Lemur bridges provide crossing structures over roads within a forested mining concession near Moramanga, Toamasina Province, Madagascar

Vanessa Mass[1*], Barson Rakotomanga[1], Gilbert Rakotondratsimba[1], Solomampionona Razafindramisa[1], Paul Andrianaivomahefa[1], Steven Dickinson[2], Pierre O. Berner[1] & Andrew Cooke[1]

[1] *Environment Department Mine site, Ambatovy Minerals SA, Moramanga, Madagascar*

[2] *Biodiversity Adviser, Golder Associates Pty Ltd, Queensland 4066, Australia*

*Corresponding author e-mail: Vanessa.Mass@ambatovy.mg

SUMMARY

The Ambatovy Project includes a large, open-pit nickel mine located in Madagascar's eastern humid forest, and an associated pipeline to remove laterite slurry off site. The area is recognized for its high biodiversity exemplified by the presence of at least 13 lemur species in forests surrounding the mine site. In order to reduce potential habitat fragmentation impacts on the lemur populations as a consequence of recent access road construction, seven crossing structures (referred to as 'lemur bridges') were erected within the mine footprint area and along the slurry pipeline that will remain in place until rehabilitated forest allows for movement over roads via the forest canopy. Two bridge designs were used due to differences in road width and vehicle traffic type. Lemur bridges have been monitored since their construction in January-February 2009. To date (10 August 2010), bridges have been used by six lemur species. Mine footprint type bridges (suspension bridge design) have been used more frequently than slurry pipeline bridges (plank bridge design) and, overall, there has been an increase in bridge use in 2010 when compared to 2009 (from 8 % to 24 % of total observations where lemurs are present in proximity to bridges). These results suggest that although a certain time period may be required for lemurs to locate and habituate to bridges, these crossing structures offer an effective mitigation measure to assist in reducing the impacts of habitat fragmentation.

BACKGROUND

The Ambatovy Project is a large nickel mining project in eastern Madagascar. Mine site and associated infrastructure construction began in 2007. Production is due to begin in 2011, reaching full capacity by 2013/2014. The Project's expected lifecycle is 27 years, although operation beyond this is likely.

The Project comprises six major components (Fig. 1). The mine is located at an elevation of approximately 1,000 m above sea level, on Madagascar's eastern escarpment, near the town of Moramanga (18.95ºS, 48.23ºE). The main industrial complex (plant, tailings management facility and harbour) associated with the mining operation is located 130 km to the northeast of the mine site, in the seaport city of Toamasina. A 218 km pipeline carrying a water laterite slurry, which contains the ore, links the mine and plant. Ankerana, the Project's proposed biodiversity off-site offset, is situated in Madagascar's remaining eastern forest corridor in a remote area to the north east of the mine. The Project aims to ensure the long-term protection of this large (11,600 ha) forest area that has similar biotic and abiotic conditions to those found at the mine site.

