Chapter 1

Tropical deforestation: a threat to life on Earth

Tropical forests, which are home to around half of the Earth's terrestrial plant and animal species, are being destroyed at rates unprecedented in geological history. The result is a wave of species extinctions that is leaving our planet both biologically impoverished and ecologically less stable. Although this is widely accepted by scientists, putting precise global figures on rates of tropical deforestation and species losses is not straightforward.

1.1 Rate and causes of tropical deforestation

How fast are tropical forests being destroyed?

Since pre-industrial times, the Earth's tropical forests have shrunk in area by 35–50% (Wright & Muller-Landau, 2006). If losses continue at current rates, the last remnants of primary tropical forest will probably disappear sometime between 2100 and 2150, although global climate change (if unchecked) would undoubtedly accelerate the process.

The United Nations' Food and Agriculture Organisation (FAO) provides the most comprehensive global estimates of tropical forest cover, collating statistics reported by the forest agencies of individual countries (FAO, 2009). Such estimates are, however, far from perfect and are often revised as survey methods become more reliable. Furthermore, definitions of 'forest' vary (e.g. plantations are sometimes included, sometimes not), there is often debate over where the 'edge' of a forest lies, and geographical information technologies are constantly changing. A review of FAO estimates by Grainger (2008) reported that between 1980 and 2005, the area of natural tropical forests[1] worldwide declined from 19.7 to 17.7 million km^2 (**Table 1.1**), an average loss of about 0.37% per year.

The loss of original primary forests[2] is of particular concern for the conservation of biodiversity[3]. Globally[4], FAO (2006) estimates that an average of 60,000 km^2 of primary forest has been destroyed or substantially modified each year since 1990, with just two tropical countries, Brazil and Indonesia, accounting for 82% of this global loss. In terms of percentage losses, both Nigeria and Vietnam lost more than half of their remaining primary forest between 2000 and 2005, while Cambodia lost 29% and Sri Lanka and Malawi each lost 15% (FAO, 2006).

Table 1.1. Natural tropical forest[1] cover (million km^2), 1980–2005 (adapted from Grainger (2008)).

Region	1980[a]	1990[b]	2000[b]	2005[b]
Africa	7.03	6.72	6.28	6.07
Asia-Pacific	3.37	3.42	3.12	2.96
Latin America	9.31	9.34	8.89	8.65
Totals	**19.71**	**19.48**	**18.29**	**17.68**

Sources: *Food and Agriculture Organisation Global Forest Resource Assessments*, [a]1981 and [b]2006. Adapted from Grainger (2008).

[1] 'All naturally occurring woody vegetation with >10% canopy cover, excluding timber plantations, shrub-land etc.'

[2] Forests of native species, with undisturbed ecological processes and not seriously impacted by human activity.

[3] Biodiversity is the variety of life forms, including genes, species and ecosystems (Wilson, 1992). In this book we use the term to refer to all species that naturally comprise the flora and fauna of tropical forests, excluding exotic or domesticated species.

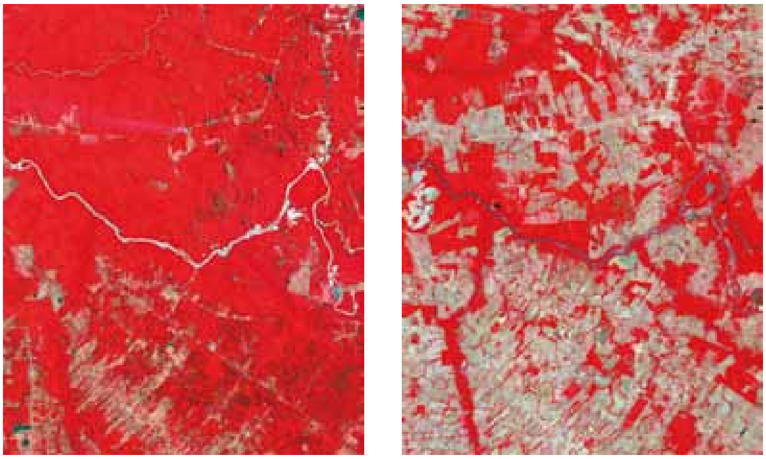
[4] Excluding Russia.

The front line of tropical deforestation — in this case for establishment of oil palm plantations in Southeast Asia. This wholesale destruction is the main cause of the biodiversity crisis and is contributing substantially to global warming. (Photo: A. McRobb).

Although global estimates of tropical forest loss may be problematic, there are many well-documented examples of severe and rapid deforestation at the regional level. For example, between 1990 and 2000, the Indonesian island of Sumatra lost 25.6% of its forest cover (at least 50,078 km^2 of forest). The scale of the destruction is well illustrated on Google Earth (www.sumatranforest.org/sumatranWide.php)

In Brazilian Amazonia, forest cover has been reduced by 10% (377,108 km^2), since 1988. About 80% of forest loss has been caused by clearance for cattle ranches, with much of the rest following highway construction. However, up to 30% of deforested areas may be undergoing natural regeneration (Lucas *et al.*, 2000).

Loss of primary tropical forests and their replacement with secondary forests are likely to continue, despite greater awareness of forest biodiversity and the impact of forest destruction on the environment and climate change. Therefore, whereas conservation of primary forest remains important, management of regenerating secondary tropical forests is fast becoming a major global issue in minimizing biodiversity losses.



Deforestation in the Brazilian state of Mato Grosso, following paving of highway BR 364 (forest in red): left 1992, right 2006 (from NASA Earth Laboratory).

Why are tropical forests destroyed?

The ultimate cause of tropical forest destruction is too many people making too many demands on too little land. The United Nations (2009) predicts that the global human population will surpass 9 billion by 2050 (up from 7 billion at the time of writing); well on the way to exceeding Earth's estimated carrying capacity of about 10 billion (United Nations, 2001). The fate of tropical forests, and that of most other natural ecosystems, ultimately depends on controlling human population growth and consumption.

In most tropical countries, forest destruction usually begins with logging. Logging opens up forest areas by introducing roads and, as the supply of timber trees becomes exhausted, the loggers are followed by landless rural people looking for farmland. The remaining trees are cleared and replaced with small-scale agriculture. Small-holders may initially practice low-intensity, slash-and-burn agriculture, but as a growing population increases pressure on the land, more intensive agricultural systems are typically adopted. As the land value increases, small-scale farmers often sell out to large agro-companies, moving on to clear forest elsewhere.

Tropical deforestion often begins with logging for the timber industry, but many other factors are involved.

