Introduction to the early 2009 biological inventories conducted by the Association Vahatra in the Ambatovy-Analamay region

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Introduction

The process of properly evaluating programs in the domains of industrial and mineral exploitation, as compared to environmental conservation, are extremely important to accurately balance economic growth versus the maintenance of natural habitats and associated biodiversity. In Madagascar, which is one of the world's most biologically rich and unique areas (Myers *et al*., 2000) and, at the same time , poorest nations (The Economist Intelligence Unit, 2006, www.eiu.com), the proper evaluation of this equilibrium is particularly crucial. The acquisition of solid scientific information on ecosystem function and biodiversity is fundamental to properly develop and advance a sensible strategy for both sides of the development-conservation equation. Further, the approach of comparing biodiversity information from the area planned for development or exploitation to relatively intact peripheral zones allows the establishment of clear priorities associated with mitigation or compensation. This style of investigation depends on viable and updated biodiversity information, using comparable methodologies, which allow the prerequisite analyses.

Over the past decades, there has been an ever-increasing public concern about the impacts of mining on natural ecosystems and the need for mining companies to demonstrate that they are properly addressing environmental concerns. This apprehension, through external pressures from the public via different types of conservation and human rights organizations, has also reached the level of the banking industry providing loans for development projects. Consequently, numerous companies are developing new initiatives to reduce their impacts on the environment. One approach is for the exploitation projects, particularly in the mining sector, to have reduced effects on ecosystems and biodiversity, which has been referred to as 'net zero' or 'net positive' impact (see Dickinson & Berner, p. 2). This involves, for example, *in situ* and *ex situ* conservation, site rehabilitation, or biodiversity offset programs. This latter type of program can take several different forms ranging from the creation of new conservation areas, translocation of species, funding for biodiversity conservation and purchase of land. In each case, the goal of a biodiversity offset is to compensate some detrimental aspect imposed by the exploitation project concerning biodiversity and ecosystem functioning. One of the key notions in biodiversity-offset programs is the idea of equivalence, where some measurable biological parameters in the zone of exploitation are similar or less than to that in the zone associated with the offset, such as a new protected area. These aspects have led to a formalized program referred to as Business and Biodiversity Offset Program (BBOP), which has been organized and advanced by several leading conservation agencies in association with companies, governments, and the banking industry (see http://www.forest-trends.org/biodiversityoffsetprogram).

In the context of assuring a certain level of conservation development, the mineral exploitation project in the region of Moramanga, in central eastern Madagascar, known as the Ambatovy project, requested the Association Vahatra to conduct a biological diagnosis of nine different habitat types within the Ambatovy-Analamay forest and in close proximity to the zone of exploitation. The intent of this research was to obtain needed comparative data for a proposed BBOP conservation area to the east of Ambatovy as an offset to forest habitat destruction associated with the mining project. This special issue of *Malagasy Nature* emphasizes the data stemming from the field research associated with the first phase of this project (also Dickinson & Berner, p. 2), as well as presenting information on the biota of this region based on the research of other scientists and organizations.

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Specific objectives of the Association Vahatra fieldwork

The purposes of these biological inventories were to gather quantitative and qualitative information on the terrestrial vertebrates of the Ambatovy-Analamay region using a clear and repeatable methodology. These field inventories concentrated on seven groups of terrestrial vertebrates and the results are presented within this monograph: amphibians and reptiles (Raselimanana, p. 99); birds (Raherilalao, p. 124); rodents, tenrecs, and carnivorans (Soarimalala & Raheriarisena, p. 153); and lemurs (Ralison, p. 178). These data will form the comparative basis for a proposed large (11 600 ha) endangered forest offset site, known as the Ankerana forest, to the Northeast of Ambatovy-Analamay.

The Ankerana forest has several biotic and abiotic traits similar to the Ambatovy-Analamay region, such as ultrabasic soils, elevational range, natural forest structure and presumed taxonomic composition, etc. that makes it a good candidate for a biodiversity offset (Ambatovy Project, 2006; see Dickinson & Berner, p. 2). The data obtained in early 2009 by researchers from the Association Vahatra to evaluate the vertebrate communities of the Ambatovy-Analamay forest is the first stage of this process. The second stage involves conducting parallel inventories in Ankerana to assess ecological parallels between these sites and, therefore, to evaluate whether the Ankerana forest is an appropriate offset for the Ambatovy-Analamay site.