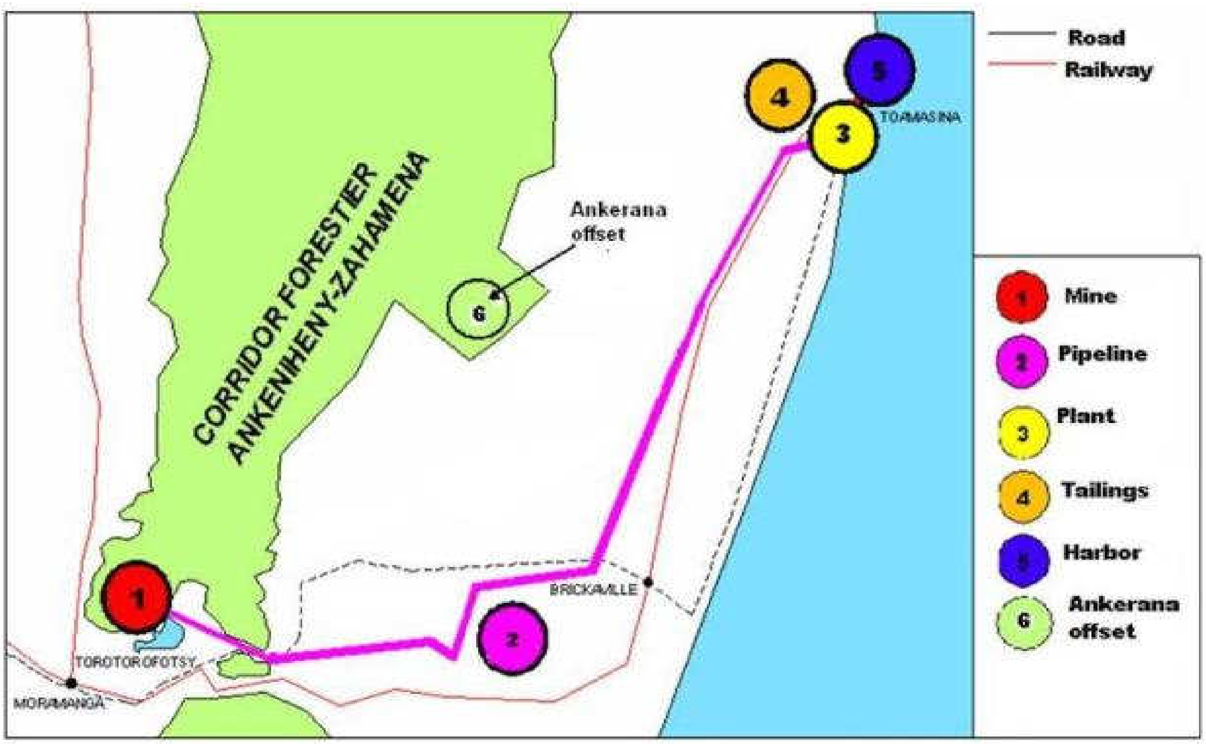

Figure 1. Ambatovy project location (Toamasina Province) and Project components.

The Project mine site and first 33 km of the slurry pipeline Right-of-Way (PPL) are located in a forested area recognized for its high regional biodiversity (Goodman 2010). At least 13 lemur species are present in this area (Dynatec 2006; Ralison 2010) including two (greater bamboo lemur *Prolemur simus* and black-and-white ruffed lemur *Varecia variegata*) listed as 'critically endangered' and two (diademed sifaka *Propithecus diadema* and indri *Indri indri*) as 'endangered' species (IUCN 2009). The Ambatovy Project's vision states that it will 'operate a sustainable nickel / cobalt mining and processing enterprise that delivers outstanding environmental and social records', where sustainable refers to the management of the site in terms of social, economic and environmental gains post mining activities. As part of its biodiversity policy and to adhere to 'International Finance Corporation Performance Standard 6' on biodiversity conservation and sustainable natural resource management (IFC 2006), the project is committed to 1) avoiding species extinctions, 2) minimizing impacts to flora, fauna and aquatic resources, 3) realizing an actual net increase in the conservation of rare habitats (on-site and off-site offsets), 4) assuring the viability of priority habitats (minimize fragmentation impacts) by maintaining or increasing habitat connectivity, and 5) link Project actions in support of biodiversity with other regional biodiversity initiatives. The project received its environmental permit on 1 December 2006 from the Government of Madagascar after evaluation of the environmental and social impact assessment (Ambatovy Project 2006).

As part of mitigation initiatives to maintain forest connectivity, installation of road crossing structures (lemur bridges) along forest linear cuttings (roads and PPL) was undertaken as a measure to potentially reduce impacts of forest fragmentation on lemur populations within the mining concession. Similar crossing structures installed in the tropical rainforest of northeast Queensland have proven to be effective in restoring habitat connectivity for several arboreal mammal species (Goosem *et al*. 2005). Habitat fragmentation may result in population isolation by preventing emigration and immigration, which, in turn, may have impacts on genetic diversity, health and population survival (Junge *et al*. 2008). Therefore, the maintenance of forest fragment connectivity by providing aerial crossing structures is considered pertinent for the conservation of lemur populations, most of which are highly arboreal and several of which are reluctant to descend from trees and to cross open ground. Where lemur territories have effectively been divided by roads and the PPL, it was hoped that bridges would maintain territory connectivity within areas of home ranges otherwise divided by roads or the PPL.

The installation and monitoring of these lemur bridges is one activity undertaken as part of the 'Project's Lemur Management Plan' (LMP) which is monitoring lemur population viability over the long term. Here we describe the process of bridge location selection and construction in early 2009, and present preliminary results on bridge use by the lemurs within the Ambatovy Project mine area forests.

