extinction (*see* **Ecology**: Biological Impacts of Deforestation and Fragmentation).

Conclusions

Although patterns in forest plant diversity at large spatial scales are now well described, there are still substantial lacunae in the record that can only be resolved by additional botanical exploration. In some parts of world (for example, areas of the Philippines, Indonesia, and the Atlantic forest of Brazil), it is likely that deforestation and forest fragmentation have already eliminated any further scope for describing natural patterns of forest plant diversity at a more local scale. The mechanisms that determine the large-scale patterns in plant diversity remain poorly understood and are likely to vary substantially between regions and localities. Current theories suggest that the diversity of forest floras reflects a balance between biophysical, historical, and anthropogenic causes, but robust predictions of diversity at a local scale are not yet possible.

See also: **Ecology**: Biological Impacts of Deforestation and Fragmentation; Natural Disturbance in Forest Environments. **Environment**: Impacts of Elevated CO_2 and Climate Change. **Sustainable Forest Management**: Causes of Deforestation and Forest Fragmentation. **Tree Physiology**: Forests, Tree Physiology and Climate.

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Endangered Species of Trees

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Introduction

Unfortunately the topic of endangered species of trees is a vast one because of the extensive loss of their habitat in most parts of the world and in many cases because of overexploitation. The World Conservation Union's (IUCN) *Red List of Threatened Plants*, published in 1997, lists almost 34000 species of plants that are now threatened with extinction. That is just over 10% of the total number of plant species in the world. These lists include many species of trees. Red data lists exist for many countries and are catalogs of species where future survival in nature is uncertain. Most threatened species of trees are those of the tropical regions and on oceanic islands, in the tropics because of habitat destruction and because of the enormous diversity and often localized distribution of individual species, and on islands because they tend to have many unique endemic species, but also because of habitat destruction and the introduction of alien invasive species that take the place of the native flora. For example, about 85% of the Madagascan flora is endemic to that island nation and only 20% of the original vegetation remains. It is therefore inevitable that some species have gone extinct and others are under threat. A recent red data book for the ten countries of southern Africa cataloged 3900

taxa that are threatened with extinction and listed 33 that are recorded as being extinct.

Areas of the world such as Madagascar where wildlife and plants are richest and are most endangered have been termed 'hot spots' by ecologist Norman Myers. It is in these areas where most species of trees are also endangered. One particularly critical hot spot is the Atlantic Forest Region or *mata atlântica* of Brazil. This narrow strip of rainforest along the coast contains many endemic species of plants and animals. A study of a sample of tree species from that region carried out in 1981 showed that 53.8% of the sample of 127 tree species were endemic to the Atlantic forest and another 11.8% endemic to the coastal forest plus some part of the rapidly disappearing forests of the Planalto of Central Brazil, for example jequitibá (*Cariniana estrellensis*) (see **Figure 3**). It has been estimated that 6000 species of plants are endemic to the coastal forest hot spot. This region is classified as a hot spot because only about 7% of the original vegetation remains. The forest has been replaced by sugar cane, cattle pasture, and cacao plantations. Many species of trees that were collected and classified during the nineteenth century have not been re-collected in recent times. For example, *Roupala thomesiana* (a species of *Roupala*, a genus of trees whose wood is much used) was collected in the forests of Bahia state by Swiss botanist Jacques Samuel Blanchet in 1833. It has never been seen since the original collection and this is a common feature of Atlantic coastal forest species.

Another important hot spot for trees is the Guinean forests of West Africa that extend from Sierra Leone to Cameroon. The entire Guinean forest ecosystem has been reduced to a series of small fragments in each of the countries where it occurs. It is estimated that only 14.3% of the original closed canopy forest remains. This area too, like the coastal forests of Brazil, houses many endemic species of trees with at least 25% of the vascular plant species endemic to the hot spot.

The Wallacea hot spot includes the central islands of Indonesia from Sulawesi to Ceram and from Lombok to the Tanimbar Islands. This area named after the co-discoverer of evolution, Alfred Russel Wallace, contains many endemic species of animals and plants including many commercial timbers such as kawi (*Agathis* spp.) and the magnificent yellow-flowered legume *Pterocarpus indicus*. It is in many of the 27 areas defined as hot spots that the greatest number of tree species are endangered.

Here a selection of endangered tree species from different places and endangered for different reasons, have been chosen to illustrate the situation.