However, logging is now declining as a primary cause of tropical forest loss as more timber is produced from plantations. Asia-Pacific leads the way in plantation forestry, having a total of 90 million ha of plantations for wood production in 2005. So, although logging has historically been a major cause of tropical deforestation, it has now been overtaken by the exponential surge in demand for farmland, driven by global markets (Butler, 2009).

In Africa, more than half (59%) of deforestation is carried out by families establishing small-scale farms, whereas in Latin America deforestation is mostly (47%) the result of industrial agriculture, caused by global demand for agricultural products. In Asia, conversion of forest to small-scale farms and replacement of shifting agriculture with more intensive agricultural practices account for 13% and 23% of deforestation, respectively, whereas industrial agriculture, particularly oil palm and rubber plantations, account for 29% (FAO, 2009).

Charcoal making in Brazil. The reliance of more than 80% of people in developing countries on wood or charcoal to cook their food contributes significantly to forest degradation. (Photo: A. McRobb).

Montane forest has been destroyed to make way for tea plantations in Likombe, Cameroon. (Photo: A. McRobb).

An over-grazed landscape in northeast Brazil. (Photo: A. McRobb).

The development of infrastructure, especially roads and dams, can also have a very destructive effect on tropical forests. Although such development impacts relatively small areas of forest, it opens up forest areas for settlement and fragments them, isolating small wildlife populations in ever-shrinking forest fragments.

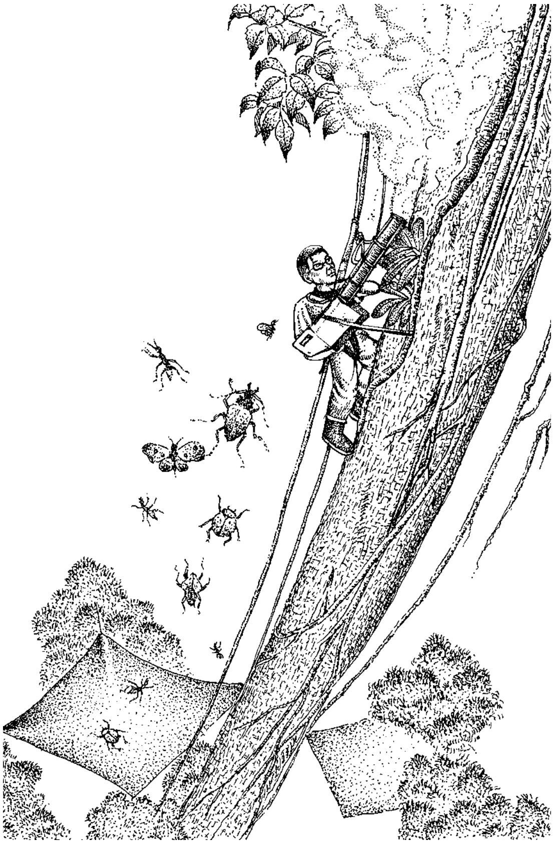
Finally, weak governance is a major factor that enables deforestation to occur. Although most countries have laws to control forest exploitation, forest departments often lack the authority and funding needed to enforce them. Consequently, in many tropical countries, more than half of the timber produced is extracted illegally (Environmental Investigation Agency, 2008). Forest officials are often poorly paid and are therefore easily corrupted. Local communities are marginalised in decision making and therefore lose their sense of forest stewardship. Consequently, strengthening governing institutions, as well as empowering local communities is fundamental to the survival of Earth's tropical forests.

1.2 Consequences of tropical deforestation

The disastrous effects of tropical forest destruction have been well-documented for decades (Myers, 1992). Of most concern is the greatest extinction event in our planet's geological history.

How much biodiversity is being lost?

Although tropical forests now cover only about 13.5% of Earth's land area, they are home to more than half of the planet's terrestrial plant and animal species. So, it is not surprising that their destruction is causing a substantial proportion of Earth's biota to go extinct. It is difficult to put a precise figure on exactly how many species are likely to die out as a result of tropical deforestation, however, because there is no definitive list of all tropical forest species. Vertebrates and vascular plants have been fairly well counted and named, though new species discoveries are not uncommon so this task is certainly not complete. But it is the smaller animals, particularly insects and other arthropods,



In the 1980s, fogging insects in the canopies of tropical forests began to show that Earth's biodiversity was much higher than anyone expected and that tropical forest destruction was a major threat to it.

that contribute most to tropical biodiversity and there are not enough taxonomists working in the tropics to identify and count all of these species.

Back in the 1980s, the work of Terry Erwin began to reveal just how many arthropod species there might be in tropical forests. Erwin (1982) studied beetle communities in tropical tree crowns. He used an insecticidal fogging machine, hoisted into the crowns, to knock down insects. In the crowns of trees of just one species (*Luehea seemannii*), he found 1,100 beetle species, of which about 160 lived exclusively in that tree species. Since beetles account for about 40% of insect species, we can estimate that the crowns of *L. seemannii* trees probably support around 400 specialist insect species, with a further 200 species living on other parts of the tree. The number of tropical tree species known to science is around 50,000. Were each of these to support a number of specialist insect species similar to that of *L. seemannii*, then the world's tropical forests could support around 30 million insect species.

Even though this calculation makes many (still largely untested) assumptions, and relies on work that is 30 years old, it remains one of the most widely quoted estimates of tropical biodiversity; a sad reflection on the progress of taxonomy in tropical forests over the past three decades. A more recent study by Ødegaard (2008), which tested some of Erwin's assumptions, suggested that the global arthropod fauna may be nearer 5–10 million species.

If counting surviving species is problematic, then counting extinct ones is even more so. The continued existence of a species is verified from a single observation, but it is impossible to be certain that a species is extinct, as it may persist where biologists have not yet looked. Rediscovery of 'extinct' species still happens, so, we must rely on biological theory instead of direct species counts to estimate extinction rates.

The most widely applied model is the species-area curve, which is derived from counting species in consecutive, equal-sized, sample plots. As the number of sampled plots increases, the cumulative number of species discovered increases. At first, the increase is steep but the curve levels off, as more sample plots are added because fewer species remain to be discovered. The number of new species in each subsequent sample plot eventually declines to zero when all species have been discovered, and thus the species-area curve reaches an upper asymptote.

To estimate extinction rates, species-area curves are used in reverse to address the question: "how many species will disappear as the area of a habitat is reduced?" Using this logic, Wilson (1992) estimated that about 27,000 tropical forest species go extinct each year on the basis of published rates of forest destruction and a species-area curve that predicts an eventual 50% decline in species numbers when a forest is reduced in area by 90% (**Figure 1.1**).

