DETERMINING THE VIABILITY OF TEAK GROWTH IN CENTRAL AMERICA

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An Interactive Qualifying Project Proposal
Submitted to the Faculty of the
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Abstract

Teak is a popular plantation species and long-term investment across Central America. This project investigated favorable growth factors for teak as well as its economic and environmental sustainability, and then determined its viability in the region. The team conducted archival research and four expert interviews. Our organization of interview results revealed that soil, landscape, and plantation management are key factors in teak growth and helped the team come to this conclusion: while teak is a high value crop, the market is overly saturated, and the crop harms the water cycle and biodiversity. We compiled a series of recommendations for potential stakeholders that outline more sustainable alternatives such as intercropping, incorporation of native species, and silvopastoral systems.

Executive Summary

Introduction and Background

Teak, a tropical hardwood tree species, is native to Southeast Asia, mainly in countries such as India, Indonesia, and Myanmar (Panama Teak and Forestry Inc., 2012). Consumers are highly interested in its desirable properties such as color, durability, and rot resistance, leading to increased appeal in its cultivation. This led to farming and production of teak beginning in the late 17th century in the country of Sri Lanka. Due to its desirable properties and subsequently high price, teak production rapidly expanded, becoming the third most widely planted tree around the world as of 2000 (Behaghel, 1999). In the wake of extreme marketing and deforestation, farmers and investors saw teak as a smart business investment and began expanding its production to Panama's Summit Gardens, Northwestern Costa Rica, and Belize in the 20th century (Hall, 2018; Hansen, 2017; Schmincke, n.d.; Kasper, 2012; Belize Teak, n.d.).

However, teak plantations were not as successful as many farmers expected because teak can only grow in very fertile soil, which is not available in many areas in Central America. Unfortunately, many farmers found themselves in debt after their teak plantations did not succeed (Hall, 2018).

The urge to escape poverty is a thread that is tied to many problems and investments in Central America. Some of the most prevalent problems the region faces are poverty, climate change, and deforestation. In Central America, over half of the population lives in poverty. Of those living in poverty, half live in extreme poverty. Many governments and international organizations established efforts to combat poverty, but none were monumentally successful (Hammill, 2007). Climate change also puts the Central American region in significant jeopardy as large sections of the region exist within the Central American dry corridor, a region of land that experiences incredibly severe weather—drought, flooding, and torrential rain—resulting from climate change (Chapman, 2017). Deforestation became a real concern in Central America during the 1980's when illegal logging, cattle ranching, and construction removed significant portions of forest, leading a few countries to declare states of emergencies (Martin, 2011). To aid in reforestation, governments offered incentives for people to start tree plantations, particularly teak trees due to their high commercial value (Hall, 2018).

The goal of our project was to investigate favorable growth factors for teak production in the Central American region and account for the limitations and barriers native to the region. This comprises issues such as erratic weather conditions resulting from climate change as well as lower incomes which may inhibit many farmers from investing in the industry. Stakeholders in this project include current teak plantation managers and farmers as well as investors and farmers interested in establishing their own teak plantation or farm. In order to provide the best recommendations for stakeholders in the region, the project focused on the ideal conditions for teak growth in general, such as soil pH, exposure to sunlight, harvesting strategies and other teak growth factors, without accommodating any specific country or plantation-oriented issues. To accomplish our goal, the team developed two objectives: to understand every consideration that needs to be made before, during and after the teak growing process, and then determine the viability of growing teak in Central America based on all information available. The team achieved these objectives through comprehensive online research and interviews with various experts. Upon analysis and review of the information received, the team concluded that expanding the teak industry in Central America will result in more negative consequences than positive impacts. However, our recommendations describe possible improvements for each potential stakeholder.

Methods

In order to reveal the most productive and cost-efficient way of growing teak and the limitations of the industry, the team collected information from various sources, including experts in the industry as well as online resources. First, the team conducted extensive online research to understand the most impactful factors on teak growth, as well as potential barriers of the teak industry. With this knowledge, the team then interviewed four experts in the fields of teak, plant research, and tropical farming. Each interview had a list of predetermined questions, some very general and others more specific regarding the expert informants and their specializations. The team wrote thorough notes and, if the interviewee permitted, recorded the interview to transcribe later. After researching online and collecting interview responses, the team implemented inductive coding to organize the results.

To achieve the second objective, the team compiled all issues, barriers, and concerns that farmers must consider before establishing a teak farm. After determining the findings, the team made final recommendations specific to the variety of situations that farmers may find themselves in and determined the overall viability of teak in Central America.

Results

Optimal Land Conditions

Teak has a number of preferred site conditions, including the soil where it would grow, the topography of the area, and the amount of water it receives. Teak grows best in fertile well-drained soils with a non-acidic pH, high base cations (calcium, magnesium, sodium, potassium), and high phosphorus (Personal Communication, Hall, Sept. 18, 2020; Finkral, Sept. 25, 2020). The tree prefers a hilly landscape in a region that is not too high (dry soil) and not too low (very wet soil). More specifically, teak grows best when planted lower than 600 meters above sea level (Personal Communication, Finkral, Sept. 25, 2020; de Camino, 2002). Although certain areas in Central America exhibit these soil characteristics, most soils in the region are too poor to support teak (Personal Communication, Hall, Sept. 18, 2020).

Additionally, teak relies on an adequate water supply to achieve ample growth and can experience problems with under or overwatering. Although experts regard teak as drought tolerant and well suited for Central America's dry season, it prefers consistent watering. Watering through the season can enhance productivity; Dr. Finkral, one of the expert interviewees, explained that "...by irrigating through that dry period, you're increasing growth by [about] 25-35% ...our experiments in Honduras [showed] we could grow teak to a final rotation age of… ten to twelve years" (Personal Communication, Finkral, Sept. 25, 2020).

Site Management

Some of the most important factors of a successful teak plantation include proper site management techniques. The methods implemented can vary from location to location, but the overall concepts are essential to foster strong and high-quality lumber. Examples of these factors to consider are equipment, labor force, thinning, mowing, general upkeep, and overall costs.

Thinning is a process where workers remove trees, often targeting those in worse conditions, to allow greater growth of the trees nearby, and mowing is the process of workers clearing away undergrowth with machetes to make room for growth of the trees (Personal Communication, Finkral, Sept. 25, 2020). The farmer's thinning strategy can have a significant impact on the financial success of the teak plantation.

Labor, Equipment, and Cost

Labor and equipment can quickly increase the cost of operating a teak farm or plantation. In the early years, trees require favorable soil conditions and plenty of water to survive; fertilizer and drip irrigation to combat this is very expensive. The plantation must also pay for labor multiple times in a twenty-year span as well as equipment like machetes for mowing, pole pruners for reaching high branches, and chainsaws for later harvests (Personal Communication, Finkral, Sept. 25, 2020). Overall, running a plantation is expensive, especially in the first few years—with an estimated average cost of about $866/ha in the first three years compared to an average of about $509/ha in years four and five, though this will likely differ depending on inflation and differences in labor costs across Central America (Griess & Knoke, 2011).

Final Harvest & Sales

Final harvesting is the last process during an entire rotation on a teak farm. This is when workers cut down the remaining trees about five years after the last thinning. Roughly 25% of the originally planted trees remain after periodic strategic thinnings of trees of poor quality. These remaining trees are the best quality and therefore, the plantation receives the greatest profit per tree. Commonly, laborers cut the trees into two-meter logs with the bottom "butt log" being the most valuable as it has the greatest diameter (Personal Communications, Finkral, Sept. 25, 2020). After workers have harvested the final trees, the logs are, most commonly, sent to India for processing. Processing costs are lower in India than they are in Central America and India is one of the biggest consumers of teak in the world (Personal Communications, Finkral, Sept. 25, 2020).

Negative Effects of Teak

Despite advocates for teak lauding the tree for its contributions to climate change mitigation, the current monoculture system in which farms plant teak, as well as the tree itself, may harm the environment more than it helps it. In general, monocultures tend to harm the soil where they grow. The continuous planting of a single species will drain soil of specific nutrients, not giving it sufficient time to replenish its natural stock of said nutrients. Monocultures also tend to limit native biodiversity and create "biological desert[s]" according to Dr. Finkral, which can harm the region's ecosystem (Personal Communication, Finkral, Sept. 25, 2020).

Specifically, teak induces low to moderate soil erosion, and when combined with poor plantation management strategies such as weed control via herbicide or controlled fires, teak can exacerbate erosion (Fernandez-Moya et. al, 2014). Additionally, teak needs an exorbitant amount of water for growth, which tends to dry out the soil beneath it and create water shortages (Personal Communication, Hall, Sept. 18, 2020). Teak also contributes less than other native species to ecological services such as carbon sequestration and the "sponge effect," or a plant's tendency to store water from the wet season to then slowly release and redistribute over the dry season. Studies have shown that numerous native species severely outcompete teak in both of these trials (Sinacore, 2018; Cernusak et al, 2006).

Potential Alternatives to Teak Monocultures

There are several alternatives to a teak monoculture that are more beneficial both financially and environmentally. One alternative is intercropping, a practice that grows two or more crops together. Intercropping (see Figure 1) helps in regenerating the soil's nutrients, promoting greater productivity of crops, fostering greater biodiversity, and providing sustained incomes (Personal Communication, Weathers, Sept. 16, 2020). Some options for intercropping include planting teak with other types of timber, with fruit trees for an additional annual income, with crops in the understory for sustenance farmers, or in rows with other crops (Roshetko, 2013).

When a teak tree plantation underperforms, farmers or landowners can rehabilitate the land through enrichment planting, which increases economic value and biodiversity of forests by planting valuable species (Mangueira, 2018). A potential valuable crop for an underperforming teak farm are native trees, such as *Terminalia amazonia* and *Dalbergia retusa*, instead of teak. These trees either outperform or are competitive with teak in regard to economic and environmental factors, as their market prices can be 27 times larger than teak per hectare, they perform better in low quality soil, and have significant cultural value (Marshall et. al, 2020; Sinacore 2018).

Figure 1 – Intercropping with Ginger and Papaya.

Costa Rica Invest, 2014.

Figure 2 – Silvopastoral System.

Global Silvopastoral Network, n.d.

Silvopastoral systems (see Figure 2) are an additional alternative to monocultures and combine timber farming and the common practice of cattle ranching. Cattle ranching accounts for 37% of land use in Central America and, due to its cultural ties and reliable market, ranchers are not abandoning it anytime soon (Murgueitio, 2011). Silvopastoral systems marry cattle farming and forestry into a symbiotic relationship where the vegetation reintroduces nutrients into the soil for the cattle's food source to thrive, subsequently helping the cattle (Personal Communication, Hobbs, Sept. 17, 2020). Both teak and native trees have the potential to grow on cattle farms as the system is very flexible (Personal Communication, Hall, Sept. 18, 2020; Finkral, Sept. 25, 2020).

Conclusion and Recommendations

Upon analysis and review of the information received from online research and expert interviews, the team concludes that expanding the teak industry in Central America will result in more negative consequences than positive impacts. The environmental impact of teak, poor land conditions in Central America, and current oversaturation of the market are compelling reasons to

look into alternate investment opportunities that the team describes in the Results chapter. However, if the desired objective of any government or organization is the improvement of current teak production, there are a number of alternative approaches that are more economically and environmentally sustainable. Additionally, plantations that have already invested in teak may currently face a variety of issues regarding teak yield. Some plantations may be struggling to produce a successful final harvest while others may simply want to boost their overall productivity. There are improvements for these problems, as well.

Although this report focuses mainly on Panama and Costa Rica, due to the abundance of teak research conducted in those two countries, we believe our recommendations are applicable across Central America.

Ultimately the plans and options that landowners have to consider vary widely depending on their current land use and objectives. Below the team offers financially and environmentally competitive alternatives for stakeholders, as well as methods to incorporate teak into a number of different ventures.

For established teak plantations that are in need of better results or are located on poor soil:

- *Introduce enrichment planting into the plantation*. By planting more native species that thrive in poor soil conditions, landowners can potentially rehabilitate their sites and increase their profit margins through the addition of valuable native wood.
- *Introduce patches of native monocultures after current rotation of wood*. Native species do not require the same soil conditions as teak and can survive on poorer soil.
- *Invest in fertigation and drip irrigation for the next cycle.* If the financial situation allows, fertilizing and irrigating through the Central American dry season in the next teak growth cycle can boost productivity and reduce the time between teak rotations by years.

For smaller subsistence farmers that may be hoping to earn additional income:

- *Conduct a soil survey to understand the physical and chemical properties of the land*. If it matches site conditions for teak, one can plant 1-10 hectares of teak.
- *Plant cocobolo*. If the land is relatively unfertile, planting cocobolo and allowing it to grow could be a worthwhile investment. Cocobolo is a tree native to the region used for furniture and musical instruments and outcompeted teak in environmental sustainability studies.
- *Intercrop teak with other crops in the understory or with fruit trees.* These other crops can generate a consistent income while teak matures.

For larger companies seeking to invest in teak:

- *Choose a different investment.* The teak market is already highly saturated and the supply is more than enough for the demand.

or

- *Purchase fertile, nutrient rich land and invest in fertigation and drip irrigation*. This combination can boost productivity during the Central American dry season and reduce rotation time by years.

For current cattle ranchers seeking to improve productivity and sustainability of their farms:

- *Establish silvopastoral systems*. These systems can enhance ecology of the pasture and introduce a long-term investment if planting a tree for lumber.

For government or nongovernmental projects seeking to mitigate the effects of climate change, conduct land restoration, or carbon sequestration efforts:

- *Invest in native species*. Various studies proved native species have better water-use efficiency carbon storing properties, contribute more to the sponge effect, and are better suited for the region than teak.

