Description of the Paysage Harmonieux Protégé d'Andrafiamena-Andavakoera, Madagascar, and the 2023 biological inventory of the protected area

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Abstract

Between 16 November and 8 December 2023, a biological inventory was conducted of three sites (Binara, Antsahabe, and Anjakely) in the Paysage Harmonieux Protégé d'Andrafiamena-Andavakoera in northern Madagascar. Two different vegetational types were surveyed: semi-deciduous humid forest at Binara and Anjakely, and dry deciduous forest on limestone at Antsahabe. Located in the northern sector of the Western Phytogeographical Domain and within 50 km of the Sambirano Domain, represented by the Galoko-Kalobinono protected area, Andrafiamena-Andavakoera is part of a series of sites in the northern portion of the island with dry forest formations that are connected or nearly connected sites – to the northwest of Andrafiamena-Andavakoera is Ankarana, to the northeast is Analamerana, notably to the north is Montagne des Français, and to the southeast Loky-Manambato. Biological groups studied during the inventory by specialists making up part of the inventory team included: vascular plants, amphibians, reptiles, birds, small mammals, bats, and primates. Further specimens of a range of different invertebrates were collected and worked up by taxonomic authorities. This monograph reports on the findings of the inventory, the various habitats represented at the three inventoried sites and their constituent species, forest cover changes over time, and the biological importance of the protected area in both the regional and national sense with respect to the island's protected areas system. We also present a series of recommendations associated with the future research programs of the Andrafiamena-Andavakoera protected area for monitoring key species and aspects associated with invasive species.

Résumé détaillé

Le Paysage Harmonieux Protégé (PHP) d'Andrafiamena-Andavakoera, situé dans le Nord de Madagascar, est géré par l'Association Fanamby et bénéficie du soutien de l'Agence Française de Développement (AFD) pour renforcer la conservation et la protection de la biodiversité et des écosystèmes représentatifs de cette région via le projet KOBABY. Dans le cadre de cette initiative, l'Association Vahatra a été sollicitée pour mener une investigation biologique ayant pour objectifs spécifiques de rendre disponibles des données qualitatives et quantitatives à jour sur la faune et la flore, d'évaluer la qualité des habitats, d'analyser les impacts des pressions et menaces anthropiques constatées, d'identifier les espèces-clé de la faune et de la flore susceptibles de faire l'objet d'un suivi écologique, et de réaliser une analyse descriptive et évolutive du paysage et de sa couverture végétale.

Trois sites ont été identifiés par échantillonnage stratifié, et validés après une mission de reconnaissance : Binara, Antsahabe et Anjakely. Une équipe pluridisciplinaire a été déployée pendant trois semaines entre 16 novembre et 8 décembre 2023 pour étudier la flore, la végétation et divers groupes faunique, notamment les amphibiens, les reptiles, les oiseaux, les mammifères non volants, les chauves-souris et les lémuriens. Des collectes aléatoires ont également été réalisées, par exemple des crabes d'eau douce, des crabes terrestres et des escargots terrestres. Pour cette investigation, les scientifiques de l'Association Vahatra ont été appuyés par la participation d'instituts partenaires, tels que les Conservatoire et Jardin Botaniques de la Ville de Genève et le Field Museum of Natural History de Chicago.

Cette monographie présente les résultats de l'investigation, avec non seulement la contribution des scientifiques experts, mais également celle du gestionnaire délégué du PHP ou l'ONG Fanamby. L'accent a été mis sur la comparaison des données

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collectées avec celles des aires protégées voisines, comme l'Ankarana, la Montagne d'Ambre, le Loky Manambato et l'Analamerana mais aussi celles du Sambirano vis-à-vis de la présence de certaines composantes de la forêt humide dans la région. Afin de mieux évaluer la richesse biologique et le potentiel écologique du site, des méthodes standards, bien connues et approuvées, ont été utilisées pour collecter les données, incluant des lignes de transects d'observation directe (pour les amphibiens, reptiles, oiseaux et lémuriens), des dispositifs de piégeage (pour les amphibiens, reptiles, micromammifères et chauves-souris), le relevé de végétation et la collecte itinérante de plantes fertiles pour l'étude de la flore et la caractérisation des habitats. Des spécimens ont été collectés et les données sur les ressources naturelles du PHP ont été mises à jour.

Les principaux types d'habitats naturels du PHP sont répartis en fonction des facteurs écologiques, et leur état de santé est influencé par l'histoire de l'impact anthropique, un élément de classification considéré par le gestionnaire pour la définition de son schéma d'aménagement. Dans ce schéma d'aménagement, les forêts de Binara et d'Anjakely font partie des noyaux durs de conservation, tandis que celle d'Antsahabe est définie comme une zone d'utilisation durable. Ces trois sites abritent une faune et une flore riches et diversifiées malgré la dégradation et la fragmentation des habitats. Le niveau de menace et de pression dans les sites visités est relativement faible ; cependant, l'écosystème y demeure précaire et sensible aux moindres perturbations. Sur la base des résultats des inventaires biologiques, deux nouvelles espèces cibles d'arbres endémiques locaux ont été proposées puis approuvées par le gestionnaire : *Capurodendron andrafiamenae* et *Donella ranirisonii* (Sapotaceae). Le suivi régulier de ces arbres menacés, disséminés par la faune (oiseaux et lémuriens frugivores, notamment *Propithecus perrieri*), permettra d'apprécier le niveau de maintien de l'intégrité de la biodiversité et des écosystèmes, ainsi que d'envisager un plan d'action pour la restauration écologique et la protection des espèces endémiques locales et régionales.

Introduction

Madagascar, with its considerable surface area approaching that of a small continent, superimposed on its habitat heterogeneity and complexity, harbors a rich and largely unparalleled high levels of biotic uniqueness for an area of its size. Different portions of the island have been the subject of biological surveys over the past decades. The often repeated findings of these extensive explorations are: 1) a high degree of biogeographic heterogeneity for many of the studied organisms with respect to the island or even across a given site, 2) important distributional extensions of considered local endemic species, 3) many of the endemic organisms having narrow geographic distributions, and 4) a considerable number of undescribed taxa. Further, data generated by these inventories have been important for the prioritization steps in the expansion and enlargement of the protected areas network of the island (Nicoll & Langrand, 1989; Kremen *et al*., 2008; Rasoavahiny *et al*., 2008; Carvalho *et al*., 2020). Hence, given these patterns and with the intent of advancing conservation programs based on solid scientific data to protect a measurable percentage of the island's biodiversity, detailed information is needed on the fauna and flora of poorly studied areas, which can be considered as critical for the inclusion of different zones, species communities, and habitats/microhabitats not sufficiently represented in the current protected areas network. These data also provide important insights into dispersal corridors and barriers for different organisms and, hence, have important implications for a range of questions in evolutionary biology.

The northern portion of Madagascar, in the areas that are now part of the SAVA and DIANA Regions, include protected areas that encompass a range of different forest types (Figure 1), which include medium altitude moist evergreen forest, semi-deciduous forest, and dry deciduous forest often on limestone (Gautier *et al*., 2018). These formations are concentrated in a narrow band between latitudes 12.415° and 13.200° S, where the protected areas of Andrafiamena-Andavakoera, Ankarana, Analamerana, Loky-Manambato, Montagne d'Ambre, Montagne des Français, and Oronjia are located (Figure 1). According to the analyses of Harper *et al*. (2007) and Vieilledent *et al*. (2018), the various forest formations of these protected areas were connected or nearly connected and form presumed corridors for dispersal of different organisms. The geographical setting of the region, specifically the influences of the trade winds (alizé, known as *varatraza* in Malagasy), which can be particularly strong during the period from April to November, the associated monsoon rains that show clines across the region, and other ecological factors, including considerable

