# Factors Contributing to Lemur Population Decline on a National Scale, and Proposed Immediate and Longer-Term Mitigation Actions

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**Deforestation and degraded forest edge at Tsinjoarivo. (Photo: Mitchell Irwin)**

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**Recent *tavy* at Tsinjoarivo. (Photo: Mitchell Irwin)**

## INTRODUCTION

The participants of the conservation planning workshop divided the objectives of the conservation strategy, and the corresponding actions, into local and national scales according to whether they would show effect if carried out locally at specific lemur conservation sites or had to be applied on a cross-regional or national level instead. Whilst the local objectives and actions provided the basis for the ensuing 30 site-based action plans, in this chapter we summarise the biggest current contributors to the decline of lemur populations on a national scale, identify the most important immediate actions that would need to be taken in order to eliminate or reduce those threats, and describe additional objectives and actions to ensure the long-term conservation of lemurs and their habitats while also improving human livelihoods.

The first three parts of this chapter overview the threats posed to lemurs from habitat loss and degradation from commercial exploitation and *tavy*; wildlife harvest; and large-scale and small-scale mining. They also attempt to identify and describe short- and medium-term conservation actions. The subsequent four parts provide longer-term objectives and actions for increasing lemur habitat and connectivity; community development and sustainable use; conservation education; and research and higher education.

## PROBLEMS AND IMMEDIATE ACTIONS

### Habitat loss and degradation arising from commercial exploitation and tavy

#### *Habitat loss*

Arguably the single most important factor driving historic losses for lemurs (in terms of species diversity and overall numbers) has been habitat loss. All lemurs need intact forest ecosystems for food, with even the largely terrestrial ring-tailed lemur relying on intact forests for food resources and sleeping sites.
Recent estimates of forest cover vary from 99,000 km$^2$ (Harper *et al*., 2007) to 173,032 km$^2$ (Dufils, 2008), with this variation likely driven by different classification methods, especially for the more dry and open forest types. Nevertheless, this range represents only 16.9–29.5 % of Madagascar's land area – a huge decrease from its original state (in which the majority of its 581,540 km$^2$ were thought to be forested), and a shockingly rapid decrease in recent decades. For example, Harper *et al.* (2007) calculated that 38% of the remaining forest cover was lost from the 1950s to 2000, with a period of extremely rapid deforestation (1.7% loss per year) between the 1970s and 1990s.

Although the causes of habitat loss nationwide are hard to rank quantitatively, they appear to be largely small-scale. To a large degree, Madagascar lacks the extensive industrial operations (such as clear-cutting and oil palm plantations) that drive deforestation in many other tropical countries. Instead, much of the loss seems to be driven by economic and subsistence decisions at the household level. This is often reflected in the configuration of remaining forest; rather than large areas of clearance interspersed with large intact areas, Madagascar's deforestation is much more patchy and often consists of a large number of very small cleared areas. This has led to a staggering degree of fragmentation, with more than 80% of remaining forest existing within 1 km of a forest edge (Harper *et al.*, 2007), leaving it extremely vulnerable to edge effects (Ries *et al.*, 2004) and other habitat change.

Habitat fragmentation is known to inhibit gene flow between populations, resulting in a loss of genetic diversity, usually linked to inbreeding depression and reduced fitness (Begon *et al.*, 2006), and lemurs do not appear to be exempt from that. A negative influence of habitat fragmentation on genetic diversity of Milne-Edwards' sportive lemur (*Lepilemur edwardsi*) has been found (Craul *et al.*, 2009). Likewise, ruffed lemurs (*Varecia* spp.) restricted to small fragments may undergo population bottlenecks as a consequence (Razakamaharavo *et al.*, 2010; Holmes *et al.*, in press). Habitat fragmentation is also known to have fostered demographic collapse among mouse lemurs, driving them into population bottlenecks (Olivieri *et al.*, 2008), as their movement between fragments of suitable habitat appears to be significantly hampered by stretches of unsuitable habitat in between (Radespiel *et al.*, 2008).

However, patterns for other lemur species are not consistent. Some mouse lemur populations revealed only limited effects of habitat fragmentation on fitness indicators (Schad *et al.*, 2004). Similarly, habitat connectivity does appear to have only a limited influence on gene flow in the golden-crowned sifaka (*Propithecus tattersalli*), which may be linked to its survival of severe habitat fragmentation already during pre-human times (Quéméré *et al.*, 2010a, 2010b, 2012). Similarly, the greater bamboo lemur (*Prolemur simus*) persists in very small habitat fragments that have been isolated for at least several decades (Ravaloharimanitra *et al.*, 2011; Wright *et al.*, 2008). This dietary specialist might be able to do so as long as its favourite bamboo, on which it almost exclusively depends, is available in sufficient quantities. On the other hand, folivorous or frugivorous lemur species that depend on a diverse miscellany of plant species for food are more likely to be impacted by habitat fragmentation and isolation, as Irwin *et al.* (2010) have shown for diademed sifakas (*Propithecus diadema*).

Negative impacts of edge effects on lemur populations may include higher vulnerability to predators (e.g. Irwin *et al.*, 2009) as well as changes in food supply and sleeping sites. Some lemurs appear to tolerate edge effects, providing one possible explanation for the fact that many have survived extreme habitat loss and fragmentation until present (Lehmann *et al.*, 2006). However, habitat fragmentation can also have repercussions on other crucial species co-existing with lemurs. Their possible extinction and subsequent trophic cascades may lead to the interruption of food chains, seed dispersal, pollination, and other ecological functions, threatening the long-term survival of these habitat fragments. While release from seed predators can favour the recruitment of certain tree species and thereby cause an apparent positive outcome for lemur populations in the near term (Dausmann *et al.*, 2008), the negative consequences of altered forest structure may outweigh it in the long run. Irrespective of the underlying cause of the decline of lemurs in habitat fragments, perfect nestedness of lemur assemblages in fragments of different sizes suggests a stepwise extinction of species over time from a once continuous habitat as a function of fragmentation size (Ganzhorn *et al.*, 2000).

In humid forest areas, *tavy* is the traditional agricultural practice (Styger *et al.*, 2007) and the major driver of deforestation. *Tavy*, also known as slash-and-burn agriculture, is the cutting of primary or secondary vegetation within a plot, waiting for that vegetation to dry, and then burning it to release nutrients from the vegetation directly into the soil. This nutrient input allows one to a few seasons of farming before soil fertility declines to a point that it is no longer productive, and the plot is abandoned (at least temporarily). The following regeneration depends on the state of the soil and the surrounding environment; less-depleted plots in a more intact environment can quickly grow back as secondary forest, gradually returning towards its original primary character. More commonly, fallow vegetation is composed of small trees, shrubs, or eventually grass. As with other parts of the world, this practice has been sustainable at times in the past when human population densities were extremely low and fallow times quite long, but all signs suggest it no longer is. Styger *et al.* (2007) documented rapidly decreasing fallow times in Betsimisaraka plots in the past 30 years, causing a more serious and irreversible sequence of land degradation and nutrient depletion that ended in stable Aristida grasslands which could no longer support either cultivation or forest formation.

