ABSTRACT

Title of Thesis:	A WILDLIFE CROSSING MODEL FOR THE GOLDEN LION TAMARIN
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The golden lion tamarin is an endangered species endemic to the Atlantic Forest of Brazil. In the 1970's, their population was only a few hundred individuals due to anthropogenic reasons, such as fragmentation, deforestation, poaching and hunting. Over time with conservation measures, their population grew, and is currently around 2,516 individuals. This number, however, is not stable. As a major highway, BR-101, continues to widen, populations of golden lion tamarins continue to be isolated, resulting in inbreeding and lack of allele transfer. Golden lion tamarins are known to avoid crossing roads, so an alternate solution must be implemented. That alternate solution is a wildlife crossing. Building a wildlife crossing over BR-101 to connect currently isolated populations of golden lion tamarins will allow for genetic exchange and will eventually stabilize the golden lion tamarin population.

A WILDLIFE CROSSING MODEL FOR THE GOLDEN LION TAMARIN

by

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List of Abbreviations

AMLD	Associação Mico-Leão-Dourado
AVC	animal-vehicle collision(s)
GLT(s)	golden lion tamarin(s) (*Leontopithecus rosalia*)
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
MU(s)	Management Unit(s)
SGLT	Save the Golden Lion Tamarin
U.S.	United States of America
WC	wildlife crossing(s)

Chapter 1: Background

The "Big Picture"

According to the 2019 report from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, or the IPBES, the current global response regarding biodiversity is insufficient. "Transformative changes" are necessary to restore and protect nature. Although there are mega corporations with vested interests in continuing to pollute and destroy the earth, positive changes can be made in order to benefit the public good. Interventions such as wildlife crossings (WC) will be vital to protecting the future of biodiversity in this world.

The "Big Picture" about biodiversity is urgent. IPBES estimates that more than 1,000,000 species are threatened with extinction, and anthropogenic causes threaten more species now than ever before. 25% of species in plant and animal groups are vulnerable, and the global extinction rate is at least ten to hundreds of times higher than the past ten million years on average. According to IPBES, there are five main drivers of unprecedented biodiversity and ecosystem change over the last fifty years, which include changes in land and sea use, direct exploitation of organisms, climate change, pollution, and invasion of alien species.

Changes in land and sea use are direct results of anthropogenic habitat fragmentation. Fragmentation is generally defined as the breaking up of a habitat, ecosystem, or land-use type into smaller parcels, but can also be defined as being the combination of habitat loss, and isolation (Foreman, 1995). The effects of fragmentation on species generally increase isolation and extinction rate. Fragmentation also commonly increases genetic inbreeding. The golden lion tamarin population has suffered due to these effects. Wildlife crossings can act as the transformative changes needed to help reduce the threat of extinction to the golden lion tamarin, and can help to protect the biodiversity of the Atlantic forest.

Why do we need Wildlife Crossings?

Though roads have been around for centuries, a couple factors have increased the number of roads by an incredible amount. The Industrial Revolution caused an increase in human population and economic prosperity, and a need for roads to transport the increased amount of goods being produced (Zanden, 2009). Though roads are an asset to humans, they come at a cost to wildlife. Roads reduce access to habitat and mating and create fragmentation, which can lead to reduced survival and breeding, and species can become more susceptible to disease and extinction (Sawaya, Kalinowski and Clevenger, 2014).

According to a study by Gray (2011), there are more than six million vehicle crashes per year in the United States, with about one to two million of these being animal-vehicle collisions (AVC). In addition, the study found that from 1990 to 2004, AVC increased by about 50%. Gray determined that AVC can have several negative consequences, such as injury or death to both animal and human, vehicle damage, and secondary vehicle collisions. In fact, AVC have become such a problem, that the United States Transportation Act known as "Moving Ahead for Progress in the 21st Century Act," included language about reducing vehicle-caused wildlife mortality and maintaining habitat connectivity across roadways (Kociolek et al., 2015). Countries with large and dense populations, such as Brazil, the fifth largest country by area and sixth most populous (Staff, 2019), experience similar problems.

A study done by Abra et al. (2019) examined animal-vehicle collisions in the state of São Paulo, which has a population of approximately 44 million people and is adjacent to the state of Rio de Janeiro. The study reported AVC to be 3.3% of total collisions in the state, and of these, 18.5% resulted in human injuries or fatalities. The average cost for an AVC was $9,269. In addition to this cost, the Brazilian legal system held the road administrators liable for AVC 91.7% of the time, based on Article 37 §6 of the Brazilian Federal Constitution and the Code of Consumer Protection. This resulted in $1,005,051 worth of compensation. These numbers show how detrimental AVC are not only to animals, but to humans as well. Providing habitat connectivity and protecting wildlife will also protect humans not only from physical injury, but from monetary impacts as well.

Though exact numbers are not known, according to Ascensão et al. (2019) AVC may contribute to the significant decline of local populations [of GLTs]. As the highway BR-101 continues to be widened and traffic on the road increases, the threat to GLTs may increase. With the golden lion tamarin (GLT) population at 2,516 individuals, even one AVC is detrimental to the population. Wildlife crossings are necessary to mitigate this problem.

<u>What is a Wildlife Crossing?</u>

According to Kociolek et al. (2015), a wildlife crossing is a mitigation technique used in areas of vehicular traffic. The study describes a WC as a structure that can be built either over or under a road to connect two pieces of fragmented land together, in hopes of reducing AVC, and encouraging safe habitat connection.

Wildlife crossings have been shown to reduce animal-vehicle collisions by an average of 87% for animals that are deer-sized or larger (Kociolek et al., 2015).

The first WC was built in France in the 1950's, and Europe has been building and utilizing WC ever since (Vartan, 2019). According to Bissonnette and Cramer (2008), the earliest WC in the U.S. were built in the 1970's and were primarily for deer. In North America, there are 684 terrestrial WC, and more than 10,692 aquatic WC (Bissonette and Cramer, 2008).

According to Kintsch and Cramer (2011), there are seven classes of crossings, which include Small Underpass, Medium Underpass, Large Underpass (Figure 1), Extensive Bridge, Wildlife Overpass (Figure 2), Specialized Culverts, and Canopy Bridges (Figure 3).

Figure 1. Large underpass (Kintsch and Cramer, 2011)

Figure 2. Wildlife overpass (Kintsch and Cramer, 2011)


Figure 3. Canopy bridge (Kintsch and Cramer, 2011)

The study determined that each class of WC has certain species that are most likely to succeed. The study explains that Small Underpasses are typically used by amphibians and small mammals. Medium Underpasses are typically used by coyote and bobcat, while Large Underpasses are typically used by deer, elk, and black bear. Extensive Bridges can typically accommodate most wildlife, including species that are generally wary of crossings. Wildlife overpasses can typically accommodate most wildlife as well, including birds. Specialized Culverts are typically used by reptiles and amphibians, and Canopy Bridges are typically used by flying squirrels and arboreal rodents. This thesis will be focused on a specific extensive bridge wildlife overpass. This structure will be referred to simply as the golden lion tamarin (GLT) wildlife crossing (WC).

Chapter 2: Literature Review

There have been studies in several countries on the impact wildlife crossings have had on various animal populations. Each of these studies contributes to the growing field and knowledge base regarding WC.

Studies in Banff National Park

Numerous studies have been done on WC in and around Banff National Park in Alberta, Canada. A study done by Barrueto, Ford and Clevenger (2014), examined several ecologically important species in Banff, including, but not limited to, elk, coyote, grizzly bear, and black bear. This study used motion-activated cameras to record and evaluate whether animal behavior at WC changed based on the level of human activity surrounding the WC. Based on these recordings, it was found that deer, elk, black bears and coyotes were sensitive to certain human activities, such as certain traffic volumes, while large carnivores were sensitive to all forms of human disturbance. These findings are important as they helped to discourage incorporating any type of human activity on or near the GLT WC in order to best protect the species that will be utilizing it.

In addition to these findings, Barrueto, Ford and Clevenger (2014), found several general rules, some that are particularly applicable to WC in the Atlantic Forest. These rules are; noise reduction is generally beneficial, in general, reduced human use in the vicinity of the crossings is important, small mammals may need cover in the form of logs, rocks and bushes, and protecting both sides of WC for long-term conservation is cost effective. Each of these findings will contribute to the GLT

WC design in order to make it as beneficial to the species endemic to the Atlantic Forest as possible.

Another important study conducted in Banff National Park by Clevenger, Ford and Sawaya (2009), determined that in order to have greater highway permeability, there must be many WC. In addition, the study determined it is generally better to have larger WC. It was also discovered that certain species prefer large open WC, while others prefer small covered WC. This study provided information that reinforced the need for another WC for golden lion tamarins in the Atlantic Forest, as greater highway permeability is necessary due to the widening of BR-101.

Ford and Clevenger (2010), evaluated the prey-trap hypothesis, which is a hypothesis that predators will exploit WC in order to capture prey. The study looked at twenty-eight different WC in Banff National Park over the course of thirteen years. The studies evaluated if ungulate kill sites were found closer to WC and roads than they were before the implementation of WC. This extensive study found no evidence indicating that predator behavior at WC was affected by prey movement. In fact, it was found that kill sites were almost the exact same distance from the roadway before and after WC implementation. This is a beneficial study because it suggests that the GLT WC will not create a space of increased predation of the GLT.

A study in Banff National Park published by Sawaya, Kalinowski and Clevenger (2014), became an important indicator of the genetic diversity amongst species who utilize WC. This study evaluated hair samples that were taken from twenty WC in Banff National Park. The study determined that the Trans-Canada highway affected two fragmentation sensitive carnivores' populations; black bear and grizzly bear, however the highway did not isolate their populations completely. The study found that WC provide genetic connectivity for both species. This is relevant work not only because it shows that WC can positively affect biodiversity of the world, but also because it can directly relate to GLTs. GLTs have a limited, endangered population and are suffering from lack of genetic diversity. This study shows that a WC may help isolated populations of GLTs to exchange genetic information and improve genetic diversity.

Studies in the United States

A study done by Kociolek et al. (2015), discussed the U.S. Transportation Act known as "Moving Ahead for Progress in the 21st Century Act." This act, for the first time ever, included explicit language authorizing officials to reduce vehicle-caused wildlife mortality. It also authorized officials to maintain habitat connectivity across roadways. This study concluded that based on cost-benefit analyses, there are many road sections in the U.S. and Canada where it would be more economical to build a wildlife crossing than to pay for the costs associated with AVC. This study also surveyed department of transportation professionals from all fifty states. The results of the surveys indicated that most professionals agree that WC improve habitat and the safety of wildlife. The most common response to the question about the biggest barrier to WC implementation included economic reasons and available funding. These findings indicate that professionals are starting to realize the positive impact that WC can have on both habitat and wildlife.