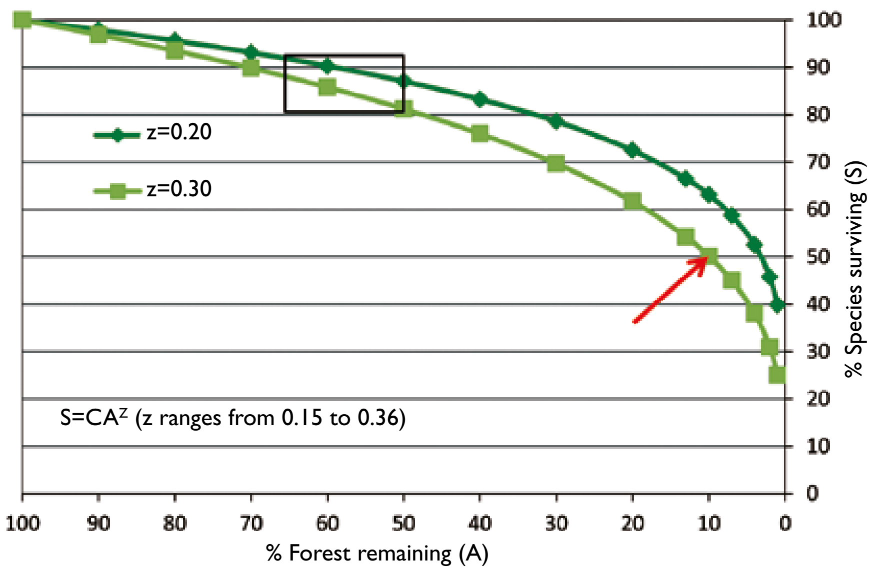


Figure 1.1. Despite their flaws, species-area models still contribute to predictions of extinction rates. For tropical forests, values of the parameter 'z' vary from 0.2 to 0.35 (from empirical studies). A value of 0.3 predicts a 50% decline in biodiversity with 90% forest loss (arrow). The rectangle shows an 8–20% loss of tropical species since pre-industrial times (assuming a 35–50% reduction in tropical forest cover).

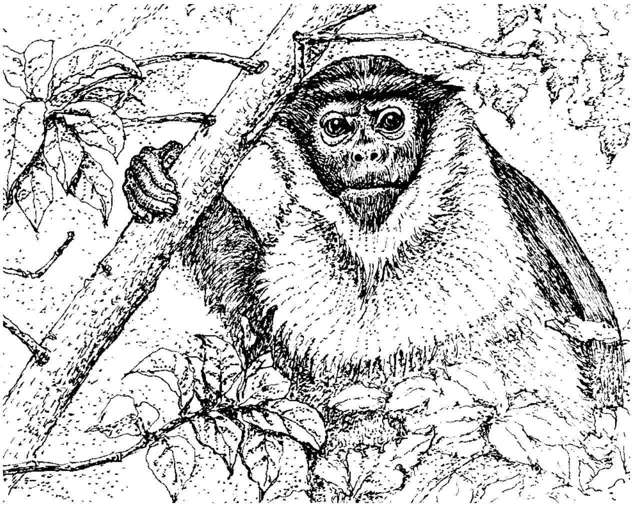
Wright and Muller-Landau (2006) also incorporated species-area relationships into their analysis of tropical species extinctions. They also demonstrated a negative relationship between human population density, especially in rural areas, and forest cover. These authors predicted the continued loss of primary forests for timber exploitation, but expected a fall in rural population density in tropical countries by 2030, resulting in the regeneration of secondary forests on abandoned land. Consequently, they predicted little change in overall forest cover over the next 20 years, although most primary forest will be replaced by secondary forests, with the latter providing a refuge for most tropical forest species[5]. Applying species-area relationships to this scenario, the authors projected species extinctions of 21–24% in Asia, 16–35% in Africa and 'significantly less' in Latin America by 2030.

There are several problems with these projections. One is that species-area relationships are based on the total area of remaining forest, rather than on the size of individual forest fragments. If a country's total forest cover is high but that forest is highly fragmented, each fragment may not be large enough to support viable plant and animal populations. In this situation, inbreeding will gradually kill off each small population, fragment by fragment, and as species start to disappear, the web of species relationships that is vital for the maintenance of tropical forest biodiversity will unravel. As plants lose their pollinators or seed dispersers, they will fail to reproduce, and as key species die out, a cascade of extinctions will reduce the rich biodiversity of tropical forests to a few, common weedy species that dominate the landscape. Thus, it is not the overall rate of deforestation that drives extinction, but also the degree to which the remaining forest is fragmented.

Another problem is Wright and Muller-Landau's assumption that secondary tropical forests will provide refuges for primary forest species (Gardner *et al*., 2007), especially if such areas are separated by vast expanses of agricultural land, over which most primary forest species cannot move. That is, the problem may have more to do with fragmentation of forests rather than simply whether a forest is 'secondary' or 'primary'. And last, their analysis does not consider the effects of hunting and global climate change on species extinctions.

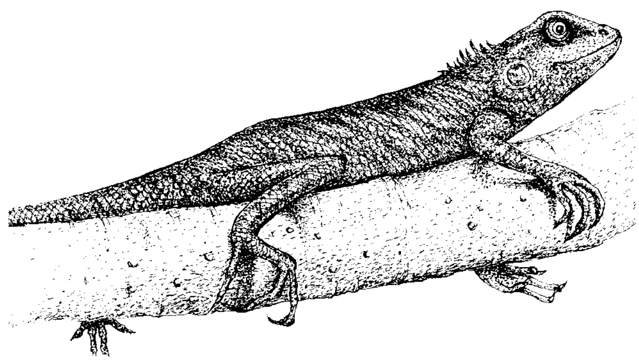
[5] In Asia, fragmented secondary forest already covers a greater area than primary forest (Silk, 2005).

Just a few of the many tropical animal species threatened with extinction as a direct result of deforestation.

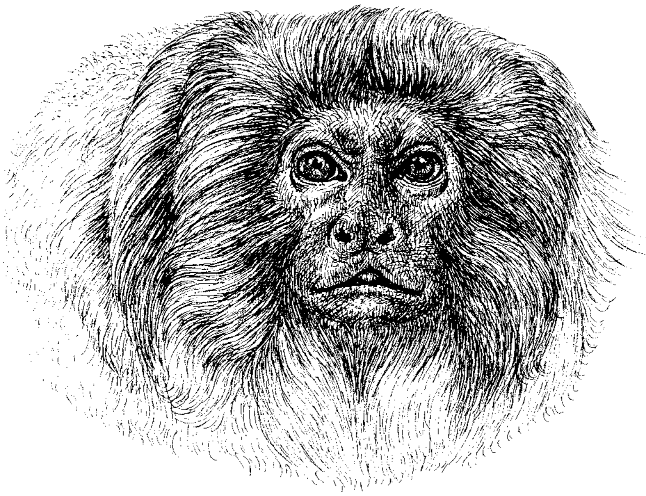


The spectacular black and white Roloway monkey (*Cercopithecus diana*) has been brought perilously close to extinction by conversion of West African forests to agricultural land. Hunting now endangers the few remaining animals.