The problem of *tavy* today is twofold: more rapid land depletion causes more forest clearing per farmer in the course of a lifetime, and the recent rapid population growth (2.68% annually; CIA Factbook 2013) means that each successive generation collectively needs more land area for cultivation. Some efforts have been made to intensify agricultural production and prolong the time frame for which a single plot can be utilized. For example rice intensification (SRI; Moser & Barrett, 2003) has been publicized as a partial solution to deforestation pressures, but so far the implementation of such programs has been patchy, and even where implementation is attempted, efforts may fail. The typical reality for Malagasy farmers is that few or no other options are known: traditional *tavy*, passed down from the ancestors, is the only known way to survive in a rural environment.

Another massive driver of deforestation is the production of wood charcoal (*charbon*) for cooking. People in rural areas cut and partially burn natural forest in order to harvest the remains as charcoal – still energy-rich but much lighter and easier to carry. Only a small part of this problem is supplying the rural areas where the charcoal is obtained – the larger problem is the sale and transport to urban markets. These markets have access to gas and electric stoves, but charcoal is substantially cheaper and therefore widely used. It is common on all highways throughout Madagascar to see large stocks of charcoal for sale at the roadsides, and trucks laden with charcoal travelling towards the larger cities.

**Forest fire raging inside Sahamalaza–Iles Radama National Park (Photos: Melanie Seiler), and (below) charcoal production near Sambava (Photo: Erik Patel).**

Clearly the solution to the *tavy* and charcoal problems must be multifaceted. Application of the laws preventing deforestation is necessary, though certainly not sufficient. What is needed is a broader effort reaching out to rural farmers and restoring the balance between the quality and quantity of ecosystem services that people need (including food production) and the inherent limits of what the landscape can offer, as well as taking into account the minimum forest areas and connectivity required to sustain healthy ecosystems. In the case of *tavy*, this will include more effective and sustainable agricultural techniques, while in the case of charcoal this will necessitate the broad adoption of more efficient and sustainable cooking methods, perhaps through subsidizing the currently out-of-reach alternatives.

### *Habitat modification and degradation*

Although the amount of forest habitat Madagascar has lost (and is still losing) is staggering, it is also crucial to consider that much of the remaining forest has been degraded through human actions. Despite the fact that it may still appear in satellite images and forest inventories, its capacity to support viable lemur populations may be diminished. Extraction of forest products for local use (both timber and non-timber) has been occurring since the arrival of humans on Madagascar. Although worth monitoring, especially as the human population increases, it is the extraction feeding regional, national and international markets that is much more damaging.

The most pervasive form of habitat degradation is selective logging. Logging affects different primate species in different ways (Cowlishaw and Dunbar, 2000; Johns and Skorupa, 1987). Although much variation exists, folivores are more likely to increase in density in the face of moderate disturbance (Ganzhorn, 1995; Irwin, 2008), and frugivores more likely to decline; however, all species start to decline as disturbance becomes severe, and even small amounts of disturbance may significantly reduce the primate species richness in an area.

Selective logging of hardwood has always existed in Madagascar, and a demand in the capital and other large cities has fueled a supply from primary forest areas, both protected and unprotected. Some of this logging, that arising from management transfers (*transfert de gestion*) giving local communities limited extraction privileges, has been legal; the rest is illegal. The 2009 political crisis triggered a crisis in illegal logging of a magnitude not before seen in Madagascar. However, illegal logging of rosewood (*Dalbergia* spp.) and ebony (*Diospyros* spp.) did not begin in 2009. A major illegal logging crisis in World Heritage Sites (Masoala National Park and Marojejy National Park) took place during 2004/05 (Patel, 2007), a time of political stability. Foreign exports of Madagascar rosewood occurred at "low" levels (1,000–5,000 t) between 1998 and 2007. In 2008, exports jumped to 13,000 t, and jumped again in 2009 to more than 35,000 t (Randriamalala and Liu, 2010; Global Witness and Environmental Investigation Agency, 2009). In 2009, approximately 100,000 rosewood and ebony trees were illegally cut in the UNESCO World Heritage Sites of Masoala National Park, Marojejy National Park, the Makira Conservation Site, and Mananara Biosphere Reserve (also a national park).

In actual practice, rosewood logging has turned out to be far less selective than widely believed. Often, rafts made of a lighter species of wood (*Dombeya* sp.) are constructed to float the much more dense rosewood logs down rivers. Approximately five Dombeya trees are cut as "raft wood" for every rosewood tree (Randriamalala and Liu, 2010). Tall adult trees of a variety of species, that simply happen to be very close to rosewood trees, must often be cut to gain access to cut down a rosewood tree. All told, the impacts of such selective logging include (but are not limited to), increased likelihood of fire, invasive species,

**Illegally logged rosewood stockpiled in Maroantsetra (Photo: Erik Patel) and (right) logging under *transfert de gestion* agreement at Tsinjoarivo, 2006 (Photo: Jean-Luc Raharison).**

impaired habitat, loss of genetic diversity, as well as violating local taboos, as ebony is sacred to some Sakalava ethnic groups in Madagascar (Patel, 2007).

Red ruffed lemurs (*Varecia rubra*) are probably the most negatively impacted lemur species, since many were hunted by loggers and this species is known to feed on ebony trees (*Diospyros* spp.) as well as pallisandre (*Dalbergia* spp.) in Masoala (N. Vasey, pers. comm.). *Varecia rubra* probably also feeds on the fruits and leaves of the "raft wood" *Dombeya* sp., as *Varecia v. editorum* does in Manombo Forest in southeastern Madagascar (Ratsimbazafy, 2006). In Mantadia National Park, *Indri indri* and *Propithecus diadema* consume young leaves of one species of rosewood (*Dalbergia baronii*), which is also consumed by Milne-Edwards' sifakas (*Propithecus edwardsi*) in Ranomafana National Park (Powzyk and Mowry, 2003; Arrigo-Nelson, 2006). *Propithecus diadema* at Tsinjoarivo consume the unripe fruits of ebony trees (Irwin, 2006). In Marojejy, silky sifakas (*Propithecus candidus*) commonly feed on the fruits, seeds and leaves of ebony trees (*Diospyros* spp.) and to a lesser extent the young leaves of pallisandre (*Dalbergia chapelieri*), which is also a preferred sleeping tree (Patel, 2011).