Kociolek et al. (2015), mentioned a wildlife crossing competition that occurred in 2010, known as "Animal Road Crossings (ARC)." One of the study authors, Angela Kociolek of Western Transportation Institute at Montana State University, described the ARC competition as a call for new methods, new materials, and new thinking. The design submissions were meant to be compelling, safe, efficient, cost-effective and ecologically responsible. The winning entry was called "hypar-nature" and was modular. The design seamlessly connected habitat on either side of the roadway. This design competition highlights the importance of WC and how they are becoming a necessary part of design conversations. It will also influence the design of the GLT WC in that it is meant to seamlessly connect to the habitat, be compelling, be ecologically responsible and be safe.

Studies in European Countries

Because the first wildlife crossing was built in France, European countries are generally in tune with road ecology. A study by Bank et al. (2002) evaluated the differences in WC in different European countries. The study found that in general, European overpasses vary in width from eight meters to several hundred meters. The study also determined that in 1991, France had 125 overpasses and continue to use these for habitat connectivity. At the time of the study, Germany had thirty-two overpasses, with eight under construction and twenty more planned. It was also found that overpasses are generally incorporated into landscape design in Germany, and the country has several overpasses that are built for both animal and human recreational use. The study found that the country of Switzerland had more than twenty overpasses and was continuing to build more. The study found that in the

Netherlands, there were four overpasses, each crossing a four-lane highway. Each of these countries recognizes WC as part of a solution to habitat fragmentation and transportation infrastructure.

Additional Studies

Many more studies have been done throughout the U.S. and other countries and regions. Though they were examined for the purpose of this thesis, it was ultimately found that WC in the form of culverts or underpasses, as well as interventions such as transportation adjustments like reduced speeds, were not entirely relevant to this thesis.

Design Philosophy

The Handbook of Road Ecology (2015), explains three principles that must be used in wildlife crossing design. These principles include encouraging use of structure for the target species, guiding animals toward the entrance of the structure, and minimizing negative effects of traffic. Each of these principles will be discussed and addressed in the design of the GLT WC. The handbook also goes on to explain how to determine the type of WC most appropriate for the species and the space. The first step discussed is to narrow down the type of crossing. Because the GLT is an arboreal species, it was determined that an overpass crossing was most appropriate, as it could connect the forest on either side of the road. Next, an hourglass shape was determined for the WC. An hourglass shape is beneficial to species, as it is wider on either side to allow easier access to the crossing for species, and then comes to a pinch point. This pinch point is designed to also be beneficial to other species, as it provides different sightlines for both prey and predators (van der Ree, Smith and Grilo, 2015).

Criteria

Each study evaluated in this literature review led to a gathering of criteria meant to inform the design and success of the golden lion tamarin wildlife crossing. The criteria are centered around four categories of design including ecological, safety, educational, and research. The ecological criteria include several interventions intended to encourage use of the GLT WC by animal species; thus, benefitting the local ecology. These interventions include making the GLT WC several meters wide, connecting habitat on either side of the GLT WC, planting ecologically significant species, and replicating Atlantic Forest habitat on the GLT WC through things like boulders and fallen logs. The safety criteria are intended to keep both humans and animal species safe and prolific. These criteria begin with the GLT WC itself, as WC are generally created as a solution to fragmentation, which can decrease the health and population of affected animal species. In addition, the safety criteria consist of excluding humans from the GLT WC and reducing the possibility of vegetation from falling off the GLT WC which could potentially damage vehicles and harm people. The educational criteria of the GLT WC include visual components that can be easily understood by passersby. These components are intended to inform the public about the goals and purpose of the GLT WC. The research criteria include several measures that are meant to evaluate the success of the GLT WC, as well as inform the design of future WC. Several data points will be collected and analyzed for these purposes.

Chapter 3: The Golden Lion Tamarin

<u>*Introduction*</u>

Figure 4. Golden lion tamarin (Golden Lion Tamarin, n.d.)

The rest of this thesis will focus on the golden lion tamarin (*Leontopithecus rosalia*; GLT) (Figure 4). GLTs are arboreal marmosets that have a bright golden-orange pelage, and a distinct lion-like mane (Dietz et al., 2019). They are the largest member of the family Callitrichidae and are represented by four chromatic forms (Dietz, Peres, and Pinder, 1997). According to the article “Golden Lion Tamarin,” by the Smithsonian’s National Zoo & Conservation Biology Institute, their weight range is between seventeen and twenty-four ounces, and they have a length range of six to ten inches. This article also indicates that their tail length can range from twelve to fifteen inches and they have a lifespan of about eight years. They are beneficial to their ecosystems, as they are seed dispersers, and help to regenerate the forest (Lucas et al., 2019).

GLTs are an endangered species, and in 2018, there were an estimated 2,516 individual GLTs (Dietz et al., 2019). GLTs live in groups of three to fourteen individuals, with each group having one breeding pair (Lucas et al., 2019). The GLT has an infant mortality rate of 50% within the first year of life (Golden lion tamarin, n.d.). These factors combined are why GLTs are in such need of population growth and stabilization through outside factors such as the GLT WC.

Communication

According to Lang (2010), GLTs communicate within their groups through visual, vocal and chemical systems. Lang explains that visually, GLTs signal using rump displays and piloerection, tongue flicking, arch-walking and tail-thrashing. Chemically, they communicate by scent marking through glands on their chest and around their genitals. According to Lang (2010), vocal communication is the most important form of long-distance communication. There are six categories of vocalization including tonal, clucks, trills, atonal, multisyllable and combination. Each vocalization type is used for a different purpose, with trills serving as indicators of location to others over long distances. In addition, multisyllable calls are important for group cohesion (Lang, 2010). These vocalizations will be important for identification of GLTs using the GLT WC, as they will be recorded and analyzed for research purposes.

Diet

Golden lion tamarins are omnivores, and primarily rely on fruit, nectar, and invertebrates to fulfill their dietary needs (Lucas et al., 2019). A study done by Dietz, Peres and Pinder (1997), revealed that the two foods most consumed by GLTs are nectar and fruits. This study found that GLTs fed on sixty-four plant species in twenty-three families (Table 1).

Table 1. Plant species in the diet of golden lion tamarins. Adapted from Dietz, Peres and Pinder (1997) by Turner

Latin Name	**Plant Item Eaten**	**Family**
Monstera sp.	Nectar/Ripe Fruit	Araceae
Cordia sellowiana	Ripe Fruit	Boraginaceae
Cordia sp.	Ripe Fruit	Boraginaceae
Jacaratia dodecaphylla	Ripe Fruit	Caricaceae
Combretum fruticosum	Nectar	Combretaceae
Thoracocarpus bissectus	Ripe Fruit	Cyclanthaceae
Diospyros hispida	Ripe Fruit	Ebenaceae
Symphonia globulifera	Nectar	Guttiferae
Tovomita sp.	Ripe Fruit	Guttiferae
Inga edulis	Ripe Fruit	Leg. Mimosoideae
Inga leptantha	Ripe Fruit	Leg. Mimosoideae
Inga thibaudiana	Ripe Fruit	Leg. Mimosoideae
Inga fagifolia	Ripe Fruit	Leg. Mimosoideae
Inga leptandra	Ripe Fruit	Leg. Mimosoideae
Liana 1	Exudate	Leg. Mimosoideae
Machaerium sp.	Exudate	Leg. Papilionaceae
Clidemia bulbosa	Ripe Fruit	Melastomataceae
Clidemia biserrata	Ripe Fruit, Flowers	Melastomataceae
Miconia candolleana	Ripe Fruit	Melastomataceae
Miconia hypoleuca	Ripe Fruit	Melastomataceae

Miconia ibaguensis	Ripe Fruit	Melastomataceae
Miconia clavescens	Ripe Fruit	Melastomataceae
Henriettea saldanhai	Ripe Fruit	Melastomataceae
Abuta sellowiana	Ripe Fruit	Menispermaceae
Siparuna guianensis	Ripe Fruit	Monimiaceae
Cecropia lyratifolia	Ripe Fruit	Moraceae
Cecropia hololeuca	Ripe Fruit	Moraceae
Ficus obtusiuscula	Unknown	Moraceae
Ficus cluseaefolia	Ripe Fruit	Moraceae
Musa paradisiaca	Ripe Fruit	Musaceae
M. rosaceae	Ripe Fruit	Musaceae
Eugenia glomerata	Ripe Fruit	Myrtaceae
Myristicia theidora	Ripe Fruit	Myristicaceae
Eugenia fusca	Ripe Fruit	Myrtaceae
Eugenia sp.	Ripe Fruit	Myrtaceae
Psidium guineense	Ripe Fruit	Myrtaceae
Psidium sp.	Ripe Fruit	Myrtaceae
Syzygium jambos	Ripe Fruit	Myrtaceae
Marliera racemosa	Ripe Fruit	Myrtaceae
Marlierea edulis	Ripe Fruit	Myrtaceae
Myrcia sp.	Ripe Fruit	Myrtaceae
Campomanesia sp.	Ripe Fruit	Myrtaceae
Myrtaceae 1	Ripe Fruit	Myrtaceae
Euterpe edulis	Unripe Fruit	Palmae
Bactris sp.	Ripe Fruit	Palmae
Astrocaryum airi	Unripe Fruit	Palmae
Geonoma gracilis	Ripe Fruit	Palmae
Palmae 1	Ripe Fruit	Palmae
Palmae 2	Fluid	Palmae
Genipa americana	Ripe Fruit	Rubiaceae
Randia spinosa	Ripe Fruit	Rubiaceae
Sabicea cinerea	Ripe Fruit	Rubiaceae
Coussarea sp.	Ripe Fruit	Rubiaceae
Rubiaceae 1	Ripe Fruit	Rubiaceae
Paullinia carpopodea	Ripe Fruit	Sapindaceae
Chrysophyllum splendens	Ripe Fruit	Sapotaceae
Pouteria parviflora	Ripe Fruit	Sapotaceae
Pouteria sp. 1	Ripe Fruit	Sapotaceae

Pouteria sp. 2	Ripe Fruit	Sapotaceae
Pradosia latescens	Ripe Fruit	Sapotaceae
Mimusops salzmannii	Ripe Fruit	Sapotaceae
Celtis sp.	Ripe Fruit	Ulmaceae
Vitex polygama	Ripe Fruit	Verbenaceae
Cissus sp.	Ripe Fruit	Vitaceae

Dietz, Peres and Pinder (1997), determined that often, when fruit is not ripe, GLTs will rely on nectar from common plants like Symphonia. However, the study also found that during the dry season, GLTs consume foods such as exudates from trees and woody lianas. According to the study, GLTs search microhabitats such as dead leaves, epiphytic growth, overhanging palm leaves, tree bark, vine tangles, hollow debris and humid debris for prey. The prey include small vertebrates such as lizards, frogs, snakes, arthropods and snails, as well as nesting birds. The study found that capture of mobile prey that were directly exposed on foliage were rare; 98% of observed captures were of embedded and cryptic prey items, and majority of these captures included insects and adult orthopteran and larvae of Coleoptera and Lepidoptera. In addition, observation found that young and adult spiders were plucked from web colonies, yet millipedes and centipedes were often avoided. The study also found that GLTs in lowland habitats frequently searched Bromeliads and palms for animal prey, especially in swamp forest and ginger patches. The GLT WC is designed to support appropriate microhabitats to provide a food source for the GLT.