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Tyler Stack: Primary author of Introduction; Background: Environmental Conditions of Central America, Payment for Ecosystem Services; Methodology: Objective 2; Results and Analysis: Interview with Dr. Peter Hobbs, Cornell Professor, Interview Cross-Analysis, Erosion, Water Usage and Irrigation, Required Equipment/Labor, Cost, Final Harvesting, Processing and Sales; Conclusion and Recommendations

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Chapter 1: Introduction

The farming and production of teak, a tropical hardwood tree species, originated in the late 17th century in the country of Sri Lanka (Owen, 2018). Teak is native to Southeast Asia, mainly in countries such as India, Indonesia, and Myanmar (Panama Teak and Forestry Inc., 2012). For hundreds of years that region of the world was the only area with teak farms until 1926 when teak farming spread to Panama's Summit Gardens, an area located approximately 15 miles north of Panama City (Hansen, 2017). Teak production expanded to the Costa Rican Guanacaste province, the northern Pacific region of the country, around 1980 and quickly became a popular investment—about 30 farms existed 10 years later (Schmincke, n.d.; Kasper, 2012).

As of 2012 there were 132,770 hectares of teak planted across Central America, with over 86% of the plantations existing in Panama, Costa Rica, and Guatemala. The remaining 14% was mainly concentrated in El Salvador and Nicaragua with a small outcropping in Honduras and Belize (Fernandez-Moya, 2015).

Viewed as a smart business investment, teak's rapid expansion is understandable and, as of 2000, it was the third most widely planted tree around the world (Behaghel, 1999). Although getting hardwood can take about 20 years, teak has highly desirable properties when properly grown and managed. These properties include physical and visual aspects of the wood, such as its color, durability and hue, as well as properties that allow for easy growing, such as resistance to rot, mold, and insect attack (Behaghel, 1999). Selling quality teak leads to profit and economic growth, highlighting the value of creating the best environment and conditions possible for the tree. India dominates global teak trade, accounting for 74% of the world's import of teak (Kollert, 2015). Central American countries (Costa Rica, Belize, Panama, Guatemala, Nicaragua, Honduras, and El Salvador) acquired $139 million through the sale of wood and wood products in the first half of 2019, with India serving as the primary consumer and accounting for 41% of exports (Central America Data, 2020).

Teak in Central America has been a partial focus of a number of WPI IQP teams in the past. The efforts of those projects generally addressed smaller issues such as how plantations could deal with excess wood waste that came from trimmings and exploring why local artisans had a preference for teak over native tree species (Rush et al., 2012). Other projects that researched the tree found that monocultures (sites only growing one type of plant) of teak were harmful to the natural environment as they harmed both biodiversity and the soil due to the competition for specific nutrients in the soil (Argyrakis et al., 2019; Cloutier et al., 2017).

While the expansion of the teak industry may have been a financially enticing endeavor, the industry may be too risky for the average farmer to consider, and its ecological services may not be the best route for climate change mitigation efforts.

The goal of our project was to investigate favorable growth factors for teak production in the Central American region and account for the limitations and barriers native to the region. This includes issues such as erratic weather conditions resulting from climate change as well as lower incomes which may inhibit many farmers from investing in the industry. In order to provide the best recommendations for the entire region, the project focused on the ideal conditions for teak growth in general, such as soil pH, exposure to sunlight, harvesting strategies

and other teak growth factors, without accommodating any specific country or plantation-oriented issues.

To accomplish our goal, the team developed two objectives: to understand every consideration that needs to be made before, during and after the teak growing process, and then determine the viability of growing teak in Central America based on all information available. The team achieved these objectives through comprehensive online research and interviews with various experts. The team compiled a list of recommendations for five potential stakeholders: current teak plantations, smaller subsistence farmers, cattle ranchers, large companies looking to invest into teak, and government or non-government organizations looking into environmental projects. Upon analysis and review of the information received, the team concluded that expanding the teak industry in Central America will result in more negative consequences than positive impacts. However, our recommendations describe possible improvements or alternatives for each potential stakeholder.

Chapter 2: Background

2.1 Teak

Teak is a tree native to southeastern Asia that spread to various tropical regions throughout the world, including those in Africa and Latin America, throughout the last two hundred years (The Wood Database, 2015; Panama Teak and Forestry, Inc., 2012). It can withstand a dry period ranging from 3-5 months, appropriate for the Central American climate (Rush et al, 2012; The Editors of Encyclopedia Britannica, 2019). Natural teak thrives in hilly land with soil that drains well and remains fertile deep enough for the roots, which spread vertically down (see Figure 2.1) rather than horizontally out (Rush et al, 2012; Panama Teak and Forestry Inc., 2012). Usually teak plantations have flat land (see Figure 2.2), but if the soil composition is good, teak will grow anywhere (Rush et al, 2012). Interestingly, pure teak plantations fail quicker than those with mixed species because the non-teak vegetation decreases the impact of soil erosion and defoliating pests (Panama Teak and Forestry Inc., 2012). Thus, the introduction of other species aids teak growth rather than hindering it. Teak also needs unobstructed light for proper growth, a characteristic the Central American climate provides (Panama Teak and Forestry Inc., 2012).

Figure 2.1 – Deep Root Diagram.

Strand, 2004.

Figure 2.2 – Tectona grandis.

Sanga, 2017.

The wood teak (see Figure 2.3) produces is highly desirable and expensive due to its significant dimensional stability (the degree to which wood shrinks and swells in response to moisture gain or loss), decay resistance, and durability in a variety of weather conditions including sun, frost, and snow (The Wood Database, 2015; The Editors of Encyclopedia

Britannica, 2019; Cuenin, 2016). These ideal qualities require anywhere between twenty-five to thirty-five years of tree growth, with flexibility in this range based on the stem form and diameter of the individual tree (Panama Teak and Forestry Inc., 2012).

At the beginning of a cycle, an average plantation plants up to 800 trees depending on the size and condition of the land. As the trees grow and mature, the laborers cut smaller trees and thin the land to better accommodate the bigger trees. This process is vital—too many trees can cause competition for resources and a less than ideal final product (Kasper, 2012).

Figure 2.3 – Teak Hardwood.

Hearne Hardwoods, n.d.

2.2 Central America Poverty and Wealth Inequality

Poverty is a very real concern in Central America, with over half of the population living in poverty. Of those living in poverty, half live in extreme poverty. Central America saw a shift in its economic structure in the 1990's. After enduring civil wars, conflicts, structural and debt crises, the region needed to rethink its economy. They shifted to an open and market-oriented economy with smaller government and greater incentives to privatize businesses such as utilities, banks, and telecommunications (Hammill, 2007). With this shift, Central American governments created many social outreach programs to help those struggling financially to get out of poverty. Unfortunately, these social programs have not been very effective, with few citizens rising out of poverty. Due to the privatization of many business fields, those who are wealthy can maintain and grow their wealth while those in poverty see very little social mobility. This has created extreme wealth inequality in Central America (Hammill, 2007). Despite efforts from individual countries to close the wealth gap, the overall trends of wealth inequality have remained about the same. As depicted in Figure 2.4, there has been very little change overall in income inequality in Central America. The figure represents the Gini index, a measure of inequality where 0 is perfectly equal and 1 is perfectly unequal, of each Central American country's wealth inequality. From 1990 to 2004, the Gini index of Central America's income inequality rose one point from 0.55 to 0.56 (Hammill, 2007).

Some sources of inequality in Central America are unequal access to education, a lack of hours from part time jobs, and rural versus urban wage gaps. Unequal access to education accounts for 14-24% of income inequality in Central America. When countries had more public sector jobs, people could find more full-time jobs. Due to an increase in the private sector, more people are finding themselves in multiple part time jobs with less benefits. The gap in income

between rural and urban areas ranges from 14% to 68% across the Central American countries, with Guatemala seeing the largest disparity between the two areas (Gindling 2013).

Belize has seen significant economic growth over 9 years, growing the GDP an average of 2.1% from 2007 to 2016. Additionally, Belize has the third highest per capita income in Central America. However, they have very large income inequality, with 41% of the population living below the poverty line. The government has aimed to diminish the income inequality through the help of international donors (CIA, 2018). Guatemala also has some of the most extreme income inequality in Central America, with those in the top 20% income bracket making up over 51% of the country's overall consumption. Almost 60% of the population lives below the poverty line. Indigenous communities feel an amplification of this poverty where 79% are living in poverty and 40% are living in extreme poverty (CIA, 2018).

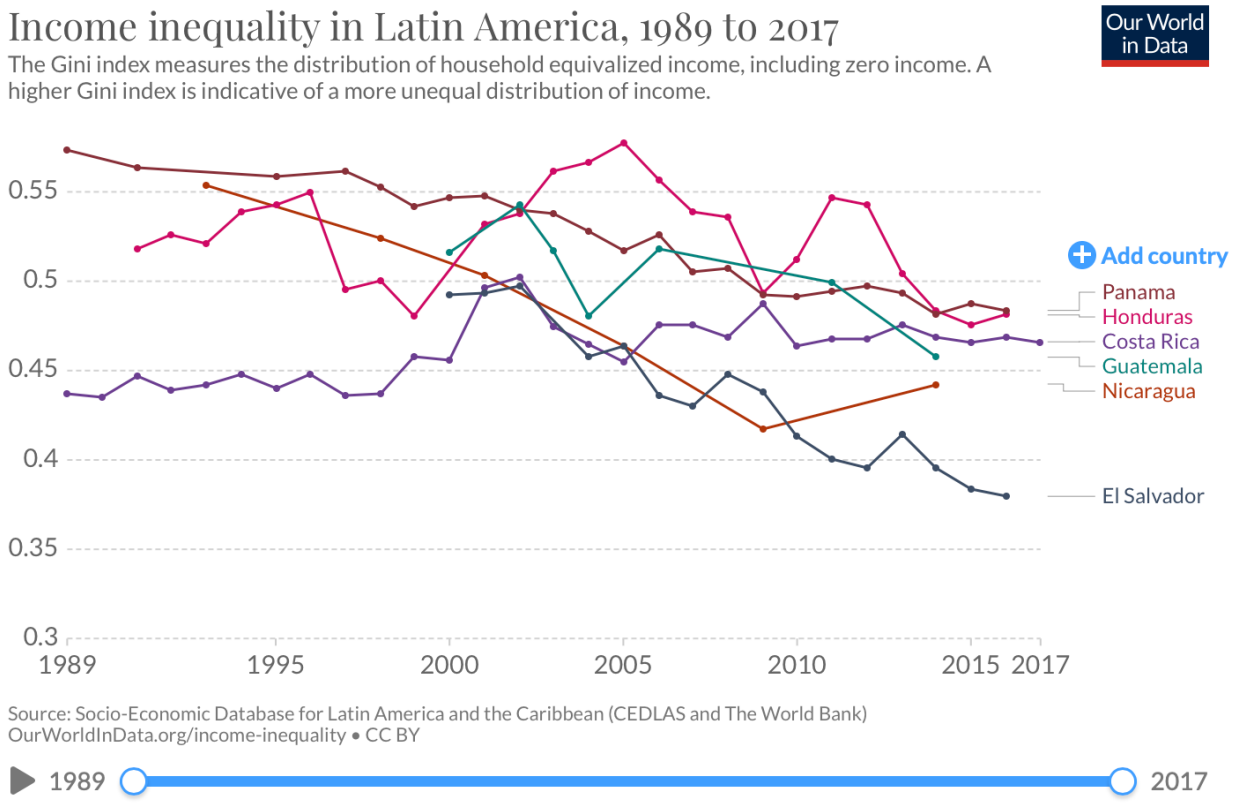

Figure 2.4 – Income inequality.

Our World in Data, n.d.

Costa Rica is one of the most successful countries in Central America. The majority of its citizens have access to healthcare and education. Over the past twenty years, Costa Rica's poverty rate has remained about the same at about 20% living below the poverty line (CIA, 2018). In Honduras, the GDP has seen an average growth of 3.5% from 2010 to 2017. Despite the economic growth, 65% of the population lives in poverty (CIA, 2018). Nicaragua saw an

extraordinary 4.9% growth to its GDP in 2017, but 30% of its population is living below the poverty line. Many Nicaraguans struggle to find work in Nicaragua and migrate to Costa Rica for seasonal work on farms (CIA, 2018). El Salvador has seen little growth in its GDP, averaging at about a 2% GDP growth from 2010 to 2014. Approximately 20% of its population finds work outside of El Salvador and sends money back home. This practice is the second largest contributor to the El Salvadorian's income. Unfortunately, 33% of citizens find themselves living below the poverty line (CIA, 2018).

Since the United States granted sole ownership and control of the Panama Canal to Panama in 1999, Panama's national wealth has surged. From 2014 to 2019, Panama saw a 5.6% average annual growth rate of the economy, making it one of the fastest growing economies in Latin America (The World Bank, 2019). However, this wealth is unequally distributed throughout Panama as the country has the second greatest income inequality in Latin America, with approximately one fourth of Panamanians living below the poverty line. The Panamanian government has implemented actions that significantly reduced the number of people living below the poverty line, but the income disparity is still quite large (CIA, 2018).

2.3 Effects of a Local Lumber Industry

The tree farming industry can benefit both local and national economies through the production and trade of lumber. Before farmers harvest lumber for sale, they must first propagate the tree, which is a process to increase the number of plants by using a cutting of a parent plant. Then, the farmers plant the saplings. Lumbar, a particular type of teak, can take up to twenty-five years before reaching maturity. After reaching the proper age, workers cut down the trees with chainsaws and transport the logs to the back of trucks. The truck drivers bring the logs to a factory where machines remove the bark and cut the log into smaller and uniform planks. The logs then undergo a lengthy process of drying in kilns for up to a month to transform the planks from green wood to usable wood. After a final sanding, the wood planks are ready for sale (The Wood Technology Society, n.d.).

