The Ambatovy lemur population spatial monitoring program: Summary of primary objectives and methods

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Abstract

The Ambatovy project includes an open pit mine located in Madagascar's eastern humid forest, an area recognized for its high regional biodiversity exemplified by the presence of 13 confirmed lemur species. Due to the mine's location in a biodiversity hotspot, a comprehensive biodiversity management plan has been prepared. The lemur viability assessment program, based on the objectives outlined in the lemur management plan, aims to verify that the mine's activities do not lead to a long term reduction in the pre-construction (baseline) viability levels of priority lemur species' populations (IUCN critically endangered and endangered species) present in the forests of the mine area. These priority IUCN species include *Indri indri* (EN) and *Propithecus diadema* (EN). The primary work to be conducted through the spatial monitoring program is 1) to assess the ability of lemur species to move away from areas being cleared for mining and 2) to monitor radio-collared lemurs and their movements in nearby refuge forests. Here, we outline three aspects of the Ambatovy project's lemur spatial monitoring program: density and abundance assessment, spatial monitoring via radio tracking, and behavioral research via focal animal scan sampling. The objectives and hypotheses for each aspect of the program are explained, and detailed methodologies are provided. Data collected during lemur monitoring work will be integrated into a lemur species population impact assessment matrix and lemur assemblage integrity index. These parameters will allow an integrated measure of the impacts of mine activities on lemur populations found within the Ambatovy forests and provide needed feedback to the Ambatovy project for mitigation actions.

Keywords: Biodiversity, lemurs, mine, Madagascar, spatial monitoring, impact assessment, assemblage integrity index

Résumé détaillé

Le projet Ambatovy comprend une mine à ciel ouvert située dans la forêt côtière de l'Est de Madagascar, une région reconnue pour sa biodiversité régionale élevée comme en témoigne la présence de 13 espèces de lémuriens confirmées. Un plan de gestion de la biodiversité a été élaboré en raison de l'emplacement de la mine. Le programme d'évaluation de la viabilité des lémuriens a été établi à partir des objectifs du plan de gestion des lémuriens. Ce programme vise à vérifier que les activités de la mine ne conduisent pas à une réduction à long terme des niveaux de viabilité, antérieurs à ceux de la phase de construction, des populations de lémuriens prioritaires présents dans la région de la mine. Le principal travail à effectuer par l'intermédiaire du programme de surveillance spatiale est d'évaluer la capacité des espèces de lémuriens à s'éloigner des zones d'impact et de suivre les lémuriens équipés de radio-colliers dans les forêts refuges. Nous présentons ici les trois composantes du programme de surveillance spatiale des lémuriens d'Ambatovy : l'évaluation des densités et abondances par travail de « transect », la surveillance spatial par radio-pistage et le suivi par « *focal animal scan sampling* » des espèces prioritaires pour le projet (UICN en danger et en danger critique). Les principaux objectifs du programme « transect » sont de fournir des informations sur les densités et l'abondance des lémuriens dans les forêts de la zone des mines et de suivre l'évolution de ces variables. Ces données seront également utilisées pour évaluer la capacité de chaque animal de s'éloigner des zones ainsi dégagées en testant l'hypothèse que les densités de lémurien et l'abondance se creusent dans la zone de conservation autour de la zone d'impact par rapport aux données de référence recueillies avant le défrichement. Les données collectées pendant la surveillance spatiale par radio-pistage sont recueillies en vue de contrôler les mouvements des espèces lors du défrichage des forêts et d'évaluer aussi la capacité des individus et des groupes de s'éloigner sans l'aide des zones d'impact vers la zone de conservation. En outre, les

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données démographiques de base seront collectées. Finalement, le suivi par « *focal animal scan sampling* » sont menées sur des espèces prioritaires du projet qui sont définies comme des espèces figurant sur la liste rouge de l'UICN comme en danger et en danger critique (*Indri indri* (EN) et *Propithecus diadema* (EN)) afin d'évaluer les changements de comportement et de collecter des données démographiques de base. Les données recueillies lors des travaux de suivi seront intégrées dans une matrice d'impact sur les populations des espèces de lémuriens et un indice d'intégrité des assemblages de lémuriens, ceci afin de commencer à évaluer les impacts potentiels des activités de la mine sur la population de lémuriens se trouvant dans les forêts Ambatovy.