Habitat

Golden lion tamarins are endemic to the lowland Atlantic Forest of Brazil (Valle et al., 2018). The Atlantic forest is a biodiversity hotspot, and one of the most endangered ecoregions worldwide (Ascensão et al., 2011). The Atlantic forest originally covered around 150 million hectares, but it has been reduced to about 12% of its original vegetation. Of this remaining 12%, 83.4% of Atlantic Forest fragments are smaller than fifty hectares (Ribeiro et al., 2009). This is especially concerning for the golden lion tamarin, as the Annual Progress Report (2018), by the Associação Mico-Leão-Dourado (AMLD) and Save the Golden Lion Tamarin (SGLT) suggest a block of 25,000 hectares of protected and connected forest for the GLT population to grow and thrive. Golden lion tamarins spend most of their daylight hours at lower elevations, often at thirty-five meters above sea level and lower because their habitat is largely discontinuous portions of permanently inundated swamp forest, which supports the highest density of foraging microhabitats and animal prey (Dietz, Peres and Pinder, 1997).

Environment

Climate

Dietz, Peres and Pinder (1997), evaluated the climate of Poço das Antas, a biological reserve in Brazil that is inhabited by golden lion tamarins. The study found that the reserve has a mean monthly precipitation in June and July of less than 75mm, and a mean monthly precipitation of more than 250mm in December through January. The study explains that the maximum temperature in the hottest months of December through February reaches between 39 and 41 degrees Celsius, and the minimum temperature in the winter months of June through August can dip between 9 and 11 degrees Celsius.

Soil

GLT habitat has mostly Argissolo soil which has a noticeable clay content and increased clay films in lower horizons. In addition, there is a low nutrient capacity in the soils, and they are like Latossolos in that they have low natural fertility characteristics (Mendonça-Santos, Santos, Dart, & Pares, 2008).

Range and Travel

Dietz, Peres and Pinder (1997), determined that GLTs use the largest home range per unit group of biomass of all New World primates, ranging from 21.3 to 73 hectares. Dietz, Peres and Pinder (1997) also determined that GLT travel routes were usually found to be between long-lasting superabundant resources such as Symphonia globulifera trees in flower, and fruit trees such as Pouteria and Randia. Lucas et al. (2019), determined that GLTs spend 33% of their day moving around their territory, which shows how important connected habitat is for the GLT. Their rate of travel is found to be variable and GLT's were found to sleep in tree holes and occasionally tangles of vines, palm crowns and bamboo thickets (Dietz et al, 2019).

The Annual Progress Report (2018), explains that GLT range is limited to five municipalities in the São João river basin in Rio de Janeiro state, 80 km northeast of the city of Rio de Janeiro, which contains over twelve million human inhabitants. This number of human inhabitants is why there has been fragmentation and transportation infrastructure implemented in the area. Because of this, a wildlife crossing is needed for the GLT.

History

Golden lion tamarins are endangered species that nearly went extinct, as their population was as low as a few hundred individuals in the 1960's and 1970's (Ruiz-Miranda et al., 2019). Timber and charcoal production, as well as agriculture, cattle ranching and urban expansion have reduced GLT habitat to 0.4% of its original area (Ruiz-Miranda et al., 2019). In addition to these practices, hunting and capture for the pet trade also contributed to population decline. The reduced population size and habitat then caused a reduction in gene flow and genetic diversity (Lucas et al., 2019). Drastic measures had to be taken to build the GLT population back up. Biologists began breeding GLTs in captivity, and then reintroduced zoo-born individuals to the Atlantic Forest between 1984-2000 (Dietz et al., 2019). Due to this reintroduction and increased protections of the species, the GLT population rose to about 3,700 in 2014 (Annual Progress Report, 2018). However, due to Yellow Fever, which will be discussed in the next section, their population fell to 2,516 individuals in 2018 (Dietz et al., 2019).

Threats

Current Threats

According to the Annual Progress Report (2018), put out by AMLD, the remaining forest habitat of the golden lion tamarin is fragmented into islands and is separated by towns and cattle pastures. In addition, BR-101 is a major highway with about 18,000 vehicles using it per day (Ascensão et al., 2019). This highway presents a strong barrier to GLT movement, as Lucas et al. (2019), found that GLTs actively avoid crossing paved roads. In addition, BR-101 bisects two biological reserves (Poço das Antas Biological Reserve and União Biological Reserve). These biological reserves are the largest legally protected areas in the region and provide habitat to populations of GLTs that contain important genetic diversity and alleles (Annual Progress Report, 2018). Between these two reserves, the highway is being widened to four lanes, which will result in roughly 55 meters of disturbed area, thus reducing GLT habitat even more, and creating more of a barrier of movement. Because of these barriers, no existing forest fragment is large enough to support a viable population of GLTs (2018 Annual Progress Report).

Yellow Fever

A study done by Dietz et al. (2019), discussed the effects of the yellow fever virus, which is endemic to regions of Africa and the Americas. The study explains that the yellow fever virus is transmitted to humans or non-human primates through the bite of infected mosquitoes, and all Brazilian primates (such as the golden lion tamarin) are susceptible to it. The study finds that currently, no yellow fever vaccine exists for non-human primates, and that the mortality rate in non-human primates infected with the yellow fever virus varies with species. The mortality is high in howler monkeys (Alouatta spp.) and marmosets (Callithrix spp.), and intermediate in capuchin monkeys (Sapajus spp.). The golden lion tamarin is a marmoset, and therefore has been drastically affected by yellow fever. As found in the study, as of April 2018, there were 1,833 reported cases and 578 deaths due to yellow fever in humans, and from July 2017 to May 2018, 752 non-human primate deaths were attributed to yellow fever in Rio de Janeiro state as confirmed by laboratory analyses. As of November of 2016, Brazil saw the most severe yellow fever epidemic/epizootic in the country in eighty years, which led to the first death of a GLT in May 2018. The study determined that since the first death, GLT numbers have declined by 32%, with 2,516 remaining in situ. It was found that loss was significantly greater in larger forest patches with greater connectivity, and less forest edge because the vector is mosquito. This poses the question; will GLTs survive the disease, and will they acquire immunity? Or will a vaccine be developed to prevent deaths?

Chapter 4: Design

Site Characteristics

Management Units

Golden lion tamarin populations have been identified by Associação Mico-Leão-Dourado and Save the Golden Lion Tamarin as separated into 13 isolated groups, known as management units (MUs). In order to determine the placement of the wildlife crossing the characteristics of each of the 13 management units (Figure 5) of GLTs were analyzed based on location and population number. The first thing looked at was potential for connectivity among management units.

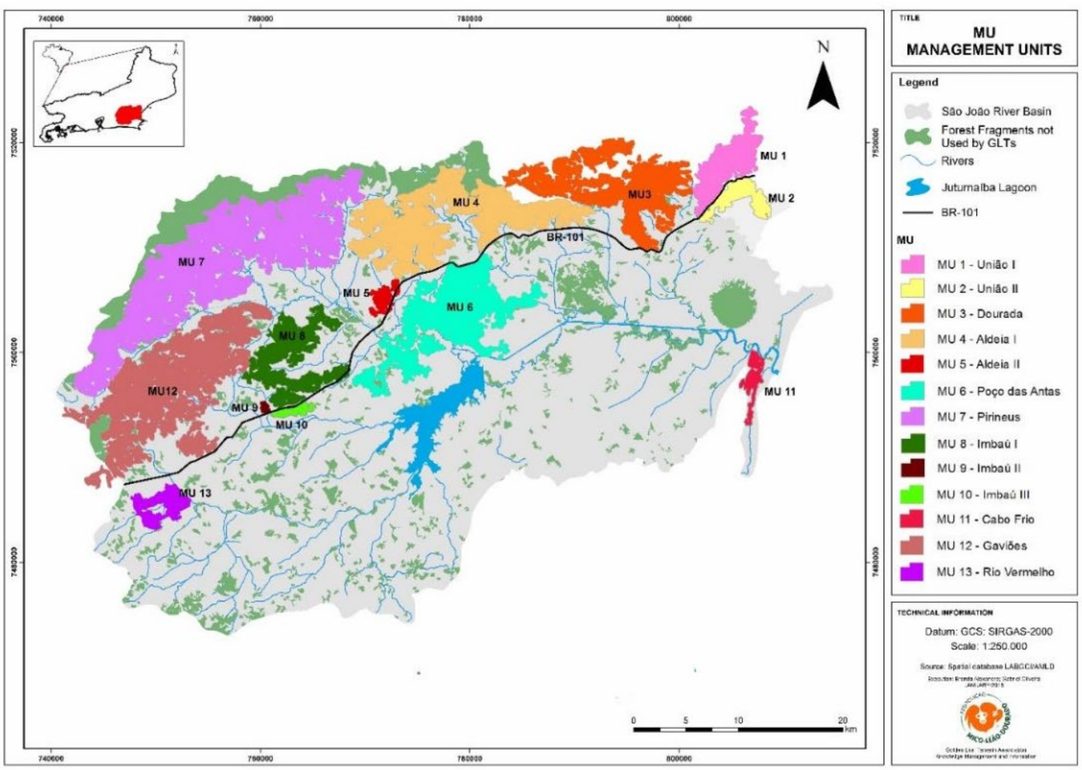

Figure 5. Golden lion tamarin management units (Annual Progress Report, 2018)

According to the Annual Progress Report (2018), GLTs utilize 49,159 total hectares of forest, although these hectares are fragmented. There are existing connections between some MUs, which is necessary to keep a viable population of

GLTs. The largest contiguous forest block is 15,240 hectares, but as mentioned previously, the goal is 25,000 hectares. Even more concerning, the largest contiguous protected area is only 6,941 hectares.

