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Survey of Invasive Lantana camara at Makirovana-Tsihomanaomby Forest Complex

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Abstract

Lantana camara is a shrub known globally as an invasive pest that grows primarily in degraded areas. The species is known to exist at Makirovana-Tsihomanaomby, a forest complex in northeastern Madagascar with 167 endemic species of flora and fauna, several of which are on the IUCN Red List. The complex, specifically Tsihomanaomby forest, is used as a resource for the three rural communes that live on its outskirts, meaning that it experiences much human activity. The objective of this study was to survey the population of *L. camara* at two sites: one just outside of the Tsihomanaomby forest and one 100 km into the forest. The survey was completed with 5 transects at each site, in addition to PCQ and understory analysis of certain *L. camara* individuals in order to asses associations with other plant species. *L. camara* was more abundant at the degraded site than at the site inside the forest, where it was found exclusively on vanilla plantations and along walking paths. Other analyses showed multiple species growing in association with *L. camara.* While further studies are required to investigate the effects of *L. camara* on other species at this complex, a viable plan for the species' current management is to harvest it for economic gain.

Introduction

I. Makirovana-Tsihomanaomby Forest Complex

Madagascar is widely renowned as a biodiversity hotspot due to its high levels of endemism (Ganzhorn *et al.* 2014). However, the dominant narrative surrounding biodiversity in Madagascar is that of the disappearance of this *patrimoine mondiale* due to human activity, primarily deforestation (McConnell & Kull 2014). Missouri Botanical Garden (MBG) is a botanical research and education facility in the United States that has extended its mission to include research and conservation of Madagascar's flora and fauna. Today the Garden has 11 conservation sites protecting diverse habitats all over the island (Fathman 2013).

Located in northeastern Madagascar, 30 kilometers north of the capital of the Sava region, is the Makirovana-Tsihomanaomby forest complex. The complex is made up of two forests: Makirovana, which contains 3 parcels of forest to the southwest, and Tsihomanaomby, which is made up of a single parcel to the northeast. The complex covers a surface area of 7067 hectares and has an altitude varying from 80 to 900 meters. Due to the significant differences in altitude, the complex is home to an array of habitats present in humid low- and mid-altitude forests that are not often found in protected areas on the island. In comparison with other areas in the Sava region, Makirovana-Tsihomanaomby has a high concentration of endemic species, specifically 94 floral and 73 faunal species, including 8 species of primates. Several of these species are locally endemic to northern Madagascar. Many are listed on the IUCN Red List while others are listed as Data Deficient (DD).

Created in 2008, the complex is managed by MBG and three local communities: Anjangoveratra, Anstirabe Nord, and Marogoan. The forest is classified as an IUCN Category VI protected area, meaning that it is a Managed Resource-Protected Area and must have 60% of the area conserved. The protected area, or *Nouvelle Aire Protégée* (NAP), has three sections: the *Noyau Dur, Zone Tampon,* and *Zone Peripherique*. The *Noyau Dur* (1610 ha) covers the center of each forest parcel and is where the strictest conservation is applied and no cultivation is allowed. Outside of this is the *Zone Tampon* (4258 ha) where use of the forest resources, such as cutting wood, hunting certain species, or cultivating crops, is allowed and controlled. The *Zone Peripherique* concerns the buffer zone between protected forest and surrounding rural communes.

The goal of creating the Makirovana-Tsihomanaomby complex was to preserve the ecosystems within for the benefit of the species living there and to ensure the sustainability of the forests as a resource for the surrounding communities. The complex protects the sources of several rivers supplying multiple communities with water and provides land for much of the 95% of the local population practicing agriculture. Unfortunately many income generating activities practiced by local people are counterproductive with the goals of the protected area. For example the majority of people in the surrounding communities practice *tavy*–the clearing and burning of land to prepare it for cultivation–in order to grow rice. Several more lucrative crops such as vanilla are grown at lower, more accessible, elevations within the forests and require land to be cleared for cultivation. In addition, selective cutting of trees for construction wood is a popular activity and indeed the majority of the wood circulating the district comes from Makirovana-Tsihomanaomby. A less widely practiced but still harmful endeavor is the hunting of birds and lemurs to be sold in hotel restaurants.

Many of the activities listed above are legal for those with permits working in the *Zone Tampon,* however the issue is that it is not uncommon for people to use forest resources without a permit. In addition, there are unforeseen consequences to human activities in the forest, primarily due to deforestation. Clearing of land for cultivation and cutting of trees for wood results in fragmentation of the forest. This disrupts the ecosystems within the forest and allows for the introduction of nonnative and invasive species, thus contradicting the goals of the NAP.

While both forests in the complex are affected by these threats, Tsihomanaomby forest is significantly more impacted due to its more accessible elevations and presumably due to its smaller size, making activities deeper in the forest more feasible. (Equipe du Goldman 2008)

II. Invasive Species in Madagascar: *Lantana camara*

Over the years Madagascar has been subject to multiple waves of biological invasion along with each successive wave of human colonization (Binggeli 2003a). Introduced species pose a problem for Madagascar in particular because of the potential for these species to become invasive, as invasive species are one of the main threats to biodiversity across the world (Mooney & Hobbs 2000). Furthermore, introduced species can reach the status of invasive species with the help of human activities such as tavy cultivation that threaten endemic species and create niches for introduced species to fill (Binggeli 2003a).

Lantana camara, or "calabera" as it is referred to in the Sava region, is a prime example of this. The shrub originates in tropical America and spread after being brought to Europe from Brazil in the 1600s and cultivated in glasshouses to be exported as an ornamental plant (Day *et al.* 2003). The species is thought to have spread to Madagascar by way of Mauritius or Réunion in the late 19th century (Binggeli 2003b). Also commonly referred to as "lantana," the shrub can be found in over 60 countries or island groups between the latitudes 35ºN and 35ºS and is known to have around 650 varieties due to its ability to hybridize easily (Day *et al.* 2003).

The species' morphology is extremely variable, however in general it has flowering heads with 20-40 flowers, colors ranging from white to pink to red, and ovate green leaves of 2-10 centimeters in length, arranged in opposite pairs on the stem ("Invasive Pest Fact Sheet: *Lantana camara*"). Height is typically between 2 and 4 and the stem is characterized by curved thorns that are absent from the cultivated ornamental varieties. Flowering usually occurs between August and March but is year-round in tropical climates, peaking in the first two months of the rainy season. Green seeds are produced between September and May that turn black as they ripen and are dispersed by birds and rodents. Seed germination is stimulated by exposure to light and high soil temperatures, and seeds are even known to survive "the hottest of fires" ("Invasive Pest Fact Sheet: *Lantana camara*").

L. camara is often labelled as an invasive species because it rapidly forms dense and impenetrable thickets in disturbed areas (Day *et al.* 2003; Binggeli 2003b). A "disturbed area" can take many forms: agricultural, urban, riparian, beachfront, grassland, and roadside areas are all habitable by this species (Day *et al.* 2003; "Invasive Pest Fact Sheet: *Lantana camara*"). The species' tolerance to fire and affinity for sunlight allow it to become dominant in secondary succession following slash and burn agriculture (Binggeli 2003b). Most importantly, *L. camara* is often found at forest edges and even within natural forests that have been disrupted by logging or forestry plantations (Day *et al.* 2003; "Invasive Pest Fact Sheet: *Lantana camara*"; Binggeli 2003b). There the species is known to become the dominant understory, disrupting forest succession and decreasing biodiversity (Day *et al.* 2003; "Invasive Pest Fact Sheet: *Lantana camara*"; Binggeli 2003b). In addition to its aggressive growth patterns, *L. camara* has been shown to have allelopathic properties that can inhibit growth of native species and agricultural crops (Mishra 2014; Ahmed *et al.* 2007).

In Madagascar in particular this species poses a threat for the conservation of the island's biodiversity because it benefits from human disturbance in natural areas. The prevalence of *tavy* in eastern Madagascar has allowed *L. camara* to become dominant in fallows in certain areas (Styger et al. 2007). This combined with the reliance of communities on the use of forest resources could affect the invasive species' population, which could in turn have effects on forest biodiversity.

III. Study Objectives

L. camara has been the subject of many studies following its invasions around the world, however in comparison few studies have been done on the species in Madagascar (Styger et al. 2007, Binggeli 2003b). This is the first study collecting data on *L. camara* at Makirovana-Tsihomanaomby. The objective of this study is to survey a portion of the populations of *L. camara* inside and outside of the NAP in order to compare the two with reference to level of human activity. The Tsihomanaomby forest is particularly affected by human activity, thus given the time constraints of the project only this forest was chosen for study. The data collected from this survey will be used to inform future management methods of the *L. camara* population at this site, including the potential for its exploitation for the economic gain of the population surrounding the NAP.

