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REVIEW

# Conservation of Tropical Plant Biodiversity: What Have We Done, Where Are We Going?

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## ABSTRACT

Plant biodiversity in the tropics is threatened by intense anthropogenic pressures. Deforestation, habitat degradation, habitat fragmentation, overexploitation, invasive species, pollution, global climate change, and the synergies among them have had a major impact on biodiversity. This review paper provides a brief, yet comprehensive and broad, overview of the main threats to tropical plant biodiversity and how they differ from threats in temperate regions. The Global Strategy for Plant Conservation, an international program with 16 global targets set for 2020 aimed at understanding, conserving, and using sustainably the world's plant biodiversity, is then used as a framework to explore efforts in assessing and managing tropical plant conservation in a changing world. Progress on 13 of the 16 outcome-oriented targets of the Strategy is explored at the pantropical scale. Within each target, I address current challenges in assessing and managing tropical plant biodiversity, identify key questions that should be addressed, and suggest ways for how these challenges might be overcome.

Abstract in Spanish is available in the online version of this article.

*Key words*: climate change; global strategy for plant conservation; management; protected areas; threatened species; tropical ecosystems.



OUR WORLD IS IN TROUBLE. Natural habitats are diminishing at alarming rates. Animal and plant species are being introduced into ecosystems outside their native distributions, and becoming invasive, outcompeting the native fauna and flora. The climate is changing with increased temperatures, increased rainfall and drought, and more violent storms. As tropical ecologists and conservation biologists, it is our role to record these biological changes, to model future changes, and to make recommendations to prevent further loss of species and their habitats.

Pitman and Jørgensen (2002) estimated that, of the 300,000–420,000 plant species (Prance *et al.* 2000, Govaerts 2001, Thorne 2002, Mora *et al.* 2011), as many as 94,000–193,000 species are threatened with extinction worldwide. The tropics harbor more plant species than other region in the world (Kier *et al.* 2005), with the Amazon alone having at least 12 percent of all flowering plants (around 50,000 species) (Feeley & Silman 2009). New tropical plant species are continually being discovered and described, including a few species that were surprisingly in local use for a long time before scientists had described them, like *Globba sherwoodiana* (Zingiberaceae) commonly sold in the markets of Myanmar (Gowda *et al.* 2012) or *Monstera maderaverde* (Araceae) used by local Hondurans in hat weaving (Karney & Grayum 2012). With the current level of habitat loss and alteration, many new tropical species are often endangered before we even describe them.

The tropical and subtropical realm harbors 46 of the 51 botanically richest ecoregions of the world (Kier *et al.* 2005), and 35 percent of all terrestrial ecoregions fall within the tropical and subtropical moist forests biomes (Olson & Dinerstein 2002). Of the 34 world's hotspots (areas with high endemism and greatest habitat loss), 18 are in the tropics (Mittermeier *et al.* 2004). Levels of floristic endemism are high in the tropics, especially in island systems. For example, approximately 60 percent of the indigenous vascular plant taxa of Indonesia (Sodhi *et al.* 2004) and 71 percent of the vascular plant taxa of the West Indies (Acevedo-Rodríguez & Strong 2012) do not occur anywhere else.

Like other biotic regions, human pressure is changing the health of the tropics (Millennium Ecosystem Assessment 2005, Wright 2010), resulting in high loss of biodiversity (Vamosi & Vamosi 2008, Stork 2010), which shows no evidence of slowing down (Butchart *et al.* 2010). Overcoming these pressures will be a challenge. As the Association for Tropical Biology and Conservation celebrates its 50th anniversary in 2013, it is timely to look back at the progress, challenges, and shortcomings in the field of tropical plant conservation, and examine where we are today and what the future holds.

This review is divided into two parts: (1) an overview of the anthropological threats to tropical plants species; and (2) an evaluation of knowledge gaps in the fields of tropical plant conservation and species management, using the Global Strategy for Plant Conservation (GSPC) as a framework. Even though much of what is discussed below is directed toward the conservation biology of tropical plant species, many of the threats and the strategies to overcome these threats are not specific to plants and can be applied to tropical animal species as well. Some strategies take

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a holistic approach, looking at community-level management and restoration, whereas other strategies focus at the species level, which can be unique to tropical plants.

## OVERVIEW OF THREATS

In the past 50 years, there has been an increase in the size of the human population in the tropics and a decrease in the amount of wild lands (Wright 2005). In addition to habitat loss, habitats are being fragmented and their structure is being altered. This section reviews the drivers of this change.

HABITAT LOSS.—The most prominent cause of local plant extinctions and species endangerment in the tropics is habitat destruction and deforestation (Dirzo & Raven 2003, Rodrigues *et al.* 2006, Wright 2010). More than 15 million hectares of tropical rain forest is lost each year (Bradshaw *et al.* 2009). In the past two decades, Southeast Asia, where more than 40 percent of rain forest has already been lost (Wright 2005), had the highest deforestation rate compared with other tropical regions (*i.e.*, Meso-America, South America, and Sub-Saharan Africa) (DeFries *et al.* 2005, Bradshaw *et al.* 2009, Sodhi *et al.* 2010). This figure does not take into account the amount of forest cover that satellites erroneously record as primary forests, those that are secondary forests or plantations (Bradshaw *et al.* 2009, Sánchez-Cuervo *et al.* 2012). Global predictions in the loss of vegetation and rates of forecasted urban growth over the next 15 years are highest in the undisturbed regions of the Eastern Afromontane, the Guinean Forests of West Africa, and the Western Ghats and Sri Lanka hotspots (Seto *et al.* 2012). Furthermore, it is predicted that Southeast Asia could lose almost three-quarters of its original forests by 2100 (Sodhi *et al.* 2004). In addition to tropical rain forests, tropical savannas and mangroves around the world are also being reduced in size (Bradshaw *et al.* 2009).

Habitat is lost in the tropics due to mining and other resource extractions, cattle ranching, and agriculture, which often takes the form of monocultures such as oil palm, rubber, soybean (Sodhi *et al.* 2004, Koh & Wilcove 2008, Wright 2010), and in more recent years, crop-based biofuel production (Fargione *et al.* 2008). In tropical countries, croplands, for example, have expanded by approximately 48,000 $km^2$ per year from 1999 to 2008, primarily at the expense of tropical dry broadleaf forests (Phalan *et al.* 2013). In a study of over 16,000 South American plant species, Ramirez-Villegas *et al.* (2012) found that expansion of agriculture and grazing pressure was the key driver of immediate extinction risk. Most studies, however, only imply that habitat lost directly causes local extinctions, and only a few have measured this loss, such as the loss of 6549 vascular plant species following the 99.6 percent loss of primary lowland evergreen rain forest cover since 1819 in Singapore (Brook *et al.* 2003).