Mots clés : Biodiversité, lémuriens, mine, Madagascar, surveillance spatiale, matrice d'impact, indice d'intégrité des assemblages

Introduction

The Ambatovy project is a large-tonnage nickel-mining project in central eastern Madagascar. The project received its permit in December 2006, following submission of an environmental impact assessment to the Malagasy government (Dynatec, 2006; Dickinson & Berner, p. 2). Construction began in early 2007 and production is due to commence by the end of 2010, and reaching full capacity by 2013. The project's expected life cycle is 27 years, although operation beyond this is likely.

The mine is located at an elevation of approximately 1,000 m above sea level, in Madagascar's east coast rain forest region, near the town of Moramanga (see Figure 2 in Dickinson & Berner, p. 10). This area is recognized for its high regional biodiversity (Goodman, p. 14) exemplified by the presence of 13 confirmed lemur species (Dynatec, 2006; Ralison, p. 178) including two endangered species, *Propithecus diadema* and *Indri indri* (IUCN, 2009). Expanding on the many commitments made in the environmental impact assessment, the project developed an environmental strategy aimed at honoring its vision to deliver outstanding environmental stewardship (Ambatovy project, 2009). As part of its biodiversity policy, and to follow the International Finance Corporation's performance standards on social and environmental sustainability (IFC PS6, www.ifc.org), the project is committed to 1) avoid any species extinctions, 2) avoid reductions and ensure the viability of all populations red-listed Critically Endangered and Endangered by the IUCN (project priority species), and 3) apply best practices for non-priority species.

A biodiversity management plan was developed for different project components, which lays out a set of future actions associated with the project that will lead to the conservation or enhancement of biodiversity. In addition, a taxon specific conservation management plan was developed for lemurs (lemur management program). These programs were created as part of the biodiversity management plan and aim at ensuring the conservation of the species assemblages present in the mine area's forest habitats.

The lemur management program consists of several components including both spatial and health monitoring of the lemur populations found within the mine area forests. Here we focus on the spatial monitoring program. The principal objectives of this program are to:

1) Identify changes in species population densities and abundances;
2) Assess the ability of lemur species to move away from impact areas (the "mine footprint") and to assess the viability of these displaced populations in their refuge areas;
3) Assess the cascade effect of displaced lemur populations on recipient lemur populations located in the nearby refuge forests or conservation zone;
4) Detect any changes in lemur behavior, demography, and population viability due to mining activities post clearing within their refuge forest habitats;
5) Compile the data collected via spatial monitoring in a lemur species population impact monitoring matrix and lemur assemblage integrity index; and
6) Ensure that any negative trends in the population dynamics of lemur populations are detected at an early stage and that corrective mitigation actions are implemented.

The lemur spatial monitoring program

Spatial monitoring: Density and abundance

Objectives and hypotheses

One of the main objectives of the lemur spatial monitoring program is to provide information on existing lemur densities and abundances in the mine area forests and to monitor changes in these variables. These data will also be used to assess the ability of individual animals to move away from the cleared zones by testing the hypothesis that lemur densities and abundances will increase in the conservation

zone around the impacted area when compared to baseline data collected pre-clearing.

The density and abundance data collected will also be used to assess the lemur carrying capacity within the mine area forests. We hypothesize that an increase in lemur species densities in the conservation zone should not exceed forest carrying capacity as this area is expected to be working under capacity due to past hunting activities in the Ambatovy forests. In evaluating both changes in density and abundance, and forest carrying capacity, decisions can be made on whether further mitigation measures are necessary, such as species relocation to off-site refuge locations.

