Surveying the Distributions of Melaleuca quinquenervia, Psidium cattleianum, and Litsea glutinosa at Analalava Special Reserve

Hanusia Higgins

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Surveying the Distributions of *Melaleuca quinquenervia, Psidium cattleianum,* and *Litsea glutinosa* at Analalava Special Reserve

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Abstract

This study surveyed the distributions of three invasive plant species, *Melaleuca quinquenervia*, *Psidium cattleianum*, and *Litsea glutinosa* at the Analalava Special Reserve in Mahavelona, Madagascar. Analalava is a 229-hectare degraded patch of low-elevation humid forest on the northeast coast of Madagascar, and one of the last forest fragments remaining in the region. It is a haven for biodiversity, containing 343 recorded species of plants, 12 of which are locally endemic. Invasive species are considered the second-most significant threat to biodiversity, both worldwide and specifically at Analalava. Based on a systematic transect survey of these three targeted invasive species, their distributions appear to correlate mainly with open, degraded, swampy, and edge habitats. With the partial exception of *L. glutinosa*, these plants were not found in the closed-canopy forest interior, and when present, they were usually classified as a “low” level of invasion. Due to Analalava’s protected status and ongoing reforestation efforts, the area of degraded forest is not likely to increase, which should limit the amount of preferred habitat for these invasive species. Suggestions for management of each of the three species involve an integrated approach, incorporating chemical control for *M. quinquenervia* and cultural control for *P. cattleianum* and *L. glutinosa*. Although invasive species do present a significant risk to biodiversity at Analalava, the populations of the three target species in this study are not widespread throughout the reserve. They can be managed, or at the very least monitored, to achieve the short-term objective of containment and control.

Introduction

I. Analalava Special Reserve

The island of Madagascar is home to a stunningly diverse array of flora and fauna, but unfortunately, many of its primary habitats—especially forests—have been altered and degraded by human activity. Analalava Special Reserve is one of the last forest fragments remaining in the northeast coastal region of Madagascar, and the very last one within the Mahavelona district. It is composed of three distinct forest types: swamp forest; secondary/degraded forest; and primary, low-altitude human forest, which makes up the
majority of the reserve. Analalava is located on a ridge, but the entirety of the park remains close to sea level; it is intersected by many small streams and a few larger rivers. Located 6 km inland from the beachfront town of Mahavelona, it is a hotspot of local, endemic biodiversity—a label that, admittedly, can be applied to almost any location in Madagascar, but is especially true at Analalava.

Although this forest is partially degraded from previous land use, its current protected status makes it a regional biodiversity haven. 343 plant species have been recorded at Analalava, 12 of which are locally endemic—meaning that, outside of this small, 2.29-square-kilometer parcel of land, they are known to exist nowhere else in the world (Plan). In addition, Analalava is the sixth-most important “hotspot” for palm biodiversity in all of Madagascar, with 26 species of palms existing at this relatively tiny, degraded site (Rakotoarinivo et al.). Many of the plant species at Analalava are extremely rare, threatened, and/or endangered, rendering the conservation of this forest an important goal.

The reserve’s biodiversity is not only floral in nature: Analalava forest is home to five species of lemurs, two species of tenrecs, and three species of bats, including the huge and charismatic Madagascar flying fox, *Pteropus rufus*. Over 50 species of birds, 35 species of reptiles, and 24 species of amphibians have been recorded at the site, although further study is needed to adequately catalog the herpetofauna (Plan). As one of the last remaining forest patches in the region, Analalava is a sanctuary for native species: taking an active role in its protection is incredibly important to conserving local, unique biodiversity.

Analalava has been protected intermittently since 1975. Classified as a forest, it was previously managed by the Ministry of the Environment, Water, and Forests; however, several gaps in protection during the 1990s and early 2000s resulted in significant degradation of the land (Plan). Beginning in 2004, Analalava has been continuously managed by the Missouri Botanical Garden (MBG). It was the first site in Madagascar operated by MBG, and now is one of a dozen such sites (Rakotoarinivo et al.). Prior to MBG’s intervention at Analalava, the forest was being heavily exploited for timber, and deforested for agricultural land uses. This habitat destruction was a serious threat to Analalava’s biodiversity, but it officially ended when MBG began to manage the site in 2004. Currently, the Analalava forest is cooperatively supported by MBG and by local community organizations, including the local non-governmental organization Velonala. It is also supported by the Madagascar Biodiversity Fund (MBF).
In 2006, Analalava was officially granted governmental status as a new protected area (nouvelle aire protégée, or NAP). This resulted from a 2003 resolution by the Malagasy government to triple the area of protected lands in Madagascar, to over 10% of the country’s total land area (Lavialle et al. 2015). Then, in 2015, Analalava was designated as a Category IV Protected Area by the International Union for the Conservation of Nature (IUCN). Category IV status designates a Habitat/Species Management Area, with the primary objective “to maintain, conserve and restore species and habitats” (“Category”). A crucial part of achieving this goal of conservation is understanding, and effectively managing, factors that threaten those species and habitats. As deforestation and slash-and-burn land clearing encroach on the surrounding, unprotected forestland, one of the most looming threats to Analalava’s biodiversity is one that’s less visually obvious: Invasive species.