On an international scale, Central America's export of wood and wood products generated almost $139 million in from January to June of 2019. Panama and Costa Rica account for most of the exports, with both making around $38 million (see Figure 2.5). Central America exports 41% of its wood to India, a country which has risen from 18% of exports in 2012 (Central America Data, 2020). On a local scale, wood-related industries boost the economy either through the creation of jobs or through the access to materials. Jobs are available at any of the many levels of lumber processing. Artisans can use the wood planks to make furniture, bowls and cutting boards, or artwork, and building developers may use the planks for local construction projects.

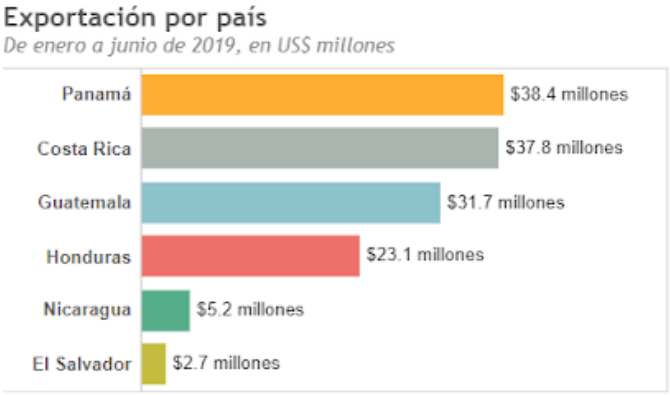

Figure 2.5 – Wood Export Profits in USD for 2019.

Central America Data, 2020.

2.4 Environmental Conditions of Central America

Costa Rica, Belize, Panama, Guatemala, Nicaragua, Honduras, and El Salvador house a humid, tropical climate with two distinct wet and dry seasons. The wet season is a five-month period spanning from June through October, also known as the 'green season' due to the excessive rainfall's effect on plant life. The dry season lasts from November to May with an average rainfall of zero to twelve inches per month (Hubbard, 2019). These seasons may vary from country to country in the region but are relatively around the same time period.

Climate change caused select regions in Central America to experience changes in annual rainfall in 2011 (see Figure 2.6). The figure shows the severity of change—no change, very low, low, medium, high, and very high—and each level corresponds with a color: light green indicates no change and red signifies very high severity. These rainfall changes can drastically affect the length of wet and dry seasons, especially with repetition year after year.

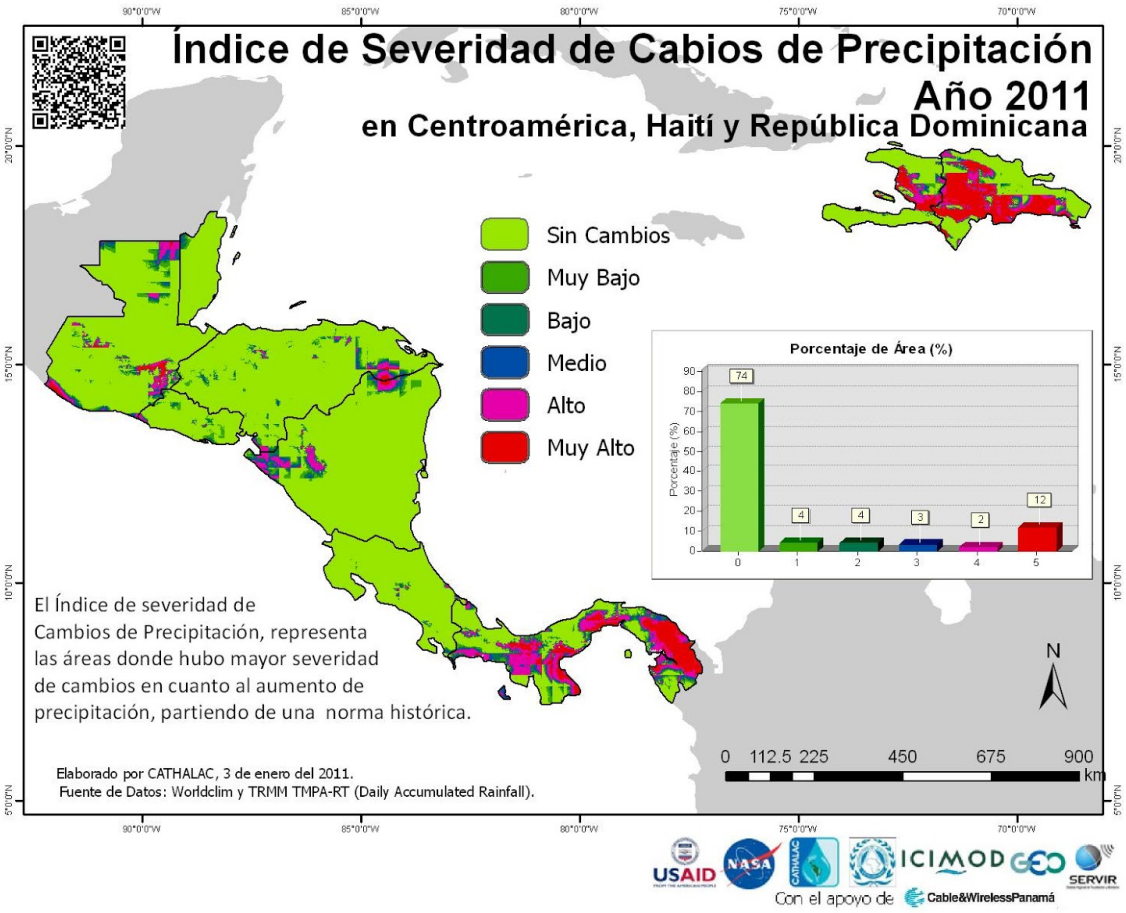

Figure 2.6 – Precipitation Change Severity Index for Central America, Haiti and the Dominican Republic in 2011.

Servir Global, 2012.

2.5 Soil Trends and Agricultural Trends Central America

Agriculture constitutes a large portion of Central America's land use, with the Food and Agriculture Organization (FAO) estimating that agricultural land accounts for around 36.45% of the average Central American country's total land (Index Mundi, n.d.). Countries such as Panama and Costa Rica export large quantities of agricultural products such as coffee, bananas, pineapples, and other tropical fruits as a source of revenue (Office of the United States Trade Representative, n.d.; Costa Rica Information, n.d.). However, ventures driven by greed or basic survival may have overlooked site conditions when developing land for these industries. Overlooking the environmental and physical properties of the land can inhibit the productivity and profitability of whatever the farmer or landowner's purpose or objective may be. Examples of land objectives include more agricultural production, wildlife conservation efforts through reforestation, or something else with a distinct environmental, economic or cultural goal.

Soil surveys are among the various useful tools for analyzing composition of land and soil in different areas. Scientists conduct soil surveys to understand broad trends of land. With

the aid of soil surveys, policy makers can propose plans for land development that complement the soil type and promote good growing practices. Soil surveys can be categorized and analyzed using a number of different classifications like the United States Department of Agriculture (USDA) Soil taxonomy, which the USDA developed in 1975. The system separates soil types into twelve different orders, or soil classifications, differentiating the orders by a number of different factors (USDA NRCS, 1999).

The FAO completed and published a global soil survey in 1975 including a map of Mexico and Central America outlining the various subtypes of soils found in the area. In 2005, US soil taxonomists interpreted and translated this data into the US Soil taxonomy system. Then, the US Department of Agriculture Natural Resources Conservation Service (NRCS) published an adapted map and survey. The survey provides an estimated description of the various soil conditions throughout Central America as seen in Figure 2.7. It is difficult to quantify any order of soil as being good or bad, due to the different subtypes and differentiation between orders. A single order may range in properties such as nutrient content, fertility, and acidity. However, research has shown that in general Inceptisols, marked in orange, are soils suited for teak growth. The general properties of Inceptisols are that they are younger, fairly undeveloped soils with very little horizon development, which are the various layers of soil (see Figure 2.8). The largest soil distribution in Central America, Ultisols (yellow), can support teak growth with good management, however, Ultisols are less suited for the tree due to it being more acidic, less fertile, and having low calcium, magnesium and potassium content. Alfisols (light green) are slightly acidic and have higher native fertility. They too can be used for teak, but again need good management practices to offset its natural properties (Personal Communication Teaknet, October 9, 2020). There are additional soil orders in Central America, but their performance with teak is less established than that of the previously mentioned orders. The region has smaller more localized regions of Andisols, Histosols, Mollisols, and Vertisols. Andisols (dark purple) have high water-holding capacity and leech phosphorus away from plants. Organic materials mainly compose Histosols (brown) and miners generally unearth them for fuel or horticultural products. Vertisols (dark blue) are rich in clay and shrink or swell depending on the moisture content of the soil. Mollisols (dark green) are some of the most fertile soil available and are an incredibly productive agricultural soil (Global Rangelands, n.d.).

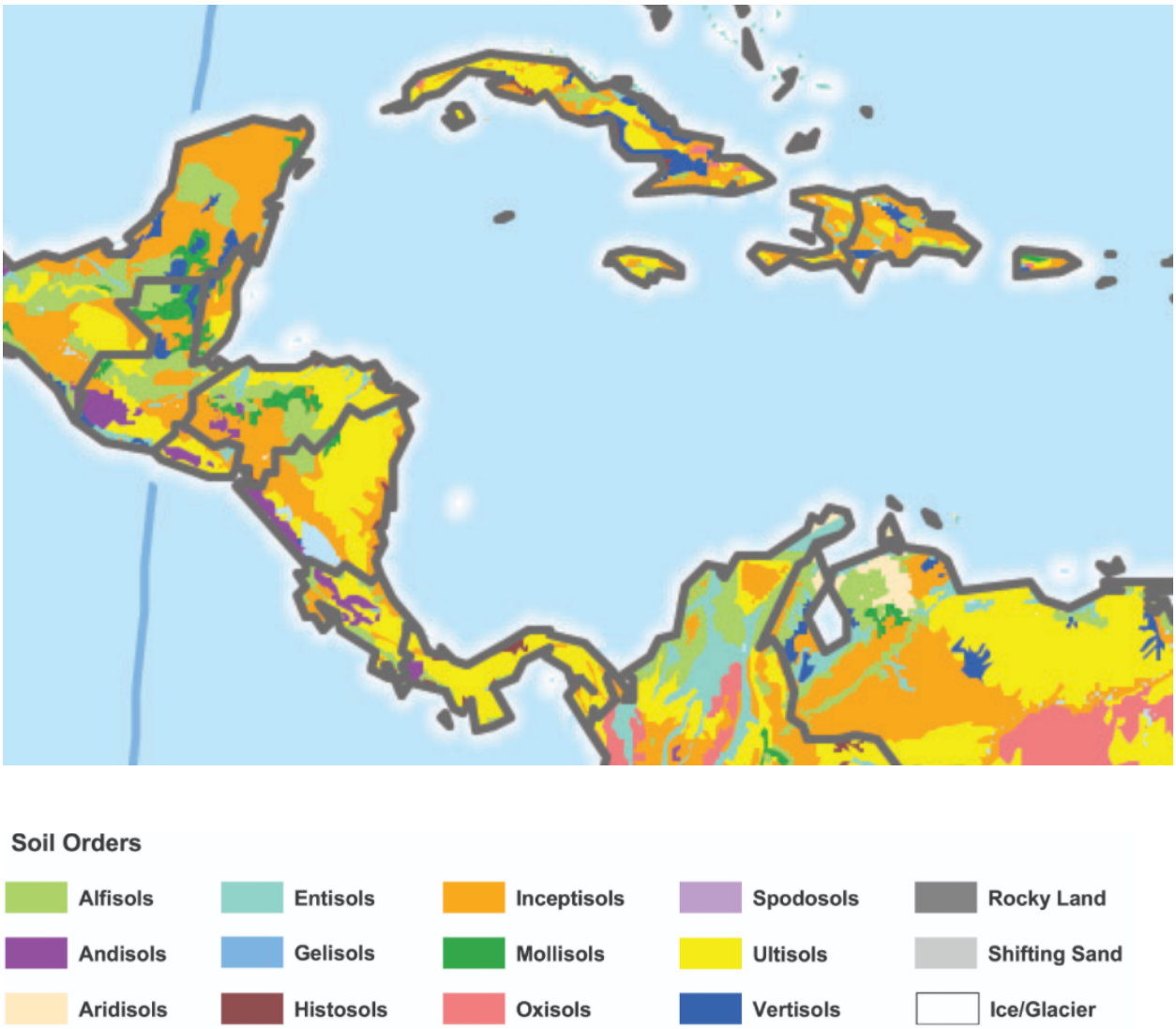

Figure 2.7 – Soil Map and Soil Orders Central America.

USDA NCRS, 2005.

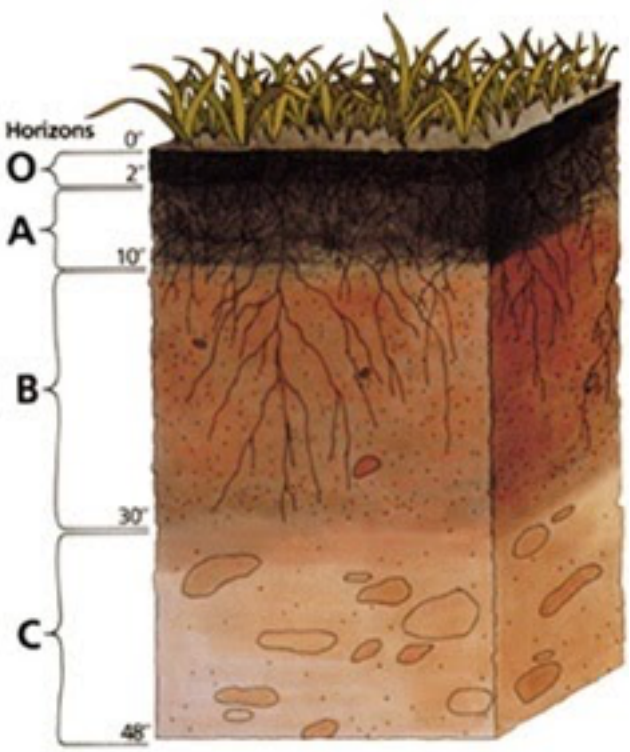

Figure 2.8 – Soil Horizons Diagram.