The Conifers or Softwood Species

The cone-bearing trees are some of our most ancient species that have survived through the ages and many changes in world climate. The data from the World Conservation Union estimate that 327 of the 586 species of Pinopsida (pines and their close relatives) are threatened. 133 species or 53% of the pine family (Pinaceae) are listed in the *Red Data Book*. Conifers include many magnificent trees such as the giant redwoods of California and are still one of the major sources of timber and so it is unfortunate that so many species are under threat of extinction.

The Wollemi Pine and the Dawn Redwood

The Wollemi pine is an Australian conifer that was only discovered in 1994 in a gorge only 150 km from Sydney. It belongs to an evolutionary line thought to have been extinct for many millions of years. Studies of fossil pollen showed that this genus was once widespread and abundant in Australia. Its population declined for natural reasons and one small population has survived in the Wollemi National Park. It is a member of the plant family Araucariaceae which include the much cultivated species the monkey-puzzle tree from Chile (*Araucaria araucana*) and the Norfolk Island pine (*Araucaria heterophylla*). Once it was discovered, the Wollemi pine soon became listed as rare and endangered and considerable efforts are being made by the Royal Botanic Gardens in Sydney to protect and propagate this species, of which fewer than 40 individuals exist in the wild.

A similar situation occurred for the dawn redwood (*Metasequoia glyptostroboides*) from China. This living fossil was discovered in the early 1940s. Since over 2000 trees of this species existed, seeds have been widely distributed to gardens around the world to ensure its survival as a species.

Alerce: The Patagonian Cypress

Alerce (*Fitzroya cupressoides*) is a magnificent tree of the forests of southern Chile and Argentina. The huge trees are slow-growing and take many hundred years to reach their full height of 50 meters and up to 2 meters diameter. Trees of $70\,m \times 4\,m$ have even been recorded. The timber of alerce has been much used in house construction and for roof shingles and even for boat building. As a result of its valuable timber this species has become so rare that it is listed both in *Red Data Books* and in the Convention on Trade in Endangered Species (CITES). The pressure on this species is from overuse rather than rarity. Clandestine shipments of alerce wood are still occasionally apprehended by UK Customs. Many of the conifers that are endangered are so because of

overuse of the timber and poor management of the resource.

Monterey Cypress

The Monterey cypress (*Cupressus macrocarpa*) is a small to medium-sized tree now confined to two small groves on the Pacific coast of central California. This picturesque tree has a small often contorted cone-shaped crown. It is not of importance as lumber, but is now often cultivated as an ornamental and in windbreaks and hedges. This is endangered in the wild because of the destruction of its native habitat, but is unlikely to become extinct because of its wide use in gardens around the world. Fortunately the entire wild population is protected within the Point Lobos Reserve and the Del Monte Forest and so it is unlikely to become extinct.

Bermuda Cedar

The Bermuda cedar (*Juniperus bermudiana*) is the last conifer discussed here. It is under threat for another reason. Approximately 90% of the trees died between 1944 and 1950 because of infestation by two accidentally introduced scale insects, the juniper scale (*Carulaspis visci*) and the oyster-shell scale (*Lepidosaphes newsteadi*). This tree, which dominated the forests of Bermuda, was a great loss and many exotic species were introduced to replace it. Some trees have survived but destruction of habitat for tourist resorts has reduced the possibility of reafforestation efforts. The species itself is unlikely to become extinct because it is now grown elsewhere and has become common on the island of Saint Helena. Many island species around the world have become endangered through the introduction of alien pests and diseases, or even other species of trees such as *Eucalyptus*, which take over at the expense of the native forest.

The Monocotyledons

The flowering plants have generally been divided into two major groups, the monocotyledons and the dicotyledons, based on the number of seed leaves in the embryo. Most of the monocots are narrow-leafed with parallel veins and are herbaceous, but one group, the palms, are secondarily woody and constitute one of the most important components of tropical rainforest. Since many palm species are critically endangered, a few examples are discussed here. Of the approximately 3000 species of palm, 869 (26%) are listed in the IUCN *Red Data Book*.