Materials and Methods

Two areas were chosen for data collection at Tsihomanaomby forest: one located about 500 m from the forest delimitation in the zone degraded by human activity and one less than 100 m into the *Nouvelle Aire Protégée* (NAP) (Appendix I: Figures 1-2). These areas were chosen based on accessibility and feasibility of walking transects through the surrounding vegetation.

I. Degraded Site

Five transects of 500 m by 2 m (1 m on either side of the transect) were completed at the degraded site. Transect 1 began at the campsite where the author stayed for the duration of data collection and continued South to North. Each subsequent transect began 100 m South-West of the transect before it, so that the transects approached the NAP. Although Figure 3 in Appendix I shows that all five of the transects were outside of the forest delimitation, the actual delimitation is about 300 m farther East, so at times Transect 5 entered into the forest. Initially the transects were intended to be parallel so as to form a parcel of 500 m by 500 m, however the difficulty of traversing the terrain often resulted in nonlinear and nonparallel transects.

II. Nouvelle Aire Protégée Site

To compare with the degraded site, five transects of the same size (500 m by 2 m) were completed within the NAP (Appendix I: Figure 4). Similar to the degraded site the first transect for the NAP site began at the second campsite, however the transects in this site were completed in the North-South direction to ensure that the entirety of each transect was inside the forest. The transects were again placed 100 m apart and starting points were parallel penetrating deeper into the forest. Once again, the terrain made parallel and linear transects difficult.

III. Data Collection

Transect length was measured using two 50-meter ropes: one rope was tied to a tree at the start of the transect and then the orientation was verified with a compass, the 50 m were traversed and then at the end of one rope one guide walked back to untie the first rope while the second guide went ahead with the second rope to complete the 100 m. Each time the end of a rope was reached the orientation was verified again to maintain the direction of the transect.

i. Continuous

For all 10 transects continuous data was collected for each *L. camara* individual observed within the area of the transect. Height, which was defined at the length from the base of the plant to the tip of the longest branch, was recorded to the nearest 0.01 cm with a 150 cm measuring tape. At times the longest branch was too difficult to reach for measurement so an estimate was taken. Circumference was taken at the widest part of the stem, since the species is typically too short for Diameter at Breast Height (DBH) or Circumference at Chest Height (CCH) (130 cm), and was recorded to the nearest cm (*cite PCQM)*. When an individual had a circumference of less than 1 cm no circumference was recorded. Each individual was assigned an age-class: *petit* ("small" in French), *jeune* ("young"), or *mature*. The diagnostics for these three age-classes can be found in Appendix II. In addition, every 50 m the distance along the transect was recorded in order to later quantify how many individuals were seen in each 50 m segment, since the individuals were too numerous to take GPS coordinates of each.

ii. 100 Meters

Every 100 m (after two 50-meter rope lengths) of each transect the coordinate was taken using a Garmin eTrex 2000-2006 portable GPS unit in degrees, minutes, and seconds (DMS). Percentage of canopy cover was measured using a 15 by 15 cm square of plastic with a grid of 100 cells drawn on. Canopy cover was observed by standing at the 100 m point on the transect and looking up through the square of plastic at the canopy, or lack thereof, above. The number of cells fully covered, partially covered, and not covered were counted. For analysis, each fully covered cell counts as 1% of cover, partially covered as 0.5% cover, and not covered as 0% cover. These values are then added to determine the percentage canopy cover at that point along the transect.

Point-Centered Quarter (PCQ) method was used to analyze the species found nearest to *L. camara* (Mitchell 2015). The *L. camara* individual closest to the 100 m point on the transect was used as the center, and the individual's height and circumference were recorded. The closest trees or shrubs in the North-East, North-West, South-West, and South-East quadrants from the center individual were measured. For the plants in each quadrant height, circumference and vernacular Malagasy name were recorded. Height was estimated from base to the top of foliage to the closest 0.1 m for plants taller than 1.5 m because of the difficulty of measurement and was measured from base to top of foliage using a 1.5 m measuring tape for plants shorter than the length of the tape. If the plant closest to the center individual in one quadrant was a shrub then circumference was taken at the widest part of the stem and if the plant was a tree then CCH was measured to the nearest centimeter. The distance between the center individual and the individuals in each quadrant was measured using a 50 m surveyor's tape to the closest 0.01 m.

When no *L. camara* was present near enough to the 100 m point to be used for PCQ analysis the tree closest to the 100 m point was used as the center, regardless of the tree's species. In these cases the methods used were the same as above. In this way the author was able to obtain some data, although minimal, on species other than *L. camara* present at the study site and on species present within the NAP.

iii. Understory Analysis

In order to obtain information about species that are able to coexist with *L. camara,* five individuals on each transect were chosen for understory analysis. The individuals were chosen semi-randomly, whenever the surrounding vegetation changed. For example, when the transect passed through a dense thicket made of *L. camara* one individual was analyzed and when the transect emerged from the thicket into a grassy field another individual was analyzed. For each understory analysis the height, circumference, and age class of the individual were recorded. In addition, the radius of the foliage was recorded. This measurement was taken to the nearest centimeter with a 150 cm measuring tape, measuring horizontally from the base of the individual to the farthest reach of the longest branch. The percentage of canopy cover of each individual was recorded using the methods listed above although in this case the canopy being measured was that of the *L. camara* individual itself. The Malagasy names of each of the species observed underneath the canopy of the *L. camara* individual were recorded with the help of a guide. In addition, notes were taken on the surrounding vegetation and existence of taller trees providing shade for the species underneath the *L. camara* individual if the individual itself was not large enough to provide shade.

Results

I. Invasion Level

A total of 1053 individuals of *L. camara* were found in this survey, with 1005 found at the degraded site and 48 found at the site within the NAP.

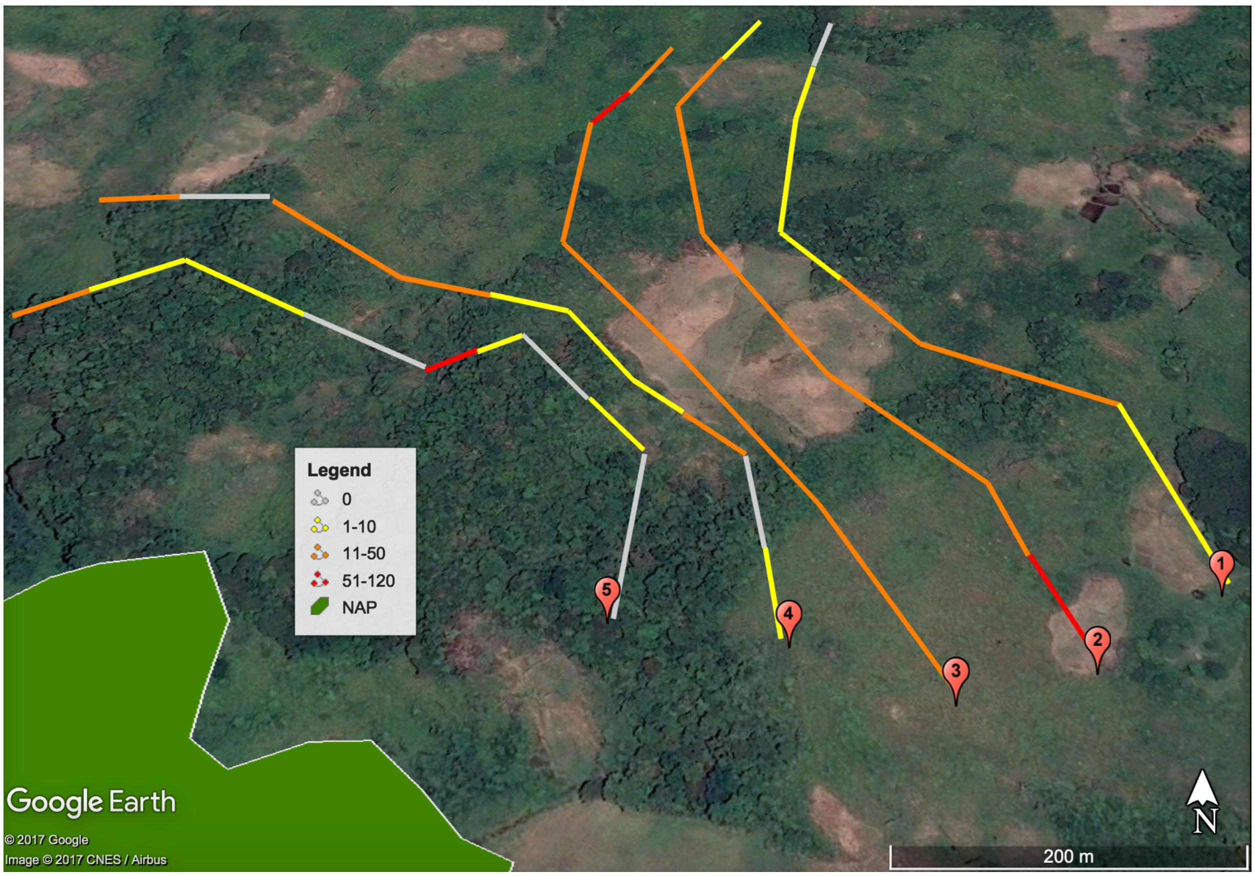


Figure 1. Map of *L. camara* invasion level at degraded site. Legend shows number of individuals per 50 m segment, divided into classes. Transects are labelled.

