Investigating the Interactions Between Biological Corridors and Teak Production at Batipa

By:
Ryan Brunelle
Kevin Pine
Jacob Salerno
Elizabeth Viveiros

Investigating the Interactions Between the Biological Corridor at Batipa and Teak Production

An Interactive Qualifying Project Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the degree requirements for a Bachelor of Science

By:
Ryan Brunelle
Kevin Pine
Jacob Salerno
Elizabeth Viveiros

Date: October 11, 2021

Submitted to:
Project Advisors: Professor James Chiarelli, Professor Alex Sphar
Worcester Polytechnic Institute

Project Sponsors: Dr. Francisco Ugel, Señor Edmundo González
Universidad Tecnológica Oteima

Abstract:

Teak production is a significant agricultural activity in tropical regions and therefore has an impact on their ecosystems. The team worked with Universidad Tecnológica Oteima to investigate how teak production influences the ecosystem in the Batipa area, determine means to reduce teak's negative ecological impact, and maintain sustainable teak production revenue. The team conducted research through interviews, surveys, image analysis, and compilation of relevant data. The research revealed that teak has the greatest ecological impact during stages of the production process involving vegetation reduction. To address the issues with teak, recommendations for crop size, crop planting timing, and clearing practices were produced.

Acknowledgments:

Our team would like to recognize the people who helped shape this project into what it is today. Our success would not have been possible without them.

Thank you to

Professors James Chiarelli and Professor Alex Sphar, our advisors for the project, for supporting our project and giving us guidence.

Edmundo González, our sponsor for the project, who gave us great ideas for the project and excellent insight in his interview.

Luis Ríos Gnaegi for his informative interview.

The anonymous workers at the BFI, without their survey responses our data would not have been as thorough.

Online research papers that supplemented our background and findings.

Authorship:

Ryan Brunelle: Primary author of Table of Contents; Background and Literature Review: History of Oteima University, The Impacts of Soil Conditions on Teak Growth; Research Methods: Objective 1; Conclusion and Recommendations; Bibliography

Kevin Pine: Primary author of Background and Literature Review: Abstract, Overview of Biological Corridors, Conservation Research and Methods from Other Biological Corridors, The Biological Corridor Connecting Coastal and Cerro Batipa, Influence of Teak on Plant Life; Research Methods: Objective 2; Findings and Analysis: Teak and Animals, Teak and Soil; Conclusion and Recommendations; Original figures and graphics

Jacob Salerno: Primary author of Introduction; Background and Literature Review: Nature Preserves and Protected Lands, Wildlife Interactions with Teak; Research Methods: Objective 2; Findings and Analysis: Teak Cultivation Findings, Biological Corridor Findings; Primary editor of paper

Elizabeth Viveiros: Primary author of Executive Summary; Background and Literature Review: Overview of Biological Corridor, Common Problems for Biological Corridors, The Impacts of Soil Conditions on Teak Growth; Research Methods: Objective 3; Findings and Analysis: Teak and Plants

Executive Summary:

Introduction and Background

A biological corridor is a passageway between two areas of ecological activity separated by a region with less activity. It is a unique type of connectivity between two ecosystems that depend on each other, and generally include waterways and migration paths. These corridors are being threatened all over the world by agricultural practices, infrastructure, pollution, and deforestation (Rosenberg, 1997). Ultimately, human land use is the main threat to such corridors, and efforts to reverse the damage are not currently making up for the devastation occurring for plant and animal biodiversity and wellbeing. These efforts primarily consist of “nature preserves” and “protected lands” and they aim to physically protect endangered species and prevent development in the area. Protected areas are arguably the most effective tactic for the conservation of at-risk species.

The biological corridor connecting coastal and Cerro Batipa connects and consists of regions including forest preservation, teak production and agriculture operations, and the coastal ecosystem (Ponce, 2016). In this particular corridor, it is important to note the chemical balance in the soil that is caused by the relationship between teak trees and coastal mangrove trees. We wanted to explore this relationship and that of other species and pests in our research to attempt to improve teak plantation practices and the overall wellbeing of the biological corridor.

Teak trees are a tropical hardwood, very popular in Southeast Asia when cut and used for lumber. Due to teak bans in that area, it is largely imported from areas in Latin America including Panama. The high demand for teak wood combined with its extremely rapid growth rates and “luxury” look make for a great source of income for the plantations at Batipa. Teak production is also tax-exempt there and comes with certain benefits for plantation owners.

Understanding the optimal conditions for teak growth was a priority at the beginning and throughout our project. The soil should be “deep, well-drained and fertile” (Kaosa-ard) and the pH and calcium levels in the soil play a role in the growth of teak as well as moisture, light, elevation and temperature. Studies have been conducted to investigate the effect of other micronutrients on young teak seedlings, showing that the lack of one key nutrient or the presence of a detrimental one can have major impacts on teak health.

The success of a teak plantation can have much to do with the effects of teak on native species in the area. The knowledge of these interactions can be one of the most valuable aspects of a teak plantation toolbelt. Biodiversity is an important factor to consider, and we mostly found in our research that depending on the maturity of the teak in the area, the soil should not become unsuitable for undergrowth of other plant species. While compared to that of native forests in one study, the biodiversity around the young teak was not a noticeable difference. However, as the teak matured, it seemed that other species in the teak production area were not so prevalent in the area. Overall, the prosperity of other plants in teak plantation areas was negatively impacted by teak, although there are practices such as enrichment planting.

Unfortunately, the effects of teak on native animal biodiversity according to our research proved to have similar effects to that of plant species. Mitigation of this issue, though, appears to be more easily accomplished. Wildlife in the area might be hesitant to go near a non-native species such as teak, but studies show that biodiversity can be better maintained if the planted forests can imitate the natural forests in the area.

After establishing our background research and the problems we wanted to solve, we were able to produce a series of objectives that we felt would accomplish our project goal: to understand the complex relationship between the biological corridors and teak production at the Batipa Field Institute.

Methods

Our priorities in data collection and analysis were focused on animal movement, soil chemistry, native plant species, and teak production practices. The analysis of these aspects would later prompt further research, such as that of viability of teak production (medium and long term) and the environmentally conscious practices at the Batipa teak plantations that make them so different from other production centers.

> **Objective 1:** Find the ways that teak production impacts animal species in the biological corridors at the Batipa Field Institute and identify which elements of teak production influence these animals.
>
> **Objective 2:** Assess the ways in which the teak production changes its environment by altering soil conditions including: nutrient concentrations, resistance to erosion, and the proportion of organic material. Additionally, environmental factors such as soil changes from previous teak, the geographic characteristics of the area teak is planted in, and how the amount of water available influences the rate of teak production were also assessed.
>
> **Objective 3:** Identify the ways that native plant life and teak cultivation affect each other at Batipa and the ways the biological corridors are ultimately affected by these interactions. From these interactions with the biological corridors, potential strategies to mitigate mutually negative outcomes between teak production and native plants can be constructed. The newly created plan would then be assessed by how effectively it would address the problems identified in the set of plant-teak interactions.

In a remote setting, obtaining data was most valuable to our team in the form of surveys, interviews, and any existing original data that our project sponsors had to offer. Observation and analysis of existing photos and soil test data in Batipa were useful sources of information, as well as the original accounts from Señor González (head of many operations at BFI) and Señor Luis Rios Gnaegi (manager of current practices at BFI and son of its founder).

Findings and Analysis

The data we gathered using our research methods demonstrates our findings on the two-way relationships between teak and the biological corridors around Batipa, including native plants and other plant species, surrounding wildlife, and soil conditions. We also provided an assessment as to whether teak production at Batipa is worthwhile. Our findings suggest that although teak production may be detrimental overall to the corridors at Batipa, it is not always degrading to the corridors, instead the different stages of teak production can have very different impacts on them, and these impacts are not always detrimental. Additionally, there are multiple practices that have been employed by BFI that can be impactful, such as integrating native species into production initiatives and changing the way teak is harvested and planted, keeping in mind the stages of teak growth and production that can be harmful to the ecosystem.

In terms of teak's relationship with animals, there are many impacts the production process can have on the natve wildlife. The analysis of survey responses, interviews, and game camera images taken during a previous study at Batipa by Marcos Ponce revealed two primary mechanisms by which teak influences animal movement in the biological corridors at Batipa. It was clear that animals moving through the corridor can be hindered by teak; it forms a sort of barrier of non-domestic, unfamiliar trees with little to no undergrowth for cover and safety. In fact, the game camera images we reviewed showed a strong positive correlation between undergrowth in areas with teak and animal movement. Besides the density of undergrowth, the main factor in wildlife integration is human interference. The way that the plantations are run makes the environment much less hospitable for wildlife. The understanding of the overall animal impact including the undergrowth density and wildlife relationship discovered during analysis of existing animal images revealed the specific mechanisms through which teak impacts wildlife and at what stage it occurs.

The running of teak production in Batipa has evolved to take the native vegetation into account while planting; they use certain practices, such as a staggering technique that integrates grazing areas into the teak plantations. They also use "thinning", where the harvesters will remove certain, less profitable trees for sale, leaving more space and resources for the newly planted trees.

According to our research, teak production does change the composition on the soil and actively hinders future teak production in the area. Teak, when planted in an area, will disrupt the levels of the soil's moisture, organic material, and sunlight as well as contribute to Batipa's extensive erosion. Fertilizers used in production can also contribute to the soil composition, and our interviews and soil test data established that the pH, alumina, and nutrient levels in Batipa's soil were below average.

Cultivation practices in teak production are the most adaptable aspect of the teak production process. By growing teak in conjunction with cattle ranching, the farmers of Batipa would receive monetary aid for teak growth which they could then reinvest into cattle farming (Edmundo González, Personal Communications). Although this may seem to be a great financial decision for these farmers, it is more harmful to the ecosystem and more economically viable. Some practices that could be useful to the ecological community might be creating a better cover for migratory birds, improving water management, or intercropping other tree species such as rosewood or amarillo (Smithsonian Tropical Research Institute, 2020).

When considering the outcomes of teak production as a whole, specific considerations must be taken to protect the biological corridors that surround them. The aspects of teak production that would have large scale effects on the corridor are of great importance in this matter. For example, small adjustments to drainage flow throughout the corridor may not affect the works of the ecosystem. Thus, the effects of human practices must be fully explored as they are the most likely to affect the corridor. Changes in animal foot traffic, structure of the corridor, and plant life are the key indicators of teak production tampering with the biological corridors.

Conclusion and Recommendations

After compilation of background research and data obtained and analyzed using survey and original expert interviews as well as original photos and research from BFI, our team has acquired a greater understanding of the impact of the biological corridors on teak production and more importantly, the effects of teak production on the corridors. We have a series of recommendations to offer to our sponsors for their future teak practices and to anyone who might want to participate in a more sustainable lumber production process, as follows.

1. <u>Plant more small crops of teak several years apart rather than planting only a few large crops.</u> This will decrease the amount of land that does not have tree cover or undergrowth at a single time. This will make teak during planting and harvest less of a barrier to animal traffic through the biological corridors. This practice will also prevent too much land from being at a severe erosion risk at one time. This suggestion could also provide an economic improvement by allowing teak production to produce a more steady income stream.

2. <u>Reduce the undergrowth clearing required for new teak by introducing slow growing/determinant native plant species combined with mulching.</u> In terms of economic gains, implementing this method could reduce teak production costs via requiring less labor to clear vegetation during the teak planting period. An additional economic benefit is a possible improvement in the development of the teak saplings due to more stabilized moisture levels. This suggestion would also have positive ecological impacts if implemented including erosion control and improved animal traffic as a result of having some vegetation at all times.

3. <u>Allow some time between planting teak crops in the same location.</u> This suggestion would improve the health of the biological corridors at Batipa by allowing any disrupted animal movements to be restored. Additionally improved soil nutrients would make it easier for undergrowth to re-grow when teak is planted again, helping maintain animal traffic through the corridor. Waiting after harvest to replant rather than immediate replanting can also reduce teak production costs by enabling the purchase and use of less fertilizer during the planting process.

Table of Contents

Table of Figures

Table of Tables

Chapter 1: Introduction

Teak trees are a tropical hardwood indigenous to Southeast Asia that were naturalized and cultivated in countries with similar climates. The trees' natural oils give them resistances to humid climates and pests. Furthermore, teak's use as lumber for outdoor furniture makes the harvesting of teak an economically viable and lucrative source of income for many nations (Lotha, 1998). In Panama, there exist many teak plantations, such as the Panama Teak Forestry which boasts over 7,000 acres of teak trees (Panama Teak and Forestry Inc., 2021). Due to its status as a cash crop, teak production is prolific in many tropical regions which undoubtedly has an influence on these regions' ecosystems.