Wildlife Crossing in Construction

Currently, there is a wildlife crossing under construction specifically being built to benefit the GLT (Figures 6 and 7). After years of efforts by organizations such as the AMLD and SGLT, their goal is being achieved. The location of the wildlife crossing currently under construction is between MUs 4 and 6. The WC is connected on one side to the Igarape Farm (Figure 8), which is in MU4, and has 150 hectares of pasture restored to forest.

Figure 6. Vehicle view of wildlife crossing under construction (James Dietz)

Figure 7. Bird's eye view of wildlife crossing under construction (Gorman, 2020)

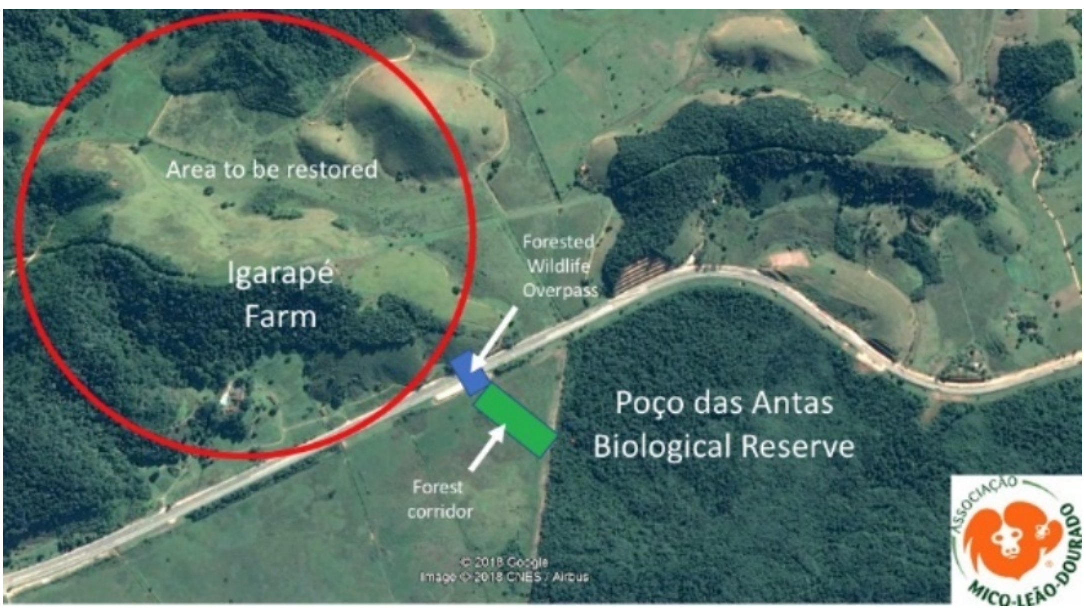

Figure 8. Igarape Farm and wildlife crossing location (AMLD and SGLT, 2018)

Construction Information

Based on information gathered from various maps, highway BR-101 is approximately 33.5 meters wide, including shoulders. The current WC construction seems to go about 4 meters past the shoulders, which gives a length estimate of about 41.5 meters. The WC stands around 4.5 meters above the road and will have the height of the vegetation added to that when it is complete. These approximations were the guide for the dimensioning and design of the wildlife crossing in this thesis.

Site Selection

Connecting Management Units

The goal for implementing a wildlife crossing is to connect management units that are currently separated by the highway BR-101. This was done by evaluating the GLT population number, and forest size of the 13 management units (Table 2).

Table 2. Population and forest size of golden lion tamarin management units. Adapted from (Annual Progress Report, 2018) by Turner

Management Units	**Population**	**Forest Size (ha)**
MU1, MU2 and MU3	249	4,112
MU4 and MU5	499	6,993
MU6	731	4,503
MU7	1,301	13,444
MU8, MU9 and MU10	593	3,120
MU11	Unknown	Unknown
MU12	142	8,243
MU13	189	996

An image received through personal correspondence with Dr. James Dietz of SGLT indicated four potential wildlife crossing locations, as determined by AMLD and SGLT. These four locations were heavily considered, because they were already agreed to in negotiations with the transportation company that is widening BR-101 (Dietz). Because of these negotiations, the feasibility that a WC will be implemented is much greater than at a location not discussed with the transportation company. Figure 9 indicates these four potential locations. It is important to note that Figure 9 calls these locations “WC 1, 2, 3 and 4” and that is synonymous with the following discussion of Sites 1, 2, 3 and 4, respectively.

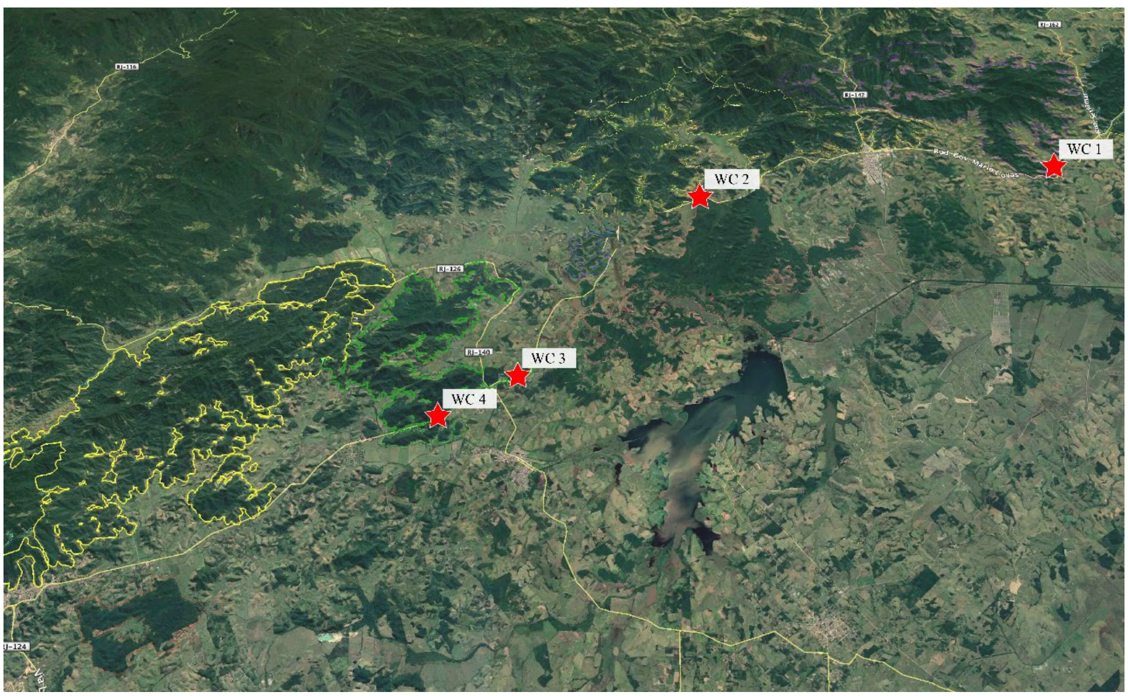

Figure 9. Map of wildlide crossings agreed to in the negotiations for permits necessary to widen the highway (Adapted from Dietz by Turner)

The first step in determining the appropriate MUs to connect using a wildlife crossing was to eliminate MU combinations that would not work or would be least beneficial. These eliminated connections can be seen in Table 3.

Table 3. Eliminated management unit connection information (Turner)

Management units 6 and 7 suffered the most from Yellow Fever due to

Potential Connections	**Relationship to BR-101**	**Notes**	**Site**
MU3	MU3 is north of BR-101	MU3 does not have a MU on the south side of BR-101 to connect to	1
MU6, MU10, MU13	All MU's south of BR-101	MU's are not currently within range of each other	
MU6 and MU7	MU7 is quite north of BR-101 and MU6 is south of BR-101	MU7 is not close to BR-101, and these two units suffered the most from Yellow Fever	
MU11 and MU13	Both MU's are south of BR-101	Not close to other MU's or BR-101	
MU12 and MU13	MU12 is north of BR-101 and MU13 is quite south of BR-101	MU12 and MU13 are not close to BR-101	

highest connectivity (Annual Progress Report, 2018). As seen in the notes section of the previous table, all listed MUs were easily eliminated from contention for various reasons.

After eliminating these potential MU connections, several others were evaluated as well (Table 4).

Table 4. Potential management unit connection information (Turner)

Potential Connections	**Relationship to BR-101**	**Notes**	**Site**
MU1 and MU2	MU1 is north of BR-101 and MU2 is south of BR-101		
MU4 and MU6	MU4 is north of BR-101 and MU6 is south of BR-101	Wildlife crossing under construction is between these two MU's	2
MU5 and MU6	MU5 is north of BR-101 and MU6 is south of BR-101		
MU6 and MU8	MU8 is north of BR-101 and MU6 is south of BR-101		3
MU8 and MU10	MU8 is north of BR-101 and MU10 is south of BR-101		4
MU9 and MU10	MU9 is north of BR-101 and MU10 is south of BR-101		

MU population numbers were very important in determining a site for the second ever wildlife crossing dedicated to the golden lion tamarin. In order to create a WC with the most impact and best chance of improving the population of the GLT, the goal was to connect two MUs with the highest populations, in order to increase the opportunity for gene exchange between populations to achieve eventual stabilization of the GLT population (Table 5). Based on the sites and these population numbers, it was determined that Site 1 did not seem to connect two management units across BR-101. Site 2 is the location of the current WC that is being built. Site 3 has the potential for 775-1,115 individuals to be connected, and Site 4 has the potential to strengthen the population of 380-593 individuals. Based on these numbers, Site 3 was chosen as the site for the wildlife crossing discussed in this thesis to be built.