As shown in Figure 1, the number of *L. camara* individuals, and thus the invasion level, varies per transect but does show a trend of decreasing the closer the transects are to the NAP (green polygon to the left).

Figure 2. Map of *L. camara* level at NAP site. Legend shows number of individuals per 50 m segment, divided into classes. Transects are labelled.

In comparison with Figure 1, it is clear that fewer *L. camara* individuals can be found within the NAP because the transects here are dominated by grey segments, signifying no individuals found.

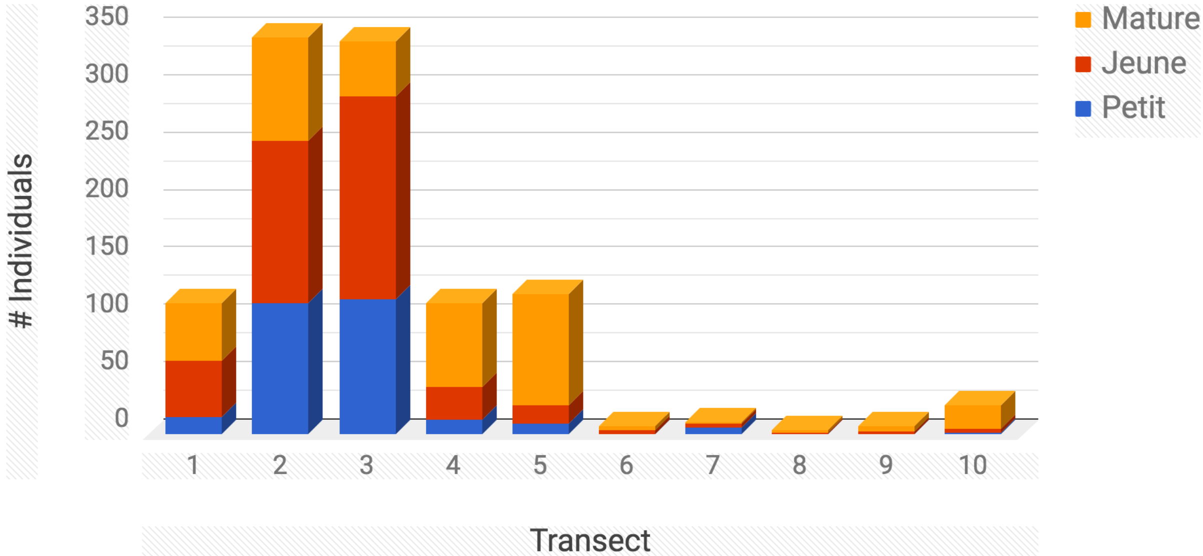
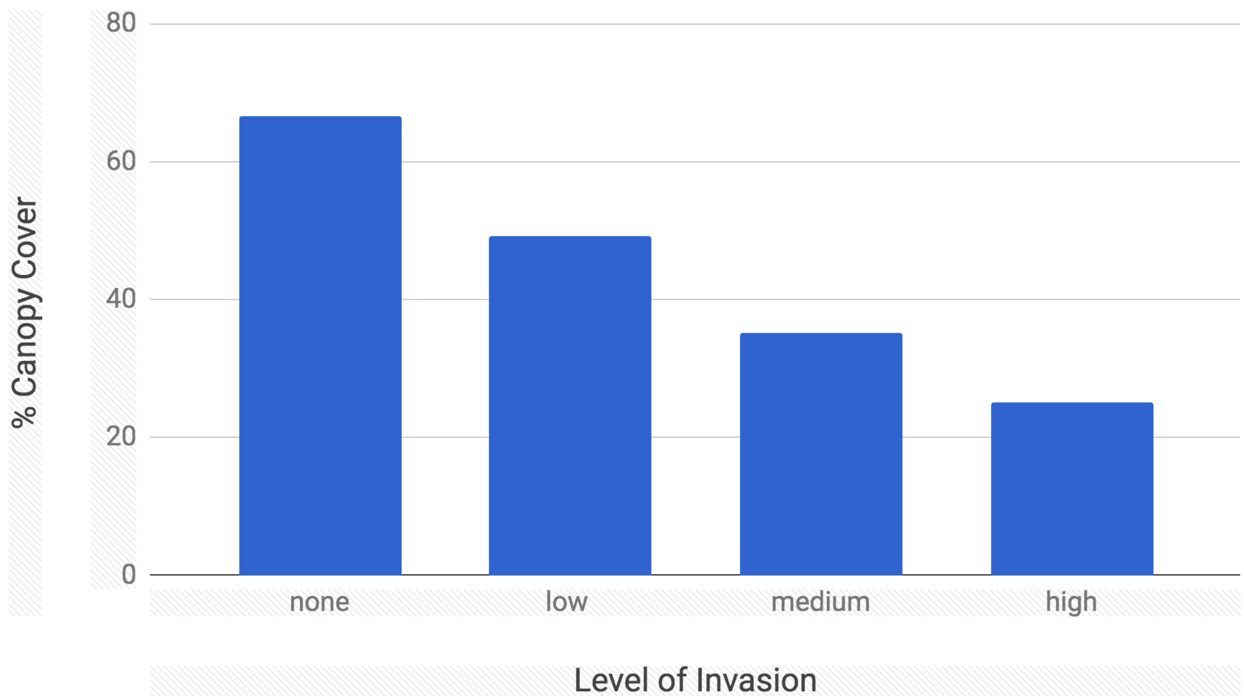


Figure 3. Age classes of *L. camara* by Transect

Figure 3 shows the breakdown of *L. camara* individuals found on each transect by age class. The figure shows that the vast majority of individuals were found within the first 5 transects, at the degraded site, and of those individuals most of them were classified as *jeune*.

Figure 4. Average percent canopy cover by level of invasion.



Each level of invasion in Figure 4 corresponds with the classes used in Figures 1-2: “none” means 0 individuals of *L. camara* present, “low” is 1-10, “medium” is 11-50, and “high” is 51-120. Figure 4 shows that across all transects, the areas with no *L. camara* had the highest percent canopy cover, and thus the most shade. In comparison, the areas with the highest levels of individuals were characterized by the least amount of canopy cover, on average.

II. PCQ

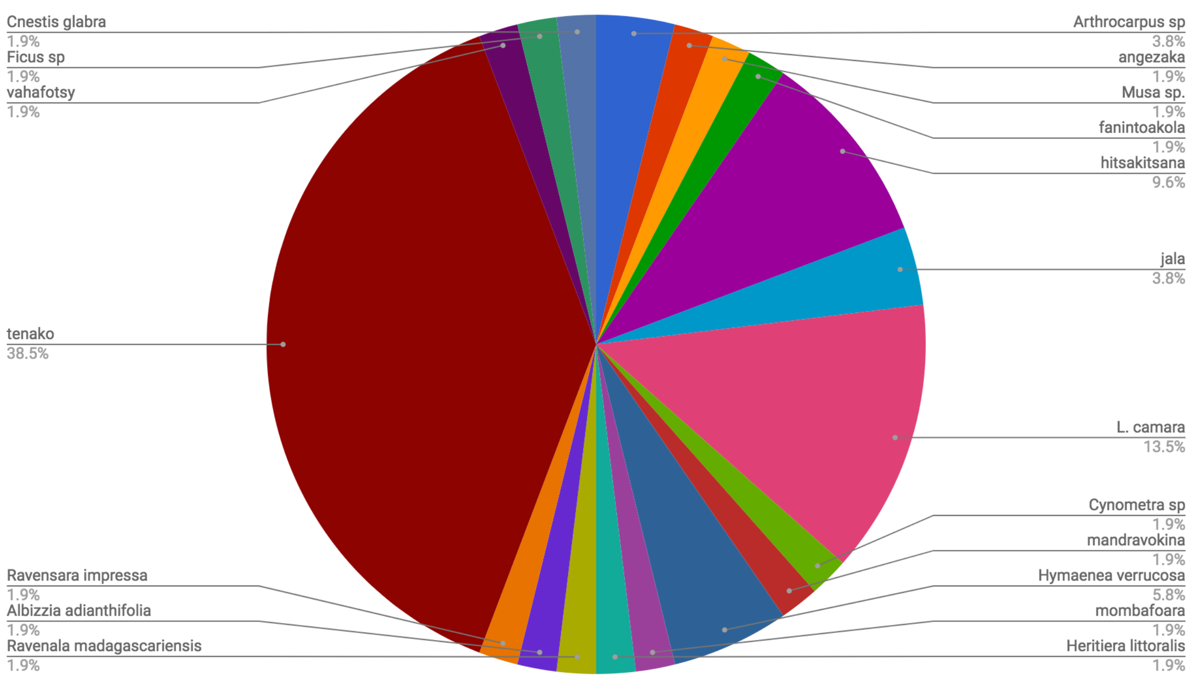
A total of 50 PCQ analyses were completed, 25 at the degraded site and 25 at the NAP site. There were 50 data points were percent canopy cover was measured.