The spineless forest lizard (*Calotes liocephalus*) is endemic to tropical moist montane forest in Sri Lanka. It is threatened by habitat destruction and fragmentation due to cardamom cultivation, grazing livestock and logging.

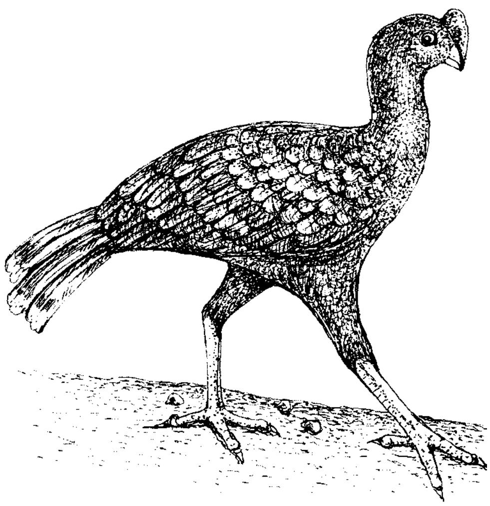


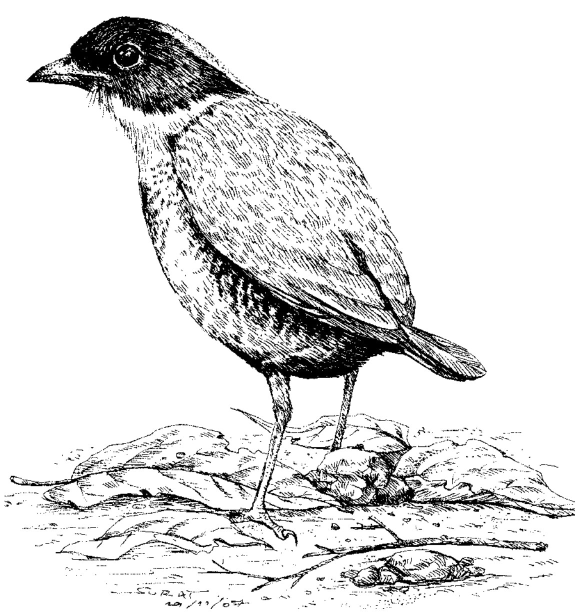
The flat-headed cat (*Prionailurus planiceps*) is endangered in Indonesia and Malaysia, mostly due to conversion of its tropical lowland forest habitat into oil palm plantations.



The golden lion tamarin (*Leontopithecus rosalia*) is endemic to lowland coastal forests of Rio de Janeiro, one of the most endangered of tropical forest types. Now reduced to fewer than 1,000 individuals, the species continues to teeter on the brink of extinction despite a re-introduction program.

The Alagoas currassow (*Mitu mitu*) is extinct in the wild because of destruction of lowland primary forest in Brazil. Consequently, this forest ecosystem has lost an important seed disperser. Two captive populations remain the only hope for the survival of this species.





Gurney's Pitta (*Pitta gurneyi*) has already been declared extinct because of the conversion of lowland evergreen tropical forest in Thailand and Burma to rubber and oil palm plantations. Its rediscovery in 1986 was followed by frantic efforts to protect, restore and 'unfragment' the tiny forest patches at the rediscovery site.
www.birdlife.org/news/features/2003/06/gurneys_pitta_stronghold.html

Although a loss of between a quarter and one-third of tropical biodiversity over the next 20 years is serious, many scientists argue that Wright and Muller-Landau actually underestimated tropical extinctions. The rise of industrial agriculture and plantations as the main drivers of tropical deforestation may render the relationship between human population and deforestation invalid. Cattle ranches, tree plantations and bio-fuel production often increase deforestation, while simultaneously reducing human population density.

Clearly a better model is needed for estimations of extinction rate, but developing ever more precise predictions of species extinctions will not solve the problem. In a world where secondary tropical forests will largely replace primary forest, the survival of most species will depend on ensuring that secondary forests grow well, support rapid biodiversity recovery and are well-connected, so that they become ecologically similar to primary forests as quickly as possible. The science of tropical forest restoration can certainly help with that.

Contribution of tropical deforestation to global climate change

Deforestation makes a significant contribution to global climate change. Carbon dioxide (CO_2), released by clearing or burning tropical forests currently contributes about 15% of the total CO_2 emitted into the atmosphere from human activities (Union of Concerned Scientists, 2009). The rest comes from burning fossil fuels. Several countries have deforestation and degradation as their largest source of CO_2 emissions, with Brazil and Indonesia jointly accounting for almost half of global CO_2 emissions from tropical deforestation (Boucher, 2008).

Tropical forests store 17% of the total of carbon contained in all of Earth's terrestrial vegetation. The pan-tropical average works out at about 240 tonnes of carbon stored per hectare of forest, split more or less equally between the trees and soil (IPCC, 2000). Drier tropical forests store less than this average, whereas rain forests store more. By contrast, crop lands store, on average, only 80 tonnes of carbon per hectare (almost all of it in the soil). So, on average, clearing 1 ha of tropical forest for agriculture emits approximately a net 160 tonnes of carbon, while reducing future carbon absorption by diminishing the global carbon sink. Furthermore, agriculture (particularly rice cultivation and cattle ranching) often releases substantial quantities of methane, which is 20 times more efficient at trapping heat in the atmosphere than CO_2.

These facts show that although tropical forest destruction contributes significantly to global climate change, forest restoration could be a significant part of the solution.

Deforestation and water resources

Tropical forests produce huge quantities of leaf litter, resulting in organic-matter-rich soils that are capable of storing large amounts of water per unit volume. These soils soak up water during the rainy season, helping to replenish groundwater and thus ensuring that water is released slowly during the dry season. Deforestation results in an increase in overall water yield from a catchment (as trees, which transpire water through their leaves, are removed), but that increased yield often becomes more seasonal. Without input of leaf litter into the soil and tree roots to reduce soil erosion, the absorptive top soil is rapidly washed away. Soil compaction (resulting from exposure

Deforestation can cause water sources to dry up in the dry season, as pictured here in northeast Brazil. (Photo: A. McRobb).

to intense rainfall), disappearance of soil fauna, overgrazing and road construction all reduce infiltration of rain water into the soil and groundwater replenishment. So in the rainy season, storms result in rapid surges of water from the catchment, sometimes causing floods. Conversely in the dry season, insufficient water is retained in the catchment to sustain stream flow. Streams dry up and agricultural production in the dry season declines (Bruijnzeel, 2004).

