Conservation Efforts for Pied Tamarins (*Saguinus bicolor*)

- Evaluating Ecological Corridors for Restoring the Forest Fragments of Urban Manaus, Brazil

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Abstract

One of the Amazon´s most endangered species is the small New World primate, ´pied tamarin´ (*Saguinus bicolor)*. The species only occurs in the vicinity of the Brazilian Amazonas state capital city Manaus, where greatly scattered and fragmented small patches of highly degraded forest remain. The on-going growth of Manaus urban area has created habitat fragments where the pied tamarins now try to persevere. However, the city's incriminating matrix of busy roads and power lines, along with humans and both feral and domesticated pets, creates an impenetrable landscape for the dispersal of the species. The reduced size and poor quality of most forest fragments and the ultimate need for the dispersal of surplus individuals has highly deleterious implications for the survival of the local populations. By analysing the remaining forest fragments in urban Manaus, the aim of this study was to identify specific corridors in central Manaus that can be implemented and then to rank them according to their attributes. Having knowledge of the attributes of each passage while creating a ranking list makes planning of how to connect the fragments in order to aid the tamarin dispersal quicker and more direct. By assessing the individual grades of the corridors it will be easily recognisable where Governments, Universities, Zoos and Conservation Organizations should concentrate the most energy and resources into conserving the species.

Contents

1. Introduction

1.1 Amazonian biodiversity

The Amazon Basin contains the most extensive rainforest in the world, and approximately one-sixth of all broadleaf forest in the world lies within the Amazon (Goulding et al., 2003). Rainforests are the richest ecosystems that have ever existed on our planet. There exists a close correlation between total ecosystem size and number of species, and the Amazon basin is generally accepted as the bio-geological hub in terms of species richness (Goulding et al., 2003). The rainforest of Amazonia is considered as such a hotspot, but its high levels of biodiversity face immediate threats from human activities (Goulding et al., 2003).

Until the 1970´s, rainforest covered about two-thirds, or 4 million km^2 of the Amazon, but since then approximately 10-15 percent of the forest have been heavily modified (Goulding et al., 2003). Biodiversity at all scales is increasingly threatened by a multiplicity of human impacts, ranging from small tree fall gaps to large clear-cuts (Peres et al., 2010). It is well known that lowland and Andean Amazonia exhibit the greatest expression of tropical biodiversity on Earth, but unfortunately also the highest absolute rates of tropical deforestation (Peres et al., 2010).

1.2 Manaus urban expansion

Manaus is the capital city of the state of Amazonas and is located within northern Brazil. During the 1970´s, Manaus was comprised of less than 500.000 inhabitants (ICMBio, 2012). But with the growing industries and the Brazilian Governments objective of developing the Amazon, today the region is growing in a highly disorganized manner at an alarming rate, and the region's population is now over 2 million inhabitants (ICMBio, 2012). This extreme growth in a short amount of time has led to deforestation and fragmentation of contiguous forests, causing the formation of countless isolated islands of vegetation in the middle of a hostile urban matrix (ICMBio, 2012). Unfortunately, today many forest fragments are fading or condemned, and are removed to make way for housings, buildings and highways (ICMBio, 2012), see Fig. 1. Manaus growth is so accelerated and disordered so that the city has lost more than half of its green area in the last ten years (Gordo, 2012). The vegetation of the remaining fragments are intensely exploited (for removal of wood, bark, fruits, etc.), and hunting the indigenous fauna (Gordo, 2012). The on-going growth of Manaus city has created habitat fragments where many local and endemic species now tries to persist. The matrix of busy roads, power lines as well as human settlements and domesticated pets creates an impenetrable landscape (Gordo et al., 2013), particularly for mammals. With the increasing population, there is an accompanying increase of need of land and housings for all. The remaining fragments in inner city Manaus and outskirts of the city are drastically being replaced by legal and illegal invasions of large groups of people in need of space (Da Costa et al., 2012). A few green parks and some forest reserves make up the majority of the green areas, although there are few or no connections in-between them (Vidal & Cintra, 2006). Alas, with the rapid expansion of the city and human impacts such as deforestation, fires, building of roads and as well as selective withdrawal of wood, secondary forests in different successional stages are now occupying large areas (Gordo, 2012).

Fig. 1. Images representing the destruction of urban Manaus during March 2015. Top left: Trash from neighbouring housings thrown out and compiled in forested areas. Top right: Image showing the pollution and discolouration of a small local river. Low left: The clearing of a forest for the construction of the new highway "Avenida das Flores", which intersects central Manaus and the last remaining forest fragments in the area. Low right: Image revealing the settlement of illegal housings in what used to be an undisturbed forested valley. (Photos by S. Barr).

1.3 Habitat fragmentation

Habitat fragmentation is a landscape scale process in which continuous habitat is broken apart into fragments scattered within a matrix of non-habitat (Arroyo-Rodriguez, et al., 2013). Unfortunately, loss and fragmentation of habitat is among the biggest problems for the conservation of biological diversity (Gordo, 2012). Fragmentation affects environments in a multitude of ways. It creates loss of biodiversity, changes in composition of communities, changes in population density, allows the invasion of opportunistic species and reduces in gene flow (Gordo, 2012).

The main difficulties of habitat fragmentations stem from three factors; (I) the habitats´ reduced area, (II) changes at the habitats edges (also called `edge effects`) and (III) increased isolation (Hambler, 2004). Edge effects pose a serious problem with smaller fragments since the effect of predation increases, as does the exposure to human disturbances and the risk of animals being killed by roads (Hambler, 2004). These problems may be so serious that it will create a `sink population´ within the small fragments. Regions with high human density pose a particular threat to the endangered species because this intensifies the negative factors associated with fragmentation (Gordo, 2012). With decreased area available for a given population, due to the fragmentation and habitat loss, the total number of individuals tends to decrease (Gordo, 2012). Thus, the risk of local extinction will increase since many factors cause natural fluctuations in population size of small populations. Reed et al., (2003) estimated minimum population viability of different taxonomic groups, and concluded that vertebrates require populations with thousands of individuals to be sustainable in the long term.

Fragmentations also cause disruption of gene flow between the remaining populations, and may eventually reduce the genetic variability of metapopulations (Gordo, 2012). Loss of genetic variation and rapid changes of genetic parameters in general can reduce a population's ability to respond to changes in the environment (Gordo, 2012).

1.4 Pied tamarins

Primates are the mammal order which has the largest amount of threatened species in the world. Almost 20% of Brazilian primates are on the Official list of Brazilian fauna species threatened with extinction (ICMBio, 2012). One of the most threatened species of the Amazonian rainforest is the pied tamarin (*Saguinus bicolor, Spyx 1823*) (Vidal & Cintra, 2006), and according to IUCN´s Red List, the species is considered as `Endangered` (Mittermeier et. al., 2008; Rylands et al., 2008).

The pied tamarin is highly endemic, with a distribution almost exclusive to the area around Manaus (ICMBio, 2012). Destruction and fragmentation of *S. bicolor* habitat are the main threats to the conservation of the species, particularly in the urban area of Manaus, due to fragmentation (ICMBio, 2012). Small and isolated populations are already a reality for many species of Neotropical primates, including *S. bicolor* (Gordo, 2012), which has been affected by fragmentation and loss of habitats in different biomes. The fragmented and isolated populations of this species are often heavily reduced, and are often only visible in suboptimal environmental conditions (Gordo, 2012).

Pied tamarin groups currently survive in small, highly degraded forest patches around housings, and in the suburbs of Manaus. Within these fragments, Gordo (2012) estimated that less than 500 individuals of *S. bicolor* remain. The pied tamarin suffers extensively from road kills, shocks from electrical power, attacks from domestic animals, abuse and capture by the inhabitants in the surrounding towns of the matrix (Gordo et al., 2013). It is common to find groups of *S. bicolor* surviving in fragments that are extremely degraded and reduced in size (between two and ten hectares), i.e. with area and quality below what appears to be necessary to sustain a healthy group (Gordo, 2012).

Within Manaus matrix, the pied tamarins largest protected areas are the Amazonas Federal University campus (UFAM) of 760 ha, and the buffer zone of Eduardo Gomes International Airport of 800 ha. *S. bicolor* also remain in the larger preserved areas outside Manaus, e.g. Adolpho Ducke reserve (10.000 ha), and Centro de Instrucao de Guerra na Selva (CIGS) reserve (110.000 ha) (Gordo, 2012; ICMBio, 2012). Unfortunately, these large areas are not a part of the National System of Protected Areas (SNUC) or the State (SEUC) or Municipal systems of protected areas (ICMBio, 2012). The reduction of the pied tamarins already restricted geographic distribution, combined with population declines, are considered to be the main factors that threaten the species.

Because of the severe situation of pied tamarins, the Instituto Chico Mendes de Conservacao da Biodiversidade in Brazil (ICMBio) established the Executive Summary of National Action Plan (NAP) for the Conservation of the Pied Tamarin in 2012. The goal for the project was that the NAP should be implemented within five years in an attempt to reverse the situation for the primate (ICMBio, 2012).

1.5 Connecting fragments through wildlife corridors

A promising and successful outgrowth of the biodiversity approach has been the conservation corridor concept (Corlatti et al., 2008; Teixeira et al., 2013; Humphrey et al., 2014; Lee, et al., 2014; Matisziw et al., 2014). The concept calls for efforts to link already protected areas by officially protecting the areas that separate them, especially when these are relatively close to each other. By linking protected areas together, a conservation corridor is created (Goulding et al., 2003). These conservation corridors are also referred to as `migration corridors´, ´wildlife corridors´ and ´ecological corridors´ (Goulding et al., 2003). Corridors can act as an undisturbed path where the species can disperse, allow natural behaviour, adapt, take shelter from human disturbances and potentially create the possibility for gene flow (Tillmann, 2005). However, the use of corridors may increase population viability, but negative effects such as greater risk of dispersal of invasive species, increased exposure to predators, increased exposure to and dispersal of pathogens and spread of fire may occur (Hambler, 2004; Haddad et al., 2014). Furthermore, conservationists must be aware that corridors may increase edge effects and take this into consideration when assessing if corridors are the best conservation tools (Hambler, 2004).

Luckily there are many successful wildlife corridors projects. One of them is the 700-hectare forest corridor linking the two major biome protected areas in Pontal do Paranapanema (west of the State of São Paulo, Brazil) and the State Park of Morro do Diabo. This is where the highly endemic and endangered black lion tamarin (*Leontopithecus chrysopygus, Mikan, 1823*) still persists. The objective of this wildlife corridor project was to conserve the biodiversity of the Atlantic Forest through extensive forest restoration. In 2002, a total of 1.4 million trees were planted and are now monitored by the Institute for Ecological Research in Brazil (IPE, 2015). In Manaus, the remaining fragments may be optimally connected through the re-planting of trees. Important genera of trees for pied tamarins include *Inga*, *Spondias*, *Platonia*, *Celba*, *Hymenaeau*, *Parkia*, *Poraqueiba*, *Clitoria*, and *Sthryphnodendron* as they have good, long living timber and create great canopies for connection (Gordo, 2012). Fruit bearing trees such as *Theobroma (Cacao)*, *Musa (Banana)*, *Carica (Papaya)* and *Mangifera (Mango)* species are also suitable as they create pronounced umbrella canopies, and have either flowers with nectar or fruits that *S. bicolor* can eat. Palms can also be suitable, as the tamarins sleep in them and hunt for insects (Gordo pers. comment, April 7 2015).

Unfortunately, forests are frequently being intersected and fragmented by human activities, e.g. construction of roads. These have direct effects on animal populations by affecting mortality, habitat availability, habitat quality, and degree of fragmentation (Bissonnette et al., 2008). Roads also have indirect detrimental effects by creating barriers, reducing connectivity and permeability, and increasing edge effects (Groom et al., 2006). Thus, the expansion of roads results in diminishing ability for animals to move and disperse, which in turn has profound impact on individual fitness, population structure, life history strategies, foraging dynamics, and species diversity (Bissonnette et al., 2008). Just within the fragment of Universidade Federal do Amazonas campus (UFAM) in central Manaus, traffic kills an average of 10 *S. bicolor* individuals per year (Gordo pers. comment, April 1 2015).