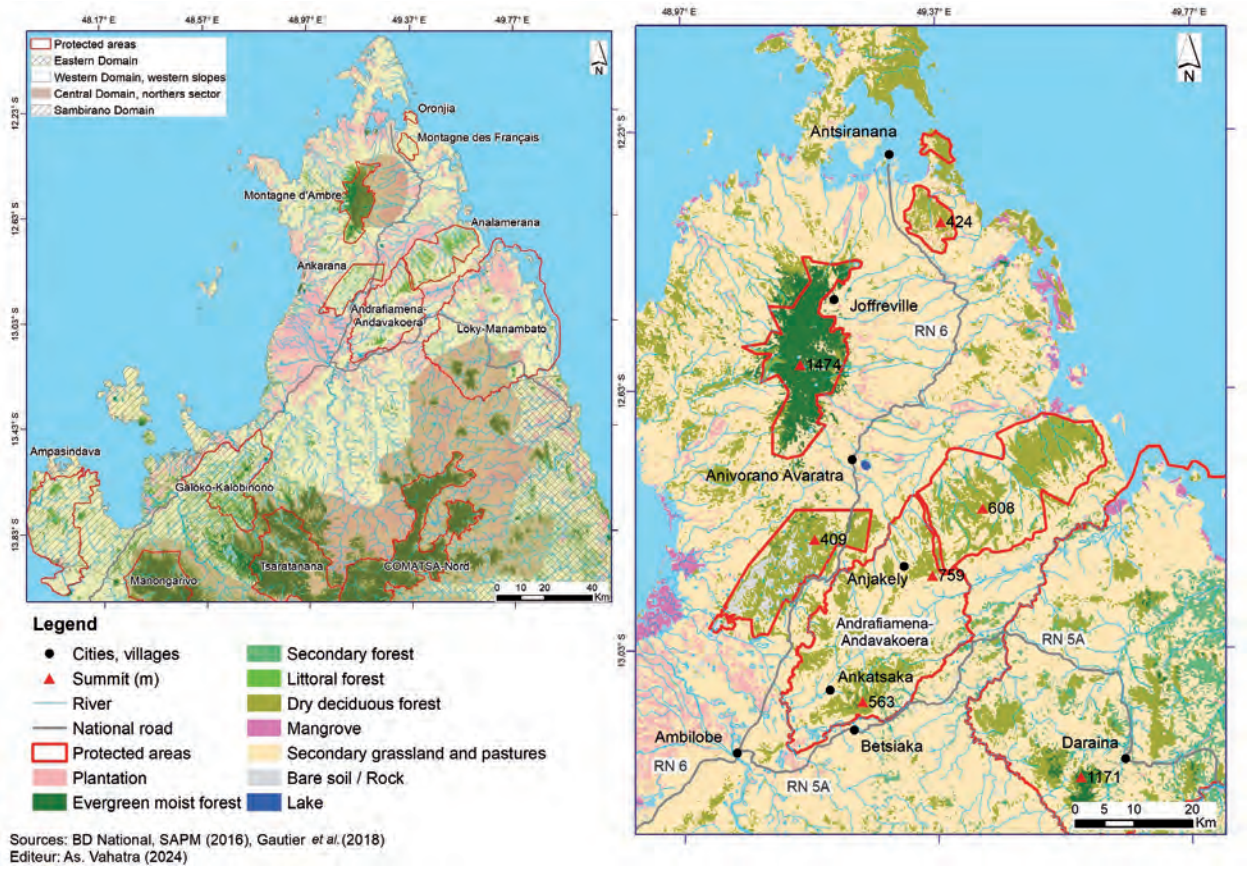

Figure 1. Maps of northern Madagascar, with that to the left showing remaining natural vegetation cover, vegetational domains, and protected areas at a broad scale and that to the right mapping different forest types and the protected areas in close proximity to and including Andrafiamena-Andavakoera.

topographical variation and a remarkable mosaic of underlying bedrock and substrata, help explain the high levels of biological diversity in northern Madagascar. This includes floristic and faunal similarities and dissimilarities among these protected areas, as well as in some cases important levels of species turnover.

From the biotic perspective, several of these protected areas with humid semi-deciduous or dry deciduous forest are reasonably well-known for land vertebrates (Goodman *et al*., 2018a). In an assessment dating from early 2018 of the "state of knowledge" of 98 terrestrial protected areas on Madagascar by different faunal specialists, which were scored individually for a given site using a system of 0 = no information (lacking a detailed inventory to date) to 5 = well known (extensive inventory work has been conducted), protected areas in the north (see Figure 1), received the following marks (MEF = moist evergreen forest, DF = dry forest, and arranged from north to south): Montagne des Français (DF) – 2.4, Montagne d'Ambre (MEF) – 3.0, Loky-Manambato (MEF and DF) – 2.5, Analamerana (DF) – 2.5, Andrafiamena-Andavakoera (DF) – 1.8, and Ankarana (DF) – 3.4 (Goodman *et al*., 2018b).

From the floristic side for each of these sites, using a measure of the density of plant herbarium collections divided by the surface area of a given protected area (not taking proportional forest cover into account), the following values were calculated in early 2018 based on catalogued specimens in the world's herbaria with important holdings of Malagasy plants (Phillipson *et al*., 2018): Montagne des Français – 19 collections/km^2, Montagne d'Ambre – 12 collections/km^2, Ankarana – 7 collections/km^2, Andrafiamena-Andavakoera – 1 collection/km^2, and Analamerana – <1 collection/km^2. The relatively low values for the last two sites underlines that from the botanical perspective they are not well collected.

Using the available literature for each site and based on a compilation of unpublished reports, scientific publications, and other forms of documentation that were uploaded to the Madagascar Protected Areas website (protectedareas.mg), there are notable differences in the level of available information on these sites based on the number of posted pdfs: Ankarana – 417 pdfs, Montagne

Table 1. Measures of natural forest loss from 1996 to 2006 and from 2006 to 2016 in different natural formations of the Andrafiamena-Andavakoera protected area that was officially named in 2015. Data derived from Rabenandrasana *et al*. (2018a, 2018b).

Habitat type	Forest cover (ha) in 1996	Forest cover (ha) in 2006	Forest loss (ha) between 1996-2006 (% loss)	Forest cover (ha) in 2016	Forest loss (ha) between 2006-2016 (% loss)
Moist evergreen forest[1]	5177	312	4865 (94.0%)	235	77 (24.6%)
Dry deciduous forest	12,329	12,329	0 (0%)	12,300	29 (0.2%)
Total	**17,506**	**12,641**	**4865 (27.8%)**	**12,535**	**106 (0.9%)**

[1] This is the term used in the cited reference, but is best considered moist semi-deciduous forest.

d'Ambre – 314 pdfs, Loky-Manambato – 157 pdfs, Montagne des Français – 149 pdfs, Analamerana – 117 pdfs, and Andrafiamena-Andavakoera – 79 pdfs.

On the basis of these different evaluations, the protected area of Andrafiamena-Andavakoera can be considered poorly known with regards to its plant and animal biota, as well as not having been a site of extensive ecological and biological research with the exception of primates to some extent (Rafalimanana, 2025, herein). It is also a region that has been heavily subjected to human pressures of its natural forests, which in 2015 became a protected area. An analysis of forest loss during two periods, from 1996 to 2006 and 2006 to 2016, found that during the first period over 4860 ha of "moist evergreen forest" (best referred to as moist semi-deciduous forest) was lost, representing 94.0% of this formation in the zone, and in the second period, 77 ha was destroyed (Table 1). The dry deciduous forests occurring at the site have not been dramatically reduced over the two periods. Hence, this information clearly underlines the need of documenting and archiving information on the organisms that occur locally, particularly in the remaining moist semi-deciduous forests of this protected area.

In short, to better understand the importance of the Andrafiamena-Andavakoera protected area in terms of its biodiversity, the role it plays as a forest corridor for dispersal to neighboring and regional protected areas, and valorizing the site for ecotourism, it was deemed important to conduct a biological inventory of different habitats and portions of the protected area. This work was conducted in late 2023 by a group of plant and animal biologists and is the subject of this monograph. Herein we present the results of this work and offer insights on the importance of Andrafiamena-Andavakoera with respect to the biota of northern Madagascar and in a broader sense to the island's protected area system.

Why is it important to collect specimens during a biological inventory?

As a general procedure, scientific teams conducting biological surveys incorporate in their field methodology the collection of reference material. These include specimens for the proper documentation of the organisms encountered, a percentage might be new to science, for which this material is key for the formal description, as well as the need for material to properly identify specimens via classical taxonomical studies, molecular genetics, or both in an integrative manner. In many ways, these specimens represent the archives of the scientific results of the inventory and in a greater sense the natural patrimony of Madagascar (Figure 2).

Figure 2. Scientists conducting biological surveys generally incorporate in their field methodology the collection of reference specimens that are deposited in herbariums and natural history museums. This material serves as the definitive documentation of the organisms encountered, as well as what is needed for a range of different studies. Here is shown the botanical group during the Andrafiamena-Andavakoera survey preparing collected plants as herbarium specimens. The group in the immediate foreground includes (from left to right): Laurent Gautier, Alain Rasolonjatovo, local assistants, and Jacquis Tahinarivony. (Photo by Carlos G. Boluda.)

On Madagascar, applications to obtain permits for different types of scientific research are passed by a committee of national experts, known as Commission Ad'hoc Faune et Flore/Comité d'Orientation de la Recherche Environnementale (CAFF/CORE), who decide if the proposed work is warranted and, if so, set limits on the number of specimens that can be collected and where the material needs to be deposited. Once a research project has been approved by the committee, the application is transferred to the national authorities to issue the needed permits. The expedition reported on herein to the Andrafiamena-Andavakoera protected area and the specimens collected was authorized by a research permit issued by the Ministère de l'Environnement et du Développement Durable (MEED), reference N° 308/23/MEDD/SG/DGGE/DAPRNE/SCBE.Re, dated 19 September 2023.

The number of plant and animal taxa described as new to science from the island between 2003 and 2022 is simply remarkable (Goodman, 2023) and with few parallels in other tropical countries of the world. This is particularly the result for sites that have been extensively sampled during biological inventories. For example, at Marojejy, a massif in the northeast, that has been the subject of considerable botanical and zoological exploration between 1988 and late 2021 the study of collected specimens led to the description of four species of Bryophytes, 14 species of Pteridophytes, 97 species of Angiosperms, 41 species of Gastropoda, 71 species of non-insect Arthropoda, 181 species of insects, and 42 species of Vertebrata or a total of 450 species new to science (Goodman *et al*., 2023). For Andrafiamena-Andavakoera, these figures include no species of Bryophytes or Pteridophytes, 14 species of Angiosperms, one species of Gastropoda, three species of non-insect Arthropoda, 20 species of insects, and two species of Vertebrata or a total of 40 species new to science (Goodman *et al*., 2025, herein). An excellent example of the previous lack of and importance of conducting new biological inventories in this protected area is a visit by Brian L. Fisher and colleagues from the Madagascar Biodiversity Center who inventoried invertebrates on the Andavakoera Massif from 15 to 17 December 2003, and on the basis of material they collected, 22 species were described as new to science (Goodman & Fisher, 2025, herein). Hence, with further exploration of the protected area and associated taxonomic studies, it is certain that a number of organism unique to the site and perhaps new to science will be found, which includes specimens collected during our late 2023 work. This aspect is exemplified by random collections of aquatic invertebrates made during the late 2023 inventory that resulted in the description of a new genus and species of freshwater crab (Cumberlidge & Daniels, 2025, herein). However, in most cases, it takes a number of years to advance and complete taxonomic revisions by specialists, including molecular studies, and for certain groups such analyses can take over a decade.