Table 1. Measurements of species found with PCQ, categorized by center species.

Center Species	**Average height (m)**	**Average circumference (cm)**	**Average distance (m)**
L. camara	2.59	13.53	0.29
other	5.68	22.75	2.78

Table 1 shows average measurements taken for the trees from each quadrant of each PCQ analysis. In order to note differences between the status of plants found near *L. camara* versus those found semi-randomly the calculations above are divided by the species of the center plant used for PCQ analysis. It should be noted that while every PCQ with a *L. camara* individual as the center was completed in the degraded area outside of the NAP, analyses done with center trees of other species were done inside *and* outside of the NAP due to the instances in the degraded site when no *L. camara* was present on the transect.

Figure 5. Frequencies of species found near *L. camara* at the degraded site.



The three species most commonly found near a *L. camara* individual were tenako, other individuals of *L. camara,* and hitsakitsana*.* The total number of species found near the invasive species was 19. Note that not all scientific names for the species are present, due to difficulties translating from vernacular Malagasy names and lack of easily accessible records for each species.

At the NAP site, 47 species were found from PCQ analysis. The most common species found at this site was drombiampototra (7.1% relative frequency), along with *Arthrocarpus* sp., *Canarium boivini*, *Cynometra* sp., nanto, and tenako (all 4.8%). All species frequencies found inside the NAP can be found in Appendix III.

III. Understory Analysis

A total of 59 different species were found underneath the 38 *L. camara* individuals chosen for understory analysis. The most frequent species found were tenako (17.1%), *Vepris arenicola* (9.3%), and serasera, ahidrasoa, and tompontany-misiora (all 4.7%).

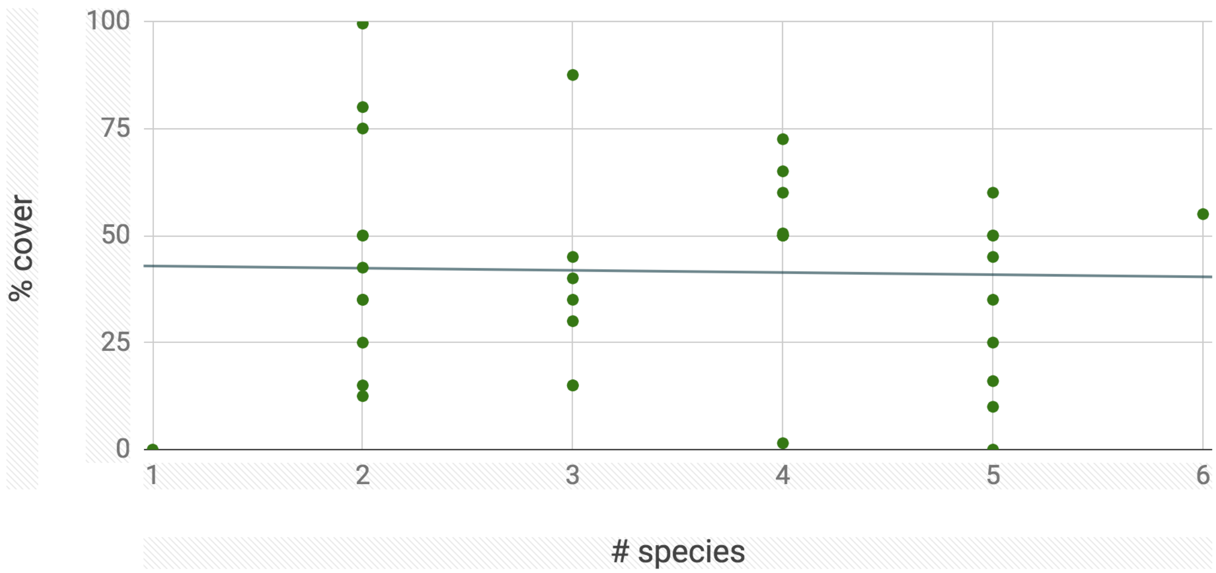
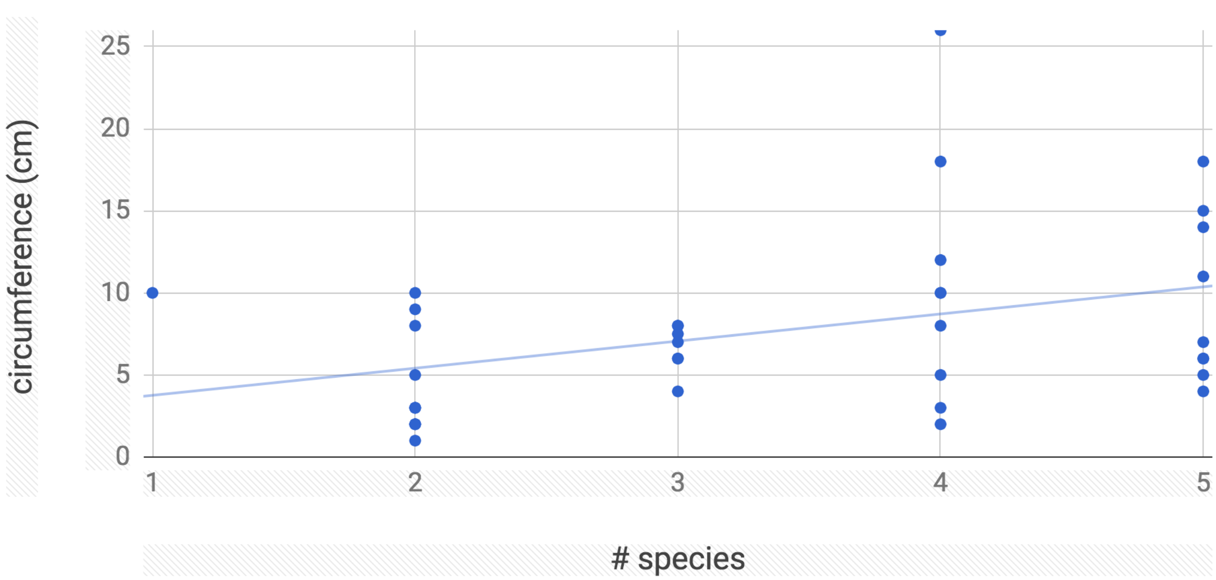


Figure 6. Percent canopy cover versus number of species found underneath *L. camara*. Note that here canopy cover refers to the canopy of *L. camara and* larger trees providing it with shade.

The R-squared value for the trend line in Figure 6 is 0.001, meaning that only 0.1% of the variability in the data follows this trend. Thus the number of species found present underneath *L. camara* in this study was not dependent on the amount of cover provided by the *L. camara.*

Figure 7. Circumference of individual versus number of species found underneath.



In Figure 7 there is a slight trend between the circumference of the *L. camara* individual and the species found underneath. The R-squared value for this figure is 0.147, meaning that only 14.7% of the variability in the data follows this trend.

Figure 8. Height of individual versus number of species found underneath.