However, fragments and intersections may be reduced and connected through wildlife crossings, bridges and/or tunnels. These are structures that aim to re-establish the movement of animals over a road, helping to connect the divided areas. Generally, current knowledge of the effectiveness of wildlife crossing structures is still limited, although increasing quickly (Corlatti et al., 2008). The key elements for the design of effective mitigation measures are not fully understood and different solutions may be needed for different faunal groups (Teixeira et al., 2013).

1.6 Ex-situ conservation

Another point of conservation for the species is breeding the species ex-situ. There is a captive breeding programme for *S. bicolor*, derived largely from the Rio de Janeiro Primate Centre (CPRJ) and the Universität Bielefeld, Germany, and all ex-situ *S. bicolor* are registered as the property of the Brazilian government (Mittermeier et. al., 2008). Among other ex-situ keepers, Universeum Science Park and Museum in Sweden holds 2 female *S. bicolor* as a part of a European Endangered Species Programme (EEP), the most intensive type of population management for a species kept in European Association of Zoos and Aquaria (EAZA) zoos. The primary aims of zoos is to maintain a large enough unaltered gene pool to ensure the species survival and create prospects to reintroduce the species back into protected areas, but also to educate and inform the visitors of the challenges vulnerable and endangered species undergo, along with the current conservation efforts (WAZA, 2015).

1.7 Intentions for this project

By analysing the remaining forest fragments in urban Manaus, my aim was to identify specific corridors that can be implemented and then rank them according to their attributes. By knowing the attributes of each passage and then ranking them, to find the best routes, it is possible to connect the fragments in order to aid the species dispersal. If ensuring that the fragments are connected and by controlling other defining parameters at each site, such as amount of traffic, trash and invasive species, there is an elevated chance that the pied tamarins will be able not only to disperse from the city´s isolated fragments, but also elevate the city´s ecological state and awareness of the local endemic species. I also looked into connecting the fragments with a hypothetical corridor (test corridor) that will connect them all and create one large fragment that connects into the protected areas of Adolpho Ducke reserve, north of Manaus.

With my ranking of the corridors, it will be easily recognisable where to put the most effort into conserving the species. Hopefully, this is not only usable for the Municipal region of Manaus and the Brazilian Government, but also for other conservation advocates that may use this information to increase support to the conservation of the species.

2. Methods and materials

2.1 Species description

The Neotropical region of South America hosts more than one hundred species of primates (suborder *Platyrrhini*). The family of *Callitrichidae*, which consists of marmosets and tamarins, is currently the most numerous with 41 species in seven genera (Schneider & Sampaio, 2013; Buckner et al. 2014). Callitrichids are small primates (adult weight ≤ 600 g), with their nails claw shaped and generalist habits to explore different environments (Gordo, 2012; ICMBio, 2012). *Callitrichidae* distribution includes Panama, Paraguay, and Paraná, and occurs in all regions of Brazil (Eisenberg & Redford, 1999). *Saguinus bicolor* occurs North of the Rio Amazonas, East of the Rio Negro, and in the vicinity of Manaus (Fig. 2) (Mittermeier et. al., 2008; Rylands et al., 2008; ICMBio, 2012; Boubli et al., 2014; Buckner et al., 2014). In the Northern parts, *S. bicolor* distribution extends to approximately 50 km of the river Amazon (Gordo, 2012). It has been suggested that *S. bicolor* does not expand further north, because of competition from *Saguinus midas (L., 1758)*, a parapatric species with a broad distribution East of the Rio Negro (ICMBio, 2012). As the *S. bicolor* geographic range of 7500 km^2 coincides with the Manaus city region, populations within the region are almost all completely isolated from each other (ICMBio, 2012; Gordo et al., 2013).

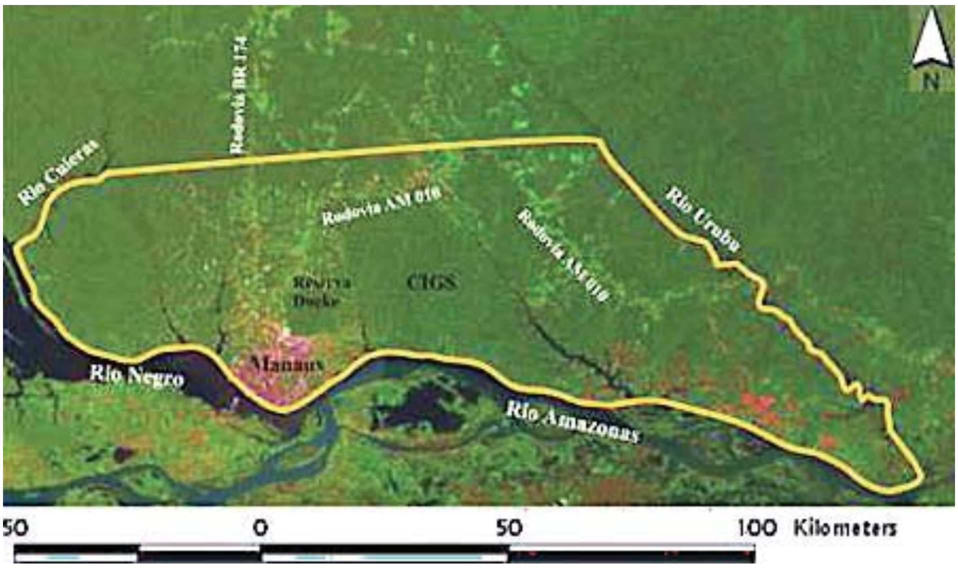

Fig. 2. Distribution of *Saguinus bicolor* in Amazonas Brazil.

The name ´pied tamarin´ is inherited from the white fur on the primate's neck, back and thorax, with the remaining fur a brownish orange to dark brown colour (Fig. 3).
The other predominant characteristics include the hairless black skin on its face, head and ears, hence the species other common name as ´bare face tamarin´ (Rylands et al., 2008; ICMBio, 2012).

Fig. 3. Photo of *Saguinus bicolor* showing the characteristics of the pied tamarin. Photo taken in local urban forest fragment of Manaus, Brazil. (Photo by S. Barr).

Although it is shown that they prefer the lower layer of dense forests and marginal vegetation, the tamarins mainly feed on fruits and insects, but can also eat small vertebrates, eggs, nectar, and sap from trees (Gordo, 2012), as well as nectar and flowers (ICMBio, 2012). The availability of food in tropical forests varies systematically throughout the year, and has a strong influence on the pattern of primate behaviour (Peres, 1994). Behavioural parameters, such territory size, can vary widely not only within a species, but also within the same social group over time (Peres, 1994). *S. bicolor* exhibits diurnal behaviour, and are active just after sunrise, rest during the hottest hours of the day, and then search for a location to sleep a couple of hours before sunset (ICMBio, 2012). The species is not sexually dimorphic, and the female will usually carry 1-2 offspring once or twice a year. The infants are raised by all members of the groups (ICMBio, 2012). The primates form groups of different sizes varying from 2 to 12 individuals, with one dominant matriarch. Both sexes disperse to form new group by the age of 2-3 years (ICMBio, 2012). Pied tamarins are extremely territorial, and physical confrontations may occur between neighbouring groups (ICMBio, 2012). The size of the home range varies significantly between different species of Callitrichids, but usually a group occupy areas in the range of 20 to 50 hectares (Gordo, 2012). Callitrichids are known for their tendency to efficiently colonize disturbed and marginal forest environments (Gordo, 2012). In general terms they prefer the dense vegetation of low vegetation habitats, where they feed on insects. But even though Callitrichids often act as opportunistic and colonizing species and will change environments and use fragmented habitats, they can still suffer from serious problems of fragmentation, isolation and degradation of the environment (Gordo, 2012).

2.2 Study area

Manaus is the capital city of the state of Amazonas, located in northern Brazil (Fig. 4), and is situated at the union of the Negro and Solimões rivers (Goulding, et al. 2003). The city is inhabited by 2 million people, but the population is quickly increasing (ICMBio, 2012). The climate of the region is humid and with little or no water deficiency, high temperatures and potential evapotranspiration distributed evenly throughout the year. The rainier season occurs from December to April, with an average monthly temperature of 23°C and relative humidity between 85 and 90%. The less rainy season runs from July to September, with monthly average temperature of 28° C and relative humidity between 75 and 80%. The characteristic vegetation cover in the region of Manaus is tropical moist forest, corresponding to dense forests with emergent trees and high diversity (Goulding, et al. 2003; Gordo, 2012).
This study was conducted in the urban areas of Manaus, between March and May 2015.

Fig. 4. Manaus location in the Amazonas State of Brazil, South America.

2.3 Methodology

2.3.1 Forest fragments

The forest fragments within the city of Manaus are widely spread. In the eastern and western parts large fragments of over 100 ha still remain, and have relatively good connectivity with one another. Within the central parts, only small and extremely fragmented forest remnants remain and these are largely disconnected (Fig. 5). Since these fragments are disappearing quickly, it is considered most important to maintain and connect these remaining fragments, in order to conserve a viable and breeding metapopulations of pied tamarin. The goal by creating connecting passages to these scattered fragments is to reduce the inbreeding coefficient as well as support dispersal of the species.

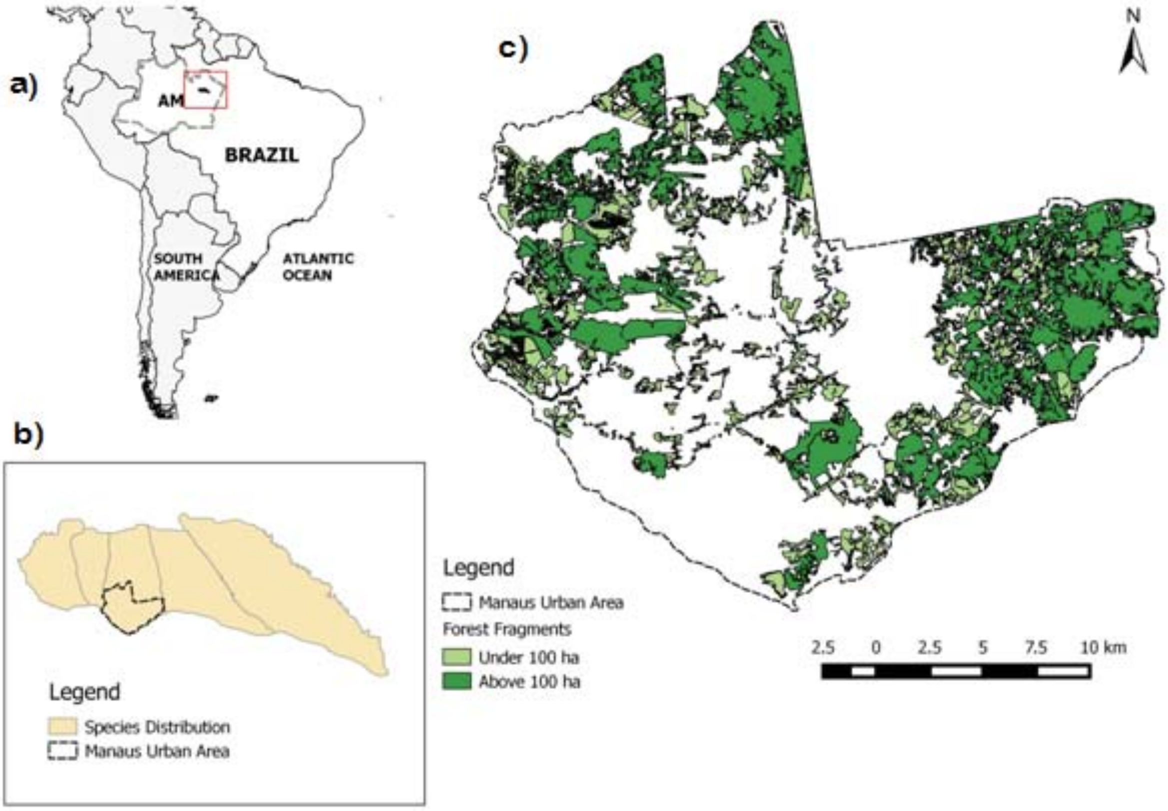

Fig. 5. Figure describing a) the location of South America, b) the Amazonas region and Manaus urban area, and c) representing the forest fragments <100 ha and >100 ha in urban Manaus.

