Climate change and the cost of conserving biodiversity in Madagascar

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Abstract: *In Madagascar as across the world, new temperature and precipitation patterns caused by climate change are expected to alter species' suitable climatic ranges. We calculate the cost of ensuring minimum acceptable viable areas of stable forest habitat for 72 endemic plant species under successively greater levels of climate change. We identify four categories of species, requiring four successively more costly levels of management action to maintain minimum viable habitat areas. Exacerbated climate change forces society to confront a choice between spending more to maintain habitat for the same number of species, or maintaining habitat for fewer species at the same cost. We estimate that avoiding forest degradation ($160-265/Ha) and avoiding deforestation ($160-880/Ha) are substantially cheaper strategies for ensuring forest cover than restoring natural forest once it has been cleared ($802-2650/Ha). Natural forest restoration will be necessary for some species, but should be highly targeted and will likely require new sources of financing.*

Keywords: Biodiversity conservation, climate change, adaptation cost, Madagascar

Introduction:

The Madagascar biodiversity hotspot (Myers *et al*, 2000) is characterized by almost unparalleled levels of endemism (Goodman and Benstead, 2005). To protect its globally important biodiversity, the Government of Madagascar has committed to tripling the country's terrestrial and marine protected areas network over a period of five years—a commitment announced in 2003 at the World Parks Congress in Durban, South Africa and known as the Durban Vision. Expansion of the protected areas network under the Durban Vision is already underway. International aid agencies and conservation groups have invested over $150 million in Madagascar since 1997 (World Bank, 2008a).

The long-term success of the protected areas network put in place under the Durban Vision will depend on the resilience of the network to continuing changes in climate and land use. In Madagascar as across the world, new temperature and precipitation patterns are expected to alter species' suitable climatic range. Repeat transect surveys in 1993 and 2003 demonstrate that montane endemic amphibians and reptiles in Madagascar are already moving upslope, consistent with predictions under a warming climate (Raxworthy *et al*, 2008). Some species may be unable to move with their suitable climatic range, particularly where anthropogenic land use has created barriers between areas of suitable habitat.

An experts workshop in Antananarivo in January, 2008 recommended three approaches to reduce climate change impact on biodiversity and facilitate species' range migrations (Hannah *et al*, 2008). These recommendations were reducing deforestation pressure in remaining natural forests, restoring connectivity between isolated forest fragments, and restoring natural forests along riverine corridors. The workshop also recommended that forest management efforts consider human climate change adaptation needs.

At the same time, any strategy for biodiversity conservation under climate change must recognize that Madagascar is a poor country, economically dependent on the environment. 85% of Malagasy survive on less than US$2 a day (World Bank, 2008b). This poverty is both a cause and a consequence of forest loss. Approximately 80% of Madagascar's population lives in rural areas and relies on subsistence agriculture for survival (Kistler and Spack, 2003). Shifting, slash and burn cultivation of rice, known as *tavy,* is a main driver of deforestation throughout much of Madagascar (Erdmann, 2003). Furthermore, 17 million Malagasy consume 22 million m^3 of wood annually for cooking and construction (Rabenandrasana, 2007). As a consequence, Madagascar has a deforestation rate more than twice the global tropical average (FAO, 2005), and only 10% of original forest cover remaining (Harper et al, 2007). Decades of deforestation have led to less clean water available for drinking and farming. Protected forests provide 8.4 million m^3 in downstream drinkable water, and irrigation water for 431,000 Ha of cropland (Carret and Loyer, 2003) Loss of habitat for charismatic wildlife such as lemurs and chameleons impacts Madagascar's tourism industry, which provides jobs and economic growth (estimated 5.1% of employment; 6.3% of GDP; WTTC, 2008).

It is therefore essential that land use planning for the conservation of biodiversity under climate change should safeguard species at the least cost, while reducing poverty through substitute provision of wood and agricultural commodities. In this paper, we calculate the cost of ensuring minimum viable areas of stable natural forest habitat for 72 endemic plant species in Madagascar, under successively greater levels of climate change. We identify four categories of species, requiring four successively more costly levels of management action to ensure viable habitat. We find that as climate change is exacerbated, society increasingly faces a choice between spending more to protect the same number of species, or protecting fewer species at the same cost.