The Andrafiamena-Andavakoera protected area

The Paysage Harmonieux Protégé d'Andrafiamena-Andavakoera, hereafter Andrafiamena-Andavakoera protected area, in extreme northeastern Madagascar, is composed of two different geological features, the Andrafiamena mountain chain and the isolated Andavakoera Massif, that are discussed below. The protected area has several different vehicle access points, in the north via a road from Anivorano-Avaratra (Anivorano Nord) towards Ambery, to the central portion a road from Marotaolana to Anjakely (sometimes referred to as Anjahankely or Anjahakely), in the west from different entry points of the Route Nationale (RN) 6 (National Road linking Antsiranana [Diego Suarez] to Ambanja and points further south), and in the south from the RN 5A (linking Ambilobe to Vohemar [Iharana]) (Figure 1). As indicated in the previous section, the protected area is biologically poorly known and based on information available as of early 2018, that is to say a few years before our recent inventory, on the basis of registered specimens in the herbaria of the world with major collections from the island, the flora included 182 documented species, with82.9% endemic to Madagascar (Phillipson *et al*., 2018). However, field collections made in the protected area mostly around Anjakely between 1 November 2010 and 28 February 2011, found at least 276 species (Burivalova, 2011).

Also, as of early 2018, the vertebrate fauna included six species of frogs, 21 species of reptiles, 69 species of birds, and 20 species of native mammals (Goodman *et al*., 2018a; Phillipson *et al*., 2018). In comparison to the known species diversity of reasonably well-known neighboring protected areas with some of the same vegetation formations, these figures certainly underrepresent the real biodiversity of Andrafiamena-Andavakoera and underline the need for further biological exploration of the site.

In late April 2015 under the direction of Association Fanamby, the area was named as a new protected area and with an IUCN category V status (Goodman *et al*., 2018a). The Forêt Classée d'Andavakoera (Ambilobe), an area of 12,575 ha, was integrated into the Andrafiamena-Andavakoera protected area. Association Fanamby (https://association-fanamby.org/accueil/), who undertook the steps to create the protected area and remains the site manager, has their principal office in Antsiranana and employees in villages in close proximity to the limit of the protected area. In several surrounding villages, local people are members of the Komity Miaro ny Tontolo iainana or KMT (Committee for the Protection of the Environment), which play an important role in the governance of the site in the form of local monitoring and enforcing regulations. To help advance the role of members of the KMT, they receive equipment and occasional training surveillance.The northern portion of Madagascar has a number of official protected areas, several of which abut or are in close proximity to Andavakoera-Andrafiamena (Figure 1). These include three isolated sites to the north (Paysage Harmonieux Protégé d'Oronjia with dry deciduous forest on sandy soils, Parc National de Montagne d'Ambre with medium altitude moist evergreen forest, and Paysage Harmonieux Protégé d'Ambohitr'Antsingy [= Montagne des Français] with dry deciduous forest); two largely contiguous sites (Réserve Spéciale d'Analamerana and Réserve Spéciale d'Ankarana) with different types of forest from dry deciduous to moist semi-deciduous, abut or are in close proximity to Andrafiamena-Andavakoera, and one, Paysage Harmonieux Protégé de Loky

Figure 3. The biogeography of the remaining forested areas of northern Madagascar, most of which have been integrated into the island's protected area system, is rather fascinating and includes aspects associated with forested habitat corridors allowing for dispersal between the blocks and abrupt geological formations acting as barriers. Here is a view from the northern slopes of the Anjakely Forest with secondary moist semi-deciduous vegetation, the plateau to the immediate left is the Antsahabe Forest with dry deciduous forest on limestone (*tsingy*), and in the distant center the slopes of Montagne d'Ambre (partially covered by clouds), about 26 km direct line distance, and with moist evergreen forests. Given the height of Montagne d'Ambre with its summit at 1474 m, in close proximity to the sea with circulating meteorological systems, and being isolated from other nearby topographic features, the massif has an important orographic effect in producing regional rainfall. The moisture-laden air passes upwards, causing it to rapidly cool and then releases moisture in the form of precipitation on a local and regional basis. (Photo by Voahangy Soarimalala.)

Manambato, occurs to the southwest of this block and with moist evergreen forest and dry deciduous forest. Even for disjunct forest blocks, the direct line distances separating these sites are not large, for example between Anjakely to the closest side of Montagne d'Ambre is about 26 km (Figure 3). On the basis of published and unpublished information on the land vertebrates occurring in these different protected areas it is possible to examine biogeographic patterns and the role of former (in recent historical time) and existing forest corridors had/have as dispersal connections for a range of different species. These types of analyses help in certain cases to explain why certain taxa have broad distributional patterns across northern Madagascar. Alternatively, the role of abrupt changes in vegetation or geological formations, such as cliff faces at the southern limit of the Andrafiamena Mountains (see below), as barriers to dispersal. However, in certain of these protected areas, particularly Andrafiamena-Andavakoera, where few data are available on the locally occurring animal species, the aspect of the site acting as a corridor or barrier to dispersal is currently assumed and information from inventories is needed to substantiate such interpretations.

Geology, soils, and topography

The Andrafiamena section of the protected area is composed of two separate geological elements (de Saint Ours, 1958; Roig *et al*., 2012; Crowley & Sparks, 2018). In the north is largely marine limestone deposited during the Middle Jurassic, with elements of clayey-limestone and marls. This is the area where limestone pinnacles are found, known as *tsingy* in Malagasy, and associated cave formations. These limestone formations are largely contiguous with those found in the neighboring Ankarana and Analamerana protected areas. The southern two-thirds of Andrafiamena is geologically complex and composed of exposed sandstone, sandy limestone, dolomite, marl, shale, and gypsum also dating for the most part from the Middle Jurassic, and older formations of sandstone, shale, and conglomerates dating from Triassic and lower Jurassic. This extensive conglomerate formation ends abruptly at the southern edge of the Andrafiamena Plateau with a cliff face of several hundred meters that descends into the lower Loky River watershed (Figure 4).

The Andavakoera Massif is also a composite of different formations and forms the limit between metamorphic formations dating from the Precambrian and more recent sedimentary rock, including Triassic and lower Jurassic sandstones (Besaire, 1973; Crowley & Sparks, 2018). The southern limit of the massif, just to the north of the village of Betsiaka, is a pronounced cliff face that in less than 2 km rises more than 500 m in elevation. Of local economic interest, this massif has gold deposits that are still exploited today by both commercial and artisanal manners, and between 1906 and 1919 something approaching seven tons of gold were extracted from these deposits (Besaire & Collignon, 1971; Rambeloson, 1999).

Following Armstrong and McGroddy (2018), the most common soils in the protected areas are Haplic Acrisols and Haplic Ferralsols, which are highly weathered, acidic, have poor capacity to retain essential cations, and relatively high abundance of iron and aluminum. Lithic Leptosols are also present, which are composed of shallow soils in the early stages of development and generally found in areas

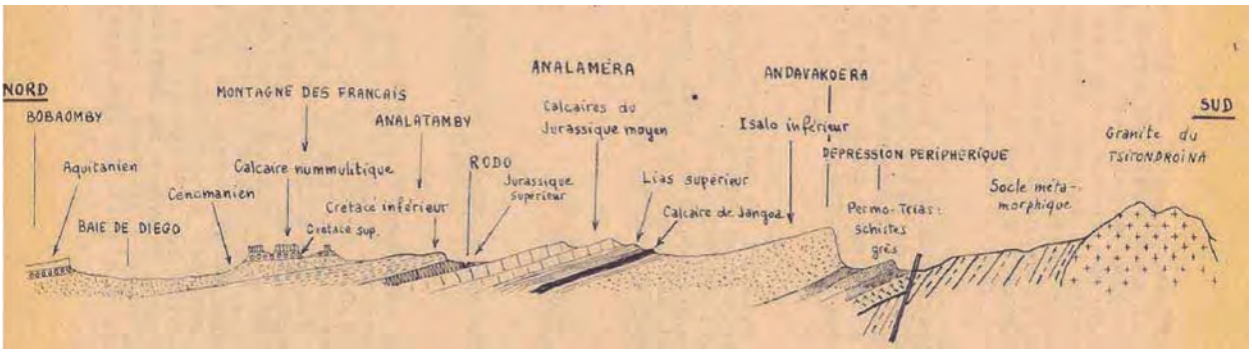

Figure 4. Here is presented a cross-section of the geology of northern Madagascar from the northern most point at Bobaomby south to the granitic zone to the south of Andavakoera. Two different formations may serve as dispersal barriers for certain organisms. The first is the southern edge of the Andrafiamena Mountains falling in the cut between "Analamera" and Andavakoera and specifically to the north (left) of the "Isalo inférieur" formation. The second is the cliff face to the south (right) of the Andavakoera Massif, an abrupt geological feature and dropping to what is today a portion of the Loky-Manambato protected area. The figure is reproduced from de Saint Ours (1958).

of high soil erosion and disturbance. In both cases, these soils are notably poor for agricultural activities.

