mahogany is used as an integral component in

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agroforestry systems and in reforestation efforts, as well as in the restoration of degraded forest ecosystems in order to protect the genetic resources of the species. *The aim of this review was to highlight the threats to the sustainability of the species*. We conducted literature review to examine the geographic distributional range of a mahogany complex (*Khaya spp, Entandrophragma spp, Cedrela spp, Toona spp, Swietenia spp*) at global, regional and ecosystem scales. We used maps as annotated diagrams to show the probable geographic global distribution range of the mahogany complex. The *Khaya spp. and Entandrophragma spp.* are native to Africa*, Cedrela* spp*. and Swietenia* spp. are native to Central and South America*,* whereas, *Toona* spp. are found primarily in southeast Asia.

Keywords: Mahogany; Khaya; entandrophragma; Swietenia; genetic resources; sustainability.

1. INTRODUCTION

Mahogany is the collective international trade name for economically high-value tropical and subtropical hardwood timber tree species [1,2,3]. Mahogany accounts for a relatively high proportion of the international trade in tropical hardwoods [3,4,5]. Characteristically, they are noted for their fine grain, red-brown heartwood, and resistance to drought and pest infestations [6,7,8] Most mahoganies are members of the family Meliaceae, with the exception of the *Shorea* species (Philippine mahogany), which is a member of Dipterocarpaceae. Over 30 species belonging to genera *Khaya, Entandrophragma, Toona, Cedrela and Swietenia* are involved in the international trade associated with the mahogany label (see Fig. 1). The genus *Khaya* consists of six species: *K. anthotheca, K. grandifoliola, K. ivorensis, K. madagascariensis, K. nyasica* and *K. senegalensis* [3,9,10,11]. However, *K madagascariensis* is considered to be endangered by International Union of Conservation of Nature (IUCN) due to lost habitats [12]. Four species are recognized in the genus *Entandrophragma*; *E. utile, E. cylindricum, E. angolenses* and *E.candollei* [4]. The *Khaya* and *Entandrophragma* species are described as African mahoganies [13,14,15]. In appearance and working properties, African mahogany is difficult to distinguish from American mahogany as *Khaya*, *Entandrophragma* and *Swietenia* are closely related genera and belong to the same family (i.e. Meliaceae) [7]. The basic morphological distinction between African mahogany and American mahogany is that the former has four parted flowers and the latter has five [16]. Strictly speaking, true mahoganies belong to the genus *Swietenia*, which consists of the three main economic timber tree species, namely *S. humilis, S. mahagoni* and *S. macrophylla*. The latter is by far the most overexploited species, and illegal logging and habitat destruction have resulted in low natural population numbers throughout its native range. Thus, *S. macrophylla* was placed on Appendix II of the Convention on International Trade in Endangered Species (CITES) in 2002 [17,18,19]. True mahoganies have been harvested for hundreds of years. The initial exports of *S. macrophylla* to Europe and United States were carried out around the sixteenth and eighteenth centuries respectively (see 17). In the genus *Swietenia,* the three species can crossbreed to produce hybrids (e.g., *S. x aubrevilleana*) within zones of distributional convergence [10,20]. The genera *Cedrela* and *Toona* are closely related, and all belong to the same family (Meliaceae), subfamily (Swietenioideae) and tribe (Cedreleae) [21,22]. These two genera (*Toona* and Cedrela) contain 69 species that occur in the Americas, Southeast Asia, Australasia and India [23]. Indeed, they were previously classified taxonomically under the same genus *Cedrela* [24]. All the eastern (Southeast Asia or Australasia) species of Cedrela are now classified under the genus *Toona* [25,26] , thus leaving nine species of *Cedrela* that occur in the Americas [23]. The genus *Toona* has six major timber species of economic importance namely: *T. calantas (*Kalantas or Philippine mahogany), *T. ciliate* (syn. *T. australis* — Australian red cedar or Indian mahogany), *T. sinensis* (Chinese mahogany or Chinese *Toona*), *T. sureni* (syn. *T. febrifuga* —Vietnamese mahogany; Indonesian mahogany) and *T.* fargesii. The Western (or Americas) *Cedrela* consists of the following seven species important from a timber and forestry point of view [9,10], *C. fissilis, C. lilloi, C. montana, C. oaxacensis, C. odorata, C. salvadorensis* and *C. tonduzii* [9,23]. Nevertheless, 17 neotropical tree species are currently described under the genus *Cedrela* that have a wide geographic distribution from northern Mexico, through the Caribbean islands, Central and South America as far as northern Argentina [27,28,21,29]. A lack of information on the distributional range and status of mahogany

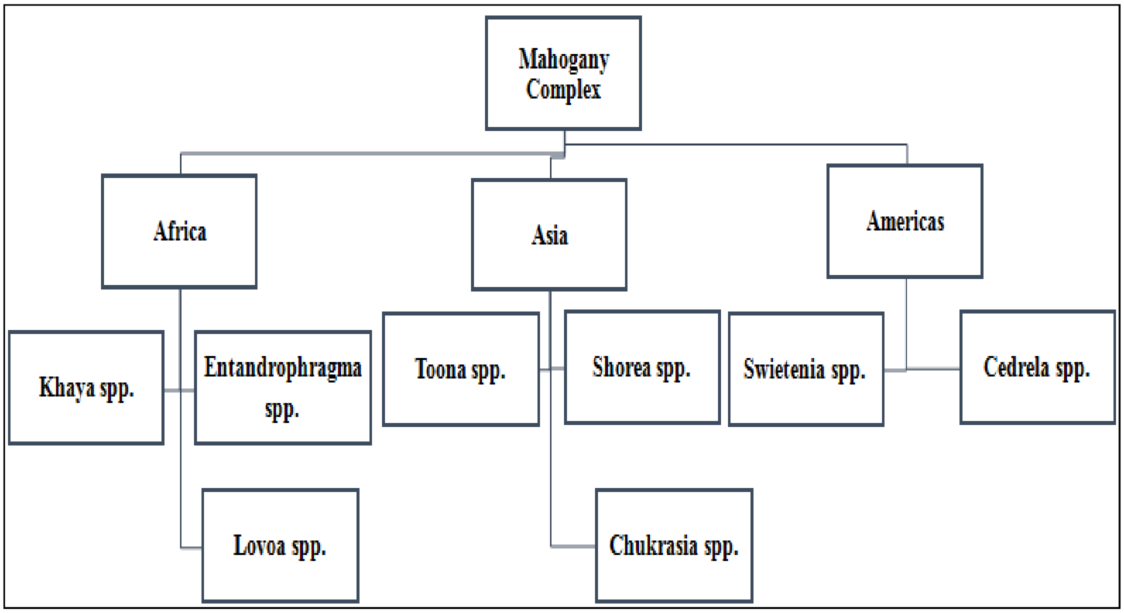

Fig. 1. Commercial timber species from Africa, Asia and the Americas with the trade name mahogany

complex around the world impedes holistic efforts for the conservation of genetic resources of these species. This review seeks to provide abridged information on the global distribution of mahogany complex and highlight the threats to the sustainability of the species. This study provides a comprehensive review on the geographical distribution of the five main economically important genera (*Khaya, Entandrophragma, Toona, Cedrela and Swietenia*) that are associated with the mahogany trade globally. In addition, the review highlights the overlooked loss of genetic resources of the mahogany complex, and discusses its implications for the livelihoods of rural communities. This information is critical to determine actions that will resolve some of the challenges facing the conservation of mahogany species.