Aspects of the sites, logistics, field surveys

Vegetational structure and different habitats of the Ambatovy-Analamay region

Following the recently proposed classification of Moat & Smith (2007), the Ambatovy-Analamay region is part of the humid forest zone of Madagascar. Differences associated with soil substrates (clay and loam soils, including zones with ultrabasic soils, and densely packed ferruginous cuirass) give rise to considerable variation in associated vegetational structure. Previous botanical research in the Ambatovy-Analamay region (Ambatovy Project, 2006) resulted in the establishment of a vegetational classification of the zone. Three principal forest habitat groups were identified within this classification (azonal, zonal, and transitional) and these were divided into specific sub-habitat types. On the basis of our field observations, overlaid on this classification (Ambatovy Project, 2006), we can present the following generalized observations on the three principal mid-altitude forest habitats, as well as other natural and anthropogenic habitats in the zone.

Azonal

Azonal is defined in the geological sense as soils without well-developed profile characteristics, owing to their relatively young geological age (Foucault & Raoult, 2005) and in the ecological sense as vegetational communities with nutrient poor soils that, associated with stress factors, are not able to reach climax conditions (Walters, 1954).

Azonal (sclerophyllous) thicket. **-** This habitat consists of forest thicket on consolidated ferruginous cuirass substrate and is characterized by dense, short-tree thicket vegetation (canopy about 9 m tall) on shallow and organically depauperate soils. This habitat type is poorly represented on Madagascar and in the Ambatovy-Analamay region is dominanted by *Uapaca densifolia* and *U. thouarsii* (Family Uapacaceae), *Leptolaena multiflora* and *Sarcolaena multiflora* (Family Sarcolaenaceae), *Asteropeia mcphersonii* (Family Asteropeiaceae), and *Weinmannia rutenbergii* (Family Cunoniaceae). This vegetation type covers 133 ha, or less than 1%, of the mine site surface area.

Azonal (sclerophyllous) forest. - This habitat consists of forest on broken ferruginous cuirass soil. It is characterized by dense woody vegetation with a relatively short canopy (about 13 m), and on highly variable substrate types. In many ways, this habitat forms a continuum with both azonal thicket and transitional forest concerning vegetation and structure. The azonal forest is often rich in epiphytic orchids and other plants that show phytogeographic affinities with Madagascar's Central Domain (sensu Humbert, 1965). Like the azonal thicket, azonal forest is poorly represented elsewhere in Madagascar. Dominant species within this vegetation type include *Uapaca densifolia*, *Asteropeia mcphersonii*, *Leptolaena multiflora*, *Sarcolaena multiflora*, *Protorhus ditimena* (Family Anacardiaceae), and *Syzygium emirnense* (Family Myrtaceae). This vegetation type covers 826 ha or 4% of the mine site surface area.

Azonal disturbed. - This is a disturbed azonal habitat type and as such represents areas that are virtually clear of vegetation, areas of sparse vegetation due to human influence or recent fire, or scrubby areas at different successional stages of development because of fire. *Erica* (Family Ericaceae) bush is the dominant formation in such areas, which is notably susceptible to fire. This vegetation type covers 421 ha or 2% of the mine surface area.

Zonal forest

Zonal is defined in the geological sense as soils with stratigraphic features and in the ecological sense as vegetational communities with relatively organic rich soils that reach climax conditions (Walters, 1954; Foucault & Raoult, 2005). This habitat consists of mid-altitude dense humid forest on relatively rich red and yellow clay soils with ground humus. The canopy is relatively high, with a mean of about 16 m in unlogged areas, and emergents reaching 25 m.

The forest habitat belongs to the Eastern Domain, but has some phytogeographical traits of the Central Domain (sensu Humbert, 1965). As elsewhere in eastern Madagascar, this habitat type is under considerable human pressure for slash and burn agriculture (*tavy*), which then results in secondary forest and anthropogenic grasslands. Dominant forest trees include *Ocotea laevis* (Family Lauraceae), *Syzygium emirnense*, *Thecacoris perrieri*, *Chrysophyllum boivinianum*, *Rhodolaena bakeriana* (Family Sarcolaenaceae), and *Tannodia perrieri* (Family Euphorbiaceae). Further, the understory is relatively open and large lianas, ferns, and *Pandanus* are common. This is the dominant vegetation type in the region and covers an area of 12,527 ha or 55% of the mine site, although over half of this forest type at the site has been at least partially logged.