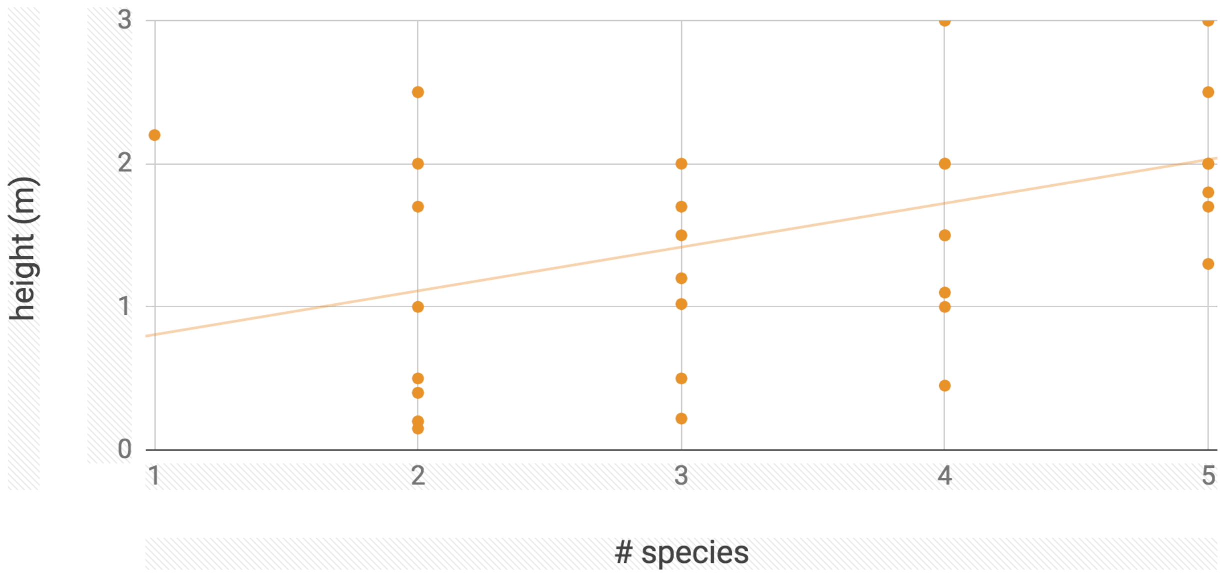
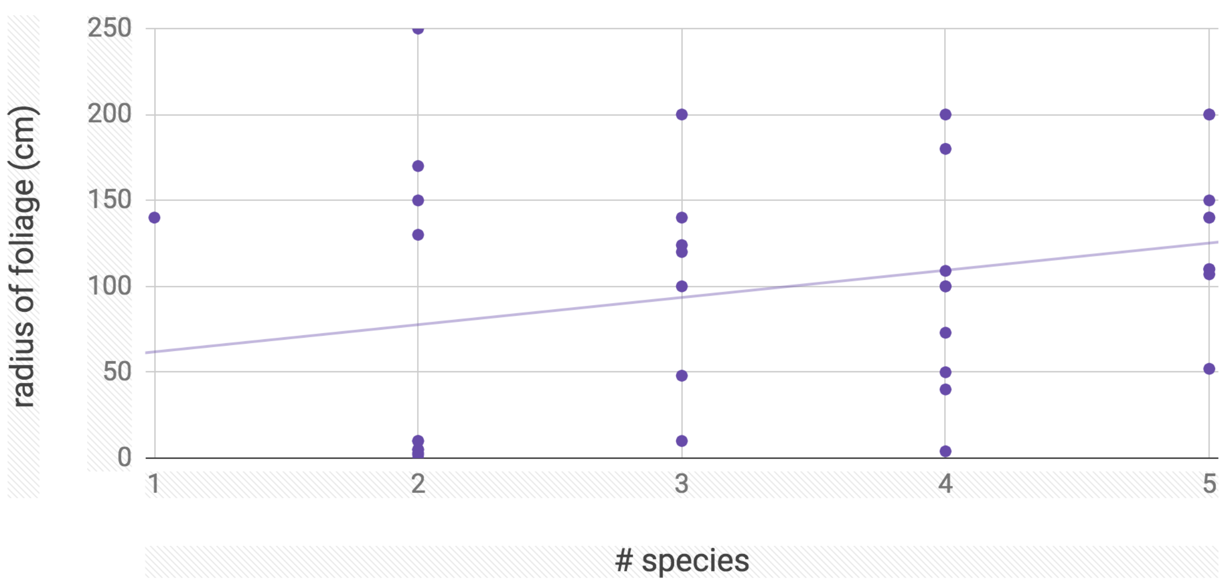


Figure 8 shows a slightly stronger trend between height and number of species, although the R-squared for the trend line is still quite low (0.184).

Figure 9. Radius of *L. camara* foliage by number of species underneath.



Based on Figure 9 it can be seen that there is a very slight trend between radius of the foliage of an *L. camara* individual and the number of species present underneath. The R-squared value for this trend line is 0.076 (7.6% of variability of data follows the trend).

Discussion

I. Methods Analysis

In general the methods used for this study could have been more thoroughly researched and thought out. In scientific research it is important to use reputable methods from other studies so as to ensure that data collection is as efficient and uniform as possible. This was not always done in this study due to time constraints before fieldwork began. It is also important to plan out the methods details beforehand, such as how precisely to record a measurement. The precision with which each measurement was recorded was decided in the field but was not always adhered to based on feasibility. For example, the author did not have instruments to accurately measure the height of trees taller than 1.5 m, so estimates were taken. In addition, it would have been useful to record precise data on distance to vanilla plantations or fallow fields as these characterized the landscape where much of *L. camara* was found growing.

The length of 500 m was chosen for the transects purely because it was believed to be a length feasible to complete in a single day yet long enough to collect a decent amount of data. It would have been useful to research what length and number of transects is usually used for invasive plant surveys. In addition, the distance of 100 m between transects and the number of transects (10 total) were both chosen arbitrarily. The main reason why these numbers were chosen was to ensure completion of the study given the time constraints (two weeks) while allowing buffer room for any technical problems that might arise. The distance between transects was also chosen after Transect 1 had been completed and the distance between this transect and the NAP was estimated. This was done in the hope that the final one or two transects at the degraded site would pass through parts of the NAP, so as to collect data on the *L. camara* population at the forest edge.

The age-classes used for *L. camara* were decided upon during fieldwork, with the help of the author's advisor, Dorian Andrindrainy. During the first few transects Andrindrainy assigned age-classes to each individual, however there were several days when he was unable to attend fieldwork so the classes were assigned by the author herself. Due to this there may be some discrepancies between individuals in different age-classes, although by the end of data collection at the first site Andrindrainy and Pessereau had decided on the criteria of each age-class (found in Appendix II). There were also instances when *L. camara* individuals were observed with multiple stems but had been cut so they did not meet the height criteria to be classified as *mature*, however they were recorded as such.

For PCQ analysis the challenge was deciding which tree or shrub to measure in each quadrant. At the degraded site the majority of the plants found near *L. camara* were either small shrubs or trees that were many meters away, which made it clear which plants should be measured. However at the NAP site the tree density was much higher. This made it difficult to use the same criteria used for PCQ analysis at the degraded site because the author had to be conscious to look for the closest tree *or* shrub. Because of this many small trees were counted, which might have been done differently in a different study. For future studies it would be useful to specify criteria for the trees in each quadrant early on.

The instrument used to measure the percentage of canopy cover was made by the author herself out of a piece of plastic cut from the cover of the SIT syllabus and crudely drawn on with a marker and a straight edge. Thus it may not have provided the most accurate measurements.

At times during the study there was difficulty adhering to the methods due primarily to the difficulty of the terrain. There were a few instances when it was deemed unsafe to take measurements of *L. camara* along the transect because of the steepness of the slope where the individuals were seen. In these instances estimates were recorded on the number of individuals and their measurements. The drastic changes in slope also made maintaining the linear direction of the transect unsafe at times, resulting in the jagged transects shown in Figures 1 and 2.

One of the main sources of error that greatly affects the analysis is the naming of species. Since the author was working with local Malagasy guides, the names of each plant found were given in Malagasy. Due to the author's limited knowledge of the Malagasy language and the pace at which data was collected it is possible that the spelling of some of these vernacular names is erroneous. After data collection was completed the scientific names of each species were translated using online sources (www.lemurdolls.com/ravina.htm and www.tropicos.org), however due to potential misspellings, still-unnamed species, and vernacular names that apply to multiple species not all of the scientific names were found.

Many of these sources of error can be combined into 2 categories: lack of background research and lack of precision. It is advised that further studies on this topic, as with any scientific study, include reputable and precise methodology.

II. Analysis of Findings

A. Invasion Level

The invasion level of *L. camara* at the degraded site was high in some areas–"high" meaning that the transect passed through a thicket of the species–and medium in others–where the species was present in a grassy field but not in such high densities. The degraded site was characterized by fields used for *tavy*, many of which were being left to fallow. As mentioned earlier *L. camara* is a secondary succession species that often dominates fallow fields (Binggeli 2003b), which is exactly what was seen in this study. The majority of individuals seen at this site were classified as *jeune,* followed closely by *mature,* which shows that the presumably the fields had been left to fallow for a few years already. A study done on the margins of the Ankeniheny-Zahamena rainforest corridor in eastern Madagascar found that *L. camara* becomes one of the principal fallow shrubs following the third cycle after deforestation (Styger *et al.* 2007). This may be the same case at Makirovana-Tsihomanaomby, since the fallows at the degraded site seemed to be all populated by *L. camara* and the areas around the forest complex have been used for *tavy* since before the protected area was created in 2008. The same study (Styger *et al.* 2007) found that fallow cycles are increasing in length in order to restore optimal soil fertility, which could allow *L. camara* populations within fallow plots to become more established, although this was not specifically observed at Tsihomanaomby forest.