The future outlook for land-use in the tropics looks bleak. In an analysis of the world's terrestrial realms, Lee and Jetz (2008) found that the land cover near the equator is projected to face the highest levels of land-use change, owing to consequences of high population and economic growth. To reduce future agricultural expansion, for instance, there is an urgent need to understand how production lands can increase productivity yields without negatively impacting the environment.

HABITAT LOSS AND FRAGMENTATION.—Habitats that were once continuous can become fragmented by land conversion, resulting in edge effects, isolation effects, and effects of habitat loss for the remaining organisms. As a result of fragmentation, seedling recruitment, survivorship, and fecundity have been predicted to drop in the short term, whereas in the long term, growth rates may be reduced and detrimental genetic effects may appear (Heywood & Iriondo 2003, Gagnon *et al.* 2011), yet few actual demonstrations exist. Most studies have focused on the effect of fragmentation on reproductive output rather than regeneration success (Hobbs & Yates 2003). For example, seeds of an Amazonian understory herb *Heliconia acuminata* in forest fragments, which are exposed to hotter, drier and sunnier conditions, are less likely to germinate than those in continuous forest (Bruna 1999). Yet, studies of pollinator behavior, reproductive success, and gene flow in a variety of plant species suggest that pollination systems in forest fragments are quite resilient (Cane 2001).

Advancements in molecular methods are expanding our understanding of the genetic consequences of fragmentation on plant species in the tropics (Aguilar *et al.* 2008, Sork & Waits 2010). For example, a study on the tropical tree *Dinizia excelsa* found higher rates of selfing in isolated forest fragments (Dick *et al.* 2003). In contrast, paternity analysis on the endangered tropical timber tree *Dysoxylum malabaricum* recently revealed high genetic connectivity across a fragmented landscape by pollen dispersal, yet low local tree density in isolated fragments elevated mating between individuals and increases the likelihood of inbreeding (Ismail *et al.* 2012). More studies are needed to understand the interaction between ecological consequences of fragmentation and genetic declines (Kramer *et al.* 2008). Furthermore, the rate of extinction of tropical plant species in fragmented habitats remains an open question (Tollefson 2013).

At the community level, differences in species composition and plant structure have been found between large well-protected fragments and smaller fragments (Arroyo-Rodríguez & Mandujano 2006), with pioneer species increasing in abundance in smaller fragmented tropical forests and along the fragment edges (Tabarelli *et al.* 2010). Forest fragmentation contributes to the taxonomic homogenization of the flora through the increased abundance of native pioneer species. For example, Lôbo *et al.* (2011) found that the tree floras across the Atlantic forest of northeastern Brazil have become more similar to each other in the past three decades with the proliferation of native short-lived and small-seeded pioneer species.

OVEREXPLOITATION.—Plant and animal species are often overexploited causing direct and indirect threats to tropical plant species. Commercial logging operations are on the increase in the tropics due to continued high demand for American and Asian timber (Jepson *et al.* 2001, Sodhi *et al.* 2004, Wright 2010). The trade in illegal timber is threatening the rain forests of Southeast Asia, Madagascar, and tropical Africa (Sodhi *et al.* 2004, Patel 2007, Laurance 2008). If current trends continue, overharvesting could threaten the supply of tropical timber (Shearman *et al.* 2012). Dipterocarp tree species, many of which have a unique role in forest ecology through their strong synchrony of fruiting, are highly valued for their timber and are particularly vulnerable in Southeast Asia (Ashton & Kettle 2012). Many of these threatened dipterocarp species only exist outside of protected areas (Maycock *et al.* 2012). Likewise, the illegal logging of endemic rosewoods (*Dalbergia* species) from protected areas in Madagascar has been widespread, resulting in the reduction in the species distribution by 54–98 percent, depending on the species, in the past decade (Barrett *et al.* 2010).

Selective logging may result in reduced native species diversity (Patel 2007) and increased likelihood of fires (Cochrane & Schulze 1998). The impact to the forest canopy structure and tree species composition is not only immediate but has also shown to be evident even after four decades of regeneration (Okuda *et al.* 2003). Logging roads made during timber harvest can also lead to increased access to the forest, illegal colonization of undisturbed areas, and extraction of other resources including mining and hunting (Laurance *et al.* 2009).

Unsustainable harvesting practices of non-timber forest products (NTFP), such as firewood for fuel, lianas for basket weaving, plant parts for consumption (e.g., hearts of palm in *Euterpe* species), and plants used in botanical ethnomedicines, can also lead to the overexploitation and endangerment of many tropical plant species (Anyinam 1995, Ticktin 2004). Extraction of wild-harvested plants can affect growth, reproduction, and survival of the plant populations, which can further affect population dynamics (*e.g.*,Ticktin 2004, Schmidt *et al.* 2011). Unsustainable harvesting practices of wild plants are widespread, and can be found in tropical South America (Peres *et al.* 2003), Africa (Ndangalasi *et al.* 2007), India (Veach *et al.* 2003), and Southeast Asia (Soehartono & Newton 2001, Van Sam *et al.* 2008). Not all harvesting practices of NTFPs are unsustainable, and the current challenge among practitioners is finding the balance between maintaining population viability of the harvested species while supplying adequate household income needs to those who harvest the plants (Shaanker *et al.* 2004), as recently analyzed in the Amazonian palm, *Mauritia flexuosa* (Holm *et al.* 2008).

Bushmeat hunting and the illegal poaching of animals for medicine and trade has increased throughout the tropics driven by market demand and rising human densities, development of roads, modern hunting equipment, and poor management practices (Bennett 2002). A depletion of tropical animal species can have severe consequences on forest structure and plant population dynamics when those hunted animals influence seed production and plant regeneration (Wright *et al.* 2007). For example, hunting leads to reduced seed movement of plants with large diaspores, which alter species composition of seedling and sapling layers (Stoner *et al.* 2007). A study by Donatti *et al.* (2009) on an endemic Atlantic forest palm, *Astrocaryum aculeatissimum*, suggest that plants that rely on scatter-hoarding rodents such as agoutis are at risk of regional extinction due to defaunation.