One location where teak production and native tropical ecosystems exist together is at Batipa, a region of Chiriquí, Panama. The Batipa Field Institute (BFI) is an area of land managed and utilized by Universidad Tecnológica Oteima for scientific, economic, and other applications. For example, applications include functioning as a nature reserve and hosting a teak plantation to raise revenue. Previous research on the ecosystem at Batipa highlights how the mixed land use produces biological corridors that are similar in structure to larger scale corridors in Panama (*PLAN MAESTRO CENTRO BATIPA*, n.d.). The biological corridors in Panama are the paths that species take when transiting between forests at higher elevations and the coastal region, typically covering several natural or man-made boundaries between areas with varying levels of ecological activity (*PLAN MAESTRO CENTRO BATIPA*, n.d.). The structure of Batipa combined with its highly biodiverse reserve areas make the conservation strategies used there directly relevant to the greater region.

Universidad Tecnológica Oteima, in conjunction with partners including WPI, has previously researched both teak production in the Batipa region --as part of the research for a 2020 IQP-- and the movements of animals in the agricultural and reserve areas. The data regarding the environmental factors that negatively impacted teak trees are invaluable resources in understanding the larger ecosystem. In addition to the work done by the WPI team on teak, other researchers have established the impact of teak on different elements of the ecosystem, both in Central America and other tropical regions. Research shows teak impacts its surroundings through changes in plant biodiversity, altered wildlife movement, and soil erosion.

The findings of previous research conducted by an IQP team in 2020, in conjunction with research on teak and the environment in other tropical regions show both how teak interacts with specific elements of the environment as well as what is needed for successful teak cultivation. While this information is applicable to many specific components of the ecosystem at Batipa, there is little existing research covering how teak's influence on specific elements of the environment together change biological corridors overall. Until it is further understood how teak impacts biological corridors as a system, identifying the most effective conservation and or agricultural practices remains difficult.

Our project goal is to work with the BFI to further understand how teak production interacts with the biological corridors at Batipa. This will inform decisions addressing the ongoing preservation of the ecosystem while also continuing agricultural activities via the cultivation of teak or an alternative crop. The research goals include identifying the influence of teak cultivation on the biological corridor, analyzing data relevant to teak's impact on different parts of a tropical ecosystem, and analyzing data previously gathered in the context of interactions between teak and the biological corridor. Finally, we used the research findings to inform our set of recommendations to the Batipa Field Institute.

In order to achieve the aforementioned research goals we drafted 3 objectives. The first focused primarily on understanding the relationship between teak trees and the biological corridors. Surveys and interviews were set up in order to identify the potential effects that the teak plantations have on the preexisting corridors. The second objective investigates the soil chemistry of Batipa and what impact it will have on teak growth. Results were taken from both previous research on the matter, and our own analysis of Panamanian soil quality. Lastly, how native species interact with teak was investigated. This was done through surveys, and data collection from available public records in Panama. By achieving these objectives the team ensured all factors had been considered before the creation of our recommendations to the BFI regarding their teak operations.

Enacting the aforementioned methodologies for each research objective yielded original data composed of interview transcripts, survey responses, and image sets. The original data combined with the data sets produced in previous research enabled the identification of important characteristics of teak production's ecological impacts, allowing recommendations for cultivation practices to be created. The research revealed that teak production has a detrimental impact on the biological corridors at Batipa as a result of its impacts on plants, animals, and soil. It was also noted though that teak production only has a significant impact on the biological corridor during specific steps of the teak production process. The recommendations and information produced through this project will be helpful at Batipa, greater Panama, and anywhere teak is produced. While this study increases the understanding of the impacts of teak cultivation on its surroundings, more research is still needed to ensure that all of the mechanisms for teak's ecological impacts are identified and understood in their entirety.

Chapter 2: Background and Literature Review

2.1 - Nature Preserves and Protected Lands

Nature preserves and protected lands are important in protecting the biodiversity of an ecosystem. They preserve the propagation of native species and ensure they grow in optimal environments. This is especially important in the Batipa region as it has immense biodiversity. Should certain animals or plant life become scarce in a biodiverse ecosystem it will disrupt the food chain in the area. Furthermore, the natural services provided by these lands are numerous. Specifically in the Batipa region protected lands can help keep the biological corridors safe from any man-made disaster.

Despite being useful for natural preservation, there exist limitations with nature preserves and protected lands. For example, resources for these types of lands are limited. Thus, it becomes more important to have a focused goal when suggesting an implementation of a natural preserve. Furthermore, with too strict of boundaries imposed on the natural reserve section, some animals may have their habitats cut off from them. Overall, we can not say that protected lands are the only solution needed to conserve the biological corridor we are researching.

Protected land also can change how the land around them is interacted with. A land use change can isolate protected areas from their surrounding landscapes (Defries, 2007). How nature reserves are used depends entirely on the characteristics of the preexisting land. Differences of biodiversity in the protected areas and their surroundings, ecological interactions in the surrounding landscape, and the shift socioeconomic dynamic are all factors which inform how nature preserves should be set up. Legal land developments in these protected areas and around them also negatively impact conservation efforts in some instances (Defries, 2007). With this in mind, the biodiversity of the biological corridors directly relates to our team's ability to manage teak production in these areas.

2.2 - Overview of Biological Corridors

A biological corridor is a passageway between two areas of ecological activity separated by a region with less activity. The region of decreased biological activity can be naturally formed, such as a dry region between coastal and mountainous ecosystems, or it can be man made (Ponce & Vargas, 2018). As such, nature preserves are often linked by these corridors.

Typically, biological corridors connecting protected lands take the form of having three distinct layers. These layers are the protected land at the start, the protected land at the end, and the developed land between the two. What is unique about this type of corridor is that the boundaries between each layer are clearly defined as they are the result of the hard borders of the preserves. These hard borders can become problematic particularly when no corridor is able to form, as these boundaries tend to result in unmitigated "habitat fragmentation" (U.S. Forest Service, 1997).

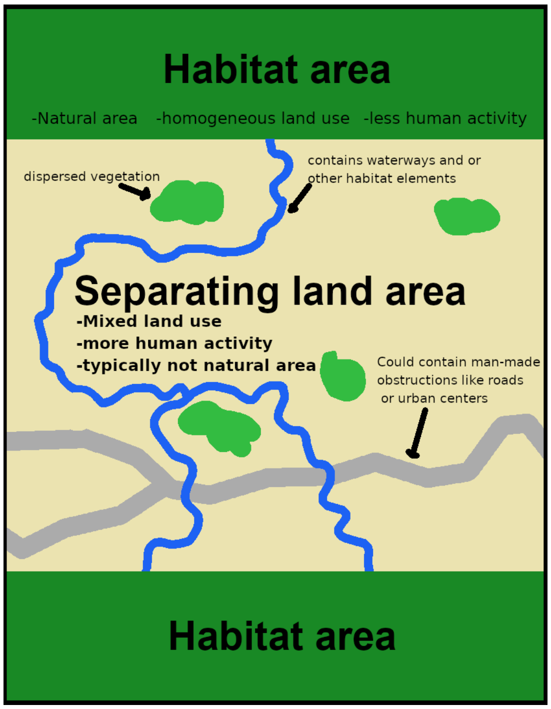

Figure 2.2.1 – General Corridor Layout

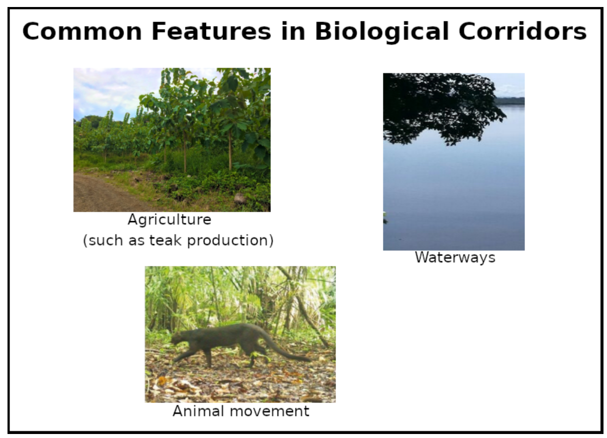

Figure 2.2.2 - Common Corridor Features
Ponce, 2016
Stack et al., 2020

Though many areas have ecosystems separated by a region with less natural activity, biological corridors don't appear in all cases. Generally speaking, biological corridors tend to form when connectivity between two ecosystems supports each others' plant and animal species (*PLAN MAESTRO CENTRO BATIPA*, n.d.). This relationship between the two ecosystems, where one ecosystem is dependent on another to maintain its population of the species who travel through the corridor, is identified as a defining feature by the US Forest Service (U.S. Forest Service, 1997).

Besides just having two separated ecosystems, biological corridors also have other features. These features include waterways between both ecosystems, regular migration paths for one or more species, and vegetation that serve a habitat function in the middle region to support animal movement (U.S. Forest Service, 1997).

Biological corridors also impact the ecosystems they link. As noted by Oteima University, biological corridors are a means for ecosystems to maintain biodiversity (*PLAN MAESTRO CENTRO BATIPA*, n.d.). Also, as previously mentioned, biological corridors serve as migration routes in many cases, enabling an important stage in the life cycle for many species (U.S. Forest Service, 1997).

2.3 - Common Problems for Biological Corridors

Biological corridors are becoming increasingly threatened by human practices and lifestyles. Ecosystem fragmentation due to infrastructure, pollution and other disruptions have ultimately led to habitat loss and a decrease in biodiversity (Rosenberg, 1997). Despite the establishment of projects focused on addressing the problem, the situation continues to worsen. In some cases such benevolent attempts have even unintentionally caused further destruction. By analyzing the effects of the human race on these areas, we can understand some feasible ways to prevent any further loss to the corridors in and around Batipa and promote the growth of the existing ecosystem.

The deterioration of the landscapes in biological corridors in North and Central America have a direct correlation with human exposure (Parks, 2020). “Protected area” initiatives can be expanded to mitigate this problem. Tillage, pasturing, pesticides, and other agricultural practices are extremely detrimental to the area. Since much of the land is dedicated to farming, it is debatably the leading issue for wildlife corridors (Mineau, 1995). Experts propose organic fertilizers and other climate-friendly alternatives, however these solutions are costly and can sometimes be disadvantageous to the industry, leading to the further downfall of the biological corridors. In the future it could be beneficial to the area to implement farms and other biological disruptions while taking into account the natural climate connectivity of the corridor. This approach allows for the movement of existing wildlife, waterways, and vegetation without disruption.

Barriers such as large highways and fencing can also result in reduced movement of species throughout a biological corridor. In a 2019 WPI MQP project, students conducted research around a significant barrier to species surrounding the Batipa Field Institute; Highway 1 in Batipa (Boccio, 2019). The purpose of this project was to design a wildlife crossing across the highway. Their research provides insight into the severity of interruptions to vital migration routes that highways can cause, especially in the area of Batipa. This includes injuries, casualties of various species, and deterioration of the state of local ecosystems.

Garbage and other pollution plays a pivotal role in the water quality of many of the rivers in Panama. According to a local environmental NGO coordinator, over 100 tons of garbage are disposed of into the Panamanian seas and coasts, the Panama Canal, and the rivers of Chiriqui on a daily basis (Aguilar, 2020). The recent global pandemic has worsened the circumstances by limiting and halting cleanup initiatives in these areas. Canal construction is also a major contributor to Panama's water pollution.

In the study of the biological corridors in Batipa, it should be noted that biological fragmentation and degradation is largely due to human use of the land, whether it be for agricultural, transportation, disposal, or other purposes. This understanding will inform possible rehabilitation responses to the modification of human practices, as opposed to working around these harmful practices for a separate solution.

2.4 - History of Oteima University

Oteima University, founded in 1986, was originally a company called "Fertica", which was created to help bring education and employment to the surrounding community in western Panama. At the same time, the country was in a state of social and political tension as the United States' "War on Drugs" spread to this region of Central America. The company's founders, Luis Ríos Espinosa and Elena Nixsa Gnaegi de Ríos, aimed to bring their knowledge and experience from their higher education to Panama. Their company helped to improve agricultural practices in western Panama through technology and innovations, and in the 1980's "Oteima Training Center for Executives" was born. This training center was registered as a "post-secondary training institute" and their goal was "dedicated to the training of professionals at a technical level" (Universidad Tecnológica Oteima, 2021). Shortly after the United States government ceded control over the Panama Canal to the Panamanian Government, Luis and Elena decided to create "La Universidad Tecnológica Oteima" or "The Oteima Technological University" in order to better raise the next generation of educators and professionals.

The acronym OTEIMA in English stands for Computers, Technology, Education, Languages, Environment, and Agriculture. Their mission is "to train professional leaders, entrepreneurs and committed to the human and sustainable development of the country"(Universidad Tecnológica Oteima, 2021). The university is recognized for their business approach and sustainable education and development. This mission aligns with our project goal, as we are striving for a sustainable approach to the conservation and advancement of the biological corridor in Batipa.