Table 5. Sites 1-4 and the potential population connection between management units (Turner)

Management Units	**Site**	**Potential Population Connection**
MU3	1	No potential for connection across BR-101
MU4 and MU6	2	Wildlife crossing currently under construction
MU6 and MU8	3	775-1,115
MU8 and MU10	4	380-593

Site 3

Site 3 is characterized by forested areas on both sides, with BR-101 bisecting the two patches (Figure 10 and 11). The north side forest is elevated above the road, while the south side forest is lower than the road. The site is in the state of Rio de Janeiro, is less than a kilometer east of the town of Boqueirão and is approximately 100 km northeast of the city of Rio de Janeiro (Google Earth).

Figure 10. Eastern view of Site 3 (Google Earth)

Figure 11. Map of Site 3 (Adapted from Google Earth by Turner)

Criteria and Goals for the Design

The design and goals of the GLT WC are based on the previously established categories of criteria which include ecological, safety, educational and research. These criteria are intended to achieve the goal of stabilizing and growing the number of GLTs living in the wild. Each previously discussed criteria-based intervention will be discussed throughout this chapter.

The Golden Lion Tamarin Wildlife Crossing

Structure

The length, width, and height of the GLT WC is based on the dimensions of the crossing being built now, as well as recommendations by Dr. James Dietz. The width of the wildlife crossing at either end is 40 meters, while the width at the pinch point is 30 meters. As mentioned earlier in the literature review, the bigger the wildlife crossing is generally better, but that must be balanced with cost. The wildlife crossing being built currently was originally planned to be 30 meters wide but was reduced to 20 meters due to cost. The constructed wildlife crossing is approximately 41.5 meters from one end to the other. This length is appropriate as it goes across the entire width of the road and extends past the shoulder as well (Figure 12).

Though the WC has a pinch point in relation to the area to be used by the GLT and other species, the pinch point does not entirely shape the WC. Where the pinch point exists creates a semi-circle on either side of the WC that is designed to act as a utility space for monitoring equipment, pipes connected to the cistern, and any other storage needs (Figure 13).

Figure 12. Bird's eye view of wildlife crossing (Turner)

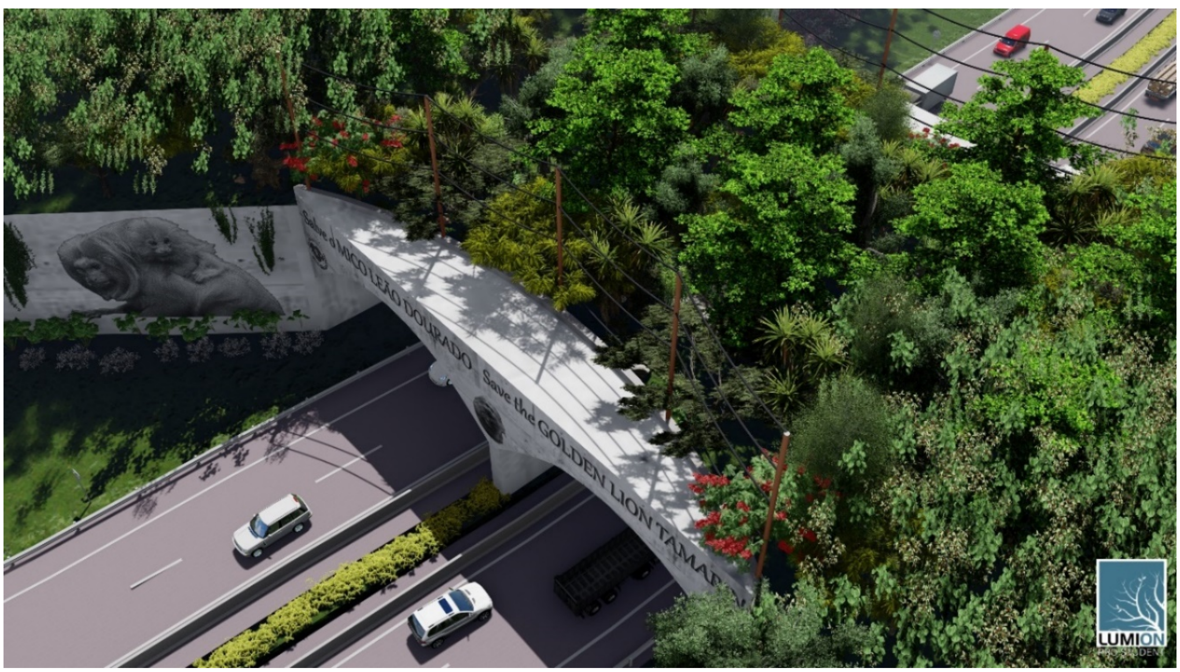

Figure 13. Utility space on wildlife crossing (Turner)

The WC has an arch over each direction of highway in order to provide ample clearance for trucks that often utilize BR-101. In order to avoid any issue and to best connect to the surrounding land, the WC is approximately 8.5 meters above the road, and approximately 7 meters at the lower arch points (Figure 14). This results in a significant amount of clearance that should protect both the animals using the crossing from noise, but also protect any motorists from interfering with or getting harmed by the crossing. Jersey barriers and guard rails were adjusted on this stretch of BR-101 to protect the structural properties of the GLT WC from any damage. A median strip of vegetation was also added for habitat and aesthetic value.

Figure 14. Structural arch design of wildlife crossing (Turner)

The GLT WC includes a soil depth of 2 meters in order to support healthy plant growth. This depth was chosen as it mimics the depth of Argissolo soil, which is commonly found in GLT habitat (Lepsch, 2013). Beyond that, there is a 1.5-meter-high wall that is designed as a barrier between the plant material and the edge, as well as a safety precaution. On top of this are 10-meter tall wooden posts. There are 5 posts on either side of the WC, placed about 10 meters apart from one another. These posts are meant to be supports to hold connecting wires. The wires are vertically spaced about 2.5 meters apart from one another. These wires are placed to stop and catch any plant material that may die from falling off the edge of the GLT WC and onto the road. A cistern has been placed below the structure in order to collect water and provide irrigation to the GLT WC when necessary (Figure 15). The cistern spans the width of the GLT WC, has dimensions of 40m x 30m x 5m and a capacity of 6000 m^3 (1,585,032 gallons) when full.

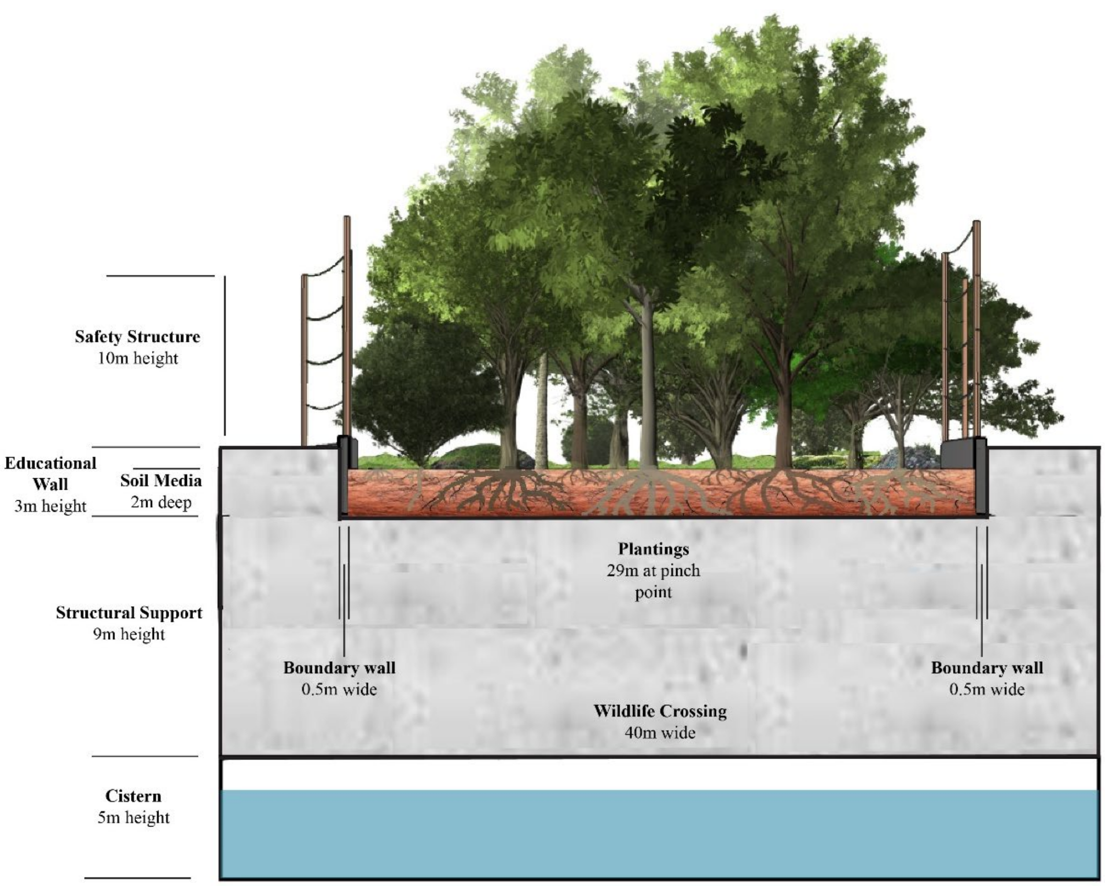

Figure 15. Wildlife crossing details (Turner)

Material Design

The wildlife crossing structure is to be made primarily of concrete for safety, structural, and economic reasons. The faces that will be seen by those in vehicles are to be stamped concrete. To bring interest, character and educational qualities to the GLT WC, there will be multiple stampings; some words, and some images. The words are meant to be educational. On both sides of the WC above the arches the words read "Save the golden lion tamarin," in both Portuguese and English. Surrounding these words are the AMLD and SGLT logo in both Portuguese and English, as well as an image of a golden lion tamarin (Figure 16).

Figure 16. Wildlife crossing text details (Turner)

These stampings are meant to immediately educate any viewers of the purpose of the WC, which is to save the golden lion tamarin. In addition, including the logos of the associations promotes both familiarity and intrigue as to what the associations do.

Surrounding the WC are retaining walls meant to hold back the graded soil and plantings. These retaining walls have large stamped concrete images of various golden lion tamarins (Figures 17 and 18). Each retaining wall has a different image of a GLT to bring interest to the viewers. Those passing the GLT WC should immediately recognize the GLTs and understand the purpose of the WC. Next to these images are several varieties of vines growing on the retaining walls. These vines are meant to bring a more natural feel to the walls. The vines also provide a microclimate for different animal species to inhabit, which contributes to the ecologically focused goals of the WC.