Transitional forest

This forest type consists of a mixture of azonal and zonal formations, hence the term transitional.

Azonal Type Transitional forest. **-** This habitat consists of transitional forest on clay substrates. The tree canopy is variable, but with a mean height of about 10 m. The locally occurring vegetation is a mixture of species, but most similar to the azonal forest type, although the major difference is that it occurs on the same substrate as the Transitional forest (see below). Dominant species include *Schefflera longipedicellata* (Family Araliaceae), *Vernonia garnieriana* (Family Asteraceae), *Asteropeia mcphersonii*, *Uapaca densifolia*, and *U. mangorensis*. This vegetation type covers 438 ha or 2% of the mine site.

Transitional forest. - This habitat consists of a mixed formation of azonal and zonal formations resting on ferruginous cuirass soil or other types of nutrient depauperate substrates. It is characterized by closed canopy forest with variable canopy height (mean about 15 m). Dominant species within this vegetation type include *Syzygium emirnense*, *Blotia oblongifolia* and *Thecacoris perrieri* (Family Euphorbiaceae), *Pittosporum verticillatum* (Family Pittosporaceae), *Xylopia buxifolia* (Family Annonaceae), and *Chrysophyllum boivinianum* (Family Sapotaceae). Some moss and lichen occur on tree trunks and the understory is often lush and open with lianas, ferns, and *Pandanus*. This vegetation type covers 1,051 ha or 5% of the mine site.

Other habitats

Ephemeral ponds. - This habitat consists of numerous shallow ephemeral ponds in sunken bowls in the ferruginous cuirass soil, often surrounded by azonal thickets and azonal forests. These ponds cover 5 ha of the mine site.

Eucalyptus and other woodlots. - This habitat consists primarily of non-native *Eucalyptus* (Family Myrtaceae) plantations or unmanaged groves. Because the focus of the Vahatra biological inventories was on natural habitats, this habitat was not surveyed. A total of 831 ha or 4% of the mine site falls within this vegetation type.

Forested and non-forested marsh edge. - These habitats occur in the local aquatic ecosystems, particularly in connection to the various branches of the Torotorofotsy wetlands system. The vegetation of the marsh-forest ecotone is characterized with extensive areas of *Pandanus* (Family Pandanaceae). Other notable plant species include *Cyathea dregei* (Family Cyatheaceae) and *Dalbergia baronii* (Family Fabaceae). Approximately 36 ha of this habitat is represented within the mining site.

Marsh herbaceous vegetation and rice paddies. - These wetland habitats occur in low-lying areas and have particular vegetation features, as well as different levels of human influence. The most natural type is herbaceous marsh vegetation (largely of the Family Cyperaceae), which consists of nutrient-rich, shallow marsh with a deep peat layer, occurs within the Torotorofotsy wetlands system and covers about 102 ha. Marshlands converted into rice paddies are also present and represent about 305 ha within the mine site. Due to human-induced factors, this habitat type is one of the most threatened in Madagascar.

Reconnaissance

In order to properly carry out the biological inventories in the Ambatovy-Analamay forest, a reconnaissance trip was conducted in mid-December 2008. This visit allowed for a broad overview of the local ecological settings, specifically the different habitat types and sites to be inventoried, as well as understanding logistical constraints. Further, this visit provided insight into local levels of habitat heterogeneity (microhabitats), which was critical for the proper implementation of the inventory, particularly sampling effort and trap installation, to best estimate local vertebrate community composition.

Field survey

For a number of reasons, including questions of security, during a portion of the field surveys conducted between 6 January (first 3 days associated with additional reconnaissance and installation of inventory materials) and 21 February 2009, it was necessary for the inventory team to be lodged in a tented village within the Ambatovy project area referred to as the "Biocamp". During the periods designated in Table 1 as "camp 1" and "camp 2" nights were spent in the Biocamp, but a tarp was installed next or in close proximity to the study habitat(s), which facilitated handling of captured animals and other field related activities. At the sites referred to in Table 1 as "camp 3" to "camp 5", the group lived in field camps within the forest; this greatly facilitated the inventory operations and reduced travel time back to the Biocamp. These five different camps were also the sites where temporary meteorological stations were installed (see below).