2. GEOGRAPHIC DISTRIBUTION

2.1 Khaya Species

K. anthotheca (Welw.) C.DC. has a wide geographic distribution in West, Central, East and parts of Southern Africa. The species is found in Guinea-Bissau, throughout Sierra Leone, eastwards to South Sudan, Uganda and Tanzania, and southwards to Angola, parts of DR Congo, Zambia, Zimbabwe, Malawi and Mozambique (Figs. 2 and 3A) [30,31]. *K. anthotheca* is restricted to moist and dry semi-deciduous forest zones and is virtually absent in the Upper Guinean and Lower Guinean rainforest of the Guineo-Congolian phytochorion, where it is replaced by *K. ivorensis*.

K. grandifoliola (Welw) C. DC. is found in dry, semi-deciduous forest zones [32]. It has a restricted geographic distribution in West Africa and parts of Central and East Africa [33]. Its geographic range starts from Guinea, extends through Ivory Coast, Ghana, Benin, Nigeria, Cameroon and Central Africa Republic and eastwards to Uganda and South Sudan [33,34,35]. The species is also found in the northern fringes of DR Congo [33] (Figs. 2 and 3B).

K. ivorensis (A. Chev.) has a restricted distribution in West and Central Africa. The species is found primarily in wet and moist evergreen and moist semi-deciduous ecological zones, as well as in areas with an average annual rainfall of about 1600–2500 mm [36]. The geographic range starts from Ivory Coast in West Africa and terminates in Gabon in Central Africa (Figs. 2 and 3 C). It is virtually absent in Dahomey Gap; the 200 km wide coastal savannah corridor that separates the dense tropical humid forests of the Guineo-Congolian phytochorion into Upper Guinean and Lower Guinean rainforest [37].

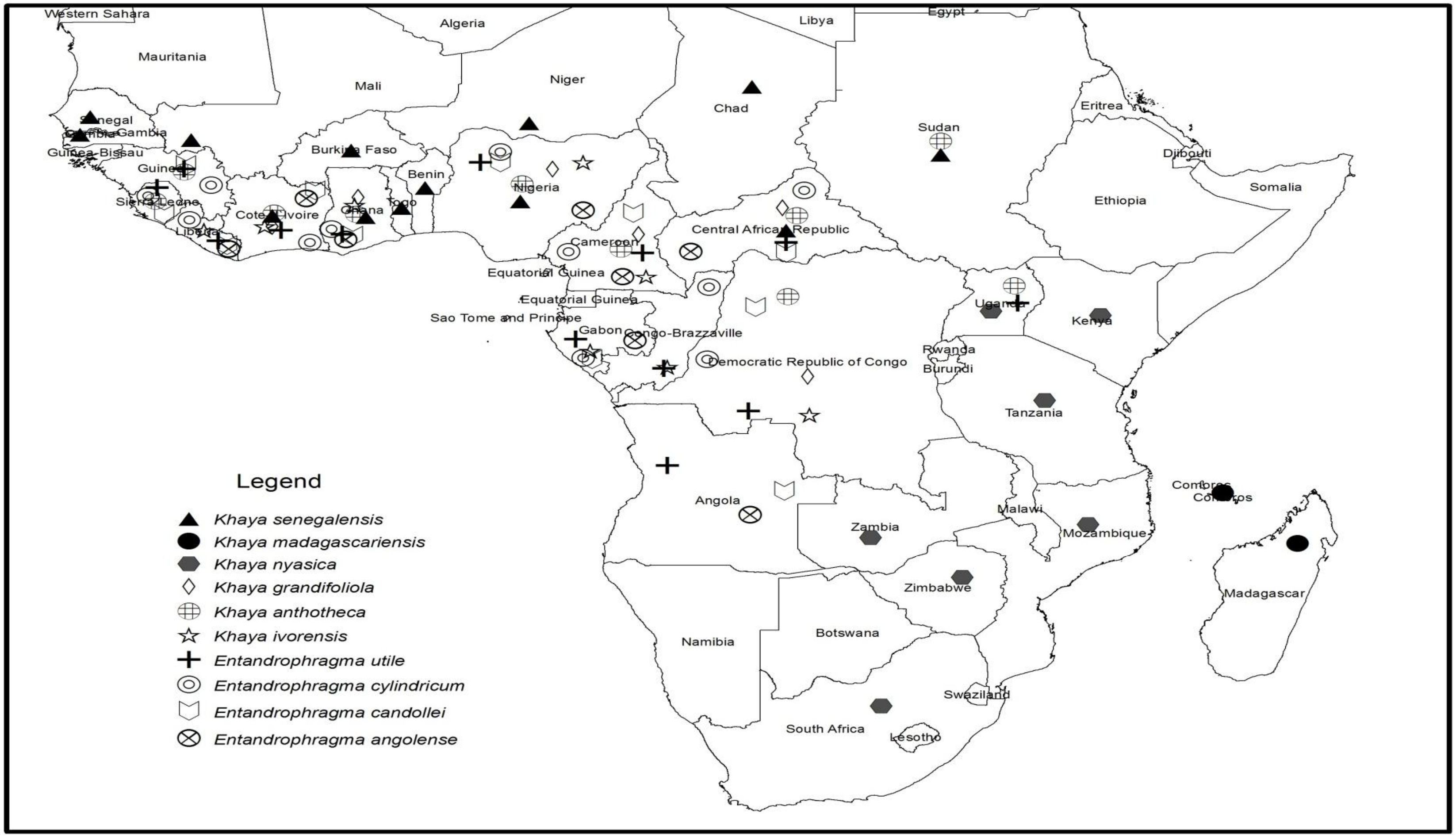

Fig. 2. Distribution of Khaya and *Entandrophragma* species in Africa

K. madagascariensis (Jum. & Perr.) has a restricted natural distribution. The species is native and only endemic to Madagascar and Comoros Islands in the Indian Ocean [12,38] *K. madagascariensis* grows fairly well in plantations. However, the population is under threat from selective harvesting and habitat destruction. It is listed on the IUCN Red list of endangered species [12]. *K. madagascariensis* has a unique adaptation to brackish water and marshy conditions [12].