INVASIVE SPECIES.—Non-native animals and plants can have detrimental effects on native tropical biodiversity. Invasive plant species can out-compete native plant species for abiotic resources (sunlight, nutrients, water) and biotic resources (pollinators, seed dispersers). Invasive animal species can lead to an increase in herbivory and grazing and a decrease in pollination (*e.g.*, nectar robbers; Dohzono *et al.* 2008). Invasive species have been shown to directly cause extinction in many animal species (Clavero & García-Berthou 2005), but there is little evidence for the extinction of plant species, especially in the tropics (Gurevitch & Padilla 2004, Sax & Gaines 2008). One example comes from Mauritius in which two native plant species previously known to be locally extinct reappeared after removal of the non-native vegetation (Baider & Florens 2011).

The impact of invasives on tropical islands, which generally have a greater number of endemics, can be large and noticeable. The number of invasive species on many islands has increased linearly over time and models suggest that many more species will become naturalized on islands in the foreseeable future (Sax & Gaines 2008). The amount of invasive species in intact continental tropical ecosystems is less noticeable and viewed as less intense, where it is generally assumed that undisturbed tropical forests are highly resistant to the invasion of non-native plant species (Corlett 2010). With increased fragmentation, road access, and altered fire regimes, however, tropical continental ecosystems are experiencing an increase in the rate of alien plant naturalization (Delnatte & Meyer 2012). Martin *et al.* (2009) found that at least 59 shade-tolerant, late-successional species are known to have invaded deeply shaded tropical forest understories around the world, including the invasive *Cinnamonum verum,* which dominates the canopy of many inland forests of the Seychelles (Schumacher *et al.* 2009). The tropical forests of Australia, for example, have recently seen an increase in the rate of spread of invasive plant species (Bradshaw 2012), although a history of deforestation and fragmentation may have made them particulary prone to invasion.

Whether these invasive species cause extinction, or more likely cause displacement and community change, requires more research. Although evidence of plant extinction caused by non-native plant species is rare (Powell *et al.* 2013), Gilbert and Levine (2013) recently found that it may take decades to centuries for native plant extinctions to be realized. This delay, or 'extinction debt,' is caused by invasive species decreasing the size of the habitat of the native species, which leads to decreased seed production, and invasive species reducing the connectivity between native populations (Gilbert & Levine 2013).

Species-level interactions can be very complex in the case of invasive species. In some cases, certain invasive species may facilitate the invasion of additional invasive species. For example, Lach *et al.* (2010) found that on an islet off of Mauritius, an invasive ant, *Technomyrmex albipes*, protects an invasive plant, *Leucaena leucocephala*, from the plant's primary herbivore (the psyllid *Heteropsylla cubana*), while negatively affecting the native shrub, *Scaevola taccada*, by tending to its sap-sucking hemipterans. More research is needed in the field of multi-level interactions among tropical species, which will ultimately aid in the development of management plans for invasive species.

Pollution.—Studies on the effects of pollution on biodiversity have largely focused on birds, amphibians, fish, and aquatic invertebrates, primarily in temperate areas (McNeely 1992). Nitrogen deposition, as a result of agricultural fertilization and fossil fuel combustion, has greater consequences on the temperate flora, which is nitrogen limited, than in tropical ecosystems (Matson *et al.* 1999). Biodiversity in the tropics, however, can still be harmed by pollutants. Urban waste, fertilizer and pesticide runoff, and industrial pollutants were identified as leading causes in the decline of carnivorous plants worldwide, including tropical species (Jennings & Rohr 2011). Tropical mangrove forests are particularly susceptible to chemical, industrial, and urban wastes (Ellison & Farnsworth 1996), as well as oil spills (Duke *et al.* 1997), which has led to cases of tree defoliation and stand death.

Climate change.—Pollutants such as carbon dioxide emissions are the leading cause of global climate change. Current measures of carbon dioxide emissions are following the high end of emission scenarios used by the Intergovernmental Panel on Climate Change (Peters *et al.* 2013). If emissions continue to remain at today's levels, it will be unfeasible to prevent an increase in global average temperatures less than 2°C (Peters *et al.* 2013), with climate models showing an increase in annual mean temperature by 2.5–4.7°C in the tropics (Cramer *et al.* 2004). In addition to increasing temperatures, rainfall patterns are expected to change. According to computer models, tropical precipitation is predicted to shift northward, increasing the likelihood of monsoon weather systems in Asia and a shifting of the wet season from south to north in tropical Africa and South America (Friedman *et al.* 2013). With the wet season shifting northward, areas such as the Amazon will experience severe droughts. Models predict that dry-season water stress will lead to a large-scale 'dieback' or degradation of the Amazon rain forest (Cox *et al.* 2004, Malhi *et al.* 2009). Models for the Hawaiian Islands also predict drier winter seasons and a reduction in heavy rain events (Timm *et al.* 2013). The link between climate change and drought, however, has recently been questioned (Sheffield *et al.* 2012).

Projected estimates show that climate change may differentially affect biodiversity in tropical and temperate regions, with initial estimates showing a greater impact on biodiversity in arctic and boreal zones, and less in the tropics (Sala *et al.* 2000, Lee & Jetz 2008). Furthermore, some recent arguments based on comparative phylogeographic data show that mass extinction of tropical plants due to a moderate increase in temperatures is unlikely (Dick *et al.* 2013). Yet, empirical evidence shows that in tropical wet forests, in Costa Rica, for example, tree growth is highly sensitive to dry-season conditions and variations in mean annual nighttime temperatures (Clark *et al.* 2010). Recent models predict that tropical lowlands will experience a net loss of plant species richness because projected temperatures may go beyond the current range of heat tolerance (Colwell *et al.* 2008). Thomas *et al.* (2004) predicts that 38–57 percent (under various future climate scenarios) of Brazilian plants in the cerrado is committed to extinction due to climate change.

Plant species in the tropics will either tolerate increased temperatures or they will respond through adaptation, evolutionary changes, distribution shifts, or extinction. It is hypothesized that tropical lowland species are already living near their thermal optimum (Colwell *et al.* 2008). It is theorized that tropical plants will be sensitive to climate change because these species experience low temperature variation and have low tolerance to high temperatures (Laurance *et al.* 2011). Ecophysiological studies suggest that while some tropical tree species have a high-heat tolerance threshold (Lloyd & Farquhar 2008), other species have little capacity to acclimate to further heat stress (Krause *et al.* 2010). Other current research suggests that plant communities around the world respond better to drought conditions than previously thought, using water more efficiently during periods of decreased rainfall (Ponce Campos *et al.* 2013). This study, however, included only five tropical sites (Puerto Rico, Panama, and Queensland, Australia) in its study of 43 long-term experimental sites, suggesting that more research in ecosystem resilience is needed throughout various tropical regions.