2.3.2 Research points

As a part of the ICMBio´s "Executive Summary of National Action Plan for the conservation of the Pied Tamarin" in 2012, Coelho (2013) performed a mapping of areas of suitable habitat in central Manaus, and analysed the degree of fragmentation and functional connectivity of the Manaus urban area for the pied tamarin. His main results included that the total area mapped of Manaus is 48.000 ha, and that 40.17% was covered by habitat for *S. bicolor*. 4281 corridors were identified between all fragments, concentrated to the regions North, West and Southeast of the urban area. He also identified 29 priority fragment complexes. These 29 fragments are made up of highly deforested areas, with high amounts of human disturbances. Coelho (2013) concluded that although seriously fragmented, the Manaus urban area still features large tracts of habitat in its periphery, but 29 priority fragments complexes need urgent installation of conservation corridors and the use of speed reducers.

For this project, I have added the research points of the Municipal Park of Mindu and Sumauma State Park, for their importance in habitat size and since they undergo fragmentation by intersecting roads and other human disturbances. Consequently, I studied a total of 31 research points (Fig. 6). For a detailed overview of each research points coordinates, see Appendix I, Table I.

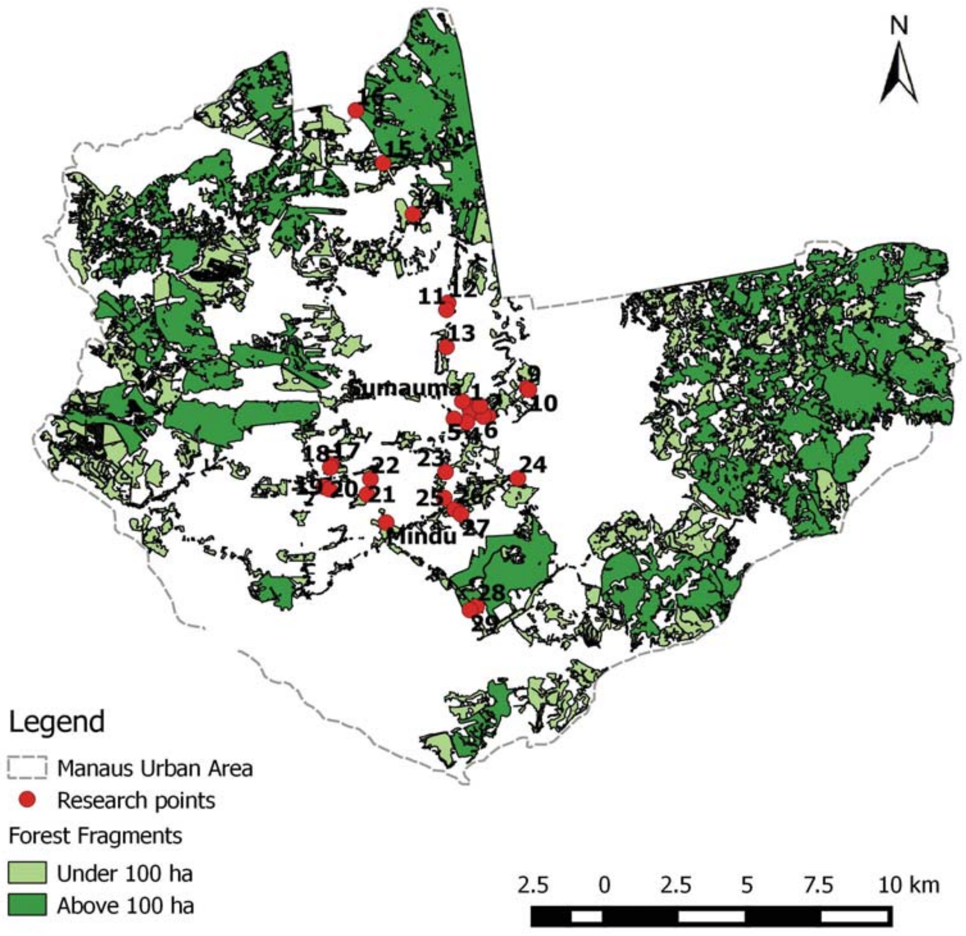

Fig. 6. Map of the 31 research points and forest fragments under 100 ha and above 100 ha in urban Manaus, Brazil. Numbers 1-29 were identified by Coelho (2013), whereas Mindu and Sumauma where added in the present study.

Since it is of great importance for the species to disperse into larger reserved areas, I also examined whether it was possible to connect the central Mindu corridor to the outskirts of Manaus and Adolpho Ducke reserve, trough what I later will describe as a “test corridor” (see *3.2 Test Corridor*).

2.3.3 Parameters at each corridor

In order to implement the best option of corridor, a certain amount of parameters were needed to be specified for each site. By scoring each site according to the passages parameters and difficulty to implement, it becomes much clearer which passages that are most essential and easiest to implement. I therefore developed a scoring system in collaboration with my supervisors Dr. Gordo and Dr. Rasiera, in order to obtain useful ranges and classifications.

2.3.4 Description of parameters

(I) Water - Because Manaus has a wide variety of rivers and streams, water bodies were important to locate because these influence the natural distribution of vegetation and the degree of human disturbances (Goulding, et al. 2003). The parameter was observed and measured by visual localization of stream/river. The presence of water was calculated within the distance of 10 meters. Scoring ranged between 0-5 p, where 0 indicates no water present.

(II) Pollution and trash - The amount of clean up needed before re-vegetation and re-plantation. The amount of trash and the amount of pollution of the corridors was determined visually as the amount of rubbish on the ground and the clarity of water relative to the sites natural surroundings. Scoring ranged between 0-10 p.

(III) Electric wiring – Because the lack of isolation in the electric wiring electrocutes *S. bicolor* and other wildlife (Gordo pers. comment, 1 April 2015), I identified the places where there was a need to isolate the wires. Scoring ranged between 0-10 p.

(IV) Traffic - The amount of traffic at a site is highly correlated to the amount of road kill each year (Gordo pers. comment, 1 April 2015). The amount of traffic was observed by visually determining the number of vehicles per minute (total time 1 minute at each point). Scoring ranged between 0-10 p.

(V) Speed bumps - The extent of traffic determines whether or not it is possible for speed bumps to be applied, as intense traffic will cause difficulties implementing speed bumps. The possibility for implementation for speed bumps was thus correlated with the amount of traffic, and also to whether or not a speed bump would be possible. Scoring ranged between 0-10 p.

(VI) Warning signs – Warning signs are presumed to reduce the number of wild animals killed. I recorded all warning signs at each site. Scoring ranged between 0-5 p.

(VII) Canopies connecting over road - If canopies are enclosed over the intersecting road this is crucial, because it allows safe passage for wildlife. This will also determine the species of trees to be re-planted. I observed if one or several tree canopies were connecting overhead. Scoring ranged between 0-10 p.

(VIII) Rope ladders - Determining whether or not a rope ladder is possible to implement is important, as this conservation act can be implemented immediately. I determined the possibility for ladders based on connecting canopies and height of the trees. Scoring ranged between 0-10 p.

(IX) Vegetation type (reoccurring species) - A characterization of the surrounding vegetation was conducted at all sites. The vegetation type of reoccurring species has a major implication for what species and distribution a re-plantation should have. A number of photos were taken

at all sites in order to classify the genera of the surrounding trees of the projected corridor points. The photos were taken from the central point of each potential corridor. Scoring was conducted through estimation of genus (Gordo, pers. comment, 1 April 2015), 1 p per genus.
(X) Possibility to re-vegetate area – I determined whether or not the area was possible to re-vegetate, taking photos of vegetation from each site. Scoring ranged between 0-10 p.
(XI) Height of vegetation – I measured the height of the vegetation at all corridors. The average height (in meters) was determined visually. Scoring ranged between 0-10 p.
(XII) Width of road and fragment - The width of the habitat corridor and the width of road was measured in Google Earth (in meters). Scoring ranged between 0-10 p.

2.4 Set-up of field study

This study examined 31 fragments (Fig. 6) and identified whether or not a corridor was possible to implement at each site. In addition, I looked at 13 points for a test corridor (Fig. 7) to connect to the protected areas of Adolpho Ducke reserve. Moreover, I classified how each corridor was manageable (Simple, Moderate or Difficult), based on the measures needed to be taken in form of re-plantations, speed bumps, warning signs, rope ladder implementation, de-pollution and cleaning up trash and removing invasive and/or non useful plant species. The corridors were ranked by connectivity to each other and range of difficulty to implement and maintain. A brief classification of the surrounding genera of trees of each corridor was also performed, to determine need for re-vegetation and maintenance.

2.5 Analyses

With the use of a Garmin GPSMAP Model 76CSx, the locations of my research points could be located using defined GPS-coordinates described in Appendix I, Table I. Data was input using Excel, implementing the data onto maps in QGIS Wien (Version 2.8). If the central point of a site was not possible to visit, the nearest possible point was examined, and photos and descriptions of the vicinity were noted. Using the statistical SPSS software (Version 22), a Kruskal-Wallis test was used to determine any statistically significant differences between the three corridor classification groups (Simple, Moderate and Difficult) describing the difficulty of implementation of each corridor correlating to the number of plant genus found. Also, a Spearman Correlation test was used to determine the relationship between the importance of the plants to *S. bicolor*, and the rankings of the passages.

3. Results

Overall, the sites varied largely regarding specific attributes and parameters, local vegetation and connectivity to one another (as described in *2.3 Methodology*).

3.1 Fragment connectivity

90% of the 29 sites from Coelho (2013) are within close proximity of each other (Fig. 6). The passages that are isolated are #17-22, which are located northeast from The Municipal park of Mindu (which can be perceived as being central in the passages I have studied).
#17-22 will remain isolated from the Mindu passage, although with relative close connectivity to one another. Also, passages #11-12 and #14-16 are far apart, with passages #14-16 completely isolated from one another. This is due to the current construction of the large motorway named "Avenida das Flores", which intersects a huge part of central Manaus. Otherwise, the rest of the passages are in close proximity of one another.

3.2 Test corridor

In the landscape analysed, there were several areas of habitat crossed by streets, paved by houses and intersected by large avenues. In the outskirts of Manaus, the fragments are larger and less urbanized. Since it is of great importance for the species to disperse into larger reserved areas like CIGS and the Adolpho Ducke reserve, I examined whether it was possible to connect the central Mindu corridor to the outskirts of Manaus and Adolpho Ducke reserve. I tested 13 points in northern Manaus, now named S1 to S13, to see if a connection could be possible (Fig. 7).

3.2.1 The Mindu corridor

The Test corridor was designed to have a close proximity to the Mindu corridor. The Mindu corridor is based on a chain of fragments projecting east from the Municipal Park of Mindu (see Fig. 7, Passage #Mindu). These fragments lie in close connection to one another. Therefore it would be probable to create a decent chain of corridors that protrude out of Municipal park of Mindu, and through my Test corridor, connect with Adolpho Ducke reserve. This will create an almost unbroken string of forest fragments to help the tamarins disperse out of the Mindu Park and the other close fragments.