At the 16th CITES Conference of the Parties in March 2013, all 48 accepted species of *Dalbergia* and 83 accepted species of *Diospyros* endemic to Madagascar were uplisted from Appendix 3 to Appendix 2, and an action plan was adopted to facilitate adequate implementation of the listings. Appendices 2 and 3 only aim to regulate trade, not prohibit it. Appendix 2, unlike Appendix 3, does require that the CITES authorities in the export nation determine that the specimens were legally obtained and that their export will not be detrimental to species survival. The surest way to reduce illegal logging of ebony and rosewood in Madagascar, however, would be to list all species of *Dalbergia* and *Diospyros* on Appendix 1 of CITES. Globally, only one species of rosewood, Brazilian rosewood (*Dalbergia nigra*), is listed on Appendix 1. This is the most stringent category and prohibits all commercial trade of that wood from the date of listing. Guitars in the United States made of Brazilian rosewood are known to have risen in price and are harder to find since Appendix 1 listing. Similarly, Appendix 1 listing of Alerce (*Fitzroya cupressoides*), a heavily logged South American conifer, has significantly reduced logging and trade (Barrett *et al*., 2010; Keong, 2006). In any case, the agency chosen as the CITES management authority should be free of corruption and have experience in forest management, and current problems with species identification need to be overcome. For the latter, genetic techniques would be of great assistance. DNA testing has already been used to track timber, but not yet in Madagascar. One of the biggest methodological challenges is extracting DNA from the heartwood of dead tree trunks (e.g. rosewood stockpiles), which consist of dead cells with partly degraded DNA. Nevertheless, several new techniques have successfully extracted DNA from dry wood, including 1000-year-old beech (*Fagus* spp.) (Nielsen and Kjaer, 2008).

In addition to CITES listing, actual improvements in forest monitoring on the ground are needed. A new system called independent forest monitoring (IFM) may help reduce illegal logging (Tegtmeyer *et al*., 2010). IFM has been defined as "the use of an independent third party that, by agreement with state authorities, provides an assessment of legal compliance, and observation of and guidance on official forest law enforcement systems" (Global Witness, 2005, p.18). It is similar in principle to unbiased international election observers. Local and international expertise is utilized, and monitoring teams operate independently but with the consent of the host government. Independent forest monitors are observers; law enforcement remains the responsibility of local officials and governments. IFM has already been used successfully in several African and Central American countries seeking to improve the effectiveness of their forest monitoring. Examples of the impact of IFM in these countries include: documentation of hundreds of forest crimes, cancellation of logging concessions, moratoriums on logging and timber transport, and creation of new "forest crime monitoring units" within the forestry administrations.

**Wildlife harvest and its impact on lemur species**

Throughout Madagascar, wildlife harvest for food has become an increasingly recognized threat to the viability of lemur populations (Golden, 2009; Golden *et al*., 2011; Jenkins *et al*., 2011). In many parts of Africa and South-East Asia, hunting is pervasive and yet practiced by only a skilled fraction of the population, and wild meats are then marketed to consumers from various social strata in villages, towns and cities. This type of market/commercial hunting is a major threat to species viability and requires very specific conservation solutions. In Madagascar, the vast majority of wildlife harvest is driven by a need for food. This requires different types of interventions, especially where the behaviour is common. For instance, in the Makira Protected Area, approximately one half of the population actively harvests and consumes lemur species (Golden, unpublished data), even though lemurs are illegal to hunt throughout Madagascar (whether inside or outside of a protected area). In other areas of Madagascar, it is believed that hunting is increasingly becoming a threat as social values dissolve and political support for conservation becomes elusive (Jenkins *et al*., 2011). Further, people have worried that as central government support for the environment weakens from a lack of political stability, a commercial trade of luxury bushmeat may emerge (Barrett and Ratsimbazafy, 2009). Thus far, hunting behaviours have been reported widely across the island (e.g. Cardiff *et al*., 2009; Garcia and Goodman, 2003; Goodman, 2006; Bollen and Donati, 2006) and continue to become better known.





**White-fronted brown lemur (*Eulemur albifrons*), Endangered, that has been snared (top left photo) and then cooked over an open fire, prior to consumption (top right photo) (Photos: top left: Gerlain; top right: Christopher Golden); Indri (*Indri indri*), Critically Endangered, hunted for human consumption (below left photo) (Photo: Madagasikara Voakajy); Tree with *Lepilemur sahamalazensis* sleeping tree hole, cut open at the bottom to harvest the animal (below center photo) (Photo: Melanie Seiler); Sahamalaza sportive lemur (*Lepilemur sahamalazensis*), Critically Endangered, roasted for human consumption (below right photo) (Photo: Melanie Seiler).**

As far as we can tell from documented evidence, rural farmers who hunt as a side activity to their primary pursuit of rice agriculture conduct the majority of hunting. Hunting with firearms, although a known threat to primate species around the world, does not appear to be the primary threat to lemurs in Madagascar. People actively hunt with slingshots (for small carnivore and lemur species), spears (for lemurs and bush pigs), nets (for bats) and dogs (for lemur, carnivore and tenrec species). However, hunters harvest the majority of mammals with passive traps and snares. For lemur hunting, two snare types are frequently used that utilize a method of clearing areas of forest to force lemur movement across specified wooden bridges. When these bridges are constructed to connect forest fragments the snares are called *laly lava* and can capture lemurs regardless of their preference for particular fruit trees. If the bridges are constructed to connect a fruit tree to surrounding forest fragments, the snares are called *laly totoko* and focus on the capture of species that utilize a particular type of fruit tree.

Active hunting may target the largest animals, and those will usually be adult males and females in reproductive age that are necessary for population sustainability. Lemurs, like most primates, have life history characteristics that put them at high risk of rapid depletion in the presence of hunting. Populations of species such as lemurs, with late ages of first reproduction, long gestation periods, long lifespans and small litter sizes, can withstand only *very* low levels of extrinsic mortality, such as hunting (Golden 2009).

Knowledge of hunting methods can help conservationists understand the distribution of human hunting pressure. For instance, data collected on hunters' travel behaviour in the Makira Protected Area (86 reports of distance covered and 154 reports of time spent travelling) indicated that people covered a radius of 4.40 ± 2.90 km from village centres for hunting activities (mean ± SD; Golden, in review). Information like this can inform the creation of buffer areas around protected areas where humans are free to use resources.

Madagascar has one of the most rapidly growing human populations of all countries that possess rainforest (CIA World Factbook, 2013). Moreover, the human population of Madagascar has increased sevenfold in the past 100 years. As forested areas become increasingly inhabited, areas that once held unexploited wildlife may soon become depleted. Pressure to provide food for families, complicated by a lack of livestock farming and other livelihood strategies, creates a multifaceted incentive for bushmeat hunting.

Recently published data showed that households in the Makira Protected Area that consumed wildlife were less likely to have children with iron deficiency anaemia, an important factor in delayed childhood development (Golden *et al*., 2011). A conundrum exists. Unbridled hunting will lead to local biodiversity and habitat loss. Restricting wildlife hunting through enforcement of wildlife conservation policies will have a negative impact on the nutritional status of local people, unless strategies are in place to mitigate these effects. There is a potential solution: the ubiquitous village chicken. A major factor behind hunting is the inconsistent availability of alternative animal food sources such as chicken, a source of high-quality food and income through meat and egg production. Village chickens are raised extensively and require minimal input of food and labour. Unfortunately, extensively raised chickens are susceptible to adverse events such as predation, theft, and epidemic disease, and so they are not a secure food item. Frequent disease epidemics can decimate entire village flocks, and when an epidemic strikes, it often spreads quickly to adjacent communities, rendering an entire region without a primary food source.