II. Threats to Biodiversity at Analalava

Invasive species are considered the second-largest threat to biodiversity worldwide, second only to habitat loss (Reid et al.). With increasing globalization promoting inter-habitat exchanges of exotic species, and with the effects of climate change continually altering potential habitat ranges, this problem is not going away anytime soon (Clout and Williams). Interestingly, the ultimate effects of invasive species on biodiversity at a large scale have been debated; according to Powell et al., “Although invasive predators and parasites are known to have caused extinctions of many species, competition with invasive plants is rarely implicated in extinction.” At the least, exotic invaders disturb the biotic and/or abiotic equilibrium of native ecosystems; at the most, they may factor in to native species’ extinctions or extirpations (Powell et al.). These effects are especially pronounced on islands: many islands across the globe have suffered the negative effects of exotic introduced species, such as Hawaii, Guam, and of course, Madagascar.

In Madagascar, invasive plants are nationally recognized as a major threat to the island’s breadth of biodiversity and high levels of endemism (Tassin et al.) According to the popular ecological framework of island biogeography theory, island habitats are able to support and sustain a certain number of species; this number is constrained by factors including the island’s size and its distance from the mainland. Tassin et al. assessed 406 species introduced to Madagascar by anthropologic vectors, finding that nearly forty percent
of these species “carried an environmental risk of potential naturalization”—in other words, a risk of invasion. Even on an island as large as Madagascar, 400 species is a significant number that could disrupt floral and faunal equilibrium. And, as Tassin et al. point out, adequate biosecurity measures to protect against further potentially invasive exotic species are not in place in Madagascar, which could exacerbate the problem. Clearly, invasion is a serious and ongoing threat to Madagascar’s unique biodiversity.

Specifically at Analalava Special Reserve, invasive species have been identified as the second most important threat to the reserve. Due to the area’s protected status, habitat in the form of forest degradation is no longer an official concern (Tilahimena). The number-one threat to Analalava is actually fire: With five villages directly adjacent to the reserve and many others in the vicinity, “tavy,” or slash-and-burn clearing of unprotected vegetation for agriculture and other land uses, is prevalent in the area (Figure 1) (Plan). Thus, fire is a primary concern for protection of the forest and its species. In addition to extensive education and outreach efforts with local communities, a manually cleared fire break (“pare-feux”) surrounds the perimeter of the reserve.

The fire break is an important tool which prevents fire from spreading into the reserve. Unfortunately, this tree-free border cannot protect against the spread of invasive species. Detection and management of invasives is somewhat more nuanced, and requires a longer-term effort, than detection and management of fire. Several species of plants (and two animals: Potamochoerus larvatus, the wild pig and Rattus rattus, the house rat) are well-known to be invasive in Analalava. This study will focus on the three most widespread exotic plants: Melaleuca quinquenervia, Psidium cattleianum, and Litsea glutinosa. Although there are certainly others present (such as Grevillea banksii), these three invasive species present the largest threats to Analalava Special Reserve (Plan).

*Melaleuca quinquenervia*

*Melaleuca quinquenervia*, the paperbark tree, is a broadleaved perennial tree in the family Myrtaceae, native to Australia and several other Oceanic nations. Its popularity as an ornamental plant, as well as its commercial use for production of niaouli oil, has led to its introduction and subsequent invasion in many countries around the world, including the United States and Madagascar (“Melaleuca”). Although its initial time of introduction to Madagascar is unknown, there was a well-established colony of *M. quinquenervia* near Tamatave by 1916, when seeds were sent from the Ivoloina Agricultural Station (now called
the Parc Zoologique d’Ivoloinia) to the United States Department of Agriculture. Interestingly, these seeds were distributed in southeast Florida, propagating the invasion of this species as a noxious weed in Florida and several other states (Dray et al.).

*M. quinquenervia* is found in humid lowlands and especially often in riparian and wetland habitats, making it well-suited to the low-altitude coastal climate and swampy forest character of Analalava. Once established in an area, it often becomes the dominant tree species, forming dense stands that crowd out native flora and have a negative effect on local biodiversity (“Melaleuca”). Examples of this monocultural clustering of *M. quinquenervia* can be readily observed along the secondary road between Analalava Special Reserve and Foulpointe/Mahavelona. The species is easily recognizable at Analalava due to its extremely shaggy, flaky, light-colored bark (Figure 2). Its presence and at Analalava is well-documented, but its specific distribution, and potential effects on native flora and fauna, are not (Miandrimanana et al.). Individuals of *M. quinquenervia* produce copious seeds, and the seed capsules may remain on their parent trees for extended periods of time. These seeds are fairly hardy; after dissemination they remain viable for 2-3 years, and they can disperse successfully after fires and other ecosystem disturbances (“Melaleuca”). This last feature is particularly notable, as the primary threat to Analalava’s biodiversity—fire—could create a vector for the spread of one of its secondary threats—the invasive *M. quinquenervia*.

**Psidium cattleianum**

*Psidium cattleianum*, the strawberry guava, is a perennial evergreen shrub/tree in the family *Myrtaceae*, native to South America. It has been introduced in many tropical regions for use as an ornamental and fruit tree. It is considered one of the top 100 World’s Worst Invaders by the IUCN, due to its aggressive tendencies in several of the countries it has been introduced to, including Madagascar’s Indian Ocean neighbors Mauritius, Réunion, and the Seychelles. Although the date of its arrival at Analalava specifically is unknown, it was introduced to the Ambendrana area near Ranomafana National Park by the early 20th century, most likely for its fruit. Faunal dispersal by humans and other mammals, due to its edible fruit, is a significant vector of invasion for this species in Madagascar (“Psidium”).