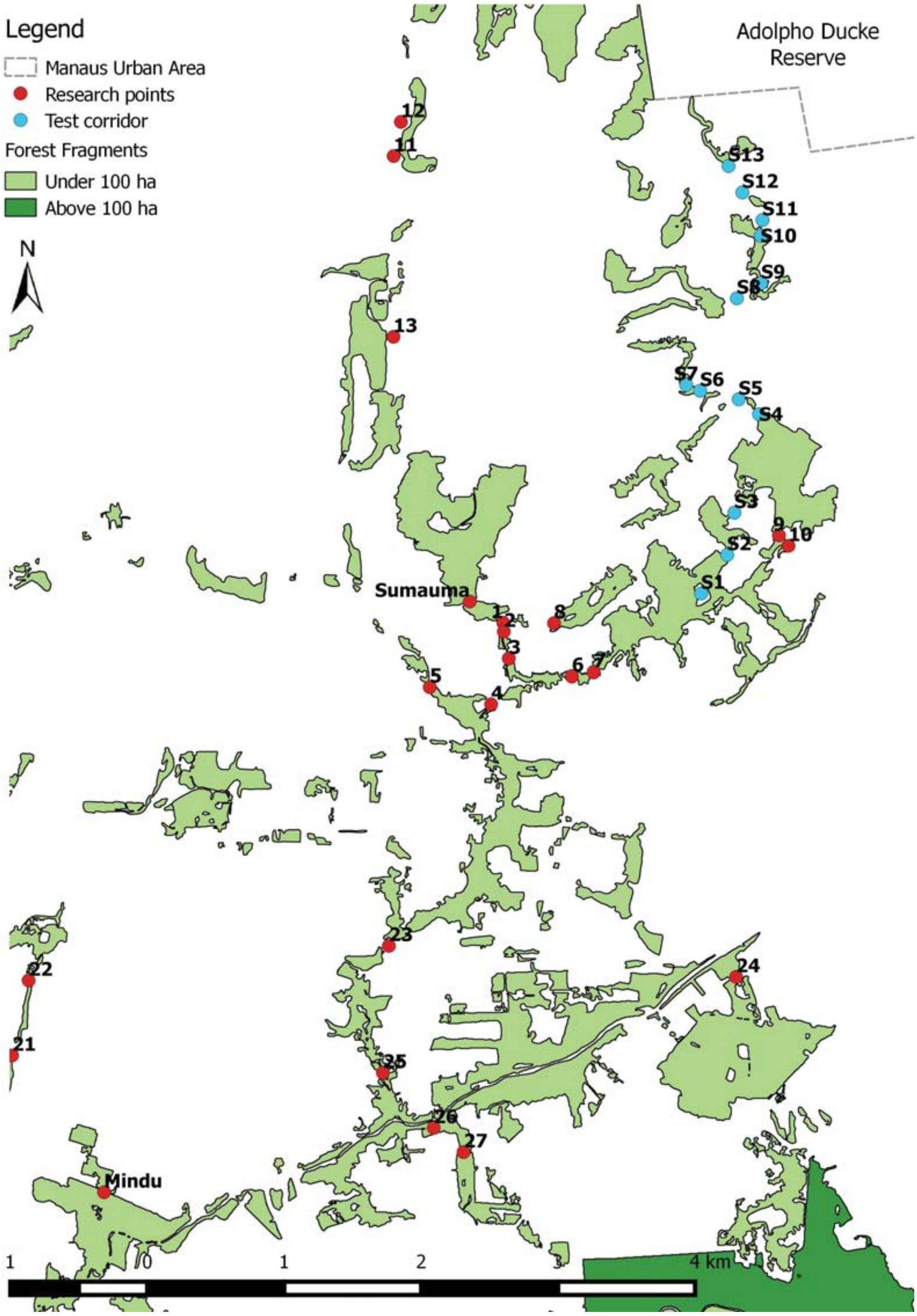

Fig. 7. The map shows the area locally named “The Mindu Corridor”, because of the location of the Municipal park of Mindu in the low left corner. The figure also shows the 13 sites in the Test corridor potentially connecting the central Mindu passage with the Adolpho Ducke reserve.

3.3 Rankings of the passages

By using the parameters for each site described in *2.3.4 Description of parameters*, there was a possibility to define and rank each site according to the characteristics of the parameters.

3.3.1 Simple passages

The definition of ranking a potential conservation corridor as “Simple” was a passage that either instantly can be connected with rope ladders or that it already contains small connecting canopy (Fig. 8). It was a passage that could be easily improved by cleaning up a limited amount of existing trash and pollution, removing a limited amount of seedlings of invasive species, and with the possibility of planting seedlings for buffer effect and successional re-planting high canopy trees with extended longevity. It is expected to be low cost and fast to implement at a low cost due to already existing canopy trees and/or high-quality vegetation with a decent height (exceeding 15 m). Speed bumps and warning signs could easily be established, and there is a low or no need of electric wiring isolation. Traffic is generally low, and the roads are narrow. The corridor fragments are usually larger. 12 passages were determined as Simple passages. These had a total score from 54 to 96 (Table 2).

Fig. 8. Photos represent in order; top left was a passage of “Simple” characters, top right shows a passage of “Moderate” characters, and photo below represents a passage of “Difficult” characters (Photos by S. Barr).

3.3.2 Moderate passages

A passage classified as “Moderate” was a passage that needs a fair amount of re-vegetation and cleaning at first, and can then be connected by rope ladders and/or canopies (Fig. 8). There were some existing vegetation fragments, but usually there remains one side of fragment that is acceptable. These passages will be more expensive and time consuming than that of an easy ranking. There will be some need to isolate electric wiring, and the quality of the existing vegetation is varying. There will also be a higher amount of re-plantation needed. In some cases, I ranked points as moderate yet they characterize as difficult to connect, because there is still time and the prospect to implement new changes into the habitat corridor and its surroundings. Speed bumps and warning signs are vital, as traffic is generally moderate to high, and the roads are wide. The corridor fragments were usually small or moderate. 13 passages were determined as Moderate passages. These had a total score from 39 to 53 (Table 2).

3.3.3 Difficult passages

“Difficult” was a passage that will be problematic to create and maintain, and where in the vicinity of the passage there is a high risk of *S. bicolor* to be hurt or killed (Fig. 8). It was a passage in which it occurs heavy amounts of traffic and the corridor fragments are small. These habitat corridors are heavily fragmented, and vegetation is highly degraded. Therefore, there is a high amount of re-plantation needed, along with isolations of electric wiring. The passage was characterized as heavily polluted and with a high-risk of human interference in form of illegal invasions of housings and intense traffic. It will be the most expensive and time consuming of all passages. Speed bumps not always possible as the vicinity of heavy-duty roads, but warning signs and speed cameras are essential in these passages. 7 passages were determined as Difficult passages. These had a total score from 22 to 35 (Table 2).

3.4 Rankings of the passages by manageability

3.4.1 Corridor parameters

By scoring each site according to the passages parameters and difficulty to implement, it becomes clear which passages that can be implemented faster (Table 1). The testing sites of S1-S13 were not evaluated, since they were of extremely low class, not even possible to classify in the parameters or vegetation characterization. Some parameters have a higher impact than others, simply because of the importance of the parameter.

For example "Connecting overhead vegetation - 10 p" versus "Warning signs for *Saguinus* – 5 p", as it is more important to have connecting overhead vegetation than warning signs. Maximum points were 10, minimum 0. Scores are presented in Table 2.

Table 1. Description of each of the parameters and correlating scoring.

Classification for parameter scoring in points (p):	Points (p):
Warning signs for *Saguinus*:	Yes – 5 p No – 0 p
Grade of trash:	None – 10 p Low – 7 p Medium – 4 p High – 0 p
Electric wiring with isolation:	No wiring – 10 p Yes – 5 p No – 0 p
Road width (m):	<5 m – 10 p 6 -10 m – 7 p 10 -15 m – 4 p >15 m – 0 p
Grade of traffic:	None – 10 p Low – 7 p Medium – 4 p High – 0 p

Possibility for speed bumps:	Yes – 10 p No – 0 p
Corridor width (m):	<50 m – 0 p 51-100 m – 4 p 101-150 m – 7 p >151 m – 10 p
Connecting overhead vegetation:	Yes – 10 p No – 0 p
Grade of possibility for re-vegetation:	None – 0 p Low – 4 p Medium – 7 p High – 10 p
Water presence:	Yes – 5 p No – 0 p
Possibility for rope ladder:	Yes – 10 p No – 0 p
Vegetation height:	<1 m – 0 p 1-5 m – 4 p 5-10 m – 7 p >10 m – 10 p

Table 2. The scores determined for the 12 parameters of each site. The classification "Simple" is coloured blue, "Moderate" is coloured orange and "Difficult" is coloured in red.

Passage #	Warning signs for Saguinus	Grade of Trash	Electric wiring with isolation	Road width (m)	Grade of Traffic	Poss. Speed bumps	Corridor width (m)	Connecting overhead vegetation	Grade of possibility for re-vegetation	Water precence	Poss. Rope ladder	Veg. height	Total score
6	0	10	10	10	10	10	4	10	10	5	10	7	96
27	5	7	5	7	4	10	0	10	7	5	10	7	77
18	0	10	10	10	10	10	4	0	7	0	0	10	71
Sumauma	5	7	5	4	4	10	7	0	7	5	10	7	71
25	5	10	5	7	7	10	0	0	7	5	10	4	70
19	0	4	0	7	7	10	0	10	7	5	10	7	67
26	0	10	5	7	4	10	4	0	7	5	10	4	66
Mindu	0	7	0	7	4	10	7	0	7	5	10	7	64
20	0	7	0	10	10	10	0	0	10	0	0	10	57
29	0	7	5	4	7	10	7	0	7	2	0	7	56
28	0	7	5	4	7	10	7	0	7	0	0	7	54
5	0	4	5	4	4	10	7	0	7	5	0	7	53
24	0	4	5	4	4	10	7	0	7	5	0	7	53
11	0	10	10	0	10	0	7	0	7	0	0	7	51
12	0	10	10	0	10	0	7	0	7	0	0	7	51
13	0	10	10	0	10	0	7	0	7	0	0	7	51
14	0	10	10	0	10	0	7	0	7	0	0	7	51
15	0	10	10	0	10	0	7	0	7	0	0	7	51
16	0	10	10	0	10	0	7	0	7	0	0	7	51
8	0	7	0	7	7	10	0	0	4	5	0	7	47
7	0	7	5	4	4	10	0	0	7	5	0	4	46
10	0	7	5	4	7	10	0	0	7	5	0	0	45
17	0	4	5	7	4	10	0	0	4	5	0	4	43
9	0	7	5	0	0	10	4	0	4	5	0	4	39
3	0	4	5	0	4	10	0	0	0	5	0	7	35
22	0	7	5	4	4	10	0	0	0	5	0	0	35
4	0	4	0	10	10	0	4	0	0	5	0	0	33
21	0	4	0	10	4	10	0	0	0	5	0	0	33
1	0	0	0	10	7	10	0	0	0	5	0	0	32
2	0	0	0	10	7	10	0	0	0	5	0	0	32
23	0	4	5	0	0	0	4	0	0	5	0	4	22

3.4.2 Vegetation parameters

By scoring each site according to the passages vegetation characterization and arranging them by difficulty to implement, it becomes clearer which passages that are most essential to implement faster (Table 3). The testing sites of S1-S13 were excluded, since they were of extremely low quality. Unfortunately, with the heavy deforestation and clearing of the construction site of "Avenida das Flores", it was not possible to count the plant genus at the sites. I only made the observation that there are a lot of large, long-standing trees and good vegetation in the distance, but was during this study impossible to see how close they would be to the road under construction. I therefore set a high score in the "Number of plant genera" for passages #11-16 (with the ambition to create a large score because of the determination to increase the prioritisation for these passages in order to implement the changes faster). Scores are presented in Table 4.

Table 3. Description of each of the vegetation parameters and their scoring.

Classification for parameter	Points (p):
Number of plant genera:	1 p per genus
Reconstruction requirement:	None, best possible scenario – 20 p Possible rope ladder now – 15 p New construction site – 10 p Possible rope ladder soon – 5 p Need of reconstruction – 1 p
Need for a re-vegetation plan:	None – 20 p Minor – 10 p Large – 5 p Very large – 1 p

Table 4. The scores collected for the vegetation parameters of each site. In this table the blue colour represents the classification "Simple" to implement passages, orange represents the "Moderate" passages and red represents the "Difficult" passages to implement.

Passage #	No. of plant genera	Particular plan	Re-vegetation plan	Total score
20	13	20	20	53
Mindu	16	15	10	41
28	12	15	10	37
26	10	15	10	35
27	10	15	10	35
25	9	15	10	34
19	8	15	10	33
6	7	15	10	32
29	7	15	10	32
Sumauma	6	15	10	31
18	14	5	10	29
11	15	10	5	30
12	15	10	5	30
13	15	10	5	30
14	15	10	5	30
15	15	10	5	30
16	15	10	5	30
7	12	5	10	27
9	15	5	5	25
17	13	5	5	23
8	15	1	5	21
10	15	1	5	21
24	11	5	5	21
5	13	1	5	20
22	13	1	5	19
2	17	1	1	19
21	11	1	5	17
3	7	1	5	13
23	4	1	5	10
1	5	1	1	7
4	3	1	1	5

3.4.3 Total score

By adding the two scores (corridor and vegetation parameters) I obtained a total score, which in turn was used to set all the passages in order of priority (Table 5).

Table 5. Combined score and prioritization of all of the passages according to the sum of all the scores described in *3.4.1 Corridor parameters* and *3.4.2 Vegetation parameters*.