ACTION

Study species: Thirteen lemur species (with the possibility of three additional species), are found within the Ambatovy Project's mine area forests: six nocturnal species (eastern woolly lemur *Avahi laniger,* hairy-eared dwarf lemur *Allocebus trichotis,* greater dwarf lemur *Cheirogaleus major,* aye-aye *Daubentonia madagascariensis*, weasel sportive lemur *Lepilemur mustelinus* and Goodman's mouse lemur *Microcebus lehilahytsara*), four diurnal species (grey bamboo lemur *Hapalemur griseus*, indri *Indri indri,* diademed sifaka *Propithecus diadema* and black-and-white ruffed lemur *Varacia variegata*) and three cathemeral species (brown lemur *Eulemur fulvus,* red-bellied lemur *E. rubriventer* and greater bamboo lemur *Prolemur simus*).

Bridge site selection: In order to identify where best to install lemur bridges, mine area roads and the PPL were monitored for 14 consecutive days (22 November to 5 December 2007) to identify existing movement areas. Observations were conducted between 07:00 to 15:00 h and 18:30 to 22:00 h to gather data on both diurnal and nocturnal species. Approximately 2 km of PPL and 2.5 km of mine area roads were surveyed. Main mine area road and PPL lemur crossing points were determined by lemur experts from the Groupe d'Etudes et de Recherches sur les Primates de Madagascar (GERP) through direct observations of lemur road crossings and crossing attempts (GERP 2008). This allowed for crossing structures to be built in locations that would allow fauna to pass at key road points between habitat patches.

Seven lemur species were observed to cross the roads and PPL including two diurnal, four nocturnal and one cathemeral species. 35 crossings and attempted crossings were observed on roads while 28 crossings and attempted crossings were observed along the PPL (GERP 2008). The location of road crossings and crossing attempts were mapped using GIS and three main areas with the highest crossing frequency were identified as sites for potential bridge construction including the mine's main access road (P3), the south dam road (P1 and P2) and four locations along the PPL (P4-7) (Fig. 2). The precise location of bridge installation was determined by both the frequency of crossings and habitat quality on either side of the road or PPL, specifically, the presence of trees that would be tall enough (minimum height of 8 m) to provide access to the bridges.

Bridge type and construction: Two different bridge designs were required due to differences in road width and vehicle traffic type. The roads within the mine area are smaller in width and are used by both light weight vehicles and large machinery whereas the road along the PPL is wider (the pipeline itself measures 610 mm in diameter) but used mainly by smaller vehicles. Both bridge designs are planned to allow the passage of all species of lemurs including clingers and leapers and species that move quadrupedally. The design of the bridges was determined by the Project Environment Department with the support of local lemur experts (GERP) and structural engineers. Seven bridges were constructed and erected between January and February 2009: three in the mine area and four along the PPL (Fig. 2). Two additional bridges along the PPL are under construction. All bridges will remain in place until rehabilitated forest is present that allows for movement over roads via the forest canopy.

Mine site bridges were constructed following a suspension bridge model as it was not possible to put a support post in the middle of the road. The bridges were installed at approximately 5 m height above the ground at their lowest point, and ranged between 8-15 m in length and between 0.6-1 m in width (Fig. 3). Mine bridges took approximately 2 weeks to construct and required more materials and machinery than the more simple PPL bridges, including cables, tensors and carabineers, wood collected from clearing areas and a forklift. The approximate cost for each mine area bridge was $ 3,000 USD.

Figure 2. Lemur bridge location map. Mine area bridges (P1-P3) connect habitat fragments within the mine footprint. Pipeline bridges (P4-P7) connect forest fragmented by the construction of the pipeline.

PPL bridges were constructed using support posts instead of suspension wires. These bridges are installed as 5 m above the ground, 22-25 m in length and 0.6 m in width (Fig. 4). PPL bridges are simpler in design requiring mainly wood collected from clearing areas and therefore took approximately 3-4 days to construct. The approximate cost for each PPL bridge was $ 500 USD.