Method:

For each of 72 endemic vascular plant species, we projected species range for the year 2020, 2050, and 2080, corresponding to a rise in decadal mean surface temperatures above pre-industrial level of 1.0-1.5 °C, 2.0-2.5 °C , and 3.0-3.5 °C respectively (IPCC, 2007). For each species in each year, we calculated the additional area of stable forest habitat required to obtain minimum viable habitat area. We estimated the cost of obtaining stable forest habitat from field studies for each of six land uses. We calculated the cost of obtaining minimum viable habitat area for each species by pursuing sequentially more costly management actions until minimum viable habitat area was achieved.

Species distributions under climate change

We generated present and future species distributions for 72 endemic vascular plant species using Maxent, a species distributional model based on the physical principal of entropy (Phillips and Dudik 2008). All species were endemic and known from at least seven unique localities. Species were selected to provide representation from all vegetation types, bioclimatic zones, and geographic areas. The modeling methods follow those described in detail in Kremen et al. (2008) with three improvements to the methods: we used logistic outputs; we applied species specific thresholds during the removal of biogeographic over-prediction from the present (year~2000) distribution; and we removed sample bias by selecting a random sample of background data drawn from the sampling distribution. The resulting models were fitted to current and future climate conditions. Current climate layers were downloaded from the WorldClim website <www.worldclim.org> at 30 Arc-second resolution. Matching future climate layers for 2020, 2050, and 2080 were prepared for the HadCM3 Coupled Atmospheric-Oceanic General Circulation Model, from the Hadley Centre, United Kingdom, for the A2a IPCC (Intergovernmental Panel on Climate Change) scenario. A total of nine climate variables were used (see Hannah et al. 2008, and Kremen et al. 2008). Percent forest cover for 2000, at the 30 Arc-second grid resolution, derived from forest change maps at 28m resolution, (Harper et al.2007) was included as a continuous variable, and was assumed to remain constant between current and future climate conditions. Future climate predictions were constrained by the climatic limits currently experienced across the whole of Madagascar, so no prediction was made where the future climate did not have a current analogue.

Cost of achieving stable natural forest habitat

We categorized units of land as one of six land use types based on two classes of forest cover and three classes of land management. We identified units of land as forest or non-forest based on Conservation International's 2000 forest cover change map (Harper et al. 2007). We identified units of land as managed for biodiversity, managed for community wood needs, or unmanaged based on a new map of existing and proposed Madagascar protected areas (Government of Madagascar, 2008). We identified pre-Durban Vision protected areas as managed for biodiversity or community wood needs based on IUCN world protected areas' categorizations. Pending final status and creation, we assumed that all new protected areas were co-managed by government and communities for community wood needs.

We estimated the cost of achieving stable natural forest cover for each of six land uses. We defined stable natural forest cover as natural forest within an area managed for biodiversity, or natural forest within an area managed for community wood needs, for which a sufficient quantity of wood commodities could be provided locally to substitute for forest degradation. We assumed that natural forest outside of these areas was vulnerable to clearing over the time scale of this analysis.

Achieving stable natural forest cover on a unit of land included the following cost components, based on current land use (Table 1):

- for forests in areas managed for biodiversity, we assume no cost, though in reality additional management costs may be needed here as well
- for forests in areas managed for community wood needs, the cost of stabilizing forests from degradation through the substitute provision of wood products by local plantation forests
- for forests in unmanaged areas, the cost of stabilizing forests from deforestation for agriculture, plus the cost of establishing community management

- for non-forests in areas managed for biodiversity, the cost of natural forest restoration
- for non-forests in areas managed for community woods needs, the cost of natural forest restoration, plus the cost of stabilizing forests from degradation
- for non-forests in unmanaged areas, the cost of natural forest restoration, plus the cost of stabilizing forests from deforestation for agriculture, plus the cost of establishing community management

We converted all costs to net present 2008 US$. We converted historical costs in Madagascar Ariary to 2008 Ariary using average consumer prices from the 2008 IMF World Economic Outlook (IMF, 2008). We converted historical costs in US$ to 2008 US$ using the Bureau of Labor Statistics inflation calculator (<http://146.142.4.24/cgi-bin/cpicalc.pl>). We converted current Ariary to US$ using the average exchange rate for July 2007-August 2008 of US$1 = 1753 Ariary (<www.oanda.com>). We discounted future costs to net present value at a discount rate of 8%, consistent with a previous study of forestry costs in Madagascar (Lopez *et al*, 2007).