If tropical plants are thermally specialized, they may not be able to tolerate global warming as easily as temperate plant species. Populations of tropical plants that cannot tolerate climate change may instead undergo evolutionary adaptation to increased temperatures. Evolutionary change to a changing climate can be rapid, as demonstrated in a study of a temperate annual plant, in which flowering phenology shifted in 7 yr as an adaptive evolutionary response to climatic fluctuations (Franks *et al.* 2007). Whether tropical plant populations can respond as rapidly as this temperate case study remains to be tested.

If adaptation to a changing climate is problematic, tropical plant populations may shift in elevational or altitudinal range. Habitat loss and fragmentation interrupt ecological flows and will decrease the ability of many species to shift their distribution (Beaumont & Duursma 2012). Some argue that the most vulnerable plant species in the tropics are upper-zone specialists (*i.e.*, high tropical montane, páramo, puna, tropical alpine) (Laurance *et al.* 2011). Recent studies have examined the projected altitudinal upward shift of tropical montane plant species in Africa (Kreyling *et al.* 2010) and South America (Rull *et al.* 2009). Each of these studies finds a high level of lowland attrition, range-shift gaps, and mountain-top extinctions. Species that shift upward will also have fewer habitats to colonize. For example, Rojas-Soto *et al.* (2012) show that, under two different climate change scenarios, climatically suitable areas for cloud forests in Mexico will be reduced 54–76 percent in the next four decades. Spatial analysis forecasts in Vegas-Vilarrúbia *et al.* (2012) predict that habitats in the Guayana Highlands mountain biome will experience more than 80 percent loss, which would put over 1700 vascular plant species in danger of extinction (Nogué *et al.* 2009).

Population-wide assessments of plant mortality and recruitment are already showing responses to a warmer and drier environment on mountains. Feeley *et al.* (2011) shows that 23 of 38

Andean tropical tree genera have shifted their mean distributions higher in altitude this past decade, and more tree genera from lower elevations are increasing in abundance higher up. For species at the top of mountains, the situation is dire. For example, the Haleakalā silversword, *Argyroxyphium sandwicense* subsp. *macrocephalum*, in Hawaii has already seen high levels of mortality at the lower end of its distributional range over the past 30 years, believed to be caused by increasing air temperatures and solar radiation and decreasing rainfall (Krushelnycky *et al.* 2013), foreshadowing a bleak outlook if these trends continue.

Global climate change is predicted to change the species composition of tropical forests. The distribution of exotic vines is predicted to increase in tropical rain forests under future climate scenarios (Gallagher *et al.* 2010), particularly under increased frequency of disturbances (Horvitz *et al.* 1998). In the tropical lowlands, global warming may lead to a novel community of heat-tolerant plant species (Colwell *et al.* 2008). Changes in species composition are already being observed. Using repeated censuses of plots in the central Amazon, Laurance *et al.* (2004) found that over a 20-year period, undisturbed tropical forests saw an increase in faster growing canopy and emergent trees and a decrease in slower growing subcanopy trees. They could not explain, however, if the cause of those changes was due to alterations in regional temperature, atmospheric $CO_2$ concentrations, rainfall, or nutrient deposition (Laurance *et al.* 2004). In a study using dated herbarium specimens collected from tropical South America over the past 40 years, Feeley (2012) found that over half of the 239 species examined exhibited some evidence of distribution shift toward cooler areas.

Tropical coastal species and island endemics may also be acutely vulnerable to climate change (Fordham & Brook 2010), due to the melting of glaciers in Greenland and Antarctica, which may cause a sea level rise as high as 1 meter by the end of the century (Bamber & Aspinall 2013).

CO-EXTINCTION.—The loss of one species can lead to domino effect on another species when they are obligately dependent on each other. Koh *et al.* (2004) found that 6300 species will be endangered should their host species become extinct, including butterflies on their larval host plants and pollinating fig wasps and *Ficus* species. Most of these studies examine the effect of plant loss on animals, but the reverse may prove to be true too. Plants can be vulnerable when the animal species they interact with (*i.e.*, pollinators, frugivores, seed dispersers) are threatened. Case studies show that seedling density is higher in fragments inhabited by their frugivores than in fragments where the frugivores are absent due to over-hunting (Nuñez-Iturri *et al.* 2008, Anzures-Dadda *et al.* 2011). Invertebrate seed dispersers, such as dung beetles, can also be indirectly affected by hunting when dung-producing vertebrates decline (Stoner *et al.* 2007), which will lead to cascading effects on plants that benefit from these animals.

Animals pollinate an estimated 94 percent of all tropical plant species (Ollerton *et al.* 2011). Any significant decline in the populations of the pollinating animal species will impede plant reproduction in the populations of those plants that are dependent on the affected pollinator (National Research Council 2007). Many tropical pollinating animals, such as birds, bats, and insects, are currently at risk from overexploitation (Struebig *et al.* 2007), invasive species (Abe *et al.* 2008), pesticides (Whitehorn *et al.* 2012), and global climate change (Deutsch *et al.* 2008). Projections show the Indomalayan, Malagasy, and Oceania regions among those that will experience the highest proportion of real and functional avian extinctions, suggesting severe consequences for plant populations and community dynamics due to reduced bird pollination and seed dispersal (Şekercioğlu *et al.* 2004). Specialization, however, of both pollination and seed dispersal networks decreases toward tropical latitudes (Schleuning *et al.* 2012), buffering these mutualistic networks in the tropics against co-extinction. More studies are needed on the interplay between animal loss and tropical plant population dynamics, especially in the light of climate change and its role in shifting animal habitats.

SYNERGIES.—The Millennium Ecosystem Assessment (2005) argues that the greatest threat to tropical plant biodiversity is the combined effect of landscape modification and accelerated climate change. Most endangered species have a higher risk of extinction than previously thought because the threats they face are interacting and self-reinforcing (Brook *et al.* 2008). Fragmentation, for example, might lead to changes in the abiotic environment of a species causing population decline, but the threats are reinforced by habitat access to harvesting, invasive species, and the impact of climate change. If organisms must shift their distribution to avoid increased temperatures or drought, fragmentation and habitat destruction may prevent their dispersal. Reduced precipitation and a longer dry season in the tropics could increase the accessibility of remote forests, leading to increased habitat disturbance such as fires, which in turn will decrease the resilience of the ecosystem to climate change (Brodie *et al.* 2012). Increased frequency of extreme climatic events (*e.g.*, hurricanes, droughts) brought on by climate change may facilitate the increased rate of invasive species introductions (Diez *et al.* 2012).

Future conservation actions should not just target single threats, but rather examine the cascading effects caused by the synergies of multiple threats (Brook *et al.* 2008). The interactions among the various drivers of species endangerment remain the largest stumbling block in modeling human impacts on the health of tropical biodiversity.