Madagascan Palms

There are about 170 species of palm in Madagascar and all but five are endemic. Many of the palms have very restricted distribution and are known from areas of less than 1 square kilometer in the wild. Since natural habitats are being destroyed so rapidly in Madagascar, a large number of the palm species are critically endangered. The species *Voaniola gerardii* was only described in 1989 in the Masoala Peninsula of northeastern Madagascar. Fewer than ten trees of the robust forest palm that is 15–20 m tall are known to exist. The fruit are a rich red-brown and seeds have been collected and germinated at Kew. *Voaniola* is also of interest because it has 596 chromosomes, the most ever recorded for a monocotyledon. Apparently this palm has been much harvested destructively to collect the palm cabbage or heart-of-palm for use as a salad vegetable. The ravimbe palm (*Marojejya darianii*) is another recent discovery that was named in 1984. This magnificent large-leafed palm reaches 15 m in height. It is only known from a single locality in swamp forest near Maroantsetra also in the northeastern part of the country. Unfortunately one of the threats to the existence of *Marojejya* has been the destructive collecting by palm fanatics, who often collect all the seed from a tree. A tree of the rare *Beccariophoenix madagascariensis* was actually cut down to obtain seed. At Mantaly where one of the two known populations of this tree occurs, in July 1992 nine mature trees had been felled for their palm-heart, leaving fewer than 20 mature trees alive. *Lemurophoenix halleuxii* (**Figure 1**) is probably the most majestic palm of the whole island. The 50 remaining trees are not regenerating well because the seeds are much sought after and regularly harvested for export to palm enthusiasts. The wonderful selection of palms from Madagascar are in a precarious state through destruction of habitat, harvesting for timber and palm-heart and collecting by palm fanatics and so it is probable that several species will soon be extinct in the wild (**Figure 2**).

New Caledonian and Other Island Palms

New Caledonia is another island territory where the majority of plant species are endemic. All 31 species of palm and all but one of the 17 genera are endemic and at least eight species are highly endangered. *Burretiokentia hapala* with its bright green trunk marked with pale rings of the leaf scars is an elegant palm that is known only from a few individuals in two localities. *Cyphophoenix nucele* is known from a single small population on the island of Lifou. The only other species of this genus, *C. elegans*, is also found in a very small population which is

Figure 1 The palm *Lemurophoenix halleuxii* from Madagascar. There are only about 30 individuals left of this majestic species. Photograph courtesy of H. Beentje.

Figure 2 The palm *Orania ravalea* from Madagascar was only described as new in 1995 and fewer than 500 individuals remain of this elegant tree. Photograph courtesy of H. Beentje.

endangered by frequent forest fires. Thus the whole genus *Cyphophoenix* is endangered, as is the case with many other genera of palms. Most tropical islands have listed species of palms and could be mentioned. There are several endangered species of palms in Hawaii in the genus *Pritchardia* and the once common vuleito palm of Fiji (*Neoveitchia storckii*) is reduced to a single population of about 150 trees. The only palm of Easter Island, *Paschalococcus disperta*, is extinct and was only described from subfossil fruit. The chonta palm (*Juania australis*) of Juan Fernández Islands or Robinson Crusoe Island is highly endangered from illegal felling and habitat destruction by grazing animals.

Continental Palms

It is not just island palms that are endangered, there are also many examples from continental areas. The IUCN *Red List* names three species of *Maxburretia* from Thailand and the Malay Peninsula. The most endangered is *M. rupicola* which is confined to three limestone hilltops all near to the city of Kuala Lumpur. One site is threatened by quarrying and another experiences frequent fires caused by careless climbers. The palm genus *Aiphanes* has 22 species most occurring along the Andes in Colombia, Peru, Ecuador, and Bolivia. Most of the species are narrow endemics in an area where much destruction of the natural vegetation has occurred. It is hardly surprising that 17 of the 22 species have found their way into the IUCN *Red Data Book*. For example, *Aiphanes duquei* is now restricted to two National Parks in the Cordillera Occidental of Colombia.

The urgoun or dalla palm (*Medemia arjun*) of Egypt and Sudan was abundant there in ancient times. The population has been decimated by exploitation of the leaves for making mats and by destruction of its habitat by irrigation schemes along the River Nile. It was known only from three localities in Egypt and one in the Sudan. Two of

Figure 3 This lone individual of the jequitibá tree, *Cariniana legalis* (Lecythidaceae) remains in the botanical garden in Rio de Janeiro. (It is believed that this same tree was once kissed by Einstein.) Because of its excellent timber it is becoming rarer even in the conserved remnant of Brazil's Atlantic coastal rainforest.

these localities have only a single tree left and it is dubious that any trees remain at the third.

These few examples serve to show that many palms around the world are severely threatened and some even extinct. Palms are one of the most useful of all groups of plants and it is tragic that so many are being lost forever.