The transects also passed through patches of burned *L. camera* (Appendix I: Photo 3) where farmers had begun to prepare the land for cultivation. However, multiple sources say that *L. camara* seeds can survive and even germinate in the presence of fire (Binggeli 2003b; Day *et al.* 2003; "Invasive Pest Fact Sheet: *Lantana camara*"). This means that while farmers are using fire as a form of control for the species and to clear their land *L. camara* continues to persist. The large number of *petit* individuals that were found in this study suggests that control of the species is not entirely successful. Further evidence of this is the frequency with which *mature L. camara* individuals were observed that had been cut low on the stem but had sprouted small green seedlings.

This was especially seen at the NAP site, where the majority of *L. camara* individuals were seen on vanilla plantations. At this site most of the individuals were *mature* and distributed far apart from one another. No dense thickets were found, although a few of the *mature* individuals observed were between 2 and 4 m in height, suggesting that they had been growing undisturbed. While the invasion level of *L. camara* at the NAP site was low in comparison to that of the degraded site, it should be noted that the local guides helping the author with this study assumed that no "calabera" would be found within the forest. This is due to the knowledge that the species grows only in disturbed areas, which was assumed to mean areas outside of the forest.

Each transect at the NAP site passed through at least one vanilla plantation and one area cleared to cut wood (Appendix I: Photo 7). The campsite where the author and guides stayed for the duration of data collection at the NAP site was beside one of the paths through the Tsihomanaomby forest. At the campsite and while walking transects the crew encountered at least 10 people a day, walking through the forest, pollinating vanilla, or cutting trees with long saws. All 5 of the transects at this site started from this same path through the forest, and at the beginning of each transect at least one *L. camara* individual was noted whereas there were far fewer farther from the path. This supports the idea that gaps created by human activity allow *L. camara* to encroach on forest interior ("Invasive Pest Fact Sheet: *Lantana camara*"; Day *et al.* 2003).

Not only do walking paths and other human disturbances allow *L. camara* the space to extend into the forest, they also clear away taller trees and provide the species with enough sunlight to survive. Figure 4 shows a clear distinction between the average percent canopy cover of the *L. camara* at different levels of invasion: the highest invasion level has the lowest percent cover and the lowest level of invasion has the highest percent cover. This is in line with the literature on *L. camara,* which says that the species grows best in areas with lots of sunlight (Day *et al.* 2003; Binggeli 2003b; "Invasive Pest Fact Sheet: *Lantana camara*") although there have been reports of shade-tolerant varieties of this species (Carrìon-Tacuri *et al.* 2011).

Since vanilla is lucrative crop for export, its cultivation is extremely popular in the Sava region, practiced by 55% of people in the Sambava district and 28% in the Vohémar district in 2008. Vanillaculture occupied the largest surface area of all crops cultivated in the areas surrounding the Makirovana-Tsihomanaomby forest in 2008, with 0.75 ha (Groupe du Goldman 2008). The low slopes of Tsihomanaomby are suitable for vanilla plantations, which explains how frequently the transects at the NAP site passed through them. In order to create a vanilla plantation within the forest, a parcel of land is cleared of trees regenerating from the previous season (the size of these parcels is unclear although they looked to be 50 by 50 m in Tsihomanaomby) and short stakes are planted to prop up the vanilla (Groupe du Goldman 2008). This disrupts the forest canopy allows ample sunlight for *L. camara* to grow within the forest, as was frequently seen during this study.

In comparing the two sites, degraded and NAP, the degraded site had a much higher level of invasion given its characteristics making it a suitable habitat for *L. camara*. Both sites were greatly affected by human activity, be it fallow plots, walking paths, vanilla plantations, or plots cleared for cutting wood. The vast majority of *L. camara* was observed in areas clearly affected by human activity.

B. PCQ

Analyses done at the degraded site with a *L. camara* individual as the center point show the three species most frequently found in proximity to be tenako, other individuals of *L. camara,* and hitsakitsana. Tenako was the tree seen most frequently at both sites of this study, from seedlings of less than 50 cm to mature individuals over 2 m. This explains why the species was also found most frequently (38.5% relative frequency) near *L. camara.* The presence of multiple *L. camara* individuals next to one another has also been seen before, given the species' tendency to form monospecific thickets (Day *et al.* 2003). Unfortunately, the difficulty in translating vernacular names to scientific prevents detailed analysis on tenako and hitsakitsana.

The most frequent species found in PCQ analyses with non-*L.camara* individuals as center points were drombiampototra, along with *Arthrocarpus* sp., *Canarium boivini*, *Cynometra* sp., nanto, and tenako. Here tenako was much less frequent, 4.8% relative frequency, and drombiampototra had the highest relative frequency, with 7.1%. This is likely due to the fact that the majority of these PCQ analyses were done at the NAP site, within the Tsihomanaomby forest. The frequencies of species found here are much more similar to one another, in comparison to tenako's high frequency associated with *L. camara* at the degraded site.

Many studies around the world have shown *L. camara* to have allelopathic properties (Mishra 2014; Ahmed *et al.* 2007) as many of the species' chemical constituents can inhibit growth of neighboring plants. Referring to the values in Table 1, the average height and circumference of plants found in quadrants surrounding a *L. camera* individual is lower than those found around a center point of a different species. This could potentially be due to allelopathic qualities of *L. camara*, however it is more likely attributed to the types of plants found in the same habitat as *L. camara.* Since all of the PCQ analyses with *L. camara* as a center point were done at the degraded site, this skews the other species present. The transects at the degraded site passed primarily through open grassland, so the plants chosen in each quadrant for PCQ were usually smaller shrubs. In contrast, the majority of PCQ analyses done with other species at the center were at the NAP cite, therefore the species in each quadrant were typically tall trees of primary forest. In addition, the average distance from the center point to the plants in each quadrant was much lower for *L. camara* center points (Table 1), which is again likely due to the type of habitat where these analyses were done.

C. Understory Analysis

Binggeli (2003b) notes that much of the literature concerning *L. camara* in Madagascar does not report the same adverse effects known to other countries. This has yet to be further tested, although as a start it is helpful to take note of which species can grow near or underneath the canopy of *L. camara.* Of the 59 species found growing underneath *L. camara,* the most common were tenako (17.1%), *Vepris arenicola* (9.3%), and serasera, ahidrasoa, and tompontany-misiora (all 4.7%). Once again, the high relative frequency of tenako is to be expected given the species' prevalence at Tsihomanaomby forest. As for the other four species, very little information can be found, even for *Vepris arenicola.*

None of the four analyses investigating correlation between number of species and various *L. camara* measurements (Figures 6-9) showed a high correlation. It can be concluded from this dataset that the canopy cover provided by the *L. camara* individual has little affect on the number of species present underneath (Figure 6). The highest correlation was found between height and number of species (Figure 8), although this could be due simply to the fact that taller individuals of *L. camara* often have a farther lateral reach as well and thus more species were counted as "underneath". It might be assumed that because of this there would be a high correlation between radius of foliage and number of species (Figure 9), however the correlation found here was lower than with the height variable. Figure 7 shows the circumference may have an effect on number of species, although the correlation here is also lower than with the height variable.

III. Uses of *L. camara*

Complete eradication of invasive species proves to be time-consuming and costly, making it unfeasible in Madagascar. As an alternative many invasive species in Madagascar are used to the economic benefit of Malagasy people as food, wood, or charcoal (Kull et al. 2014). Because in this study *L. camara* was found in areas frequently affected by human activity, eradication of the population at Tsihomanaomby, even at a small scale, is unlikely. Instead, the best option is to exploit the population for the economic gain of the surrounding communities.

L. camara leaf extracts have been used effectively as herbicides (Day *et al.* 2003; "Invasive Pest Fact Sheet: *Lantana camara*"), although the materials and funding necessary to prepare this treatment are nonexistent at Makirovana-Tsihomanaomby. More realistically, lantana can be used to produce an antiseptic oil, artisanal baskets, wood fuel ("Invasive Pest Fact Sheet: *Lantana camara*"). Lantana oil can also treat skin itches, scabies, and leprosy (Day *et al.* 2003).

Rather than burn *L. camara* after clearing it from a fallow plot, farmers could set aside the branches and stems to be used to weave baskets, a popular product, or to be used as fuel which is always in demand. Given the prevalence of medicinal plants in Madagascar it is likely feasible to prepare medicinal oil from lantana leaves as well. The *L. camara* population at the Tsihomanaomby forest is likely to persist into the future, and in this way the seemingly invasive plant could be used to generate more revenue for local people surrounding the Makirovana-Tsihomanaomby forest complex.

IV. Suggestions for Future Studies

Future studies should be conducted on the *L. camara* population in the Makirovana-Tsihomanaomby complex at large, in order to determine the species' spread outside of the sites used in this study. In addition, it would be useful to look specifically at interactions between *L. camara* and vanilla plantation or *tavy* in the area. Data collection focused on human activities and *L. camara* prevalence would bolster the results of this study. Perhaps the most useful step forward would be to study the feasibility of exploiting *L. camara* and producing viable products from it.