K. nyasica (stapf. ex Baker f.*)* has a wider distribution in the eastern parts of Africa. Its geographic range extends from eastern DRC Congo through southern Uganda, parts of Kenya, Tanzania, Zambia, Zimbabwe, Malawi, Mozambique and as far as the Limpopo regions of South Africa (Figs. 2 & 3E) [39,40,41]. *K. nyasica* and *K. anthotheca* have often been considered to be synonymous, but are in fact two separate species [42]**.**

K. senegalensis (Desr.) occurs over a wide range of climatic, altitudinal, ecological and edaphic conditions in the tropics of 15 African countries from Senegal in the west to Sudan and Uganda in the east (Figs. 2 and 3D) [38,43,44,45,46]. The species thrives well in the savannah ecosystems of Sahel, Sudan and Guinea [46,47]. Its geographical distribution range falls approximately between 8° and 15°N latitudes (38) and experiences average annual rainfall of 700–1,750 mm at altitudes 1,800 m above sea level [38,44,48].

2.2 Entandrophragma Species

Entandrophragma is a genus of four commercially important timber species restricted to tropical Africa. The species is distributed in West, Central and East Africa (Figure 3) (4). The species can be found in rain- and deciduous-forests, as well as in transitional zones (i.e., the boundary between high forest zone and the savannah) [49].

E. utile (Dawe & Sprague) is widespread in Western, Central and parts of East Africa, and is prevalent in moist semi-deciduous forest zones. Its geographic distribution range encompasses Sierra Leone, Liberia, Ivory Coast, Ghana, Nigeria, Cameroon, Central African Republic, Congo, DR Congo, Angola and parts of Uganda [50,51,52] (Figs. 2 and 4D). Ecologically, *E. utile* is a lowland tree species and thrives well at altitudes of about 500 m above sea level, with average annual rainfall in the range 1600–1800 mm, particularly in West Africa [50]. However, in Uganda it can be found at elevations up to 1400 m above sea level [50,52,53].

E. cylindricum (Sprague) is prevalent in moist semi-deciduous forests, especially in ecological zones with average annual rainfall of about 1750 mm. However, it can also thrive in evergreen forests, but this is very rare. In Uganda, *E. cylindricum* occurs in rainforests at altitudes of 1100–1500 m above sea level [54] and prefers well drained soils. The species is distributed from Guinea to DR Congo (Fig. 2 and 4C [55].

E. angolenses (Welw. C.D.C) has a wide geographic range from Guinea in West Africa to Angola and extends through Central Africa Republic as far as Tanzania, Uganda, Kenya and South Sudan (Figs. 2 and 4A) [56,57,58].

E. candollei (Harms) is found in evergreen, moist semi-deciduous and transitional formations, although the species is relatively prevalent in regions with average annual rainfall of about 1800 mm [59,Burkill, 1997). *E. candollei* has a low population density and is rarer at a local level than other members of the genus*,* although its distribution is scattered [58]. Its distribution starts in Guinea in West Africa through DR Congo to Cabinda in Angola. However, the species is restricted to the moist high forest zone in Ghana (Figs. 2 and 4B).

2.3 Swietenia Species

The genus *Swietenia* contains three economically important species that are considered as the true or genuine mahogany timber [18]. The genus is native to the neotropics, but has been cultivated extensively in plantations outside of its natural range, particularly in Asia. The attempt to introduce some species of *Swietenia* into tropical Africa in plantations was not successful because of the severity of shoot borer (*Hypsipyla robusta; Lepidoptera: Pyralidae*) attacks [60]. This insect causes proliferation of the apical meristem leading to a reduction in the quality of the merchantable bole [61].

S. macrophylla (King) is native to Latin America and the western parts of South America*,* particularly in the Amazon basin. *S. macrophylla* is considered the true mahogany [62], the name is associated with other related genera within the family Meliaceae that exhibit the same physical properties, notably *Khaya* (African mahogany), *Cedrela* (cedar), *Lovoa, Toona, Entandrophragma* and *Chukrasia* [63].The native geographic distribution range of *S. macrophylla* begins at the southern tip of Florida extends through the southern parts of Mexico in the Tamaulipas region following the Yucatan peninsula and extends southward through the Panama Isthmus, and Central America, Costa Rica, Belize to the northeastern section of South America, passing through High Amazon in Colombia, Venezuela, Ecuador, Peru, Bolivia and the southern Amazon basin of Brazil (Fig. 5A) [23,64,65,66]. Due to overexploitation, Big Leaf Mahogany (*S. macrophylla)* has become relatively rare throughout much of its natural range (67). As a result *S. macrophylla* has been listed on Appendix II of CITES. Thus, requires legal verification for export on the international market [68,69,70]. *S. mahagoni* (L.) Jacq is endemic and native to southern Florida and the islands of the Caribbean (Bahamas, Netherlands Antilles, Haiti, Cuba, Jamaica and the Dominican Republic (Fig. 5C) [23,60,66,71,72]. However, it has been planted out of its natural range in Puerto Rico, the Virgin Islands, the Bermudas, the Lesser Antilles, Trinidad and Tobago, and southward to South America and the island of Curaçao [23]. *S. mahagoni* has been extensively planted as an exotic timber tree species in southern Asia (India, Sri Lanka, and Bangladesh) and in the Pacific (Malaysia, Philippines, Indonesia and Fiji) [71].