Deforestation dramatically increases soil erosion, especially where the understorey and soil litter layer are damaged (Douglas, 1996; Wiersum, 1984). This in turn causes siltation of streams, rivers and reservoirs, which reduces the life span of irrigation systems that are vital for agriculture downstream.

Effects of deforestation on communities

People living near forests are the first to be affected by deforestation, losing the environmental benefits described above, as well as foods, medicines, fuels and construction materials.

Millions of forest-dwelling people depend on forest products for subsistence. In times of necessity, gathering or selling such products provides a safety net for the rural poor (Ros-Tonen & Wiersum, 2003). For a few, trade in forest products provides significant regular cash income, although problems with marketing and changing lifestyles have limited the commercial development of this trade (Pfund & Robinson, 2005).

However, because most forest products are not bought or sold in markets, their value does not contribute to economic development indices, such as gross domestic product (GDP). Hence, their importance is often ignored by policy makers, who sacrifice forests for conversion to other uses. Consequently, poverty worsens when local people are forced to spend cash to buy substitutes for lost forest products. Paradoxically, such transactions do count towards GDP, giving a false impression of economic growth.

1.3 What is forest restoration?

Reforestation and forest restoration are not always the same

'Reforestation' means different things to different people (Lamb, 2011) and the term can refer to actions that return any kind of tree cover to deforested land. Agro-forestry, community forestry, plantation forestry etc. are all kinds of 'reforestation'. In the tropics, tree plantations are the most common form of reforestation. Even-aged plantations of single species (often exotics) may be needed to meet economic demand for wood products and to take the pressure off natural forests. They cannot, however, supply local people with the diversity of forest products and ecological services they need, nor can they provide the range of habitats for all the plant and animal species that once inhabited the forest ecosystems they replace.

Forest restoration is a specialised form of reforestation but, unlike industrial plantations, its goals are biodiversity recovery[6] and environmental protection. The definition of forest restoration used for this book is:

… "actions to re-instate ecological processes, which accelerate recovery of forest structure, ecological functioning and biodiversity levels towards those typical of climax forest" …

… i.e. the end-stage of natural forest succession — relatively stable ecosystems that have developed the maximum biomass, structural complexity and species diversity possible within the limits imposed by climate and soil and without continued disturbance from humans (see **Section 2.2**). This represents the *target ecosystem* aimed for by forest restoration.

Since the climate is a major factor in determining the composition of the climax forest, changes in climate may alter the climax forest type in some areas and thus might change the aim of restoration (see **Sections 2.3** and **4.2**).

Forest restoration may include passive protection of remnant vegetation (see **Section 5.1**) or more active interventions to accelerate natural regeneration (ANR, see **Section 5.2**), as well as planting trees (see **Chapter 7**) and/or sowing seeds (direct seeding) of species that are representative of the target ecosystem. Tree species that are planted (or encouraged to establish) should be those typical of, or providing a critical ecological function in, the target ecosystem. Wherever people live in or near the restoration site, economic species can be included amongst those planted in order to yield subsistence or cash-generating products.

Forest restoration is an inclusive process that encourages collaboration among a wide range of stakeholders including local people, government officials, non-government organisations, scientists and funding agencies. Its success is measured in terms of increased biological diversity, biomass, primary productivity, soil organic matter and water-holding capacity, as well as by the return of rare and keystone species that are

[6] Throughout this book, 'biodiversity recovery' refers to the re-colonisation of a site by the plant and animal species that originally inhabited the climax forest ecosystem. It excludes exotic species and domesticated species.

characteristic of the target ecosystem (Elliott, 2000). Economic indices of success can include the value of forest products and the ecological services generated (e.g. watershed protection, carbon storage etc.), which ultimately contribute towards poverty reduction.

Where is forest restoration appropriate?

Forest restoration is appropriate wherever biodiversity recovery is one of the main goals of reforestation, whether it be for wildlife conservation, environmental protection, ecotourism or to supply a wide variety of forest products to local communities. Forests can be restored in a wide range of circumstances, but degraded sites within protected areas are a high priority, especially where some climax forest remains as a seed source. Even in protected areas, there are often large deforested sites: logged over areas or sites formerly cleared for agriculture. If protected areas are to fulfil their role as Earth's last wildlife refuges, restoration of such areas must be routinely included in their management plans.

But wildlife is not the only consideration. Many restoration projects are now being implemented under the umbrella of 'forest landscape restoration' (FLR; see **Section 4.3**), defined as a "planned process to regain ecological integrity and enhance human well-being in deforested or degraded landscapes". FLR recognises that forest restoration may also provide social and economic functions. It aims to achieve the best possible compromise between meeting both conservation goals and the needs of rural communities. As human pressure on landscapes increases, forest restoration will most commonly be practiced within a mosaic of other forms of forest management, to meet the economic needs of local people.

Is tree planting essential to restore forest ecosystems?

Not always. A lot can be achieved by studying how forests regenerate (see **Section 2.2**), identifying the factors that limit regeneration and devising methods to overcome them. These can include weeding and adding fertiliser around natural tree seedlings, preventing fire, removing cattle and so on. This is 'accelerated' or 'assisted' natural regeneration (ANR; see **Section 5.2**). This strategy is simple and cost-effective, but it can only operate where trees, mostly pioneer species, are already present. Such trees represent only a small fraction of the total tree species that comprise climax tropical forests. Therefore, for full biodiversity recovery, some tree planting is often required, especially of poorly dispersed species with large seeds. It is not feasible to plant all of the many hundreds of tree species that may have formerly grown in the original primary tropical forest and, fortunately, it is usually unnecessary if the framework species method can be used.

The framework species method

Planting a few, carefully selected tree species can rapidly re-establish forest ecosystems that have high biodiversity. First developed in Queensland, Australia (Goosem & Tucker, 1995; Lamb *et al*., 1997; Tucker & Murphy, 1997; Tucker, 2000; see **Box 3.1**, p. 80), the framework species method involves planting mixtures of 20–30 indigenous forest

In the 1980s, conservation organisations warned that, once destroyed, tropical forests could never be recovered. Thirty years of restoration research is beginning to challenge this long-accepted truth.