Soil Science Society of America, n.d.

2.6 Soil Modifiers

Because soil is such a crucial factor in determining the growth success of a plant, it is essential to strive for the best soil conditions for that plant. Often, achieving this involves the use of soil modifiers—various additives that can improve vegetation growth and health (Pal, 2013). With these modifiers, farmers can change how well the soil drains and help mimic the soil in other climates. Specifically, they adjust the composition, regulate the pH, or alter the absorptivity (measure of taking in or sucking up a compound), adsorptivity (measure of a compound's tendency to bind to soil particle surfaces), and desorptivity (release of compounds from soil particle surfaces). Categories of soil amendments include "other soil, organic materials, plastics, ion exchange resins, and rubber." Each modifier serves a different purpose in the soil, whether it modifies in multiple ways or mitigates one succinct problem. In terms of incorporating modifiers, the best time to utilize them is before land cultivation to ensure uniform integration. Furthermore, avoidance of layering in the soil prevents future failure due to inadequate soil homogenization (Griffin, 1972).

Soil amendments alter various properties of the soil, thus, addition of the correct modifier(s) to the teak plantation soil can improve its composition to better imitate the ideal mixture for teak trees. As mentioned earlier, teak flourishes in well-drained soil. Specifically, the best type of soil for teak is alluvium—a mixture of fine particles (namely clay, silt, sand, and gravel) that a river or stream eroded and reshaped then redeposited in a dry setting (Panama Teak

and Forestry Inc., 2012; Soil Formation and Parent Material, n.d.). The ideal alluvium pH for teak growth ranges from 6.5 to 7.5 (Panama Teak and Forestry Inc., 2012). A soil composition that yields these parameters, whether it is because of the introduction of modifiers or not, increases the probability of enhanced teak production.

2.7 Plant Propagation Techniques

Plant propagation describes the process which grows new plants from parent plants. There are two overarching types of plant propagation, sexual and asexual, each of which categorize various methods of plant extension. Sexual propagation involves the flower of the plant, joining the pollen and the egg to create a new plant from two parents. The main method of sexual propagation involves planting and fostering the seed created as a result of joining the pollen and the egg (University of Maine, 2016).

When there is a highly desirable individual of a species, a grower typically uses the asexual technique of propagation. Different from the sexual technique, the asexual technique has the ability to clone the parent. This cloning is not just for a single parent, rather, it is possible to join one parent with another to produce mixed offspring. However, these offspring are clones of the original joined parents. There are four principal methods of asexual propagation: cuttings, layering, division, and budding and grafting (University of Maine, 2016).

Cuttings involve trimming the parent plant and planting that part, whether it is a stem, leaf, or root. Layering requires any part of a stem that is still attached to a parent plant to pull the nutrients required to sprout roots from the soil, as shown in Figure 2.9. Division splits the visible part of the plant down to the roots, making two new plants in the time it takes to cut the original. Budding and grafting each define a different method to join plant parts that enables them to grow as one plant. Joining parts allows mixing of parents, thus forming a new plant by means of asexual propagation (University of Maine, 2016).

Although teak produces abundant seeds nearly every year, the asexual propagation technique is the more universal technique because it is readily repeatable as long as there is a plant, which does not typically pose any issue in a plantation setting (Panama Teak and Forestry Inc., 2012). Thus, any of these methods—cuttings, layering, division, or budding and grafting—are preferable to the time-consuming sexual technique. As any tree matures, its bark grows stiffer and more difficult to cut. Propagation methods are most effective in the early stages of growth, before tough bark develops. Furthermore, bark growth reduces the effectiveness of asexual propagation as a whole and removes the plausibility of layering method success due to lack of a stem. In conclusion, the possible successful methods are cuttings, division, and budding and grafting, as long as the teak tree is young.

By definition, plant propagation produces offspring. However, it can also increase the quantity of plants and, in accordance with the asexual technique, this can happen more readily than is typical in nature. These techniques could affect teak thus it is essential to keep them in mind when planting and fostering the trees.

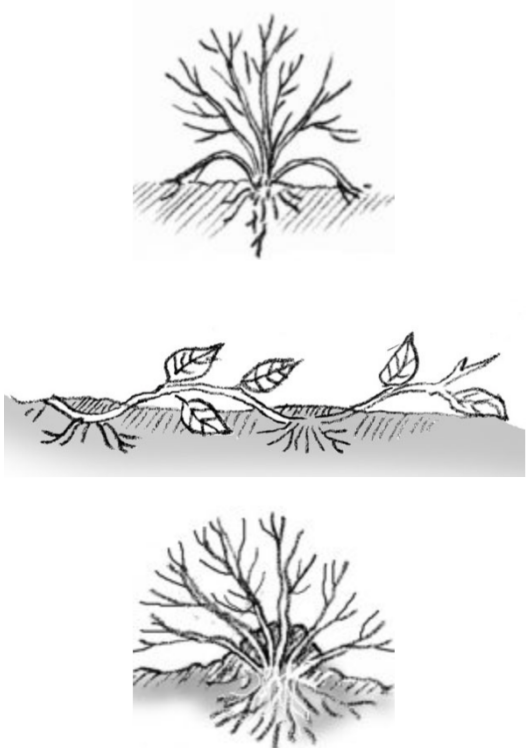

Figure 2.9 – Layering Propagation Method.

University of Maine Cooperative Extension, n.d.

2.8 Deforestation

As construction activities repurpose land for agriculture, roads, and residence, many countries lose their forest area which causes large carbon emissions and a reduction in clean water (Ceddia, 2019; Mongabay, 2006). Furthermore, logging, both legal and illegal, has augmented the rapidly decreasing numbers of trees (Mongabay, 2006). Over a span of 30 years, 1980-2010, the overall deforestation rates (a function of forest area and time) have increased to a parameter of -1 to 0 in Panama and Nicaragua and -2 to -1 in Honduras. Costa Rica deforestation rates are at a stable parameter of 0 to 1 (see Figure 2.10). The figure quantifies the loss of forest coverage and compares the deforestation rates of the Central and South American regions. Although these rates seem low in comparison to other countries, it is necessary to keep in mind the relatively small land masses of Panama, Nicaragua, Honduras, and Costa Rica.

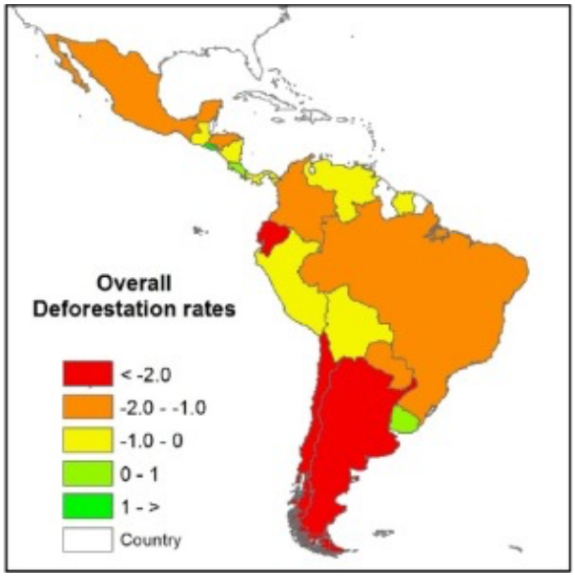

Figure 2.10 – Overall Deforestation Rates Map: Central and South American Regions.

Armenteras, 2017.

2.9 Climate Change and Reforestation

As the world continues to develop and evolve, it faces the consequences of human actions, namely climate change. Many countries and companies neglect the repercussions of this global threat in lieu of profit and personal gain. However, simply ignoring climate change does not alter its global effects, such as increased temperature and more irregular weather patterns. These effects lead to larger sociological, economic, and agricultural impacts.

Climate change puts the Central American region in significant jeopardy. Large sections of Honduras, El Salvador, Guatemala, and other affected countries exist within the Central American dry corridor (see Figure 2.11), a region of land that experiences incredibly severe weather—drought, flooding, and torrential rain—resulting from climate change (Chapman, 2017).

Many people in these regions must choose between evacuating the communities they live in or risking the consequences of staying. Climate change causes crop growth and food reserves to steadily diminish because of drought. Farmers from the dry corridor state that their most substantial problems are lack of water, erosion, and poor soil. These problems are so pronounced that in 2018, Honduras, El Salvador, and Guatemala all declared emergencies because food shortages affected over 2 million people (Gustin, 2019). Over 1 million families living in the dry corridor survive off of subsistence farming: the practice of only growing enough food to feed one's own family (Gustin, 2019). The erratic conditions of the corridor result in economic woes and increased food insecurity for these families (Gustin, 2019).

Communities face increased pressure to act because the dry corridor's conditions are so detrimental. Furthermore, instances of attempted emigration to the United States are increasingly more common. From 2010 to 2016, the number of people apprehended at the southwestern border of the U.S. increased from 50,000 to approximately 408,870 people. Many of the

emigrants blamed the lack of employment and economic hardship for their attempted crossings, and most suffered from some degree of food insecurity (Chapman, 2017). Furthermore, a report from 2018 by the World Bank stated that climate change could force between 1.4 million to 2.1 million people in Mexico and Central America to move from their communities in order to escape from the devastation it causes by 2050 if nothing is done (Moloney, 2019).

Figure 2.11 – Central America Dry Corridor.

Gotlieb 2019.

As time progresses the situations in these countries continue to exacerbate with almost every Central American country experiencing the exact same list of symptoms. These countries have varying levels of economic dependence on their agricultural industries, as well as varying levels of resources and plans of action dedicated to combating the issue.

For Belize, the agricultural sector contributes 35% to their GDP, while 41% of their employment is from fisheries and forestry. The country faces a number of difficulties moving forward. The country is prone to flooding and cyclone events due to the low-lying terrain in their coastal region which not only threatens the people that live there but also the important infrastructure around the coast. Additionally, scientists expect rainfall to decrease which will lead farms in Belize to rely more heavily on rivers as a source of water and lead to additional

problems such as beach erosion on the coast due to a lack of sedimentation deposition (The World Bank, n.d.).

In Costa Rica, the disruption of natural weather patterns and biodiversity could lead to a number of problems experienced in the rest of Central America, such as lower crop yields, risk of parasites and pests, and redistribution of species in the highlands. The threat to biodiversity and alterations to plant and animal life are especially threatening to Costa Rica, as their national parks and reserves offer important economic resources such as ecotourism, and the generation of waterpower and working places (Climate Expert, n.d.).

Honduras is one of the hardest hit countries, with climate change decimating the crop harvests of certain regions by up to 80%. Its population has also suffered, evidenced by the 500,000 Hondurans struggling to put food onto the table according to a report by the World Food Program (Moloney, 2019). The country has declined as the impact of drought begins to set in. Farming communities and families see smaller reserves of food each year, forcing them into dire conditions.

Much of the land in El Salvador is within the dry corridor, causing 192,000 of their citizens to require humanitarian assistance, according to a report from 2016 by the Food and Agriculture Organization of the United Nations (FAO, 2016). As with many other Central American countries, agriculture is a large component of El Salvador's economy, employing 21% of the country and contributing to 10% of its GDP. However, scientists project that extreme weather trends will result in a decline in the agricultural production of crops used domestically and for international trade (United States Agency of International Development, 2017). The country has seen a number of effects, either directly or as a consequence, from climate change such as a loss in forest cover, increased storms, floods and droughts.

Guatemala mirrors many of the other countries as well, suffering erratic weather patterns and a devastated population. According to the FAO, Guatemala has nearly 1.5 million people in need of humanitarian assistance, leading to migration out of the country. El Niño, the heating of the ocean's surface waters, contributed to emigration in addition to a series of devastating effects in Central America. The failed and diminishing harvests have started extending beyond small and subsistence farmers and have begun reaching larger commercial farms, further harming the poorer communities of Guatemala. Originally, poorer farmers having trouble growing their crops would work for larger farmers to feed themselves, but the decreased production and conditions have diminished this opportunity. Currently, many Guatemalans face hunger and nearly 50% of children under the age of 5 are chronically malnourished in the country according to the World Food Program (Steffens, 2018). The lack of food has caused other issues. Those that originally grew their own food now need to use their already dwindling funds to buy crops that they would originally grow, leading to less resources available for important items like medication (Steffens, 2018).

Despite not being directly in the dry corridor, Nicaragua has also seen a number of repercussions from climate change. In recent years, the country has seen an increasing number of severe storms with one unnamed storm putting almost 10% of the country under water (Haynes, 2017). The frequency of these events has caused an annual loss of 1% of Nicaragua's GDP. To put it in better perspective, the casualties and economic damage of these events would equate to the US losing around 9000 people and 200 billion dollars each year. Agriculture employs 30% of Nicaragua's population, which is seeing typical problems of climate change with declining yields and the cost of food spiking. In addition to the aforementioned problems, the country has experienced other severe side effects: the warmer and wetter conditions from climate change

may contribute to the spread of Zika Virus in the country, and the vulnerability of the population has led to epidemics of leptospirosis as well as a rise of gastro-intestinal and respiratory illnesses (Haynes, 2017).

The damage and consequences in Central America because of climate change, La Niña, El Niño, and the creation of the dry corridor are abundantly clear. However, simply relegating the casualties and damages experienced in all these countries to statistics takes away from the gravity and humanity of this crisis. For that reason, researchers should look into the impact of climate change on individual farmers further. Take Panama for instance: although only a small portion of the country lies within the dry corridor, the area outside that region also endures side effects from climate change. Panama faces the same risks many other struggling countries face, especially within its agricultural sector. If mitigation of climate change does not occur, Panama could suffer many of the same debilitating effects: higher unemployment rates, lower crop yields, and lower exports.