Conclusion

This study serves as a preliminary survey of *Lantana camara* at the Tsihomanaomby forest in the Makirovana-Tsihomanaomby forest complex. The forest is a widely used resource by local communities, which explains the existence of *L. camara* in fallow plots in the degraded area outside of the forest and within the *Nouvelle Aire Protégée* where it has been touched by human activity. Based on the results for this study, lantana does not seem to be having a negative impact on the biodiversity within the forest, given its low numbers and distribution limited to already-degraded areas there within. In addition, many different species were found growing in close proximity with *L. camara* and even underneath its foliage. Outside of the forest the species exists in high numbers, often in dense, monospecific, thickets. While eradication of the species at this site is unfeasible and unlikely it is an available resource that could be exploited for the economic benefit of the rural communes surrounding the forest complex.

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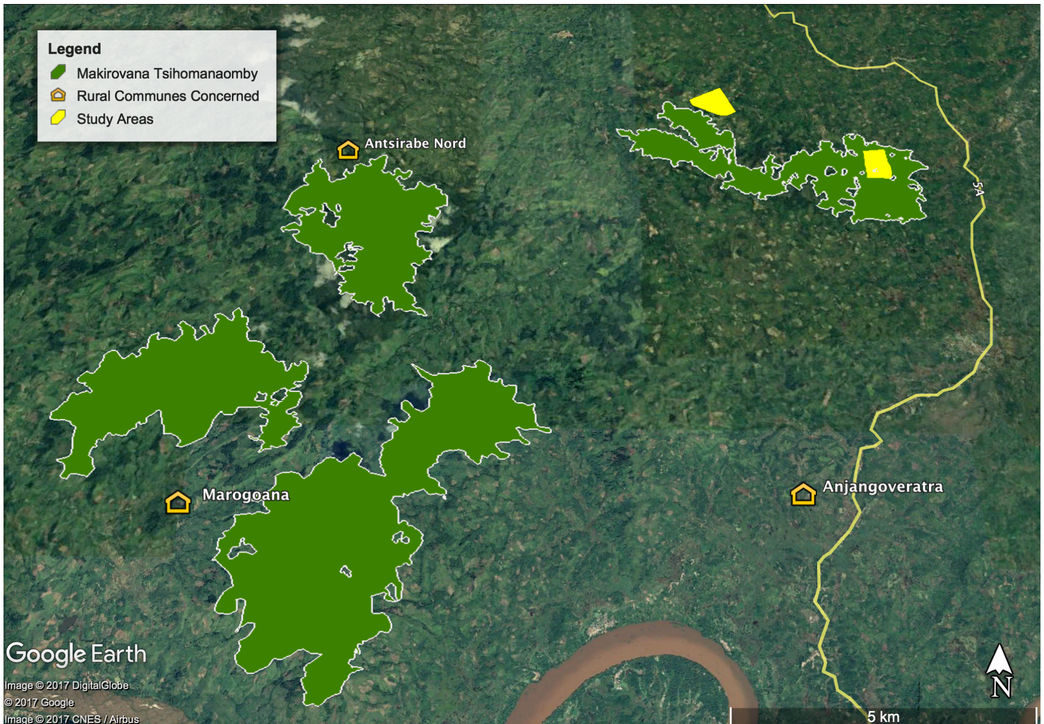
Appendix I: Useful Photos & Figures

Figure 1. Map of Makirovana-Tsihomanaomby with study areas.



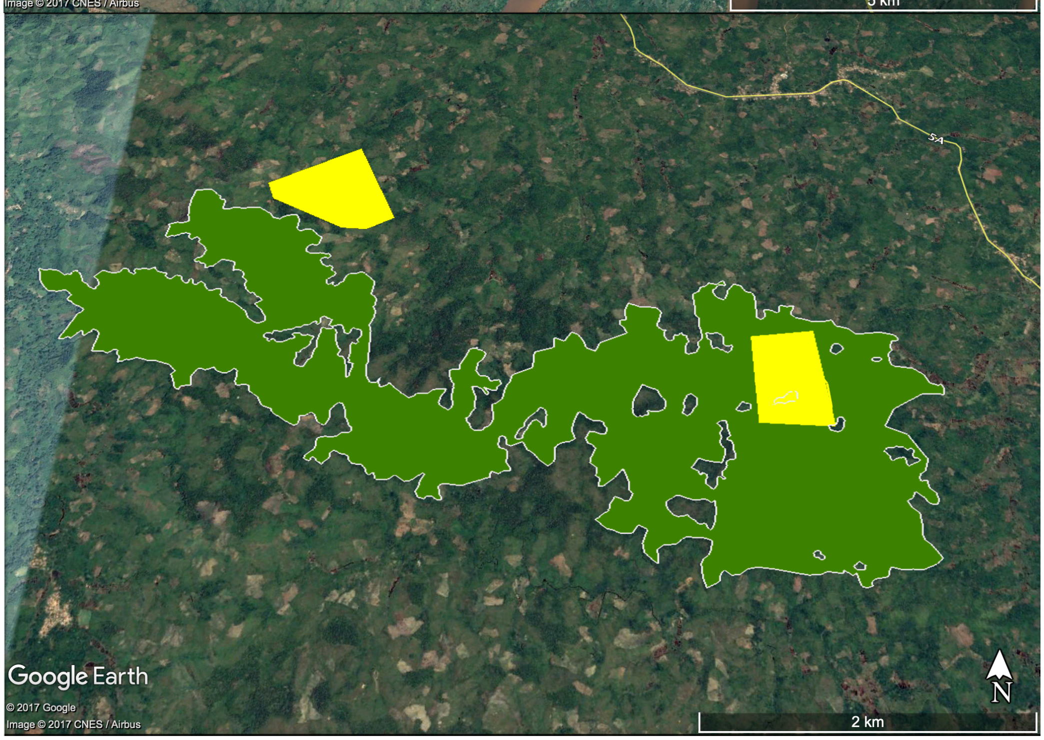


Figure 2. Close up of Tsihomanaomby forest and study sites.

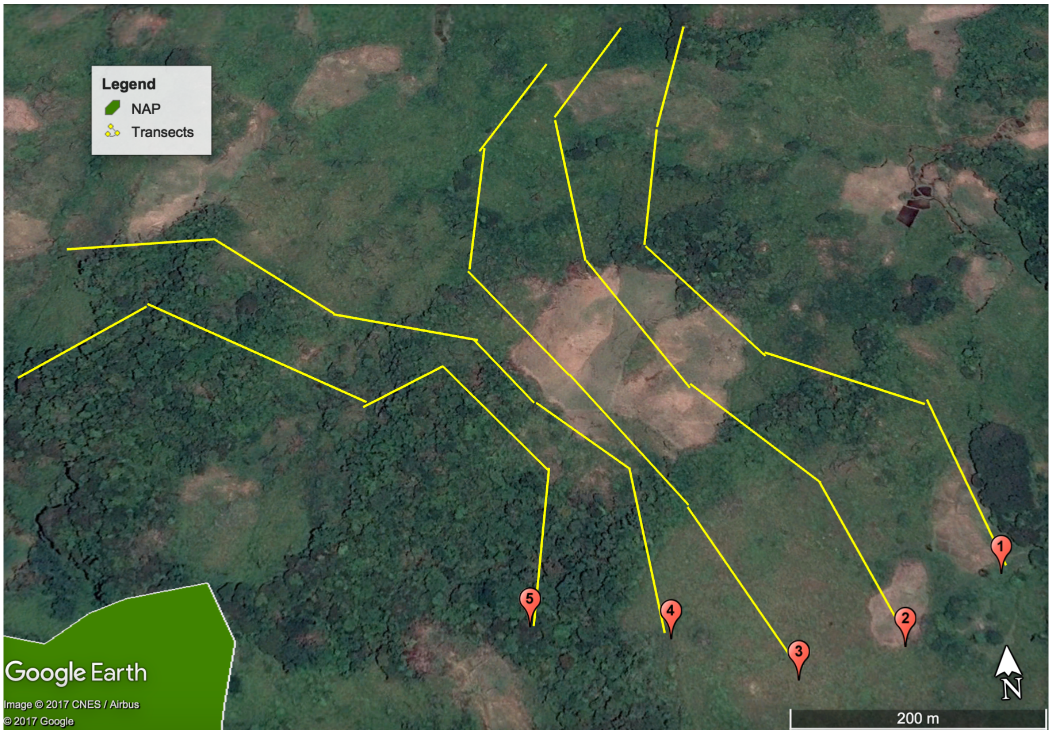


Figure 3. Map of transects 1-5 at degraded site.

Figure 4. Map of transects 6-10 at NAP site.

Photo 1. Unripe *L. camara* berries, blue transect rope in background.

Photo 2. Mature *L. camara* flowers.