Bridge monitoring: Lemur use of the seven bridges has been regularly monitored since 2 March 2009 (and is ongoing) with the exception of bridge P3 over the main haul road (Fig. 2). Observations of bridge P3 were not conducted in 2010 due to road improvement works which required the dismantling and reconstruction of the bridge. Observations will recommence once works are completed. The subsequent analysis is based on data collected during daylight observations conducted between 2 March 2009 and 10 August 2010. Bridges were monitored by trained field assistants for 10 h per day between 07:00 to 17:00 h, 4-6 days per week yielding a total of 7,640 observation hours (4,960 observation hours in 2009 and 2,680 observation hours in 2010) over 764 observation days (496 observation days in 2009 and 268 observation days in 2010). During each 10 h observation period, all bridge crossings, ground crossings and the presence of lemurs (within approx. 0-20 m of bridges) without crossing activity were recorded noting both species, number of individuals and time of day. Lemurs in proximity to bridges are highly visible due to the open canopy along the road. In addition, the frequency of vehicle and pedestrian passage was also recorded. As bridges are not specifically observed at night, data on bridge use by nocturnal species has been collected *ad libitum* by field assistants radio-tracking nocturnal lemurs to monitor demographic variables and movement patterns.

Figure 3. Construction of mine area lemur bridge.

Figure 4. Pipline Right-of-Way bridge type.

Analysis: To examine differences in the frequency of bridge use and ground crossings between sampling years and bridge types, we compared observed versus expected values using Chi-squared tests. Derived expected values take into account the unbalanced number of observation days per year and per site. Only bridge crossing and road crossing observation days were used for analysis to control for multiple crossings by the same group over a short period of time. The Wilcoxon matched pairs test was used to test for differences in frequency of lemur observations by season. Season was defined as wet (December-March) and dry (April-November) and derived values take into account the unbalanced number of months per season. All data analysis was performed using STATISTICA (StatSoft, version 6.0, 2001). The significance level was set at $p < 0.05$.

CONSEQUENCES

Lemurs were observed in proximity (within 0-20 m) of bridges on 500 occasions during 764 observation days (65% of total observation days) between 2 March 2009 and 10 August 2010. There was no difference in the number of observations of lemurs in proximity to bridges between the wet and dry season ($n = 10$, $T = 22$, $p = 0.58$). During the sampling period, lemurs were observed crossing bridges on 63 observation days (13% of total observation days when lemurs were present) and crossing roads on the ground on 68 days (14% of total observation days when lemurs were present).

A total of six lemur species have been observed crossing roads on bridges (Table 1, Fig. 5 and 6). The number of species using bridges has increased from four in 2009 to six in 2010. *A. laniger* and *E. rubriventer* were observed crossing bridges in 2010 but not in 2009. The same six species have also been observed to cross roads on the ground. *A. laniger* and *E. rubriventer* were observed crossing roads on the ground in 2009 but not in 2010. In 2010, these species have only been observed using lemur bridges. The majority, four out of six species, observed using bridges are diurnal.

There are currently three mine area type bridges and four pipeline RoW type bridges. Lemurs use mine area type bridges more often than pipeline RoW type bridges ($n = 63$ bridge crossings, $x^2 = 25.79$, $df = 1$, $p < 0.001$). This pattern is consistent for all species observed to use both bridge types except for two species, *E. rubriventer* and *C. major* as these species have only been observed crossing bridges on a single occasion. Vehicle passages (defined as light weight vehicles, trucks and heavy machinery), on both the mine area ($mean_{mine\ area} = 7.29$ vehicles / day, range = 0-58) and PPL RoWs ($mean_{PPL\ RoW} = 5.39$ vehicles / day, range = 0-58) are similar. In both cases, light weight vehicles are observed to use the road more frequently per day than other vehicle types ($mean_{light\ weight\ vehicles} = 13.25$ / day, range = 0-58; $mean_{trucks} = 4.95$ / day, range = 0-36; $mean_{heavy\ machinery} = 0.84$ / day, range = 0-21).

Table 1. Lemur species observed in proximity to bridges and numbers crossing roads using a bridge or on the ground, 2009-2010. Data collected from March to December 2009 (496 observation days) and January to August 2010 (268 observation days). Totals represent the sum of all observations of a species crossing using a bridge or on the ground.