(a) This site in Doi Suthep-Pui National Park, northern Thailand, was deforested, over-cultivated and then burnt, but local people subsequently teamed up with Chiang Mai University to repair their watershed.

(b) Fire prevention, nurturing existing regeneration and planting framework tree species began to produce results within a year.

(c) Nine years later, the blackened tree stump is dwarfed by the restored forest.

tree species that rapidly re-establish forest structure and ecosystem functioning (see **Section 5.3**). Wild animals, attracted by the planted trees, disperse the seeds of additional tree species into planted areas, while the cooler, more humid and weed-free conditions, created by the planted trees, favour seed germination and seedling establishment. Excellent results have been achieved with this technique in Australia (Tucker & Murphy, 1997) and in Thailand (FORRU, 2006).

Limits to forest restoration

"Tropical forests, once destroyed, can never be recovered" — this was the clarion call of conservation organisations 30 years ago when raising funds for tropical forest protection projects. Although restoration science has achieved much in the intervening years, protecting remaining areas of primary tropical forest, as the "cradles of evolution", must remain the top global conservation priority when seeking to reduce biodiversity loss. Although some attributes of primary forests can now be restored, their long, unbroken history of species evolution cannot. Once species that are most sensitive to forest disturbance become extinct, no amount of habitat restoration can bring them back. Furthermore, restoration is expensive and laborious, and the outcome cannot be guaranteed, so advances in restoration techniques cannot be used to support a "destroy now — restore later" policy of forest management.

1.4 The benefits of forest restoration

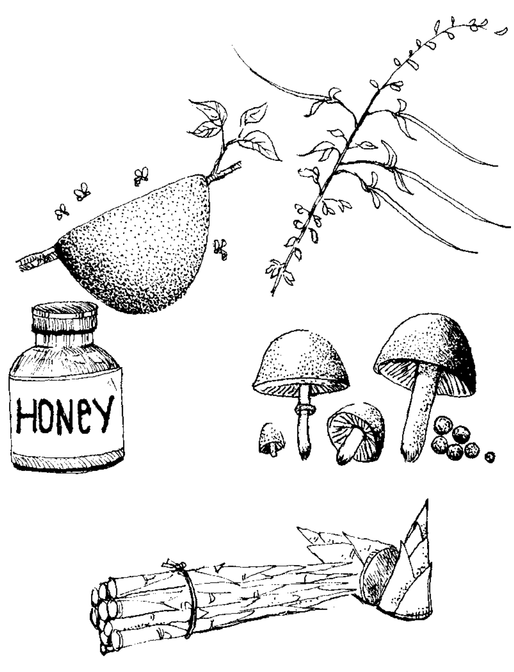
Reliable techniques are essential for the success of forest restoration, but they are of little consequence without the support, motivation and hard work of local communities. Local people benefit most from the environmental services and forest products that result from forest restoration, but they also incur the highest cost in terms of giving up potentially productive land. Their participation is assured only when they are fully aware of all benefits and confident that they will receive their fair share of them.

Numerous studies have quantified the values of tropical forests (www.teebweb.org/), but such values are realised only when someone is prepared to pay for them. Politicians, policy makers and businessmen will continue to ignore the value of tropical forests unless such values contribute to indices of economic growth. Various valuation mechanisms are now being developed that may fairly reward all those who invest their effort in forest restoration. Carbon trading is probably the most advanced of these mechanisms, but payments for water supplies, biodiversity-offset schemes and income-generation from ecotourism and trade in forest products are now also growing in acceptance.

The market value of biodiversity

One of the most obvious ways to value a tropical forest is to calculate the total substitution value of the products extracted from forests by local people. For example, if villagers lose their firewood supply because of deforestation and buy gas canisters in the market, the substitution value of the firewood is the price paid for the gas. This then is one measure of the value of the forest. Interestingly, the loss of the firewood has no effect on GDP (as it is not typically bought or sold), but the purchase of gas does contribute to GDP. In this way, deforestation appears to increase national prosperity, although the villagers become poorer. Forest restoration reverses this paradox. Restoring the supply of forest products to communities provides a powerful motive for local people to plant trees. It is a directly measurable value of forest restoration.

Forest products.



The value of tropical forest products can be calculated from market prices and traded volumes. At least 150 different forest products, including rattan, bamboo, nuts, essential oils and pharmaceuticals, are traded internationally, contributing at least US$ 4.7 billion/ year to the global economy. Forest restoration could

Preparing for ecotourists. At the Himmapaan Project, a tree nursery and an exhibition centre have been constructed specifically to involve eco-tour clients in forest restoration activities. Eco-tour guides are thoroughly trained in restoration techniques, ready to guide their clients through nursery and field techniques.

play an important role in meeting the increasing demand for such products, while generating income for local communities. The provision of such products can be included in the design of forest restoration projects, either by planting the appropriate economic species or by creating conditions that enhance their natural colonisation of the restored forest. Of course, income from the extraction of forest products can only be maintained if such products are harvested sustainably[7] and the benefits shared fairly amongst community members. However, this is more likely to occur in forests that villagers have worked to restore than in natural forests, where such resources are considered to be 'free'. Rainforestation, a restoration method developed in the Philippines, is perhaps the best-known approach for incorporating forest products into forest restoration projects (www.rainforestation.ph) (see **Box 5.3**, p. 135).

Income from ecotourism is another way to value the return of biodiversity resulting from forest restoration. For example, the Harapan[8] Rainforest Initiative in Indonesia, run by a coalition of conservation organisations[9], aims to restore more than 1,000 km^2 of Sumatran rain forest for wildlife conservation and plans to generate funding for the project by creating a unique ecotourism destination. By contrast, eco-tour companies[10] and villagers in northern Thailand have set up a forest restoration project, The Himmapaan[11] Foundation, to involve their clients in tree seed collection, working in the project's tree nursery and planting and caring for trees in restored sites.

International markets that put a value on biodiversity as a whole are also being developed. In some countries, the destruction of biodiversity by development must be amended by restoring equivalent biodiversity elsewhere. This is called 'biodiversity-offset' or 'bio-banking'. Developers purchase biodiversity credits that are generated by conservation projects that restore or enhance biodiversity. For example, a mining company, which destroys 100 hectares of tropical forest in one location, pays the full cost of restoring an equal area with the same biodiversity elsewhere. Such schemes could pay for forest restoration, but they are highly controversial. Buying the 'right to destroy biodiversity'

[7] i.e. the amount harvested per year does not exceed the annual productivity.

[8] 'hope' in Indonesian.