Improvements in village chicken production have been shown to have profound effects on the wellbeing of rural families, directly contributing to household food security, income generation, poverty alleviation, and wildlife conservation. Even simple husbandry improvements, such as predator-proof night housing, separate chick rearing and egg-laying quarters, and disease prevention through quarantine can lead to improvements in overall chicken health. When appropriate, more comprehensive poultry health interventions such as vaccination can result in greater enhancements of chicken health.

Aside from chickens, native freshwater fish farms also represent a sustainable and desirable source of animal protein. In the Andapa region, *Paratilapia* sp. (*fony*) projects, originally initiated by Dr Paul Loiselle and colleagues, have found this endangered fish to be easy to raise and breed by rural residents, who reintroduce 25% of their harvest into local streams while eating or selling the rest. However, digging the ponds can be labour-intensive and theft can be a problem.

**Impact of mining on lemurs**

Madagascar has a wide variety of metals, industrial minerals, and mineral fuels located across the island. Currently, Madagascar accounts for 3% of ilmenite production globally and prior to the political upheaval of 2009 was one of the top global producers of sapphires (Yager, 2010). Most of Madagascar's mining and mineral processing operations are privately owned. However, artisanal miners produce a large proportion of the gemstones, gold and crystal (Yager, 2010; Duffy, 2005; Sarrasin, 2006).

There is a great difference between artisanal and industrial mining in terms of mining practices, laws and enforcement relevant to each sector. All mining operations theoretically must comply with the existing "Making Investment Compatible with

**Native freshwater fish farm near Andapa. This single pond now contains thousands of endemic *Paratilapia*; less than one year ago only 400 fishlings were added. (Photo: Erik Patel)**

the Environment" (MECIE)[1] legislation, which requires all companies to incorporate budget provisions for environmental impact assessments, submit Environmental Impact Evaluation (EIE), and advance environmental authorization before conducting operations (Sarrasin, 2006; Code Minier, 2005). Given high levels of corruption in the mining sector coupled with frequent shifts in the political regime in Madagascar, not all companies, especially smaller operations, fully comply with the required practices for documentation (Baker-Médard, 2012). Also, despite more recent efforts of the Mineral Resource Governance Project (PGRM) to decentralize governmental management of mineral resources and formalize the artisanal mining sector, much small-scale mining occurs illegally (Tilghman *et al*., 2007; Economist, 2005).

***Large-scale mining***

Large-scale mining operations such as QMM/Rio Tinto's ilmenite and titanium dioxide project (QMM) along the south-eastern coast or the Ambatovy Nickel Project (Ambatovy) in the forested eastern corridor of Madagascar have well-developed environmental programs operating in conjunction with their mines. Both companies claim to not only comply with the environmental rules and regulations imposed by the Malagasy government, but to exceed requirements. QMM aims for a net "positive" impact on the environment via reforestation and funding new conservation areas as an offset for the deforestation and environmental destruction caused by the mineral extraction process (Ganzhorn *et al*., 2007a). Both companies have programs that target lemurs specifically. For example, Ambatovy's biodiversity team identified and "salvaged" all lemurs from mining, pipeline and plant site clearings and relocated them to refuge forests where they were monitored (Dickenson and Berner, 2010). QMM also has a threatened lemur translocation program[2] (Vincelette *et al*., 2007). To address the problem of increased lemur habitat fragmentation, lemur bridges were constructed by Ambatovy to facilitate movement between forested patches divided by new roads constructed by the mining company. According to company reports, these bridges are currently being used by six lemur species and have been used increasingly over time (Mass *et al*., 2011). QMM also avoided mining and has committed to reforesting a set of corridors between forest patches specifically to enhance connectivity of lemur habitat to help conserve species such as *Cheirogaleus* spp., *Avahi meridionalis*, and *Eulemur collaris* (Ganzhorn *et al*., 2007a).

[1] MECIE (Mise En Compatibilité des Investissements avec l'Environnement) Decree: Decree No. 99-954 of December 15, 1999 relating to the compatibility of investments with the environment (Republic of Madagascar, 2000:2)

[2] They determine threat level according to a study of population dynamics in association with forest fragmentation in the larger mining area.

The destruction of habitat, decreasing the size and increasing fragmentation of forested areas, is one of the most harmful aspects of large-scale mining on lemur populations. However, the impact of deforestation on lemur populations varies by species; generally larger species with larger home ranges are more negatively impacted (Ganzhorn *et al*., 2007b). Other impacts on lemurs engendered by large-scale mining operations include emission and effluents from mining that contribute to toxics in the soil, air and water, the introduction of new species into a region, and noise pollution. Recently, a group of primatologists found that in the Ambatovy mining region, *Indri indri* living in forests adjacent to mining operations experienced physiological changes that increased their susceptibility to parasitism, thus impairing reproductive success and long-term survival (Junge *et al*., 2011).

***Small-scale mining***

Small-scale, largely artisanal mining in Madagascar has a different set of dynamics concerning environmental degradation and impact on lemur populations. Unfortunately, as a map produced by USAID in 2004 showed, much of the country's potentially gem-rich areas are contiguous with protected areas and tropical rainforests with high levels of biodiversity (Duffy, 2005). There are three major categories of environmental degradation that can be assigned directly to artisanal mining in Madagascar, as well as a variety of indirect impacts that stem from the boom in migrant miners that often accompany new discoveries of precious and semi-precious stones or minerals. Similar to large-scale mining, artisanal mining often leads to deforestation. In order to access soil for digging, trees are cleared and/or roots are damaged; tree trunks, limbs and shrubs are often chopped down to reinforce mine shafts, build structures to haul stones out of holes, and construct tools for mining. Some deforestation also occurs due to uncontained fire, which is used in some gemstone mining areas to crack and render brittle hard substrate under or in which gems could be found.

In addition to some of the direct impacts on lemur habitat from deforestation due to mining, there is a host of non-mining activities that threaten lemurs as the number of people living in a mining area increases and the standing economy is disrupted. Perhaps the most destructive component of artisanal mining on lemur populations is the indirect pressure caused by a rush of hundreds, or even thousands, of migrant miners to a small area that was previously inhabited by few or no people. This accelerates the destruction of lemur habitat as people chop down trees for basic needs such as shelter, fuel, and household items. Additionally, secondary economies emerge in mining sites such as charcoal production and bushmeat trade, both of which directly impact lemur habitat and survival. Lemur hunting is commonly associated with artisanal mining boomtowns. Lemur meat supplements the diets of miners working in areas farther away from towns and villages, which are more regularly provisioned with regional or national sources of meat than the booming mining towns. Many artisanal mining areas are located in highly biodiverse areas that harbour numerous lemur species. For example, there is a recent explosion of gemstone mining in the Ankeniheny–Zahamena corridor (Mongabay, 2012), ongoing sapphire extraction in Ankarana (Walsh, 2003; Walsh, 2004; Baker-Médard, 2012), amethyst and beryl mining near Andapa (Pezzotta, 2001), quartz in Mananara (Sodikoff, 2012; Yager, 2000), and quartz and gemstones in Makira (Jaozandry and Holmes, 2005). Bushmeat hunting by artisanal miners in these areas is likely to have a significant and negative impact on lemur populations.