Photo 3. Burnt *L. camara* leaves in fallow.

Photo 4. Red paint on tree marking delimitation of the NAP.

Photo 5. Green transect rope passing through dense thicket of *L. camara.*

Photo 6. Blue transect rope passing through vanilla plantation, *L. camara* individual pictured at base of vanilla plant (low right).

Photo 7. Area cleared for chopping wood in Tsihomanaomby forest.

Appendix II: Age-Class Criteria

Age-Class	Qualifications	Photo
Petit	Shorter than 50 cm, circumference 2 cm or less	
Jeune	Taller than 50 cm but no other height or circumference constraint, *single stem* at the base (as shown in photo)	
Mature	Taller than 50 cm but no other height or circumference constraint, *multiple stems* at the base (as shown in photo) (individuals with multiple stems that had been cut were classified as Mature)	

Appendix III: Species Found with PCQ Analysis

Species (at NAP site)	**Relative Frequencies**
afatra-ankora	1.19047619
Ambavia sp	1.19047619
Arthrocarpus sp	4.761904762
Canarium boivini	4.761904762
benofotra	1.19047619
biafotra	1.19047619
Coffea sp.	2.380952381
drombampototra	7.142857143
faho	1.19047619
fomolakantsy	1.19047619
fondamba	1.19047619
hasina	2.380952381
Micronychia madagascariensis	2.380952381
Mauloutchia humblotii	1.19047619
Rauvolfia capuroni	3.571428571
Homalium albiflorum	1.19047619
jala	2.380952381
mayimtompototra	2.380952381
Cynometra sp	4.761904762
mandravokina	3.571428571
Hymaenea verrucosa	1.19047619
maronvongy	1.19047619
mayimbo-hitska	1.19047619
nanto	4.761904762
noftrakoho	1.19047619
paka	2.380952381
Cleistanthus capuroni	1.19047619

Species (at NAP site)	Relative Frequencies
Cabucala erythrocarpa	3.571428571
Ravenala madagascariensis	2.380952381
MELASTOMATACEAE	1.19047619
saonambo	1.19047619
saritroa	1.19047619
sely	2.380952381
soihy	1.19047619
sonvongo	1.19047619
tamenaka	1.19047619
tavolo	1.19047619
Strychnopsis thouarsii	1.19047619
tenako	4.761904762
tsararavina	2.380952381
tsimamasatronkina	1.19047619
tsipalimbaritra	1.19047619
tsivango	1.19047619
tsivongo	1.19047619
valavelona	2.380952381
vosondirina	2.380952381
zamby	1.19047619

Species (at degraded site)	Relative Frequencies
Tambourissa sp	7.317073171
Arthrocarpus sp	2.43902439
angezaka	2.43902439
Musa sp.	2.43902439
fanintoakola	2.43902439
hitsakitsana	7.317073171

Species (at degraded site)	Relative Frequencies
jala	4.87804878
L. camara	9.756097561
Cynometra sp	2.43902439
mandravokina	2.43902439
Hymaenea verrucosa	4.87804878
mombafoara	2.43902439
Heritiera littoralis	2.43902439
Ravenala madagascariensis	2.43902439
Albizzia adianthifolia	2.43902439
Ravensara impressa	2.43902439
tenako	29.26829268
vahafotsy	2.43902439
Ficus sp	2.43902439
Cnestis glabra	2.43902439
vodipaso	2.43902439

Appendix IV: Understory Analysis Species

Species	Relative Frequencies
ahidrasoa	0.0465
ahimalemy	0.0078
ampalo	0.0078
Ampalis madagascariensis	0.0233
Crassocephalum rubens	0.0078
anandrambobe	0.0078
andrano-manoro	0.0310
Solanum indicum	0.0233
antsandry	0.0078

Species	Relative Frequencies
antsantso	0.0155
apisaka	0.0155
apodibe	0.0078
Vepris arenicola	0.0930
Harunga madagascariensis	0.0078
atafodi	0.0078
avetso	0.0078
bongampiso	0.0078
famatralanga	0.0078
famehifary	0.0233
fonstapoko	0.0078
hasimbe	0.0078
hasina	0.0078
Rauvolfia capuroni	0.0078
hinttsakintsana	0.0078
hofoki	0.0078
Conyza aegyptiaca	0.0078
Lantana camara	0.0155
longosoa	0.0078
mangezoka	0.0155
Cabucala erythrocarpa	0.0078
rengesoky	0.0078
sala	0.0078
Albizzia adianthifolia	0.0078
samboaboa	0.0078
sangasanga	0.0155
sangasanga	0.0233
serasera	0.0465

Species	Relative Frequencies
siasia	0.0155
Vernonia poissonii	0.0155
Cressa sp.	0.0078
somtorona	0.0078
taka	0.0078
tavolo	0.0078
teloravina	0.0310
tenako	0.1705
tompontans-sora	0.0078
tompontany-misiora	0.0465
tsilavo-ndrivotra	0.0078
tsimitombo	0.0078
tsipoltra	0.0078
vahabe	0.0155
vahinamalo	0.0078
vamantoaran	0.0078
vambahia	0.0155
vambaye	0.0078
vasiki	0.0078
velona-ahantona	0.0078
volopalo	0.0078
vongo	0.0078

Appendix V: All Species Malagasy and Scientific Names

Vernacular	Scientific
adrasoa	
afatra-ankora	

Vernacular	**Scientific**
ahidrasoa	
ahimalemy	
ambavy	*Ambavia sp*
amboara	*Tambourissa sp*
amboaradjia	*Tambourissa sp*
ampa	*Antiaris madagascariensis*
ampalibe/ampaly	*Arthrocarpus sp*
ampalo	
ampaly	*Ampalis madagascariensis*
anandrambo	*Crassocephalum rubens*
anandrambobe	
andrambofafy	
andrano-manoro	
angezaka	
angivibe	*Solanum indicum*
ankoara	
antsandry	
antsantso	
antsimay	
apisaka	
apody	*Vepris arenicola*
aramy	*Canarium boivini*
aroangana	*Harunga madagascariensis*
atafodi	
avetso	
banana	*Musa sp.*
benofotra	

Vernacular	**Scientific**
beteza	
biafotra	
bomngampiso	
cafe	*Coffea sp.*
drala/jala	
drobiambototra	
faho	*Cycas thouarsii*
famatralanga	
famehifary	
faminifary	
fanintoakola	
fomolakantsy	
fondamba	
fonstapoko	
hasimbe	
hasina	
hatromalimy	
hazomafana	*Micronychia madagascariensis*
hazomalang	*Mauloutchia humblotii*
hazomalemy	*Rauvolfia capuroni*
hazombato	*Homalium albiflorum*
hintsakintsana	
hofoki	
janga	*Canavalia ensiformis*
keliravina	*Conyza aegyptiaca*
longosoa	
makarongana	

Vernacular	Scientific
malamekaty	
mampay	*Cynometra sp*
mandravokina	
mandrofo	*Hymaenea verrucosa*
manga	
mangezoka	
manioc	*Manihot esculenta*
maronvongy	
mayimbo-hitska	
mayimtompototra	
mekaty	
menavolo	
mombafoara	
mony	*Heritiera littoralis*
moranga	*Xylopia sp.*
nanto	
noftrakoho	
paka	
palissandre	*Dalbergia sp.*
rahin	*Cleistanthus sp.*
rahiny	*Cleistanthus capuroni*
rambafotsy	*Cabucala erythrocarpa*
ravinala	*Ravenala madagascariensis*
ravinasira	
rengesoky	
rotro	MELASTOMATACEAE
sakondro-manta	

Vernacular	Scientific
sambala	*Albizzia adianthifolia*
samboaboa	
sangasanga	
saonambo	
saritroa	
sely	
serasera	
sidikadambo	*Vernonia poissonii*
siho	*Salix madagascariensis*
sirasira	*Cressa sp.*
soihy	
somtorona	
sonvongo	
taka	
tamenaka	
tangina	*Phellolophium madagascariense*
tavolo	
tavolobe	*Ravensara impressa*
teloravina	
telotritry	*Strychnopsis thouarsii*
tenako	
tompontans-sora	
tompontany-misiora	
trinahombilahy	
tsararavina	
tsilavo-ndrivotra	
tsimamasatronkina	

Vernacular	Scientific
tsimamasatsonky	
tsimitombo	
tsimpalimbaritra	
tsipoltra	
tsiriky	
tsivango	
tsivongo	
vahabe	
vahafotsy	
vahinamalo	*Vanilla aphylla*
valavelona	
vamantoaran	
vamaranga	
vambahia	
vambaye	
vasiki	
velona-ahantona	
voantsila	*Ocotea madagascariensis*
voara	*Ficus sp*
voasefaka	*Cnestis glabra*
vodipaso	
volopalo	
vongo	
vosirindrina/voasirinjiny/vosondirina	
zamby	