[9] Burung Indonesia, Birdlife International, Royal Society for the Protection of Birds and others (www.birdlife.org./action/ground/sumatra/harapan_vision.html).

[10] East West Siam Travel, Asian Oasis, Gebeco and Travel Indochina.

[11] A mythical forest in oriental cultures, equivalent to the Garden of Eden (himmapaan.com).

is morally questionable. By its very nature, biodiversity is not a uniform commodity (like carbon). For highly diverse tropical forests, the restoration of *all* of the species impacted by a development at another site is impossible to guarantee, no matter how much money is spent. So, whilst corporate sponsorship of forest restoration is laudable, biodiversity 'offset' in its current form remains of questionable conservation value.

The value of carbon storage

Tropical forests absorb more CO_2 through photosynthesis than they emit by respiration. Recent research has quantified this 'sink' at about 1.3 gigatonnes of carbon (GtC) per year (Lewis *et al*., 2009), equivalent to 16.6% of carbon emissions from the cement industry and burning fossil fuels[12] and contributing 60% of the sink provided by all of the terrestrial vegetation on Earth. In Africa, tropical forests actually absorb more carbon than is released by fossil fuel emissions (Lewis *et al*., 2009). As atmospheric CO_2 concentration increases, tropical forests could become even more efficient at mopping up CO_2, as high CO_2 concentrations stimulate photosynthesis. Tropical forests cannot be relied upon to solve the problem of global climate change, but they may help to slow it down sufficiently to provide the time needed for the seismic shift from a carbon-based global economy to a carbon-neutral one.

Trading in carbon credits could turn the carbon storage potential of forest restoration projects into cash. The idea seems simple. Carbon dioxide is the most important greenhouse gas. Power stations that burn coal or oil release CO_2 into the atmosphere, while tropical forests absorb it. So if a power company pays for forest restoration, they could continue to emit CO_2 without actually increasing the atmospheric CO_2 concentration. A company that buys carbon credits buys the right to emit a certain amount of CO_2. The money paid for those carbon credits could then used to finance forest restoration thereby increasing the capacity of the global carbon sink. Carbon credits are traded, like stocks and shares. So their prices can go up or down according to demand. There are two kinds:

- Compliance credits are bought by corporations and governments in order to meet their international obligations under the Kyoto Protocol, thereby offsetting some of the carbon they emit. The protocol's Clean Development Mechanism (CDM) channels the credited money into projects that absorb CO_2 or reduce emissions.
- Voluntary credits are bought by individuals or organisations seeking to reduce their 'carbon footprints'. The 'voluntary market' is much smaller than the compliance market and the credits are cheaper because the projects supported by it don't have to meet the stringent requirements of the CDM.

At present, few forest restoration projects have been approved for support under the CDM because it is difficult to measure the amount of carbon stored in forests, which have very variable growth rates and which could easily burn or become degraded. Furthermore, credits could encourage the establishment of plantations of fast-growing trees over large areas, which displace local people. So, several obstacles must be overcome before compliance credits could generate income for forest restoration projects.

The voluntary principle, however, is proving to be much more successful. All over the world, corporations are sponsoring tree planting, partly to off-set their carbon footprints, but also to promote a cleaner, greener image. The challenge is to ensure

[12] 7.8 GtC per year, as of 2005, increasing by 3% per year (Marland *et al*., 2006).

that such projects result in more than just carbon storage by restoring biodiversity-rich forest ecosystems that will provide the full range of products and environmental services to both local people and wildlife.

Another international scheme worthy of mention here is REDD+, which stands for ‘reducing emissions from deforestation and forest degradation’. This is a set of policies and incentives being developed under the UN Framework Convention on Climate Change (UNFCCC) to reduce CO_2 emissions derived from clearing and burning tropical forests. The concept was recently expanded to include the ‘enhancement of carbon stocks’, i.e. forest restoration to actually increase CO_2 absorption[13]. Once established, this international framework will provide approved funding and monitoring mechanisms for both forest conservation and forest restoration projects that enhance the net global forest ‘sink’ for CO_2, while also conserving biodiversity and benefiting local people. Funding would come from both established carbon credit markets and specially created international funds, but as yet no formal international agreement has been reached. The success of REDD+ will also depend on considerable improvements in forest governance as well as capacity-building at all levels, from villagers to policy makers. Despite these challenges, several pilot REDD+ projects are already underway, which will doubtless provide valuable lessons for the future development of the program.

What about water?

Forest stream in Thailand.

In many tropical countries, clean water supplies depend on the conservation of forested catchments. The organic-matter-rich soil beneath forests provides a natural storage mechanism and a natural filter, which maintain dry-season water flows and prevent siltation of water infrastructure (Bruijnzeel, 2004). Maintaining forest cover incurs a cost to the people that live in the catchments (i.e. agricultural land foregone) but benefits farmers and city dwellers downstream. To guarantee clean water supplies, therefore, some water companies have come up with novel mechanisms to pay for forest conservation. For example, the Public Utilities Company of Heredia, Costa Rica, charges customers an extra 10 US cents per cubic meter of water consumed. This money is paid to state forest parks and landowners to protect or restore forests at a rate of US$ 110/ha/yr (Gamez, undated). In fact, Costa Rica leads the world in payments for environmental services (PES). The country’s National PES Program, funded mostly from a fuel tax, pays forest owners for four bundled environmental services (watershed protection, carbon storage, landscape beauty and biodiversity). Over 9 years, it paid out US$ 110 million to 6,000 owners of more than 5,000 km^2 of forest (Rodriguez, 2005).

[13] www.scribd.com/doc/23533826/Decoding-REDD-RESTORATION-IN-REDD-Forest-Restoration-for-Enhancing-Carbon-Stocks

The value of tropical forests

If *all* forest values were marketed and paid for, forest restoration could become more profitable than other land uses. The Economics of Ecosystems and Biodiversity study (TEEB)[14] has estimated the average total value of all ecosystem services from tropical forests at more than US$ 6,000/ha/yr (**Table 1.2**), which is more profitable than palm oil. The elegance of the forest restoration business model is that it generates several different revenue streams that are shared amongst many stakeholders. So, if the market price of one service or product falls, another one can be developed to maintain overall profitability. Forest restoration is no longer just a pipedream of conservationists; it could very well become a highly lucrative global industry.

Table 1.2. Average values of ecosystem services from tropical forest.