The Dicotyledons

This vast group includes all other trees that are not either conifers or palms. There are many endangered species of dicots (**Figure 3**) and a few are highlighted here to illustrate what is happening to trees around the world.

South American Mahogany

This species (*Swietenia macrophylla*) grows in Central America and in Mexico and in an arc around the western and southern fringes of the Amazon basin. It is severely threatened due to overexploitation for its much sought-after timber and because of habitat loss. Mahogany is the most valuable timber of the American tropics. The area where it grows in southern Amazonia is also one of the major areas of deforestation. Mahogany, due to its high value, has been logged illegally from parks, reserves, and indigenous areas. For several years efforts to have this species listed in the CITES treaty was resisted by the principal exporting countries such as Brazil and Colombia, but in 2002 it was finally included in Appendix II which means that companies will have to alter the way in which they harvest the species and prove that it was obtained legally from a sustainable source. This was a major step forward because mahogany logging companies opened many roads to reach the scattered populations of wild mahogany which gave farmers access to remote areas. This process will now be slowed down by the listing of mahogany and will help to spare other trees. Mahogany has largely been harvested from wild trees because it has not done well in plantations due to attack from the shoot-boring insect *Hypsipyla grandella*.

Brazilian Rosewood

Rosewood (*Aniba rosaeodora*) contains the essential oil linalol which has become much used by the perfume industry. To harvest linalol, trees are felled and the wood chipped and steam distilled. Local distilleries have been built in many parts of Amazonia and teams sent out to harvest all the trees within range. This means that this species is now rare and as a consequence the level of harvesting has also decreased considerably, but not before the species has become threatened.

Saint Helena Ebony and the Toromiro

The ebony (*Trochetiopsis melanoxylon*) was the major timber of the island of Saint Helena in the South Atlantic (**Figure 4**). It was much sought after by trading ships for its wood and was believed extinct from the beginning of the nineteenth century. However two depauperate trees were discovered on a cliff in 1970 and cuttings taken from them have been successfully propagated in efforts to reintroduce the species. Like many island endemics it quickly suffered from both overuse and habitat destruction. It is notable that many of the most endangered species of trees are also those of most use. Another example of this is the toromiro tree (*Sophora toromiro*) from Easter Island in the South Pacific. The toromiro was also a useful timber that was much used by the natives for their elegant wood carvings. By 1917 only

Figure 4 *Trochetiopsis melanoxylon*, the Saint Helena ebony, was reduced to two impoverished individuals in the wild which were growing on a cliff face. Propagation and reintroduction programs of several institutions have assured the survival of this species that was on the brink of extinction.

one tree remained and fortunately explorer Thor Heyerdahl collected seeds before it was exterminated by grazing in 1972. The toromiro has survived in botanic gardens from the seeds collected by Heyerdahl and also in a few private gardens in Chile. From this genetically small population efforts are now being made to reintroduce to Easter Island what was once its most useful species of tree.

Brazil Wood

Brazil is the only country named after a wood. The Brazil wood (*Caesalpinia echinata*) is native to the Atlantic coastal forest hot spot and is listed as vulnerable in the IUCN *Red Data Book*. Within Brazil it is listed as endangered in five eastern coastal states. This wood was much sought after for the purple dye that was mainly exported to Portugal, often in exchange for enormous numbers of cattle. The heartwood is still much sought after for violin and cello bows. The species was almost eliminated by overuse, but since it is a national symbol, widespread replanting is taking place and this is a species that is unlikely to become extinct.

Meranti and Balan Woods

There are 357 species of the meranti and balan genus (*Shorea*) of the Dipterocarpaceae family of the Asian tropics. *Shorea* is the most important timber genus in tropical Asia and species grow in Sri Lanka, to South China, Malaysia and throughout Indonesia. Many species of this genus have localized distributions on one or only a few islands and so are particularly vulnerable to over exploitation. It is sad to see that 72 species of *Shorea* are listed in the IUCN *Red Data Book* as well as seven species of the related timber genus *Parashorea*. *Shorea fulcata* from Vietnam is listed as recently thought to have become extinct. The cause of endangerment of species of *Shorea* are mainly from habitat destruction. Many of the more commercially important species are now in managed forests and plantations, but all the wild species could be of importance to future breeding programs and would be a serious loss to forestry if they should become extinct.