Priority	Passage #	Parameter score	Vegetation score	Total Score
1	6	96	32	128
2	27	77	35	112
3	20	57	53	110
4	Mindu	64	41	105
5	25	70	34	104
6	Sumauma	71	31	102
7	26	66	35	101
8	18	71	29	100
9	19	67	33	100
10	28	54	37	91
11	29	56	32	88
12	11	51	30	81
13	12	51	30	81
14	13	51	30	81
15	14	51	30	81
16	15	51	30	81
17	16	51	30	81
18	24	53	21	74
19	7	46	27	73
20	5	53	20	73
21	8	47	21	68
22	17	43	23	66
23	10	45	21	66
24	9	39	25	64
25	22	35	19	54
26	2	32	19	51
27	21	33	17	50
28	3	35	13	48
29	1	32	7	39
30	4	33	5	38
31	23	22	10	32

The results of the rankings of the potential habitat corridors are portrayed in Fig. 9.

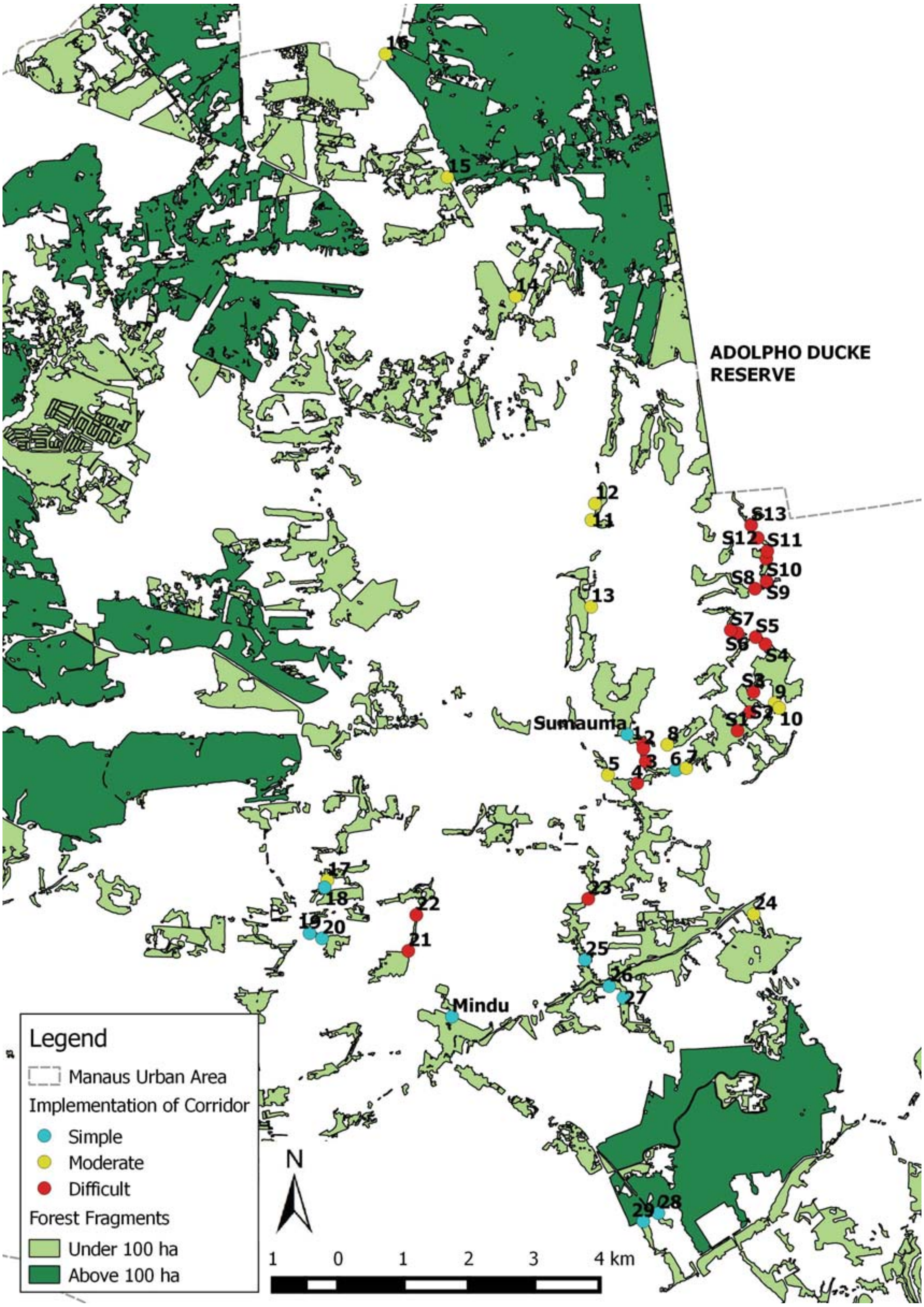

Fig. 9. Map of urban Manaus to show the range of difficulty to implement a corridor in the research point. Blue dots represent corridors categorized as Simple, orange dots represent Moderate corridors and red dots represent Difficult corridors.

3.5 Vegetation distribution

There is a clear trend that 6 species are dominating the fragments, but with the difficulties in classifying the quality of the remaining fragments in close proximity of "Avenida das Flores", I did not calculate any genera in the passages of #11-16. The most common trees found in the 31 sites are *Cecropia* in 24 (77,42%) of the places, *Clitoria* in 19 (61,29%) places, *Mauritia* in 17 (54,84%) and *Bertholletia*, *Inga* and *Euterpe* in 15 (51,61%) places (Fig. 10).

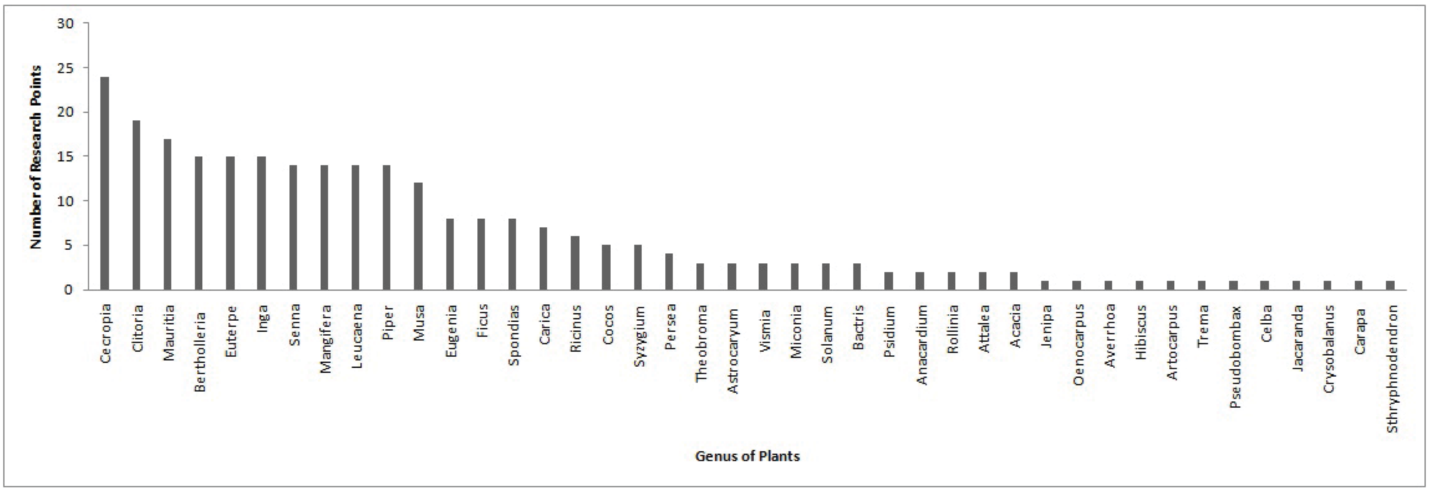

Fig. 10. Number of plant genera found at the different research points.

Of the 42 genera in total found in all localities, plants of the genera *Clitoria, Mangifera, Carica, Theobroma, Musa, Anacardium, Inga, Spondias, Attalea, Vismia, Miconia, Celba* and *Sthryphnodendron* (13 in total) were considered as being of high importance (Gordo, pers. comment, 1 April 2015). Plants of the genera *Eugenia, Bertholletia, Mauritia, Cecropia, Ficus, Senna, Psidium, Leucaena, Euterpe, Jenipa, Persea, Cocos, Oenocarpus, Rollinia, Averrhoa, Astrocaryum, Hibiscus, Acacia, Artocarpus, Bactris, Trema, Pseudobombax, Jacaranda, Crysobalanus* and *Carapa* (25 in total) were considered being of medium importance, and plants of genera *Solanum, Piper, Syzygium* and *Ricinus* (4 in total) were considered to be of low importance for *S. bicolor* (Gordo, pers. comment, 1 April 2015).

The total number of plant genera did not differ significantly between the three corridor categories (Simple, Moderate and Difficult; Kruskal-Wallis: p= 0.2926). Also, the distribution of plant genera of different importance for *Saguinus bicolor* (High, Medium and Low importance) was calculated for each of the three corridor categories, Fig. 11.

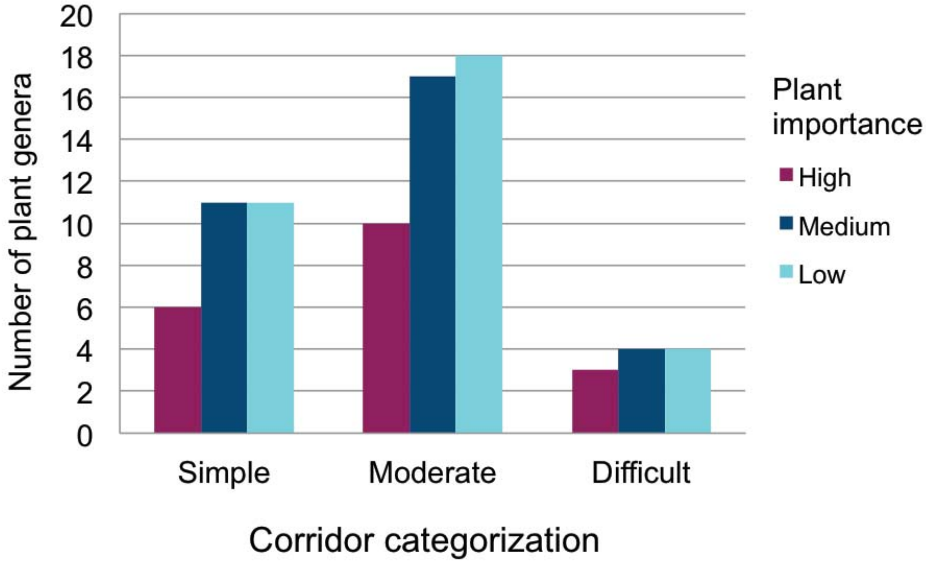

Fig. 11. Number of plant genera found in the three different corridor categorizations (Simple, Moderate and Difficult), divided into the three categories of plant importance (High, Medium and Low importance) for *Saguinus bicolor*. More detailed data are presented in Appendix II, Fig. I-III.

Correspondingly, calculations were made regarding the percentage of plant genera found in relation to their importance for *S. bicolor*, Fig. 12. A detailed overview of each corridor is presented in Appendix II.

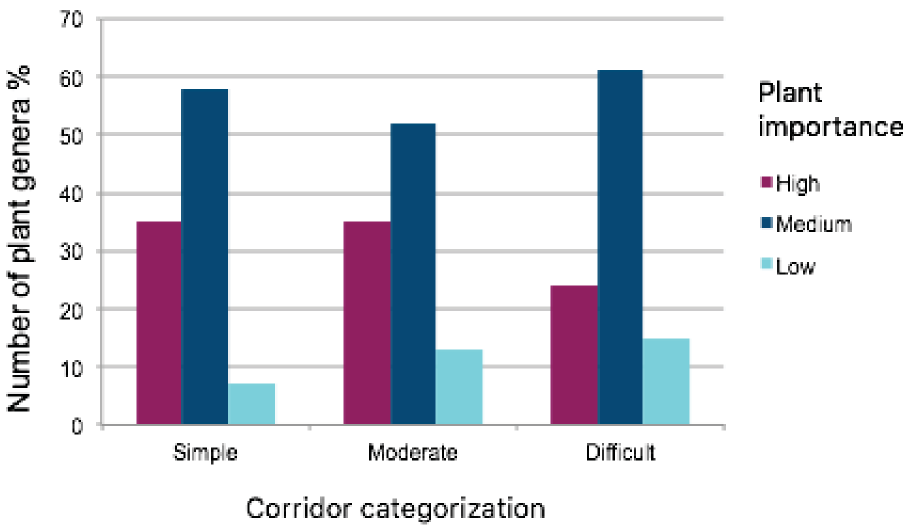

Fig. 12. Percentage of plant genera found in the three different corridor categorizations (Simple, Moderate and Difficult), divided into the three categories of plant importance (High, Medium and Low importance) for *Saguinus bicolor*.