2.5 - The Batipa Field Institute

The Batipa Field Institute was bought and developed in 1995 with the intent to transform the majority of the surrounding area into teak plantations. It is located approximately 13 miles (or 20.5 km) from the city of David and offers a way for the locals to learn more about the wildlife and the ecosystems they live in. The BFI contains a protected wildlife habitat located at the top of Cerro Batipa and various biological corridors that lead down from this reserve through the teak plantations towards the coastal mangrove forests. The BFI's mission involves agriculture and habitat preservation in the tropical environment of Batipa with an added focus on climate change and other challenges (Bosari et al. 2021). In the past, they have collaborated with Conservación Internacional and other renowned organizations. Both BFI and Oteima University have worked closely with WPI previously for a variety of projects involving teak growth, water sustainability, wildlife crossings, and energy and resource evaluation/repurposing. These projects give direct insight into biological corridors, teak growth, and local natural research that can be applied to our project goal.

2.6 - Conservation Research and Methods from Other Biological Corridors

The US Forest Service has identified various aspects of a strong biological corridor and compared several different Biological corridor structures in order to identify the best conservation practices. The study found that improving the quality of the habitat within a corridor, increasing the size of the corridor, and increasing the size of the habitats at either end of a corridor can all have positive impacts on the system, overall. But in addition to this, they also identified that in practice increasing one variable may have less desirable effects on the condition of the others. Part of Figure 2.6.1 was included in the study and shows how the size of the habitats on either end, the width of the corridor, and the quality and distribution of habitat components in the corridor are affected by each other (U.S. Forest Service, 1997).

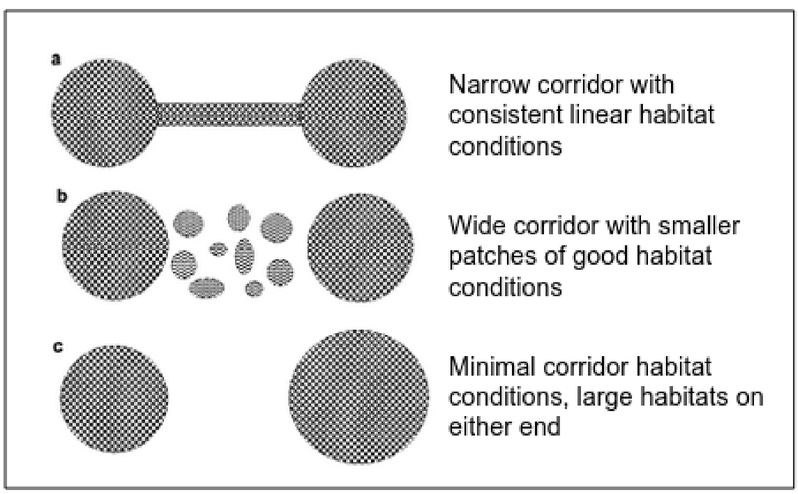

Figure 2.6.1 - Corridors and Habitats
U.S. Forest Service, 1997

These findings reveal that conserving a biological corridor involves addressing all components of the system rather than any one component. It is important to note, however, that for most ecosystems, addressing any one aspect of the system for conservation will likely not have an inverse impact on other components of the system to the same extent as in the study (U.S. Forest Service, 1997).

2.7 - The Biological Corridor Connecting Coastal and Cerro Batipa

In Batipa, there are several local biological corridors that have been identified as suitable research subjects both for improving the conservation of the natural ecosystem and finding new sustainability practices for the agriculture operations, such as teak plantations operated by the university (*PLAN MAESTRO CENTRO BATIPA*, n.d.). Findings in the research of these corridors are likely scalable to the much larger regional corridor connecting the coastal region Batipa is located in with preserves in the mountains to the east (*PLAN MAESTRO CENTRO BATIPA*, n.d.).

This corridor, like all biological corridors, consists of two ecosystems separated by a region of land not definitively part of either. These regions for this particular corridor are the forest preservation, a ring of teak and agriculture operations, and the coastal ecosystem (Ponce, 2016).

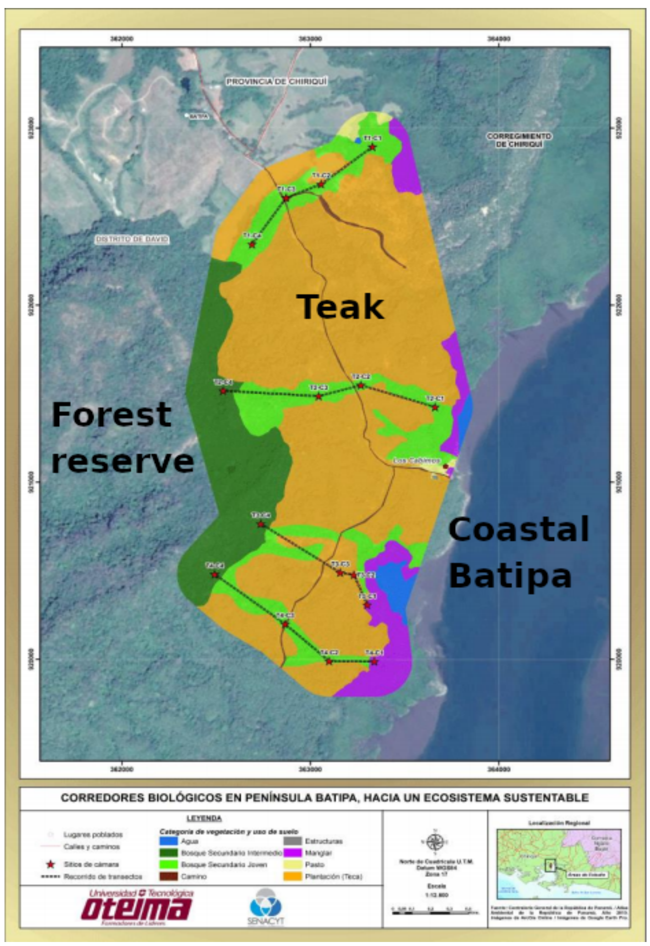

Figure 2.7.1 - Biological Corridors at Batipa
Ponce, 2016.

Some potential threats to the corridor have been suggested in the findings of previous research in the area. The first of these is the relationship that teak trees and coastal mangroves influence the chemical balance of the soil in the area. Past research has also suggested that while the existence of a biological corridor at Batipa has been established, it is unclear if the teak plantations influence the amount of animal traffic in a corridor (Ponce, 2016).

The research regarding teak production conducted by a previous IQP team in Batipa also found that growing teak alongside other species is effective in reducing the impact of pests and helping maintain soil quality. However; the interactions among teak trees, non-teak tree species, the soil, and pest species with regards to teak production has not been fully established and research here could help improve teak production as well as reveal information about the biological corridor (Stack et al., 2020).

2.8 - Economic Effects of the Teak Production Industry

The teak growing industry is one of Batipa's main sources of income. The rapid growth of the plant makes for an accelerated turnover rate and therefore an easy source of income. Teak wood's "luxury" look and hardiness contributes to the high demand for furniture, infrastructure, and ship building teak around the world (Brown, 2000). According to Edmundo González, Principal of Integrated Environmental Solutions at BFI, their biggest clients are China, India, and Vietnam. Domestic teak wood production in Southeast Asia used to be more widespread before extensive illegal logging and exportation bans became prevalent in the natural forests there (McGeehan, 2020). Consequently, the imports to these countries have increased due to the decline in domestic harvest, and Latin America is one of their biggest sources of teak.

Panama is home to upward of 55,000 hectares of teak growing land, and illegal logging is not as large of an issue in the plantations. Naturally, the business is thriving with the increased demand, decline in competitors, and the contrast between profit and cultivation costs (Yadav, 2020). Therefore while the managers of this operation may be aware of teak's effects on the surrounding ecosystem, they would be extremely hesitant to cut down on production due to the essential source of income and benefit for the institution.

2.9 - The Impacts of Soil Conditions on Teak Growth

The optimal conditions for teak growth and the factors that affect the production of teak are vitally important to the project, specifically the soil that influences the conditions of the surrounding landscapes as well. The Panama Forestry website provides further information on the categories of soil that teak thrives in.

One factor that is discussed in the Panama Forestry site is the soil type. The types of soil Teak grows best in are “deep, well-drained and fertile soils” and Dr. Kaosa-ard, a source the Panama Forestry uses, further elaborates on this matter stating in his paper, *Overview of problems in teak plantation establishment,* that teak does not do well in shallow, compacted soils, especially when they are not maintained after planting. He goes on to describe that this soil is usually derived from “limestone, schist, gneiss, shale (and some volcanic rocks, such as basalt” (Kaosa-ard).

Another factor is the pH and calcium content of the soil. Panama Forestry noted that a pH level of 6.5 to 7.5 was optimal for teak growth, and Koasa-ard’s findings agree with that. He also includes that a large calcium content is needed for proper teak growth and that teak trees are considered a “calcareous species”, meaning they contain calcium carbonate.

Other miscellaneous factors include moisture content, light intensity, and temperature , but Kaosa-ard explains that the temperature in which Teak grows is especially important. He states that “teak poorly tolerates cold and frost conditions during the winter period” (Kaosa-ard) and as a result, teak is sensitive to elevation. Temperatures from 27 to 36 degrees celsius and elevations of under 700 meters will be optimal for growth.

A study conducted by M. P. Sujatha of the Kerala Forest Research Institute explored the importance and impact of various micronutrients present in the soil during the infancy of teak trees, namely that of iron, copper, zinc, manganese , molybdenum, and boron. This study showed the impacts certain deficiencies of these micronutrients had on the growth and health of teak tree seedlings in regards to their leaves, root structure, and height. This was done by taking young teak trees from an isolated culture, washing them and their root systems thoroughly so as to ensure no residual substances, and replanting them in purified, nutrient free sand. Sujatha supplied the plants with a “modified Hoagland No.2 nutrient solution” two weeks after their placement into the sand. This solution provided the plants with everything they needed to grow, but Sujatha modified six other solutions to be free of Fe, Zn, Cu, Mn, Mo, and B and would be used on different batches of plants to monitor the effects that the lack of these respective nutrients would have. They also included a control group that got a solution with all of the necessary nutrients. For the various deficiencies, Sujatha noted the effects on the leaves of the plants, their height, and root structure:

Deficiency	Time elapsed until symptoms appeared	Description of symptoms
Fe	55 days	Chlorosis (yellowing) of the interveinal sections followed by the chlorosis of the entire leaf and shortly after, full necrosis (death). Cupping of the leaves was also noticed.

Cu	84 days	Similar chlorosis of interveinal sections with necrosis of leaf tips later in growth. Younger leaves had become "crispy" as well as wrinkled with stunted growth.
Zn	64 days	Younger leaves became "crispy" similar to the Cu deficient plants, and became abnormally large and droopy. These leaves also experienced patches of necrosis starting at the leaf tip.
Mn	65 days	Lower leaves of the plant became chlorotic (unable to produce chlorophyll) but the newer leaves towards the top of the plant did not experience this same effect.
Mo	65 days	The absence of a leaf tip was noted in Mo deficient trees as well as chlorosis and necrosis after some time.
B	6 months	The abnormalities in B deficient trees occurred much later than the others, and resulted in the leaves becoming brittle, as well as clustered in the formation of new leaves. Eventually these leaves experienced premature necrosis as well.

Table 1: Effect of micronutrient deficiencies on teak seedling leaves

One effect that was consistent across almost every single deficiency was the premature death of the leaves of the plant. They also shared chlorosis, or the yellowing of the leaves due to the inability to produce chlorophyll.

This study also recorded the heights of these trees as another factor of the impact micronutrient deficient soil may have. For each of the cases explored, all six had noticeably worse performance than the control group. For reference, the control group grew to 42.2 cm within 3 months and 62.3 cm within 6 months. The iron deficient group only grew to 28.4 cm within the 3 month mark, and 33.6 cm within 6 months. This is approximately a 40% reduction in height from just a single nutrient missing. Similar size reductions were recorded for the copper, zinc, manganese, and molybdenum cases, with the boron deficient section coming the closest to the control group with an average of a 20% reduction.

The number of healthy leaves for each of the trees varied slightly more than the height. After 3 months, the control group had an average of 13 health leaves, the iron group had 4, copper and zinc had 8, manganese and molybdenum had 10, and the boron had 13, the same as the control. Unfortunately, by the 6 month mark all of the testing groups except the control had lost almost all of their healthy leaves. The control group saw an increase with 16 leaves after 6 months, but the deficient trees had an average of 2 to 3.

Lastly, Sujatha inspected the roots of these plants. It was noted that the mass of the root systems were relatively consistent among all tests (including the control) with the exception of the copper deficiency. The copper deficient plant weighed 3 to 4 grams less than the average of 12 to 13 grams seen in the other tests.