Cost of natural forest restoration: We estimated the per-hectare cost of natural forest restoration following interviews with the managers of 13 natural forest restoration projects across the island of Madagascar. We identified restoration projects through discussions with more than 30 experts in NGOs, government, and bilateral aid agencies. The per-hectare restoration cost included both project start-up costs (obtaining land rights, community consultation, scientific research) and recurring costs (labor, trees and materials, maintenance, transportation, training, and administration). Where both budgeted and incurred costs per hectare were available for the same project, we used the mean of these two costs.

Per-hectare net present costs of natural forest restoration ranged from $291/Ha to $20,000/Ha. The wide variation across projects in the per-hectare cost of restoration can be explained by differences in forest type, soil type, distance of restoration site from mature forest, density of trees planted per hectare, ability of project to leverage local labor, and years a project had been in place. To reduce sensitivity to outliers, we selected the 25th percentile costs ($802/Ha) and 75th percentile costs ($2650/Ha) as high and low values. Start-up costs contributed $105-229, while recurring costs contributed $697-$2421 to total project costs.

A number of important caveats apply to our estimates of the cost of natural forest restoration. The sample size of restoration projects was small. Cost figures were self-reported. Projects were frequently sited in the best or cheapest sites, so may not be representative of a project at a randomly selected site. Many projects were very new, soI it is too early to judge the success rate of projects, though in most cases short-term plant survivorship was high. Furthermore, it will be decades before replanted seedlings will be biologically equivalent to mature forest. Climate change could change the feasibility, and the cost, of restoring forest in different regions. And finally, the effect restoration will ultimately have on species' ability to move under climate change is unknown. These uncertainties underscore the need for more sizable, long term, on-the-ground natural forest restoration projects, with monitoring, from which to improve the accuracy of cost estimates.

Cost of avoiding forest degradation through wood product substitution: The cost of stabilizing a hectare of natural forest from degradation was the net present cost of substituting the provision of wood products through nearby plantation forestry with fast growing exotic species. We assume that for any forest in Madagascar a sufficient quantity of degraded land exists for plantation forestry within market distance. Estimates of this cost were based on analyses of eucalyptus plantations in the Antsiranana (Diego Suarez) dry forest region, and eucalyptus plantations in the Taolagnaro (Ft. Dauphin) wet forest region. The net present cost per hectare of stabilizing natural forest from degradation was the net present cost per hectare of planting and replanting a plantation forest, divided by the annual usable wood content (construction, firewood, and charcoal) per hectare of plantation forest SWITCH (Lopez *et al*, 2007; Rabenandrasana, 2007), multiplied by the annual usable wood content per hectare of natural forest (Rabenandrasana, 2007). We selected costs from the Diego Suarez region ($160/Ha) to represent low costs, while we selected costs from the Ft. Dauphin region ($265/Ha) to represent high costs. As with natural forest restoration, cost estimates of avoided forest degradation could be improved through the implementation of more sizable wood substitution programs.

Cost of avoiding deforestation through agricultural stabilization: The per-hectare cost of stabilizing natural forest in unmanaged areas has two components—the cost of establishing community management, and the cost of substitute provision of agricultural goods to local users. We derived cost estimates for the establishment of community management from Meyers *et al* (2005), who found low and high annual costs for management of a medium (2000-20,000 Ha) conservation site to be $7.38-$15.15/Ha, corresponding to net present costs of $92-$210/Ha. We did not include the cost of unmet management needs, including enforcement, in existing protected areas, which in some cases may be substantial. The low substitution cost estimate assumed substitute provision of wood products only. The high substitution cost estimate assumed substitute provision of rice. This cost was based on a study in the Maraonsetra region, which found the net present value of farmers' median annual stated willingness to accept payment in rice in exchange for ceasing tavy practices to be $880 per hectare (Minten, 2003). In the absence of comparable studies elsewhere in Madagascar, this figure is assumed to be representative of the entire island. Estimates of the cost of avoiding deforestation could be greatly improved through the implementation of real avoided deforestation projects.