## CHALLENGES AND OPPORTUNITIES

To halt the current and continuing loss of plant diversity, the Global Strategy for Plant Conservation (http://www.cbd.int/gspc/) was adopted in 2002 at the sixth meeting of the Conference of the Parties to the Convention on Biological Diversity. Sixteen outcome-oriented targets were established and designed to explicitly address the survival and sustainable use of the world's plant biodiversity (GSPC 2002). By the original 2010 deadline, considerable progress had been made toward achieving eight of the 16 targets at the global level, but limited progress was achieved in the others (https://www.cbd.int/doc/meetings/cop/cop-09/information/cop-09-inf-25-en.pdf). In 2010, the GSPC was revised with modified targets and an extended deadline of 2020 (Convention on Biological Diversity 2010).

Various countries have developed national strategies and targets of their own, including some tropical countries such as Brazil, Colombia, and Malaysia. Regional strategies can be more complicated than national strategies as they require the cooperation of neighboring countries. Torres-Santana *et al.* (2010) comprehensively examined each target among the island nations of the Caribbean and found that even though there had been considerable activity, accomplishments had been limited and there was relatively little collaboration among island plant conservationists.

In this section, progress on 13 of the 16 targets is examined for the tropical flora. Targets 6, 9, and 13 focus on crop management and indigenous knowledge and will not be examined in this review. For each target, critical research needs necessary to achieve the targets will be discussed, and emerging questions and opportunities relevant to the tropics will be highlighted.

TARGET 1: AN ONLINE FLORA OF ALL KNOWN PLANTS.—A working list of all known plant species is available at The Plant List (http://www.theplantlist.org/), and the next stage of this target is to create an online flora. One cannot prevent a species from going extinct unless that species is known to science. The world's flora has not yet been fully described, several tropical areas remain unsurveyed (Posa *et al.* 2011), and the tropical flora remains poorly known (Chen *et al.* 2009). With enough effort, we are less than 50 years away from discovering and describing the last new species of plant on Earth (Kress & Krupnick 2005, Wheeler *et al.* 2012). Rapid DNA sequencing, electronic field guides, image-recognition software, advanced cyberinfrastructure, and fully referenced, archived and digitized herbarium collections will aid in this effort. The conservation benefits of completing a world's flora are broad, from the development of baseline data on species occurrences to the assessment and prioritization of threatened species and ecoregions (Wheeler *et al.* 2012).

Building a broader collection of plant specimens within the world's herbaria will not only aid in completing the world's flora, but will be important in many other aspects of tropical ecology and conservation (Kress *et al.* 2001, Graham *et al.* 2004, Lister 2011). The world's herbaria contain millions of specimens, yet the tropics remain under-sampled because of difficulty of access and are thus not adequately represented in these collections (*e.g.*, Myanmar; Kress *et al.* 2003). Nevertheless, specimen data have value in predictive modeling of conservation priority areas, conservation assessments of species, and predicting the impacts of global climate change (Donaldson 2009). For instance, a lack of basic data has made it difficult to create species distribution models for many tropical plant species (Feeley & Silman 2011b). Feeley and Silman (2011a) found that geo-referenced collections of 90 percent of tropical plant species were too small for contemporary modeling of climate change responses. Global biodiversity data sets are generally skewed toward the poles (Collen *et al.* 2008). An increase in the collection and databasing of new tropical plant specimens is needed.

New methods in taxonomy and molecular biology will help lead the way in the discovery of new tropical plant species. DNA barcoding has proven to be a valuable, cost-effective tool in the identification of new species, invasive species, medicinal species, and other highly traded species including those listed under the Convention on International Trade in Endangered Species (CITES) of Wild Fauna and Flora (Kress & Erickson 2008, Lahaye *et al.* 2008, Hollingsworth *et al.* 2009). DNA barcoding can also be used in reconstructing plant–animal networks (García-Robledo *et al.* 2013), which may lead to the discovery and conservation management of new interactions.

TARGET 2: AN ASSESSMENT OF THE CONSERVATION STATUS OF ALL KNOWN PLANT SPECIES, AS FAR AS POSSIBLE, TO GUIDE CONSERVATION ACTION.—To date, insufficient progress has been made on meeting this target. Of the more than 350,000 known plant species, only 15,501 vascular plant taxa appear in the 2012 IUCN Red List of Threatened Species (IUCN 2012), and only two groups of plants (conifers and cycads) have been fully assessed, far fewer than that for vertebrate taxa. The procedures of Red Listing require data that are generally not available for many tropical plant species. Although many regional assessments in the tropics have been completed (*e.g.*, Jorgensen & León-Yánez 1999, Llamozas *et al.* 2003, Zona *et al.* 2007), most of these efforts have assessed species on a regional or national, rather than global, basis or only include those species identified as threatened.

The Red List is a powerful tool for conservation planning, management, and decision making (Rodrigues *et al.* 2006). The data on extinct and endangered species are frequently being used in assessing trends and making comparisons among the various threats, habitats, and taxa. It is unfortunate, however, that while the assessments for vascular plant species are less than 5 percent of the world's flora, many published analyses are making very strong assumptions based on very limited data (*e.g.*, Gurevitch & Padilla 2004, Sax & Gaines 2008). It is urgent that we accelerate plant species assessments, particularly in areas where the degree of future plant species endangerment is predicted to be high (Giam *et al.* 2010).

With 95 percent of plant species still yet to be assessed at the global scale, new approaches to conservation assessment are urgently needed (Lughadha *et al.* 2005, Krupnick *et al.* 2009, Schatz 2009, Miller *et al.* 2012). Red List indices based on a representative subset of plant species are one approach to understanding how many plant species are threatened (Lughadha *et al.* 2005). Target 2, however, calls for the assessment of all known plant species and not just a subset. Full conservation assessments are best done with expert knowledge and population data from the field. One alternative to a preliminary approach is to use data from herbarium specimens with (Rivers *et al.* 2010, 2011, Miller *et al.* 2012) and without (Krupnick *et al.* 2009) geo-referenced coordinates. Adapting these approaches will assist in the timely completion of Target 2.

TARGET 3: INFORMATION, RESEARCH AND ASSOCIATED OUTPUTS, AND METHODS NECESSARY TO IMPLEMENT THE STRATEGY DEVELOPED AND SHARED.—An internet-based toolkit developed by BGCI (http://www.plants2020.net) provides information, technical details, links to manuals, and case studies relevant to each of the targets of the Strategy. Many unpublished reports developed in tropical countries, however, are not readily accessible to plant conservation practitioners. Retrieval of these methodologies and practices, and translation into multiple languages, should be a top priority to meet the goals of this target.