The devastation of La Niña, the cooling of the ocean surface waters, exemplifies the recent effects of climate change in the country. This phenomenon induced losses of 6 billion dollars and 15,000 hectares of land (The World Bank, n.d.). Climate change will likely continue affecting the nation, as studies hypothesize that the production of primary crops in Panama will decrease as temperatures rise. Temperature, however, only accounts for one of the numerous inhibitors of crop growth resulting from climate change. Other factors affecting crop production include erratic rainfall and more frequent, intense hurricanes.

Evidence of the effects of this global crisis on Panamanian farmers is increasing. A study by Hobeika & Wagner (see Table 2.1) investigated the impact of climate change in Tierras Altas, a region of Panama in the Chiriquí Province which provides approximately 14.3% of the country's total agricultural production. Researchers asked farmers in Tierras Altas if they noticed any changes in the environment as a result of climate change. The farmers explained that they experienced more drought, observed increased irregularity of rainfall between years, and endured a shift in dry and wet seasons. When asked how these environmental fluctuations affected their crops, the farmers responded that crop quality decreased, and the prevalence of crop damage increased. Consequently, farmers faced smaller yields. The study also found that countless farmers outside the corridor started experiencing similar conditions of drought, harder rains, and soil erosion (Hobeika & Wagner, 2018).

Table 2.1 – Climate Change in Tierras Altas: Quantified Response Chart

Hobeika, M., & Wagner, A. C., 2018.

Rank	Observed Climate Changes in Tierras Altas	Frequency of Answer in % (Multiple Answers)
1	More Drought	46.6
2	Irregularity Between Years	43.3
3	Changes In End/Beginning Of Wet/Dry Season	43.3
4	Irregularity in Month of Rainfall	36.6
5	Higher Levels of Rainfall	30
6	Higher Temperatures in the Dry Season	30
7	Harder Rain/ Higher Rain Intensity	23.3
8	Extreme Temperatures	16.6
9	More Extreme Weather Events	16.6
10	Lower Temperatures	16.6
11	Higher Intensity of Dry Season	16.6
12	Stronger Winds	16.6
13	Higher Intensity of Wet Season	16.6
14	Less Sunlight	16.6
15	Higher Intensity of the Sun	6.6

These shifts and irregularities drastically affect small farmers' ability to earn a living and provide food for themselves. If Panama ignores this issue, it could undergo waves of emigration and community devastation similar to those in harder hit countries. In 2004, the UN reported that 67% of these small farmers lived below the poverty line and had an average annual income of around $11,110, making them extremely vulnerable to any economic instability from these inconsistencies (FAO, 2003). The prevalence of these issues begs for a large-scale response to inhibit the negative effects of climate change on the wellbeing of the Panamanian population.

One country that has seen great strides in their attempts at fighting climate change is Costa Rica. The country unveiled a plan to decarbonize itself by 2050. The plan involves a number of changes, such as converting the major forms of public transportation, taxis and buses, to electricity, since transport accounts for 40% of Costa Rica's emissions. Additionally, the plan would attempt to curb the number of cars used in the country, phase out fossil fuels, and expand the country's forests. The country has shown its resolve through a number of impressive results, such as 99% of its electricity production coming from clean sources (Dempsey, 2019). However, as with any major overhaul to a country's infrastructure, the plan risks creating economic damage and harming its citizens. Certain scientists from Costa Rica are skeptical about the plan's goals, as it presents an arduous journey ahead of them (The Guardian, 2019). Going carbon neutral will be difficult as it needs to be tackled on two fronts, decreasing the number of emissions, and sustaining or increasing natural resources that offset said emissions.

Reforestation outlines a potential solution to combat climate change and benefit the environment and economy as its counterpart, deforestation, contributes to and augments the effects of climate change. An example of this is Sumatra, an Indonesian island which cleared most of its forests to cultivate palm oil (Pearce, 2018). The temperature in regions that laborers deforested to harvest palm oil had considerably higher temperatures than forested areas—six to ten degrees Celsius higher in some cases.

Trees and forests cool the environment and subsequently assist evapotranspiration, the transfer of water from the land to the atmosphere. Evapotranspiration could conceivably help

resist notable effects of climate change like drought (Pearce, 2018). Furthermore, reforestation can improve water quality, biodiversity and soil health and provide sustainable timber fiber and fuel. The additional trees introduce a need for jobs to create and manage these forests. Along with this, the trees provide artisans with more material. These new developments from reforestation can boost the economy (Faruqi et al, 2018).

The striking benefits of reforestation have increased reforestation advocacy around the world. The UN, through its UN-REDD (United Nations Collaborative Programme on Reducing Emissions from Deforestation and Degradation) Program, helps partnering countries by providing support on the design and implementation of REDD programs. In addition, the UN shares knowledge, methods, data, and other information to educate participating countries (UN-REDD, 2016).

One country that has taken advantage of this opportunity is Panama. Since its inception, Panama has accepted and utilized more than $5 million from the program. As of 2016, UN-REDD has supported 14 different projects centered in Panama (UN-REDD, 2016). Panama's effort to support reforestation is clear, especially in setting the goal in 2015 to restore 1 million hectares of deforested land in the next 20 years (Initiative 20 x 20, n.d.).

The "Alianza por el Millón" or "Alliance by the Million" movement helped establish this goal. "Alianza por el Millón" is a partnership led by Panama's ministry of environment and consists of civil society organizations, the private sector, and the government. With government backing and support, the program has planted 5 million trees since the goal's inception (Initiative 20 x 20, n.d.). One species of tree favored by those seeking to profit from the program is teak.

Teak stands out for multiple reasons, but most pronounced are its physical hardness and popularity in the global market. Teak fares better under drought-like conditions than other trees and is a highly researched tree variety in forestry. Because of these beneficial attributes, scientists have investigated different variants of the tree to learn which genes allow teak to survive under extreme conditions (Galeano, 2019).

Countries that choose to grow teak should hold its merits in context to the region. Although optimizing its production could potentially increase reforestation efforts, combat climate change, and provide an economic boost, these benefits may pale in comparison to other options. Thus it is necessary to delve further into the details of teak's effects on the environment, as well as potential alternatives that may foster greater economic and environmental growth in Central America.

2.10 Payment for Ecosystem Services

As climate change becomes an extremely pressing matter in today's world, it is vital to acknowledge this threat and put policies in place to combat these environmental issues. One program relevant to our project is known as Payment for Ecosystem Services (PES). PES is "a concept to compensate and encourage landowners to improve land management practices for the maintenance and provision of ecosystem services" (Grima, 2016). Panama and Costa Rica are examples of countries that use programs like these today. In 1997, Costa Rica established its PES program, Pagos por Servicios Ambientales (PSA). This program was the first of its kind implemented nationally. Costa Rica's plan specifically set the groundwork for developing countries looking to follow in their footsteps (Pagiola, 2008). PES programs incentivize landowners to preserve their forests instead of clearing the land for other uses. In most cases the landowners are compensated through government grants or through non-governmental

environmental conservation groups. Another benefit that these landowners receive is the ability to officially claim their land. Some of these farmers that live in low-income communities do not own their land in the eyes of the government. These programs protect the land, determining the farmers can keep it because they are using it in a beneficial manner.

2.11 Teak Fever

In the 1990's, "Teak Fever" infected Central America—a trend where farmers and investors rapidly established teak plantations. From 1990 to 2010, the total area of teak plantations increased by 16.4 times in Guatemala, 14.1 in Panama, 12.6 in Nicaragua, and 4.9 in El Salvador (see Figure 2.12). Deforestation became a real concern in Central America during the 1980's. Illegal logging, cattle ranching, and construction are still contributing factors to deforestation in Central America. Deforestation affected Costa Rica so drastically that President Oscar Arias declared a state of emergency to help restore their forests (Martin, 2011). To combat deforestation, many Central American governments offered incentives for people to start tree plantations, particularly teak trees due to their high value. As described earlier, Panama, Nicaragua, and Costa Rica house the most popular government incentives. Many marketing and investing companies saw a new market for lumber in Central America as the desire to reforest the area increased. These companies invested a great amount of money into marketing the establishment of teak plantations. They explained that farmers could make upwards of $250,000 per hectare in twenty years. However, this deal was too good to be true for many farmers. Teak can only grow in very fertile soil, which is not available in many areas in Central America. Many farmers found themselves in debt after soil conditions caused their teak plantations to fail (Hall, 2018).

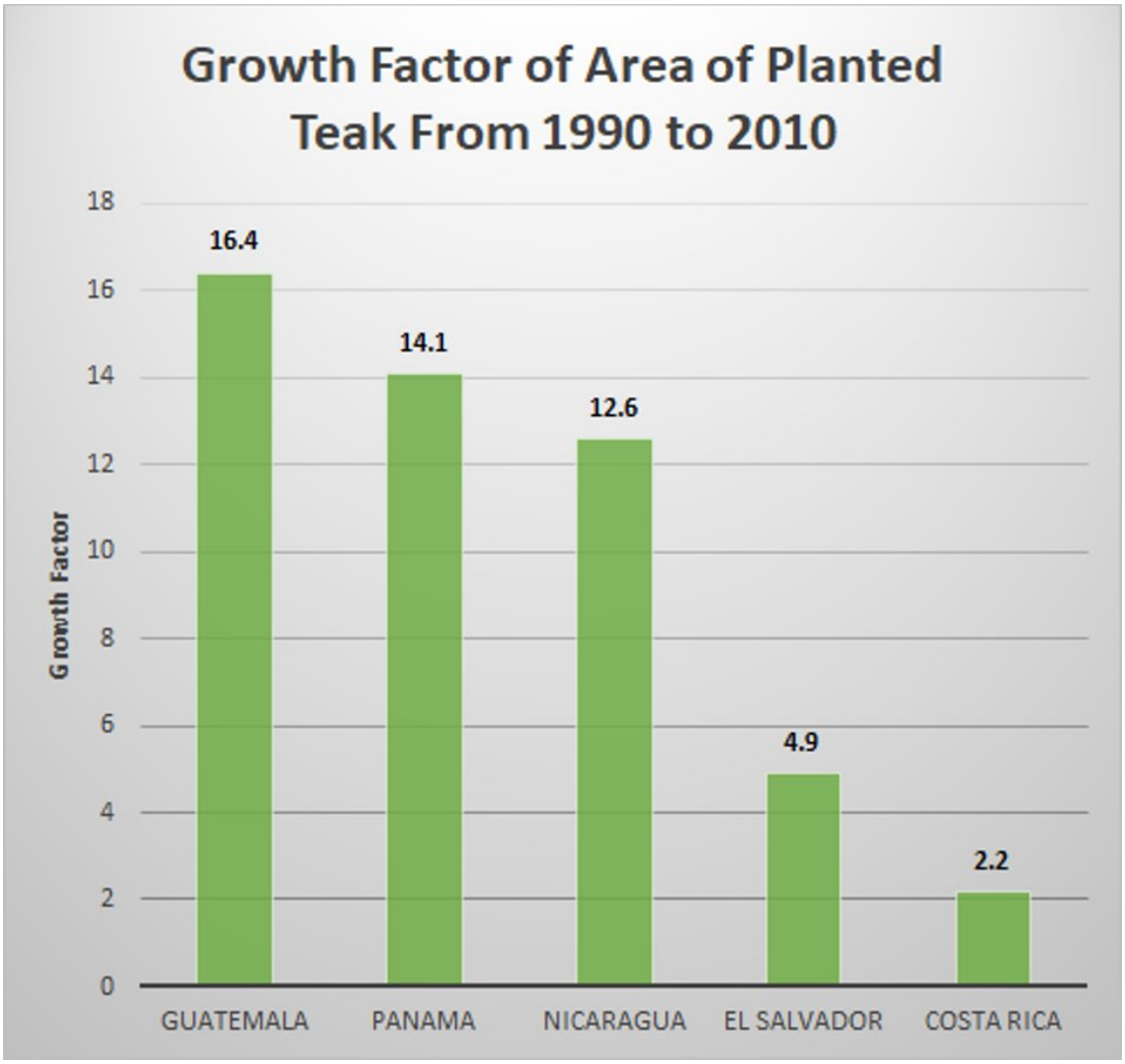

Figure 2.12 – Growth Factor of Area of Planted Teak from 1990 to 2010.

Kollert, 2012.

2.12 Stakeholders

The project's primary stakeholders are teak farms and farmers in the Central American region. Ideally, the recommendations would elicit positive effects across the teak farms and assist the stakeholders in fulfilling their respective organization missions.

Several secondary project stakeholders include local farmers, artisans, and industries. With our recommendations, local farmers may choose to seek employment on nearby teak farms or establish their own teak farm. Due to the regions' high poverty rates, our recommendations accommodate low budget teak farms. Depending on the teak hardwood's next destination post-harvest, local artisans that make furniture and international consumers constitute additional potential stakeholders.

Chapter 3: Methodology

The goal of this project was to investigate favorable growth factors for teak production in the Central American region and account for the limitations and barriers native to the area. This includes issues such as erratic weather conditions resulting from climate change as well as lower incomes which may inhibit many farmers from investing in the industry. In order to provide the best recommendations for the entire region, the project focuses on the ideal conditions for teak growth in general, such as soil pH, exposure to sunlight, harvesting strategies and other teak growth factors, without favoring any country or plantation-oriented issues. To achieve this goal, we developed the following objectives and methods:

Objective 1: Collect information from various sources to understand every consideration that needs to be made before, during and after the teak growing process.

Method 1.1. Perform extensive online research on important teak growth factors and potential barriers.

Method 1.2. Conduct interviews with experts in relevant fields.

Objective 2. Determine the viability of growing teak in Central America based on all information available.