Cost of achieving minimum cover: For each species, in each time step, we calculated the cost of achieving greater than 10,000 Ha (100 km^2) of stable natural forest. This area represents the habitat area below which a plant species is classified as "very restricted" by the IUCN Red List, and follows Hannah (2007). We calculated this cost determining how much land in the species range required a change in management or land cover type to bring the species range to 10,000 Ha stable forest cover. For each species, we selected land use changes to be put in place from least to most expensive per hectare until minimum cover was achieved. So, land was added first from forest managed for community wood needs ($160-265/Ha), then from forest in unmanaged areas ($252-1090/Ha), then from non-forest in areas managed for biodiversity ($802-2650/Ha), then from non-forest in areas managed for community wood needs ($962-2915), and finally from non-forest in unmanaged areas ($1054-$3740). That is,

$$C_{it} = \sum_{n=A_{it}+1}^{10,000} x_n \mid x_n \leq x_{n+1}$$

Where C_{it} represents the total cost of ensuring a minimum viable area of stable forest habitat for species i in year t, A_{it} represents the existing area in stable forest habitat for species i in year t, and x_n represents the cost of achieving stable forest habitat on the n^{th} hectare of land, where land units are rank-ordered from lowest to highest cost per hectare.

Results:

Under climate change, ranges for most species are projected to shrink (Table 2b) and shift (Table 2c-d). We categorize species in four broad categories (Table 2e-i), based on the management action required to ensure minimum stable forest cover for the species.

Although most species are projected to lose range, many species are projected to retain greater than 10,000 Ha of stable forest cover within their range (Table 2e). These Category I species can remain above minimum suitable levels of habitat area without additional management action. The *Rhodolaena bakeriana*, a vascular plant of the mid-elevation rainforest; is such a species (Fig. 1a).

For some species, climate change is projected to result in ranges containing greater than 10,000 Ha of forest, but less than 10,000 Ha in stable forest habitat (Table 2f). These Category II species only require avoiding degradation or deforestation, which is relatively cheap. The *Brenierea insignis*, a legume of the southwestern subarid forest thicket and the only species of its genus, is such a species (Fig.1b).

For other species, climate change is projected to result in ranges containing less than 10,000 Ha of range in forest (Table 2g). For these Category III species, ensuring minimum suitable habitat area requires relatively expensive forest restoration, which is five to ten times more expensive than avoiding degradation or deforestation. The *Schizolaena laurina*, a humid eastern littoral forest plant, is such a species (Fig. 1c).

Finally, an increasing number of species are projected to have their range size fall below 10,000 Ha in total, or are projected to lose range entirely. For these Category IV species, achieving minimum viable habitat is not possible through avoided degradation, avoided deforestation, or forest restoration. If these species are to survive, intensive species management or *ex situ* conservation must be considered. The *Rhodolaena altivola*, a vascular plant of the lowland humid forest, is such a species (Fig. 1d).

Cumulative cost curves to achieve minimum viable habitat for a given number of plant species at least cost are displayed in Figure 2. Cumulative cost curves shift upward and inward with climate change, as more species move from no-cost Category I to costly Categories II and III, and from these categories to no-management-possible-at-any-cost Category IV. This means that at a given cost minimum viable habitat could be provided for fewer species, or minimum viable habitat could be provided for the same number of species at higher cost. With $20 million to spend on land use changes for species conservation, minimum suitable habitat could be achieved for 66-69 species in 2020, 62-66 species in 2050, or 55-58 species in 2080. Alternatively, the goal of achieving minimum suitable habitat for 60 of 72 species would cost $0.3-0.6 million in 2020, $3.5-7.2 million in 2050, or $36.3 to 120.3 million in 2080. By 2080, achieving minimum suitable habitat for more than 60 or 72 species would not be possible at any expenditure.

Discussion: We have identified four categories of species, requiring four successively more costly levels of management action to maintain minimum habitat areas under climate change. Category I species are predicted to maintain ranges greater than the minimum acceptable level of suitable habitat under climate change, and require no additional management action. Category II species are predicted to shift range into forests requiring stabilization from degradation or deforestation, which can be achieved relatively cheaply. Category III species are predicted to shift range out of forest, requiring relatively expensive natural forest restoration. Finally, Category IV species are predicted to have range size shrink below minimum acceptable levels. No amount of forest stabilization or restoration can ensure survival in the wild for these species. If these species are to survive, *ex situ* conservation must be considered.