Sapele

The sapele (*Entandophragma cylindricum*) is a mahogany relative that occurs in West Africa from the Ivory Coast to Nigeria in the Guinea hot spot. The wood is much exploited and is sought after for veneer, doors, and furniture. Over harvesting is occurring and it has been listed as a priority for genetic resource conservation before all the best timber trees are removed. The IUCN stated in 1996 that 'harvest and milling of the current species mix based on sapelli and sipo (*Entandophragma utile*) is clearly not sustainable ecologically or economically.' This is unfortunately true for many timber species of the tropics in America, Africa and Asia.

Endangered Trees Mean Endangered Wildlife

Many species of animals are dependent on trees for their existence and so the endangerment of trees also means the endangerment of animals that feed on their leaves, nectar, or fruit, or depend on trees for shelter. In 1992 entomologist Terry Erwin showed that rainforest canopy contains an incredible amount of insect diversity and that much of this is specific to individual species of tree. Therefore to lose a species of tree is also a threat to the many species of insects and other organisms that depend upon it for their existence. Likewise trees are dependent upon animals for their pollination and the dispersal of their diaspores. Pollinator extinction is becoming an increasing threat to many species of plant. For example Hawaii's native screwpine (*Freycinetia arborea*) was once pollinated by four bird species that are now either extinct or endangered: the Hawaiian crow (*Corvus tropicus*), the o'u parrot (*Psittirostra psittacea*), the Kona grosbeak (*Ehloridops kona*), and the palila (*Loxioides japonica*). The screwpine might have become extinct had not the introduced Japanese white-eye (*Zosteropsis japonica*) become a substitute effective pollinator.

Fruit bats play an important role as pollinators and seed dispersers of many species of trees in the Old World tropics and many oceanic islands. The Rodrigues flying fox (*Pteropus rodricensis*) once

Figure 5 This maçaranduba tree (*Manilkara huberi*) was felled to collect a few dollars worth of latex and illustrates the wanton destruction of many forest trees for little gain.

Figure 6 This rare treelet, *Rhabdodendron macrophyllum*, grows only in white sand areas around the city of Manaus, Brazil. Most of its habitat has been destroyed as the building industry mines the sand for house construction in the city.

occurred on both the islands of Rodrigues and Mauritius in the Indian ocean. It was exterminated from Mauritius many years ago but remained abundant on Rodrigues until, by the mid-1990s, its population was reduced to fewer than 100 animals through a combination of habitat destruction, hunting, and cyclone damage. Reforestation and protection of the bats has now increased the population to almost 2000 individuals, so there is renewed hope for the bat and for the plants that depend on it for their pollination and dispersal.

Selective logging often removes trees that provide important resources for forest fauna, such as timber species that provide fleshy fruits eaten by birds and frugivore mammals. The maçarandaba tree of Amazonia (*Manilkara huberi*) is an important timber tree (**Figure 5**) that is being logged but its fruit are eaten by parrots, monkeys, coati, deer, and tortoises. The populations of some vertebrate frugivores and seed predators can markedly decline in logged forests.

The important Brazil nut tree of the Amazon forest depends upon two species of bee to pollinate its flowers and the agouti to disperse its seeds. Many such interdependencies between trees and animals exist and to avoid extinction it is vital to maintain habitat that allows this web of biological interaction to continue.

Conclusions

The examples of threatened species of trees chosen here are just a few of the many that are now listed, but they show that wherever humans are active in a forested region of the world, often the most useful species of trees are becoming rare through overexploitation and loss of habitat (**Figure 6**). From the Amazon to Asia, from Africa to Australia important tree species are under threat of extinction. Particularly susceptible are those on islands such as Saint Helena, Hawaii, New Caledonia, and Madagascar where endemism is high but habitat destruction and introduced alien species are both also rife. Trees are vital to the survival of many other organisms and

each tree species has many other species that depend upon it for survival. Much more still needs to be done before it is too late to ensure that some of the most useful species of trees are not lost forever. We also need the large variety of trees that exist to sustain climate and ecological balance and perhaps even the future of all life on earth.

See also: **Biodiversity**: Plant Diversity in Forests. **Ecology**: Biological Impacts of Deforestation and Fragmentation; Human Influences on Tropical Forest Wildlife. **Environment**: Environmental Impacts; Impacts of Air Pollution on Forest Ecosystems; Impacts of Elevated CO_2 and Climate Change. **Genetics and Genetic Resources**: Forest Management for Conservation; Population, Conservation and Ecological Genetics. **Sustainable Forest Management**: Causes of Deforestation and Forest Fragmentation. **Tropical Ecosystems**: Bamboos, Palms and Rattans; Swietenia (American mahogany); Lecythidaceae.

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