*P. cattleianum* is found in a variety of humid habitat types, including the lowland tropical forest present at Analalava. It is often characterized as a pioneer species, due to its ability to colonize disturbed, degraded, and edge-habitat areas. Like many other plants with
invasive character, *P. cattleianum* can form dense monospecific stands that out-crowd and out-compete native plants. In addition, it can propagate via both seeds and suckers, such as from stump re-sprouting, so simply cutting down individuals of this species is not an effective management strategy (Figure 4) (“Psidium”). In the forest of Analalava, *P. cattleianum* is visually distinguishable by its distinctly reddish bark (Figure 3). It is a fast-growing, resource-efficient species, and these factors, along with its flexibility in habitat type, help it spread quickly and become invasive in new ranges (“Psidium”). The partially degraded nature of the Analalava forest, with plenty of open and edge areas, make it a potential site for the expansion of *P. cattleianum*.

**Litsea Glutinosa**

*Litsea glutinosa*, the Indian laurel, is a woody evergreen tree/shrub in the family *Lauraceae*. Its native range spans parts of India, China, Malaysia, Australia, and several western Pacific islands. Its invasive range includes many Pacific and Indian Ocean islands, including the Comoros, Reunion, and Mauritius. Not much information is available regarding the introduction, presence, or distribution of *L. glutinosa* across Madagascar. In fact, its presence at Analalava may be one of the only recorded occurrence of *L. glutinosa* in Madagascar. However, it has been introduced in other nearby islands for ornamental, medicinal, timber, and soil-stabilization purposes (Vos).

*L. glutinosa* occurs in humid tropical and subtropical forests at a wide range of altitudes, especially in forest edge and riparian habitats (Vos). Therefore, it well-suited to the open and degraded/edge areas of Analalava Reserve. *L. glutinosa* is recognizable at Analalava by its pale, whitish bark and its leaves’ wavy margins (Figure 5). This species often becomes invasive in introduced ranges due to its ability to rapidly proliferate and displace native vegetation. It grows quickly, and regenerates both vegetatively and with seeds. Seeds can germinate under a variety of conditions, although they do best in open areas (Vos). The fleshy fruits of this species are consumed by frugivorous birds, and this consumption is a likely vector of dispersal and invasion at Analalava.
III. Study Objectives

As one of the last forest fragments remaining in the region, Analalava is clearly an important habitat to conserve to continue preserving Madagascar’s unique biodiversity. Part of that conservation means managing threats to the reserve and its biota, including the significant threat of invasive species. This study aims to survey the distributions and invasion levels of the three most aggressive exotic invaders, *Melaleuca quinquenervia*, *Psidium cattleianum*, and *Litsea glutinosa*. No data of this nature has been collected at Analalava in the past; this survey will provide the first, basic summary of the invasive plants’ distributions in the reserve. The primary objective in collecting this data is to help inform future management decisions and strategies at Analalava. In the long term, the eventual management goal is to eradicate these three invasive species from the reserve, but a more feasible short-term goal is to limit their populations where possible, using management strategies that are already tested and known to be effective (Tilahimena). Understanding the distributions and general invasion levels of these species will assist managers and staff in effectively controlling them, thereby taking an active role to conserve the unique, locally important biodiversity at Analalava Special Reserve.

Methods

To assess the distributions of the three target species (*M. quinquenervia*, *P. cattleianum*, and *L. glutinosa*) at Analalava Special Reserve, an unbiased systematic survey of the reserve was conducted. Information was collected about the presence or absence of each species, as well as the level of invasion for each recorded appearance. In addition, relevant information about environmental factors was noted, but not in a quantified fashion. This sampling effort took the form of an exploratory/reconnaissance survey, aiming to gain a baseline understanding of the distribution of these three invasive species (Rew and Pokorny). Because data of this nature has not been collected previously at Analalava, an unbiased survey method was chosen, as opposed to a targeted/biased survey (Rew and Pokorny).

This systematic survey consisted of thirteen linear transects. Each transect ran in parallel in an east-west orientation, spanning the width of the reserve at each pre-determined
latitude\(^1\) (Figure 6). This method was chosen because systematic sampling by way of transects is a relatively time- and resource-efficient method compared to, for example, random point sampling or a more comprehensive species inventory (Rew and Pokorny). In addition, the reserve’s relatively long and narrow shape makes horizontal (East-West) transects feasible to complete on a day-to-day basis. Adjacent transects were placed between 100 meters and 250 meters apart. Initially, transects were spaced at 100 m apart, but this distance was adjusted to 250 m after the first week of field work to ensure that the entire length of the reserve could be surveyed within the available time. This methodology was informed by a similar study conducted by the manager of Ifotaka North Protected Area, surveying the presence of Opuntia sp. (Ferguson).

Data collection for each transect commenced at the fire break delimiting the perimeter of the reserve. To determine even spacing of the transects, latitude measurements as recorded on a portable GPS (Global Positioning System) device were converted into meters using a standard value of 111,319.9 meters per degree of latitude (Humerfelt). The latitude at the starting point of the previous transect was used to calculate the target latitude for the beginning of the subsequent transect, given that the transects would be a standard distance apart (either 100 m or 250 m). An example of this calculation can be found in Appendix II, along with the coordinates of the easternmost and westernmost points of each transect. To ensure that the number of transects remained consistent, the pre-determined latitudes were adhered to as much as possible, even when transects progressed unevenly. As a result, some portions of adjacent transects ended up closer than others.