To give a better sense of the protected area's topography, more than 90% of the site falls within the elevational range from about 100 to 500 m above sea-level. The summit of the Andavakoera Massif is 563 m and the highest point along the Andrafiamena Plateau is about 760 m in the eastern portion (Figure 1). Most rain-bearing weather systems in the north of the island arrive from the Indian Ocean. Given that the higher elevations in the Andrafiamena-Andavakoera area are in the eastern portion, it is possible that this section receives a greater amount of rainfall than areas to the west, which would have a direct bearing on the vegetation structure of the zone and the locally occurring animals; there is no meteorological data we are aware of to support the premise of clinal east-west differences in weather patterns. In short, the considerable topographic variation of northern Madagascar, which produces important regional orographic variation in meteorological patterns, combined with a mosaic of geological formations including limestone, sandstone, and volcanic rock, provides a very heterogeneous landscape. These aspects are directly related to a patchwork distributional pattern of different plants and animals in northern Madagascar, comprising many regional and local endemic species, which includes the Andrafiamena-Andavakoera area.

Meteorology

The generalities presented here on the climate of the Andrafiamena-Andavakoera protected area are derived from Rakotondrafara *et al*. (2018). Temperature records used by these authors are from 1985 to 2014 and based on MODIS satellite data with a resolution of 0.1° (approximately 11 km), as well as 22 weather stations scattered around the island. Precipitation data from the same period are divided into 10-day periods (decadal), and derived from TAMSAT with the same resolution mentioned above. It is important to underline that these analyses use a single point in an unspecified portion of the protected area, presumably towards the center, and the derived data do not necessarily reflect subtle meteorological differences across the zone, particularly at varying elevations and along east-west clines.

The protected area and surrounding areas are dominated by the dry climate of the north, with average annual rainfall being 1654 mm (1981 to 2017), of which 90% falls between November and April. Between 1985 and 2014, dry episodes of up to 10 days occurred at the height of the rainy season, and during this period precipitation increased by about 0.1% annually, or around 27 mm. Towards the end of this 30-year period, the rainy season tended to start 20 days earlier, as compared to period before 1985.

On average, the daily temperature varies between 21.0°C and 30.8°C. The cold season falls between June and August, with temperatures dropping to on average of 17.4°C. The warm season is generally between December and February, with peak temperatures over 34.0°C. From 1985 to 2014, the average minimum daily temperature showed no measurable change, while the average maximum temperature increased by 1.0°C. This augmentation could be considered of potential importance to shifts in certain vegetation habitats in the protected area and the associated implications for the constituent species.

During the 2023 inventory of Andrafiamena-Andavakoera, the research team occupied two camp sites: Binara within the Andavakoera forest and the Fanamby office in an open area and just outside of the Anjakely (village), from which the Antsahabe and Anjakely Forests were surveyed. A simple weather station was installed at each camp site, which consisted of a rain gauge place in an open area without overhanging vegetation and a minimum-maximum thermometer installed under tree cover and out of direct sunlight. Each day around dawn, the weather data were recorded from each of these devices, the rain gauge was emptied, and the temperature indices of the thermometer returned to "zero". The descriptive statistics for the weather data from the two sites are presented in Table 2.

Table 2. Summary of meteorological measurements during the 2023 inventory of the Andrafiamena-Andavakoera protected area. Data are presented as mean ± standard deviation, range of measurements, and number of data points (n).

	Minimum (°C)	Maximum (°C)	Rainfall (mm)
Binara 16 to 23 November 2023	23.6 ± 1.40 21-25, n=7	34.0 ± 1.91 32-36, n=7	No rain
Anjakely 24 November to 7 December 2023	22.4 ± 1.22 21-25, n=14	35.9 ± 2.00 32-39, n=14	1.8 ± 3.24 0-9.2, n=3

During the inventory period, there was little recorded precipitation, with no rainfall at the Binara Forest site and during a 14-day period some rainfall on three occasions at Anjakely with the maximum rainfall being 9.2 mm in a 24-hour period. The minimum and maximum temperatures in the Binara Forest varied from 21-25°C (average 23.6°C) and 32-36°C (average 24.0°C), respectively, and at Anjakely varied from 21-25°C (average 22.4°C) and 32-39°C (average 35.9°C), respectively.

Montagne d'Ambre in the extreme north of the island is an isolated volcano with the summit at 1474 m. This massif dominates much of the extreme north of the island and is isolated from other nearby topographic features, as well as being close to the sea. The massif has an important orographic effect in producing regional rainfall, with moisture-laden air passing upwards, causing it to rapidly cool and to release moisture in the form of precipitation. For example, most of the rain systems that pass by Andrafiamena-Andavakoera have their origins on Montagne d'Ambre (Figure 3), with the exception of cyclonic systems that can arrive from any direction.

Human environment and socio-economic aspects

The northern portion of Madagascar, including its agricultural potential and especially its mineral wealth, have led to the settlement of human populations in what is currently the Andrafiamena-Andavakoera protected area. As described in the Environmental Management and Social Safeguard Plan (PGESS; Fanamby, 2023) and the Management Plan associated with this protected area (PAG; Fanamby 2104a, 2014b, 2023), the considerable ethnic diversity of the local populations is part of the human value of the protected area. The Antakarana, considered as indigenous to the area, are a minority compared to the Betsimisaraka (from the east), the Tsimihety (from the west), and the Sakalava (from the northwest). On the basis of figures that are now presumably out of date, Fanamby (2014a) cite about 21,500 people living within or close to the protected area.

The primary economic activity of the local communities is agriculture. Livestock farming is extensive and for cattle a free-ranging system is employed, these animals being rarely used for working the land associated with for crop planting. In the southern portion of the protected area, specifically on the slopes and surrounding watersheds of Andavakoera, artisanal gold mining is practiced by local populations both within legally titled mining areas and in unauthorized zones within the conservation zone. Before the establishment of the protected area in 2015, logging was a primary activity for some local community members, as well as regional companies, and this explains the current state of the forests, particularly moist semi-deciduous formations (Table 1) and the spatial and functional structure of the protected area. This activity continues illicitly despite control and monitoring efforts by the management authority and its stakeholders. This formation in the protected area was mistakenly referred to as moist evergreen forest in an analysis of forest loss at the site (Goodman *et al*., 2018a).

Previous research and conservation activities in the protected area

As mentioned earlier, little has been published on the flora and fauna of the Andrafiamena-Andavakoera protected area, with the exception of a number of studies concerning lemurs (Rafalimanana, 2025, herein). A monograph was edited by Goodman and Wilmé (2003) that presents work on different floristic and faunal studies, mostly associated with biological inventories in the Loky-Manambato area and less detailed information from Analamerana and Andavakoera. A study was conducted on the vegetation types of the protected area based on remote sensing data and on site fieldwork (Burivalova, 2021), including areas we surveyed in 2023 at Anjakely and Antsahabe. A number of documents have been produced associated with the creation, monitoring, and conservation of the Andrafiamena-Andavakoera protected area (Fanamby, 2014a, 2014b, 2015, 2023; Klein & Mullard, 2023), and the Fanamby pdfs can be downloaded from the protectedareas.mg website, under the document field, and associated with the Andrafiamena-Andavakoera protected area (Site 7).

Reconnaissance trip, sites chosen for the inventory, logistics, and participants

On 5 November 2023, Steve Goodman left Antananarivo by plane for Antsiranana. That afternoon was spent in Antsiranana with colleagues from Fanamby and the Université d'Antsiranana interviewing students to be chosen to take part in field studies associated with the biological survey. It was decided that the inventory would be at three sites within the Andrafiamena-Andavakoera protected

area, covering different areas and vegetation formations, with at least one site in the remaining moist evergreen forest.

The following morning Rio Heriniaina and Parfait Raherinandrasana, representing Association Fanamby, Steve Goodman, and a driver with a 4 x 4 vehicle left Antsiranana along Route National no. 6 (RN 6) for Anivorano Avaratra and then south on a secondary road to the village of Ambery, at the northern limit of the Andrafiamena-Andavakoera protected area (Figure 5). The road south of Anivorano Avaratra after the Lac Sacré is in poor condition, with numerous large rocks and ruts, and the crossing of the Irodo River just before the village of Ambery would be difficult during the rainy season. The road from Anivorano Avaratra to Ambery, about 10 km straight-line distance and via the road probably closer to 20 km, took about five hours to negotiate with a 4 x 4 vehicle. After a brief meeting in Ambery with village elders, including members of Komity Miaro ny Tontolo Iainana (KMT or Committee for the Protection of the Environment), we left with a local guide for Andavapanihy Cave, about 1.5 hours on foot from the village. The extensive Ambery Forest in this portion of the protected area is several more hours walking from the cave. Associated with possible complicated logistics to get in and out of the village of Ambery during the rainy season, which would probably coincide with the period of the inventory, it was decided that the Ambery Forest was not a good choice for one of the three sites to be inventoried. After the cave visit we returned to Ambery for the night.