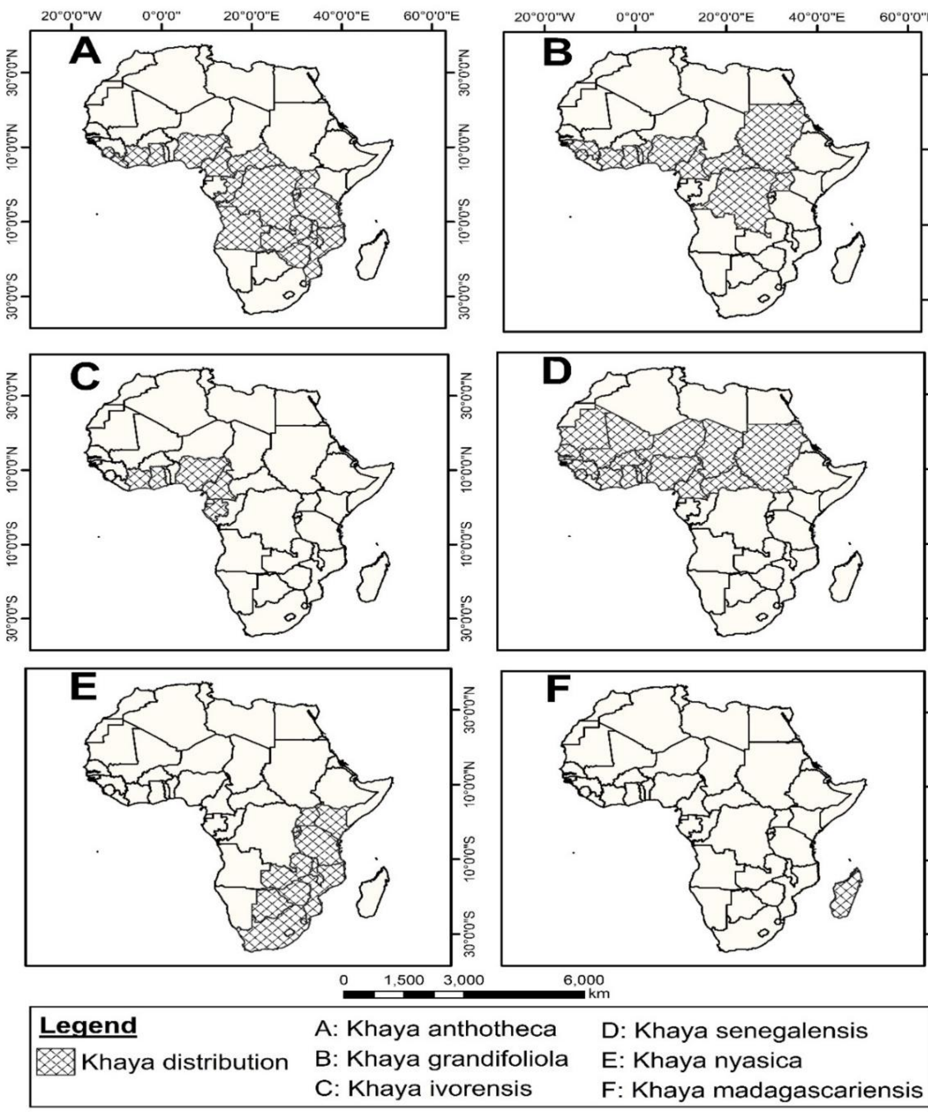

Fig. 3. Geographic distribution of *Khaya* species in Africa

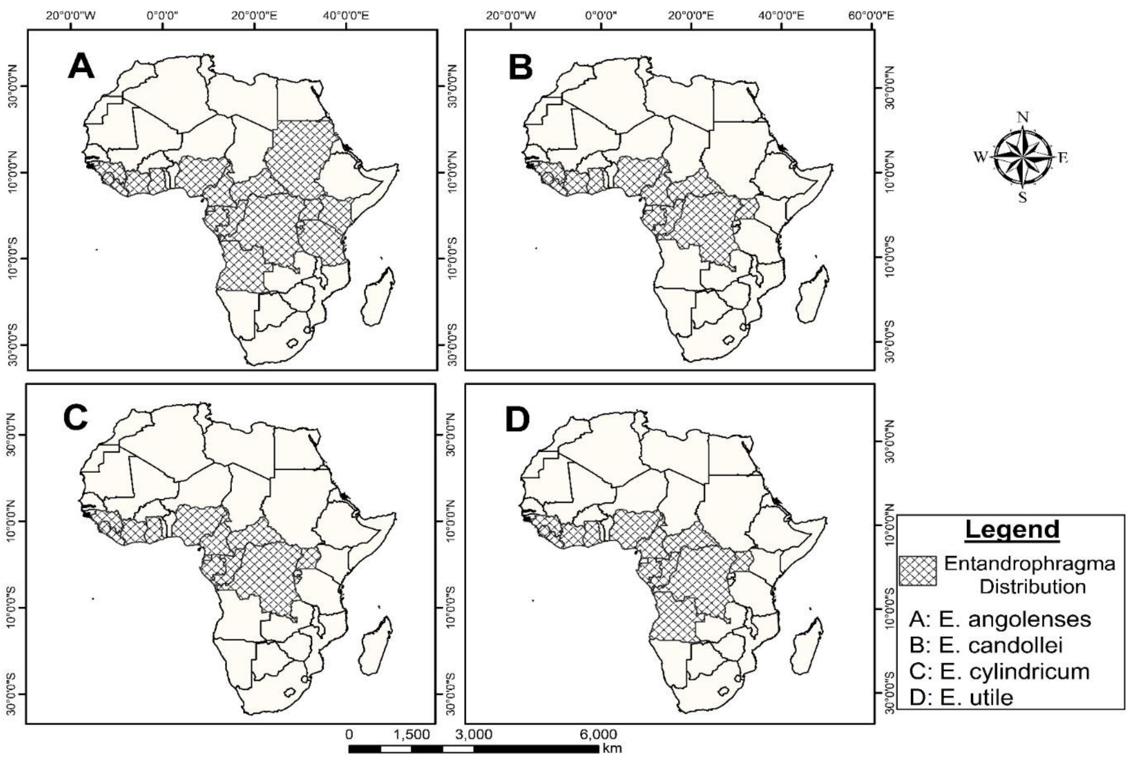

Fig. 4. Geographic distribution of *Entandrophragma* species in Africa

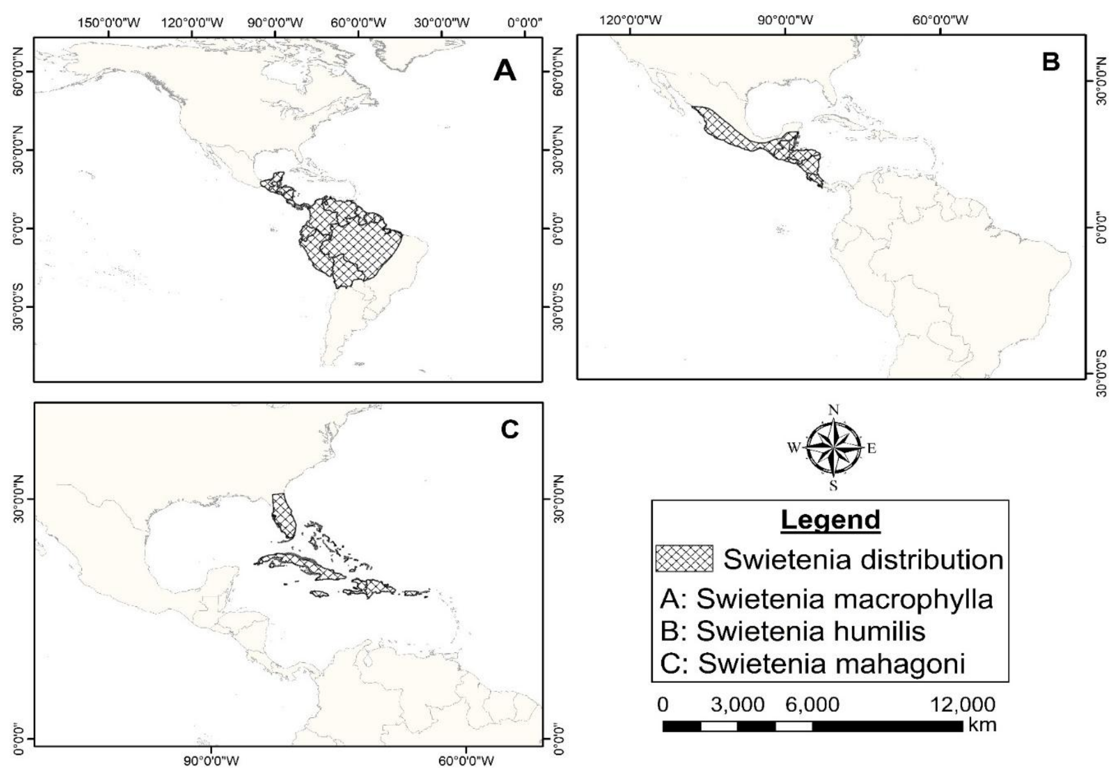

Fig. 5. Geographic distribution of *Swietenia* species in Latin America (Neotropics)

S. humilis Zucc has a narrow geographic distribution range within Central America along the Pacific Coast, starting from Sinaloa in southern Mexico through Belize, Guatemala, El Salvador, Honduras, Nicaragua, Panama and north to Punta Arenas in Costa Rica (Fig. 5B) [23,73,74]. *S. humilis* is endangered over much of its natural distribution area due to degradation of its habitat and is listed in Appendix II of CITES [75].