This chapter details the methodology established to collect information from various sources, including experts in the industry as well as online resources, in order to carry out our goal. Methods 1.1 and 1.2 aim to reveal more productive and cost-efficient ways of growing teak, as well as the limitations of the industry. Specifically, whether the expansion of the teak industry makes sense sustainably and economically.

3.1 Objective 1: Collect information from various sources to understand every consideration that needs to be made before, during and after the teak growing process.

3.2 Method 1.1: Perform extensive online research on important teak growth factors and potential barriers.

Many factors impact the growth and harvesting of teak. Farmers devote thoughtfulness and preparation to produce the best quality product. Factors include general environmental details, such as sunlight exposure and rainfall levels, and other important site management practices pertaining to teak farming. In order to provide competent and helpful recommendations, the team conducted extensive research on the behavior of teak in Central American climates.

Farmers must consider details other than teak growth when improving the industry. Relevant information, such as viable areas for plantations, and the equipment required to produce and harvest the plant, are important factors to consider before one can begin growing the tree.

Certain elements contributing to teak growth are also barriers. For example, location is an important factor, but a location with poor teak growing conditions is a barrier. For that reason, the team not only focused on ideal conditions of teak itself, but all conditions relevant to it.

Additionally, the team investigated aspects necessary for consideration after harvest, such as how to prepare the wood, where to find buyers, how to transport it, and other relevant details.

The team established a list of items for further research using two different methods. First, the team members intensely deliberated to judge and decide the most important factors to consider. Then, the team gathered the responses from the interviews in Method 1.2 and delved into deeper research based on the experts' opinions.

After each member researched, the team reconvened and compared findings, compiled the information, and eliminated redundancies. Finally, the members wrote a final list of those factors which the group felt were most important when growing teak and managing their subsequent plantations.

3.3 Method 1.2: Conduct interviews with experts in relevant fields.

The team interviewed four experts in fields related to teak production to learn more about growing teak, managing plantations, and possible issues regarding harvest or sales. These interviews provided insight into lesser known aspects of teak growth and associated industries and formed the foundation for recommendations.

To begin the interview process, the team identified and created a list of sources that worked in relevant fields, for example, individuals from biology departments, agricultural colleges, garden centers, teak plantations, botanical gardens, and especially any experts residing in Central America. Within these organizations, the team sought those who work closely with teak or any trees.

Initially, the team developed two separate questionnaires for interviewees. The first questionnaire listed general questions related to forestry, soil properties, the effects of climate change on farms, and the specific conditions of Central America while the second contained teak-specific questions to identify any unique traits and the most relevant information. However, after the first interview the team determined that a generalized questionnaire was not the best method of getting information from the subsequent expert interviews. As the depth and scope of each expert's knowledge ranged in variety we decided to create individualized questionnaires catering to each interviewee's field of expertise and past research available online. After establishing a list of credible sources, the team contacted each source via email requesting an interview. All interviews were remote via Zoom. The interviews were semi-structured, with the questionnaires guiding the conversation. After establishing a dialogue with the questionnaire, the team asked other questions to address relevant topics or details to aid research. The team also emailed a list of questions to one source instead of an in-person interview due to our time constraints.

After conducting the interviews, the team transcribed the responses and performed qualitative analysis via inductive coding. Inductive coding is "...a data analysis process whereby the researcher reads and interprets raw textual data to develop concepts, themes or a process model through interpretations based on data" (Chandra, 2019). Following the establishment of themes in our interviews the team was more cognizant of important factors to consider when trying to improve teak production in the Central American region.

3.4 Objective 2: Determine the viability of growing teak in Central America based on all information available.

The final phase of this investigation involved outlining the issues, barriers, and concerns that farmers considering growing teak need to review. The data collected from Methods 1.1 and 1.2 provided results for analysis. After this analysis, the team determined the most significant results which lead to the final conclusion of whether or not teak should be grown in Central America. In addition, the team used the key results to create a final list of recommendations for potential stakeholders that suggested alternative farming methods to improve the economic and ecological sustainability of the region.

Chapter 4: Results and Analysis

The following chapter details the information the team gained using the aforementioned methods. The first section details the interviews the team had with various experts and compares the sum of their statements to determine information pertinent to the project. The chapter continues to discuss relevant teak growth factors and plantation management strategies. The final section outlines the drawbacks of teak and compares it to alternative land uses, the current state of teak land use in Central America, its competitors, as well as alternative strategies to potentially spread or alter the use of teak.

4.1 Interview Analysis

4.1.1 Interview with WPI Professor Dr. Pamela Weathers

Our first interview was with Dr. Pamela Weathers from WPI. She is a plant biologist who works mainly with medicinal plants and studies them for their application to sustainably treat infectious diseases at a low cost. She informed us of plant principles from the perspective of someone who does not know teak.

Dr. Weathers described the importance of healthy soil and the three major elements that growers add to improve it: nitrogen, phosphorus, and potassium. She explained that the best way to replenish the soil with these is with natural fertilizer as deposits of these elements used for soil additives are quickly depleting.

When asked how to minimize erosion, Weathers responded that leaving leaf litter and biomass on the ground after it falls from the trees is the simplest approach to prevent erosion. Other techniques she mentioned were terracing and berms—these barriers capture runoff and prevent the nutrients in the soil from cascading down the land away from the vegetation.

Intercropping is a technique with the possibility to both decrease the impact of erosion and enhance the productivity of a farm, according to Professor Weathers. She pointed out that growing other crops in the space between individuals retains the soil and, depending on the species, can result in better productivity compared to a monoculture, especially if this other crop is commercially important.

Weathers spoke about her past experiences in Belize, where locals conserve drinking water in cisterns and reuse it as best they can, but mentioned that in agricultural settings, farmers water plants with either drip irrigation or by hand.

She illustrated that the depth of knowledge of local farmers is profound, especially in terms of the abilities of the land these farmers cultivate. This knowledge is not something to dismiss, she urged. Furthermore, Professor Weathers knew that people work with the land regularly and some of this information may not be explicitly in English which provides a vast opportunity to learn more about teak and the land in Central America.

4.1.2 Interview with Dr. Peter Hobbs, Cornell Professor

The team's second interview was with Dr. Peter Hobbs, an adjunct professor at Cornell University. Dr. Hobbs received his doctorate degree at Cornell in crop physiology and his other areas of expertise include tropical cropping systems, international agriculture, and conservation agriculture. The team hoped this interview would better our understanding of soil and crop sciences. Dr. Hobbs had never worked with teak directly, however, he did provide useful information, mainly regarding soil and general agriculture.

The team inquired about the most important factors of soil that determine its quality. Hobbs explained that physical, chemical, and biological properties are the most important. In order to correct the soil, it is necessary to evaluate these three properties and address them by appropriate treatments. When asked how to improve nutrient levels in the soil, Dr. Hobbs discussed manure as a fertilizer, a very cost effective and easy way to prep the soil. Hobbs also described chemical additives, specifically dolomite, which helps raise the pH of the soil if it is too low.

When asked about climate change concerns, Hobbs expressed that climate change will be the number one problem for future food security, and that we must maintain our water usage as efficiently as possible: "water availability is connected to climate change, but whatever water is available needs to be used as efficiently as possible—drip irrigation is one way to achieve that" (Personal Communication, Hobbs, Sept. 17, 2020). He suggested potentially using drip irrigation systems during the first few years of cultivation to ensure quality growth of the plants as the early stages are crucial to the long run. Hobbs added that in many of the smaller farms, this technique may be difficult to implement because it is an expensive upfront cost.

Dr. Hobbs strongly emphasized that one of the most important things to do is to work with the local farmers. They have dealt with the challenges and obstacles of trying to grow teak, so it is important to remember these farmers because they have the local knowledge. This, specifically, was a challenge for the team due the COVID-19 global pandemic.

4.1.3 Interview with Dr. Jefferson Hall, Smithsonian Tropical Research Institute Agua Salud Project Director

Our interview with Dr. Jefferson Hall was our first interview with a teak expert. Specifically, his fields of expertise are in applied ecology, tropical forestry, ecosystem dynamics and reforestation in plantations. Hall is the Project Director of the Agua Salud Project for the Smithsonian Tropical Research Institute (STRI), whose goal is "to understand and quantify the ecological, social, and economic services provided by tropical forests in the Panama Canal Watershed" (ForestGEO, n.d.). Hall's research gave him the opportunity to work extensively with teak throughout his career. The team hoped to gain a few key insights from the interview with Dr. Hall, namely, teak's effects on the environment, various growth factors affecting it, site management strategies, as well as further clarification from publications co-authored by Hall.

Despite working with teak periodically for 13 years, Dr. Hall is not particularly fond of the tree: he thinks it is a fairly boring species. The rest of the interview was critical of the tree and reflected this sentiment.

Hall remarked that most soils in Central America don't meet the conditions needed for successful plantations, mostly emphasizing soil composition that is fertile, has a non-acidic pH, high base cations and phosphorus. He added that you can find more "wrong places" than "right

places" to grow teak. He did, however, say that a region of Panama near the Darien Gap has good conditions for teak. Unfortunately, this area is extremely dangerous because of crime and drug trafficking.

When asked about how teak farms fare with a diminishing water supply, Hall continued to express his cynical view of teak, mentioning teak's tendency to use an exorbitant amount of water and subsequently disrupt the water cycle. He described how the tree dries out the soil it is planted on and creates water shortages, which he concluded are not optimal as the risk of drought increases and the human population grows.

Aside from the negative aspects of teak, Hall discussed other necessary considerations for the maintenance and running of a plantation. He explained that the tools needed to manage a plantation depended on how flat the land was. For instance, a flatter plantation with low topographic relief allowed the use of more mechanized equipment such as weed whackers or lawn mowers to cut down overgrowth, whereas a hillier plantation with greater topographic relief required techniques similar to laborers with machetes. He added that teak's fire resistance lets landowners use controlled burns to clean the plantation but stressed that these farmers must know what they are doing to prevent the fire from going out of control.

Later on, Hall explained the thinning process of a plantation: in order to optimize the growth, someone (likely laborers) must thin the plantation so that there is not too much competition between adjacent trees. To accomplish thinning, the laborers cut down the weaker and less desirable trees and leave them to decompose on the plantation. This process happens a few times every few years until around year 11 when the first commercial thinning occurs. He noted that although it is expensive to get trees out of the plantation, it is one of the first times the farmers see profit from their plantation.

Additionally, Hall described the complications with teak pricing. He mentioned that India, the largest teak buyer, had recently stopped subsidizing teak buyers, which destabilized the teak market. He discussed part of his paper that looked into why teak from Panama sold for less than the global average. He explained the various factors that go into determining the prices of teak, noting that form, volume, long height, and diameter are all limiting factors of the price, and if the wood has weaving, knots, insect damage, or smaller logs, the prices will decrease. According to Hall, one reason for Panamanian teak's lower quality could be the poor soil conditions he acknowledged earlier.

The interviewer continued to ask about the two articles that Hall co-authored with other agricultural researchers. The first paper discusses the trade-offs between farmers choosing to raise cattle or grow teak in the Panama Canal Watershed. Hall explained that many farmers see cattle ranching as a safer investment than teak. Cattle represent a "bank account" to many farmers, as they are able to sell cows freely at any given time without much worry. Teak is a larger and more risky investment because farmers have to wait years before they see any initial profits. He expressed that there are additional risks when developing teak plantations, such as insecure land rights. Much like Native Americans in the United States, certain indigenous populations lay claim to or have lived on certain areas of land for long periods of time, however, this ownership of land is still not formally recognized by the Panamanian government because the natives did not buy the rights. Although many people in Panama are confident in squatter's rights and are willing to make long term decisions with their unprotected land, they could easily fall victim to someone buying the title to the land and removing them from their homes.

Hall went into detail regarding another recent paper he had helped write which investigated and found early indications that the planting of native tree species within a failing

teak plantation could rehabilitate the site and return a profit. The paper and Hall explained that native species themselves were likely to grow better and return a larger profit margin by themselves without incorporating teak. However, in an already established teak plantation, planting native trees is relatively inexpensive, and allows the farmers to gain more profit. Additionally, this interplanting or enrichment planting strategy improves the "sponge effect" of the trees, or the tendency for the trees to retain water from the wet season and slowly release it during the dry season. Hall emphasized the point that native species—and diversification of trees in general—is best for the environment and the farmer. Native trees tend to grow better in their native lands, and with climate change worsening, investing into a diverse portfolio of lumber ensures that potential damage to one species does not cripple the operations of a plantation.

Later, the team inquired why teak is so popular in Central America if it seems to harbor all of these negative effects and is not suited to the environment. Hall explained that its popularity is partially due to the teak fever of the 1990s, which allowed it to blossom in Central America. He continued by explaining that the Panamanian government today is not very keen on teak. However, it is also faced with a strong lobby for teak plantations in Panama, which may contribute to teak's continuing popularity.

Hall mentioned that teak is exceptionally good at sequestering carbon, even if it is greatly disruptive towards the native ecosystem. Ultimately, the team asked for his recommendation for future land development in Panama. His personal opinion was against growing teak, but he emphasized that it all depends on the conditions of the site as well as the management objective of the landowner.

4.1.4 Interview with Dr. Alex Finkral, Chief Forester and VP of Conservation at The Forestland Group

For our fourth interview, we spoke to Dr. Alex Finkral, Chief Forester and VP of Conservation at The Forestland Group. He has expertise in forestry and silviculture, managing teak plantations, and promoting rapid teak growth. Dr. Finkral has worked closely with teak throughout his career. In 2007, he assisted in a study in Honduras examining investing in teak. From 2013 to present day, he works with The Forestland Group and aids in managing larger teak plantations in Central America. The team's interview focused on the growing operations of teak plantations in Central America, the methods that managers implement to foster a better teak product, and the economics of teak farming. Several of the most noteworthy points in Dr. Finkral's responses were about industrial thinnings, drip irrigation and fertilization, teak processing, and investing in teak.