On 7 November 2023, we left Ambery, returning towards Anivorano Avaratra along the same secondary road used the previous day, and then towards the southwest along RN 6 to the village of Marotaolana, where we turned off in a southerly direction along the road that leads to the village of Anjakely – the complete trajectory about 4 to 5 hour drive. In general, the road was in relatively good shape and forms the access route to the Akiba Lodge (formerly called Black Lemur Camp Hotel) in the Anjakely Forest managed by Association Fanamby and the partner organization Sahanala. Time was spent during the day looking for a camping place

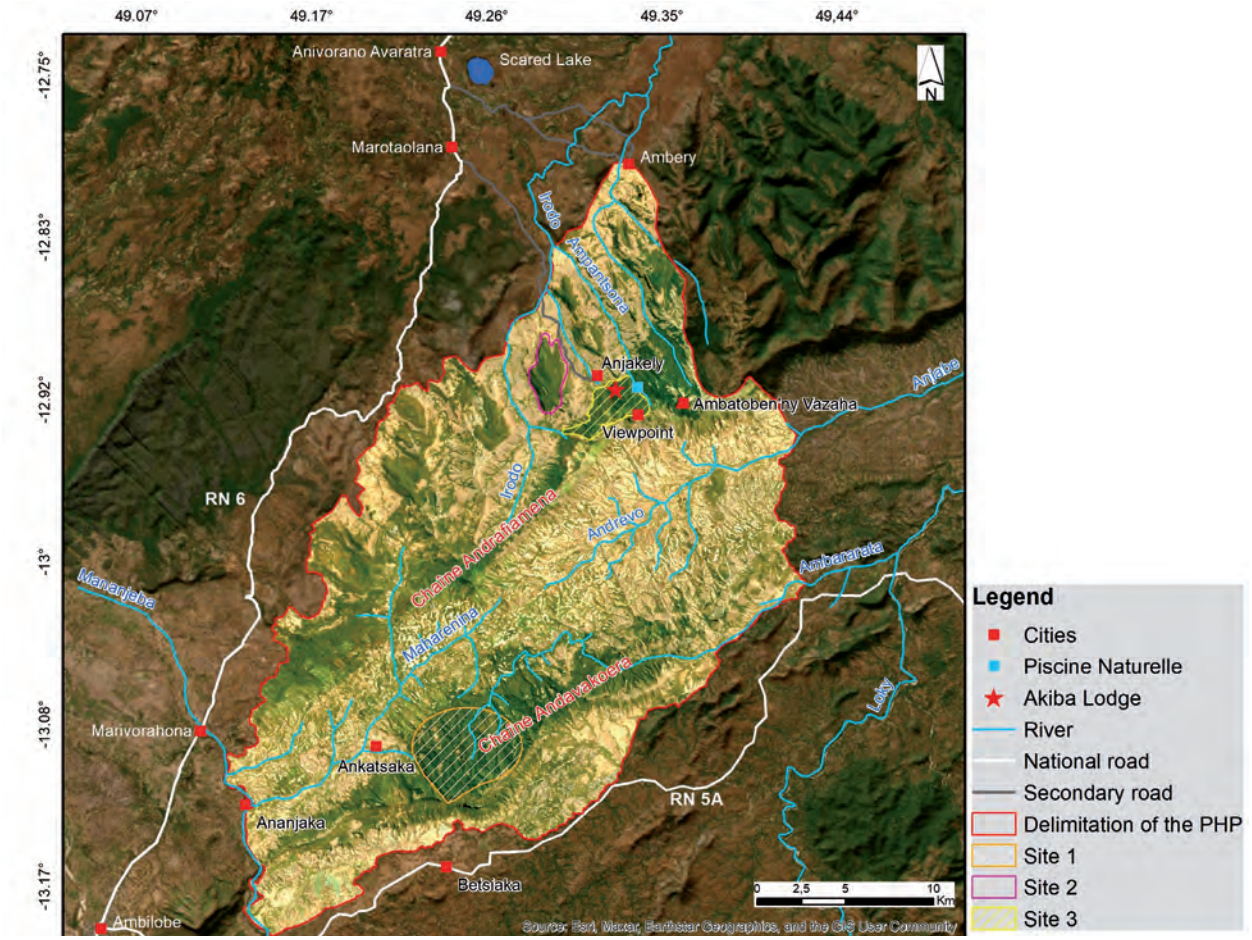

Figure 5. Map of the Andrafiamena-Andavakoera protected area, the three study sites and local features, and localities mentioned in the text.

in the Anjakely Forest near a water source and sufficiently large to accommodate the field team, as well as exploration of the local trail system. Given that precipitation in this area is highly seasonal and rains had yet to commence, the needed camping locality with running water was not found. The trail system in the Anjakely Forest is extensive, providing access to a range of different areas. Night in Anjakely.

Early the morning of 8 November we drove to the nearby Antsahabe Massif, which is called Antserasera on the Foiben Taosarintanin'i Madagasikara (FTM) maps, largely composed of dry deciduous forest on limestone to evaluate the quality of the forest, the trail system, and the possibility of a local camping site with a water source. The site included a different and interesting ecosystem to be included in the survey, but the main problems were the trail system needed to be reopened, which was easy to resolve with the help of local people, and no accessible water source sufficient for the camp needs. With the lack of potable water sources in the Anjakely and Antsahabe Forests, it was decided to camp next to the Fanamby office, a short distance from the village of Anjakely, which has running water and bathroom facilities. This locality provided walking access to the Anjakely Forest and a relatively short drive to the Antsahabe Forest.

On that same day, we continued back to the RN 6 and at Marotaolana headed to the south on the road to Ambilobe and just south of the village of Marivorahona took a secondary road to the village of Ananjaka. The president of the local KMT committee was waiting for us and soon thereafter we headed via tertiary roads to the north of the Andavakoera Massif and arrived at the village of Ankatsaka, passing across the Mananjeby River, the water level of which was relatively low. The afternoon was spent discussing with residents of Ankatsaka and local members of the KMT about potential camping sites in relatively intact forest near a water source. Night spent at Ankatsaka.

Early morning on 9 November, we left with local people and KMT members to climb up to the plateau to the east of the village and then drop down into the Ambaratra River basin. An ideal locality was found for the camp and inventory site next to a tributary of the Ambaratra River and in an area referred to as Binara-Andavakoera, which we refer to herein as the Binara Forest (Site 1). Travel time on foot from Ankatsaka to the camp site (Site 1) was about 3 hours. Returned the same day to Ankatsaka and then to Antsiranana by late afternoon.

The field team left Antananarivo on 14 November in two vehicles carrying the research materials and canned provisions for Sites 1 to 3. They spent the night in Port-Bergé (Boriziny). On 15 November, Steve Goodman with the three students from the Université d'Antsiranana drove with a third vehicle from Antsiranana to Ambilobe, where they purchased certain provisions. The two vehicles from Antananarivo arrived that evening, and the team was joined by two botanists of CJBG. Early on 16 November the baggage was rearranged and all three vehicles left for Ankatsaka. As some heavy rain fell the previous days, the route we used during the reconnaissance was impassable as the Mananjeby River valley was too flooded for a four-wheel drive vehicle to pass. The alternative route, passing to the north of this river and of Marivorahona along RN 6 was used; given the state of the track and often muddy conditions this added several hours to get to Ankatsaka. A total of 56 porters were waiting for us in Ankatsaka (Figure 6). Some materials were stored in the two vehicles that remained in the village along with a driver, including provisions for Sites 2 and 3, as well as supplies for the Binara Forest (Site 1); the latter material was carried to the camp site over the next following days. The bush camp was established during the afternoon and installation of transects the following morning (Figure 7).

On 24 November, after folding up research materials the previous day, we returned to Ankatsaka with about 40 porters (Figure 8) and left the area with the two vehicles parked in the village and one other that arrived from Antsiranana. We then returned to the RN 6 and carried on to Marotaolana and then on to Anjakely. Camp was established around the Fanamby office. On 25 November we started work in the Antsahabe Forest (Site 2) and transferred to the Anjakely Forest (Site 3) on 2 December. All the research materials were folded up on 8 December and on 9 December the research and student group returned to Antsiranana. In the afternoon a debriefing on the mission was held at the Fanamby office in Antsiranana, which was attended by employees of that organization, and colleagues from KOBABY, Direction Régionale de l'Environnement et du Développement Durable (DREED) DIANA, and Université d'Antsiranana. After the meeting, two of the vehicles started for Antananarivo, arriving on 11 December.

During the 2023 mission, the team was principally composed of Malagasy researchers and students. The scientific field group included 17 individuals

Figure 6. The people of Ankatsaka and nearby villages were engaged as porters to get food supplies and different field materials to the Binara Forest and back to Ankatsaka. Here is shown the preparation of baggage for the departure, which included a wide range of items, such as natural gas canisters to dry plants in the field. (Photograph by Carlos G. Boluda.)

Figure 7. The Binara Forest camp was just above a tributary of the Ambaratra River and was a bush-style with the kitchen and eating area without any constructed tables or other structures. The person standing in the center with the red tank top shirt is Rachel Razafindravao, known as Ledada, who was responsible for supervising food preparation and has worked in this capacity with Association Vahatra and the precursor organization, the Ecology Training Program of WWF-Madagascar, since the early 1990s. (Photograph by Carlos G. Boluda.)

Figure 8. The early morning assembly of porters on 25 November 2023 at the edge of the Binara Forest camp to carry materials back down to Ankatsaka, where three vehicles were waiting to take the team and materials to Anjakely. (Photograph by Carlos G. Boluda.)

(organized alphabetically by family name): Clemson Anthoni (bats), Carlos G. Boluda (plants), Laurent Gautier (plants), Steven M. Goodman (birds, bats, and small mammals), Fandresena Rhynia Hanitriniana (primates), Arianna Kuhn (amphibians and reptiles) mostly for Site 3 and some work at Site 2, Tojonirina Patrick Rafalimanana (primates), Marie Jeanne Raherilalao (birds), Fandresena Rakotoarimalala (amphibians and reptiles), Andry Rakotomanga (driver that remained with the group during the complete mission), Achille P. Raselimanana (amphibians and reptiles), Alain Patrick Rasolonjatovo (plants), Loïta Vatsy Razafindranosy (bats) for Sites 2 and 3, Rachel Razafindravao or "Ledada" (logistics and camp cook), Sara Ruane (amphibians and reptiles) mostly for Site 3 and some work at Site 2, Voahangy Soarimalala (small mammals), and Andonahary Jacquis Tahinarivony (plants). At Binara (Site 1), seven individuals from local communities were engaged on a full time basis as research assistants and helping with food preparation, and for Antsahabe (Site 2) and Anjakely (Site 3), five individuals based in Anjakely or other communities were hired for similar work. Rachel Razafindravao was responsible for overseeing the preparation of food (Figure 7).