Species	Total number of observations of lemurs in proximity to bridges		Bridge crossings		Road crossings	
	2009	2010	2009	2010	2009	2010
A. laniger	12	78	0	3	1	0
C. major	1	10	1	0	0	0
E. fulvus	78	35	24	4	23	2
E. rubriventer	16	4	0	1	2	0
H. griseus	164	116	5	23	21	3
P. diadema	179	68	4	3	17	1
Total	450	311	34	34	64	6

Figure 5. *Eulemur fulvus* crossing mine area type bridge.

Figure 6. *Propithecus diadema* crossing pipeline Right-of-Way type bridge.

In 2009, 30 bridge crossing days were observed out of 361 observation days where lemurs were present in the area. In 2010, 33 crossings were observed out of 139 observation days where lemurs were present. There has been a significant increase in bridge use from 2009 to 2010 (n = 63 bridge crossings, $x^2 = 17.5$, df = 1, $p < 0.001$), and a subsequent decrease in ground crossings. Roads were crossed on the ground a total of 62 times in 2009 and six times in 2010 (n = 68 ground crossings, $x^2 = 12.34$, df = 1, $p < 0.001$) (Fig. 7).

Discussion: Results demonstrate that lemur bridges have been successfully used by at least six lemur species. Currently, diurnal species have been observed to use the bridges more frequently than nocturnal species. This may be explained by the lack of night sampling as documented nocturnal bridge use observations have been recorded either at the end of the diurnal sampling session or *ad libitum*. In order to gain a better insight into nocturnal use, 'security poles', required to protect against extreme weather and possible stealing, are being erected to mount infra-red motion detection cameras (Sony Digital CamTrakker™ W-50 DC). Cameras will be mounted on two bridges (bridge P3 within the mine area and bridge P5 over the PPL) to monitor nocturnal bridge use and aid in species identification. This strategy has been effective in identifying nocturnal species using crossing structures in Australia (Goosem *et al*. 2005).

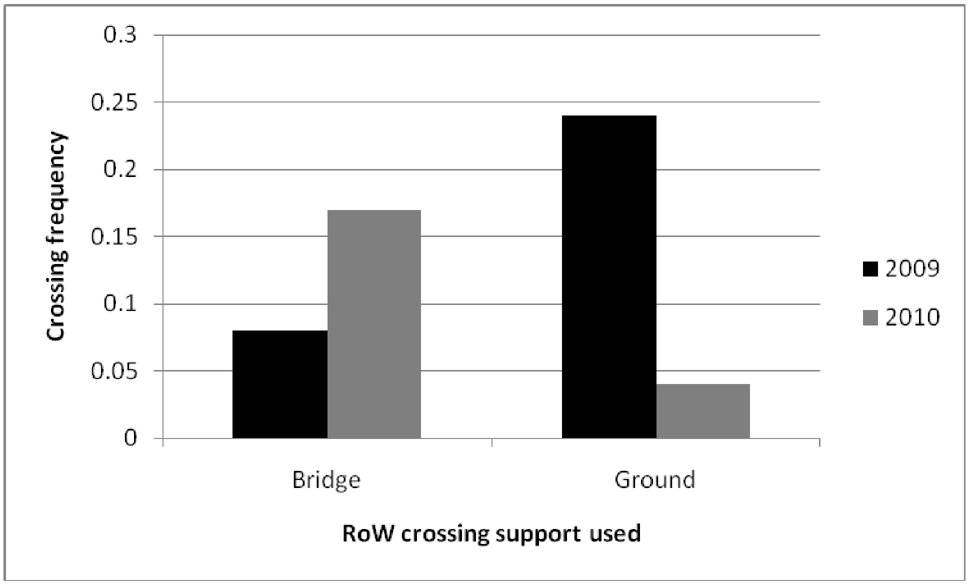

Figure 7. Road crossing frequency via lemur bridges or on the ground, 2009-2010. Frequencies are calculated based on the total number of observation days that lemurs were observed in proximity to crossing structures. There was a significant increase in bridge use in 2010 and a subsequent decrease in road crossings on the ground.

Although both lemur bridge types are used by lemurs, the mine area bridges were observed to be used more frequently than the bridge type installed over the PPL. This may be due to several factors including, a shorter distance to cross and better (more closed) canopy cover over mine area bridges that may offer more protection from predators, but appears unrelated to differences in vehicle traffic. Additionally, the mine area bridge design type may be more appropriate for lemur use due to the inclusion of vertical as well as horizontal supports.