Methods

In order to assess changes in lemur density and abundance, as well as the ability of species to move away from impact areas, and carrying capacity, eight permanent transects have been established in the mine area forests. Each transect measures 2 km in length. These transects are located on the edge of the mine footprint (impact areas), in the conservation zone and around the Analamay deposit area located to the north of the Ambatovy deposit (Figure 1). As mining activity in the Analamay forest is planned to begin 10 years from now, this area presently serves as a control area for analytical comparative purposes.

All transects are walked three times per day (morning, afternoon, and night) bimonthly for a duration of 10 days. All eight transects are inventoried simultaneously. Previous rapid assessment transect work conducted at the site demonstrated that species accumulation curves reach a plateau after 5-6 days of observation (Ralison, p. 182). Data recording methodology and analyses follow standard line sampling methods (Whitesides *et al*., 1988). These methods were used in previous density assessments of the area and thus, the same methods are applied to maintain consistency for comparative purposes. Species identified solely via vocalizations or other indicators (i.e. species-specific feeding marks) are included in presence/absence analysis but not in density and abundance calculations. Results are compared for the same transect over time and between transects in different forest areas to establish spatial use trends. Re-using the same transects over time can lead to a reduction in variation around the density estimate and improve resolution (Plumptre, 2000).

In addition, an average of 43 vegetation plots (25 x 25 m) per transect will be established along each permanent transect line and will be used to calculate the densities of different plant species used by lemurs for food and structural resources (tree holes, dormitories, and locomotion). By combining data on vegetation and lemur densities, we can begin to gain a better insight into correlations between lemur and resource densities that will ultimately help in understanding issues related to forest carrying capacity.

Data obtained on absolute abundance and densities based on these transects will also be used to complete a lemur species assemblage integrity index. These types of indexes are useful for monitoring changes in ecosystem health by using indicator species (Hilty & Merenlender, 2000). The index that will be used compares changes in density and absolute abundance ratios of generalist to specialist lemur species for the same transect over time. This method tests the hypothesis that specialist primate species will be more affected by deforestation activities than generalist species. For example, generalists such as *Macaca* spp., *Colobus* spp., and *Cebus* spp. have been found to be more likely to survive in disturbed habitats than specialists, such as *Hylobates* spp., *Cercopithecus* spp., and *Chiropotes* spp. as the later group tend to be more highly dependent on undisturbed forest (Johns, 1997; Azevedo-Ramos *et al.*, 2002). Generalist and specialist classification employed is based on dietary regime. Thus, examining changes in ratios of generalists to specialists, using data collected during transect work, will aid in evaluating the potential impact of mining deforestation activities on the lemur population.

Spatial monitoring: Radio-tracking

Objectives and hypotheses

Spatial data on collared individuals is being collected via radio-tracking in order to monitor species movements during forest clearing and to assess the ability of individuals and groups to move away unaided from impact areas and into the conservation zone. Moreover, post-clearing movements are monitored and spatial data recorded to identify the redistribution of individual and group home ranges and to assess changes in home range size and overlap. Continued post-clearing monitoring of individuals will also provide information on the potential impact the displaced lemur populations have on resident populations within the conservation zone. Finally, as spatial data are only collected when visual contact with the individual/group is made, baseline demography data are also noted in order to establish trends in regard to social organization, birth and mortality rate.