Figure 17. Eastern stamped retaining walls with vines (Turner)

Figure 18. Western stamped retaining walls with vines (Turner)

Connecting Forests

On either side of the WC is an extensive amount of soil and vegetation meant to establish a contiguous forest patch (Figure 19). Because the GLT WC site is elevated on one side of BR-101 and lower on the other side of BR-101, there is necessary grading to be done in order to create an appropriate slope toward the WC on both sides. This connecting land is meant to blend the forest patches together and provide a safe and reliable path for animal species to get to the WC. Without this, the WC may not be easily accessed by the GLT and other species and may not feel naturally connected to the surrounding habitat.

Figure 19. Connection to surrounding area (Turner)

Habitat Design

Biotic Material

The plantings on and around the GLT WC are meant to replicate the surrounding Atlantic Forest patches. This is done by planting native species. Through correspondence with Dr. James Dietz, a list of reforestation plantings used by organizations like AMLD and SGLT was procured. Using this list, a planting plan was made for the GLT WC (Figure 20 and Table 6). The planting plan encompasses a variety of native trees, shrubs, grasses, ferns and epiphytes. A more detailed chart of the trees and shrubs in the planting plan can be seen in Figure 21. These plants range in foliage type, height at maturity, blooming and fruiting time, adaption to surrounding conditions, and family (Table 7). The plants were chosen because they also benefit other species endemic to the Atlantic forest. The plants can serve as nesting sites for birds, nectar opportunities for birds and bats, habitat and cover for species from insects to mammals, as well as a food source for various species, especially the ones discussed later in this thesis.

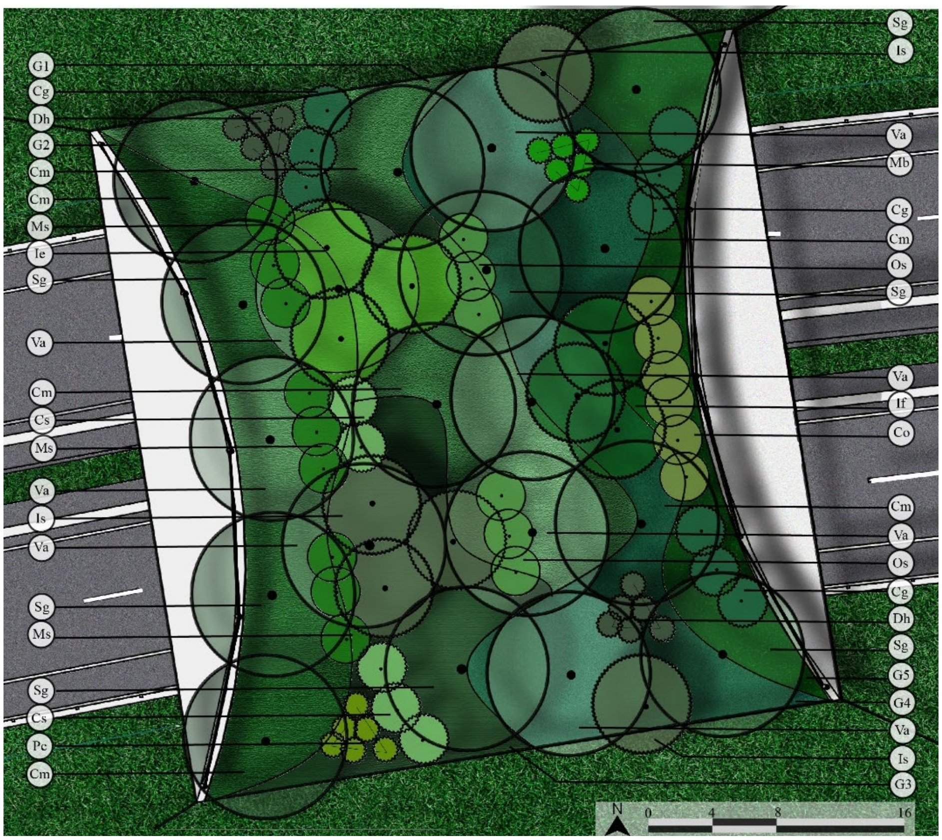

Figure 20. Sample planting plan (Turner)

Table 6. Planting plan key (Turner)

Quantity	Abbreviation	Botanic Name	Common Name
9	Cg	*Cecropia glaziovi*	embaúba
6	Cm	*Centrolobium microchaete*	araribá
6	Co	*Cupania oblongifolia*	caboatã
5	Cs	*Chyrsophyllum splendens*	bapeba
12	Dh	*Diospyros hispida*	Fruta-de-boi

3	Ie	*Ingá edulis*	St. John's bread
3	If	*Ingá fagifolia*	inga branco
5	Is	*Inga sessilis*	ice cream bean
6	Mb	*Mimosa bimucronata*	maricá
9	Ms	*Mimusops salzmannii*	maçaranduba
6	Os	*Ocotea spixiana*	canela
6	Pc	*Psidium cattleianum*	araçá
6	Sg	*Symphonia globulifera*	guanandi
7	Va	*Vataireopsis araroba*	angelim pedra
Mixed seed	G1	*Aechmea conifera, Aphelandra blanchetiana, Pleurostachys guadichaudii*	
Mixed seed	G2	*Araeococcus parvifolius, Ruellia affinis, Dracontioides descisens*	
Mixed seed	G3	*Rhodospatha latifolia, Baccharis singularis, Zomicarpa steigeriana*	
Mixed seed	G4	*Rhipsalis pachyptera, Anthurium bellum, Begonia subacida*	
Mixed seed	G5	*Codonanthe uleana, Asterostigma riedelianum, Dichorisandra leucopthalmos*	

In addition to these plantings, Table 7 also expresses additional plantings to be used in the reforestation efforts. The variety of plantings is intended to prevent the GLT WC and surrounding area from becoming a monoculture and will encourage diversity of species. In addition, the variety of blooming and fruiting times will ensure food access for species year-round.

The interspersing of evergreen plants will ensure coverage and habitat on the WC despite the season. There are both selective hygrophytic and xerophytic species suggested. When conditions are drier, the xerophytic species should thrive, and in wetter conditions, the hygrophytic species should thrive. Overall, the mixing of species should create a balanced planting plan that will safeguard the GLT WC from devastation due to drought, disease or invasive species.

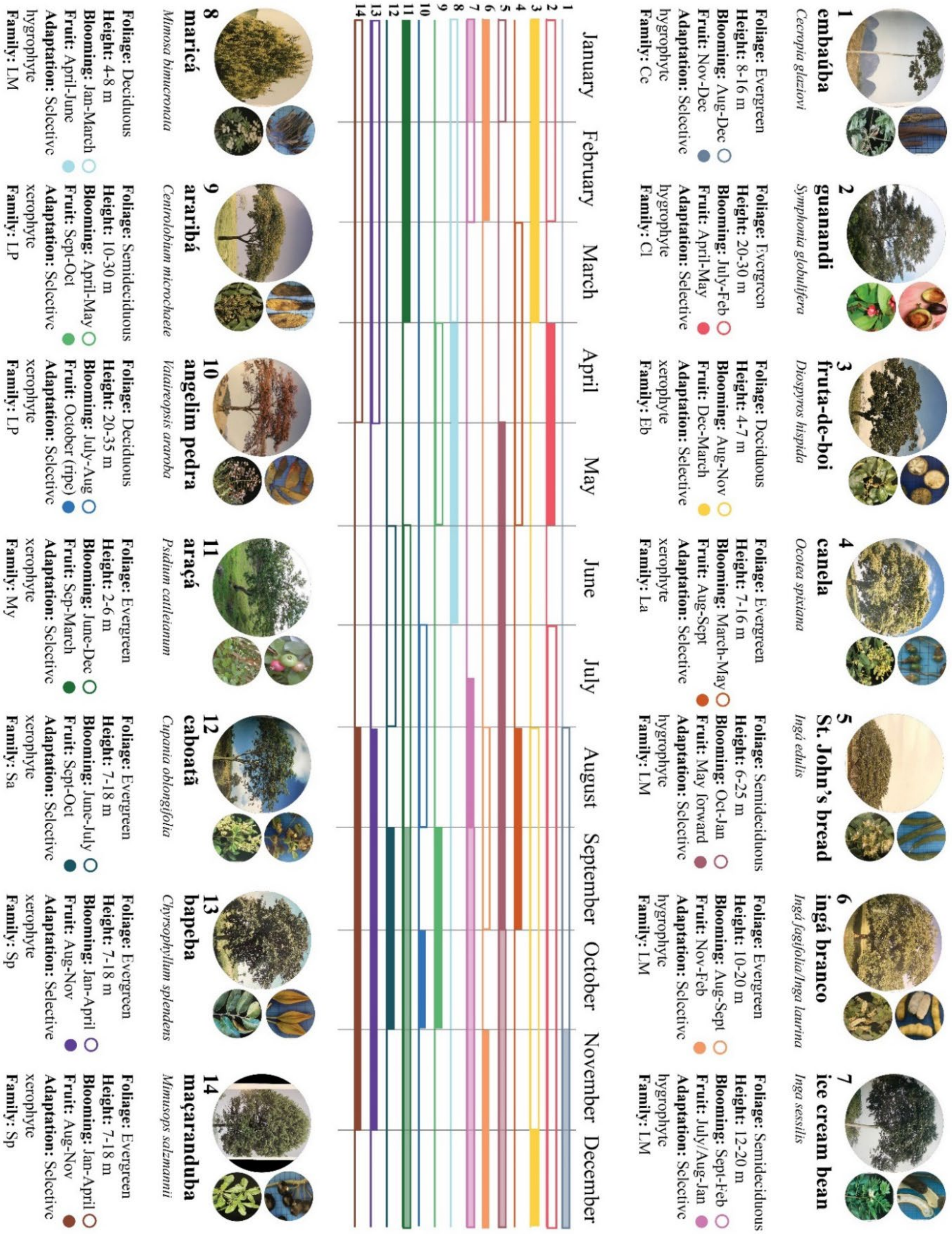

Figure 21. Sample tree and shrub planting palette. 1, 3-10, 12-14 retrieved from (Lorenzi, 2000)*, 2 retrieved from* (Fournier) *11 retrieved from* (Sabine, n.d.)*, adapted by (Turner)*

Table 7. Plant families. Adapted from (Lorenzi, 2000) by (Turner)