Maintaining biodiversity security in the face of climate change requires sufficient species richness to ensure an unimpaired supply ecosystem services for human well-being (Midgley *et al*, 2009) Yet exacerbated climate change forces society to confront a choice between spending more to protect the same number of species, or protecting fewer species at the same cost. The most species can be protected most cheaply under climate change by focusing resources on avoiding forest degradation and deforestation now, through the creation of substitute sources of wood products and agricultural commodities. Avoiding forest degradation and deforestation is considerably cheaper, quicker, and more biologically valuable than restoring forest once it has been cleared.

Still, some species are not predicted to maintain minimum habitat without natural forest restoration. Climate change imposes a growing role for natural forest restoration, even though it is relatively more expensive than avoiding degradation and deforestation of current forest. To maximize cost-effectiveness, natural forest restoration should be targeted to promote connectivity between existing patches of stable natural forest, especially along elevational or latitudinal gradients. Rivers and rail corridors present natural opportunities for restoring natural forest along such gradients. Natural forest restoration should also target areas where eco-system based adaptation can provide for human adaptation needs in a changing climate.

Future work can build upon this analysis along three avenues. First, future estimates of the costs of management actions will benefit from additional examples of forest restoration and agricultural and wood product substitution projects from which to gather primary cost data. Second, an actual conservation planning optimization for Madagascar species under climate change would spatially identify and prioritize units of land which provide habitat for multiple species species simultaneously, and could use species-specific minimum area thresholds. This paper is merely intended to illustrate rising costs under climate change rather than to provide precise total cost estimates or to identify priority sites. Total cost figures would be lower under a multi-species conservation planning optimization. Third, future theoretical studies of conservation under climate change could work to develop a dynamic site selection algorithm. By calculating least-cost strategies separately for each time step, we have left aside the question of whether investments in earlier time steps would remain valuable in later time steps.

A portion of the cost of stabilizing natural forest from degradation and deforestation could be offset directly through carbon financing (e.g. REDD) and indirectly through downstream hydrological benefits (clean water provision for drinking and farming). We estimate average REDD potential in Madagascar to be $45 per hectare per year.[1] Downstream net present hydrological benefits in Madagascar have been estimated on the order of $44/Ha (Carret and Loyer, 2003). The cost of natural forest restoration projects could be partially offset through afforestation and reforestation mechanisms of a global climate agreement. Stable natural forests also provide the important co-benefits of sustainable harvesting of medicine, food, and construction materials, as well as eco-tourism potential. Even with monetary and non-monetary co-benefits, funding for forest protection is likely to continue to require external financing.

Our findings have implications for other high biodiversity, high deforestation hotspots, including the Philippines, the Western Ghats, the Atlantic Forest of Brazil, Mesoamerica, West Africa and others (Myers, 2000). In these other hotspots, as in Madagascar, conservation of some species under climate change is likely to require reconnection of forest patches. The relative difference between the cost of avoided forest degradation and deforestation and the cost of natural forest restoration is likely to hold in these regions as well, due to similar economic conditions and the technical challenges of tropical forest restoration. At the same time, all of these regions have urgent poverty alleviation needs in the present and human climate change adaptation needs into the future. Conservation strategies in these hotspots can and must be designed to alleviate poverty, through commodity substitution and employment, and to provide resilience for human needs in the face of climate change, through the ongoing provision of ecosystem services.

In these hotspots, as in Madagascar, national economic situations are likely to preclude domestic funding of the magnitude required for climate change adaptation. There is therefore an urgent need for global financing of conservation and human adaptation in high deforestation areas. One potential source of finance is a set-aside of revenues from carbon allowance auctions, as proposed in the Waxman-Markey climate change legislation in the U.S. Congress. Carbon auctions arise to support climate change mitigation efforts, so it is appropriate that the revenues from such auctions be used to support conservation and human adaptation activities under climate change that will be necessary despite mitigation. Auction revenue set-asides offer the potential to achieve financing for ecosystem based adaptation on the scale needed to ensure biodiversity security under climate change.