Within each transect, data was collected at a point every five meters. This data included the latitude, longitude, and elevation of the point (when available), and the number of individuals and estimated level of invasion for each of the three target species. In addition, relevant information about environmental conditions, habitat type, and other nearby species was qualitatively noted. The latitude, longitude, and elevation were measured and recorded with a portable GPS device; the model used in this study was the Garmin etrex 10. For each of the three target species, individuals were counted within 2.5 meters in each direction north and south of the point, for a total five-meter distance perpendicular to the main transect line. The number of individuals and invasion level for each species at each point was manually recorded. Invasion level was assigned based on the diagnostic tool provided

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\(^1\) Transect K did not cover the entire intended width due to time constraints. However, the data collected during this incomplete transect is still included in the study.
Level of invasion in each instance was categorized as not present (N), low (L), medium (M), or high (H).

To facilitate efficient data collection, a 105-meter-long rope with markings at every five meters was employed during the transects. This rope was staked at the starting location and carried through the forest in a straight cardinal direction (either east or west, measured with a compass), then staked again at the end. Thus, data could be efficiently and accurately collected at each five-meter point marked on the rope, without having to measure direction and distance each time. The rope was re-staked for each subsequent 105-meter portion of the transect. At each point, a GPS waypoint was taken, and then the area was visually assessed. If any individuals of the target species were identified in this initial visual assessment, a smaller rope measured at 2.5 meters was employed to determine whether they fell within the five-meter perpendicular distance of the point. If any portion of an individual plant—trunk, branches, or leaves—visibly intersected the five-meter perpendicular of the point, it was included in the count for that point (Figure 7). The number of individuals and level of invasion (as assessed by the diagnostic tool provided in Appendix III) were recorded for each species at each point. In addition, environmental conditions for a point were noted manually when relevant— for example, if an area was especially swampy, or especially dominated by the widespread fern *Dicranopteris linearis*, this information was recorded qualitatively to further contextualize the data collected. To create the maps presented in the “Results” section of this report, the data points collected were plotted on Google Maps using the Google Fusion Tables tool. The graphs in the “Results” section were created in Microsoft Excel.

**Results**

This study surveyed nearly 2000 points within Analalava Special Reserve, resulting in a set 1,936 data points. A small proportion of the points (fewer than 10) were excluded from the final data set due to incomplete or erroneous information. These data are utilized here to create distribution maps, and to compare invasion level and abundance between the three target species.
I. Species Distributions

*Melaleuca quinquenervia*

In total, *Melaleuca quinquenervia*’s presence was recorded at 43 points. For the most part, these points were located near the perimeter of the reserve, as well as in wetland/riparian areas (Figure 8).

Figure 8a. Map of all points, separated by *M. quinquenervia* presence and invasion level.

Figure 8b. Heatmap of all points with *M. quinquenervia* present, weighted by invasion level. Reserve perimeter is outlined in red.
Psidium cattleianum’s presence was recorded at 57 points within Analalava. The majority of these points occurred in open and edge habitats, which at Analalava occur in previously degraded areas, and near the perimeter of the reserve (Figure 9).
*Litsea glutinosa*

**Figure 10a.** Map of all points, separated by *L. glutinosa* presence and invasion level.

**Figure 10b.** Heatmap of all points with *L. glutinosa* present, weighted by invasion level. Reserve perimeter is outlined in red.
Litsea glutinosa was recorded as present at 93 points within the transects conducted. In addition to being the most widespread of the three target species, it was also the most likely to be found in the interior, more closed-canopy forest. During the course of fieldwork, it was noted that many incidences of L. glutinosa consisted of only one or a few seedlings, without any mature individuals in the vicinity. Under the initial scheme for classifying invasion level, these were grouped with the rest of the low-invasion level points, but from transects A through I a sub-classification of “jeune” (“young” in French) was noted for points with only one or two Litsea seedlings. Further discussion of this trend can be found in Appendix III.

Figure 11 visually represents this sub-categorization of isolated L. glutinosa seedlings. For the transects in which the distinction was made, most of this species’ occurrences in the forest interior are part of this sub-class.

II. Interspecific Comparison

In general, L. glutinosa was found the most abundant species and M. quinquenervia was found to be the least abundant, both in terms of the raw number of individuals and in points recorded at each level of invasion (Table 1).
Table 1. Basic summary of abundances of the three target species

<table>
<thead>
<tr>
<th>Species</th>
<th># of individuals observed (approximate)</th>
<th># of points: Not Present</th>
<th># of points: Low invasion level</th>
<th># of points: Medium invasion level</th>
<th># of points: High invasion level</th>
</tr>
</thead>
<tbody>
<tr>
<td>M. quinquenervia</td>
<td>191</td>
<td>1893</td>
<td>37</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>P. cattleianum</td>
<td>269</td>
<td>1879</td>
<td>51</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>L. glutinosa</td>
<td>536</td>
<td>1834</td>
<td>93</td>
<td>9</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>996</td>
<td>5606</td>
<td>180</td>
<td>21</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 12. Comparison of invasion level frequency between the three target species.

\(^2\) For points with numerous seedlings, the number of individuals was estimated, not exact.
Interestingly, the difference between the abundance of *L. glutinosa* and the other two species, specifically in the “low” invasion level category, is much less pronounced when the subset of “jeune” *Litsea* points is specified (Figures 12 and 13).