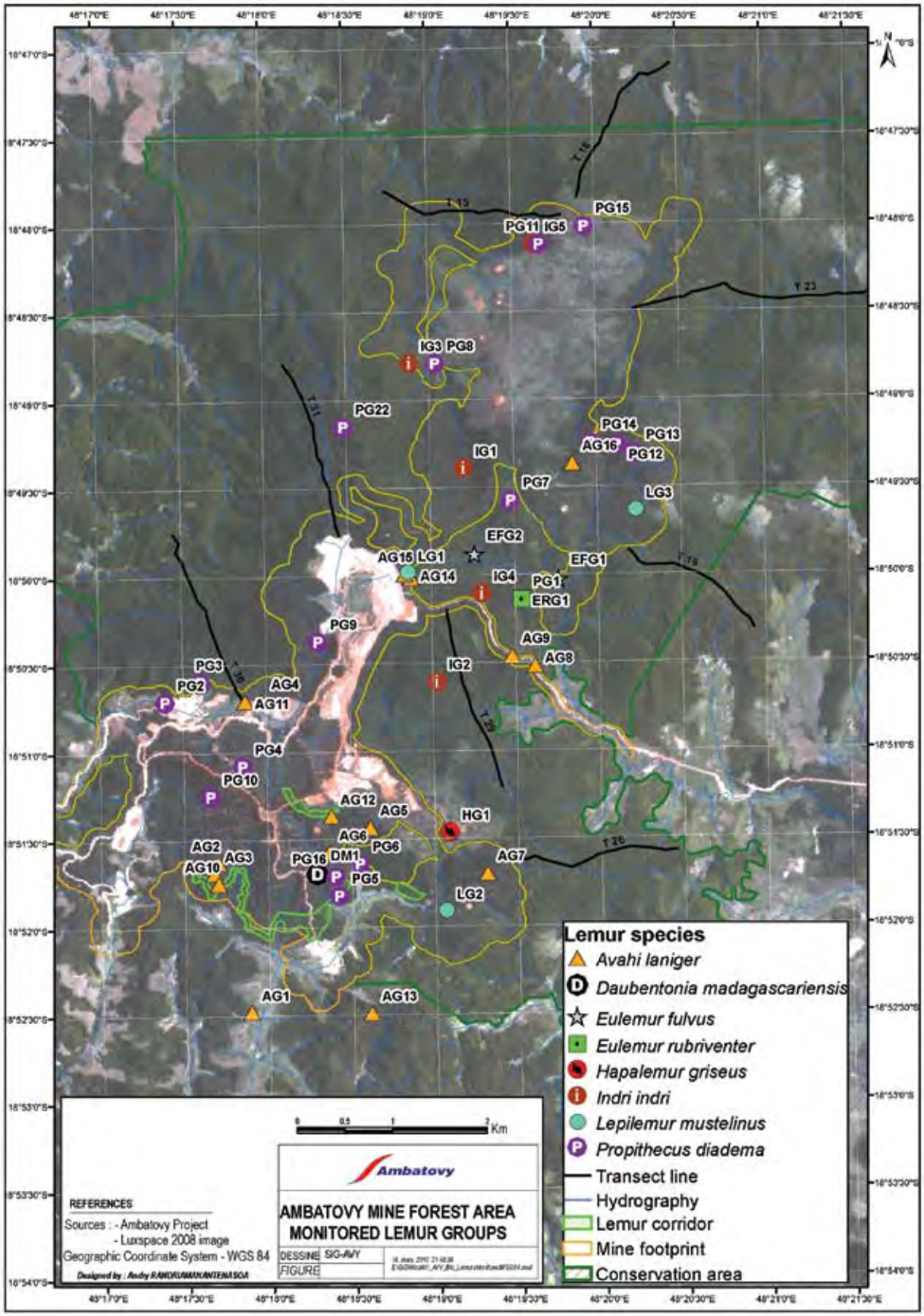

Figure 1. Map depicting transect location, the mine footprint (including areas already deforested), the surrounding conservation zone and the Analamay forest (control area). Each point on the map represents one monitored group for group living species or one monitored individual for solitary species. Symbols are species specific and alphanumeric codes represent the species group reference code (for example, IG1 refers to *Indri* group 1).

Spatial data collected on radio-collared animals are used to test the hypothesis that individuals and groups are able to move unaided from impacted areas into the conservation zone. However, groups and individuals are expected, at the same time, to limit their dispersal movements and remain close to their original territories. Home ranges of displaced lemurs are hypothesized to be smaller than those of groups found in the Analamay forest, a relatively intact area serving as a control area. In other words, an increase in habitat disturbance is expected to lead to an associated increase in density and decreased home range size, a trend that has been shown for *Indri indri* (Glessner & Britt, 2005) and other folivorous primates (Struhsaker, 1975; Skorupa, 1986; Onderdonk & Chapman, 2000) surveyed in disturbed habitats.