TARGET 4: AT LEAST 15 PERCENT OF EACH ECOLOGICAL REGION OR VEGETATION TYPE SECURED THROUGH EFFECTIVE MANAGEMENT AND/OR RESTORATION.—Protecting a percentage of each ecoregion will assist in the conservation of the different species within each vegetation type. A recent overview by Schmitt *et al.* (2009) shows the amount of forest, with 10 percent tree cover, that is protected in Global Forest Map (GFM) forest types and WWF realms and ecoregions. The study found that only 3 of the 12 tropical GFM forest types (tropical upper montane forests, tropical semi-evergreen moist broadleaf forests, and tropical sclerophyllous dry forests) are above the 15 percent threshold for protection using the restrictive IUCN management categories I–IV. In contrast, tropical mixed needleleaf/broadleaf forests have only 4.3 percent protection. The study further found that the WWF Neotropical realm has the most protection at 10.6 percent, with the Indo-Malayan realm (9.9%), Oceanian realm (7.5%), and Afrotropical realm (6.4%) lagging behind.

Protected area designations are not permanent. Protected areas can at any time be delineated or redrawn by local governments, putting these areas at risk of further degradation and deforestation (*e.g.*, Curran *et al.* 2004). For example, in a recent study on the designation of protected areas by Mascia and Pailler (2011), it was found that at least 63 protected areas in 20 tropical countries have experienced downgrading, downsizing, and degazettment events since 1900. Zimmerer *et al.* (2004) reports evidence that five tropical countries (Cameroon, Gabon, Ghana, Guinea-Bissau, and Togo) had experienced a 5–60 percent decline in protected area coverage between 1985 and 1997. It is essential that management of endangered species take into account the impermanence of protected area designations.

Neither are protected areas inviolate. Identifying and monitoring illegal logging, encroachment, and other anthropogenic interventions in real time is one way to increase the effective management of protected areas. Urgent calls to build an international satellite monitoring system have recently been made (Lynch *et al.* 2013). Global Forest Watch 2.0 (GFW 2.0) is a new forest monitoring system that is currently under development and is slated to launch at the end of 2013 (http://www.wri.org/gfw2). GFW 2.0 uses satellite technology, mobile phone technology, data sharing, and human networks around the world to monitor and address illegal logging and deforestation. The new technology will make it possible to identify forest clearing within a 2-week period.

Target 4 also calls for the effective restoration of disturbed and degraded lands within ecological regions. The recovery and reintroduction of individual species is covered in Target 8. Landscape-scale restoration of forests and degraded lands are an approach often motivated by the recovery of biodiversity and ecosystem services and connecting fragmented areas (Sodhi *et al.* 2011, Ciccarese *et al.* 2012). Broadscale forest recovery via satellite observations has recently been seen in the Caribbean (Cuba, Puerto Rico, and Haiti), Mexico, and Central America (Honduras, Costa Rica, and El Salvador), primarily in tropical moist forests at high elevation (Aide *et al.* 2013). The satellite imagery in this study, however, could not separate out the cause of woody vegetation gain as natural regeneration, encroachment, or direct human intervention.

The biggest hurdles in landscape-scale restoration in the tropics are that both successes and failures are not reported and that research attention has not been directed across multiple sites working over multiple years (Holl *et al.* 2003, Brudvig 2011, Menz *et al.* 2013). Revegetation projects should also update their methods by sourcing seeds from climatically diverse areas to maximize evolutionary potential and adaptation to climate change (Hoffmann & Sgrò 2011).

One approach to the large-scale restoration of tropical habitats that is beginning to receive attention is the development and use of unmanned aerial vehicles (drones), which have the potential for remote sensing of forest cover, species distributions, and illegal harvesting of timber (Koh & Wich 2012). Aerial reseeding using planes and helicopters is currently being utilized to revegetate temperate areas of China (Wenhua 2004). Currently under review are opportunities of using drones in aerial reseeding, which are cheaper than helicopters and less dangerous in mountainous areas, in tropical areas, such as Thailand (Sutherland *et al.* 2013).

TARGET 5: AT LEAST 75 PERCENT OF THE MOST IMPORTANT AREAS FOR PLANT DIVERSITY OF EACH ECOLOGICAL REGION WERE PROTECTED, WITH EFFECTIVE MANAGEMENT IN PLACE FOR CONSERVING PLANTS AND THEIR GENETIC DIVERSITY.—Important plant areas are typically defined as those areas with outstanding assemblages of rare, threatened, or endemic plant species. As of 2010, 66 countries have become engaged in projects to identify important plant areas, and of these, a mere 19 are in the tropics (5 countries in the Afrotropics, 10 in Indo-Malay, and 4 in the Neotropics) (Plantlife 2010), indicating that more involvement by tropical countries is needed. Butchart *et al.* (2012) show that, on a global scale, 51 percent of the Alliance for Zero Extinction sites is unprotected, arguing that better targeted expansion of protected areas is necessary.

Important plant areas are selected based on three criteria: (1) threatened species, (2) species richness, and (3) threatened habitats. The identification of important plant areas can be improved through recent advances in survey-gap analyses and the modeling distributions of rare species (Funk *et al.* 2005). Yet, with increasing knowledge of how phylogenetic diversity can contribute to nature conservation, the integration of evolutionary knowledge into international biodiversity policies and practice has been largely neglected (Winter *et al.* 2013).

TARGET 7: AT LEAST 75 PERCENT OF KNOWN THREATENED PLANT SPECIES CONSERVED *IN SITU*.—The goal of *in situ* plant conservation at the species level is to prevent the loss of the species in nature. Progress in identifying priority species for this target has been hampered by the lack of data on the conservation status of many species (GSPC Target 2). The principal approach for *in situ* conservation is the establishment and maintenance of a network of protected reserves. Few undisturbed tropical forests exist today, even though these are better at sustaining tropical biodiversity than disturbed forests (Gibson *et al.* 2011). As more threatened species are found outside of protected areas, successful conservation of these species will require strategic efforts to protect them wherever they are, including secondary forests and other human-modified landscapes (Wright 2005, Chazdon *et al.* 2009).

Protected area systems in the tropics are not entirely infallible either, and thus just knowing that a threatened species exists in a reserve is no assurance that it will remain safe. To maintain the viability of a threatened plant population in a protected area, the species must not suffer from the 'benign neglect' approach to conservation (Heywood & Iriondo 2003). Species within protected areas must be monitored and actively managed. In addition, neighbors of protected reserves should be treated as 'partners in conservation', rather than managing a reserve as a 'fortress' that should never be touched (Heywood & Iriondo 2003).