Of the three target species, *P. cattleianum* and *L. glutinosa* co-occurred the most frequently; *P. cattleianum* and *M. quinquenervia* were simultaneously present only a handful of times; and *L. glutinosa* and *M. quinquenervia* only co-occurred once, when all three species were present (Table 2). This result makes sense based on the known ecological traits of each species; *P. cattleianum* and *L. glutinosa* thrive in similar habitat types, whereas *M. quinquenervia*’s ideal habitat is somewhat different. However, it is also important to note that each species was most often present without the others.

![Graph showing frequency of invasion level between three species](image)

**Figure 13.** Comparison of invasion level frequency between the three target species, including the sub-categorization of “jeune.”

<table>
<thead>
<tr>
<th>Co-occurrence Category</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>M. quinquenervia</em> only</td>
<td>37</td>
</tr>
<tr>
<td><em>P. cattleianum</em> only</td>
<td>37</td>
</tr>
<tr>
<td><em>L. glutinosa</em> only</td>
<td>88</td>
</tr>
<tr>
<td><em>M. quinquenervia</em> and <em>P. cattleianum</em> only</td>
<td>5</td>
</tr>
<tr>
<td><em>M. quinquenervia</em> and <em>L. glutinosa</em> only</td>
<td>0</td>
</tr>
<tr>
<td><em>P. cattleianum</em> and <em>L. glutinosa</em> only</td>
<td>14</td>
</tr>
<tr>
<td>All three species</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2.** Summary of the target species’ co-occurrences.
Discussion

I. Methods Analysis

The methodology for this study was designed to be straightforward and easily replicable, for the possibility of future replication for both management and scholastic objectives. For example, the population sizes and invasion levels of these species may be monitored by repeating the methods of this and identifying the changes in a species’ population over time.

Of course, several challenges were encountered over the course of the study. One such challenge was GPS accuracy: Although at times the GPS device used to record latitude, longitude, and elevation was accurate to within 3 meters, it occasionally lost connection with satellites and location accuracy was as wide as 50 meters. Therefore, the locations of points represented on the maps resulting from this study are not all exact. But, their resolution is high enough to comprehend the general trends of distribution and invasion level of the three target species in Analalava. To increase the location accuracy of points in future studies, a more powerful GPS device may be used. Alternatively, plotting farther apart than 5 meters may reduce the confusion of apparently overlapping points caused by the inaccurate GPS.

Another challenge faced during the course of this fieldwork was the inconsistency in the cardinal direction of transects. Although transects were intended to run as nearly to parallel as possible along the East-West orientation of the park, they often veered significantly north or south of the designated latitude during the course of the transect walk. This was mainly because the points were laid out in 105-meter segments with the marked cord. While this method was extremely useful for conducting fieldwork in a time-efficient manner, it often resulted in 105-meter segments of a transect that went, for example, north-east instead of directly east.

While this variation does not nullify the data collected, it does make this study more difficult to replicate in the future, such as for monitoring purposes. It also reduced efficiency of the work, as “zig-zagging” transects cover a longer distance and therefore take more time...
to complete than straight ones. Additionally, the failure to remain along the designated latitudes means that some portions of adjacent transects are much closer to each other than other portions. The intended transect widths are illustrated in Figure 14 in Appendix I. These issues were noted as they happened during the course of fieldwork; however, to complete the transects as efficiently as possible, the survey was always continued in the original direction as much as possible, not “corrected” to return to the transect’s intended latitude. To rectify this problem in future studies, it is likely that verifying the direction between each point, rather than each 20-21 points, would be a more accurate method to use. Based on experiences in the field during this study, it may also be more time-consuming, but should result in more accurate data.

Another methodological challenge of this study was the imprecision of the criteria utilized to determine invasion level while in the field. The diagnostic tool in Appendix III was developed during the course of the study as a reference for the researcher; however, when invasion level was recorded on-site during active fieldwork, it was based on the more qualitative assessment of the local guides. This may have resulted in some inconsistency in the criteria for each invasion level. Development of a more comprehensive and easy-to-use diagnostic key would be a useful tool to standardize the categorization of invasion level in future studies.

Finally, human error is, of course, a potential source of error in any study. In this case, a particular inconsistency may have arisen because different guides were employed for different parts of the project. During the first two weeks of fieldwork, one guide helped with data collection (specifically with identifying any invasive individuals present), and in the last week of fieldwork, two other guides assisted. All guides conducted thorough surveys at each point; however, there was one significant difference in the data output. During the first two weeks of data collection, there were many recorded instances of young *L. glutinosa* seedlings in the forest interior. In contrast, during the last week of fieldwork, neither *L. glutinosa* seedlings nor any individuals in the forest interior were recorded. Notably, this could be attributed to the fact that much of the last week of data collection took place in the *noyau dur*—the “core,” or least degraded, portion of the forest. The ecological difference in this northern region of the reserve may be a factor in the relative dearth of *L. glutinosa* seedlings in the data collected. However, it may also be a difference in the guides’ knowledge and recognition of the species. To correct for this potential variation in future
studies, it would be advisable to conduct the entire study with the same person or people doing the identification, if possible.

II. Analysis of Invasion Statuses

In general, the data collected suggests that the three invasive species studied—*Melaleuca quinquenervia*, *Psidium cattleianum*, and *Litsea glutinosa*—are present at Analalava Reserve mainly near the perimeter of the reserve and in degraded, open or riparian zones, with the possible exception of *Litsea glutinosa*. These findings correlate with prior knowledge about the ecology and preferred habitat of each species. Although most instances where these species were present constituted a low invasion level, there were several survey points for each species where the invasion level was classified as medium, usually due to the presence of a monospecific cluster comprising a significant part of the flora at that point. This indicates a general potential for further invasion/colonization, specifically in degraded, open areas.