Table 1. Geographic coordinates and other details of campsites occupied during the early 2009 inventories in the Ambatovy-Analamay region conducted by Association Vahatra. Camps 1 and 2 were simply tarps set up in the forest as working areas with nights spent at the Biocamp, and camps 3 to 5 were formal camps established in the forest in close proximity to research sites. ABE = Azonal Benchmark, AIG = Azonal Impacted Good Quality, AID = Azonal Impacted Degraded, TBE = Transitional Benchmark, TIG = Transitional Impacted Good Quality, TID = Transitional Impacted Degraded, ZBE = Zonal Benchmark, ZIG = Zonal Impacted Good Quality, and ZID = Zonal Impacted Degraded. Biocamp coordinates: 18°50'58''S, 48°17'36''E, 1069 m.

Camp	Direct line distance and direction from Biocamp	UPS	UTM	Latitude	Longitude	Altitude (m)	Dates of occupation	Habitats types inventoried
1	6.5 km NNE	39 K 217851	7919320	18°47'55''S	48°19'24''E	1106	9-16 January 2009	TIG, TBE, AID
2	7.5 km NNE	39 K 0219016	7919930	18°47'36''S	48°20'04''E	1105	18-24 January 2009	TBE, AID
3	6.2 km NE	39 K 219337	7918295	18°48'29''S	48°20'14''E	1060	26 January-2 February 2009	ABE, AID
4	7.2 km NE	39 K 221565	7918457	18°48'25''S	48°21'30''E	981	6-12 February 2009	ZBE, ZID
5	5.0 km NE	39 K 219010	7916551	18°49'26''S	48°20'02''E	1045	15-21 February 2009	AIG, TID, ZIG

Research sites associated with the different habitat types

Here we present each specific locality, the geographical coordinates (latitude and longitude), elevation above sea level, and dates of research for each of the sites associated with the nine habitat types inventoried. The vegetational classification follows that of the Ambatovy project.

1) Azonal Benchmark

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 10 km E of Ambohimanarivo (village), 18°48'29''S, 48°20'14''E, elevation: 1060 m, 26 January to 2 February 2009.

2) Azonal Impacted Good Quality

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 10 km E of Ambohimanarivo (village), 18°49'26''S, 48°20'02''E, elevation: 1045 m, 15 to 21 February 2009.

3) Azonal Impacted Degraded

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 9.3 km E of Ambohimanarivo (village), 18°48'26''S, 48°19'50''E, elevation: 1082 m, 26 January to 2 February 2009.

Table 2. Physical characteristics of the soil specimens collected in the Ambatovy-Analamay forest during the early 2009 biological inventories segregated by habitat type: ABE (Azonal Benchmark), AIG (Azonal Impacted Good Quality, AID (Azonal Impacted Degraded), TBE (Transitional Benchmark), TIG (Transitional Impacted Good Quality), TID (Transitional Impacted Degraded), ZBE (Zonal Benchmark), ZIG (Zonal Impacted Good Quality), and ZID (Zonal Impacted Degraded). The parameters presented here are the three major constituents of the soil, as well as color. For further information on the habitat and forest qualities of the different pit-fall lines, see Raselimanana (p. 102, Table 1). As further points of reference, information is presented for samples from two other regional sites with relatively undisturbed mid-elevation eastern humid forest: Maromiza (980 m) and Lakato (980 m).

Habitat	Pit-fall line number	% sand	% clay	% loam	Color
ABE	8	51.0	19.7	28.2	Dark chestnut
ABE	9	49.1	27.0	22.8	Dark chestnut
ABE	10	18.1	44.4	36.3	Brown
AIG	18	31.2	44.4	22.2	Dark chestnut
AIG	19	21.4	33.9	42.7	Dark chestnut
AID	11	17.3	46.2	34.6	Brown
TBE	4	11.4	26.9	58.4	Beige with black spots
TBE	5	14.2	27.8	54.8	Chestnut
TBE	6	9.0	28.6	58.9	Chestnut with black spots
TBE	7	9.6	28.3	58.9	Beige with black spots
TIG	1	8.8	26.9	59.2	Chestnut
TIG	2	9.9	27.6	57.4	Chestnut with black spots
TIG	3	10.3	28.1	56.9	Chestnut
TID	20	10.5	32.0	55.8	Dark chestnut
ZBE	15	15.4	44.4	38.9	Grey
ZBE	16	31.8	27.2	38.9	Chestnut
ZBE	17	30.1	29.0	38.7	Light chestnut
ZIG	21	8.9	46.8	42.7	Chestnut
ZIG	22	5.7	34.2	58.4	Chestnut
ZIG	23	7.7	31.9	58.8	Chestnut
ZID	12	40.8	28.9	28.2	Beige
ZID	13	22.4	32.0	43.4	Light chestnut
ZID	14	24.2	30.9	42.8	Light chestnut
Maromiza	1	34.1	20.0	44.0	Red
Maromiza	2	19.3	29.1	50.0	Red
Maromiza	3	44.7	24.1	30.0	Light chestnut
Lakato	1	7.2	13.0	64.8	Chestnut
Lakato	2	34.5	8.8	42.7	Chestnut
Lakato	3	36.1	8.7	40.7	Chestnut