2.4 Cedrela Species

C. odorata L. is a timber tree species native to tropical America. It is widely distributed in its native range in the neotropics. The geographic distribution range starts from Mexico (latitude 26°N) then moves southwards throughout Central America to the provinces of Misiones and Tucuman in northern Argentina (latitude 28°S) and then on to the Caribbean [76,10,77,78,23] (Fig. 6A). In Mexico, *C. odorata* is distributed along the Pacific coast(Gulf of Mexico), from Sinaloa in the north (latitude 26° N) to the Chiapas in the south through Tamaulipas, Campeche and southeast of San Luis Potosí to the Yucatan Peninsula, and Quintana Roo on the Atlantic coast [77,23]. *C. odorata* is widely cultivated as a timber tree species within and outside the neotropics. In the tropics, it is extensively cultivated as an exotic timber tree species in industrial plantation estates in Ghana, Nigeria, South Africa, Tanzania, Thailand, Uganda and Kenya.

C. fissilis (Vellozo) is native to Central and South America. The geographic distribution range starts in the north in Costa Rica through the western parts of South America to Brazil, Bolivia and northern Argentina (Fig. 6 B) [78,27]. In Brazil, *C. fissilis* is distributed from Rio Grande del Sur to Minas Gerais, in semi-deciduous forests and in the Atlantic Forest [23].The species is widespread within Brazil but uncommon in Amazonia, except in lowland evergreen forests and flooded forests [79]. *C. fissilis* generally occurs at lower elevations and is usually associated with seasonal forests [80]. However, it can also be found in other closed-canopy forests types that are within proximate of seasonal forests [81,27]. *C. fissilis* and *C. odorata* are two major *Cedrela* species that are widely distributed in the neotropics [81].

C. lilloi C.DC. is endemic to South America. The species is confined or restricted to South American montane regions [82]. The geographic distribution range starts from Ecuador, Peru extends through Bolivia, Brazil (Santa Catarina) and Paraguay, and terminates in Argentina [83] (Fig. 6 C). C. lilloi is usually found within upland forests (subtropical montane rainforest) at altitudes that range between 1000–3400 m above sea level [75,84].

C. montana Moritz ex Turcz has restricted distribution in South America. *C. montana* is found in the Andes regions of Venezuela, Colombia, Ecuador and Peru up to altitudes of between 1200 and 3000 m above sea level [79,85,23,86] (Fig. 6 D). *C. montana* and *C. lilloi* are both common in subtropical montane rainforests or cloud forest belts [23]. These two species (*C. montana* and *C. lilloi)* are usually associated with highlands [75,24].The distribution range is restricted to the western part of South America, particularly in the Highlands region of the Andes [86]. *C. montana* occurs in the same ecological zones as *C. lilloi.*

C. salvadorensis (Standley) is a native species endemic to Central America. The geographic distribution range begins in the Mexican states of Jalisco to Chiapas and throughout Central America (Belize, Guatemala, Honduras, El Salvador, Nicaragua, and Costa Rica) up to North Panama (Fig. 6E) [24,75,87]The species thrives in dry tropical forests or deciduous humid forests at altitudes generally less than 1000 m above sea level [23].

C. tonduzii C. DC is a native timber tree species of Central America. *C. tonduzii* has restricted geographic distribution. The distributional range starts from Oaxaca and Chiapas in southern Mexico and extends throughout Central America to Panama (Fig. 6F) [88,89]. *C. oaxacensis* C.DC. & Rose is endemic and native to the Balsas River basin in Mexico, occurring in the dry areas of Morelos, Veracruz, Guerrero and Oaxaca states. The distribution range extends from Mexico throughout Central America up to the Isthmus of Panama (Fig. 6 G) [9,23,24, 26,75,88,90].

2.5 *Toona* Species

T. fargesii A. Chev is widely distributed in Asia; from the Assam region of India, Bhutan, through Myanmar, Thailand, Vietnam and Laos to the southern Chinese provinces of Hsueh and Kwangesi (Fig. 7 A) [91].