*Melaleuca quinquenervia*

Based on this survey, the population of *M. quinquenervia* at Analalava occurs primarily in riparian and open/degraded zones. With multiple rivers and streams running throughout the reserve, as well as a significant portion of wetland habitat, there are opportunities for the current *M. quinquenervia* population to expand its range. However, it currently seems unlikely that this species will encroach significantly in the non-degraded forest interior, especially in the noyau dur (forest core). Most of the individuals recorded during this study were adults; very few seedlings or saplings of this species were observed. Significantly, one potential vector of invasion in the future is fire: *M. quinquenervia* seeds disperse opportunistically after fire and other disturbances. This characteristic should be taken into account as an additional risk of fire spreading to the reserve.

*Psidium cattleianum*

*Psidium cattleianum* was encountered more frequently than *M. quinquenervia* during this study. However, the majority of these sightings were still classified as a low invasion level. As *P. cattleianum* is usually considered a pioneer species, thriving in open, sunny areas, it does not seem likely to spread extensively into the forest interior. Due to Analalava’s
currently protected status, as well as ongoing reforestation efforts by MBG, the area covered
by degraded forestland should decrease, or at most remain constant, in the future. In
addition, many of the existing open areas are already heavily dominated by the fern
*Dicranopteris linearis*. Therefore, the restriction of *P. cattleianum*’s preferred habitat should
limit its spread throughout Analalava. However, this species’ hardiness and considerable
propagative abilities should not be discounted.

**Litsea glutinosa**

The distribution of *Litsea glutinosa* encountered during this study was the most different
from the other species’. This was mostly due to the abundance of isolated seedlings
throughout the forest of Analalava; however, even excluding these seedlings, *L. glutinosa*
was encountered more frequently at higher invasion levels than the other two target species.
Mature individuals of *L. glutinosa* were found most frequently in open areas with lower
canopy cover. As with *P. cattleianum*, this habitat type is likely to decrease at Analalava,
which could be a limiting factor on the spread of *L. glutinosa*. However, the relative
frequency of this species’ seedlings in the forest interior could potentially have serious
implications for its future population at Analalava. Because no adults of *L. glutinosa* were
observed in the forest alongside these seedlings, the most likely explanation for their
unexpected distribution is seed dispersal by frugivorous birds feeding on *L. glutinosa*. It is
unknown whether these seedlings will be able to establish and grow in the relatively closed-
 canopy primary forest.

**III. Management Recommendations**

The long-term goal of invasive species management at Analalava Reserve is complete
eradication. On a shorter and more feasible scale, though, management will take the form of
containment and control. Methods for controlling and containing invasive plant species vary
widely, and the main categories include physical, cultural, biological, and chemical control
(Clout and Williams). Naturally, different strategies are more or less effective for each
species under consideration. In general, biological and physical control methods are not
recommended for any of the invasive species assessed in this study. An integrated
management approach is recommended in each case, including chemical control for
*Melaleuca quinquenervia* and a form of cultural control for *Psidium cattleianum* and *Litsea*
Integrated weed management (IWM) uses a combination of control strategies. It also takes into account broader-scale ecosystem factors, such as the effects of these strategies on other organisms in the system (Clout and Williams). The more comprehensive considerations of IWM are well-suited to the biodiverse and locally important environment of Analalava Reserve.

*Melaleuca quinquenervia*

Due to *Melaleuca quinquenervia*’s highly invasive status in the United States, extensive research has been conducted regarding its control and eradication (“Melaleuca”). Of the three invasive species studied here, it is the best-researched and has the most promising plan of action for successful management. *M. quinquenervia* has been shown to be effectively controlled by application of the herbicide glyphosate, a form of chemical control. In fact, a study demonstrating this success was conducted at Analalava itself. Based on the work of Miandrimanana et al., a diluted (by at least 75%) dose of glyphosate applied with a brush to the cut trunk of *M. quinquenervia* is the best and most efficient management strategy for this type of control. Notably, the glyphosate did affect nearby (non-invasive) plants, although the effect was less pronounced when brushing, rather than spraying, the herbicide. This unintended result should be closely monitored to avoid causing detriment to native biodiversity as much as possible. Nonetheless, chemical control following the conclusions of Miandrimanana et al. is this study’s recommendation for managing *M. quinquenervia* at Analalava.

Other types of control are not likely to succeed at Analalava: For example, *Melaleuca*’s preferred habitat of wetland and riparian areas will remain throughout the reserve; this fact, and the species’ strong competitive abilities, make cultural control an improbable strategy. Physical control is also unlikely to be effective. In particular, the physical control method of fire should definitely be avoided, because *M. quinquenervia* seeds disperse opportunistically after environmental disturbances, especially fire (“Melaleuca”). Current outreach and education efforts with local communities should be continued to ensure fire prevention (Plan). In addition, an intriguing potential strategy for future management is harvesting *M. quinquenervia* for its commercially valuable nirouli oil, which could be set up as an alternative livelihood activity for local farmers (Tilahimena). However, this idea requires further study to assess its feasibility and effectiveness at Analalava.
**Psidium cattleianum**

Unfortunately, considerably less data exists regarding the control of *Psidium cattleianum*. As one of the IUCN’s 100 World’s Worst Invaders, investigations into its management are no doubt underway in other countries in its invasive range. Hopefully, this research will lead to the development of effective management strategies for *Psidium cattleianum* that can be applied to the population at Analalava. In the meantime, the primary recommendation of this study is to continue ongoing reforestation efforts in degraded areas of the reserve. Reforesting these open areas will reduce the preferred habitat type of *P. cattleianum*, ideally limiting its spread throughout the forest. This strategy can be considered a type of cultural control. If possible, further research should be conducted to test potential control methods.