As threats continue to put tropical plant species in danger of extinction, regular monitoring based on observations and measurements of select species and select sites in the tropics is necessary (Bawa *et al.* 2004). SIGEO (http://www.sigeo.si.edu/), GLORIA (http://www.gloria.ac.at), and RAINFOR (http://www.rainfor.org/) are three examples that serve this purpose through networks of tropical observation sites, which will collect repeated data necessary to document the impact of climate change on biodiversity such as species range displacement. The development of Essential Biodiversity Variables, a global harmonized observation system, can help facilitate the measurement and management of biodiversity change (Pereira *et al.* 2013).

As global climate change impacts the tropics, management decisions will have to be made in regards to maintaining the viability of the native biodiversity, including the creation of new protected areas for threatened species, connectivity, adaptive management, managed relocation, and ex situ conservation (Hannah 2011). Current reserves under past management practices are unlikely to be effective when responding to climate change, and thus more intensive management is necessary (Lee & Jetz 2008, Hellmann & Pfrender 2011), even though our knowledge of ecosystem management and restoration is poor (Rands *et al.* 2010). Pre-emptive conservation planning, such as restoring forest continuity, especially along altitudinal gradients, will be necessary in consideration of the impacts of high-end estimates of global warming (Corlett 2012).

Conserving plants *in situ* will further require understanding of population genetics and climate tolerance within tropical species (Harte *et al.* 2004). A challenge is put forth in Dick *et al.* (2013) to ask whether tropical plant species have lost their tolerance for higher temperatures over time. If the species do not have the tolerance for higher temperatures and increased drought, will tropical plant populations have the necessary genetic variance for adaptation, and how will this differ between species that have large effective populations and those with small population sizes (Hoffmann & Sgrò 2011)?

TARGET 8: AT LEAST 75 PERCENT OF THREATENED PLANT SPECIES IN EX SITU COLLECTIONS, PREFERABLY IN THE COUNTRY OF ORIGIN, AND AT LEAST 20 PERCENT AVAILABLE FOR RECOVERY AND RESTORATION PROGRAMS.—Ex situ collections contain representative living specimens of appropriate genetic diversity, which are stored outside of their natural environment. These specimens take the form of living plants, viable seeds, or tissue and cell cultures, each having their own level of expense. Seed banking is considered to be the most cost-effective of ex situ conservation measures, and can cost as little as one percent of conserving the species *in situ* (Li & Pritchard 2009). The seeds of many moist tropical forest trees either germinate immediately and cannot be stored or are recalcitrant (Tweddle *et al.* 2003, Chen *et al.* 2009), but recent innovations in cryopreservation may aid in the long-term storage of many tropical species. In addition, living collections in tropical botanical gardens can pose a risk of escape and invasion (Chen *et al.* 2009), and thus new strategies must be considered.

Global progress toward Target 8 shows that at least 23 percent of the world's globally Red Listed threatened plant species are known to be scattered among the world's botanical gardens (Sharrock *et al.* 2010, Kramer *et al.* 2011). Estimates of this measure for temperate regions are higher than the global average (*e.g.*, Europe 42%, Russia 64%, North America 39%, South Africa 36%), suggesting that estimates for tropical regions, which have not been measured, are most likely well below the 75 percent goal. Efforts and approaches in the ex situ conservation and the long-term preservation of tropical plant species need to increase (Li & Pritchard 2009).

Recovery and reintroduction programs involve establishing extirpated or rare species in either protected reserves or in degraded habitats. In a review by Godefroid *et al.* (2011) on the success rates of plant reintroduction programs worldwide, reintroduced populations generally have low levels of survival, flowering, and fruiting, and success rates usually decline with time. That analysis, however, was short on tropical data. Restoration methods for tropical species are critically needed and long-term data will be highly valuable in understanding the role that ex situ collections serve in recovery and restoration (Donaldson 2009).

As climate change displaces tropical plant species from their native habitats, ex situ collections may prove to be vital in assisted migration projects. Highly controversial, assisted migration (also known as managed relocation) involves moving a species to new habitats outside its historical distribution as a managed response to a changing climate. Ecological, ethical, legal, and political arguments have been made against this practice, including the disruption of existing communities and the dangers of a translocated species becoming invasive in its new habitats

(Hewitt *et al.* 2011, Schwartz *et al.* 2012). Yet, if assisted migration programs are not chosen, the threat of climate-driven extinctions may increase. Management of these species will require the emphasis on the spread of natural populations instead (McLachlan *et al.* 2007). More research carefully examining the risks, benefits, and trade-offs to tropical lowland and montane plant species is needed. Tropical gardens with their extensive ex situ collections are positioned to play a big role in future studies (Chen *et al.* 2009).

TARGET 10: EFFECTIVE MANAGEMENT PLANS IN PLACE TO PREVENT NEW BIOLOGICAL INVASIONS AND TO MANAGE IMPORTANT AREAS FOR PLANT DIVERSITY THAT ARE INVADED.—Fewer articles have been published that address species invasions in tropical environments and developing countries than in temperate environments and developed countries (Petenon & Pivello 2008, Nuñez & Pauchard 2010), indicating that further research on tropical biological invasions and management is needed. There is a strong need for increased surveillance, early detection, and eradication of invasive species (Delnatte & Meyer 2012). Compared with developed countries in temperate regions, developing countries in tropical regions have some disadvantages in controlling exotics, such as lower levels of social awareness and lesser means for managing exotics, but advantages include lower rates of introduction and the availability of low-cost labor (Nuñez & Pauchard 2010). Endangered species can recover after manual removal of invasive species, and native vegetation has been shown to return to a pre-invasion state after labor-intensive control of invasive species in tropical areas (Jäger & Kowarik 2010). Invasive species removal, however, must be seen in the greater context of multi-species interactions, such as herbivory, pollination, and predation. For example, removal of an invasive plant species in a tropical dry forest has been shown to lead to greater levels of herbivory on the native plant population (Prasad 2010).

More effort is also needed in identifying which native species are most appropriate for reforestation, rehabilitation, and ornamentals, for which non-natives selected in those roles tend to be those that become invasive species (Denslow *et al.* 2009, Delnatte & Meyer 2012). Other key questions include knowing when and how to manage invasive species after they establish in tropical reserves, particularly if multi-level interactions with native species have been found.