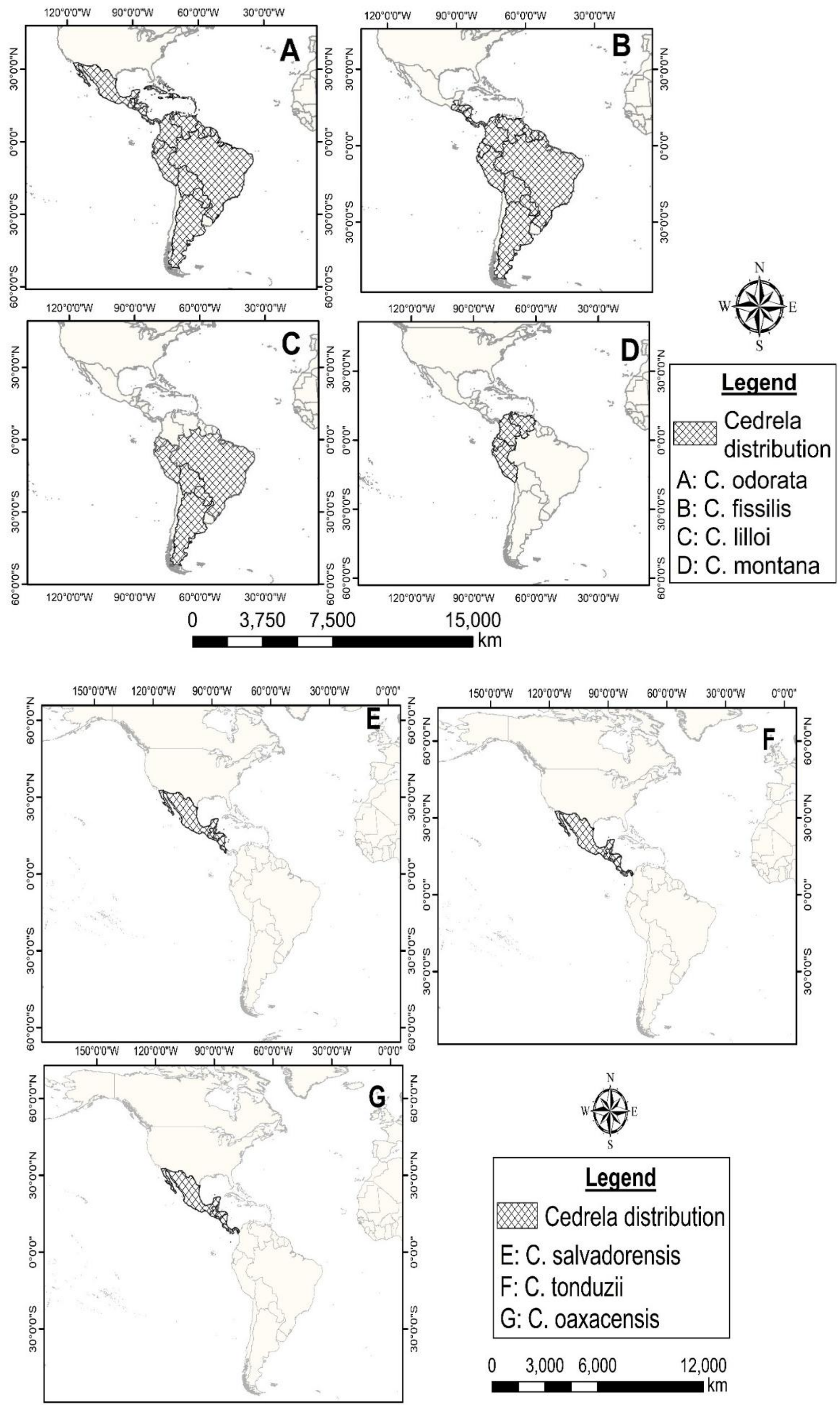

Fig. 6. Geographic distribution of *Cedrela species* in the Americas

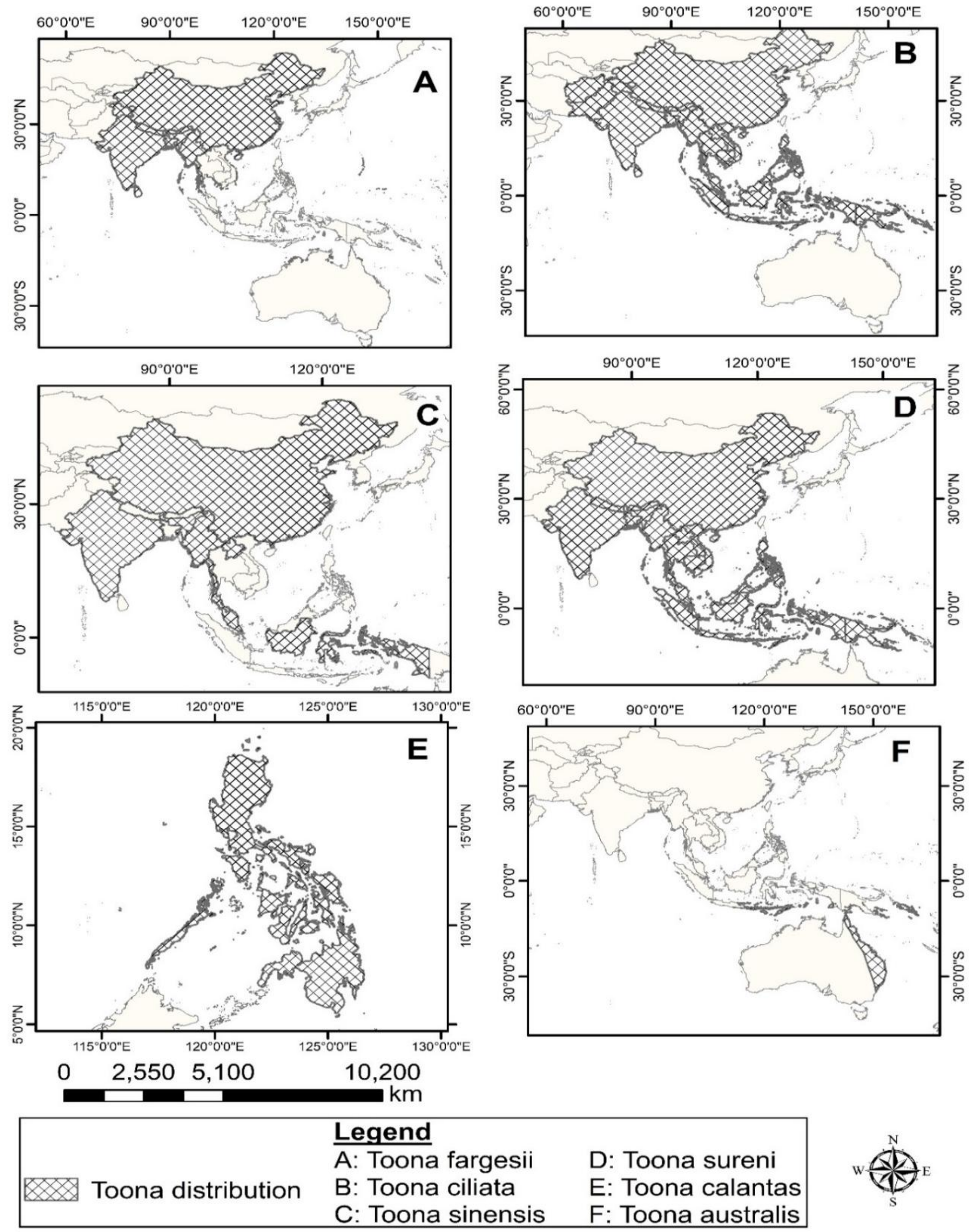

Fig. 7. Geographic distribution of *Toona* species in Asia

T. ciliata M. Roem is a native timber tree species of Southeast Asia (Fig. 7 B). The geographic distribution range starts in Afghanistan to the east and extends through India, Nepal, Bhutan, Bangladesh, Pakistan, Sri Lanka, Papua New Guinea, Cambodia, Laos, Myanmar, Thailand, Indonesia, Malaysia, Philippines and China (Guangdong, Hainan, Sichuan, Yunnan) [92,93,94,96].

T. sinensis (A. Juss.) M. Roem (Chinese mahogany) is commonly known as Chinese mahogany. It originates or is native to East Asia, particularly northern and western China. The geographic distribution range starts from Nepal, northern India and extends eastwards through Bhutan, Myanmar, Thailand, Laos, Malaysia, Java, Indonesia and China as far as North Korea (Fig. 7 C) [91,94] The species thrives well at high altitudes.