4) Transitional Benchmark

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 10.5 km NE of Ambohimanarivo (village), 18°47'36''S, 48°20'04''E, elevation: 1105 m, 18 to 24 January 2009.

5) Transitional Impacted Good Quality

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 9 km NE of Ambohimanarivo (village), 18°47'55''S, 48°19'24''E, elevation: 1106 m, 9 to 16 January 2009.

6) Transitional Impacted Degraded

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 10.5 km E of Ambohimanarivo (village), 18°49'14''S, 48°20'12''E, elevation: 1105 m, 15 to 21 February 2009.

7) Zonal Benchmark

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 12.5 km E of Ambohimanarivo (village), 18°48'21''S, 48°21'38''E, elevation: 1006 m, 6 to 12 February 2009.

8) Zonal Impacted Good Quality

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 7.2 km E of Ambohimanarivo (village), 18°49'22''S, 48°18'57''E, elevation: 1125 m, 15 to 21 February 2009.

9) Zonal Impacted Degraded

Madagascar, Region of Alaotra-Mangoro, District of Moramanga, Forêt d'Analamay, 13 km E of Ambohimanarivo (village), 18°48'29''S, 48°21'24''E, elevation: 1023 m, 6 to 12 February 2009.

Soil analysis

A number of studies have shown a close relationship between soil characteristics (physical and chemical) and biotic diversity in tropical forests, such as soil invertebrates and vegetational communities (e.g., Grubb, 1977; Vitousek, 1984; Schrumpf *et al*., 2006). Further, given that the surface geology of the Ambatovy-Analamay region is rather particular due to ultrabasic soils (Delbos & Rantoanina, 1960; Du Puy & Moat, 1996, 2003), it was deemed important to examine certain soil characteristics and attempt to correlate physical and chemical parameters with patterns of vertebrate distribution and diversity. Two regional forests, without ultrabasic soils, that have been inventoried by the Association Vahatra group are included here for comparative purposes. These include a site in the Maromiza forest (18°58.53'S, 48°27.50'E, 980 m) and another in the Lakato forest (19°03.9'S, 48°20.4'E, 980 m) – at both of these localities three soil samples were collected.

A single soil sample was collected in close proximity of each pit-fall line (see Raselimanana, p. 102, and Soarimalala & Raheriarisena, p. 156, for a detailed description of this technique), at the end of each site survey. The specific details on the placement and immediate habitat of each line are presented in Table 1 of Raselimanana (see p. 102). Soil specimens measured 10 x 10 x 10 cm and included the soil litter, although large woody material was not collected. Each sample was placed in a cotton cloth bag and submitted for analysis to the soil laboratory of l'Ecole Supérieure des Sciences Agronomiques of the Université d'Antananarivo. Twenty-three different soil specimens were collected in the Ambatovy-Analamay region and the results of the physical characteristics (Table 2) and chemical properties (Table 3) of each are presented by habitat group type.

Azonal Benchmark (ABE) – pit-fall lines 8-10

The soil texture of pit-fall line 8 was loamy-sand, line 9 clayey-sand, and line 10 loamy-clay; all with a distinctly clogged structure. The pHs of the three specimens were acidic, and the total carbon content of the specimens was moderately rich with the organic matter varying from 5.5 to 7.1% and all are very rich in nitrogen. The ratio of C/N for samples 9 and 10 fell within the range of 11.2 to 14.5, indicating that the organic material had already decomposed, while for sample 8 the ratio was 18.5 denoting that the organic material was poorly decomposed. Levels of phosphorus, potassium, magnesium, and calcium were poor. The cation exchange capacity of the soil was average.