Several other management strategies are known to be ineffective with this species and should not be used. Specifically, glyphosate is not effective against *Psidium*, and neither is the physical control method of manual removal: the species’ ability to vigorously regenerate via stump sprouting and other vegetative propagation renders manual control perhaps more detrimental than helpful (Tilahimena; “Psidium”). There is no known effective method of biological control for *P. cattleianum*, and even if there were, it would likely not be feasible to implement at Analalava.

**Litsea glutinosa**

Similarly to *P. cattleianum*, not much information exists regarding effective control strategies for *Litsea glutinosa*. In fact, this species’ very presence in Madagascar is not widely known. Therefore, conducting and keeping up with research into *Litsea* control in its invasive range is the primary avenue for its effective management. In addition—and again, mirroring the strategy for *Psidium*—continued reforestation of degraded areas at Analalava should help limit *L. glutinosa’s* preferred habitat, implementing a variety of cultural control. As forest exploitation is no longer a concern in the protected reserve, the area of open/degraded habitat zones should only decrease as reforestation continues. No types of physical, chemical, or biological control are known to be effective against *L. glutinosa* at Analalava (Tilahimena).

Another important management strategy is monitoring the population of invasive species, including any changes in distribution and abundance. This is especially important
for *L. glutinosa* because of the numerous isolated seedlings observed within the forest interior (Figure 11). As mentioned above, it is unknown whether these *L. glutinosa* seedlings can or will survive in the closed-canopy primary forest. The presence of these seedlings could be a recurring, but not progressing, trend due to seed dispersal by birds eating the *L. glutinosa* fruits. Alternatively, this finding could be an early-stage observation of the *Litsea* population’s expansion into the primary forest. Further monitoring of the *L. glutinosa* population and distribution at Analalava is crucial to determine the significance, or lack thereof, of this youthful sub-population.

**IV. Suggestions for Future Studies**

This project served as an unbiased exploratory/reconnaissance survey of the three target species: *M. quinquenervia*, *P. cattleianum*, and *L. glutinosa*. Further study of each of these species, and their presence and effects at Analalava, would likely be more useful if they were targeted toward areas where the invasives are known to exist: along forest edges, in open areas, and riparian zones. Although an unbiased method was chosen for this study, a biased or non-random methodology makes more sense for collecting more detailed data about these species. A more extensive survey could also collect a greater variety of data, such as environmental conditions and other species’ co-occurrences in areas where invasives are present. The fieldwork conducted in this exploratory/reconnaissance survey could be a useful baseline for future work on these target species, such as extensive or intensive surveys (Rew and Pokorny). In particular, an interesting factor to analyze is species density of invasives in the reserve. This is a useful statistic to have for management and planning purposes; due to the nature of this study’s methodology, it was not really feasible to calculate, but future studies would do well to include this type of analysis.

Another useful topic for future studies would be surveying other invasive species present at Analalava. *Grevillea banksii*, an exotic shrub in the family *Proteaceae*, was observed during this study, although it did not appear to be widespread. In addition, the native (but not endemic) fern *Dicranopteris linearis* is a dominant species that forms dense, monospecific mats in the forest understory. It is characterized as a pioneer species and usually found in more open, sunny areas, such as some of the degraded patches at Analalava. A “*Dicranopteris*-dominated understory” has been found to significantly alter biotic and abiotic
ecosystem processes (Zhao et al.). *D. linearis* was observed to be widespread, and usually extremely dominant, throughout Analalava Reserve during the course of this fieldwork. Although it is not exotic, *D. linearis* may represent a significant threat to rarer and/or less dominant species in the forest. This species could be considered a native invasive, and its presence and interactions at Analalava would be a good topic for future study.

**Conclusion**

The systematic exploratory/reconnaissance survey conducted in this study generated the first data about the general distributions of *Melaleuca quinquenervia*, *Psidium cattleianum*, and *Litsea glutinosa* at Analalava Species Reserve. These target species are the most significant exotic invasive plants at Analalava. Each of the three invasive species studied was not found to be widespread within the reserve, and mainly restricted to forest edges and open areas (with the exception of some *L. glutinosa* seedlings). In addition, most points where the species were present constituted a “low” invasion level. This data on distributions and invasion levels can inform management strategies to most effectively control each species. In general, this study suggests an integrated approach, with elements of chemical control for *M. quinquenervia* and cultural control for *P. cattleianum* and *L. glutinosa*. Important aspects of the suggested strategies include continuing reforestation efforts and outreach with local communities, and monitoring the populations of each species, especially *L. glutinosa*. In addition to informing realistic management recommendations, this study serves as a jumping-off point for further research into invasive species at Analalava. More detailed data about each of these plants, as well as studying other invasive present at the site, will serve to increase understanding of the second-largest threat to biodiversity at Analalava Special Reserve.

**Works Cited**


Appendices

Appendix I. Additional Figures

Figure 1. An example of *tavy* outside the eastern perimeter of Analalava Reserve.