T. sureni (Blume) Merr.(Indonesian mahogany) is synonymous with *T. febrifuga* (Blume) M.J. Roemer. It is a native species and is widely distributed throughout south Asia. The geographic range covers India (Bhutan and Nepal); Indochina (Myanmar, Laos, Cambodia, Thailand and Vietnam); China (Guizhou, Hainan, Sichuan and Yunnan); Malesia (Malaysia, Indonesia and the Philippines); and Papua New Guinea (Fig. 7D) [96,97] . It grows at elevations from 1200 –2700 m above sea level. It usually inhabits secondary semi-evergreen forests. *T. calantas* Merr. & Rolfe (Philippine mahogany) is widely distributed throughout the Philippines, especially in the Balabac group of islands (Fig. 7E) [98]. It is endemic to the Philippines (Batan Islands, Luzon, Mindoro, Samar, Negros, Leyte, Cebu and Mindanao) [99,78]. *T. calantas* is usually associated with dry seasonal forest ecotypes (Barstow, 2018). In Philippines, it is a high-value economic timber tree species [76]. T. australis (Kuntze) Harms is a native species restricted to eastern Australia (New South Wales and Queensland). It is sometimes considered to be synonymous with T. ciliata M. Roem [91], although the two species are separate species [see, 96]. *T.* australis is endemic to Australia [91].

3. MAHOGANY GENETIC RESOURCES AND LIVELIHOODS

In the tropics and subtropics where mahoganies are native species their functional uses have evolved in tandem with the culture of the people over millennia [100]. Hence, the livelihoods of such rural communities are directly dependent on the genetic resources of the species. In Latin America, Africa and parts of Asia the genetic resources are an integral part of folk medicines. The loss of the genetic resources base implies a loss of cultural diversity for such forest communities. Genetic erosion could lead to loss of livelihood and exposure to poverty, as well as a decline in the well-being of the local people [101]. In addition, the indigenous knowledge associated with the use of mahogany species could be lost forever. Some rural forest communities depend extensively on mahogany resources for subsistence and income generation. Many natural products are obtained from the trees, notwithstanding the provision of ecosystem services that cannot be quantified in monetary terms. Mahogany bark extracts have been used as astringents for wounds [16]. The bark of *K. senegalensis* has been traditionally used in local leather industries by the people of savannah zones of Africa for the tanning of leather, because of its rich red color [102]. The bark of most species of mahoganies contains low quality gum Arabic (16), and the bark of African mahoganies contains many medicinal properties that are used in the treatment of certain tropical diseases [15,103,104]. In Ghana, the bark of *K. ivorensis* is a key ingredient in the production of an alcoholic beverage called bitters. The demand for bitters is very high and attracts premium prices on the alcoholic beverage market [105]. Traditionally, mahogany seed oil has been used for a wide range of purposes, most notably as a disinfectant against infection [106,107,108]. The reddish brown wood is highly valued for construction; boat building and furniture manufacture [15]. The wood is used in the production of high grade veneers and as pulpwood [44]. The wood has a high tensile strength and, as a result, is used as railway sleepers. Traditionally, it was used by the Akan people of Ghana in the manufacturing of talking drums, canoes, mortars and spoons [109,110,111,112]. The wood produces high quality charcoal noted for its high energy value. In most cities across Africa, *K. senegalensis* is planted as an avenue plant along the major streets and roads, for noise abatement and to provide shade [113,114,114]. Finally, the importance of managing the value of intra-specific variation within mahogany species has the potential to improve the livelihoods of rural communities, and as a result should be given an impetus [sensu, 116,117].

4. THREATS TO POPULATIONS AND THE EFFECTIVENESS OF AMELIORA-TIVE ACTIONS

Conservation of plant species is mediated by the perceive threat of extinction to the existence of particular plant populations. Extinction of plant populations is perpetuated when the management system for extraction does not correspond to the regeneration rate of the standing crop of that particular species.

Moreover, this problem can be compounded as a result of habitat loss and disruption of necessary ecosystem processes. The conservation status of many mahogany species complex ranges from vulnerable to critically endangered on IUCN Red List, and relatively few of these species are least concern in terms of threat to the population particularly *Toona* species(see, Table 1). From an international trade perspective, processed mahogany products continue to attract high market premiums [119,120]. Despite the economic importance of mahogany in the economies of countries where they are found, little attention has been given to safeguarding or protecting the genetic resources of these tree species. The high quality nature of wood from African mahoganies, for instance, has led to increased demand on both local and international markets. This has led to depletion of African mahoganies and to near extinction or threatened status in some countries [121]. Big leaf mahogany (*S. macrophylla* King (Meliaceae)) has been heavily overexploited across its distribution range [18]. However, commercial exploitation involves the selective extraction of high-grade merchantable boles, thus leading to lower value timber forests [122]. Selective logging erodes the genetic base (dysgenic) for future generations of the species [123]. This is because large, mature mahogany trees are the main contributors to reproduction, as seed producers and pollen dispersers [124]. The reduction of reproductive tree density through selective logging may have a drastic effect on gene flow [18,124,125,126] and could lead to breeding depression and loss of genetic variability for adaptive evolution [125,126]. Because of the excessive logging of some species (e.g. *Khaya* and *Entandrophragma*), it is currently difficult to get germplasm or provenances for breeding and genetic improvement [2]. Moreover, the natural regeneration of African mahoganies, especially *Khaya* species, after logging is generally poor [127,128]. African mahoganies occur at relatively low densities even in mahogany rich unlogged forests [129]. Excessive fruit (or seed) harvesting and predation by natural enemies may affect the natural regeneration of mahoganies in forest ecosystems. Ecosystem fragmentation and deforestation pose a major threat to the survival of mahogany species and to their genetic diversity. Deforestation and ecosystem fragmentation increase differentiation among populations, genetic isolation emanating from reduced pollen flow, and inbreeding or outbreeding depression [see e.g., 130].

In the Anthropocene era, human induced climate change, caused by emissions of greenhouse gases, has altered rainfall patterns, increased temperatures and the occurrence of extreme climatic events. This will cause geographic shifts in climatic conditions in the future [131]. Thus, the present global geographic range of mahoganies will also be expected to shift (see Danquah 2010 [132]). Climate change events will have a tremendous effect on the phenology and survival of mahoganies as a species [133]. Rising global temperatures as a result of climate change will increase the occurrence of wildfires and this poses a threat to the survival of mahoganies species in their natural range, and will particularly hamper conservation efforts in the forest reserves (see [134].

From a silvicultural perspective, any attempt to increase the mahogany resource base on large scale plantations to meet growing global demand is faced with challenges from *Hypsipyla robusta* and *H. grandella* (Zeller) attacks [2,64,135,136,137]. The seeds of Africa mahoganies are recalcitrant and viability is rapidly lost [103,138,139]. This requires that seeds should be stored under ambient temperatures. African mahoganies are non-pioneer light demanding species with the result that young seedlings find it difficult to survive under a closed forest canopy [140].

Successful natural regeneration of mahoganies in the neotropics has been associated with catastrophic disturbances [16,123,141]. For instance, natural regeneration in *S. macrophylla* is a rare, occasional event and is only possible upon large-scale severe catastrophic forest disturbances [18,123]. This stems from the fact that mahoganies are light-demanding non-pioneer timber tree species, and natural regeneration only occurs when there is a canopy opening or gaps to aid light penetration to the understory, particularly in tropical evergreen forests [140].