Abbreviation	Plant Family
Ce	Cecropiaceae
Cl	Clusiaceae
Eb	Ebenaceae
La	Lauraceae
LM	Leguminosae-Mimosoideae
LP	Leguminosae-Papilionoideae
My	Myrtaceae
Sa	Sapindaceae
Sp	Sapotaceae

Table 8. Additional tree species (Dietz)

Common Name	Botanical Name
Aroeira	Schinus terebinthifolius
Azeitona do mato.	Vitex sp.
Baba de boi	Syagrus romanzoffiana
Candelabro	Erythrina speciosa
Capororoca	Rapanea ferruginea
Carrapeta	Guarea guidonea
Cedro	Cedrela fissilis
Cutieira	Joanesia princeps
Embira de sapo	Lonchocarpus cultratus
Grumixama	Eugenia brasiliensis
Guanandi	Calophyllum brasiliensis
Guapuruvu	Schizolobium parahyba
Ipê felpudo	Tabebuia cassinoides
Jacarandá	Dalbergia nigra
Mamão de Jaracatiá	Jacaratia spinosa
Orelha de macaco	Enterolobium contortisiliquum
Pacová de macaco	Swartzia langsdorffii
Paina do Brejo	Pseudobombax grandiflorum
Paineira	Chorisia speciosa
Palmito	Euterpe edulis
Pata de vaca	Bauhinia forficata
Quaresmeira	Tibouchina granulosa
Sapucaia	Lecythis pisonis

Abiotic Material

Inorganic materials will be added to the WC in order to mimic the surrounding habitat. It is known that GLTs search rocks and dead logs for food. These materials should be gathered and randomly placed throughout the design to provide both habitat for different species, and to mimic the natural environment (Figure 22).

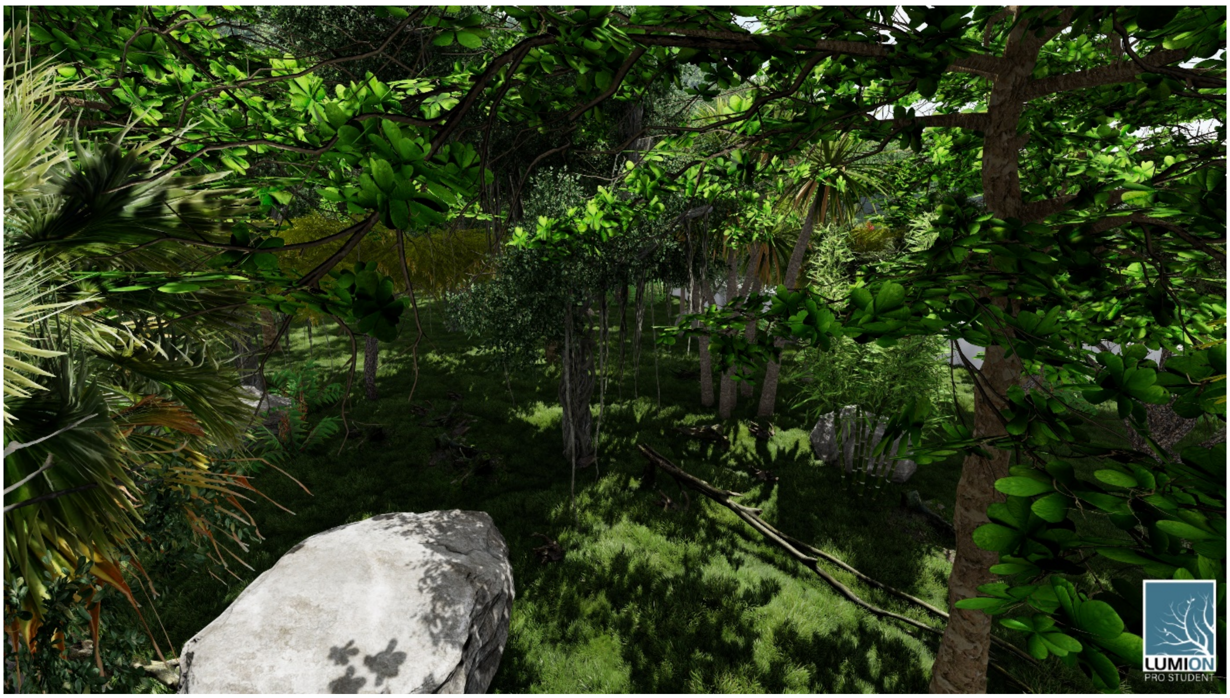

Figure 22. Abiotic materials on wildlife crossing (Turner)

<u>*Other Species*</u>

In order to make the wildlife crossing as effective and economically viable as possible, the WC is intended to be used by many species in addition to the golden lion tamarin. The Atlantic Forest is a largely fragmented forest, but also a biodiversity hotspot, so there are many species that a WC would benefit. The species range from insects to birds to bats and large mammals. The species also range in conservation protection status, from endangered to least concern, as indicated in Table 9. Species such as the critically endangered purple-winged ground dove, and the endangered Bokermann's nectar bat could benefit greatly from this WC and could potentially display increased population numbers. Additional details of an assortment of species the WC could benefit can be seen in Figure 23 and 24.

Table 9. Species Status (IUCN)

Abbreviation	**Meaning**
EX	Extinct
CR	Critically Endangered
EN	Endangered
VU	Vulnerable
NT	Near Threatened
LC	Least Concern
DD	Data Deficient
NE	Not Evaluated

1

Brazilian gold frog
Brachycephalus didactylus

Order: Anura
Class: Amphibia
Status: LC

2

white-necked hawk
Buteogallus lacernulatus

Order: Accipitriformes
Class: Aves
Status: VU

3

purple-winged ground dove
Claravis geoffroyi

Order: Columbiformes
Class: Aves
Status: CR

4

buff-throated purpletuft
Iodopleura pipra

Order: Passeriformes
Class: Aves
Status: EN

5

green-headed tanager
Tangara seledon

Order: Passeriformes
Class: Aves
Status: LC

6

Salvadori's antwren
Myrmotherula minor

Order: Passeriformes
Class: Aves
Status: VU

7

N/A

Brachymyrmex admotus

Order: Hymenoptera
Class: Insecta
Status: NE

8

N/A

Mimoides lysithous

Order: Lepidoptera
Class: Insecta
Status: LC

9

Fluminense swallowtail
Parides ascanius

Order: Lepidoptera
Class: Insecta
Status: VU

10

South American dead leaf mantis
Acanthops falcataria

Order: Mantodea
Class: Insecta
Status: NE

11

collard peccary

Pecari tajacu

Order: Artiodactyla
Class: Mammalia
Status: LC

12

cougar

Puma concolor

Order: Carnivora
Class: Mammalia
Status: LC

13

jaguar

Panthera onca

Order: Carnivora
Class: Mammalia
Status: NT

14

kinkajou

Potos flavus

Order: Carnivora
Class: Mammalia
Status: LC

15

maned wolf

Chrysocyon brachyurus

Order: Carnivora
Class: Mammalia
Status: NT

16

margay

Leopardus wiedii

Order: Carnivora
Class: Mammalia
Status: NT

17

Molina's hog nosed skunk
Conepatus chinga

Order: Carnivora
Class: Mammalia
Status: LC

18

ocelot

Leopardus pardalis

Order: Carnivora
Class: Mammalia
Status: LC

19

South American coati
Nasua nasua

Order: Carnivora
Class: Mammalia
Status: LC

20

tayra
Eira barbara

Order: Carnivora
Class: Mammalia
Status: LC

21

Bokermann's nectar bat
Lonchophylla bokermanni

Order: Chiroptera
Class: Mammalia
Status: EN

22

lesser dog like bat
Peropteryx macrotis

Order: Chiroptera
Class: Mammalia
Status: LC

23

Seba's short tailed bat
Carollia perspicillata

Order: Chiroptera
Class: Mammalia
Status: LC

24

striped hairy nosed bat
Mimon crenulatum

Order: Chiroptera
Class: Mammalia
Status: LC

25

Brazilian gracile opossum
Gracilinanus microtarsus

Order: Didelphimorphia
Class: Mammalia
Status: LC

26

Tate's woolly mouse opossum
Marmosa paraguayanus

Order: Didelphimorphia
Class: Mammalia
Status: LC

27

Bahia porcupine
Sphiggurus insidiosus

Order: Rodentia
Class: Mammalia
Status: LC

28

Elias's Atlantic spiny rat
Trinomys eliasi

Order: Rodentia
Class: Mammalia
Status: NT

29

large headed rice rat
Hylaeamys laticeps

Order: Rodentia
Class: Mammalia
Status: VU

30

long furred rice rat
Oecomys trinitatis

Order: Rodentia
Class: Mammalia
Status: LC

31

lowland paca
Agouti paca

Order: Rodentia
Class: Mammalia
Status: LC

32

maned sloth
Bradypus torquatus

Order: Pilosa
Class: Mammalia
Status: VU

33

Pallid Atlantic Forest rat
Delomys sublineatus

Order: Rodentia
Class: Mammalia
Status: LC

34

striped Atlantic Forest rat
Delomys dorsalis

Order: Rodentia
Class: Mammalia
Status: LC

35

unicolored rice rat
Oecomys concolor

Order: Rodentia
Class: Mammalia
Status: LC

36

jararacussu
Bothrops jararacussu

Order: Squamata
Class: Reptilia
Status: LC

Figure 23. Potential wildlife crossing species (Turner)

Chapter 5: Maintenance, Monitoring and Community Involvement

Maintenance Plan

Plants

The growth and establishment of the plants on the wildlife crossing is vital to its success, as well as the success of the golden lion tamarin. As previously mentioned, although the Atlantic Forest is a tropical rainforest, it has a "dry" season during June and July where the mean monthly precipitation is less than 75mm. Therefore, a cistern is important for the GLT WC. The cistern will be used to irrigate the plants on the WC whenever sensors determine the soil to be too dry. There will also be a weeding maintenance schedule for the first five years after planting in order to remove invasive species and help to establish and grow the native species.

Reforestation

The reforestation efforts must be scientifically evaluated in order to determine their strengths and weaknesses. In addition, evaluation and removal of invasive species will be vital during the first five years after reforestation plantings. Removal of invasives will allow the planted native species to thrive and establish. This establishment is vital in expanding the fragmented Atlantic Forest into larger patches. These larger patches will provide more habitat for not only the golden lion tamarin, but other endemic species as well.