Madagascar's mineral industry is likely to grow significantly because of recent increases in cobalt, ilmenite, nickel, rutile, and zircon production, as well as the start-up of vanadium production in 2014 (Yager, 2010). Therefore, enforcing the variety of regulations already established to protect lemurs in Madagascar is of increasing importance.

## LONGER-TERM SOLUTIONS

### Increasing habitat and connectivity

While conservation priorities should still primarily focus on preserving what forests are left, the conservation community should also step up measures to reverse the loss, fragmentation and isolation of lemur habitats. Natural regeneration that could compensate for habitat loss and reverse habitat fragmentation only takes place very slowly. Indeed, Madagascar's forests usually have long recovery cycles after slash-and-burn (Klanderud *et al*., 2010) and might actually degrade beyond the point of recovery when intervals between fires become shorter (Styger *et al*., 2009). The regenerative capacity of Madagascar's forests is particularly hampered by a depauperate community of volant seed-dispersing animals when compared to continental environments (Böhning-Gaese, 2007). Additionally, natural succession is often constrained by the higher competitiveness of exotic invasive plant species. Studying natural regeneration of corridors in Andohahela, De Wilde *et al*. (2012) found that corridors between mature forests are not colonized by species from them but are likely to be dominated by invasives.

As a consequence, restoring lemur habitats and connectivity between them require comprehensive assistance by conservationists. While the planting of trees in Madagascar's past was largely driven by economic necessities rather than ecological reflections (e.g. Carrière and Randriambanona, 2007), reforestation with native trees has only been attempted at very modest scales and with little success until the turn of the present century.

This changed in 2004 with the launch of a pioneering large-scale project called *Tetik'asa Mampody Savoka* (TAMS), which formed part of the larger Ankeniheny–Zahamena–Mantadia Biodiversity Conservation Corridor and Restoration Project (Clean Development Mechanism, 2010). Unfortunately, the project suffered from a proliferation of stakeholders and a rather inflexible top-down approach unsuited to reconciliation of community expectations and conservation objectives with tough targets for carbon sequestration set by the Kyoto Protocol (Pollini, 2009). Although it did not live up to its original multifaceted purpose as outlined by Holloway (2004), the achievements of TAMS were ground-breaking, including the establishment of Madagascar's most species-rich tree nurseries, the plantation of more than a million native trees, and invaluable experience of reforestation techniques gained. In part, project performance was due to (1) high survival rates following the inoculation of tree seedlings with fungi forging versicular-arbuscular mycorrhizae; (2) the selection of a subset of slow, modest and fast-growing trees suited to mimic natural forest structure; and (3) the selection of tree species attracting seed-dispersers (such as lemurs) that bring in seeds from even more species.

**Community-based reforestation programme in Sahamalaza. (Photos: Guy Randriatahina)**

Subsequently, a multitude of reforestation projects using native trees has sprung up, many of them also trying to increase suitable habitat for lemurs and other wildlife and re-establish connectivity between habitat fragments. While Association Mitsinjo and MATE, two organizations involved in TAMS, have since continued reforestation work around Andasibe, others focus on very fragmented sites like Ambohitantely (Pareliussen *et al.*, 2006) or on connectivity of larger forest corridors such as Fandriana–Marolambo (WWF, 2012) or Fandriana–Vondrozo. Other reforestation initiatives comprise those of the Madagascar Fauna Group in Betampona and the Madagascar Biodiversity Partnership in Kianjavato, Vakanala in Manambolo, Madagascar Feedback's TreeMad project in south-central Madagascar, Coeur de Forêt in Masoala, Tany Meva in Ankotrofotsy, Planète Urgence in the Itasy region, Graine de Vie in the SAVA region, Ho Avy in Madagascar's spiny forest and the Eden Reforestation Project in the mangroves of the Mahabana Estuary, to name but a few. A (still incomplete) compilation of Madagascar's reforestation projects has been attempted by Lisan (2012). Conventional Internet search engines produce more than 300,000 hits for the combined keywords 'reforestation Madagascar'. This digital profusion is not nearly reflected by relevant publications in scientific journals. It is therefore impossible to assess how serious, successful or long-lived all these projects are. Appreciably, most of them attempt to integrate local communities, but there seems to be little cohesion and even less exchange between existing projects.

It is highly recommended that organisations and initiatives focusing on reforestation and habitat restoration set up a network, providing for exchange of experience, mutual learning and dissemination of promising approaches. This would also facilitate evaluating successes and failures and the performance of these projects in general. Furthermore, it would also create competitiveness among them, leading to better results in the long term. Certain aspects of reforestation (germination, seedling survival, growth rates, establishment of species, changes in species composition, etc.) should also be subject to scientific scrutiny. A network of organisations and projects involved in reforestation would help to harmonize different approaches and schools, based on scientifically sound methodology. It is likely to yield the best results when it comes to restoring lemur habitat and reversing the effects of habitat fragmentation on a nationwide scale.

**Community development and sustainable use**

While lemur populations invariably continued to decline, Madagascar's human population has almost doubled over the last 20 years (United Nations, 2010). Most of the human population lives in rural areas, very often in dire living conditions, which have additionally been exacerbated by the political disorder and instability after the chaotic regime change of 2009 (Randrianja, 2012).

Poverty-driven environmental degradation has always been a key feature of Madagascar's past (Pollini, 2011; Réau, 2002). In combination with demographic growth, increasing poverty continues to accelerate the conversion of natural habitats into arable and degraded land. Many of the island's impoverished communities live in close vicinity to existing protected areas or other ecologically valuable sites. They directly compete with lemurs for space and natural resources, ultimately leading to shrinking lemur habitat.

Yet, these habitats provide numerous ecological services – such as protection from erosion, water retention, climate regulation and pollination – that are vital for the local communities' agricultural performance (Wendland *et al.*, 2010). Runaway habitat destruction thus further fuels rural impoverishment. In order to break this vicious circle, the improvement of rural livelihoods is vital and the integration of local communities into the conservation of lemurs and their habitats is imperative.
Many conservation projects all over Madagascar attempt to integrate local communities into the management of natural resources and lemur populations (Andrianandrasana *et al.*, 2005; Raik and Decker, 2007; Volampeno and Downs, 2009). Management of natural resources can be legally transferred to local communities if they are organized in associations called COBAs or *communautés de base* (Toillier *et al.*, 2009).

During the last two decades, there has been a plethora of management transfers all over Madagascar, originally applauded as the ultimate solution to both habitat destruction and poverty. It had to be learned that only a handful of COBAs were economically viable, and that community-based natural resource management can only work when it generates revenue. Management transfer as a conservation tool can only be successful if it generates higher revenue from sustainable economic activities or alternative sources than conventional (destructive) practices would fetch. In reality, most local communities struggle to be viable, even if they are legally entitled to manage their own resources. Ironically, timber and charcoal from the forests they manage remain the primary source of income for most COBAs, thus often contradicting conservation objectives (Hockley and Andriamaravololona, 2007).