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[1] We multiply a 1990-2000 national deforestation rate of 0.5%/yr by a carbon density of 244 tons of above- and below-ground biomass per hectare (FAO, 2005) by a CO_2/C ratio of 3.66, by an assumed carbon price of $10/ton CO_2.

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	Cost of wood product substitution	Cost of establishing community management	Cost of agricultural product substitution	Cost of natural forest restoration	Total cost
Forest in area managed for biodiversity	-	-	-	-	$0
Forest in area managed for community wood needs	$160-265	-	-	-	$160-265
Forest outside managed area	-	$92-210	$160-880	-	$252-1090
Non-forest in area managed for biodiversity	-	-	-	Start-up: $105-229 Recurring: $697-2421	$802-2650
Non-forest in area managed for community wood needs	$160-265	-	-	Start-up: $105-229 Recurring: $697-2421	$962-2915
Non-forest outside managed area	-	$92-210	$160-880	Start-up: $105-229 Recurring: $697-2421	$1054-3740

Table 1 – Net present cost per hectare of ensuring stable natural forest, by current land use ($/Ha; low-high cost estimates)

		Year		
Species		2020	2050	2080
Total species	n	72	72	72
(a) Species with habitat remaining	n	72	70	64
(b) Species with range size smaller than present range	n	42	41	56
(c) Species with >50% of range outside of present range	n	23	30	38
(d) Species with >90% of range outside of present range	n	6	12	18
(e) Category I Species: >10,000 Ha of range in stable natural forest	n	59	54	50
	Ave. cost/spp (million USD)	-	-	-
	Total cost (million USD)	-	-	-
(f) Category II Species: >10,000 Ha of range in natural forest; <10,000 Ha of range in stable natural forest	n	9	11	8
	Ave. cost/spp (million USD)	1.4-4.1	1.3-4.1	1.0-3.3
	Total cost (million USD)	12.3-37.2	13.8-45.6	8.4-26.5
(g) Category III Species: >10,000 Ha of range; <10,000 Ha of range in natural forest	n	3	4	3
	Ave. cost/spp (million USD)	7.1-23.5	5.5-19.4	9.1-31.0
	Total cost (million USD)	20.3-70.5	22.0-77.6	27.4-92.9
(h) Category IVa Species: <10,000 Ha range	n	1	1	3
	Ave. cost/spp (million USD)	Inf.	Inf.	Inf.
	Total cost (million USD)	Inf.	Inf.	Inf.
(i) Category IVb Species: No remaining range	n	0	2	8
	Ave. cost/spp (million USD)	Inf.	Inf.	Inf.
	Total cost (million USD)	Inf.	Inf.	Inf.