Sujatha also tested remedial solutions to these deficiencies using sulfate solutions containing the group's respective lacking micronutrient. Sujatha found that in most cases, concentrations near or above 1% would cause phytotoxicity and kill the leaves. A concentration of 0.1% was found to be enough to remedy the symptoms of the insufficient nutrients except in that of copper, iron, and boron. With iron, a concentration of 0.3% rectified the symptoms and with copper, even the average concentration of 0.1% led to plant death. In the case of boron, recovery was successful having used only a 0.05% concentration of boric acid.

Soil type, quality, and nutrient concentration play an important role in the growth of teak trees. A lack of one nutrient or the presence of a detrimental one has a major impact on teak health. This makes the maintenance of soil a high priority during all stages of teak growth as well as making sure remedial solutions are prepared in advance for any type of deficiency.

2.10 - Influence of Teak on Other Plant Life

The relationship between teak trees and native plant life plays a major role in the success of the teak plantation and heavily influences the health of the surrounding ecosystems. Understanding the ecological outcomes of teak cultivation in areas where teak is not endemic shows teak's primary impact on its surroundings.

A defining characteristic of tropical ecosystems is their high biodiversity, meaning that a large number of different plant and animal species are present within a given area of that ecosystem ("Biodiversity", 2021). As a defining trait, biodiversity serves as a useful indicator to determine the health of a given tropical ecosystem.

Unlike some other tree species used for timber, the presence of teak does not appear to result in the soil becoming unsuitable for the initial growth of plant life on the forest floor. This relationship with undergrowth is supported by a study published in the *African Journal of Ecology* that compared the number of native tree species, at different stages of maturity, in a teak plantation to the number of species found in a pure forest. The results of the study revealed that the biodiversity of saplings in the teak plantation was nearly the same as the sapling biodiversity in the pure forest. Moreover, the study was conducted in Ghana, which is not in the natural range of teak; making the findings relevant to other tropical regions where teak is non-native (Boakye, 2012).

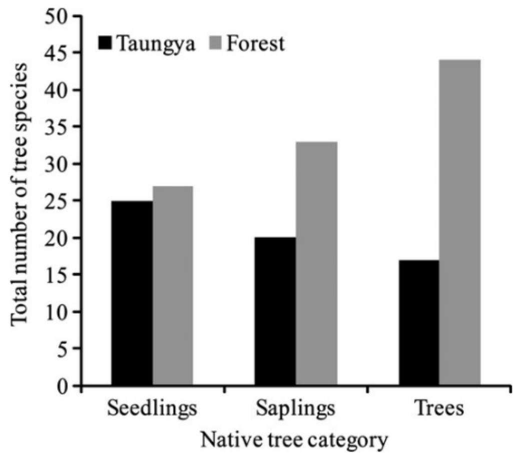

Figure 2.10.1 - Number of native species for seedlings, saplings, and trees
Boakye, 2012.

While the ability for undergrowth to form in the presence of teak trees, combined with a limited impact on tree sapling biodiversity, initially suggests teak may not adversely affect native plant species, the same study revealed that far fewer species of native tree were present in teak plantations when counting the more mature specimens. As shown in figure 2.9.1, the number of mature tree species in the teak production areas was less than half that of the natural forest.

Though the establishment of a teak production operation has been shown to decrease the plant biodiversity of the area, its ability to support an undergrowth of native plant species enables enrichment planting in teak plantations. A study published in the journal *New Forests* that tested the ability of teak plantations in Panama to support enrichment planting also found that teak plantations can support a native plant population near the forest floor, but did impede the establishment of larger native species (Marshall, 2021).

The impact of teak on native plant biodiversity was present even when introduced into a bare field to test if it could serve to accelerate reforestation as well as provide revenue. The journal *Forest Ecology and Management* list potential ways teak could serve to more rapidly create conditions for reforestation, including attracting seed-carrying birds, more rapidly forming a forest canopy, and improving soil quality. However, the soil quality claim ultimately failed to materialize in the results. When the researchers compared a bare part of a Costa Rican field to a part planted with teak, the bare field contained higher plant biodiversity than the teak area, demonstrating how teak negatively influences overall plant biodiversity (Healey, 2003).

While teak has a negative impact on plant biodiversity in areas it is introduced to, its ability to support undergrowth presents one potential avenue to reduce its negative impact on the local ecosystem. While enrichment planting in teak plantations can certainly reduce the impact teak has on plant biodiversity, other approaches will be necessary to address the decreased biodiversity of plant life that would typically be present beyond the understory.

2.11 - Wildlife Interactions with Teak

As with any monoculture plantation, pests introduce a risk to the growth of teak. Newly established plantations can be devastated by pests native to the area. Defoliating pests, ones that damage trees by eating leaves, are problematic as they target sites where understorey growth is suppressed (Pandey and Brown, 2000). Other common pests include teak defoliator *Hyblaea puera*, teak skeletonizer *Eutectona machaeralis*, and sap hole sucker *Maconellicoccus hirsutus* (Nair, 2007). However, these species are mostly limited to the South Pacific region and would not impact a Panamanian site. Overall, proper management protocols would almost completely mitigate the impact of pests on teak plantations.

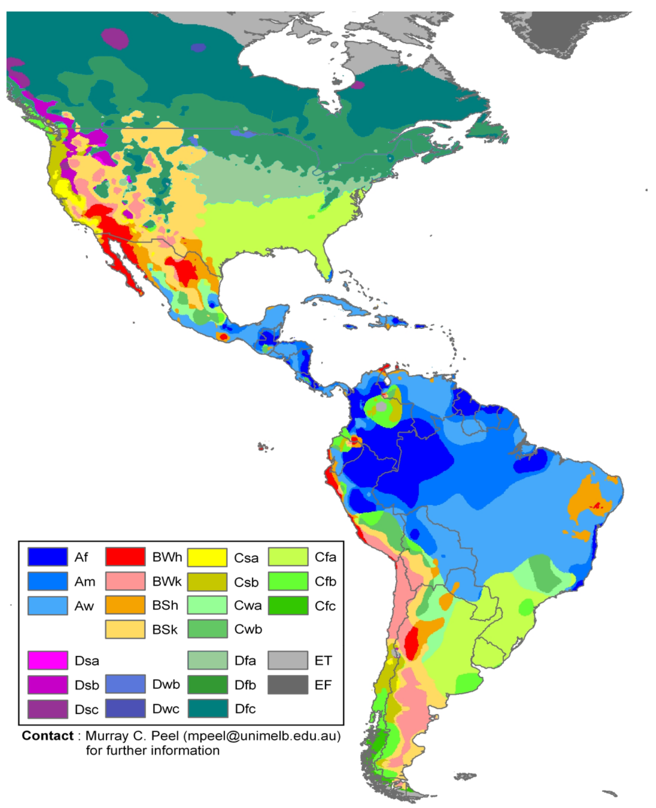

Figure 2.11.1 - Köppen climate classification map
Peel, M. C., 2008.

From studies done in regions with similar climates and species populations, the effect of teak on wildlife in Panama is better understood. Specifically, Mexico and Costa Rica are prime subjects for such comparisons. As shown in figure 2.10.1, coastal Mexico, Costa Rica and Panama are considered to be of the same climate type on a Köppen climate classification map. One researcher focused on Mexico states that teak plantations perform an important role in providing habitat connectivity and protection at a landscape level. Large mammals in Tanzania use teak plantations as corridors between fragmented islands of habitat but do not occupy them as they do natural forest types (Hallett, 2011). Similarly to natural corridors, the teak plantation corridors provide movement between isolated habitat areas. As such, for species well suited to the natural corridors of Panama, the introduction of teak plantations should not disrupt their behaviors.

The issue of decreasing biodiversity in tropical areas is somewhat mitigated by the introduction of well managed teak plantations. Typically, primary forests are considered of higher value for biodiversity conservation, however the secondary functions of man-made forests have come to the forefront in recent years (Nolte, Meilby, Yousefpour, 2018). For areas where teak is an exotic species, such as Costa Rica and Panama, there is a limited capability for the regeneration of native species. Despite this, compared to other alternative uses of land, teak plantations provide forest cover and economic incentives to plant.

Regarding the scientific community the debate on the impact of clear-cut harvesting is divided. The factors by which species are impacted include, their type and what region they reside in. Due to this, open-habitat species and early-successional specialists tend to thrive in areas where clear-cut forests exist. Consequently, closed-forest and late-successional species struggle in this enviornment (Swanson et al., 2011). Furthermore, ecological theorists believe that biodiversity is best maintained when the planted forests imitate the natural structures of native forests. Since Batipa is surrounded by natural deposits of teak trees, this would suggest that a properly maintained plantation would have a positive impact on biodiversity.

Chapter 3: Research Methods

The focus of this project is to work with Universidad Tecnológica Oteima to understand the complex relationship between the biological corridors and the teak plantation at the Batipa Field Institute. This project specifically analyzes the relationship between the teak plantation and the corridors' animal movements, soil chemistry, and native plant species. The final research findings will inform conservation efforts in the corridor, and further establish the ways that teak production affects the ecosystem of the corridor. To address this goal, the following research objectives were used to both structure the research and establish the data collection process:

Objective 1: Find the ways that teak production impacts animal species in the biological corridors at the Batipa Field Institute and identify which elements of teak production influence these animals.

Objective 2: Assess the ways in which the teak production changes its environment by altering soil conditions including: nutrient concentrations, resistance to erosion, and the proportion of organic material. Additionally, environmental factors such as soil changes from previous teak, the geographic characteristics of the area teak is planted in, and how the amount of water available influences the rate of teak production were also assessed.

Objective 3: Identify the ways that native plant life and teak cultivation affect each other at Batipa and the ways the biological corridors are ultimately affected by these interactions. From these interactions with the biological corridors, potential strategies to mitigate mutually negative outcomes between teak production and native plants can be constructed. The newly created plan would then be assessed by how effectively it would address the problems identified in the set of plant-teak interactions.

This chapter presents these objectives in detail and establishes each objectives' associated research methods. These methods discuss the ways the team will collect relevant data, analyze and interpret the data, approach additional research, and conduct interviews with subject experts. Additional data covering areas such as the medium to long term economic viability of teak production, teak production practices used at Batipa and elsewhere, non-teak elements of agroforestry, and the local conditions are discussed to facilitate the creation of our data collection strategy and provide the context needed for more specific objectives.

3.1 - Objective 1:

Obtain data from our interviews, surveys and past research to determine how various animal species present in the biological corridor at Batipa are influenced by teak production.

Objective 1 research methods:

1A). Conduct interviews

We interviewed Señor González about animals encountering the access road in the teak plantation. Additionally, academics who are knowledgeable in environmental biology and biodiversity were interviewed. The focus of these interviews were to obtain information about the animal population, the types of species present, behavior at points of interest, and the underlying reasons for any reported changes in the already listed metrics. In order to better streamline the process specific questions for each interviewee were prepared beforehand. This allowed the team to gather information on topics that could not be found through additional research. Since the interviewees were knowledgeable in the subject matter they were asked about, the interviews could lead to unplanned discussions. Follow up questions and clarifications were made during the interviews to bolster the teams understanding of the listed objectives. The interviews can be found in appendix A and B, and generally took an hour to complete. It should be noted that many of the interviewees were non-native english speakers, and some of their responses were edited to have clearer phrasing for our primarily english speaking audience.

1B). Conduct Surveys

Surveys were distributed to collect information on animal behavior from a greater number of participants. The individuals identified by Señor González at Batipa who have relevant experience received Google form links to allow easy completion of the survey questions and aggregation of the data produced. The surveys also provided quantitative data such as the number of animal sightings at different times of the year and during different stages of the teak production process. Surveys were set up to cover questions which pertain to all three of the described objectives. Furthermore, many of the questions pertain to casual observations made in and around the area of research. With broader questions that require little to no expertise in the subject matter of teak, a wider variety of people could give their responses. The survey was designed in a way that only people who worked at the BFI or study there could take it. The data from this survey is analyzed further in the “Findings and Analysis” section of the paper.

1C). Compile and assess existing/original photos and videos of animals taken in Batipa

The team accumulated pictures and videos of animals taken in Batipa from existing research reports, BFI promotional material, and other published sources. Additionally, the team worked with Señor González to obtain videos and images of animals in Batipa. The team used these photos and videos to observe how animals in the region act in different parts of Batipa such as, the forest reserve, the teak plantation, and the coastal mangrove habitat, to further establish typical animal behavior at different points in the corridor and the ways this effect the corridor as a system. This process provided data to the team in the absence of the ability to remotely collect new motion activated camera images due to resource restrictions and time constraints.

3.2 - Objective 2:

Assess the ways in which the teak production changes the surrounding landscape by altering soil conditions. The soil conditions include nutrient concentrations, resistance to erosion, and the proportion of organic material. Additionally, assess how environmental factors such as soil changes from previous teak production, the geographic characteristics of the area teak is planted, and the amount of water available, influences teak production.

Objective 2 research methods:

2A). Remote observation of soil conditions using photos produced on site

.