Figure 2. An infestation of *M. quinquenervia* in Analalava Reserve, with shaggy bark visible.

Figure 3. An infestation of *P. cattleianum* in Analalava Reserve, with reddish bark visible.

Figure 4. An example of *P. cattleianum*’s vegetative regeneration via stump sprouting.
Figure 5. A mature individual of *L. glutinosa* at Analalava Reserve.

Figure 6. The thirteen transects conducted during the fieldwork of this study.

Figure 7. Diagram of the point-transect method utilized during the fieldwork of this study.
Appendix II. Transect Endpoints and Sample Calculations

![Intended/optimal transect lines superimposed on actual transect points.](image)

<table>
<thead>
<tr>
<th>Transect</th>
<th>Intended Latitude (degrees)</th>
<th>Westernmost point</th>
<th>Easternmost point</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Latitude (degrees)</td>
<td>Longitude (degrees)</td>
</tr>
<tr>
<td>A</td>
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<td>49.45747</td>
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<td>M</td>
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<td>49.45556</td>
</tr>
</tbody>
</table>

Table 3. Latitude and longitude for the endpoints of each transect conducted. Coordinate pairs in **bold** indicate the starting point for each transect.

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³ Transect K did not extend the full distance from east to west in the reserve due to time constrains, but the data collected during this incomplete transect was still included in the study.
Sample Calculation for Transect H

Calculations are based on the starting latitude of the previous/adjacent transect to the south (transect I), which is -17.71078°

250 meters / (111319.9 meters/degree of latitude) = -17.71078° - x

x = -17.71078° - (250/111319.9)

x = 17.70853° = starting latitude for transect H

Appendix III. Diagnostic Tool to Determine Invasion Level

Four levels were designated as categories for a species’ level of invasion at a given point in the transect: Not Present (N), Low (L), Medium (M), and High (H). This level of invasion was assigned while at the point during fieldwork, with the input of local guides, and was then reevaluated during data analysis (with the exception of Not Present, which remained consistent). Below are the guidelines used to assess and assign the categorical invasion level for each occurrence of an invasive species at a given point on the transect (defined as within the 5m line perpendicular to the main transect).

<table>
<thead>
<tr>
<th>Invasion Level</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Present (N)</td>
<td>No individuals present in the designated area.</td>
</tr>
<tr>
<td>Low (L)</td>
<td>1-9 individuals present in the designated area OR the individuals in the designated area do not constitute a significant (25%) portion of the plant life at this point.</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>10-20 individuals present OR the individuals present make up a significant (&gt;25%), but not dominant (&gt;75%), portion of the plant life at the point.</td>
</tr>
<tr>
<td>High (H)</td>
<td>More than 20 individuals present OR the individuals present make up a dominant portion of the plant life at this point.</td>
</tr>
</tbody>
</table>

Table 4. Criteria to determine invasion level.

The first, numerical criterion for each invasion level is a more general guideline for rapid assessment based on a quantitative count at the point. The second criterion is more qualitative in nature, and relied mainly on the visual estimation of local guides while in the field.
For points where the target species was present, and its presence could be categorized at two different levels, it was assigned the less severe of the two levels. Although it may result in somewhat of an underestimation of invasion risk, this protocol was used because many of the individuals observed were seedlings. For example, if 3 mature *M. quinquenervia* and 25 seedlings were observed at a given point, they could fall into the category of either high or medium invasion level. Because the majority of these individuals were seedlings, the population would not make up a dominant portion of the plant life at this point. Therefore, this point would be assigned an invasion level of medium.

In addition to the levels designated above, a sub-level of invasion was specified for the case of *Litsea glutinosa* specifically. While the majority of the invasives found were present around the reserve’s perimeter, many isolated seedlings of *L. glutinosa* were found and recorded in the forest interior. Obviously, however, it is unknown whether they will establish in the forest and continue this species’ encroachment on native vegetation. Therefore, the category of “jeune” (J), or “young” in French, was designated as a subset of the points with a low invasion level assigned for *Litsea glutinosa*. This category was assigned if the point contained only 1 or 2 seedlings, and no other individuals of the species. A separate map was created for *L. glutinosa* with this sub-category visually presented (Figure 11). This trend did not occur with the other two species, so the sub-categorization of “jeune” was not applied to their data.

Appendix IV. Glossary of Terms and Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
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<tbody>
<tr>
<td>IUCN</td>
<td>International Union for the Conservation of Nature</td>
</tr>
<tr>
<td>Jeune</td>
<td>“Young” (French)</td>
</tr>
<tr>
<td>MBF</td>
<td>Madagascar Biodiversity Fund</td>
</tr>
<tr>
<td>MBG</td>
<td>Missouri Botanical Garden</td>
</tr>
<tr>
<td>NAP</td>
<td>NouvelleAire Protegee (French); New Protected Area</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-Governmental Organization</td>
</tr>
<tr>
<td>Noyau dur</td>
<td>Forest “core” (French)</td>
</tr>
<tr>
<td>PAG</td>
<td>Plan d’Amenagement et de Gestion (French); Management Plan</td>
</tr>
<tr>
<td>Pare-feux</td>
<td>“Fire break” (French)</td>
</tr>
<tr>
<td>Tavy</td>
<td>Slash-and-burn deforestation for the purpose of converting land to agricultural uses (Malagasy)</td>
</tr>
<tr>
<td>Velonala</td>
<td>Malagasy NGO composed of the words “Velona” —living— and “ala” —forest</td>
</tr>
</tbody>
</table>