Moreover, the potential of Madagascar's non-timber forest products to sustainably generate sufficient revenue for local communities appears to be overrated. Although the collection and use of medicinal plants, fruits and honey may play an important role in the livelihoods of local communities (Brown *et al.*, 2011; Dawson and Ingram, 2008), these commodities appear inadequate to generate auxiliary revenue. Still, if processed, some non-timber forest products may be better qualified to do so. In several sites throughout the eastern rainforest, wild silk from cocoons of native moth species is collected in community-managed forests, processed into textiles and sold abroad as a luxury good (SEPALI, 2012; Razafimanantosoa *et al.*, 2006). In Vohimana, also a rainforest site, essential oils from aromatic plants are produced and sold (Danthu *et al.*, 2008). However, ecological and economic viability of both approaches need to be questioned. In the case of essential oils, considerable amounts of fuel wood are used to provide the energy needed for distillation. It is required that the added value of the essential oils generates higher revenue for the local communities than the direct sale of fuel wood would have fetched. Moreover, processing and marketing of either wild silk or essential oils requires technical know-how, establishing business contacts with wholesale buyers and marketing experience, all of which local communities usually lack.

At first glance, ecotourism requires less know-how and is therefore often cited as an even more important potential source of sustainable revenue for local communities in Madagascar (Pawliczek and Mehta, 2008; Jensen, 2010). Showing lemurs and other Malagasy wildlife to tourists can additionally be combined with the production and sale of handicraft, thus providing income for both guides and craftspeople. Two successful examples of community-based ecotourism are the Anja Community Reserve close to Ambalavao and Association Mitsinjo's Analamazaotra Forest Station in Andasibe (Dolch, 2008). It comes as no surprise that both are situated along ingrained tourist routes, benefitting from geographic location and existing infrastructure. Unfortunately, most of Madagascar's COBAs are not equally advantaged since they are characterized by their geographic isolation and remoteness, off any tourist paths. Yet, remote destinations appear to be particularly promising as they might be interesting targets for both high-end and backpacker tourism (Hockley and Andriamaravololona, 2007). Again, developing these destinations requires the capacity to identify and attract potential business partners, which local communities are unlikely to achieve without assistance. Adequate mechanisms of profit (and cost) sharing within and among COBAs could also facilitate increased ecotourism.

The employment of local communities for conservation-minded research could also generate sustainable revenue. Conservation action taken for the greater bamboo lemur (*Prolemur simus*) is a prime example of how the implication of local communities into research and monitoring programmes contributes to both conservation success and improved livelihoods. Local knowledge was crucial in the discovery of new populations of the species (Dolch *et al.*, 2008; Ravaloharimanitra *et al.*, 2011). Trained as para-ecologists by the project leadership, members of the local community patrol these sites to monitor their populations and eventual threats to them (Randrianarimanana *et al.*, 2011). In doing so, they are protecting the forest and are getting paid for the monitoring, creating pride and bringing money into the coffers of the community. This approach could easily be adapted and replicated for a variety of species in different sites all over Madagascar, ideally forming a network of small community-run research stations.

Another source of revenue could be capturing the value of ecosystem services. Direct payments for ecosystem services, including maintaining biodiversity and carbon sequestration, offer considerable promise for local communities. Several conservation organizations incite competition among local communities and reward them for preserving natural habitat (e.g. Sommerville *et al.*, 2011). Carbon sequestration through avoided deforestation and/or forest restoration has also been used as a tool to generate revenue through the trading of carbon credits (Ferguson, 2009). Following the change of power in 2009, some of these incentives, such as the TAMS Project in Andasibe (Paiva and Randrianarisoa, 2010; Pollini, 2009), have been stifled by the cancellation of existing contracts at the exact time when local communities should have reaped the fruit in form of payments for carbon credits generated. Still, if executed properly, direct payments for ecosystem services (and 'direct' is the operative word here) could bring considerable revenue for local communities.

Conservationists often tend to overestimate the forest's capacity as a source of vital resources for the local communities, omitting the fact that it is primarily agricultural performance from the areas surrounding it that determines their viability. As a consequence, it is indispensable that novel forms of agriculture that are better performing and more sustainable are being developed at the same time. It has been shown that adoption of novel techniques by Malagasy farmers leads to higher crop yields (Minten and Barrett, 2008). Yet, few conservation organizations have the capacity or commitment to assist local communities on agricultural issues at the scale needed. Therefore, viable partnerships with state institutions or NGOs that specialize in agriculture should be developed and the private sector implicated. It appears essential for the conservation of lemurs and other biodiversity that agricultural programs primarily focus on local communities living close to lemur habitats. It should also not be forgotten that environmental degradation caused by local communities might not be exclusively driven by economic necessities. Alternatively, it is often considerably shaped by social and cultural dynamics within those communities (Scales, 2012; Hume, 2006; Casse *et al.*, 2005). If natural resource management by local communities is to be successful, socio-cultural contexts must therefore be considered. Generally, a holistic approach is needed. It should focus its attention on comprehensive and genuine assistance in agriculture as well as assistance in marketing through establishing contacts with the private sector (wholesale buyers, ecotourism operators, payers for ecosystem services). This requires the support of local communities by partners with long-term commitment and a local presence, likely to increase local capacities. Building organizational and managerial capacity within local communities is imperative (e.g. Fritz-Vietta and Stoll-Kleemann, 2008). The pooling of COBAs in several federations to create a network according to their geography was an important step in that direction. It is hoped to facilitate the exchange of experience among local communities and the dissemination of successful approaches.

**Conservation education in a rural school in Sahamalaza. (Photo: Guy Randriatahina)**

Many lemur species and populations occur outside Madagascar's traditional protected areas. The success of the establishment of a new Protected Areas System (SAPM) launched in 2003 is therefore critical for their survival. It has been recognized by the relevant authorities that the implication of local communities in the co-management of crucial habitats within SAPM is key to success, and a federated COBA network should play an important role in it.

**Conservation education: increasing environmental awareness nationally and internationally**

We all understand the need for improved education about the environment. Public opinion affects the success or failure of environmental management efforts. Researchers could spend years designing plans or studying biological processes, but fail to achieve conservation goals if they lack adequate public support. Conservation education shares many goals with the broader field of environmental education. These include providing learners with an opportunity to gain awareness, knowledge, attitudes, skills and participation. Conservation education also shares goals with newer programmes such as education for sustainable development: protect the environmental system that sustains life, and ensure appropriate economic development (Jacobson *et al*., 2006).

In Madagascar, as part of a lemur conservation strategy, effective conservation education is essential to raise awareness of lemur conservation on national and international scales. This will improve people's knowledge of lemurs and their habitat, promote pro-conservation behaviours and involve more people in lemur conservation and sustainability initiatives. Primate conservation education addresses cross-disciplinary issues (Jacobson, 2010); its systematic planning, implementation and evaluation as well as efficient collaboration, should help bring successful conservation strategies.