With the onsite assistance of the project sponsor, a set of images was taken of the soil at different locations at Batipa within each of its three general areas--the forest reserve, the agroforestry areas, and the coastal region--and sent to the research team. Each of the soil images were observed and the approximate amount of organic material present, the apparent moistness of the soil, the amount of sunlight reaching the ground, and potential signs of erosion were noted. Using additional information about each image--mainly the location it was taken, when teak was last grown at the location, the date the image was captured and time the image was captured-- the images and the data were grouped and compared. This resulted in the values of the stated soil properties being comparable with current and present teak growth, the forest reserve, and the coastal area at Batipa.

2B). Compilation of existing Batipa soil test data and general research to evaluate growth conditions

Batipa has been the site of past research studies covering a wide range of topics. While there are only a small number of existing studies on the biological corridors at Batipa, there are many other studies that contain data relevant to understanding the relationship between soil, teak, and the corridors.

This data consists of soil chemical measurements such as the pH value, concentrations macro and micro-nutrients, salinity, and composition. This existing data was collected from several different locations within Batipa. We combined these data sets with general research including typical sources of these soil qualities and the influence these properties have on plant growth. This enabled the formation of data aligning these properties with the general location categories the samples were taken from at Batipa to assess detrimental or beneficial interactions between teak and the soil of the biological corridors. Some of the specific data points that were compiled were the differences in growth rate, average heights, and quality of teak grown in various different soil conditions.

3.3 - Objective 3:

Identify the ways that native plant life and teak cultivation affect each other at Batipa and the ways the biological corridors are ultimately affected by these interactions. From these interactions with the biological corridors, potential strategies to mitigate mutually negative interactions between teak production and native plants are formed and compared in terms of their effectiveness.

Objective 3 research methods:

3A). Obtain and analyze general information regarding teak production techniques and their outcomes

Various practices employed in teak production at Batipa and in teak production in general were provided to the group by Señor González, as well as detailed information about the agroforestry techniques used throughout the entire agricultural process. For each critical stage of the teak production process described in the documents, specific practices were analyzed to understand how they relate to the soil or existing native plant life. This data was then combined with information about the teak yield and the information collected in objectives one and two. This compilation and comparison then produced a set of stages of teak production, the tasks associated with each stage, and the outcome for both the teak output and the native plant life. Using this data set, existing practices used to preserve native plant species can be compared to determine their effectiveness in improving metrics like biodiversity and overall health of the forest's ecosystem.

3B). Compile and analyze images and videos of plant life in different parts of Batipa.

With the assistance of Señor González, new pictures of the plant life in the different areas of Batipa were obtained, in addition to already existing images of plant life at Batipa. For each image, the general area in which it was taken was noted. Observations of the various indicators of health for both the native plants and teak were then also noted for each of the images. These health indicators included, understory density, number of different types of plants, number of different sized native plants, consistency of size between teak trees in a given section, and the quantity of discolored plant leaves. These indicators , the location where the photo was taken, and background information about what each indicator means for the health of the biological corridors were then compiled into a data set where native plant/corridor/teak health, and location could be correlated with one another.

3C). Conduct interviews with Señor González and Señior Ríos and distribute surveys

An interview was conducted with Señor González to learn about interactions between teak and native plant species. Additionally, through the interview the team was able to collect information about Señor González's observations on how the biological corridors at Batipa changed as a result of various elements of teak production and changes in native plant population and biodiversity. In a different interview, the team discussed the specific steps of the teak production process at Batipa and the main stages of the 20 year process from planting to final harvest. This interview with Señior Ríos enabled the team to identify ways in which certain teak cultivation practices improve teak yield and influence its surroundings.

Chapter 4: Findings and Analysis

In this section the data collected through the completion of the stated research methods is presented and analyzed to support findings on the relationship between teak and the biological corridors at Batipa, their interactions, and any beneficial actions that can be taken. First, the interactions teak has with components of the ecosystem at Batipa--such as animals, soil, and plants--are discussed. Next, the findings about teak production at Batipa along with ways to improve it are presented. Following the discussion of teak cultivation at Batipa, the findings on how teak impacts the biological corridors is presented along with potential conservation approaches that are supported by the data. Ultimately, the data suggests that teak production has a negative impact on the biological corridors at Batipa, but that the main ways teak production degrades the corridor are not through the addition of teak to the ecosystem. Instead, the main negative effects of teak production on the biological corridor are attributable to specific stages of the cultivation process. Taking into account that the presence of teak does not inherently cause considerable ecological degradation, making changes to cultivation practices used during the stages that have ecological consequences,such as final harvest or initial planting, can meaningfully improve the overall ecological and economic sustainability of teak production.

4.1 - Teak and Animals:

Similarly to most agricultural processes, the establishment and operation of a teak plantation impacts the surrounding wildlife. One effect agricultural activity has on wildlife is changing their movements within the local ecosystem. The analysis of survey responses, interviews, and game camera images taken during a previous study at Batipa by Marcos Ponce revealed two primary mechanisms by which teak influences animal movement in the biological corridors at Batipa.

Under certain conditions animal movement in the corridors is limited as teak plantations act as barriers preventing movement between the forest reserve and coastal Batipa. Compiling the game camera images from the study conducted by Marcos Ponce and sorting them based on the location they were taken, the general type of vegetation in the background, and the behaviors of the animal demonstrated a strong correlation between undergrowth density and animal sightings. The trend relating undergrowth density and animal observations (Figure 4.1.1) establishes a strong positive correlation between undergrowth density wildlife observations in the same areas. This relationship suggests that animals tend to avoid moving through areas with less undergrowth. Wildlife avoiding areas with low undergrowth also demonstrates that teak plantation areas primarily act as a barrier to animal movements during stages of the cultivation process that result in reduced undergrowth, such as the final harvest and the planting of a new teak crop.

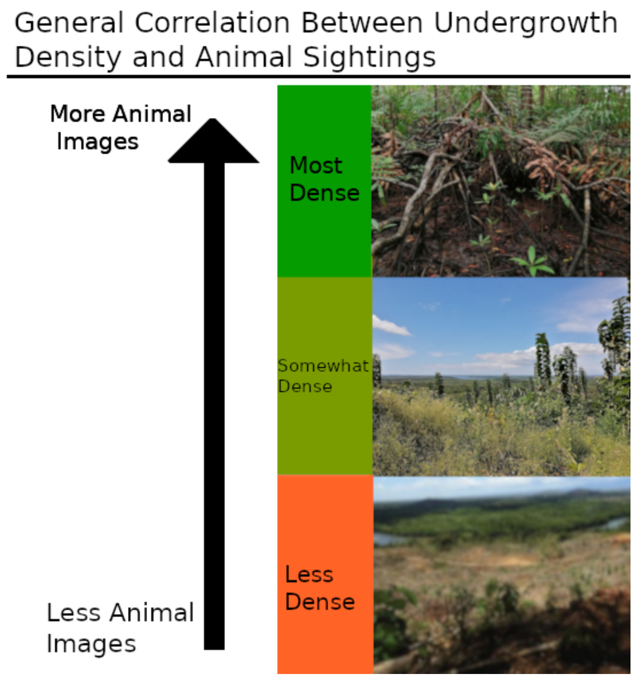

Figure 4.1.1 - Undergrowth Density and Animal Observations

The stage of a given teak crop's agricultural cycle also defines how much human intervention is happening in the teak plantation's area. Active human intervention in teak and native plant growth is the second mechanism of influencing animal movement that was able to be identified based on the research data. During our interview with Señior Rios Gnaegi, the director of Batipa, he responded to the team's inquiry about changes in the local wildlife by describing how animals move to other areas of Batipa during the first four years of the teak production process as a result frequent human activity and intervention.

The interview with Señior Rios Gnaegi and the analysis of existing game camera images reveal that teak plantations prevent animals from transiting the corridor by making the conditions less hospitable for wildlife within the area. The information gathered from the interviews with SeñorGonzález and Señior Rios Gnaegi further supports that teak plantations alter animal movements, but also revealed that teak only disrupts animal movement during specific times during the teak production process. Understanding the overall animal impact as well as the undergrowth-wildlife relationship helped establish the specific mechanism through which teak influences wildlife. Ultimately, the profile for teak's impact on wildlife was determined to be the disruption of animal movements as a result of decreased undergrowth density during stages of cultivation that involve increased human activity and clearing of vegetation. Using this criteria, it was determined that because teak only meaningfully impedes animal movements during specific stages of teak production, the overall impact of teak on animals at Batipa could be reduced substantially just by altering agricultural practices during planting, thinning, and harvest.

4.2 - Teak and Soil:

Our research suggested teak production changed soil conditions in the areas where it is grown within Batipa leading to changes in the ecosystem as well as hindering the success of future teak crops. The specific parts of the soil conditions influenced by teak that were identified are the soil chemistry, soil moisture levels, erosion rates, and amount of organic material in the topsoil. Teak growth in the area both directly and indirectly changed soil conditions, examples of which can be found in Table 2. Using data collected from existing research, interviews, surveys, and Batipa image repositories, the mechanisms by which teak production changes soil conditions at Batipa were identified along with how their influence on the biological corridors at Batipa.

By compiling existing data on soil conditions and conducting interviews with SeñorGonzález and Señior Rios Gnaegi, teak production was found to disrupt the chemical characteristics of the soil. The interviews and soil test data established that the pH, alumina, and nutrient levels in Batipa's soil were below average. Furthermore, the team established that teak can easily further deplete soil nutrients due to its rapid growth through the interview responses.. From the survey of Batipa personnel it was found that in the short term, because of the low soil nutrient content, teak production temporarily resulted in more soil nutrients due to the application of a chemical fertilizers during the first three months after planting teak. Moreover the same responses indicated that teak trees do not secrete chemicals into the soil that would inhibit the growth of other plant species. This means that teak can support a healthy understory unlike other timber species. Generally, the data suggests that the main outcome of teak growth on soil chemistry is that it depletes the nutrients in the soil that are needed to grow future teak crops.

Examples of Direct and Indirect Impacts by Teak on Soil

Directly Caused by Cultivation Practices	Indirectly Caused by Teak Cultivation
• Change in soil chemistry through addition of fertilizers during planting process • Changes in amount of biomass in top layer of soil through undergrowth clearing • Highly compacted soil in areas frequented by vehicles, equipment, or people.	• Increased sunlight levels at soil during first few years • Increased erosion rate after final teak harvest • Long-term soil nutrient depletion due to high nutrient consumption of fast growing teak • Decreased soil moisture levels during the dry season in areas where teak has not yet produced a significant canopy

Table 2: Direct and indirect impact on soil by teak production

The data from the survey results, images, and interview responses all indicated that teak production has an indirect impact on soil moisture. Images provided by the sponsor of different sections of Batipa were analyzed by compiling images of soil in known locations at Batipa. The team then made observations about the moisture of the soil shown in the images. Comparing the apparent moisture of the soil shown with the location where the image was captured suggested that soil moisture levels are generally greater in the forest reserve than the teak plantation areas. The cause of the reduced moisture levels in the topsoil within teak plantations was initially attributed to the water use of teak, however, water use was later ruled out after interview responses highlighted the high rainfall at Batipa. The distribution of rainfall at Batipa was also suggested to be evenly distributed based on the survey responses, refuting the possible presence of a wet or dry side at Batipa. The survey informed us that Batipa personnel generally observed more sunlight reaching the ground in areas with teak trees (Appendix C). One response described how the greater canopy cover in the forest areas and established teak areas resulted in greater moisture retention. Canopy cover is known to reduce sunlight levels on the forest floor and the survey responses also noted greater sunlight reaching the ground in the teak areas overall. The interviews also pointed to a reduction of vegetation during planting, thinning, and harvest. Overall, teak production generally reduces top soil moisture due to increased evaporation rates brought about by more sunlight reaching the forest floor as a result of reduced vegetation. Vegetation reduction within teak areas mostly occurs within the planting, thinning, and harvesting stages of teak production.

Both of the interviews conducted by the team highlighted the significant influence teak production has on soil erosion rates. Teak was found to significantly increase erosion from the final harvest through the initial planting of the next teak crop. The two primary factors for the increased erosion during this time period were found to be a lack of a treetop canopy and destabilization of soil due to a degraded root system. During the harvest to planting stages, undergrowth is reduced greatly and trees are not present in the area. A lack of a canopy results in the direct exposure of the soil to precipitation, which can increase erosion rates. The second factor for increased erosion, root system degradation, was found to be substantial, with both the teak tree root systems and undergrowth roots being degraded. The root system degradation is a result of the agricultural practices used during the harvest-planting time period, such as cutting all of the teak trees at harvest and regular undergrowth clearing after planting new teak. The simultaneous absence of root systems and canopy cover are particularly significant as causes of extreme erosion during the wet season at Batipa which, according to the interviews, require cleared vegetation to be distributed to prevent extreme erosion.