Summary of site localities during inventory

Below is a listing of the three sites we surveyed in the latter portion of 2023. Coordinates are based on Global Positioning Systems using the WGS 84 datum point.

Binara (Site 1), 16 to 24 November 2023

Madagascar: ex-Province d'Antsiranana, Région DIANA, District Ambilobe, Paysage Harmonieux Protégé d'Andrafiamena-Andavakoera, Forêt de Binara-Andavakoera, 5.4 km E. Ankatsaka (village), next to Ambaratra River, 13.101°S, 49.240°E, 300 m. The camp (at 13.100482°S, 49.240146°E) was the central portion of the inventory zone that spanned an elevational range of about 300 to 450 m.

Antsahabe (Site 2), 25 November to 1 December 2023

Madagascar: ex-Province d'Antsiranana, Région DIANA, District Antsiranana II, Paysage Harmonieux Protégé d'Andrafiamena-Andavakoera, Forêt d'Antsahabe, 2.8 km NW Anjakely (village), 12.894°S, 49.294°E, 360 m. These coordinates are taken from the central portion of the survey zone on the Antsahabe Plateau that spanned an elevational range of approximately 300 to 500 m.

Anjakely (Site 3), 2 to 8 December 2023

Madagascar: ex-Province d'Antsiranana, Région DIANA, District Antsiranana II, Paysage Harmonieux Protégé d'Andrafiamena-Andavakoera, Forêt d'Anjakely, 1.3 km SE Anjakely (village), 12.913°S, 49.328°E, 420 m. These coordinates are taken from the central portion of the survey zone on the trail leading up to the Cascade Naturelle that spanned an elevational range of approximately 350 to 700 m.

Descriptions of the three inventoried zones

Throughout this monograph, we adopt the system of Gautier *et al*. (2018) for the names of vegetation formations on Madagascar and specific details on Andrafiamena-Andavakoera are from Ranirison and Andriamiarantsoa (2018). When appropriate, we also mention other vegetation terms used in the literature for the different formations. For further details on the vegetation structure of the three surveyed sites see Tahinarivony and Gautier (2025, herein)

Binara Forest (Site 1)

We installed the camp at the edge of a tributary of the Ambaratra River, which had running water during the inventory (Figure 9). This river feeds into the Loky River which has several tributaries from the basin north of the Andavakoera Massif (Figure 5). The camp was at about 300 m elevation, which marked for the most part the lower end of the surveyed zone, which rose up to 450 m, including the ridge separating our study area and the descent to Ankatsaka.

Vegetation types: Moist semi-deciduous forest, largely degraded or secondary. Some gallery forest formations along the tributaries of the Ambaratra River. The previous mention of moist evergreen forest in the protected area (Goodman *et al*., 2018a) is incorrect and these formations are best referred to moist semi-deciduous forest.

Topography: Mostly composed of hills intersected by a few permanent and temporary streams, with the steepest slopes exceeding 40%. The hill crests are fairly extensive and generally covered with low vegetation.

Soil depth: Composed of weakly developed lithosols and in some areas, specifically along the Ambaratra River and nearby hills, with exposed sandstone formations. The topsoil is thin and highly susceptible to even minor erosion processes.

Forest degradation: On the western side of the ridge climbing up from Ankatsaka, the vegetation is heavily degraded and considerable soil erosion is evident (Figure 10). Once passing over to the eastern side of the ridge, the forest commences, although human utilization of different types of natural resources is evident (Figure 11). The well-preserved forests

Figure 9. A tributary of the Ambaratra River and a few meters below the Site 1 camp in the Binara Forest, had running water during the inventory. A number of bats were captured in nets spanning the water pools. (Photo by Jacquis Tahinarivony.)

Figure 10. While climbing up from Ankatsaka and on the western side of the Binara Forest plateau, the vegetation is heavily degraded and showing signs of considerable erosion. (Photo by Jacquis Tahinarivony.)

Figure 11. On the trail from Ankatsaka to the Binara Forest, after passing over east side of the principal ridge and entering the moist semi-deciduous forests, evidence of human use of forest resources was evident. Here is shown the section in close proximity to the ridge and with clear signs of different types of extraction. Cattle are also grazed here, feeding on a range of understory forest vegetation. (Photo by Patrick Rafalimanana.)

Figure 12. Photos of the relatively intact portions of the Binara Forest with the image to the left showing general forest structure (Photo by Laurent Gautier) and to the right with a notably closed canopy. (Photo by Jacquis Tahinarivony.)

Figure 13. Clear evidence was found of recurrent fires in different areas of the Binara Forest. Here is shown charred standing trees indicating the former presence of a forest formation. (Photo by Jacquis Tahinarivony.)

are found in areas least affected by slash-and-burn or itinerant agriculture, fire, and logging, and located a considerable distance east of the village of Ankatsaka (Figure 12). These forests occupy valleys and slopes with shallow soil and gradients that can exceed 30%. Secondary forests appear in several stages of regeneration, with the sandstone hills predominantly covered by a few species of

the family Sarcolaenaceae, including pioneering taxa (e.g., *Leptolaena cuspidata* and *Xyloolaena richardii*) and showing remnant scars of the habitat perturbation (e.g., burned areas, leached soils, and secondary vegetation). The most impacted areas by degradation are bare or covered by discontinuous grass formations (Figure 13).

Antsahabe Forest (Site 2)

As previously mentioned, the group did not physically camp at this site, but next to the Fanamby office, to the south of Anjakely (village), and went back and forth several times per day and at night mostly by vehicle. The surveyed zone, largely towards the upper plateau section of the Antsahabe Forest (labelled as Antserasera on the FTM maps), was an isolated outcrop of karstic limestone accessed by trails that commenced at the foot of the massif. The elevational swath of this site was mostly between 300 and 500 m. One aspect of this limestone formation, at the foot of the massif, was Antsahabe Cave, with bat day roosts (Goodman *et al*., 2025, herein).

Vegetation types: Dry deciduous forest mostly composed of dry deciduous vegetation on limestone with some eroded pinnacles (*tsingy* in Malagasy). The vegetation occurring on the plateau is adapted to the xerophytic conditions, including notably dry, with direct sunlight, desiccating high seasonal winds (*varatraza* in Malagasy), and bare rock or shallow soils that retain little moisture near surface (Figure 14). Along the slopes of the massif there was notable vertical stratification (Figure 15). The area at the foot of the massif was mostly secondary grasslands (Figure 16). The Antsahabe Forest is in close proximity to the Mahory Forest of the northeastern corner of Ankarana, which is also a *tsingy* formation.

Topography: A limestone massif rising out of the Andrafiamena watershed. The outcrop is generally uniform height and forming a distinct plateau structure and about 90% of the upper surface with exposed rock. The upper portion of the outcrop is at approximately 500 m.

Soil depth: On the upper section of the plateau, which has significant areas with exposed limestone, thin soils were restricted to nooks and crannies in the

Figure 14. The vegetation in the Antsahabe Forest is one adapted to xerophytic conditions, specifically strong seasonally winds (known as *varatraza* in Malagasy), UV radiation from direct sunlight, and shallow soils that do not retain moisture. Some cutting of trees is evident in the photo, as are exposed limestone outcrops. (Photo by Jacquis Tahinarivony.)

Figure 15. In and around the Antsahabe Massif there are distinct vertical changes in vegetation structure, plant physiognomy, and floristics starting at the base of the massif to the plateau. These vertical shifts are often in stages associated with topography and soil depth, with decreases in tree stature. Shown here is a slope with considerable exposed limestone. (Photo by Voahangy Soarimalala.)

Figure 16. Site 2 during the biological survey of Andrafiamena-Andavakoera was the Antsahabe Forest to the north of Anjakely (village). This forest block occurs on a limestone plateau surrounded by mostly secondary grasslands. The area in the center of the image with some exposed rocks and lacking vegetation was one of the trail access points to the plateau. (Photo by Voahangy Soarimalala.)

Figure 17. The flanks and upper portion of the Antsahabe Forest are often dominated by exposed limestone with notably shallow soils. Here is shown a portion of the transect trail on the plateau with considerable surface rock and open vegetation dominated by *Commiphora ankaranensis* (Burseraceae) and *Stereospermum longiflorum* (Bignoniaceae). (Photo by Voahangy Soarimalala.)

rock formations, mostly associated with deposited alluvium (Figure 17).

Forest degradation: The northern part of Antsahabe experienced a fire several years ago, resulting in the establishment of a low and sparse secondary woody formation. The tallest and densest forest is located in the southern part, although it is also disturbed due to selective logging and the collection of construction timber. This block is traversed by several footpaths, indicating the influence of anthropogenic activities in the area, particularly since it is designated as a sustainable use zone (Zone d'Utilisation Durable) for the local communities.

Anjakely Forest (Site 3)

As previously mentioned, the camp to access this site was not in or next to the forest, but a relatively short walking distance and adjacent to the Fanamby office south of Anjakely village. At least for vertebrates, the surveyed area was in the portion of the forest above the Akiba Lodge, and more specifically, started from the bifurcation of the trail leading towards the village of Ampantsona, entering into the protected area, and leading up to the Piscine Naturelle (Figure 18). In general, the field team worked in an elevational zone from about 350 to 500 m, and some botanical work was done up to 700 m.