Methods

Between March 2007 and July 2009, 166 individual lemurs representing 11 species were equipped with radio-collars. Lemurs were immobilized with a CO_2 projection rifle or blowgun with 10 mg/kg of Telazol® (Fort Dodge) or were hand-caught. Individuals were captured in impact areas, the mine conservation zone, and the Analamay control area, and re-released into their original territories. Currently, 44 groups, representing eight species, found in the impact area, conservation zone, and Analamay control, are being monitored (Table 1). Several species are not currently being monitored (*Prolemur* [*Hapalemur*] *simus*, *Allocebus trichotis*, *Cheirogaleus major*, *Varecia variegata*, and *Microcebus lehilahytsara*) or are not monitored in certain zones. This is due to several factors including low population density, species-specific ecology, flee behavior, and logistical constraints. Species occurring within the mine area forests in low densities and that have large home ranges, for example *P. simus* (Tan, 1999) are notably difficult to locate and capture.

The mine's forest area, including the impacted zone, conservation zone, and Analamay control area, has been divided into five zones. One group of two Ambatovy project research assistants, also known as Biocamp agents, track collared lemurs within their zone 5-6 days per week and collect GPS location data, as well as basic demography and behavioral data. A range of 1-17 data points are collected per group/individual per month. The variation in number of data points is due to time spent completing transect work, difficulty in locating some groups with large home ranges, and logistics. Data collected includes information on plant resources used for locomotion, resting/dormitories and feeding, group size, and composition and the spatial distribution of the group in relation to a pre-determined focal animal, generally the group's dominant female (Richard, 1987). These data will then be analyzed to identify species-specific trends in relation to potential mine impacts.

GPS data collected on lemur groups that are part of the spatial monitoring program will be used to calculate home range size and assess changes in size, location, and percentage overlap of the different groups through time. Home ranges will be calculated using the ArcView GIS 3.3 software (ESRI, Redlands, CA) with the animal movement extension (Hooge & Eichenlaub, 2000). Minimum convex polygon home ranges will be calculated and overlap areas of groups identified. The minimum convex polygon method is more accurate than other methods, such as adaptive kernel and fixed kernel, when sample sizes are small (Boyle *et al.*, 2009). As the number of data points collected per group/individual increases, the kernel method for home range size calculations can be used. This method will allow for a more sophisticated analysis of changes in home range use. Home range data for lemur taxa found in the Ambatovy forest will then be compared to published data for the same species in regional forest zones.

Demography data (births and mortality) on the local lemurs, collected during spatial monitoring, and biomedical health data, obtained during their capture, will be used to complete a species-specific impact monitoring database. This data matrix aims to identify the level or intensity of mine impacts for each monitored species. Variables are weighted according to their importance as an indicator of species viability. For example, as female reproductive success directly affects population growth (Akkoc & Williams, 2005; Milton & Hopkins, 2006), infant births, and infant survival to one year of age are variables that receive a higher weighing factor than measures of body weight and ectoparasite loads. The interdependency of variables, such as body weight and recruitment, is a mechanism that increases the robustness of the matrix. A final impact score can then be calculated for each species. This matrix will aid in modifying mitigation measures so that efforts can target species most impacted by mining activities.

Spatial monitoring: Focal animal observations

Objectives and hypotheses

Focal animal scan observations are conducted on project priority species, which are defined as species red-listed by the IUCN as Endangered

Table 1. Lemur groups/individuals monitored as part of the spatial monitoring program and their location within the mine area forests. Numbers provided represent the number of groups monitored for group living species (denoted by [1]) and the number of individuals monitored for solitary species (denoted by [2]). Species were classed as generalists (GN) or specialists (SP) based on dietary requirements.