There was a tendency towards a positive relationship between the rankings of the passages (Passages number in order as ranked, high to low) and the percentage of the genera found as of High importance for *S. bicolor* (R-value 0,344, p = 0,092), Fig. 13.

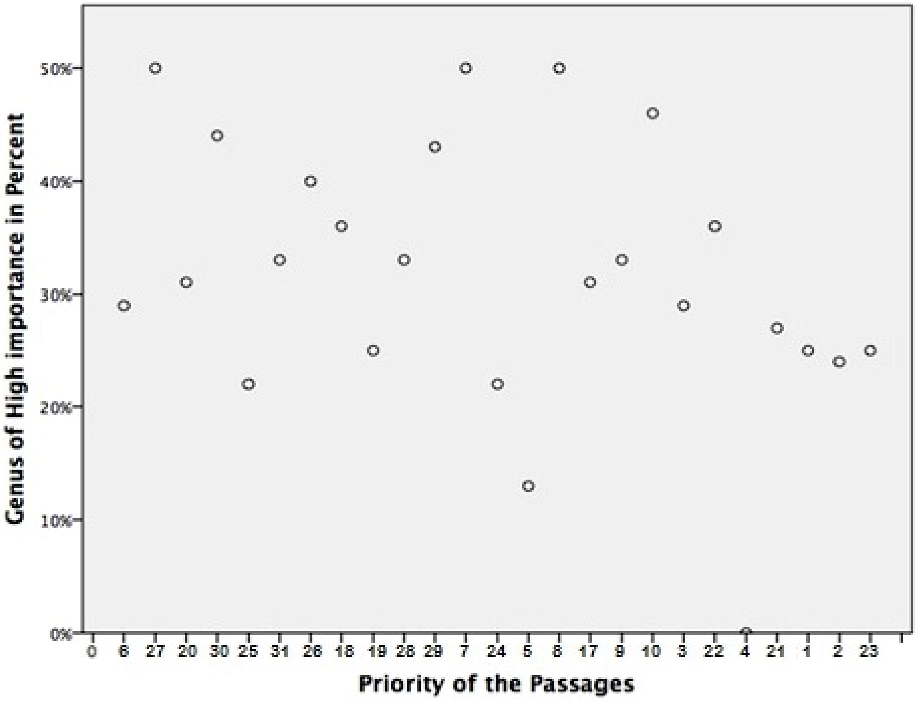

Fig. 13. The relationship between the rankings of the passages and the percentage of plant genera of "High importance for *S. bicolor*" found (R-value 0,344, p-value = 0,092). Note that the x-axis goes from high ranked (to the left) to low ranked passages (to the right).

4. Discussion

In the following pages I will discuss my findings, and whether or not I have succeeded, evaluating the ecological corridors in central Manaus, and connecting this with the current and future conservation efforts for the pied tamarin.

4.1.1 Fragment connectivity

Since there was only a very small part of the passages that were relatively isolated from one another, I did not put the connectivity of the fragments to one another into perspective in the rankings of the passages. The passages #11-16 are linked to the construction of "Avenida das Flores", and are extremely important as they can possibly be included in the changes and plans for this area.

The passages #17-22 are in fact relatively isolated from the Mindu corridor, and I initially perceived them as less important than the other passages that lie within the Mindu corridor. With that said, they indeed are of importance for each other because of the close connectivity to one another, as connecting these to one another will create a larger fragment, I do now identify them as important, and 3 of the passages are ranked in the top 10 sites to implement, but they need to be reconstructed at once. Otherwise, the rest of the passages are in relatively close vicinity of one another and will with the help of re-vegetation and connectivity create a passage connecting with the many fragments of central Manaus.

Scoring the size of the fragments could be useful because of the problem that small fragments risk of becoming sink populations due to edge effects. Almost 100% of my studied fragments were under 100 ha (Fig. 5). Relative size differences between them might still affect the parameters and this could be taken into account in a future study.

4.1.2 Test corridor

With the extreme difficulty of even determining the genus of the plants in the test corridor area (hostile situations and urban deterioration), and with the poor state of the land, I concluded that by visiting and describing the localities, it will be an exceptionally hostile and dangerous locality to place a passage for the tamarins. The area is fated by substantial poverty, extreme defragmentation and large clear cuttings, and the only places for vegetation seems to be in the back yards of local housings. The area is also prone to reoccurring illegal invasions, as it is largely isolated from central Manaus and legal organization. With the heavy fragmentation and deforestation, it would be extremely costly to create a safe corridor for the tamarins. It would need to be recreated with a large and dense avenue of high quality trees, extensive signage and speed reducers, and a broad education of the residents in order to create even a possible way to connect to the Adolpho Ducke reserve.

I would recommend searching for a better and more rational way to connect the Mindu passage to the Adolpho Ducke reserve, as I could only see this test corridor as the last resort and only if fundamental and major support is possible for many years to come.

4.1.3 Rankings of the passages

The corridors examined were widely different, but I have concluded that some of them are possible to implement straight away. The passages ranked 1 to 11 seem to be in such a decent stage that it would be a low cost project to restore them straight away. The passages of #11-16 are treated special, as at the time in March until May 2015 the passages seemed quite damaged, but with the current construction of the intersecting highway "Avenida das Flores", I perceive a possible way to immediately suggest changes to make these passages connect with each other and the surrounding vegetation, as well as to create decent and safe corridors for the animals and plants in the vicinity. These passages indeed have a high scoring (see *3.4.2 Vegetation parameters)*, yet they are determined "Moderately difficult to implement", as they are within the construction site of "Avenida das Flores" which degrades them from the "Easy" class.

Categorically, I perceive a good future for roughly 50% of the passages (in particular passages ranked 1 to 17). The passages ranked 18-31 have some difficulties, and these difficulties vary in severity and cost. With an implementation and re-vegetation focus on passages ranked 1-17, I would recommend a later look into the remaining passages, as with time it would possible that these passages will deteriorate at a high rate.

The highest ranked passage #6 has almost 4 times the score of the lowest ranked #23. Why is there such a huge gap? Passage #6 is located in the north-eastern part of central Manaus, and in the eastern part of the Mindu corridor complex. In more detail, passage #6 is almost completely isolated from any roads and human disturbances, as it is located in a breach of the passing river, and the locals have only installed simple boards to walk across the river. Therefore, with the local isolation, it will remain an isolated and well-structured corridor as long as the local people do not need a larger access of the vicinity.

The passage #23, in contrast, is located within a large gap that is dividing two large fragments. This passage will connect the fragments to the larger Mindu corridor. The gap is largely made up of heavy-duty roads and large building complexes, such as industries and commercial housing. As this area is heavily used, it will be very difficult to make any larger impact, other than reducing speed, make the possibility for speed bumps, and to re-vegetate the area in order for the tamarins to avoid the highways as much as possible. Even though the corridor would be important in order to fuse the fragments together, it will be extremely difficult to implement as the area is heavily exploited. Possibly, local authorities and legislations would not even permit any larger implementations. Consequently, passage #23 has received such a low score. My scores and rankings are just arbitrary indexes and a temporary observation of how the passages looked in early 2015.

4.1.4 Vegetation distribution

It is clear that the fragments under 100 ha have heavily degraded forest, as they are mostly made up reoccurring and opportunistic species. Nevertheless, the most abundant genera (*Cecropia, Clitoria, Mauritia, Bertholletia, Inga* and *Euterpe)* suggest that important species for the tamarins do exist, and are quite plentiful. *Cecropia* is one of the most abundant pioneer species in natural tree gaps, so it is therefore not uncommon to find this genus within degraded and fragmented localities (Plant Encyclopedia, 2015). *Clitoria* is an endemic flowering plant, which is common, and also a decent genus for the pied tamarins and other nectar and flower-eating fauna (Gordo, 2012). *Mauritia* is a fan palm, also common in these areas, and a decent genus for tamarins as they sleep and hunt for insects in them (Gordo, pers. comment, April 7 2015). *Euterpe* is a palm tree commonly found in swamps and wet areas, so not uncommon in the places with wet soil, and as it is a palm it is considered a decent species for tamarins (Gordo, pers. comment, April 7 2015). *Bertholletia* is the Brazil nut and a vulnerable species according to the IUCN (Plant Encyclopedia, 2015), and creates good timber and gives fruits that the tamarins eat. *Inga* creates good timber and flowering plants with seeds, that the tamarins eat (Gordo, 2012). Of the not so decent plants found in the sites is *Ricinus*, a member of the castor oil plants and an invasive species, which only grows as a shrub (Plant Encyclopedia, 2015), and is probably of little significance for tamarins. *Syzygium*, of the family *Myrtaceae*, is an invasive shrub (Plant Encyclopedia, 2015) and with no significance for tamarins. *Piper* (pepper) is a low herbaceous shrub with vines, with noxious fruit for primates and other mammals (Plant Encyclopedia, 2015), and *Solanum* is a low shrub, related to potatoes (Plant Encyclopedia, 2015), also not useful for tamarins.

A total of 42 genera were found in the localities examined and according to Gordo (2012), and Gordo (pers. comments 2015), these 42 genera could be categorized as of “High”, “Medium” or “Low” importance for the tamarins. 13 genera were calculated as of “High” importance for tamarins. These 13 genera (*Clitoria, Mangifera, Carica, Theobroma, Musa, Anacardium, Inga, Spondias, Attalea, Vismia, Miconia, Celba* and *Sthryphnodendron*) occured in 24 of 31 localities. The 25 genera of “Medium” importance (*Eugenia, Bertholletia, Mauritia, Cecropia, Ficus, Senna, Psidium, Leucaena, Euterpe, Jenipa, Persea, Cocos, Oenocarpus, Rollinia, Averrhoa, Astrocaryum, Hibiscus, Acacia, Artocarpus, Bactris, Trema, Pseudobombax, Jacaranda, Crysobalanus* and *Carapa*) occured in all of the 31 localities, and the four plants of genera *Solanum, Piper, Syzygium* and *Ricinus*, calculated as of “Low” importance, were found in 18 localities. With this data, I can conclude that within all 31 localities, there is overall good vegetation for the tamarins. Although the Kruskal-Wallis chi squared test found no significant difference between the groups (Simple to Difficult) for the number of plant genera, I can conclude that vegetation genus´s of high importance for the tamarins are abundant.

With regards to the rankings of the passages, a Spearman Correlation analysis showed the tendency towards a relationship between the ranking and the number of genera of “High” importance for *S. bicolor*. I will below discuss the vegetation quality of the three categories (“Simple”, “Moderate” and “Difficult”) separately. Within the “Simple” passages, localities #6, #18, #19, #29 and #Sumauma there were no plant genera of low importance, but all of them have plants considered of high importance. This agrees with that the quality of the vegetation may correlate with the scoring of the passages. If so, the localities are easily managed and will not demand re-plantings of an excess of durable plants species.

Within the determined “Moderate” passages, all passages exhibited plant genera considered as of low importance and all of them had plants considered of high importance. This indicates that the quality of the vegetation is widely varied, and that the categorization of the passages and the quality of the vegetation is correlated. In these circumstances, the localities are moderately difficult to handle, and that further research is needed to clarify where plantations will be needed. Possibly there is a relatively high demand of re-plantings of durable plants species in these places.

Within the “Difficult” passages, #1 and #3 are without any plant genera considered as of low importance, whereas passage #4 shows no plants considered of high importance. Again, this indicates that the quality of the vegetation is varied. Further research is needed to clarify

where plantations will be needed. It could indicate that there is a relatively high demand of re-plantings of many durable plants species in many of the “Difficult” passages.
Unfortunately with the heavy deforestation and clearing of the construction site of “Avenida das Flores”, it was not possible to count the plant genera at the sites. Therefore, I did not calculate any genera in the passages of #11-16. This created a lack of data in these areas, and more research will be needed when the avenue is close to completed.

4.2 Recommendations

The rankings in this study are the basis for a recommendation that was current in early 2015. The corridors change in many respects and therefore all recommendations may not be applicable to all passages. Consequently, aware of the high probability of further deterioration of the localities, I strongly recommend a general set of recommendations.