The lemur bridge use results show that there has been an increase in bridge use frequency in 2010 as compared to 2009. This may reflect the time needed to locate and habituate to these novel structures located within home ranges. Several authors report that a significant habituation period sometimes lasting several years may be required before bridges are used by target mammal species (Clevenger & Waltho 2003, Goosem *et al*. 2005). Moreover, as lemurs increase bridge use, there has been a subsequent decrease in road crossings on the ground in the vicinity of these crossing structures, suggesting that this might be so. Although lemurs can maintain connectivity of territory fragments by crossing on the ground, the increased use of bridges is a positive result as this decreases the risks associated with ground crossings such as being hit by a passing vehicle, incidences of which have not yet been reported on site, and increased exposure to predators.

Our results demonstrate that the sub-canopy crossing structures installed may assist several (especially highly arboreal) lemur species to cross between forest fragments resulting from the construction of roads. This strategy, which is relatively low cost, can be implemented by exploitation projects as a means to mitigate unavoidable impacts on primate populations.

ACKNOWLEDGEMENTS

We thank Project field assistants for their hard work to ensure continuous data collection on lemurs and without whom this program would not be possible; the Ambatovy Project for technical and logistical support, and Jonah Ratsimbazafy, Rosette Ralisoamalala, Romule Rakotondravony and Dutel Maminirina Ravoninjatovo from GERP for their invaluable field assistance and informative discussions.

REFERENCES

Ambatovy Project (2006) *Enviornmental assessment Ambatovy Project*. Report submitted by Dynatec Corportation on behalf of the Ambatovy project. Volume J: Biological appendices. The Ambatovy Project, Antananarivo. Available online at: www.sherritt.com/doc08/files/Ambatovy_EIA.

Clevenger A.P. and Waltho N. (2003) *Long-term, year-round monitoring of wildlife crossing structures and the importance of temporal and spatial variability in performance studies*. In: Irwin C.L., Garrett P. & McDermott K.P. (eds.) 2003 Proceedings of the International Conference on Ecology and Transportation, pp. 293-302.

Dynatec (2006) *Environmental impact assessment*. Report to the Malagasy government. Available online at: www.ambatovy.mg

Junge R.E., Dutton C.J., Knightly F., Williams C.V., Rasambainarivo F.T. & Louis E.E. (2008) Comparison of biomedical evaluation for white fronted brown lemurs (*Eulemur fulvus albifrons*) from four sites in Madagascar. *Journal of Zoo and Wildlife Medicine*, **39**, 567-575.

GERP (2008) *Travaux de suivi des lemuriens dans la zone d'intervention des defrichements N°3-4-5 du Projet Minier Ambatovy / Analamay Madagascar*. Report to the Ambatovy Project, Madagascar.

Goodman S.M. (2010) *Biological research conducted in the general Andasibe region of Madagascar with emphasis on enumerating the local biotic diversity*. In: Goodman S.M. & Mass V. (eds.) Biodiversity, exploration, and conservation of the natural habitats associated with the Ambatovy project. *Malagasy Nature*, **3**, 14-34.

Goosem M., Weston N. & Bushnell S. (2005) Effectiveness of rope bridge arboreal overpasses and faunal underpasses in providing connectivity for rainforest fauna. In: Irwin C.L., Garrett P. & McDermott K.P. (eds.) *Proceedings of the 2005 International Conference on Ecology and Transportation*. Center for Transportation and the Environment, North Carolina State University, Raleigh, NC: pp. 304-316.

IFC (2006) *Guidance notes: performance standards on social and environmental sustainability*. International Finance Corporation, World Bank Group, Washington, D.C, USA.

IUCN (2009) *The IUCN red list categories and criteria: version 3.1*. IUCN Species Survival Commission.

Ralison J.M. (2010) *The lemurs of the Ambatovy-Analamay region*. In: Goodman S.M. & Mass V. (eds.) Biodiversity, exploration, and conservation of the natural habitats associated with the Ambatovy project. *Malagasy Nature*, **3**, 178-191.

Sony Digital CamTrakker™ W-50 DC (2009) CamTrak South, Inc., 1050 Industrial Drive, Watkinsville, GA 30677 www.camtrakker.com