In Madagascar, rural communities often live in or near lemur forest habitats. These people depend for their survival on the biodiversity and services provided by healthy ecosystems. This is even more important for more impoverished communities. Lemurs are now one of the most threatened groups of larger vertebrates on the planet. In order to conserve lemurs and prevent further extinctions, conservation must include, work with, and educate local communities. Local communities need to be educated to take responsibility for conserving and managing natural resources in their vicinity. Keeping in mind the vital role of local community involvement, this section provides important components of conservation education programmes. These aim to (1) increase the likelihood for success of conservation education programmes; and (2) raise awareness of lemur conservation nationally and internationally. As recommended by Wallis and Lonsdorf (2010), conservation education should be relevant to the audience (welcoming ideas for protecting animals and its relation to well-being of local populations), include educator training, address poverty issues and local people's needs, and be part of an active conservation project. As conservation education grows as a focus and as a discipline, evaluation of results and exchange of information will encourage long-term success.

***Component 1: Lemur conservation education in schools***

Conservation education in schools takes many forms, including the use of occasional supplementary materials funded by wildlife agencies (e.g. Dolins *et al*., 2010) and integration of the environmental component into the curriculum. Conservation education in schools can range from a one-day field trip to the forest to greening initiatives contributing to sustainable development. In Madagascar, children are not taught about native wildlife or the science of conservation in schools (Dolins *et al*., 2010). Instead, they are more familiar with animal species that do not exist on the island (Ratsimbazafy, 2003). Malagasy culture includes many traditional proverbs inspired by domestic animals observed in daily life. Although non-governmental organizational efforts are important in conservation education, the Ministry of Education needs to incorporate biodiversity education in the curriculum at all levels from primary school to university (Dolins *et al*., 2010).

In Madagascar, integrating conservation education into legislation and educational policy is urgently needed. In the long term, comprehensive conservation education in the schools will require the systematic inclusion of environmental concepts in educational standards, capacity building for teachers and non-formal educators, funding, material development and legislative support for increasing the environmental literacy of the students (Jacobson, 2010).

a. *Environmental education handbook*
The creation of this handbook aims to bring supplementary educational materials to Malagasy schools. As with all other subjects taught in class, the capacity of teachers to integrate environmental education into their lessons needs to be built. They need to better know the value of natural resources, including lemurs, of the protected areas surrounding them and also to take part in environmental protection. The handbook should be distributed to the teachers of primary schools in the peripheries of protected areas. It is intended to be simple, easy to understand and written in the Malagasy language.

b. *Active approach in conservation education*
This approach is environment-based education that focuses on the use of the local environment, either natural or social, as a framework for the students' educational experience, with the goal of increased student achievement. Integrating the ecosystem/environment in relation to lemurs and their ecology will shape more responsible behaviour for creating a more sustainable future. This approach involves engaging students in selecting, planning, implementing and evaluating a real-world environmental project and making informed choices for action in the community. For example, schools can plan and implement a productive, healthy and ecologically sustainable environmental management system on school land, such as a garden or permaculture. Comprehensive training for teachers and students is needed to implement these active educational tools. This approach will raise awareness at the local level in the community where students' projects are conducted, and at the student's level.

c. *Connecting classrooms through lemur conservation topics*
Connecting classrooms could be part of the lemur conservation education programme to engage teachers, students and partners in direct interactions regarding conservation, ecology, ecosystems and the environment (Jacobson, 2010). This creates links between classes at the national level and could be broadened with international schools. Although this activity may need a high standard of technology, some Malagasy schools in cities would be able to be part of this connection programme to increase the awareness of lemur conservation in cities and abroad. Many schools and universities abroad adopt this connection to exchange information, cultures and experiences between teachers and students. Teachers and students in cities could take advantage of educational technology to share, to learn and to exchange conservation issues with other national or international schools, for example using video, websites and distance education. UNICEF is taking the lead on this initiative in Madagascar. Close collaboration with them should be sought to spread this to a national level.

***Component 2: Creating a network for conservation education***

Effective conservation demands the skill of networking to build relationships in a community. Networking for conservation allows teachers and students to become advocates for each other and find common interests. Networks can create synergy between groups, generate resources and support, and promote conservation objectives.

a. *Environmental clubs and groups*
Creating environmental clubs mobilizes individuals with a common interest or stake in conservation issues. Environmental clubs in schools and universities can be creative and productive. Environmental education for youth can provide significant life experiences that help develop environmental interests and actions (Chawla, 1999). The role of environmental clubs is to provide practical experiences in outdoor settings, develop hands-on conservation experiences, increase knowledge of endemic biodiversity and environmental issues, and develop environmental responsibility in young people. Developing motivation and skills through such clubs could increase positive attitudes and activities towards lemurs and their habitats, promote awareness of ways to care for the earth and its resources, enhance knowledge about surrounding schools and the community, empower students to implement environmental change, and build participation in conservation actions.

b. *Workshops and seminars*
Workshops and seminars provide a structured forum where people come together to increase their knowledge and skills, work on a common task, and build consensus for action. They constitute positive tools for raising awareness at three levels: local, national and international. Workshops use strategies such as lectures, discussions, and small and large group activities, and encourage reflection. They may address a public audience, teachers, students or members of organizations, and provide an opportunity to present the latest scientific data, influence attitudes and behaviours, and respond to questions in a community or clarify public misconceptions.

c. *Creating and printing leaflets, posters and T-shirts*
Leaflets, posters and T-shirts are important ways to publicise a direct conservation message. These resources could be distributed on any occasion including environmental and community development events such as World Environment Day, tree-planting day, local or national festivities such as local fairs, Independence Day and School Day. They should be printed in three languages: Malagasy, French and English, so that these resources could also be distributed to tourists. Regarding the leaflets, we suggest that they will show three categories of information: basic background information on the lemurs present within the protected areas, threats to the lemurs, and the conservation measures to be carried out. Concerning the posters, the message should be short and easily understood by all potential audiences. We suggest that the message should highlight flagship lemur species of the protected areas. Posters should convey information in a visual format in order to share research results and network with the public, students, teachers and professionals.