While working in Honduras in 2007 alongside other researchers on *An Investment Analysis of Honduran Teak Plantations*, Finkral and others found that teak does not need the drought period as previously thought; teak is simply a drought tolerant tree. By watering teak year-round through precipitation and drip irrigation and fertilization, a process also known as fertigation, teak achieves full maturity much quicker. In a standard teak plantation, reaching final harvest takes twenty-five to thirty-five years, but fertigation allows for final harvests in fifteen to eighteen years, sometimes even ten to twelve years. However, he noted that those working with teak do not view drip irrigation and fertilization as necessary investments and that these techniques are a costly expense that only large-scale plantations can afford.

When asked about typical thinnings and harvest cycles for teak farms, Finkral described the industrial model for basic thinning of a twenty-year teak rotation. He presented a

hypothetical example: a farm with 600-800 teak trees per hectare in either three or four meter spacing between trees. After four to six years, laborers conduct the first thinning and remove 20% of the teak trees, specifically those in the worst condition. After ten to twelve years, laborers cut down the least promising 20% of the total trees in the first commercial thinning. The plantation can usually sell the trees from this thinning, thus the title "first commercial thinning." In year fifteen, laborers clear away another 20% of trees in a second commercial thinning. This time, the plantation makes a larger profit as more trees are 15 cm in diameter or larger. At the end of twenty years, laborers cut down the remaining trees. These are the best trees because they have survived the selective thinnings and have the biggest diameters, generating a large profit for the plantation.

Dr. Finkral provided insight to the sale process when asked about processing the final harvest and finding buyers for teak. He explained that fully mature teak trees can produce four to five logs, each about two meters long. The plantation then ships these logs to India, who accounts for 96% of plantation teak consumption, for processing. Because processing teak is cheaper in India than it is in Central America, most teak plantations do not process their own teak. Once processed, India manufactures and exports the teak across the world.

When questioned why he thinks farmers should invest in teak rather than other types of plantations, Dr. Finkral described the adaptability and large market for teak. Teak can grow across the world in tropical areas with fertile soils. Additionally, once established, teak is fairly drought tolerant and can withstand dry seasons. These factors indicate teak's ability to survive through the growing process when in the correct conditions. Finkral mentioned possibly planting teak on abandoned cattle ranching areas with suitable conditions since cattle cannot remain in one area forever. Switching to a native tree or natural forest could benefit landowners in the face of climate change, but native trees have a smaller and more localized market than teak's international one. At the moment, teak is a very popular wood: it is "valuable as a species and there is a well-developed global market" that enables teak farmers to sell it at a high value (Personal Communication, Finkral, September 25, 2020).

4.1.5 Interview Cross-Analysis

Although all of the subjects we interviewed are experts in their fields, only Dr. Hall and Dr. Finkral have specialized knowledge of teak. The team's first two interviewees, Dr. Weathers and Dr. Hobbs, while not being very knowledgeable of teak's specifics, were still able to give relevant insight into the project by discussing sustainability issues and factors affecting general agriculture or lumber farms.

All interviewees urged the importance of soil conditions. These include physical, chemical, and biological properties, as Dr. Hobbs explained. All four experts mentioned the importance of various elements—nitrogen, phosphorus, and potassium—in the soil and how fertilizer or nutrient additives could boost soil conditions. Dr. Weathers discussed the importance of organic fertilizers to replenish the soil as inorganic fertilizer supplies deplete more every year and do not have replacements. Hall mentioned the necessity for a non-acidic pH, and Hobbs suggested dolomite and lime as additives to raise the pH if it dips below the neutral level of 6.5-7.5.

Appropriate irrigation is another factor the interviewees discussed. Irrigation helps bring nutrients back into the soil and water is essential to life. Erosion, however, takes both the soil and

the nutrients away from the plants. Drs. Weathers and Hobbs explained terracing, berms, and leaf cover all prevent these negative effects of erosion.

Dr. Finkral expressed the importance of the landscape, especially regarding soil conditions. Hilly land is best, but in the valleys, the soil does not drain well enough and is too wet, and on top of the hill, soil is rocky and dry. The middle of these hilly areas drain the best and promote teak growth the most.

Dr. Hall explained that much of Central America does not provide these conditions and the land requires the input of strenuous work to achieve them.

When discussing the difficulties with monoculture teak farms with all interviewees, one question was how to approach teak growth differently to improve overall productivity. A main theme in our interview with Dr. Weathers and Dr. Hobbs was the implementation of intercropping on a teak farm. They both emphasized the positives of intercropping with a monetary crop that could provide income on a regular basis while waiting for the teak trees to mature. However, as mentioned, Dr. Hobbs and Dr. Weathers had no previous experience with teak and were unsure of the viability of these ideas and intercropping specifically with teak.

The interviewees also discussed the idea of planting native trees rather than teak. During our interview with Dr. Hall, he introduced this idea, which had not been thought about by the team. We then asked Dr. Finkral about his thoughts on letting native trees grow instead of teak. He did not disagree that growing native trees is better for the environment, but he expressed that the financial advantage of growing teak is hard to turn down for small farmers.

Dr. Weathers, Dr. Hobbs, and Dr. Hall all provided insight into the benefits of working closely with the local populations. They placed deep emphasis on working with local communities to both gain more knowledge on the project and provide aid to the communities. Dr. Hobbs spoke to the importance of knowing the agriculture markets in the area of the prospective timber farm. He explained if farmers planned on intercropping for an annual income, it is important to understand which crops consumers in the area desire before planting in order to generate the greatest profit. Dr. Weathers also spoke to knowing more about the local communities, encouraging the team to not ignore the generations of knowledge that local communities have, as they know what can and cannot grow in their area. She explained that demonstrating respect towards them increases their willingness to help or to be helped. Dr. Hall expressed similar sentiments as he explained his project with the Panamanian government which plans to minimize the scope of reforestation to local populations by incentivizing the communities to plant trees. With the government paying farmers to plant trees, the farmers can help reduce the impact of climate change, receive financial compensation for offsetting their carbon footprint, and solidify their land rights.

All of the interviewees talked, in some manner, about the disadvantages of growing teak, especially in its current makeup of monocultures. Dr. Hobbs briefly mentioned the issue of teak's growth cycle, saying that the tree's long growth cycle may make it difficult for farmers to find it appealing. Dr. Weathers talked about the sustainability issue of growing anything in a monoculture, and how the loss of diversity is damaging to the environment. Dr. Hall and even Dr. Finkral mentioned how teak impairs biodiversity. Dr. Hall was the most outspoken critic of teak out of all our interviewees and mentioned further issues such as teak wasting water. Simply put, he saw growing teak in Central America as a bad choice. Dr. Finkral did not mention many other issues and instead remarked how adaptable teak was to any environment.

The largest discrepancies from the team's interviews came from the opinions of Dr. Hall and Dr. Finkral. Dr. Hall had a long list of the disadvantages that teak presented to Panama and,

to a lesser extent, Central America, describing his experience and knowledge from a researcher's perspective. He went on to describe how native species outperformed teak financially and in certain ecological services. However, Dr. Finkral, a professed fan of the tree, presented a very different business perspective, saying that the "financial model [of teak] in a spreadsheet is pretty hard to beat" (Personal Communication, Finkral, Sept. 25, 2020).

4.2 Results

4.2.1 Land Conditions

4.2.1.1 Soil

All plants, especially in their early stages, need appropriate soil conditions to survive. The most important aspects of soil to consider are its physical, chemical, and biological properties (Personal Communication, Hobbs, Sept. 17, 2020). Teak grows best in fertile, well-drained soils with a non-acidic pH, high base cations (calcium, magnesium, sodium, potassium), and high phosphorus (Personal Communication, Hall, Sept. 18, 2020; Finkral, Sept. 25, 2020). Most Central American soil does not express these qualities, but fertilization with nitrogen, phosphorus, and potassium (NPK) can kickstart the soil and prepare it for teak (Personal Communication, Weathers, Sept.16; Hobbs, Sept. 17, 2020; Hall, Sept. 18, 2020; Finkral, Sept. 25, 2020; Fernanadez-Moya, 2015). Addition of dolomite or lime to the soil can raise the pH to more accommodating levels (Personal Communication, Hobbs, Sept. 17, 2020). Organic fertilizer or compost could help the soil in these areas as well (Personal Communication, Weathers, Sept. 16, 2020; Hobbs, Sept. 17, 2020). Overall, it is essential to maintain the soil's health to keep growth healthy (Personal Communication, Weathers, Sept. 17, 2020).

4.2.1.2 Landscape

Although some plantation teak grows on flat land, teak grows best in a hilly landscape with good soil, as discussed earlier. Low in the valley between mountains or hills, the soil is just a little too wet and does not drain. High on top, the air is thin because of the altitude and the soil is rocky and dry. The area in between, however, is the perfect happy medium between the peak and the valley with well-drained soil, and teak grows best here, specifically, lower than 600 meters above sea level (Personal Communication, Finkral, Sept. 25, 2020; de Camino, 2002).

4.2.1.3 Erosion

Because teak thrives on hilly land, erosion is a serious problem. Especially during the wet season, heavy rains can wash away the nutrient-rich topsoil. Without the necessary nutrients, teak growth slows down severely and results in a much poorer final product.

One solution is the integration of other plant species, also known as intercropping. Plantations often plant teak in a monoculture which exposes the topsoil and promotes erosion. Introduction of other plants (possibly grasses or other compatible plants) provides more land cover, solidifies the soil, and slows down eroding effects (Personal Communication, Weathers, Sept. 16, 2020; Hobbs, Sept. 17, 2020). Intercropping teak with grass can stimulate silvopastoral systems and provide food for grass eating animals. In addition, leaving leaves on the ground as

teak loses them during the dry season provides additional topsoil coverage and prevents severe rains from washing it away.

Terracing, or making flat areas out of hilly land, is another technique to minimize erosion (Personal Communication, Weathers, Sept. 16, 2020; Hobbs, Sept. 17, 2020). To terrace, farmers must carve step-like areas within hills. This flatter land can diminish the effects of erosion as well as increase the area of available soil to plant on because it directs the water runoff strategically instead of letting it flow down the hill and take all the topsoil with it.

4.2.1.4 Water Usage & Irrigation

Adequate water supply in teak's early years is essential for proper growth and stem form. If there is an insufficient water supply, growth rate significantly slows down, delaying the return on investment. Conversely, over watering is also a problem for teak. Especially during the early stages, over watering can drown the plant. A good balance between these two extremes is crucial when beginning to plant teak in both a new farm and a new plantation cycle.

Figure 4.1 – Drip Irrigation System.

Dripworks, 2014.

Consistent watering of plants is one of the best strategies for optimizing growth, however, Central America experiences a dry season. Trees like teak must be drought resistant to withstand this five-month dry season with little to no water. An irrigation system installed in the early years of the teak farm or plantation ensures that the trees receive water year-round and "enables teak to grow really really fast... Irrigated teak just keeps growing year round at a very high rate…[and] we can control for drought events with investments in drip irrigation" (Personal Communication, Finkral, Sept. 25, 2020). A drip irrigation system (see Figure 4.1) essentially removes the dry season for teak. It supplies each tree with a sufficient amount of water over the course of its life, especially during the dry season, and leads to faster turnover rates between rotations, the entire process of planting to harvesting timber, because trees are growing faster. The trees reach final harvest quality in significantly less time without a dry season. Dr. Finkral

explained that "...by irrigating through that dry period, you're increasing growth by [about] 25-35% ...our experiments in Honduras [showed] we could grow teak to a final rotation age of… ten to twelve years" (Personal Communication, Finkral, Sept. 25, 2020). In turn, this results in a greater profit over multiple rotations because the plantation sells a greater number of trees in the same time period. The major downside to this technique is the expensive upfront cost of installation—the plantation area is enormous and the irrigation system is extremely complicated. For many low-income farmers with small farms, this investment is risky and not attainable because the return on investment takes so many years.

4.2.2 Teak Plantation Management and Financials

4.2.2.1 Site Management

Some of the most important factors of a successful teak plantation are proper site management techniques. The methods implemented can vary from location to location, but the overall concepts are essential to foster strong and high-quality lumber. This section will discuss some of the important factors to consider for plantation management—equipment, labor force, thinning, mowing, general upkeep, and overall costs. Thinning is a process where workers remove trees to allow greater growth of the trees nearby, and mowing is the process of workers clearing away undergrowth to make room for growth of the trees. The majority of the information in this section comes from Dr. Finkral, who assists in, and is very knowledgeable about, teak plantation management.

4.2.2.2 Required Equipment/Labor

Some of the most important investments in a teak farm are the labor and the tools. A 1000-hectare farm typically requires about 10 to 15 laborers "who just mow through... hectares for weeks and weeks and weeks, swinging the machete" (Personal Communication, Finkral, Sept. 25, 2020). The laborers take care of the plantation by mowing, pruning, and eventually cutting down the teak trees. The plantation must invest in machetes to clean the teak trees of stray branches or cut away other plant species, such as vines, that may be impeding the growth of teak. For pruning, the plantation must buy pole pruners or pole saws to reach high branches. The final harvest requires chainsaws so that the laborers can cut the trees down and shape them into logs. Depending on the size of a farm, more or less labor and equipment is necessary, but nonetheless, it's an investment.

4.2.2.3 Thinning

Thinning (see Figure 4.2), the selective removal of trees before the final harvest, is an essential process to promote faster growth among trees. When farmers first establish a plantation, they plant young teak trees in grids of three meter by three meter or four meter by four meter spacings. As the trees grow larger, the crowns of the trees begin to connect, forming a thick canopy (Personal Communication, Finkral, Sept. 25, 2020). The trees' growth slows as they compete with other trees for access to sunlight. Thinning the trees results in greater growth by reducing the number of trees competing for resources and allowing the best quality trees to grow as big as possible for the final harvest.

Figure 4.2 – Thinning.