The proportion of organic material present in the topsoil was found to be influenced by teak production. The interviews revealed that cleared undergrowth and branches are often spread around the ground in the teak plantation areas. When cleared undergrowth and trimmed teak branches are spread on the surface of the soil they eventually biodegrade increasing the organic material in the topsoil. During times where significant plant material may be spread across the soil in the teak plantation, such as during harvest and clearing times, the organic material in the topsoil increases substantially when compared to the steadier introduction of organic material in the forest reserve areas.

4.3 - Teak and Plants:

During the early stages of teak production, the trees are kept separate from the rest of the plant and animal life using fences, so the newly planted trees do not get trodden on or harmed. For the next 2 years, it would be unlikely to see plant life around the teak tree, but once a significant period of time has passed, when the teak trees are more mature and have reached a height of 3-4 meters a larger understory will begin to grow. Since sunlight is scarcer in teak cultivation areas, there is only enough light to facilitate the growth of smaller plants with large leaves. As discussed earlier, teak plantation areas can act as a barrier to animals, and upon evaluation of our surveys, it was found that the canopy created by the teak could be partially to blame. Señor González says that farm owners in Batipa have attempted for these areas to be used for grazing, but there is not enough light to grow grass there (Appendix A or Personal Communications, González, 2021). The plants that grow, he says, were already present in the soil; there is no planting in that area besides that of teak.

Given that only preexisting seeds of native plant species grow in teak plantations, then there will naturally be a decrease in biodiversity. If birds do not have a reason to pass through the area, there is little chance for new native plant life to be introduced to the area, as birds are important in the pollination process. Señor González noted that the non-native teak is suppressive to native plant and animal immunity. He also informed us that the plantation owners in the area are worsening the situation. They are aware of the market for teak, and they know that it will grow and sell the most quickly. These people are not willing to take their chances with growing new species of trees, says Señor González, but he believes that if they were persuaded, that alternative trees could have similar outcomes in economic benefits, increasing biodiversity, and decreasing climate change. This is why BFI is making efforts with additional tree propagation, in the hopes that the plant biodiversity in the area could be restored.

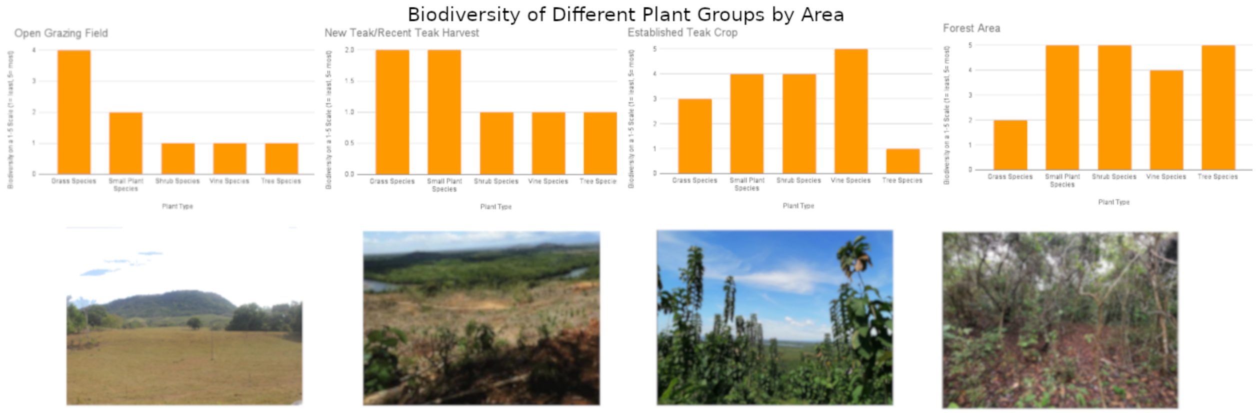

Figure 4.3.1 - Biodiversity of Plant Groups in Different Parts of Batipa

The biomass in the teak production area is largely affected by the plantation owners. The clearing of existing trees is a regular part of the teak cultivation process, according to our survey results (Appendix C). The technique of “thinning” can be used in the area. This is when the harvesters will remove certain, less profitable trees for sale, leaving more space and resources for the newly planted trees. Other efforts have been made in Batipa to preserve and increase biomass in the area. Farms currently employ a technique that involves staggering the teak growth between grazing areas. Señor González says it is typical in these areas to have 4 meters of teak and native trees, and 8 meters of grass for grazing, then 4 meters of trees again, etc. In the early stages of development, electric fences are set up in between sections, but later the less vulnerable trees will be unfenced to incorporate the two types of areas together. In addition to increasing plant biomass, this technique is also designed to offset the carbon generation from the livestock in the area.

4.4 - Teak Cultivation Findings

The assessment of whether teak cultivation is worthwhile for the BFI involves three primary factors. These factors are economic viability, land usage, and sustainability in the long term. By weighing the positive effects of teak growth in Panama with the negative ones, a conclusion can be drawn on teak cultivation. Proceeding with the creation of a teak plantation in the area means assessing all the factors involved with the planting of a teak forest.

First, the economic viability of teak in the long term must be taken into consideration. Our interview with Señor González gave much insight into this matter. Specifically, that there are tax breaks in Panama for individuals or organizations looking to grow and harvest teak (Edmundo González, Personal Communications). This means that the tools for producing and harvesting teak can be written off on tax forms. It is important to note that Panamanian law exclusively taxes residents and non-residents alike on Panamanian sourced income, not worldwide. These are all important considerations to make when fully evaluating the merits of solely planting a teak plantation.

Other markets in which the BFI could invest in using the land must also be considered as well. The other major use for land in Panama is cattle ranching. As Señor González explains it, some farmers see teak as a short term investment of about 2-5 years. By growing teak in conjunction with cattle ranching, the farmers of Panama would receive monetary aid for teak growth which they could then reinvest into cattle farming (Edmundo González, Personal Communications). However, cattle ranching in Panama is unprofitable compared to other South American countries. Furthermore, cattle ranching may be detrimental to the ecosystems in Panama. One study concludes that cattle ranching in Panama degrades the soil fertility and biodiversity of the ecosystem in which ranches are established (ELTI, 2015). Since the opportunity cost, how much an organization has to spend in order to start a buisness, of teak is higher than cattle ranching, teak is a more viable economic option (Edmundo González, Personal Communications). Overall, cattle ranching is a poor option compared to a teak plantation.

Furthermore, there exist other considerations to be made about a teak plantation's economic viability. As stated in previous sections of the paper, intercropping teak with other species provides potential additional revenue. Native trees such as rosewood and amarillo are ideal candidates for intercropping with teak. One study conducted by the Smithsonian Tropical Research Institute showed that additional rosewood sapling planted in a teak plantation all thrived (Smithsonian Tropical Research Institute, 2020). Furthermore, additional outcomes such as creating better cover for migratory birds, and benefiting water management were shown in this paper. The intercropping of rosewood and amarillo trees would be inline with all the BFI's stated goals.

Lastly, the concerns of teak cultivation's sustainability must be addressed as well. In general, teak production's sustainability is dependent on where it is planted. The practice of chopping down native trees to incorporate teak trees is unsustainable in the long term. This is further compounded by the fact that teak trees are harvested and planted in shorter cycles on plantations. Overall, teak harvesting in this manner is generally unsustainable. However, by limiting the areas in which the plantations are created and intercropping with native trees, a more environmentally safe teak plantation can be created in the biological corridors of Panama.

4.5 - Biological Corridor Findings

When considering the outcomes of teak production as a whole, specific considerations must be taken to protect the biological corridors that surround them. The aspects of teak production that would have large scale effects on the corridor are of great importance in this matter. For example, small adjustments to drainage flow throughout the corridor may not affect the works of the ecosystem. Thus, the effects of human practices must be fully explored as they are the most likely to affect the corridor. Changes in animal foot traffic, structure of the corridor, and plant life are the key indicators of teak production tampering with the biological corridors.

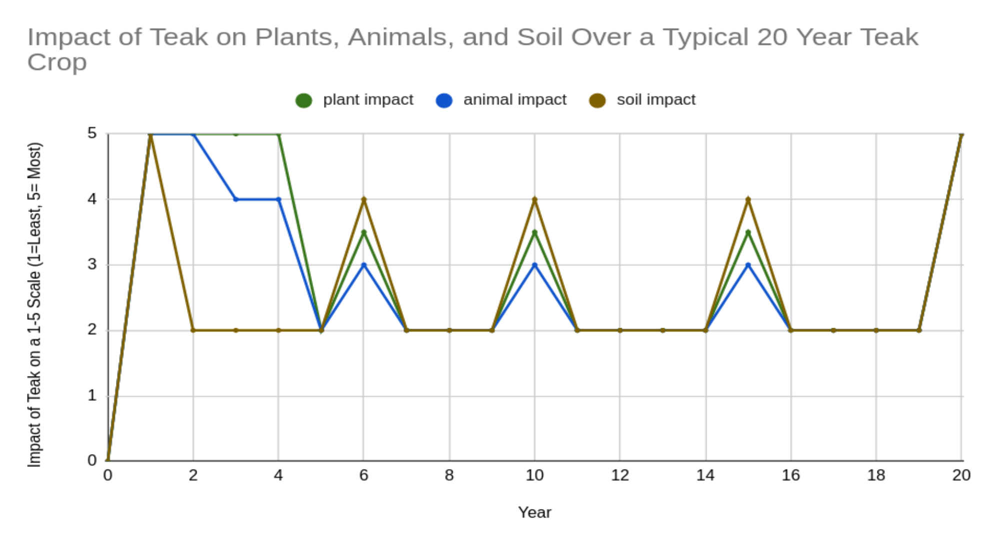

Figure 4.5.1 - The Ecological Impacts of Teak Over the 20 Year Process

The planting and harvesting stages of teak cultivation are by and large the most disruptive when considering the process' effect on the biological corridor. One reason for this are the practices farmers use in Batipa when establishing teak plantations. As shown in figure 4.5.1 the planting process of teak primarily impacts the plant life and soil quality. The teak plantation farmers will disturb the native plant life, and as the seeds begin to bud the soil chemistry is altered. As mentioned in section 4.2 survey responses indicated that the teak trees get more sunlight than the native trees of the area, causing an observed dwarfed growth in the native trees of the area. Generally, it is due to the practices implemented by teak farmers that cause these drastic shifts in the native enviornment.

Furthermore, as shown in the graph there are changes in how the cultivation process affects the animals of the corridor. Since natural homes for certain species are removed in the planting process, it is considered a large change to the animals' lives as they are forced to find habitats elsewhere in the forest. As described in section 4.1 the native species of animals in the corridors will generally avoid teak plantations. However, certain migratory birds will roost on mature trees and some small mammals use the trees as cover for travelling. Despite this, since the trees are harvested in quick cycles, the species are unable to fully adapt to the plantation harvesting system.

Chapter 5: Conclusion and Recommendations

5.1 - Conclusion

The collection of data from surveys, interviews, existing Batipa data sets, and image analysis combined with robust supporting research on teak, the economic context, biological corridors, and tropical ecosystems has furthered the understanding of the interactions between teak production and biological corridors at Batipa. From this comprehensive information, the team concluded that teak production, in general, degrades the condition of the biological corridors at Batipa. However, the negative impact of teak is more so a product of specific teak cultivation practices rather than the presence of teak in the ecosystem. When compared to the entirety of the teak production process, most of the ecologically negative impacts of teak cultivation occur only within limited time frames. Due to the periodic and condensed nature of teak cultivation's negative impacts, changes made during those teak production stages, such as planting and harvest, would considerably reduce its overall impact on the biological corridors, and improve sustainability. Additionally, these changes can be implemented while maintaining and/or improving teak output.

Though this research was able to identify the general influence of teak on Batipa's biological corridors, more research is needed to identify the full scope of teak's influence on specific parts of the ecosystem. The ecological impact of teak at Batipa compared to the ecological impact of other possible cash crops has also not been fully established.

The focus of this report is on teak production as it pertains to Batipa and its biological corridors. However, components of the findings and recommendations will likely be applicable beyond Batipa, particularly within the Gualaca regional biological corridor in Panama. Additionally, with the considerable presence of teak production throughout the tropics, elements of this research could serve as a starting point for understanding the role of teak in other regions.

5.2 - Recommendations

Using the information garnered from the background research and the collected data, the team has identified several suggestions for how teak production strategies and practices can be changed or introduced. These suggestions focus specifically on the aspects of teak production that were identified to have the most impact on the biological corridors such as planting, thinning, and harvest. The following suggestions also seek to improve or maintain the productivity of the teak plantation, while simultaneously improving sustainability in the biological corridors.

<u>Suggestion #1:</u>
Transition from a smaller number of large crops to a larger number of small crops. Plant more small crops of teak several years apart rather than planting only a few large crops. This will decrease the amount of land that does not have tree cover or undergrowth at a single time.