***Component 3: Making conservation education memorable***

The objective is to bring conservation education to life, generating enthusiasm and excitement about lemurs, biodiversity and environmental conservation. Conservation education can be made memorable by celebrating the wonders of nature, immersing learners in different perspectives, and using the outdoors as a context for new inspiration.

a. *Installation of permanent educational plaques*
Permanent educational plaques constitute another method to pass a conservation message. We suggest that information on the lemurs which make the forest habitat unique could be written on such plaques. Metal plaques could be installed within the commune or village close to the lemur forest habitats so that the villagers or visitors could see and read the messages permanently.

b. *Radio/ television broadcast on environmental topics*
Radio and TV are useful to broadcast lessons and news on environmental issues. The information could be passed on to audiences through reading text, discussions or interviews. Different topics such as threats to the lemurs, advantages and benefits from the forest and lemur conservation actions should be developed. This could be broadcasted on national or local radio/ TV. The programme could be repeated twice weekly for several weeks.

c. *Games, storytelling, role-playing, field trips*
Games constitute a complementary method of conservation education. They provide a strategy to introduce or reinforce concepts taught through other conservation education methods and could target both children and adults. Storytelling is an effective means in transmitting information. Based on Jacobson *et al.* (2006), storytelling is "simple, timeless, empowering, appealing to different audiences, fun, a form of recognition, an excellent strategy to pass along traditions". Storytelling can teach vital conservation lessons and inspire environmental actions. At the national level, compilations of lemur/biodiversity stories constitute an important resource for educators in conservation education. By assigning roles to learners in a scenario, role-playing builds real-world skills and understanding of perspectives. For example, by playing the role of a lemur, children could understand the ecology, threats and needs of these animals. This technique encourages communication and problem-solving skills, and raises awareness on conservation issues. Field trips provide first-hand experience of conservation sites and resources to enhance learning about biodiversity and conservation.

For conservation education to be successful, the topic should be integrated into teaching at all levels (primary school to university). Networking is an important component to enable sharing of activities and achievements. Making teaching memorable will engage children and people in learning and will be enhanced through direct experience. Education alone cannot achieve the desired conservation impact; a combination of the many strategies outlined in this document is needed to address the situation as a whole. Effective education and outreach are essential for influencing conservation policy, involving more people in conservation initiatives, improving people's knowledge and changing behaviours, garnering funds, and sharing scientific advances. The fate of Madagascar's fragile environments depends on effective communication with a great variety of audiences.

## Research and Higher Education

Since publication of the first lemur conservation action plan (Mittermeier *et al*., 1992), there has been a remarkable proliferation of research on lemurs. These studies have enhanced our understanding of lemur taxonomy, population genetics, distribution and abundance, demography, parasites and disease, endocrinology, feeding and ranging ecology, social behaviour, and many other important research areas (e.g., Gould and Sauther, 2006; Kappeler and Ganzhorn, 1993; Kappeler and Watts, 2012; Rakotosamimanana *et al*., 1999, and sources therein). Moreover, this research has spread over many new habitats and species, providing an ever-increasing knowledge base to inform conservation management. However, there remains much work to be done. In particular, we highlight the need for long-term monitoring of populations, environments, and threats, as well as improved management and sharing of the data critical for lemur conservation. We also underscore the necessity for encouraging the independence of Malagasy scientists through increasing their training opportunities, funding mechanisms, and access to cutting-edge research technologies and techniques, both abroad and whenever possible within Madagascar, and the implication of all conservation stakeholders, including local communities, in the research process. In the following section, we offer specific suggestions for urgent research needs.

### *Taxonomic review*

Taxonomic and phylogenetic research is essential for establishing units and setting priorities in conservation. In the past decade, there has been extraordinary growth in the number of described lemur species (see Mittermeier *et al*., 2008). While some of these represent former subspecies now elevated to species, many are wholly new to science (e.g., Louis *et al*., 2006; Yoder *et al*., 2000). However, many taxa have been described largely based on a limited range of maternally-inherited mitochondrial DNA sequences, leading some to call for incorporating a broader set of markers and traits (Horvath *et al*., 2008; Markolf *et al*., 2011). Multi-locus genomics data sets with appropriate analysis techniques may be especially promising for resolving lemur phylogenies (Weisrock *et al*., 2012). Moreover, it may be necessary to include type specimens found in museum collections in some phylogenetic analyses to apply the appropriate nomenclature, especially when locality information for original specimens is patchy.

**Conservation posters at the annual Lemur Festival in Sahamalaza. (Photo: Guy Randriatahina)**

### *Population monitoring*

Many surveys have been conducted to document the distribution and density of lemur populations across remaining habitats (e.g., Irwin *et al*., 2005). We recommend further surveys to continue to refine the known range limits, to indicate areas of exceptional diversity or abundance, and to reveal underlying biogeographical patterns and processes. This research is especially critical for the least known and more endangered taxa. To improve upon existing data, it is important to increase sampling effort for robust estimates of population density (e.g., distance methods or complete count census) and to repeat surveys at regular intervals to assess long-term demographic trends. Simultaneous documentation of the sorts of habitat conditions that may influence population size is also recommended, including landscape and vegetation types, phenology, disturbance, and climate. In parallel with ground surveys, we suggest population genetic studies, especially using non-invasive sample collection (Quéméré *et al*., 2010a, 2010b); such research promises complementary information on genetic variation, as well as data on past demographic processes and future potential. We strongly support increased application and testing of population survey methods that involve local communities, and that results are shared among all partners in conservation. To this end, we suggest the development and distribution of GIS databases that include survey localities, vegetation plots, lemur presence/absence or abundance data, and sample collection sites.

### *Long-term behavioural and ecological research*

In addition to population surveys, we recognize the tremendous conservation value of lemur behavioural ecology studies conducted over at least several decades in a few key sites, such as Ranomafana, Beza Mahafaly, Berenty, and Kirindy (Kappeler and Watts, 2012). This research has provided data critical for assessing the ecological requirements of threatened species. Such long-term study also offers more indirect – but no less important – conservation benefits, including local employment and capacity building and a presence in the forest to deter illegal hunting, logging, or mining. Such long-term commitment may also foster better relationships and communication among conservation stakeholders (researchers, managers, and local communities). We hope that this work will continue, and should be expanded to include many more new sites and ecosystems throughout Madagascar.

### *Quantification of threats*

While habitat loss and fragmentation, hunting, mining, and perhaps climate change are generally known to be among the significant threats to lemur survival, little research has been conducted to date to precisely measure these activities and their relative impact. For instance, deforestation has been quantified through remote sensing techniques (e.g., Green and Sussman, 1990; Harper *et al*., 2007), yet comparatively little is known about forest degradation and its potential impacts on lemur populations. There are several model research programs for assessing fragmentation and edge effects (e.g., Irwin, 2008; Lehman *et al*., 2006); similar studies are recommended across Madagascar's diverse environments and distinctive lemur communities. Hunting of lemur species and the commercial bushmeat trade are also topics of critical research importance. There is now extensive anecdotal evidence for widespread hunting pressure, but more systematic studies are needed, including hunter follows, market and village surveys, records of trap densities, etc. (Golden, 2006, 2009). Threats that are presently less urgent because they are localized (e.g., fire) or more long-term (e.g., climate change) nonetheless also require increased research activity.

### *Mitigation of threats*

In addition to studying the threats to lemurs, we strongly recommend more research on the programs designed to reduce them. A wide variety of tactics are used across Madagascar for these conservation aims, as well as to improve livelihoods in local communities. These include reforestation (including research on the effectiveness of forest corridors for long-term lemur adaptation and viability); development of alternative resources; community-based management of protected areas and natural resources; ecotourism and other alternative economic activities; and conservation-oriented education. There must be rigorous study, with standardized metrics of success, to evaluate these programs and ensure the best possible outcomes for lemurs, their environments, and the communities that rely on them.