Table 2 – Species categories and cost of management actions in each time step

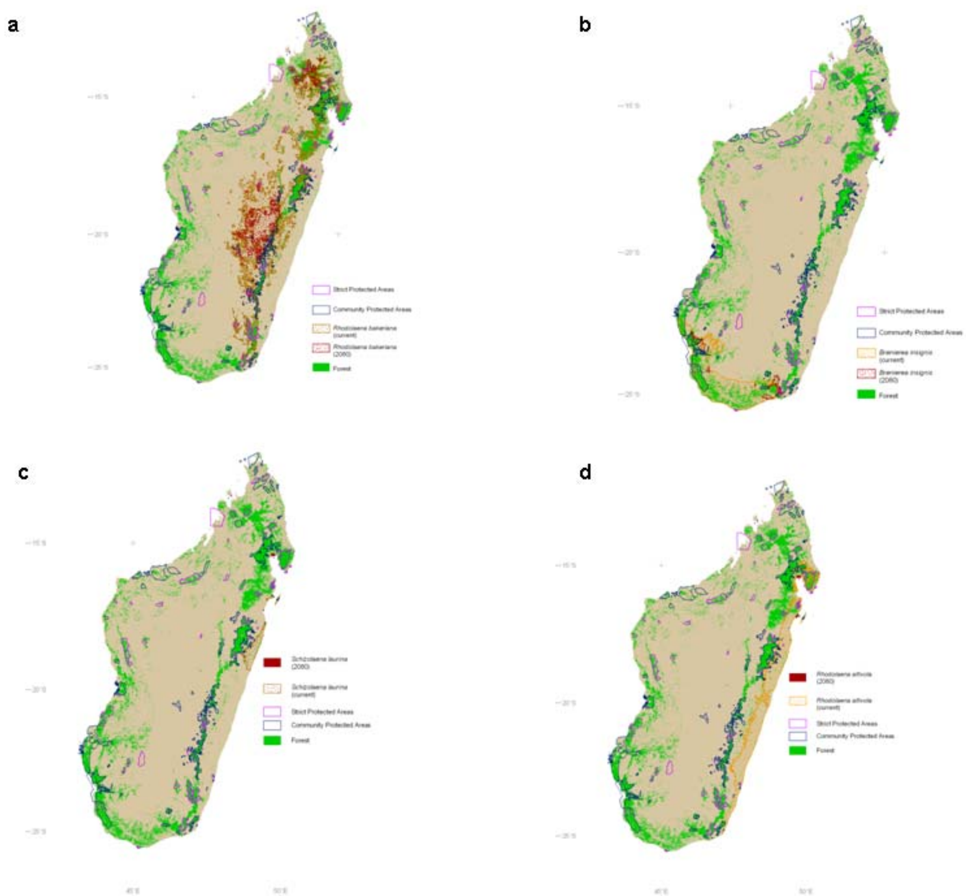

Figure 1 – Present and future distributions of species from each management category
(a) Category I –*Rhodolaena bakeriana* in the present and in the year 2080
(b) Category II – *Brenierea insignis* in the present and in the year 2080
(c) Category III – *Schizolaena laurina* in the present and in the year 2080
(d) Category IV – *Rhodolaena altivola* in the present and in the year 2080

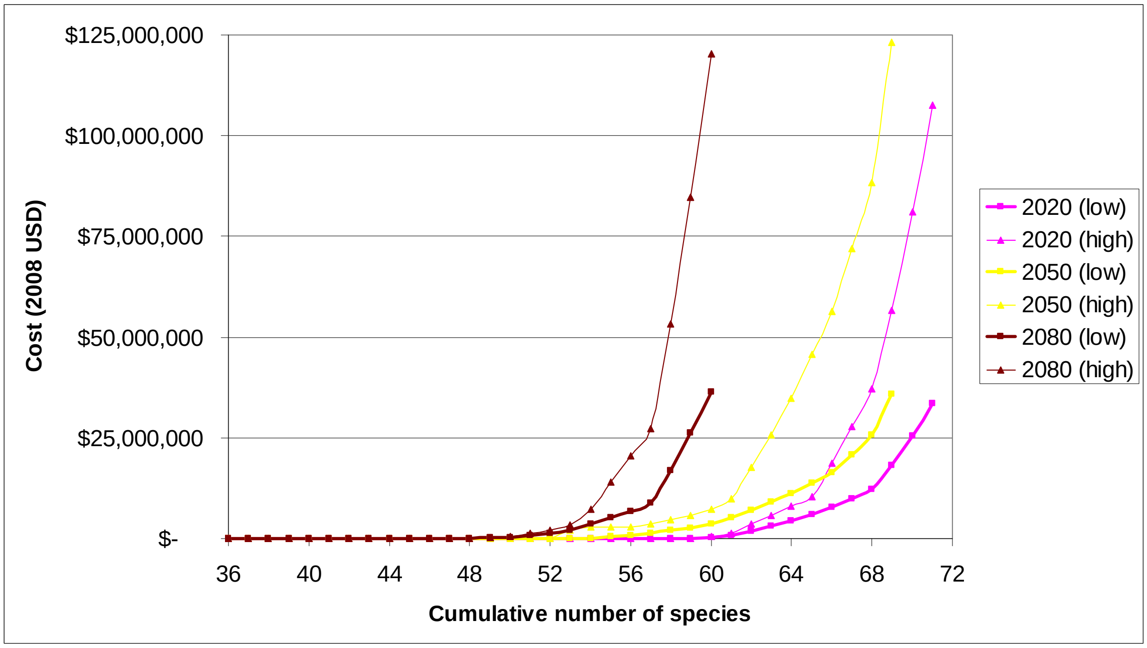

Figure 2 – Low and high cost estimates of providing >10,000 Ha stable natural forest cover to endemic plant species. To the right of cost curves, no level of expenditure can provide cover for that number of species.