	Average value (US$/ha/y)	No. of studies
Provisioning services		
Food	75	19
Water	143	3
Other raw materials	431	26
Genetic resources	483	4
Medicinal resources	181	4
Regulating services		
Air quality	230	2
Climate regulation	1,965	10
Water flow regulation	1,360	6
Waste treatment/water purification	177	6
Erosion prevention	694	9
Cultural services		
Recreation and tourism	381	20
Total	**6,120**	**109**

Source: TEEB (2009)

[14] www/teebweb.org/

CASE STUDY 1 Cristalino

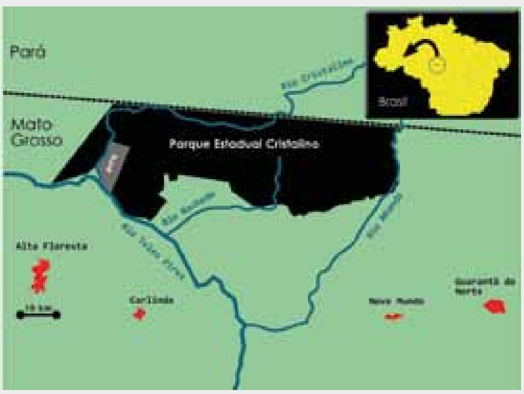
Country: Brazil

Forest type: Lowland tropical evergreen forest, seasonally flooded forest, lowland tropical dry forest and white sand formations.

Ownership: State and private protected areas, smallholdings and cattle ranches.

Management and community use: Conservation management, cattle ranching and swidden (slash-and-burn) agriculture.

Level of degradation: Substantial areas of degraded pasture and secondary vegetation.



Location of the study area.

Background

Cristalino State Park in Mato Grosso, lies at the frontier of the northward spread of deforestation into the southern Brazilian Amazon. It forms part of a proposed conservation corridor designed to block this process. Even though the area is officially protected, it has lost substantial areas of natural vegetation to cattle ranching since its establishment in 2000. Its southern and eastern boundaries have been severely deforested as a result of both legal and illegal land occupation by ranchers and smallholders.

Building the baseline: biodiversity research in the Cristalino region

In close collaboration, the Royal Botanic Gardens, Kew, the Cristalino Ecological Foundation (FEC) and the State University of Mato Grosso (UNEMAT) have carried out species inventories, vegetation mapping and quantitative analyses of species composition to provide baseline data for management planning and restoration. The work has generated a checklist of approximately 1,500 species, linked to vegetation types and ecology (Zappi *et al.*, 2011). This basic understanding of forest composition and diversity is recognised as a fundamental starting point for the development of restoration activities in the region, where the flora had not previously been studied in any significant depth.

Degraded areas in the Cristalino State Park. The red/white hatched areas were deforested before the establishment of the reserve, the solid red areas subsequently.

Discussions with local governmental and non-governmental organisations highlighted the need for the strategic recuperation of degraded areas and the development and dissemination of locally appropriate methodologies and incentives for reforestation.

Opportunities, approaches and methods for restoration

Opportunities for restoration were identified in areas of abandoned cattle pasture within the reserve, in degraded land occupied by smallholders, and along the margins of water courses in the buffer zone around the park. The selection of appropriate framework tree species for restoration will depend on both the ecological and human context. The demand for relatively short-term economic benefits within smallholdings, dictates the inclusion of species with economic value, either direct (e.g. food plants, timber trees etc.) or indirect (shade trees to nurture understorey cash crops). Data on local plant uses, collected during the baseline studies, were supplemented with published information on the uses of the same species elsewhere in the Amazon.

Undisturbed evergreen forest in the Cristalino State Park.

Fourteen native species of *Inga* (Leguminosae), a nitrogen-fixing genus capable of fast growth on poor or highly degraded soils, have been recorded in the area. They include species that are adapted to flooded forest, riversides and terra firme (dry land) forest. *Inga* seeds are surrounded by sweet white arils, which attract wildlife and are widely eaten by indigenous communities across the Amazon. *Inga edulis*, a cultivated species that also occurs in the wild at Cristalino, has been used successfully in alley-cropping trials on degraded land elsewhere in the Neotropics (Pennington & Fernandes, 1998). It enriches the soil with nutrients and organic matter (assisted by periodic pruning in the alleys) and rapidly shades out exotic *Brachiaria* grass, which inhibits tree regeneration. This system is equally appropriate for establishing forest trees, which can be planted in corridors between the managed rows (T. D. Pennington, personal communication).

Inga marginata, one of several native species found in the region.

In the Cristalino region, successful reforestation will inevitably take place at the interface between agro-forestry, forestry and ecological restoration. A local NGO, Instituto Ouro Verde (IOV), has developed a prototype web-based database to provide data on locally appropriate species for agro-forestry systems. This will enable the selection of framework species for forest restoration in the region and will provide guidance for their management. In response to a growing water-shortage problem, IOV, with input from Kew, is also engaging local communities in the restoration of gallery forest in smallholdings and is providing fencing materials. Drawing on the baseline botanical diversity data, the opportunity now exists to develop a proactive tree-planting programme that uses species adapted to the local situation.

In the Cristalino region, the native vegetation is highly variable and strongly influenced by edaphic and hydrological factors. Soils vary from almost pure white nutrient-poor sand to more fertile clayey latosols, the former commonly associated with water stress in the five-month dry season and, in places, water-logging during the wet season. This complexity necessitates careful matching of selected species with site conditions and thus underlines the importance of detailed baseline vegetation studies. For example, the terra firme (dry land) forest on clayey soils at Cristalino is dominated by species of the Burseraceae family, with *Tetragastris altissima* abundant. This large canopy tree is well adapted to the region, attracts wildlife with the sweet arils that surround its seeds and

Brachiaria pasture in the Cristalino State Park.

Dry (deciduous) forest on a granite hill, with evergreen forest on lower ground.

has several popular uses. In the semi-deciduous forest on sandy soils, however, Leguminosae is the dominant family, with abundant *Dialium guianense* and *Dipteryx odorata*. Both are commercial timber species. The latter attracts bats, which are important seed-dispersers. These important tree species are therefore promising framework species candidates. Similarly, observations on secondary vegetation have also been useful for the identification of potential framework pioneers. Both *Acacia polyphylla* (Leguminosae) and *Cecropia* spp. (Urticaceae) are excellent local candidate species; the latter also being bat-dispersed.

The future impact of climatic change will also influence the choice of species for reforestation. Preliminary models for the southern Amazon predict a shift from evergreen to dry-adapted vegetation types (Malhi *et al*., 2009) because of a drier climate. Given that dry habitats already occur in the Cristalino region, where water availability is restricted during the dry season, it may prove beneficial to incorporate dry-adapted species such as *Tabebuia* spp. (Bignoniaceae) into experimental plantings in localities where they would not naturally occur under current conditions.

By William Milliken