Vegetation types: Largely secondary moist semi-deciduous forest with some well-preserved portions, particularly in the valley associated with the Ampantsona River (Figure 19), a formation over the past decades that has been drastically reduced in extant associated with human interventions. The Anjakely Forest is exceptional due to the presence of a mixture of extensive areas of moist semi-deciduous forest, which can exceed 18 m in height. The previous reference to moist evergreen forest in the protected area (Goodman *et al*., 2018a) is incorrect and these formations are best referred to moist semi-deciduous forest.

Topography: An uneven landscape characterized by series of hills and narrow valleys. The forest slopes have gradients ranging from 10% to 40%. Edaphic variation within the forest are present and influenced by topography, slope, and substrate. The upper portion of the mountain range include summit points, such as the Viewpoint and Ambatoben'ny Vazaha (Figure 5), and provide broad perspectives of the southern limit of the Andrafiamena Mountain chain.

Soil depth: Composed of a complex of lithosols and poorly developed soils. The substrate is shallow and relatively low in organic matter. In certain areas, such as Ambatoben'ny Vazaha, sandstone outcrops are dominant. The soils in the Ampantsona River valley

Figure 18. At the upper portion of the surveyed section of the Anjakely Forest, at around 420 m, is the Piscine Naturelle, which is a natural basin filled with flowing water of a small stream forming the headwaters of the Ampantsona River. (Photo by Voahangy Soarimalala.)

Figure 19. The Anjakely Forest is exceptional due to the presence of remnant areas of moist semi-deciduous forest, which can exceed 18 m in height, and a vegetation formation that has been drastically reduced in the past decades associated with human actions. Here is shown a photo taken in 2010 of this forest type and with the regional endemic lemur species Perrier's Sifaka (*Propithecus perrieri*) pose in a tree in the center. (Photo by Laurent Gautier.)

Figure 20. The largest block of the Anjakely Forest has a distinctly heterogeneous edge, with relatively intact forest remaining on the upper slopes, different signs of human exploitation, erosion associated with rain runoff after soils are exposed, and the passage of fire. The image presented here was taken along the northern slopes below the forest, in which these different features are visible. (Photograph by Voahangy Soarimalala.)

Figure 21. Portions of the Anjakely Forest are in the process of regeneration. Here is shown a section of the block inventoried during the late 2023 inventory with numerous young trees of largely the same size. (Photo by Patrick Rafalimanana.)

are more developed and rich, although in some places the bedrock approached the surface.

Forest degradation: Prior to the establishment of the protected area, this forest block was subjected to logging activities, shifting agriculture, and fire – traces of these disturbances cover notable portions of the landscape (Figure 20). Secondary forests or forest regrowth (Figure 21) occupy a large portion of the landscape, interspersed with bamboo formations and fallow lands.

Proposed conservation actions

On the basis of our work in the Andrafiamena-Andavakoera protected area and discussions with local people and members of Komity Miaro ny Tontolo iainana (KMT or Committee for the Protection of the Environment), the following suggestions can be made with regards to different actions that need to be taken to safeguard the future of the remaining natural forest habitat of the site and problems of invasive species.

Impact of fire

One of the important aspects associated with the decline of forest cover within the Andavakoera-Andrafiamena protected area is the impact of nearly annual grassland fires that spread across the landscape and enter into natural forest formations causing often important damage. The origins of these fires are multiple, and include burning of grass formations to stimulate green growth for cattle pasture, a certain level of pyromania among local people, and acts of anarchy against governmental and non-governmental programs. Addressing the reasons fires are set are beyond what we want to communicate here, but rather we propose a solution to limit the spread of these blazes into natural forest formations.

One tool that has worked well at several conservation sites on Madagascar to keep widespread grassland fires from spreading into forest zones is the use of firebreaks. At certain sites, such as Ambohitantely in the Central Highlands, which is both ecologically and social economically different from Andrafiamena-Andavakoera, the technique employed is to remove vegetation, mostly grass and different secondary plants, and exposed the ground in two concentric bands, each 4 to 5 m, and separated from one another by an area of 15-20 m (Goodman *et al*., 2018a, p. 1341). Each year before the fire season, normally at the end of the dry season (September to early November), the area between the two bands is subject to a control burning, which creates a fire break 25-30 m wide. At Ambohitantely, even given strong seasonal winds, this non-vegetative swath has been enough to impede fires from entering the forest. Further, at this site, the installation of firebreaks as described above, now close to 55 km in length, are put in place and maintained exclusively by local people, all with hand tools and no machinery. While the amount of work is considerable, the part-time workers are paid a daily wage and the associated economic advances has had a very positive impact on the local economy, a sense of community participation in the project, protecting the forest and associated watershed critical for agricultural production, and adding different incentives on the advantages of conservation. This proposed technique to control fires in Andrafiamena-Andavakoera, as compared to Ambohitantely, has some aspects that need close consideration. At Ambohitantely, people do not live near the forest and the fires spread considerable distances across the landscape, as compared to Andrafiamena-Andavakoera, where people live in close proximity and fires start at a local level. Also the difference between moist evergreen and moist semi-deciduous forest types give rise to different levels of flammability.

Now turning back to Andrafiamena-Andavakoera, the problems of fire entering into the forest on a nearly annual basis and reducing already limited forest cover, needs to be resolved. We suggest that the installation of large firebreaks, for example around the Anjakely Forest block, should be considered. This will help aspects associated with forest conservation, which is critical, but also the engagement of local community members in the installation of the firebreaks and the associated economic incentives, could be positive to advance the long-term conservation of this forest. However, this proposed technique would not protect against fires that are started within the forest, which in certain circumstances is the case, and which would require different styles of management on the part of the protected area manager and public educational programs.

The issue of grassland fires also needs to be considered in terms of seasonality. Taking into account that grasslands represent a highly flammable 1.5-2.0 m thick layer that is prone to burn annually, risk of fire entering a forest through wind-blown embers is strongly correlated with two aspects: 1) flammability of the forest, that is to say the amount of time since onset of the dry season and 2) wind

strength and air humidity and temperature, both correlated with the period since sunrise. Through coordination between people living in nearby villages, it is possible to decide on a date for proactive burning of large areas of grasslands, and controlling for the variables as early as possible in the dry season and one hour before sunrise. In conjunction with the firebreak strategy presented above, these techniques can give excellent results to control the spread of fire into the remaining forest.

Another aspect to be considered is the use of helicopters owned and run by regional touristic operators that have the capacity to carry considerable quantities of water to help put out fires in regional protected areas, such as Andrafiamena-Andavakoera. As many of the visitors arriving at the site by helicopter are notably high-end tourists, an exhibit in French and English could be installed around the Fanamby office on problems of fire in the protected area and these individuals providing donations to help subsidize the costs of helicopter usage for fire control. A clear arrangement could be made between the protected area manager and regional tourist operators to guarantee the transparency and proper usage of these funds. In any case, the long-term sustainability of the use of helicopters certainly depends on the maintenance and conservation of local unique forests and associated biodiversity, and continued visits by ecotourists of a certain economic scale.

Invasive species - botanical aspects

Acacia mangium or Black Wattle tree (Fabaceae) – this introduced tree, which is highly invasive under certain circumstances and capable of quickly colonizing a range of habitats (Richardson *et al*., 2015), has been planted in different portions of the Andrafiamena-Andavakoera protected area, including around Anjakely. Although this tree has several benefits, which include increase soil nitrogen and fertility and higher rates of carbon sequestration as compared to non-forested area, it has negative impacts on the local natural environment and human livelihoods (Koutika & Richardson, 2019). While some efforts around Anjakely via tree cutting have been advanced to reduce the population of this tree, large downed trunks can be found around the village and local people do not exploit this resource mostly because the wood is rather soft and not of interest for cooking wood or to produce charcoal. A further problem with simply cutting standing trees is that new shots sprout from the remaining trunk. Between the Anjakely village and the entrance of the protected area, a large number of standing trees of this species remain and seeds can be found scattered on the ground; the seeds can be dispersed by wind. During our late 2023 inventory, young sprouting *A*. *mangium* trees were found in the protected area around the Akiba Lodge and the seeds appear to be locally dispersed.

In more specific terms, we suggest that a large-scale effort be put in place to remove remaining individuals of this species from within the core forest area, particularly around Anjakely, and in a radius of 4 km of the protected area. This needs to be done in a systematic manner and with at least an annual procedure at the end of the rainy season and cutting any propagation of young shoots. Further, a thick layer of black paint needs to be applied to the exposed tree stump. It is encouraged to find some use of this wood (cut and standing) by local people, to allow them to exploit this resource for firewood, fencing posts, construction wood, etc. Further, teams need to be established to collect the seed pods found on the ground in the zone of intervention and for these to be destroyed. Such actions will certainly limit the spread of this tree into the protected area.

In accordance with the IUCN guidelines on protected areas, the application of measures to eradicate and control invasive plants is recommended and specifically with the view to preserve the integrity of ecosystems and to protect biodiversity. The ecology of *A*. *mangium* and its considerable capacity to disperse and increase its local density in the Andrafiamena-Andavakoera protected area, particularly around Anjakely and approaching the limit of the natural forest, warrants a program to be followed by the protected area manager to manage this problematic species. We strongly recommend the eradication of all *A*. *mangium* plants inventoried within the critical core areas and following all possible measures to combat its introduction (voluntary or not) and propagation in the conservation and ecological restoration zones. In addition, to provide wood products to local people and in relation to reforestation or reforestation activities, some species are proposed in place of *A*. *mangium*, which are of the native type, adapted to local conditions and grow quite quickly: *Antidesma madagascariense* (Phyllantaceae), *Breonia capuronii* (Rubiaceae), *Celtis madagascariensis* (Cannabaceae), *Delonix boiviniana* (Fabaceae), *Ehretia cymosa* (Ehretiaceae), and *Terminalia* spp. (Combretaceae).