4.2.1 Corridor parameters and recommendations

My recommendations are as follows for all of the passages. Implementation of (in order of priority):

(I) Harder legislations towards protecting the fragments,
(II) Illegal housings must be kept to a minimum, need for harder legislation,
(III) Controlled speed limits (signs and cameras),
(IV) Speed bumps,
(V) Rope ladders where applicable,
(VI) Warning signs of *Saguinus* (and/or signs of crossing wildlife),
(VII) Clean up trash and de-pollute,
(VIII) Canopies and trees must outgrow electric wiring,
(IX) Isolated wirings for electric poles,
(X) Clearing of small invasive plant genera (<1 m in height).

In addition, for the road “Avenida das Flores” in passages #11-16, my recommendations are as follows:

(I) Induce higher speed limits, and use of speed cameras where applicable,
(II) Stronger legislations to maintaining these avenues and surrounding vegetation,
(III) Control and maintain invasive species, trash and pollution to a low minimum.

Rope ladders are documented effective at overpasses and road intersections (Teixeira et al., 2013). As described by Teixeira et al. (2013), howling monkeys (*Alouatta guariba clamitans*, Cabrera 1940) in Porto Alegre, Brazil use the rope ladders actively, as well as many other mammal species. They are also quite cost effective, around $100 per ladder. Rope ladders are clever, but it is also essential that power lines and electric cables are isolated when present (Teixeira et al., 2013). Ideally, each intersecting road would look like these passages in Fig. 14, in which the roads are paved with speed bumps, decorated with warning signs of crossing wildlife, have well-structured edges with decent vegetation of good height, and rope ladders implemented over the speed bumps. These pictures also describe the best layout of rope ladder to cross the roads.

Fig. 14. Left photo displaying best solution for overpass, as seen in Ponta Negra. Good rope ladder, speed bumps around overpass and warning signs with reduced speed before and after. The picture is from the north-western part of Manaus, in a newly constructed settlement in Ponta Negra. On the right, the photo displays a good example of rope ladder. Designed like ladder, with many ladders next to one another. Vines will grow upon them for good camouflage and natural looking passage. Speed bumps exist and reduced speed with warning signs of wildlife crossing. Picture from industrial area outside central Manaus (Photos by S. Barr).

Pay special attention to the photo on the right in Fig. 14, where vines are growing on the rope ladder. This is an excellent way to both camouflage the rope ladder in order to reduce human sabotage, but also a perfect way to introduce and encourage wildlife to use the rope ladders, as they now seem more natural. As one form of determining the success of the local government agreeing on the acute situation of electrocutions of tamarins and other local wildlife, Jersualsinsky (2010) describes a successful strategy in Brazil used since 1999. They documented incidents of electrocution from power lines involving howlers (*Alouatta* spp.) and other wildlife. After two years of legal proceedings, the court finally ordered the energy company of Rio Grande do Sul to coat and insulate power lines in areas where howlers and other animals are at risk of electrocution. Although, Jersualsinsky (2010) describes that electrical hazards are still present in this and other neighbourhoods, there is need of constant monitoring to prevent accidents and to rescue the affected individuals. This example could perhaps be of use also in the situation in Manaus.

4.2.2 Re-plantation recommendations

It is clear in order to create and maintain the corridors, re-plantations of the areas need a clear structure. Focus should be durable and important genera of trees. I also recommend keeping all corridors vegetated, even though not all genera present are valuable and durable at the moment. I therefore suggest that invasive species over 2 meters are kept, since they can still be used by *Saguinus* and other species, possibly slowly replacing them gradually with stronger, sturdier and endemic genera like *Inga*, *Samauma* and other genera that are of more durable wood and with high importance to *S. bicolor*.

One may argue, why replant and maintain trees of high importance for the *S. bicolor* in the ecological corridors? It would be no point in keeping the tamarins in the corridors, as the main purpose of the corridors is to allow dispersal of the species from the different fragments, and not to keep them within the corridor itself? Arguments imply that there could be a chance for the species to remain and inhabit the corridor instead of continue dispersing. This is one respectable argument, but another that one should strive towards enhancing the local flora and enrich the corridor and other localities, which the tamarins may inhabit, because of the high risk of deteriorations of the surrounding area. If we replant the localities with durable and useful species, which could sustain the monkeys, there is a higher chance that the species will be more resilient to stochastic accidents.

Regarding the circumstances around the construction site “Avenida das Flores”, there are special recommendations for these sites:

(I) Create a passage in the middle of the road, with large trees of mature quality and extensive longevity for example, *Samauma*, *Inga*, and other species that are of durable wood and with high importance to *S. bicolor*. These trees need to have a complete, connecting canopy and robust trunk. With the use of these trees, connecting canopies on each side of the highway can be maintained, and rope ladders are a possible way to connect with intermediate spaces,

(II) Do extensive replantations of durable vegetation along the highways edges in order to connect with avenue in the middle.

As described earlier, many changes may probably already have occurred since early 2015, and the longer time that passes, the more important it will be to revisit the sites to examine vegetation and the localities characteristics.

4.3 The future

4.3.1 Within the next five to ten years

So, with the results that I found, what does the future hold? Within the next five years, I predict that the corridors and fragments I have studied will have changed dramatically, possibly by increases of traffic, clear cuttings and human invasions. As described earlier, with the current high destruction rate, many passages will be harder to reconstruct and manage. Therefore, it is crucial that government researchers, public campaigns and ex-situ tamarin holders like zoos and universities (among others) can contribute as much as possible with funding and research in order to reconstruct and manage the passages as soon as possible. It is also crucial that education and public campaigns are induced within Manaus as soon as possible.

If the local community is more aware of the situation, there will be an increase of the general knowledge of local and endemic species, as well as the pending emergency of the situation. One solution would be to promote reimbursements for planting decent trees and plants in private gardens, as well as receiving compensation for giving information to local law enforcements about current or coming illegal invasions, captive tamarins or observed deaths of tamarin individuals. Likewise, the promotion of higher awareness of nature and endemic species in schools are essential. If the young public is aware and contributing in a way that they feel a part of, I believe they will be more productive in the way they treat the surrounding nature and conservation of endangered species (and perhaps even the holistic treatment of animals).

Worryingly, if the fragments and passages of Manaus are not controlled, and no measures are taken towards creating wildlife corridors, I suspect all current fragments will disappear, and so will all the local and endemic species that are depending on them. The local people will also lose contact with nature, and only perceive local flora and fauna in a desperate state, with dead or dying species throughout the city. With the diminishing probability for dispersal, the local satellite populations will experience great inbreeding, potentially reaching a deleterious inbreeding coefficient.

4.3.2 Successful conservation projects together with local people

One very successful conservation project in which the local community was included is the 'Cans for Corridors' scheme, set up by staff at Durrell Wildlife Conservation Trust (UK) in 2002. The project focuses on the critically endangered black lion tamarin *(Leontopithecus chrysopygus, Mikan 1823)*. The project was initially launched within the schools in Jersey, UK where aluminum cans were recycled and the income used to buy and replant trees in the Brazilian rainforest (Durrell, 2015). Every fifty cans donated enabled the Durrell Wildlife Conservation Trust to purchase a tree, and has now been responsible for planting around 80,000 trees in an area the size of ten football fields. The Durrell Wildlife Conservation is working in conjunction with the Brazilian conservation organization (IPE), and has now developed a powerful conservation program in an effort to save the black lion tamarin from extinction. According to Durrell (2015), the program empowers homeless people in the local region, providing them with support to start small holdings for growing tree seedlings and encouraging the planting of wildlife corridors between the isolated patches of forest that is the natural habitat of this small primate and other endangered species.

Simply, the 'Cans for Corridors' project illustrates a modest but incredibly effective way in which people in the community can do something which has a direct effect on one of the most endangered ecosystems on the planet (Durrell, 2015). Although the local community in this example is the community of Jersey, UK, I believe projects like this would be highly suitable and successful in places such as Manaus. If projects like this are supported, the increased awareness of endemic species and conservation efforts in Manaus may increase jobs and career opportunities within the conservation sector. With more jobs comes general awareness, and I believe this will promote more government paid research, which is greatly needed. As described by Gordo (2012), few studies have been published on the ecology and behaviour of the pied tamarin. I also suggest more studies need to be conducted regarding the efficiency and design of wildlife corridors.

4.3.3 Ex-situ work

The current populations of tamarins in ex-situ needs to be maintained for keeping a genetically viable captive population, which is a prerequisite for any future reintroductions into the wild. Reintroductions of *S. bicolor* are not appropriate at the time, since there is not enough funding and research done on the current wild population and there is need to create, maintain and connect viable habitat within central Manaus. More research is also needed on the tamarin behaviour, especially effects of separating families and translocating them into new areas.

Captive populations can also be used to increase the general understanding and public awareness of the species. One suitable way to organize this would to create campaigns in the local zoos. For example, the holders could create “Pied Tamarin Days” where the public would be introduced into the current situation of the tamarins and what they could do even though they are not in the Amazon. The holders could also raise money for the tamarins, and describe in detail what the funding would be used for.

4.3.4 Translocation and reintroduction of primate populations

Translocation is the intended release of animals into the wild to establish, re-establish or enhance the wild population (Griffith, et al., 1989). It contrasts to reintroduction, a term which is generally used to represent the introduction of captive individuals into the wild (Moinde et al, 2004). Reintroductions, therefore, are broadly defined as the return of animals that have spent any portion of their life in captivity, and then brought back into the wild (Moinde et al, 2004). This procedure is used in cases with species of extreme endangerment in order to supplement populations that are critically small, or to re-establish wild groups of animals that are extinct in their former ranges (Moinde et al, 2004).

Translocations of species must be done with care as in a study by Dufour et al. (2011). They found substantially increased levels of stress hormones when they relocated capuchins (*Cebus apella*, *L. 1758*) and squirrel monkeys (*Saimiri sciureus*, *L. 1758*) to novel habitats. Another study by Schaffner & Smith (2004) emphasised the importance of relocating primates with familiar and well established partners, as unfamiliar and strange individuals have an extremely prolonged stress response. Moinde et al. (2004) discovered that the factors of importance for the successful capture and relocation of forest primates include proper understanding of troop home-range utilisation and of social bond organisation within the troop, method and period of habituation, method of release, suitability of the new habitat with respect to the ecological niche requirements of the species in question, and the period of post-relocation monitoring.

Due to the problems of relocating primates and little known effect of translocations for the pied tamarin, as well as the current low quality of the natural environment, translocation of this species may not always suitable (Gordo, pers. comment, 1 April 2015). As with the case of pied tamarins, many birds, reptiles, and mammals can survive in urban and suburban areas due to their capacity to cope in highly fragmented landscapes, but there is obviously no clear consensus about the best strategy to manage fauna in these situations. Efforts to return a few individuals of non-threatened species to the wild are not usually considered conservationist measures, nor are measures focused on individual members of endangered species. Gordo (Pers. comment 1 April 2015) suggests monitoring and tracking the individuals and groups of local tamarins instead of translocating them. Through research on the local (but isolated) populations we could gain valuable knowledge about the group dynamics and what determines group dispersal.

Nevertheless, because pied tamarins are considered locally and regionally threatened and with the detrimental conflicts with humans in urban city of Manaus, there may arise situations in where individuals or groups of *S. bicolor* will be threatened with local extinction. In these acute and rare situations, a translocation of these individuals will perhaps be more successful than merely leaving them to their fate.

Correspondingly, there have been successful reintroductions of tamarins back into Brazil. One example is the endangered golden lion tamarin (*Leontopithecus rosalia, L. 1766*), which is native to the Atlantic rainforests in eastern Brazil. The first captive-born golden lion tamarins were returned to the wild in 1984. The captive population of golden lion tamarins has been maintained since the late 1970s and with the use of careful selection of breeding partners, the captive population is considered self-sustaining (WPRC, 2011).

The reintroduction of these animals has involved extensive training in captivity, in order to teach them in e.g., how to move through the forest, find and collect insects from small openings, find and collect water from flowers and other resources, as well as introducing them to predators. After having been trained in captivity at the National Zoological Park (USA), tamarins were transported to Brazil where they spent six months in quarantine to ensure they were not carrying any diseases or parasites that might infect wild tamarins (WPRC, 2011). After the quarantine period, the captive-born golden lion tamarins were released from their cages into Poço das Antas Biological Reserve and other private lands surrounding the reserve. They were also supplemented with food and sleeping sites as well as veterinary support to ensure their survival. Over time as reintroduced groups learned about natural foods and the resources within their territories, they become less reliant on food provisioning and were eventually no longer provisioned.