Currently most of Batipa's teak production is based on a few large crops that are planted and harvested at the same time. This results in a large proportion of land area being subject to agricultural practices that have considerable ecological impacts when it is time to plant, thin, or harvest a specific crop. This results in a greater area of land acting as a barrier to animal movements in the corridor when undergrowth density is low, making it harder for animals to adjust. As such, when the area lacks developed trees and vegetation, more area is exposed to the elements and liable to quicker erosion.

Transitioning to many small crops of teak planted several years apart means that during the ecologically disruptive stages of teak production, a smaller proportion of the land at Batipa is impacted. This method's first benefit is that when the undergrowth density is reduced in the teak area, the barrier presented to animals moving through the biological corridor is smaller. This enables the wildlife to easily find alternative paths around the area with reduced undergrowth. Another benefit to the ecosystem is that less soil will be subject to rapid erosion at once during time periods where teak areas have no trees or plants to control erosion. Overall, less simultaneous exposure to ecologically negative teak production practices means that the ecosystem can more easily adapt and recover.

In addition to the ecological benefits of larger amounts of smaller crops of teak is that teak revenue will be more consistent. More frequent harvests reduce the risk of loss due to price fluctuations in the price of teak. Additionally, a steady revenue stream will make it easier to manage the expenses of producing teak. However, the process of establishing many crops of teak spaced apart will be difficult, possibly requiring some amount of land to remain unplanted until the full number of teak crops have been introduced.

<u>Suggestion #2:</u>
Maintain controlled undergrowth during planting through mulching and native plant introduction. Reduce the undergrowth clearing required for new teak by introducing slow growing/determinant native plant species combined with mulching.

When a new teak crop is planted, the current practice is to completely clear all of the other vegetation from the area to prevent it from out competing the teak saplings for light, water, and nutrients. Moreover, the area around the immature teak trees must be regularly cleared for some time after planting until the teak trees have become sufficiently established. This practice is labor intensive and results in a considerable negative impact to the biological corridors at Batipa. The prolonged period of total clearing during and after planting teak means that the whole area serves as a barrier to wildlife and makes the land susceptible to rapid erosion. The lack of vegetation also means much of the soil's moisture is lost to evaporation.

Maintaining slower growing undergrowth plant species during the planting process is recommended to reduce the frequency and extensiveness of undergrowth clearing. In addition, it is recommended that the area around the base of the teak saplings be mulched or covered in plastic sheeting in order to prevent plants from out-competing the newly planted teak. Native shrubs and other small woody plants, particularly determinant varieties, would be the best species to introduce and maintain during all steps of the teak production process due to their predictable growth and relative resilience to damage.

If implemented, this practice has several benefits over the current planting approach. First, the amount of labor involved in the planting stage of teak would be reduced as clearing would need to be done less frequently, which would reduce the teak production cost. The required amount of clearing would be reduced because the presence of established plants will make it more difficult for fast growing plant species to establish themselves as they will have to compete for nutrients, sunlight, and water. This would make it so that the only required tasks are maintaining the teak mulch or plastic sheeting and some light brush removal.

Ecologically, this approach to the planting stage of teak production would reduce the ecological impact of teak production on the biological corridors. Furthermore, this approach would achieve this as a result of there always being some amount of vegetation growing during the teak production process. A base level of vegetation would help reduce the risk of rapid erosion while teak trees are still small and help protect the soil from losing excess moisture to evaporation. Lower evaporation and reduced erosion risk also ultimately improve the teak crop's profitability. Maintaining a base level of vegetation will also reduce how significant of a barrier the teak area is to animal traffic during planting and harvest periods.

Suggestion #3:
Allow time after harvesting teak for the land to recover before replanting in the same location. Instead of immediately replanting teak trees after harvest, allow a recovery period before planting in the same location. This permits the re-establishment of native plant and tree species as well as the regeneration of the soil before teak is replanted.

The current approach of replanting teak immediately after the previous harvest results in both ecological and economic impacts. Economically, the current approach continually depletes soil nutrients, requiring the purchase and application of additional fertilizer during the planting process. Ecologically, the current approach does not allow for wildlife to re-establish movement through the area that may have been impeded by teak production. A second ecological impact is that depleted nutrients can make it more difficult for an undergrowth to be established in the new teak crop, making the area a bigger barrier to animal traffic. This reduction in animal traffic generally indicates the degradation of the biological corridor through the area.

If this suggestion is implemented and the area is allowed some time to recover after a teak crop, the overall health of the biological corridors at Batipa will be improved. Additionally, when teak is later replanted less fertilizer can be used during planting, cutting the cost to produce the teak.However, One drawback to not immediately replanting is that it may result in more land being needed to maintain the same quantity of teak output.

5.3 - Project Limitations

While it is undeniable that limitations exist in every project, our team encountered many that limited the amount of research we were able to conduct. Some of these problems arose from a lack of resources, time, and the COVID-19 pandemic.

The first limitation, and the one with arguably the largest impact on our project, was the fact that our team was unable to travel to our project site in Panama. Typically, for an IQP a team spends 7 weeks on campus and 7 weeks at their project site. This allows for a hands-on approach during the latter half where they can get accustomed to the resources at their disposal and meet with their sponsors easily. Our team was unable to interact with the landscape at Batipa, as such our understanding of the landscape's topography, vegetation, animals, and teak plantation infrastructure was gained solely through pictures, word of mouth, and other secondary sources. There was a severe lack of resources available to us and so our team had to work with the overarching ideas presented to us by Señor González.

The second limitation was specific to the data collection methods. In earlier drafts of the project, our team had proposed the idea of utilizing soil tests at Batipa to help identify the available nutrients in the soil as well as soil conditions such as moisture content and pH. Unfortunately, we were unable to conduct these tests as our sponsors at Batipa did not have the resources to do so. With these tests, it is possible we would have been able to understand how the nutrients at Batipa were dispersed and identify correlations between localized plant life and abnormal nutrients levels. Our team also had other aspirations for the project that could not be completed; either due to a lack of information available from our sponsors or could not realistically be completed within our time limit.

The other areas our team was interested in studying included the impact teak has on the biodiversity of the area, the impact a native tree species might have on teak while growing in close proximity, and the options of using other cash crop tree species. These are the ideas we had to improve agricultural practices at Batipa and were unable to incorporate into the project for different reasons.

5.4 - Regional and Global Relevance

Despite the primary purpose of this paper being to provide recommendations to our sponsor, it is possible to apply our findings to a larger scope. During meetings with Señor González, he mentioned the Gualacan corridor as a possible reference during our background research. While some modifications to our methodology would be necessary it is possible we could apply our findings to this larger corridor. The conservation of this larger corridor is important, although further research would be required if our work were to be applied there.

Even greater than the application to the Gualacan corridor of Panama, our work in this project could be applied to the different teak plantations across the world. The only caveat to this idea is that it is necessary to consider the differences in the conditions of any location. The previously discussed Gualaca corridor lies close to BFI running through Panama. If the ideas presented within this paper were to be applied to any other part of the world, careful consideration of the different factors is vital.

Bibliography

(2021). Biodiversity. *Smithsonian Tropical Research Institute.* https://stri.si.edu/discipline/biodiversity.

Boakye, E.A., van Gils, H., Osei, E.M., Jr and Asare, V.N.A. (2012). Does forest restoration using taungya foster tree species diversity? The case of Afram Headwaters Forest Reserve in Ghana. African Journal of Ecology, 50(3): 319-325. https://doi-org.ezpv7-web-p-u01.wpi.edu/10.1111/j.1365-2028.2012.01329.x

Borsari B., Garrido F.U., González E. (2021). A Systems Approach to Ecotourism, Leisure and Education in Panamá: A Case Study. *Handbook of Sustainable Development and Leisure Services*, 1(1), 257-271. https://doi.org/10.1007/978-3-030-59820-4_17

Brown, Chris, and Devendra Pandey. "Teak: a Global Overview." *Unasylva - No. 201 - Teak*, www.fao.org/3/x4565e/x4565e03.htm.

Cushman, S.A., Lewis, J.S. & Landguth, E.L. (2013). Evaluating the intersection of a regional wildlife connectivity network with highways. *Movement Ecology, 1*, 12 . https://doi.org/10.1186/2051-3933-1-12

DeFries, R., Hansen, A., Turner, B. L., Reid, R., Liu, J. (2007). Land Use Change Around Protected Areas: Management to Balance Human Needs and Ecological Function. The *Ecological Applications, 17(4), 1031-1038*. https://esajournals.onlinelibrary.wiley.com/doi/10.1890/05-1111.

(2015). Ecological Restoration Strategies for Cattle Ranching Landscapes of The Azuero. *ELTI.*

https://elti.yale.edu/events/ecological-restoration-strategies-cattle-ranching-landscapes-azuero

Mullen, Russ. Establishment of Batipa Field Institute –Research and Education for Conservation and Sustainability. https://www.oteima.ac.pa/web3/wp-content/uploads/2017/09/Establishment-of-Batipa-Field-Institute.pdf.

Goddard, Hannah et al. Wildlife Crossing Development for Highway 1 in Batipa, Panama. Worcester Polytechnic Institute. Print.

Hallett, J. T., Díaz-Calvo, J., Villa-Castillo, J., & Wagner, M. R. (2011). Teak Plantations:

Economic Bonanza or Environmental Disaster? *Journal of Forestry*, *109*(5), 288–292. https://academic.oup.com/jof/article/109/5/288/4599470

Historia - Universidad Tecnológica Oteima. *Universidad Tecnológica Oteima.* https://www.oteima.ac.pa/oteima/historia/.

Kaosa-ard, A. Overview of problems in teak plantation establishment. *Teak for the Future - Proceedings of the Second Regional Seminar on Teak, 1*(1). http://www.fao.org/3/AC773E/ac773e08.htm#TopOfPage

Leroux, S. J., & Kerr, J. T. (2013). Land development in and around protected areas at the wilderness frontier. *Conservation biology : the journal of the Society for Conservation Biology*, 27(1), 166–176. https://doi.org/10.1111/j.1523-1739.2012.01953.x

Lotha, G. (n.d.). Teak. Retrieved May 17, 2021, from https://www.britannica.com/plant/teak

Marshall, Abigail et al. (2021). Early Indications of Success Rehabilitating an Underperforming Teak (Tectona Grandis) Plantation in Panama through Enrichment Planting. *New forests, 52*, 377–395. https://doi.org/10.1007/s11056-020-09801-6

McGeehan, Adam. (2021). How The Global Teak Industry Is Changing... and How You Can Profit From It. *Tropical Teak Export S.A.S.* tropicalteakec.com/how-the-global-teak-industry-is-changing-and-how-you-can-profit-from-it/

McLaughlin, A., & Mineau, P. (1995). The impact of agricultural practices on biodiversity. *Agriculture, Ecosystems & Environment, 55*(3), 201-212. https://doi.org/10.1016/0167-8809(95)00609-v

Nair, P. R. (2007). The coming of age of agroforestry. *Journal of the Science of Food and Agriculture, 87*(9), 1613–1619. https://doi.org/10.1002/jsfa.2897

Nölte, A., Meilby, H., & Yousefpour, R. (2018). Multi-purpose forest management in the tropics: Incorporating values of carbon, biodiversity and timber in managing Tectona grandis (teak) plantations in Costa Rica. *Forest Ecology and Management*, *422*, 345–357. https://doi.org/10.1016/j.foreco.2018.04.036

A company producing sustainable forest products with environmentally friendly methods. *Panama Teak and Forestry Inc.*https://www.panamateakforestry.com/.

Parks, S., Carroll, C., Dobrowski, S., & Allred, B. (2020). Human land uses reduce climate connectivity across North America. *Global Change Biology, 26*(5), 2944-2955. https://doi.org/10.1111/gcb.15009

(2020). Enrichment. *Smithsonian Tropical Research Institute*. https://stri.si.edu/story/enrichment

Ponce, M. (2016). Evaluación de la Riqueza de Especies y Distribución de Mamiferos en Corredores Biológicos de la Peninsula BATIPA. *Universidad Tecnológica Oteima.* https://drive.google.com/file/d/1Za59ZEJ2k7Ek0onbSEJLPxuC-c6A7X1N/view?usp=drive_web

Ponce, M., & Vargas, G. (2018). Corredor-Biológico-BATIPA-OTEIMA. *Universidad Tecnológica Oteima.* https://www.oteima.ac.pa/repositorio-de-investigacion/.