Invasive species - zoological aspects

Acridotheres tristis Indian Myna (Sturnidae) – this notably aggressive introduced bird species, which generally lives in areas outside of natural forest habitat or at the ecotone, poses certain problems for the endemic bird fauna. Probably the most important is that it makes its nest in tree holes or crevices, which are also used by a number of endemic bird species, and usurps these nesting spaces from the native local fauna, impeding reproduction success and on the long term reducing population numbers for species such as *Upupa marginata* Madagascar Hoopoe (Upupidae) or *Otus rutilus* Madagascar Scops Owl (Strigidae). Further, in other areas of the world it has been introduced, *A. tristis* is known to feed on eggs, chicks, and sometimes adults of smaller birds and native vertebrates (Grarock *et al*., 2012), and on Madagascar it predates on chameleons, other lizards, and frogs (Randriamiharisoa, 2020). This introduced species poses important problems for local endemics, particularly on islands (Feare *et al*., 2022). Complete eradication of this species in the protected area would be virtually impossible, but a program to reduce its local numbers through different eradication techniques would be useful.

Rattus rattus or Black Rat (Muridae) – This introduced rodent was captured at our three sites in the protected areas and in relatively low numbers (Goodman & Soarimalala, 2025, herein). Populations of this species presumably go through considerable annual or seasonal cycles (Scobie *et al*., 2023), and the timing of our visit may have coincided with the period of low numbers after the long dry season and before the rainy season. Hence, based on current data, we have no indication of high populations of this rodent in forest settings within the protected area. In any case, the manager of the Akiba Lodge near Anjakely mentioned that there is a serious problem of small mammals occupying different bungalows, damaging infrastructure, and creating problems for tourists. On the basis of his description, these animals are most likely *Rattus*, although it is possible that some individuals might include endemic *Microcebus* (mouse lemurs) or endemic rodents of the genus *Eliurus* (tufted-tail rodents) that conceivably live in the attic spaces of structures close to the forest edge.

While it is not possible to completely eradicate *Rattus* from Andrafiamena-Andavakoera, as the surface area is too large and there is certainly dispersal of these animals from outside to inside the protected area, a regular trapping system needs to be put in place to reduce numbers of *Rattus* within and around the hotel complex. This should be done by an individual trained to capture small mammals with live traps and capable of differentiating endemics, which would be released, from introduced small mammals, which would be dispatched away from the hotel complex and buried.

Invasive species - general conclusion

Given problems associated with different invasive plant and animal species in the Andrafiamena-Andavakoera area, for which the above mentioned species are by no means a complete list, and the impacts these taxa pose on the local natural ecosystems, as well as specifically on the plant and animal communities, we suggest that there be an invasive species officer on the local Fanamby staff. This person would undergo training with floral and faunal specialists and have the needed skills to intervene at the site to control different problems with invasive introduced species. Further, an annual budget would need to be established to cover the associated expenses of local staff costs and the needed material.

Future monitoring

Based on the results of biological investigations and a comprehensive analysis of available data on the local fauna and flora, including vegetation, several criteria can be proposed to identify target conservation species occurring the Andrafiamena-Andavakoera protected area. These criteria include:

- Conservation statute based on the IUCN Red List (Critically Endangered or Endangered species);
- Level and intensity of threats based on IUCN Red List status for species and their associated habitats;
- Endemic status, recognizing species as microendemics (local endemics) or regional endemics;
- Ecological characteristics of species, particularly those that are known or suspected indicators of ecosystem health and biodiversity maintenance;
- Potential for promoting ecotourism, thereby enhancing conservation efforts and supporting local economic development.

Below we present a list of proposed species to be included in monitoring programs within the protected area. The techniques to examine population numbers and threats to these species can be notably different and it is suggested that the protected area

manager consults with a range of specialists, at least at the start of these programs, to establish the needed protocols.

Plants

In light of the above mentioned criteria, two plant species can be proposed for conservation monitoring: *Capurodendron andrafiamenae* and *Donella ranirisonii* (both Sapotaceae) (Figure 22). Both species are endemic to the protected area and were recently assessed as Critically Endangered following IUCN criteria. Local community members utilize these hardwood species for different construction purposes and to manufacture tools, such as knife and shovel handles. Their growth is slow, with the majority of inventoried individuals having sprouted from cut stumps. The fruits produced by these two species are widely consumed by lemurs and large frugivorous birds. We suggest that these two tree species should be the subject of sprouting seeds and growing young plants in the Fanamby tree nursery at Anjakely and integration into any ongoing or planned ecological restoration project.

Animals

Herpetofauna – On the basis of the above criteria and a few other aspects, we suggest the following herpetofauna species be monitored for fluctuations in population numbers: frogs of the family Mantellidae that include *Gephyromantis* « *atsingy* » (Endangered) and *Mantella viridis* (Endangered) both are regional endemics; reptiles of the family Gekkonidae that include *Phelsuma roesleri* (Endangered) and *Uroplatus garamaso* (a recently described species endemic to northern Madagascar and not yet evaluated for its IUCN Red List statute), and the family Lamprophiidae, specifically two regional endemics *Phisalixella variabilis* (Endangered) and *Lycodryas inopinae* (Endangered). Further details on these taxa, as well as some others occurring in the Andrafiamena-Andavakoera protected area and suggestions for local amphibian and reptile species that should be considered for conservation monitoring can be found in Rakotoarimalala *et al*. (2025, herein).

Avifauna – For birds, there is no local endemic species (Raherilalao & Goodman, 2025, herein), although one species known from the site, *Mesitornis variegata* (Vulnerable) of the family Mesitornithidae, is seemingly rare, probably under some regional hunting pressure, and would be an ideal species to monitor based on vocalization, largely during the breeding season.

Mammals – In the case of small terrestrial mammals, at this time no microendemic species is known to occur in the protected area and regional endemics, most notably *Eliurus carletoni* (Nesomyinae), have broad distributions in the northern portion of the island (Goodman & Soarimalala, 2025, herein). For bats, two suggestions can be made for population monitoring – *Pteropus rufus* (Pteropodidae), although it is listed as Vulnerable, it is a species with considerable regional hunting pressure and the local populations should be monitored by counting the number of animals at day tree roost counts. A second bat, *Paratriaenops auritus* (Rhinonycteridae), also listed as Vulnerable, is a northern endemic, and counts can be made at diurnal cave roosts, for example, at Antsahabe Cave (Goodman *et al*., 2025).

Figure 22. Two different local microendemic species are proposed to be the subject of conservation monitoring: to the left *Capurodendron andrafiamenae* (Photo by Jacquis Tahinarivony) and to the right *Donella ranirisonii*. (Photo by Carlos G. Boluda.)

For lemurs, of which seven of the nine locally occurring species are listed as Endangered or Critically Endangered (Rafalimanana, 2025, herein), the following recommendations can be made. It is critical to continue to follow aspects of the natural history and population dynamics of *Propithecus perrieri* (Critically Endangered), family Indriidae, which is a regional endemic and of considerable interest for ecotourists visiting the site. This species has been the subject of considerable research over the past decades and this needs to be continued. For the four nocturnal species: *Cheirogaleus sheathi* (family Cheirogaleidae), *Lepilemur ankaranensis* and *L. milanoii* (family Lepilemuridae), and *Daubentonia madagascariensis* (family Daubentoniidae) and two diurnal species: *Eulemur coronatus* and *E. sanfordi* (Lemuridae) occurring at the site and listed as Endangered, further work needs to be advanced with regards to the aspects of human pressures responsible for aspects associated with population dynamics, as well as aspects of their natural history.

Conclusion

After our review of the literature on the biota of protected areas in the north, as well as conducting biological inventories of the Andrafiamena-Andavakoera protected area, several aspects are important to mention in the context of a general conclusion:

1) With the exception of lemurs, the protected area is poorly known and should be the subject of further surveys, particularly of plants and invertebrates. Such work needs to be conducted in the different habitats and microhabitats of the protected area to better understand the level of biotic heterogeneity with regards to forest types and historical and current human pressures, and to use this information to inform conservation programs at the site.
2) Given the general biogeographic pattern of numerous species shared in common between protected areas of northern Madagascar, including a range of dry deciduous forest types, particularly those protected areas that are adjacent to one another or in close proximity, it is clear that the Andrafiamena-Andavakoera protected area acts as a habitat corridor between nearby sites and these connections need to be maintained for the medium- and long-term future of the flora and fauna of northern Madagascar. A view towards some form of ecological restoration of the intervening areas between protected areas to reconnect or expand the forest connections should be seriously considered in future conservation actions. However, to maximize the effectiveness of this strategy, we strongly suggest the construction of wide fire breaks surrounding zones of intervention to reduce or exclude problems associated with natural habitat destruction of local forest habitat associated with blazes.
3) Some important conservation problems exist in the protected area, including invasive species. We present some suggestion of new measures and actions that can be put in place to ameliorate these aspects and help with future monitoring.

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Appendix 1

Participants in the project

A total of 15 students and researchers were involved in the biological inventory of Andrafiamena-Andavakoera, as well as an additional eight people that collaborated to work up specimen material or write different contributions to this monograph. The addresses of all of these individuals are given below and those names in bold took part in the fieldwork.

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