Azonal Impacted Good Quality (AIG) – pit-fall lines 18-19

The soil texture of pit-fall line 18 was sandy-clay and line 19 clayey-loam; all with a distinctly clogged structure. The pHs of the two specimens were acidic, and the total carbon content moderately rich with the organic matter varying from 9.7-9.8% and all were very rich in nitrogen. The ratio of C/N for these samples fell between 13.1 and 14.1 indicating that the organic material had already decomposed. Levels of phosphorus and potassium were moderately rich, while those of magnesium and calcium poor. The cation exchange capacity of the soil was average.

Azonal Impacted Degraded (AID) – pit-fall line 11

The soil texture of pit-fall line 11 was loamy-clay and with a clogged structure. The pH of the specimen was acidic and the total carbon content moderately rich with organic matter of 8.2% and very rich in nitrogen. The ratio of C/N for this sample was 14.6 denoting that the organic material had already decomposed. Levels of phosphorus were moderately rich, potassium moderately poor, and magnesium and calcium poor. The cation exchange capacity of the soil was average.

Transitional Benchmark (TBE) – pit-fall lines 4-7

The soil texture of pit-falls 4 to 7 was clayey-loam; all with a distinctly clogged structure. The pHs of the four specimens were acidic, and the total carbon content of these samples was moderately rich with the organic matter varying from 7.5 to 8.7% and all were very rich in nitrogen. The ratio of C/N for all of these samples fell within the range of 13.4 to 14.5, indicating that the organic material had already decomposed. Levels of phosphorus and potassium were moderately rich, while those of magnesium and calcium poor. The cation exchange capacity of the soil was average.

Transitional Impacted Good Quality (TIG) – pit-fall lines 1-3

The soil texture for these three specimens was clayey-loam; all with a distinctly clogged structure. The pHs of the three specimens were acidic, and the total carbon content of moderately rich with the organic matter varying from 9.3 to 11.1% and all very rich in nitrogen. The ratio of C/N of the samples fell

Table 3. Chemical characteristics of the soil specimens collected in the Ambatovy-Analamay forest during the early 2009 biological inventories segregated by habitat type: ABE (Azonal Benchmark), AIG (Azonal Impacted Good Quality, AID (Azonal Impacted Degraded), TBE (Transitional Benchmark), TIG (Transitional Impacted Good Quality), TID (Transitional Impacted Degraded), ZBE (Zonal Benchmark), ZIG (Zonal Impacted Good Quality), and ZID (Zonal Impacted Degraded). The parameters presented here are pH, percentage of carbon (C), percentage of nitrogen (N), carbon/nitrogen ratio (C/N), percentage of phosphorus (P_2O_5), percentage of potassium (K_2O), percentage of magnesium (MgO), percentage of calcium (CaO), cation exchange capacity (CEC), and percentage of organic matter (OM). For further information on the habitat and forest qualities of the different pit-fall lines, see Raselimanana (p. 102, Table 1). As further points of reference, information is presented for samples from two other regional sites with relatively undisturbed mid-elevation eastern humid forest: Maromiza (980 m) and Lakato (980 m). me = milliequivalents.