		Monitoring Area			
Species	**Generalist / specialist**	**Mine footprint (impact areas)**	**Conservation zones**	**Analamay control**	**Total**
Avahi laniger[1]	SP	10	4	1	**15**
Daubentonia madagascariensis[2]	GN	1	-	-	**1**
Eulemur fulvus[1]	GN	-	2	-	**2**
Eulemur rubriventer[1]	GN	-	1	-	**1**
Hapalemur griseus[1]	SP	-	1	-	**1**
Indri indri[1]	SP	-	2	3	**5**
Lepilemur mustelinus[2]	SP	-	1	2	**3**
Propithecus diadema[1]	GN	7	1	8	**16**
Total species		**18**	**12**	**14**	**44**

and Critically Endangered, namely *Indri indri* (EN) and *Propithecus diadema* (EN), in order to assess changes in behavior in post-clearing conditions within the new or restricted home ranges of a given group. As impacted or fragmented forests have been shown to have higher primate densities than continuous forest (Glessner & Britt, 2005; Irwin, 2008), data collected during focal animal observations can also be used to begin assessing any long-term impacts on population viability that may result from the predicted increase in lemur densities following forest clearings. Finally, long-term data collection on these species can provide information for the scientific community at large on species-specific behavior patterns, social organization, and demographic parameters for these two endangered species.

Long-term studies examining the impacts of deforestation on lemur populations are of increasing importance especially as much of the original forest cover in Madagascar has been lost. In 2000, it was estimated that only 17% of original forest cover remained with an annual deforestation rate of 0.9% between 1990 to 2000 (Harper *et al*., 2007; Moat & Smith, 2007). These figures highlight the importance of understanding habitat disturbance and fragmentation impacts on the flora and fauna of Madagascar.

Data collected during focal animal scan sampling will be used to test the research hypotheses that there is no difference between displaced and control groups (defined here as those remaining in their original territories) in (a) daily activity budgets (time spent foraging and locomoting), (b) reproductive success, (c) group cohesion, and (d) aggressive inter-group encounters. All occurrences of inter-group encounters are recorded *ad libitum*. Generating species-specific patterns of responses to forest loss is essential, as generalizing about primate responses to fragmentation has been cautioned against due to the lack of strong predictive variables (Onderdonk & Chapman, 2000).

Methods

Behavioral data are collected by Biocamp agents using focal animal scan sampling (Altmann, 1974). Six groups of *Propithecus diadema* and four groups of *Indri indri* are observed each day, five days per week, during all-day follows from dawn to dusk. One data point is collected every five minutes using the group's dominant female as the focal animal. The individual's behavior, location, and substrate used are noted. The distance from the focal animal to other group members is also recorded via instantaneous scan sampling (Altmann, 1974) at the onset of the observation period and at 15 minute intervals throughout the observation time.

The *Indri indri* groups observed are located in the conservation zone and Analamay forests. This species has not been found in the mine impact area. The *Propithecus diadema* groups currently observed are located within the mine impact area, the conservation zone and Analamay control. Efforts will be made to increase the number of groups studied for statistical and comparative purposes. Daily activity budgets, spatial cohesion, and inter-group encounter rates will then be compared between groups in different mine forest areas to quantify potential impacts of mining activities on these species. These comparisons will help identify and establish correlations between altered behavior and mine activities. In addition, GPS location data collected during all-day follows will be used to analyze home range size and use over time (MCP and kernel methods) in order to gain more

information on changes in territory use due to the compression effect.

Conclusion

The implementation, and subsequent results, of a comprehensive lemur-monitoring program will allow for the development of a general overview of the Ambatovy mine impacts on the viability of lemur populations within the surrounding forest. By gaining a deeper understanding of how mining activities affect the behavior and spatial dispersion of different lemur species, proper mitigation measures, both short and long term, that act to minimize these impacts for the different species can be best implemented. For example, if analysis reveals that individuals are not able to move out of clearing areas unaided then manual salvaging and translocation into the conservation zone are mitigation measures that can be applied. In addition, mitigation measures that have already been implemented and shown to work via lemur spatial movement analysis, such as the paced directional clearing technique, will continue to be utilized. In the future, the information gained from the lemur spatial monitoring program can be shared with the scientific community to possibly ensure that other future mining projects occurring in Madagascar are designed optimally to benefit from residual impact management techniques applied at Ambatovy.

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