TARGET 11: NO SPECIES OF WILD FLORA ENDANGERED BY INTERNATIONAL TRADE.—CITES is the leading coordinating agency for the implementation, monitoring, and review of Target 11. Of the approximately 300 plant species listed in CITES Appendix I and over 28,000 species (including the entire orchid and cactus families) listed in Appendix II, many tropical plant species are monitored through the issue and control of export and import permits. Many tropical timber species and medicinal plant species, however, have yet to be listed. After several years of pressure (Patel 2007, Schuurman & Lowry 2009, Barrett *et al.* 2010), the rosewoods (genus *Dalbergia*) and ebonies (genus *Diospyros*) from Asia, Central America, and Madagascar were recently added to Appendix II at the 16th meeting of the Conference of the Parties in Bangkok, Thailand (http://www.cites.org/eng/notif/2013/E-Notif-2013-012.pdf).

Although countries continue, and sometimes struggle (Blundell 2007, Phelps *et al.* 2010) to regulate trade of CITES-listed species, especially those traded in public border markets and black markets, internet commerce has opened up as a new avenue for illegal activity. In a recent study examining the sale of listed cactus species on an internet auction site, Sajeva *et al.* (2013) found that about 89 percent of a sample of 1000 plants were potentially traded without CITES-issued permits, suggesting concerns about the capability of protecting CITES species in an era of e-commerce.

DNA barcoding has the potential to serve in the identification of highly traded CITES-listed species. With advanced technology, custom officers may 1 d be able to positively identify plant species and plant fragments, and distinguish those that are listed in Appendix I from Appendix II and those not listed by CITES (Lahaye *et al.* 2008).

TARGET 12: ALL WILD-HARVESTED PLANT-BASED PRODUCTS SOURCED SUSTAINABLY.—Overharvesting of wild plant species for food, fuel, and medicines can have serious consequences on both the plant populations and the livelihoods of the people these plants support. Finding a balance between sustainably harvesting tropical NTFPs and supporting people with enough income, medicine and plants has been a focus of study for the past two decades (Hall & Bawa 1993). Recent advances in comparative analysis and the use of matrix population models (Caswell 2001) are being used to generate management recommendations for tropical NTFPs (Montúfar *et al.* 2011, Schmidt *et al.* 2011). For example, Endress *et al.* (2006) examined the effects of several leaf harvest treatments on the Mexican palm *Chamaedorea radicalis* over a 6-year period, and was able to provide recommendations for sustainable harvest of this species with only a few modifications of current harvest practices. Studies using matrix models, however, are rare for tropical African and Asian plant species, for populations of lianas, vines, ferns, and cycads, and tend to be shorter than 3 yr (Schmidt *et al.* 2011). To make successful progress on Target 12, long-term studies on a wide range of tropical plant families from multiple regions and the integration of climate change models with the matrix population models will be necessary.

TARGET 14: THE IMPORTANCE OF PLANT DIVERSITY AND THE NEED FOR ITS CONSERVATION INCORPORATED INTO COMMUNICATION, EDUCATION, AND PUBLIC AWARENESS PROGRAMS.—Tropical botanists, ecologists, and conservation biologists can play an important role in communicating and educating the public about plant conservation issues. Addressing questions, such as "how does human well-being relate to the structure and functioning of tropical ecosystems" (Bawa *et al.* 2004), is one way to connect conservation biology to the public. Social and professional networking websites, which did not exist when the Strategy was first written, are new ways to engage the public. Another way to engage the public and raise awareness is through citizen science, with projects such as those focused around plant monitoring as it relates to climate change.

TARGET 15: THE NUMBER OF TRAINED PEOPLE WORKING WITH APPROPRIATE FACILITIES SUFFICIENT ACCORDING TO NATIONAL NEEDS, TO ACHIEVE THE TARGETS OF THIS STRATEGY.—Ahrends *et al.* (2011) shows that trained botanists in tropical plant sciences are more efficient and reliable than untrained botanists in the identification of plant species, and that data quality increases with access to herbaria. Yet, herbaria, botanic gardens, and university botany facilities in many tropical countries suffer from poor support and a lack of investment (Maunder *et al.* 2008). The call for an increase in the capacity of conservation institutions across the tropics is frequently found in published literature (Bawa *et al.* 2004, Sodhi *et al.* 2010), yet the majority of this capacity remains concentrated in rich developed countries rather than in regions facing the greatest conservation challenges to biodiversity (Rands *et al.* 2010). To effectively achieve all 16 targets, we must accelerate and increase the investment in Target 15.

TARGET 16: INSTITUTIONS, NETWORKS, AND PARTNERSHIPS FOR PLANT CONSERVATION ESTABLISHED OR STRENGTHENED AT NATIONAL, REGIONAL, AND INTERNATIONAL LEVELS TO ACHIEVE THE TARGETS OF THIS STRATEGY.—Although most protected areas are located within individual countries, a number of tropical transboundary protected areas, those protected area complexes that result when different protected areas within different countries are connected across international borders, have been growing over the past few decades (Zimmerer *et al.* 2004), suggesting an increase in international coordination and cooperation.

Networks and partnerships supporting plant conservation activities have been on the increase. The Global Partnership for Plant Conservation, Asociación Latinoamericana y del Caribe de Jardines Botánicos, the Center for Tropical Forest Science, and the Organization for Tropical Studies are just a few examples of partnerships all serving an important role in the support of plant conservation. Greater efforts are needed to involve a wide variety of other sectors, such as industry, education, and faith-based organizations, if we are to achieve all targets of this Strategy.

## SUMMARY

The driving philosophy of conservation biologists in the past century was to safeguard every species in protected areas to prevent extinction and to restore degraded habitats. With non-native species invading conservation reserves, global climate change impacting protected areas, and other driving forces altering protected habitats, this philosophy can no longer stand. Plants in protected areas are not sheltered against a changing climate. It is unlikely that all plant species will respond similar to these pressures. The big key questions are can we identify which species will tolerate the predicted increase in temperature and altered precipitation, which will adapt through evolutionary change, which will migrate to more suitable habitats, and which will go extinct? Can we identify a phylogenetic pattern to the response? Different groups of plants will require different strategies for management. For those groups that cannot migrate, tolerate, or adapt to the inventible human-induced changes, what are the best courses of action both inside and outside of their natural habitats to prevent their extinction?

## CONCLUDING REMARKS

Plant ecologists and conservation biologists have a critical role to play in preserving the botanical heritage of the richest flora on Earth. Assessing the number of species, identifying those that are threatened, and understanding how to safeguard them in their native habitats continue to be essential today. Managing tropical plant species against ongoing, new and future threats and changes in the environment is essential in preventing further extinctions. Creating a backup in botanic gardens and seed banks can serve as an insurance policy against extinction in the wild, particularly in the light of climate change. It is essential that tropical plant biologists continue to work with governments and non-profit organizations in building the capacity and resources required to achieve the goals of conservation.

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