Habitat type	Pit-fall line number	pH	C%	N%	C/N	P_2O_5% me %	K_2O me %	MgO me %	CaO me %	CEC %	OM %
ABE	8	5.22	3.9	0.2	18.5	0.09	0.07	0.04	0.02	10.2	7.1
ABE	9	4.78	3.2	0.2	14.5	0.08	0.07	0.04	0.02	10.1	5.8
ABE	10	4.85	3.0	0.3	11.2	0.09	0.08	0.06	0.04	11.2	5.5
AIG	18	4.88	5.3	0.4	14.1	0.12	0.11	0.07	0.04	12.5	9.7
AIG	19	4.83	5.4	0.4	13.1	0.11	0.10	0.06	0.03	12.4	9.8
AID	11	5.81	4.5	0.3	14.6	0.10	0.09	0.05	0.04	11.1	8.2
TBE	4	5.73	4.8	0.3	14.5	0.11	0.09	0.07	0.04	11.6	8.7
TBE	5	5.54	4.1	0.3	13.4	0.12	0.10	0.06	0.02	12.8	7.5
TBE	6	5.55	4.8	0.4	13.7	0.12	0.10	0.06	0.02	12.8	8.7
TBE	7	5.25	4.8	0.4	14.2	0.11	0.08	0.07	0.04	11.3	8.7
TIG	1	4.64	6.1	0.4	14.2	0.10	0.09	0.06	0.03	11.6	11.1
TIG	2	4.95	5.0	0.4	14.3	0.09	0.08	0.04	0.02	11.5	9.1
TIG	3	5.65	5.1	0.4	14.3	0.10	0.09	0.06	0.02	11.8	9.3
TID	20	4.89	5.5	0.4	13.1	0.11	0.10	0.06	0.03	12.3	10.0
ZBE	15	5.13	4.3	0.3	13.4	0.12	0.11	0.07	0.06	12.5	7.8
ZBE	16	4.98	4.9	0.4	13.6	0.12	0.11	0.07	0.04	12.4	8.9
ZBE	17	4.95	5.4	0.4	13.1	0.11	0.11	0.07	0.03	12.5	9.7
ZIG	21	5.25	4.1	0.3	14.5	0.10	0.08	0.04	0.02	11.4	7.4
ZIG	22	5.31	3.5	0.2	14.6	0.10	0.08	0.05	0.03	11.2	6.4
ZIG	23	5.28	3.9	0.3	14.4	0.10	0.08	0.05	0.02	11.2	7.1
ZID	12	5.42	4.0	0.3	14.3	0.08	0.06	0.04	0.03	10.8	7.3
ZID	13	5.10	4.0	0.3	14.7	0.10	0.08	0.05	0.03	10.7	7.2
ZID	14	5.11	4.1	0.3	13.8	0.10	0.08	0.05	0.04	12.3	7.5
Maromiza	1	5.24	3.7	0.2	17.1	0.13	0.10	0.07	0.02	11.4	6.8
Maromiza	2	4.98	3.9	0.3	15.5	0.12	0.10	0.06	0.02	10.0	7.1
Maromiza	3	5.54	2.1	0.1	21.1	0.08	0.06	0.04	0.01	7.4	3.8
Lakato	1	5.65	5.4	0.5	11.7	0.12	0.08	0.06	0.04	8.7	9.8
Lakato	2	5.70	6.9	0.7	9.5	0.10	0.07	0.07	0.04	9.1	12.5
Lakato	3	5.72	6.6	0.5	13.2	0.11	0.07	0.06	0.05	9.2	12.0

within the range of 14.2 to 14.3, indicating that the organic material had already decomposed. Levels of phosphorus and potassium were moderately rich, magnesium moderately poor, and calcium poor. The cation exchange capacity of the soil was average.

Transitional Impacted Degraded (TID) – pit-fall line 20

The soil of pit-fall 20 had a texture of clayey-loam and with a distinctly clogged structure and the pH acidic. The total carbon content of this specimen was moderately rich in organic matter at 10.0% and very rich in nitrogen. The ratio of C/N for this sample was 13.1, indicating that the organic material had already decomposed. Levels of phosphorus and potassium were moderately rich and magnesium and calcium poor. The cation exchange capacity of the soil was average.

Zonal Benchmark (ZBE) – pit-fall lines 15-17

The soil texture for pit-fall 15 was loamy-clay, and for pit-falls 16 and 17 sandy-loam; all with a distinctly clogged structure. The pHs of the three specimens were acidic, and the total carbon content moderately rich with the organic matter varying from 7.8 to 9.7% and all very rich in nitrogen. The ratio of C/N for these samples fell within the range of 13.1 to 13.6, indicating that the organic material was already decomposed. Levels of phosphorus and potassium were moderately rich and of magnesium and calcium poor. The cation exchange capacity of the soil was average.

Zonal Impacted Good Quality (ZIG) – pit-fall lines 21-23

The soil texture for pit-fall line 21 was loamy-clay, and lines 22 and 23 clayey-loam; all with a distinctly clogged structure. The pH of the three specimens were acidic, and the total carbon content moderately rich with the organic matter varying from 6.4 to 7.4% and all very rich in nitrogen. The ratio of C/N for the samples fell within the range of 14.4 to 14.6, denoting that the organic material had already decomposed. Levels of phosphorus were moderately rich, potassium moderately poor, and magnesium and calcium poor. The cation exchange capacity of the soil was average.