Cistern

The cistern below the GLT WC will need to be evaluated and monitored in order to determine not only its efficacy, but its general status as well. Cisterns require maintenance in order to work properly, and this should be done at least annually. Some maintenance might include checking the pH level, checking the water level, monitoring for bacterial growth, and evaluating its energy usage. In addition to these measures, the cistern should be emptied and cleaned annually as well.

Monitoring Plan

Building a WC is the first step in attempting to sustain and grow the population of GLTs, thus maintaining the biodiversity of the Atlantic Forest. There are several steps after building the WC, however, that are just as important. One of the first steps for future success of not only this WC, but WC everywhere, is monitoring. The purpose of monitoring is to determine the successes and weaknesses of the WC, and learning ways to improve it in the future.

Radio Telemetry

Several types of monitoring will be implemented as design features of the WC including radio tracking. Radio telemetry is a technique often used in tracking GLTs. This method, as used by Dr. James Dietz in many studies includes the capture of an individual, usually the heaviest male in a group, and fitting that individual with a vhf radio transmitter. This transmitter then conveys data using a Global Positioning System (GPS) to record where GLT groups were within less than 3 meters of accuracy (Lucas et al., 2019). This information will continue to be important in order to track where GLTs are in reference to the GLT WC, and whether they are successfully using it. It will also track how long it takes for GLTs to become accustomed to the WC. Oftentimes when WC are built, there is a strong learning curve for use of the crossing (Sawaya, Clevenger and Kalinowski, 2012). Radio telemetry will provide data that scientists can later analyze to assess the learning curve GLTs experience with wildlife crossings and use this data in the future to alter wildlife crossing designs to better suit golden lion tamarins.

Bioacoustic Monitoring Equipment

In addition to radio telemetry, the GLT WC will be equipped with bioacoustic monitoring equipment. On either end of the wildlife crossing, as well as in the middle of the crossing, there will be bioacoustic monitoring equipment that is meant to record any animal calls or noises that may be occurring on or near the GLT WC (Figure 24). As mentioned earlier, the GLT communicates vocally through six

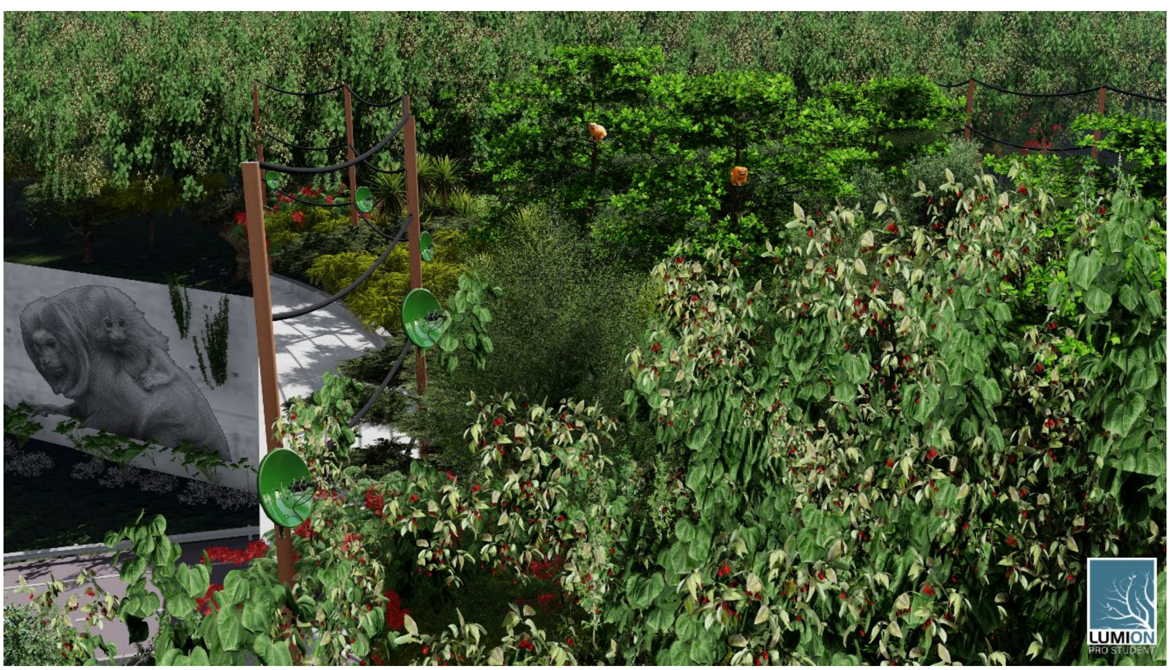

Figure 24. Bioacoustic monitoring equipment on the GLT WC (Turner)

different categories of sound. This monitoring equipment will be vital to recording these sounds and identifying behaviors of GLTs on the WC.

In addition, these recordings will then be analyzed in order to determine not only the type of animals utilizing the GLT WC but also the ages, sex and number of individuals who utilize the crossing. This information will further evaluate the species present on the GLT WC, and any expected species that may or may not be utilizing it. This information will be used to determine what additional resources the GLT WC must have in order to attract missing species to the crossing.

Visual Recording Equipment

In addition, there will be several camera traps on either end of the GLT WC, with multiple cameras facing toward the forest, and multiple facing toward the GLT WC (Figure 25). These cameras will be wide angle and will have motion sensors to

Figure 25. Visual recording equipment on the GLT WC (Turner)

capture wildlife movement around, to, and through the GLT WC. This data will be used to evaluate what species might approach the WC and leave, how often species use the WC, and what species cross the WC.

The camera equipment will also be timed stamped to determine how long each species is on the wildlife crossing, as a camera can capture the time it entered the crossing, and a camera on the opposite end of the WC will capture what time the animal leaves the crossing. There will also be cameras that can record video on either end and throughout the WC. These video recordings can show species behavior on the GLT WC, which can be evaluated to determine how potential changes to the WC can improve this behavior.

Green Roof Sensors

There will be monitoring of the actual WC. A WC is essentially a green roof, as it simply consists of a structure, soil media, and plantings. Because of this, there should be extensive green roof monitoring. This includes having several permanent technologies implemented to record data that will further the research of WC. Throughout the GLT WC there will be indicators that measure soil health and soil moisture. These recordings will help those maintaining the WC to understand the health of the soil and in turn, the plantings. It will also help determine how much, and when irrigation will be needed. In addition, throughout the first five years of the WC there will be measurements of tree and habitat health to determine the successes and failures of certain plants, in order to determine future WC planting plans.

Technology

All these monitoring techniques will provide data that should be made available to both the scientific community, and the public. The more that information about the GLT is spread, the better chance the species has of surviving and growing. A public website and database with continuous livestreamed video of the WC, and updated images of the species on the WC will be made available. In addition, this website will contain information about the species, and ways the community can get involved and help, such as reforestation efforts.

Community Involvement

The Associação Mico-Leão-Dourado (AMLD or Golden Lion Tamarin Association) is a Brazilian non-governmental organization founded in 1992 to keep golden lion tamarins from extinction (Annual Progress Report, 2018). Save the Golden Lion Tamarin (SGLT) is a U.S. charity created in 2005 to provide technical and financial support to help AMLD continue work and achievement regarding the golden lion tamarin (Annual Progress Report, 2018). These two organizations are the reason that the current WC is being built on Site 2 in Brazil. They have fought for years to create a landscape with the GLT thriving. AMLD's vision for the future includes a landscape with enough protected and connected lowland Atlantic Forest to harbor at least one self-sustaining GLT population, as well as continue to provide ecosystem services that improve the well-being of people who also live in the region.

Through the design, monitoring, and organizations such as AMLD and SGLT, community involvement regarding protecting the golden lion tamarin should grow. This growth should include additional reforestation efforts, which will help protect not only GLT habitat, but also the ecosystem services that the Atlantic Forest provides to the surrounding community.

Chapter 6: Discussion

The "Big Picture"

As the opportunity for mitigation of climate change dwindles, innovative adaptation techniques will be extremely necessary. Wildlife crossings are an adaptive technology that are growing increasingly important as human populations continue to grow, countries continue to build and expand infrastructure, and animal habitats continue to be fragmented. Though the GLT WC was designed for the golden lion tamarin, it also is meant to benefit other species, and has the potential to improve biodiversity of the surrounding habitat. This is incredibly important as the surrounding habitat is the Atlantic Forest, which is a biodiversity hotspot containing numerous significant endemic species. Protecting and growing these endemic species is not only vital for their survival, but for the benefits their ecosystem services provide to humans.

Future Studies

The goals of the GLT WC were to ensure ecological benefits to the GLT, to ensure the safety of both wildlife surrounding, and humans travelling on BR-101, and to ensure that research and education was a vital part of the design. The GLT WC attempted to meet these goals to the fullest extent possible, but there is still room for improvement in the future. Multiple WC should be built to fully permeate the landscape and connect the GLT management units. In addition, many more specific sites should be evaluated in order to determine locations for additional WC. The monitoring equipment is vital in evaluating the success of the GLT WC, and determining ways to best improve the crossing, or to change the design for future crossings. Additional research into extensive monitoring equipment and specific protocols for monitoring should be done to ensure it is being used to it full potential. In addition, the WC that is currently under construction (Site 2) should be evaluated and compared to the GLT WC. The similarities and differences in structure, plantings, habitat and design should all be evaluated to determine what components are most successful on each WC. The GLT WC design can be used as a model to encourage designers to use art in an educational way that will inform the public about wildlife crossings and different endangered species.

Lessons Learned

Many lessons can be learned from this study. If there were not a global pandemic going on during the process of this thesis, it would have been incredibly helpful to visit the potential WC sites and evaluate them in person. In addition, it would have been beneficial to observe and interact with GLTs in person to understand their habits and behaviors. I would have also liked to conduct my own species observations, to see what species were most prominent around Site 3. The greater the understanding of the species of the Atlantic Forest, the greater the potential for a successful WC. There are also lessons to be learned about data collection. When trying to gather and work with information and data from another country, it is important to be persistent and have back up plans in case the collection does not go as planned. Dealing with data and information that is primarily in a different language can present certain issues. In addition, the language barrier can prevent certain information from being accurately depicted, which can lead to error.

Though I was lucky to have a connection with Dr. James Dietz of SGLT because of his relationship with the University of Maryland, it would have been beneficial to establish additional relationships with members of AMLD or SGLT.

Appendices

Figure 19 References:

Names of all animal species Retrieved from: (Brito, Oliveira, & Mello, 2004)

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