Calls for a conscientious effort in management and conservation have been made in order to sustain mahogany tree populations, and to meet current and future demands, In order to protect the species from extinction, it is important to retain remnant local populations in the wider agro-ecological landscape to serve as a source of seeds and pollen [123]. In addition, mechanisms need to be put in place to address wildfires, deforestation and forest fragmentation so as to protect mahogany species in forest reserves and in the wider agro-ecological landscape.

Table 1. Conservation status of mahogany complex in the world

Genus	Species	Conservation status*
Khaya	*anthotheca*	*VU*
Khaya	*ivorensis*	*VU*
Khaya	*Senegalensis*	*VU*
Khaya	*madagascariensis*	*EN*
Khaya	*grandifoliola*	*VU*
Khaya	*nyasica*	*VU*
Entandrophragma	*cylindricum*	*VU*
Entandrophragma	*caudatum*	*LC*
Entandrophragma	*angolense*	*VU*
Entandrophragma	*candollei*	*VU*
Entandrophragma	*utile*	*VU*
Swietenia	*macrophylla*	*VU*
Swietenia	*humilis*	*EN*
Swietenia	*mahagoni*	*EN*
Cedrela	*odorata*	*VU*
Cedrela	*lilloi*	*EN*
Cedrela	*Salvadorensis*	*LC*
Cedrela	*fissilis*	*VU*
Cedrela	*oaxacensis*	*EN*
Cedrela	*tonduzii*	*LC*
Cedrela	*dugesii*	*CR*
Cedrela	*discolor*	*CR*
Toona	*sinensis*	*LC*
Toona	*ciliata*	*LC*
Toona	*sureni*	*LC*
Toona	*calantas*	*DD*

**Key: VU =Vulnerable; EN= Endangered; CR= Critically Endangered; LC= Least Concern; DD = Data deficient*
**Conservation status: This is a measure of likelihood of that species continuing to survive either in the present day or the future and the potential threat to their survival. It is an assessment that monitors population dynamics of species over period of time, taking into consideration other environmental factors. IUCN Conservation Red List of Threatened Species is a global conservation status listing and ranking of species (fauna and flora). It is basically a checklist of taxa that have undergone an extinction risk assessment using the IUCN Red List Categories and Criteria (Vulnerable; Endangered; Critically Endangered; Extinct, Extinct in the Wild, Near Threatened, Least Concern, Data deficient and Not Evaluated).Source: International Union conservation of Nature (IUCN) [118]; ScienceDaily [155]*

Moreover, strict adherence to harvesting limits and/or the setting of a higher minimum diameter are required to protect immature trees from being harvested (see [142]. Sustainable management of mahogany genetic resources and natural stands in their native range requires an adequate knowledge of annual incremental diameter growth within specific ecological zones. However, annual volume increment measurements of mahoganies in natural forests are lacking [123]. An absence of growth measurements and inventory data make it a challenge to determine sustainable harvest volumes. Hence, proactive data that gathers growth rates for mahoganies across their geographical range are paramount to ensure the sustainable management of these populations. The harvesting cycles of mahoganies in natural forests should be increased. *S. macrophylla*, for instance, requires a harvest cycle of 60 years or more from recruitment to commercial size [19,143], and this varies from one ecological zone to another across the natural range. A vigorous effort should be made to identify resistant provenances or populations of mahoganies resilient to *Hypsipyla* attack in order to aid in the deployment of the species on industrial plantation scales. The use of improved agroforestry systems and mixed plantation methods will reduce the incidence of *Hypsipyla* attacks [120,137]. The current geographical range of mahoganies is expected to shift in the future because of climate change [131], so increased access to planting materials or germplasm from countries with different environmental conditions will require international co-operation and a fair and equitable sharing of mahogany genetic resources [e.g., 144,145,146].

Finally, there is a need to formulate and implement stronger policies and to enforce legal instruments at the national level within countries where mahogany is endemic. These are necessary steps to protect the species [see 69,147]. To combat the illegal international mahogany trade, countries that are signatory to CITES must enforce the provisions under this regulation [69,148].

5. GENETIC CONSIDERATIONS IN RESTORATION ACTIONS

Tropical forests are disappearing at an alarming rate due to deforestation and forest degradation. However, it has been proposed that restoration of the degraded forest landscape should emphasize the use of indigenous tree species, such as mahogany in association with other native tree species, to mimic natural forests [see, 120]. The use of mahoganies in their native distribution range for the restoration of degraded ecosystems offers advantages over exotic tree species as it will conserve the mahogany populations within their natural range and, at the same time, provide high-value timber [e.g., 149]. In addition, it will provide a simple means to domesticate mahogany species and their integration into agroforestry systems in the wider agro-ecological landscape. This can also be seen as an alternative approach to in-situ or on-farm conservation of mahogany genetic resources. Domestication of mahoganies species has the potential to contribute to sustainable development through the provision of products and services that will directly or indirectly influence human livelihoods [see 150,151].The use of exotic timber tree species in reforestation, afforestation and restoration forest landscapes can lead to negative impacts for the conservation of native tree genetic diversity [152,153]. On-farm conservation of plant genetic resources, particularly forest trees, offers plants the opportunity to continually evolve in tandem with associated plant and animal communities, as well as respond to environmental changes. However, native tree species are more adapted to local biotic and abiotic conditions and thus support native biodiversity and ecosystem functioning to a greater degree [153,154].

6. CONCLUSIONS

The geographic distribution of the mahogany complex extends across four major biogeographic regions; neotropics (Central and South America), Afrotropics (Africa), Australian and Indomalayan (South East Asia). Each region is associated with particular genera and the unique physical attributes that are common to all the species of these genera are their attractive grain and red-brown heartwood. This is the hallmark of all timber tree species called mahogany. Many rural communities have their livelihoods directly tied to genetic resources of the species. Many non-timber natural forest products and ecosystem services are obtained from mahogany. Thus, from a genetic perspective managing the value of intra-specific variation within mahoganies has the potential to contribute to the sustainable livelihoods of rural communities. However, proactive conservation actions are required in order to safeguard the rich genetic resources of the species. This is in keeping with the fact that throughout their natural range, mahoganies are threatened by deforestation, habitat fragmentation and excessive logging. These factors are driving the species close to extinction in their native ranges. The problem is compounded by climate change, which could lead to a possible shift in the geographical range of the species. One measure that could be used to protect the species is domestication through utilization, namely by incorporating mahogany species into agroforestry systems in the wider agro-ecological landscape. In addition, mahoganies could be used in reforestation and in the restoration of degraded ecosystems within their native ranges. Finally, there is a need to formulate policies and enforce forest laws governing the management and the utilization of mahoganies at the national level within countries where mahoganies are endemic. In conclusion, strict adherence to the legal provisions under CITES will help protect mahoganies with regard to international trade.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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