Zonal Impacted Degraded (ZID) – pit-fall lines 12-14

The soil texture for line 12 was clayey-sand and lines 13 and 14 clayey-loam; all with a distinctly clogged structure. The pHs of the three samples were acidic, and the total carbon content moderately rich with the organic matter varying from 7.2 to 7.5% and all rich in nitrogen. The ratio of C/N for these samples fell within the range of 13.8 to 14.7, indicating that the organic material was decomposed. Levels of phosphorus were moderately rich for lines 13 and 14, while line 12 was poor. All the specimens were poor in potassium, magnesium, and calcium. The cation exchange capacity of the soil was average.

Maromiza – pit-fall lines 1-3

The soil texture for pit-fall 1 is sandy-loam with a distinctly clogged structure, pit-fall 2 clayey-loam with a distinctly clogged structure, and pit-fall 3 loamy-sand. The pHs of the three samples were acidic, and the total carbon content was moderately rich with the organic matter varying from 3.8 to 7.1%. The first two samples were rich in nitrogen. The ratio of C/N for pit-fall sample 2 was 15.5 indicating that the organic material had already decomposed, while samples from pit-falls 1 and 3 ranged from 17.1 to 21.1 denoting that the organic material was poorly decomposed. Levels of phosphorus were moderately poor. For potassium, the levels were moderately rich for pit-fall lines 1 and 2, and poor for pit-fall line 3. In the case of magnesium, all the samples were somewhat poor and for calcium very poor. The cation exchange capacity of the soil was average for samples from pit-falls 1 and 2, and poor for pit-fall 3.

Lakato – pit-fall lines 1-3

The soil texture for pit-fall 1 is loamy and pit-falls 2 and 3 sandy-loam; all with a distinctly clogged structure. The pHs of the three samples were acidic, and the total carbon content was moderately rich with the organic matter varying from 9.8 to 12.5%, and all rich in nitrogen. The ratio of C/N for the three samples fell between 9.5 to 13.2, indicating that the organic material had already decomposed. Levels of phosphorus were moderately rich, potassium moderately poor, and magnesium and calcium very poor. The cation exchange capacity of these soil samples was average.

Meteorology

The biological rhythms of various animals, particularly reptiles and amphibians, are strongly influenced by climatic factors, including temperature and rainfall. In order to correlate daily inventory activities and

Table 4. Meteorological data (minimum temperature, maximum temperature, and precipitation) recorded during designated dates in each of the different surveyed habitats in the Ambatovy-Analamay area.

Habitat type	Date (2009)	Minimum temperature (°C)	Maximum temperature (°C)	Precipitation (mm)
Transitional Impacted Good Quality	9 January	18	28	55.0
	10 January	17	27	0.8
	11 January	18	28	0.0
	12 January	18	26	0.0
	13 January	17	27	0.0
	14 January	18	26	2.0
	15 January	17	26	0.0
Transitional Benchmark	18 January	18	26	8.0
	19 January	17	26	20.0
	20 January	18	22	28.0
	21 January	18	22	4.0
	22 January	17	22	2.0
	23 January	17	26	30.0
	24 January	17	26	2.0

Table 4. (cont.)

Habitat type	Date (2009)	Minimum temperature (°C)	Maximum temperature (°C)	Precipitation (mm)
Azonal Benchmark	26 January	18	29	0.0
	27 January	18	27	2.0
	29 January	18	27	0.0
	30 January	18	28	0.0
	31 January	14	26	0.0
	1 February	14	26	0.0
	2 February	14	26	0.0
Zonal Benchmark & Zonal Impacted Degraded	6 February	16	26	8.0
	7 February	17	22	17.0
	8 February	16	21	2.0
	9 February	17	22	31.0
	10 February	17	22	79.0
	11 February	17	21	65.0
	12 February	17	19	35.0
Azonal Impacted Good Quality & Transitional Impacted Degraded	15 February	17	22	0.0
	16 February	17	23	0.0
	17 February	17	21	15.4
	18 February	18	26	0.5
	19 February	17	26	0.0
	20 February	18	26	20.0
	21 February	18	27	65.0

results with meteorological parameters, a weather station (rain gauge and a min-max thermometer) was installed at each of the camps (Table 1). Data were obtained from the station in the early morning, inclusive of the previous 24-hour period (dawn to dawn); this information is presented in Table 4.

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