Healey, S., Gara, R. (2003). The effect of a teak (Tectona grandis) plantation on the establishment of native species in an abandoned pasture in Costa Rica. *Forest Ecology and Management,* 176(1), 497-507. https://doi.org/10.1016/S0378-1127(02)00235-9.(https://www.sciencedirect.com/science/article/pii/S0378112702002359)

Stack, T., Santos-Heiman, T., Comatas, R., & Nowak, M. (2020). *Determining the Viability of Teak Growth in Central America.* [Undergraduate interactive qualifying project, Worcester Polytechnic Institute]. Digital WPI. https://digital.wpi.edu/concern/student_works/kd17cw74j

Swanson, M. E., Franklin, J. F., Beschta, R. L., Crisafulli, C. M., DellaSala, D. A., Hutto, R. L., Lindenmayer, D. B., & Swanson, F. J. (2010). The forgotten stage of forest succession: early‐successional ecosystems on forest sites. *Frontiers in Ecology and the Environment*, *9*(2), 117–125. https://doi.org/10.1890/090157

(2021). Tectona grandis L.f. — The Plant List. *Theplantlist.org*. http://www.theplantlist.org/tpl/record/kew-202018.

Rosenberg, D., Noon, B., Melsow, E. (1997). Biological Corridors: Form, Function, and Efficacy. *BioScience, 47*(10), 677–687. https://doi.org/10.2307/1313208

(2020). Trash Free Waters Initiative in the Caribbean. *The Caribbean Environment Programme*. https://www.unep.org/cep/trash-free-waters-initiative-caribbean.

PLAN MAESTRO CENTRO BATIPA.*Universidad Tecnológica Oteima.* https://www.oteima.ac.pa/repositorio-de-investigacion/.

(2014). Why do we need nature reserves? Nature Reserves and the Conservation of Singapore's Habitats.https://blogs.ntu.edu.sg/hp331-2014-30/?page_id=29#:~:text=One%20main%20reason%20why%20we,our%20ecosystem%20in%20natural%20balance.&text=A%20healthy%20biodiversity%20is%20of,of%20natural%20services%20for%20everyone.

Yadav, Ravi & Pandey, Sbs & Chopra, Rahul & Chauhan, Kanica & Singh, Bhupendra. (2020). Economics of Teak (Tectona grandis L. F.) plantation with different spacing and organic inputs in Semi-arid region of Rajasthan. *Journal of Pharmacognosy and Phytochemistry, 9*(5), 3272-3275. https://www.phytojournal.com/archives/2020/vol9issue5/PartAT/9-5-579-617.pdf

Appendix A: Edmundo González' Interview Transcript

Team member: What conditions result in a larger proportion of heartwood in teak?

Señor González: Batipa [has] bad soil. The soil is very thin. It's a red soil with low pH, high levels of aluminum. Usually you will find this kind of soil in batipa, chiriqui because in that area we have the highest levels of rain in the country. But it has something that teak likes very much, that usually has to do with the saturation in soil. The water drains quickly from the soil, which is good for teak. There are big extensions of teak productions around Batipa, but most of those areas have problems with water in the soil because the lake has higher levels of water, which leads to poorer levels of teak. The business to buy batipa formed when the Rios family was looking to plant teak, the government gave taxes 25-30 yrs ago, so that all you buy for the teak business can come out of the taxes. Of course, the real business is wood, but the owner of the farm had cows that came with the farm. After they saw the opportunity, they realized the cows could help out with the conditions. That is why they have 300 hectares just for grazing. The other farms around Batipa have teak and they want to be in the business because they don't have to pay taxes. So having teak on the land from the deal makes it so you don't have to pay for production. The people buy tractors, etc. for farming production with teak. Right now in Panama the people don't see a tree like a business because they see it as a short term 2-5 years deal because many of them don't have money. One of the managers of the batipa farm is a (financial CEO)? He is the son of Mr Rios, the owner of the farm. This family has many farms and they have a long term vision for the business, and higher level administration. The teak business is better than the cow business because having cows is more expensive for the profit compared to doing the same in other countries. There are better areas for teak production in Batipa. They harvest 1/20 of the teak being grown there. The growth of teak near batipa is bad, maybe because of their lack of business knowledge, maybe they just want the tax money, or maybe they just don't know how to manage the farm. A tree has to be over 6m and has to be able to harvest quickly, normally like 20yrs

Team member: How do the clone roots look between seeds of original and clones?

Señor González: The clone trees (will send pic) you usually see a very long tree with very low branches around, bigger leaves. Usually you can put them next to each other and notice that the clone is thinner, grows faster and higher. They have more photosynthetic leaves? The sun doesn't get in the lower portions. The most efficient production is the clone variety.

Team member:
Señor González: The original teak was from Costa rica? There is another one from Indonesia, that is very close to the origin of teak in the tropical area around Vietnam. The owners of the teak farm are from (Poland?) he will send their names. The seeds are 2-3 months

Team member: Where do you see more/less erosion?

Señor González: Really, I didn't see erosion because I wasn't looking for it. The trees go over the soil and protect it. In one rainy season when the soil is not covered, you can have 5-10cm of lost soil to the ocean, river, mangroves. It is interesting to study, because you might find that there would be more erosion from lack of teak, or you could notice that other plants have more opportunities to grow under there with the access to sunlight.

Team member: How are the trees harvested? In rounds, all at once?

Señor González: We really harvest all of it. The name in Spanish is table rasa. Basically, they cut everything, all the branches. The tree has a big level, they come under and cut the vegetation down, and they come back with a saw and a truck and put it in an area after they have classificated each wood that they pick up. They usually throw away the first part because it is undesirable, but the part that could be a container is preserved. It happens in the dry season Dec, Feb, Mar, May. Sometimes they start at the beginning of the year because December is reserved for the workers' family time. They will harvest until they feel like they have enough, then they will pick up the seeds and go to grow it all. After they have a good rainy season (they're sure there won't be even a week of a dry season) they being to plant the new trees. In December of that year, these trees could be 2m, grows very fast. And sometimes, you will have taller (but thinner), and sometimes you have to cut it over again because it could be one side or another side. The replanting of the trees takes place immediately in the same place, to avoid erosion. There is a lot of trees that have been mostly cut, but some new trees can grow from the same roots and these have to be cut down before new planting. I don't know why but these trees always die when we try to grow them. It could be a problem with the old root. In July, with 2 months of rainy season, the planting begins.

Team member: Is there a more wet or dry section of Batipa? Gets more/less sun? or mostly the same

Señor González: don't have that info, maybe there is more weather and humidity in the area with the mountains. One section of Batipa looks to the ocean, the other looks to the land.

Team member: When you first plant the teak how long does it take them to get big enough for the lower level of vegetation to be able to grow underneath?

Señor González: The trees are very soft because they grow very quickly, they don't have time to be (a redwood?) yet. It could be around 2 years until grazing underneath would be possible. Trees could be maybe 3-4 meters at this point. They might be a soda can's measurement thick in that second year. There could be grass and other plants at that point, but in the natural growth of the other plants below the trees, there is no grass. There might be smaller plants that were there in the past (in the family of bananas maybe) they have big leaves that could facilitate growth under such a canopy. Cows might be able to eat this. Mr Luis Rio has tried to put electric fences and used it to graze cows there, but the light coming through the teak is not enough to let grass grow. But after the second year, there are plants that could support such grazing.

Team member: Where might we find more information on the tree-cutting process?

Señor González: The study I sent you in the book might have a lot of info. Usually after the third year, you really don't do more cultivation activities in the reforestation area. You let them grow, and you take out the ones that have problems, this is around year 8. But in that time, you begin to see the growth of all new plants whose seeds were already in the soil. The seeds were not put there, they were previously in the soil. There are little trees and plants. Usually at years 8, 12, sometimes 18 is when they cut some of the teak but not all. They cut the low-quality trees and leave the best ones. The ones that are cut used to be able to be sold because of the demand (5-7 years ago), but the demand is decreasing and the teak is not so quickly sold in the area. 12 years could be cut just the canopy part, or you could use that wood. If you cut just the canopy you will have more space to grow more trees and the remaining lesser quality trees will not compete with the better ones.

Appendix B: Luis Ríos Gnaegi's Response to Interview Questions

1. What conditions do you think result in a larger proportion of heartwood in teak trees?
Age of the tree, best when is more than 25 years, the genetic material (malasia clons are probably the best), management.

2. Do the teak trees that are planted from clones missing a deep tap root that teak grown from seeds have?

I´m not sure, but is probably the same in both.

3. Where are the teak seeds used in Batipa purchased from and what types of seeds are used at Batipa?

We use malasia clone bought from an orchard in Darien owned by a Swedish company. Also use our own plants from Batipa seeds. 50% Batipa and 50% malasia

4. Have you noticed any differences in erosion rates in teak fields planted with seeds versus teak fields planted with clones?

No difference.

5. How do the erosion rates in the teak areas generally compare to the erosion rates in the forest reserve?

The first year erosion is a big concern because soil is exposed directly. From second year to end of rotation erosion be similar to that of natural forest.

6. Once a teak crop has matured and had several rounds of thinning (at around 20 years after the section of teak was planted), how are the remaining trees harvested? Are they cut all at once, gradually cut and replaced with other plants and trees, or harvested in some other way?

Final harvest is in a 3 month period during dry season, and the same area is planted again with teak at the beginning of rain season.

7. Does Batipa have a noticeable wet and dry side due to the path of the sun and the geography of the area? If it does, how does the teak production and overall agroforestry approach change between the two sides? Are there any changes in the type of vegetation growth between the two?

There are no differences in sides of Batipa.

8. How long after teak is first planted does it take for the teak trees to mature to a point where an understory could develop beneath them without causing a negative impact on the teak trees?

After the 4th year.

9. To what extent is an understory able to grow in teak fields and to what extent is it allowed to do so? Is there any part of the ongoing teak production process that prevents understory development?

Once we do the first thinning at year 4 the undergrowth is maintained until harvest.

10. Are there any noticeable changes in wildlife populations, proportions of species, and behaviors during any stages of the teak production process? (ex: increased rodent populations during one phase compared to the phase before it)

During the first 4 years there is a lot of intervention to the plantation so the wild life tend to go somewhere else, after that the wild life stays relatively the same throughout the rotation time. Were we see much difference is between the dry season and rain season.

Appendix C: Google Form Survey

Question 1: Do you work for the Batipa Field Institute or study at the Otiema University? (¿Trabajas para el Batipa Field Institute o estudias en la Universidad de Otiema?)

Response Options:
- Yes (Si)
- No

Question 2: Is clearing other plants a regular part of the teak production process after planting? (¿La remueve de otras plantas es una parte habitual del proceso de producción de teca después de la siembra?)

Response Options:
- Yes (Si)
- No
- Do not know (No lo se)

Question 3: Compared to the uncultivated forest area at Batipa, do the areas with mature teak trees have more, less, or about the same amount of bushes and non-tree plant life? (En comparación con el área de bosque sin cultivar en Batipa, ¿las áreas con árboles maduros de teca tienen más, menos o aproximadamente la misma cantidad de arbustos y plantas no arbóreas?)

Response Options:
- More (Mas)
- Less (Menos)
- About the same (Igual)

Question 4: Does the amount of sunlight that reaches the ground differ in the natural forest and areas with mature teak trees? If so, what area gets more sunlight? (¿La cantidad de luz solar que llega al suelo difiere en el bosque natural y en las áreas con árboles maduros de teca? Si es así, ¿qué área recibe más luz solar?)

Response Options:
- Yes - Natural forest gets more sunlight (Si - el bosque natural tiene más luz)

- Yes - Teak trees get more sunlight (Si - la teca tiene más luz)
- No

Question 5: Do you think that the trees in the forest reserve are closer together or farther apart than the teak trees in the plantation area? (¿Crees que los árboles de la reserva forestal están más juntos o más separados que los árboles de teca en el área de la plantación?)

Response Options:
- Closer (Mas juntos)
- Farther (Mas separados)
- Don't know (No lo se)

Question 6: When it rains, do more and or larger puddles form in the teak plantation or the forest reserve? (Cuando llueve, ¿se forman más o más charcos más grandes en la plantación de teca o en la reserva forestal?)

Response Options:
- Reserve (Reserva forestal)
- Teak Plantation (La plantacion de teca)
- About the same (Igual)

Question 7: When preparing an area to plant teak, what, if anything is done to the soil as a part of this process? (Al preparar un área para plantar teca, ¿qué se hace al suelo, si es que se hace algo, como parte de este proceso?)

Response Options:

[This question was left open ended]

Question 8: Is fertilizer applied to an area planted with teak at any point in the teak production process? If so, what types of fertilizer are used? (¿Se aplica fertilizante a un área plantada con teca en algún momento del proceso de producción de la teca? Si es así, ¿qué tipos de fertilizantes se utilizan?)

Response Options:

[This question was left open ended]

Question 9: Does the soil moisture noticeably vary at different locations within Batipa? If it does vary, what areas have more moist and more dry soil? (¿La humedad del suelo varía notablemente en diferentes lugares dentro de Batipa? Si varía, ¿qué áreas tienen un suelo más húmedo y más seco?)

Response Options:

[This question was left open ended]

Question 10: How moist is the soil at Batipa typically on a scale of 1-10? (¿Qué tan húmedo es el suelo en Batipa típicamente en una escala del 1 al 10?)

Response Options:

Less Moist: 0 1 2 3 4 5 6 7 8 9 10 : More Moist