To date, about 40% of the total wild population of golden lion tamarins originates from captive breeding and reintroduction efforts. Starting with 18 captive-born individuals, the population has grown as the founders produced wild-born offspring (WPRC, 2011). Although, with the knowledge of successful reintroductions of captive populations of tamarins, there is an acute need to secure and protect the remaining wildlife habitat, as otherwise all this effort will be in vain.

4.4 Conclusions

This project clearly sums up the great variability and deep fragmentation of the last remaining forested parts of central Manaus. The fragments that remain are increasingly small and declining in quality, and with this comes the worrying effects on the last local populations of *Saguinus bicolor*. Hopefully, future researchers and legislators can use this project to justify further protection of the land, and to increase the conservation effects towards saving the pied tamarins. With the fast deterioration of the land and with the increasing human population, actions must come fast. Even though ecological corridors may have negative aspects, I strongly advise to use these corridors as a conservation method for urban Manaus, as I conclude it is the best option at this moment.

With the data collected by this project, and the gained knowledge about the area, I sum up these recommendations for restoring the forest fragments of Manaus, and to create ecological corridors that will aid in the conservation for this magnificent species.
There is an instant need of implementing;

(I) Immediate protection of the last remaining fragments,
(II) Re-plantations where needed according to ranking,
(III) Speed bumps, rope ladders and warning signs where applicable,
(IV) Increased research on *Saguinus bicolor* ecology and ethology,
(V) Harder legislations against invasions, capture of wild individuals, and littering,
(VI) City (and country) campaigns with the tamarin as flagship species,
(VII) Collar the local populations of tamarins and track them,
(VIII) Increased research on the primates located within the city,
(IX) Clean up of trash and pollution,
(X) Community participation in conservation projects,
(XI) Better communal planning,
(XII) Schools start teaching conservation,

(XIII) Reimbursements and compensation for people planting trees in backyard and working with conservation,

(XIV) Use the closed but highly used UFAM road as test corridor where speed bumps, rope ladders and camera traps could be implemented for research.

(XV) Relocating primates as last resort,

(XVI) Relocating individuals with no clear future to zoos for breeding programs.

In conclusion, apart from the legislative changes that must occur to protect the remaining forests, there is a need to focus on re-establishing corridors between fragmented pockets of forest as well as broad-scale reforestation efforts that must be undertaken. Finally, efforts to increase the pied tamarin population through captive breeding and translocation (with future reintroduction) should continue in order to deter the effects of human-induced habitat destruction and degradation.

There is the overhanging chance that the last remaining pied tamarins will not prevail. Even though many researchers and local activists strongly advocate for this species (and many more), there is the pendulous risk that none of these recommendations will be possible to implement. This is of course a great tragedy for the species, but I also feel like we will lose a great battle, as many researchers and local inhabitants see the pied tamarin as a flagship species. If they lose this battle over a very special and desirable flagship species, what hope will there be for the "less wanted"?

4.5 Personal reflections

With the large and increasing poor community of Manaus, it was at many times quite difficult to work and travel around in the city. The fact that I was a young, European woman on my own made it at times quite obvious that I was not a part of the local population. Dr. Gordo and other local researchers strongly advised me not to visit the localities on my own, and not to visit or travel in many of Manaus districts. Therefore, I had Dr. Rasiera and other researchers aiding me in the field, and assisting me with driving to the different locations as well as to helping with the language barriers. This made spontaneous visits to the research points impossible, and I had to plan most of the visits several weeks ahead. Also, driving in a Government vehicle was not greatly appreciated in many of the poorer districts in town and therefore could many of the visits only be made in short stops. There is also a lack of research and information about this species in English, as most of the material that is available and the newest research on the subject are in Portuguese. Although, even with these difficulties, I found the Brazilian people to be very warm and welcoming, and are indeed very caring. I truly enjoyed every minute of my visit to the Amazon.

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Appendix I

Table I. The coordinates for the 31 research points and 13 test points in urban Manaus, Brazil.

Coordinates - WGS84 UTM			
Passage #	ZONE	Latitude	Longitude
1	21M	168938	9663347
2	21M	168942	9663282
3	21M	168978	9663085
4	21M	168849	9662756
5	21M	168400	9662881
6	21M	169439	9662959
7	21M	169598	9662990
8	21M	169309	9663347
9	21M	170952	9663988
10	21M	171023	9663914
11	21M	168136	9666772
12	21M	168189	9667021
13	21M	168134	9665445
14	21M	166963	9670181
15	20M	832981	9672005
16	20M	832037	9673889
17	20M	831112	9661272
18	20M	831072	9661161
19	20M	830837	9660466
20	20M	831028	9660390
21	20M	832348	9660193
22	20M	832474	9660743
23	21M	168101	9660992
24	21M	170638	9660762
25	21M	168055	9660060
26	21M	168428	9659654
27	21M	168646	9659476
28	21M	169190	9656188
29	21M	168960	9656061
MINDU	20M	832959	9659239
SUMAUMA	21M	168699	9663494
S1	21 M	170385	9663559
S2	21 M	170575	9663842
S3	21 M	170628	9664151
S4	21 M	170808	9664872
S5	21 M	170659	9664981
S6	21 M	170378	9665044
S7	21 M	170276	9665087
S8	21 M	170646	9665721
S9	21 M	170824	9665832
S10	21 M	170820	9666179
S11	21 M	170833	9666294
S12	21 M	170686	9666496
S13	21 M	170585	9666690

Appendix II

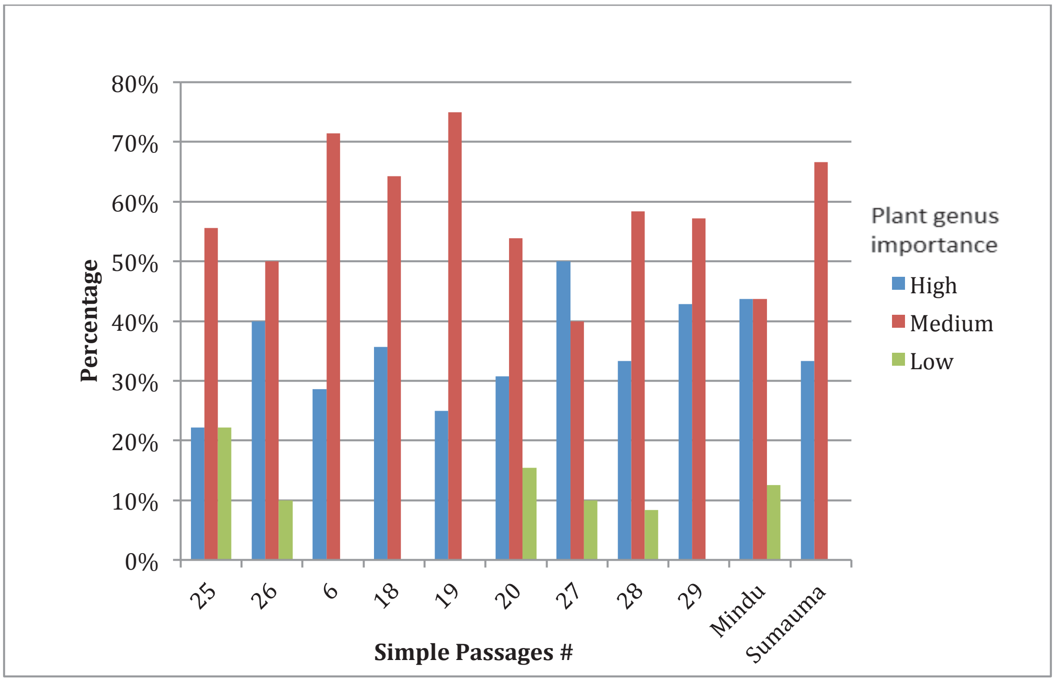

Fig. I. Proportion (%) of plants found in the Simple passages. Plant genera were classified High, Medium and Low depending on their importance for *Saguinus bicolor*.

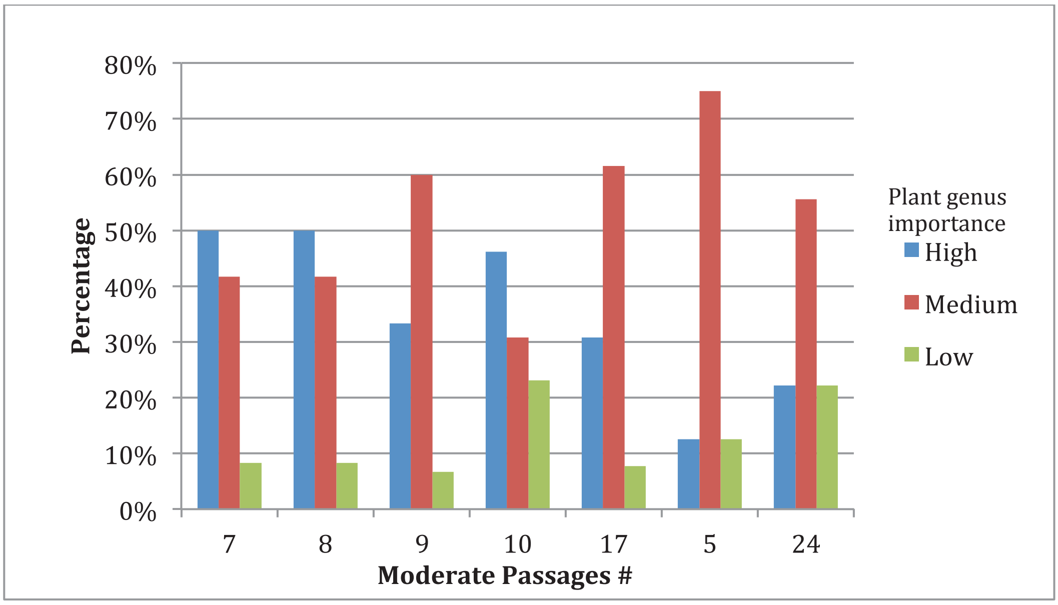

Fig. II. Proportion (%) of plants found in the Moderate passages. Plant genera were classified High, Medium and Low depending on their importance for *Saguinus bicolor*.

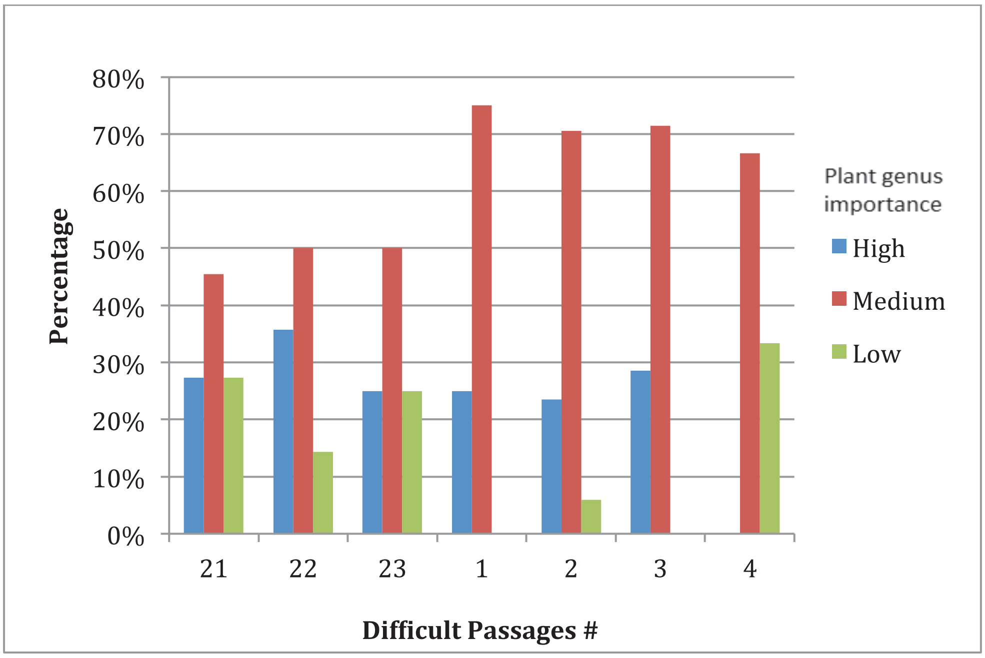

Fig. III. Proportion (%) of plants found in the Difficult passages. Plant genera were classified High, Medium and Low depending on their importance for *Saguinus bicolor*.