Courtesy of Dr. Alex Finkral, 2020.

Dr. Finkral and his colleagues established an industrial thinning model for large scale teak plantations on a twenty-year rotation. Within the first four to six years of growth, the first thinning occurs, removing 20% of the trees planted. With this, and all thinnings that follow, laborers remove the trees in the worst condition first, leaving behind only the best trees for the final harvest. Trees in the worst condition exhibit animal chew marks, snapped tops, and zigzagging trunks. Finkral explained that years ten through twelve are the time for the first commercial thinning of 20% of the total trees and the first profit. This differs from the first precommercial thinning as enough time has passed to allow for the felled trees to reach the minimum marketable size. At year fifteen, laborers conduct the second commercial thinning of 20% of the remaining trees and the plantation gains another, larger profit. After twenty years, workers harvest the remaining 20-30% of teak trees. These trees are the best quality, because of the previous thinnings, and the plantation collects the biggest profit from its final harvest. This thinning model is highly efficient and quickly produces high quality teak (Personal Communication, Finkral, Sept. 25, 2020).

Dr. Hall also described the thinning timeline established by Finkral, explaining that the first commercial thinning occurs at about eleven years into a rotation, agreeing that the benefits of thinning teak are to optimize the growth of the overall farm and that thinning results in higher quality teak in the final harvest (Personal Communication, Hall, Sept. 18, 2020).

Another method of thinning that poorer farmers can adopt is performing the first thinning around year six or seven. At this point, some trees have reached the minimum sale diameter requirement of fifteen centimeters and farmers can sell them for a small profit. However, waiting this long before thinning slows the growth of the rest of the trees and pushes back the final harvest. Smaller scale teak farms (anywhere from two to ten hectares of land) do not implement thinning to the extent of the larger plantations because they do not have the same financial

resources. They often allow the teak to grow for longer periods of time without too much maintenance to produce a final harvest after about forty years (Personal Communication, Finkral, Sept. 25, 2020).

4.2.2.4 Mowing and Upkeep

Both Finkral and Hall explained that laborers leave the excess cuttings, branches, and leaves on the ground. While both agreed that excess debris and undergrowth can help the soil, they did outline a few methods of removal. Finkral explained that in the tropical climate of Central America, leaf litter and branches are unable to last more than a few years. There is no need to mulch the larger branches because the humid and hot climate decomposes them quickly. The decomposing debris adds nutrients back into the soil and helps prevent erosion by diffusing heavy, direct rainfall during the wet season (Personal Communication, Finkral, Sept. 25, 2020; Personal Communication, Hall, Sept. 18, 2020).

Dr. Hall detailed one method of cleaning a teak plantation. Teak is a fire-resistant crop. Hence, a controlled surface fire can clean the forest of leaf litter and undergrowth while the teak remains unharmed. However, this requires significant experience and having fire towers nearby is helpful because, if done incorrectly, the fire can quickly grow out of control (Personal Communication, Hall, Sept. 18, 2020).

Mowing is another essential task to manage a plantation. For monocultures, it helps eliminate undergrowth, reducing competition for resources. Typically, a team of people equipped with machetes chop away the unwanted growth rather than using mowing machines (Personal Communication, Finkral, Sept. 25, 2020). Central American teak farms often favor workers over machines because the terrain is often hilly and difficult for larger machinery to navigate safely (Personal Communication, Hall, Sept. 18, 2020).

4.2.2.5 Overall Cost

Teak farm and plantation management is expensive—you need to spend money to make money. Having a goal in mind can help a farmer or plantation manager decide which costs to expend. For farmers with less financial resources, omitting some of the more expensive costs like irrigation systems is better for their budget. Bigger plantations can spend more, rotate through cycles quicker, and enhance productivity (Personal Communication, Finkral, Sept. 25, 2020). Plantations spend most of their money on labor for thinning, pruning, mowing, and general upkeep of the farm. Thinning requires a team of laborers with machetes for smaller trees at a diameter of less than 10cm and chainsaws for anything larger. If a plantation hires laborers for the first thinning at three or four years rather than five or six years, they do not need to hire as many people as the trees are younger, thinner and, therefore, easier to cut down. Instead of buying larger machines for mowing, plantations prefer hiring laborers to cut down growth with machetes as the labor in Central America is fairly cheap. Spending money is necessary to run a successful plantation because it allows the trees to grow uninterrupted and ultimately increases profits (Personal Communication, Finkral, Sept. 25, 2020).

The cost to establish a plantation is higher in the beginning. This is because landowners need to purchase the necessary equipment, dig holes for the trees, obtain seeds, and perform other required start up procedures. Dr. Finkral confirmed this with his own experience, explaining that “those first few years are very expensive to get your crop ... up and able to

compete on its own at year two, three, or four" (Personal Communication, Finkral, Sept. 25, 2020).

Consequently, the cost of management per hectare of teak in the early years is almost double the cost of later growth. A study from 2010 estimated that for years 0, 1, 2 and 3 the cost per hectare of plantation was $974, $748, $871, and $871, respectively. Afterwards, the cost dropped off significantly to $514/ha in year 4 and $504/ha in year 5. The study did not record the cost from years 6-25 but used an average of the past years to determine pricing. This may be an overestimate, however, due to the high initial cost of starting a plantation (Griess & Knoke, 2011). However, as this analysis was from Panama, the costs may fluctuate in other countries when accounting for differences in labor costs and inflation.

Aside from the overall management costs, additional expenses come from thinning and final harvest. The same study estimated that a thinning cost of around $300/ha is likely on the higher end. Researchers for the study also estimated that the last major cost of the plantation, the final harvest, would cost around $1300/ha (Griess & Knoke, 2011).

4.2.2.6 Final Harvest

The last big event in plantation site management is the final harvest. Harvesting for this last collection of trees begins around the 20-25 year mark for a large plantation. This schedule, however, can fluctuate depending on the plantation/farm's size. The trees removed during this harvest (see Figure 4.3) are the most valuable because they have the largest diameter, ranging from 30 to 50 cm (Personal Communication, Finkral, Sept. 25, 2020).

Figure 4.3 – Teak Logs.

Courtesy of Dr. Alex Finkral, 2020.

During the final harvest, laborers cut the trees into two-meter-long logs from the stump up: “the lower the log, the more valuable” (Personal Communication, Finkral, Sept. 25, 2020). As the laborers continue measuring and cutting these two-meter logs, the tree’s diameter shrinks, but sometimes the laborers can cut up to 4 or 5 profitable logs. Despite the number of logs that come from one tree, Dr. Finkral informed us that “That first log… it’s the most valuable. It might represent 80% of the value of the whole tree.” The workers cut off any branches stemming from the main trunk (Personal Communication, Finkral, Sept. 25, 2020).

4.2.2.7 Processing & Sales

India has been the main consumer of teak for hundreds of years across the world, currently making up 96% of exports of plantation teak. The main reasons for India’s large consumption of teak are cultural importance and cheap labor. India uses teak everywhere, from furniture to moldings, flooring to doors. It is a “pretty appreciated wood, and it's been that way for a long time” (Personal Communication, Finkral, Sept. 25, 2020). Most companies choose to complete the majority of teak processing in India because of the low labor rates and long-established teak processing system (see Figure 4.4). Laborers process the teak by cutting the logs into sheets of lumber before exporting it again (Personal Communication, Finkral, Sept. 25, 2020).

Normally, plantations ship the two-meter logs “as is” to India for processing. One approach whereby plantations could sell a high volume of hardwood would be to have workers square the logs before export. This would allow for more teak logs to compactly stack up instead of the usual stockpile of cylindrical logs. Unfortunately, the cost to square the logs and the profit made from the extra volume exported cancel out, meaning it does not make financial sense to perform this extra step, especially because of the lower processing rates available in India (Personal Communication, Finkral, Sept. 25, 2020).

Figure 4.4 – Processing.

Courtesy of Dr. Alex Finkral, 2020.

4.2.3 Alternative Land Uses

To understand why farmers and plantation managers must consider alternative land uses besides teak monocultures, one must understand teak's effects on the environment. Although teak may present a better financial or environmental option than certain land uses, it may not offer the same level of benefits available from alternate land use. There are regions where teak may grow poorly, where farmers are unlikely to convert their land from its current use, or areas that have seen significant harm due to the creation of teak plantations. This section analyzes teak's environmental impact and investigates potential alternative strategies to incorporate the tree into current land use.

4.2.3.1 Soil Degradation

Teak tends to harm the soil it grows in. Without a system in place to replenish natural nutrients in the soil coveted by a single species, the soil can quickly turn poor. To combat this, farmers often employ rotation cropping or intercropping, whereas one species uses up a nutrient, the other crop replenishes it (Personal Communication, Weathers, Sept. 16, 2020). With extensive teak monocultures and their uninterrupted replanting, plantations either depend on continuous fertilization or just accept poorer soil conditions. Furthermore, soil erosion is a concern for the future. Since soil cannot replenish its nutrients in a human's lifetime, scientists consider it a nonrenewable resource. Therefore, any loss of soil can harm the environment (FAO, 2015).

A study from 2014 showed that teak plantations do not hold soil as well as natural forests do. Instead, plantations experience low to moderate soil erosion. Poor plantation management practices, such as weed control via herbicide or controlled fires, can further exacerbate erosion. Weeds and understory—plants below the canopy of the trees—contribute to more organic matter in and on top of the soil, but their removal exposes it, leaving it vulnerable to degradation (Fernandez-Moya et. al, 2014).

4.2.3.2 Burden on Water

As mentioned previously, teak thrives when farmers and plantations consistently water it. However, a downside of teak's need for water is its potential harm to the water cycle, as Dr. Hall revealed (Personal Communication, Hall, Sept.18 2020). A possible explanation for this is teak's low water use efficiency. A study investigating this found that teak had the lowest water use efficiency compared to other tropical trees (*Dalbergia retusa, Ficus insipida, Pachira quinata, Platymiscium pinnatum, Pseudobombax septenatum, Swietenia macrophylla, Saccharum spontaneum*) (Cernusak et al, 2006). Another possible explanation is teak's low or negligible contribution to the "sponge effect", or a plant's tendency to store water from the wet season to then slowly release and redistribute over the dry season, which helps regulate water levels either by absorbing more water during floods or distributing water during droughts (Sinacore, 2018). With a low water efficiency and a negligible contribution to the sponge effect of forests, teak tends to strongly dry out soil and consequently create water shortages (Personal Communication, Hall, Sept. 18, 2020).

4.2.3.3 Climate Change

Climate change can affect teak growth and vice versa. Dr. Finkral explained that while the industry may experience a slight hit in profits as a result of less favorable growing conditions, teak is a quick rotation crop and plantations can plant it without much relative change in the environment between cycle rotations (Personal Communication, Finkral, Sept. 25, 2020). On the other hand, Dr. Hall discussed how teak strongly affects the course of climate change and that farmers should not continue to grow it because it tends to create droughts and biological deserts—situations that only serve to exacerbate the effects of climate change (Personal Communication, Hall, Sept. 18, 2020).

4.2.3.4 Monoculture Harm

Teak monocultures, the primary method of plantation production, are incredibly harmful to both the native environment and biodiversity. Greedy logging companies and disenfranchised subsistence farmers continue to deforest Central America, increasingly threatening the native animals and ecology of the region. The introduction of teak monoculture systems to these areas is incredibly damaging, with Dr. Finkral even attesting that the system creates a "biological desert". He explained that there are no jaguars living in a teak plantation due to a lack of stratification, brushy cover, and plant species that would provide food to potential prey (Personal Communication, Finkral, Sept. 25, 2020). Dr. Weathers seemed to echo this sentiment with another monoculture plantation tree, oil palm, saying "Oil palm is… replacing forests and it's not good because we're losing diversity" (Personal Communication, Weathers, Sept. 16, 2020). Replacing natural forest or open land with teak monocultures is undoubtedly harmful for biodiversity in the region, not only because of teak plantation management practices specifically made to kill local plant life such as mowing or weed whacking, but also because teak serves no ecological purpose for native animals (Personal Communication, Finkral, Sept. 25, 2020).

4.2.3.5 Monocultures, Intercropping, and Enrichment Planting

A monoculture can grow very fast and is easy to manage. It is one of the most common practices for larger farmland and plantations, but as previously mentioned this type of planting has no biodiversity and introduces a lot of competition between individual plants (Personal Communication, Weathers, Sept. 16, 2020; Finkral, Sept. 25, 2020). Intercropping (see Figure 4.5) is one method that farmers employ to rejuvenate the soil and diversify plant life. Additionally, there is evidence that intercropping produces greater productivity than monocultures (Personal Communication, Weathers, Sept. 16, 2020; Hobbs, Sept. 17, 2020).

A common misconception when intercropping with teak is that the leaf litter caused by teak is allopathic and inhibits the growth of other plants. However, this is not the case (Personal Communication, Hall, Sept. 18, 2020). Landowners can intercrop teak with a wide variety of plants, including, but not limited to, maize, cassava, peanuts, upland rice, soybeans, other types of timber, long beans, bananas, and ginger (Roshetko, 2013). When choosing which plant to intercrop with teak, it is important for there to be a market in the surrounding area for the crop to ensure the intercrop will be profitable as it takes teak 20-25 years to mature for profits. (Personal Communication, Hobbs, Sept. 17, 2020).

Intercropping makes sense both financially and environmentally. The revenue the agricultural product generates can offset the cost of the plantation establishment while the additional crops foster greater biodiversity. Although intercropping teak is not common in Central America, farmers employ this technique widely in Southeast Asia, specifically on smaller holder farms (Roshetko, 2013).

Figure 4.5 – Intercropping with Ginger and Papaya.

Costa Rica Invest, 2014.

There are several different approaches that a farmer can use to intercrop with teak. One method is to plant teak with other types of timber. This method is only slightly more biodiverse than a teak monoculture, but it creates the greatest tree density and yield. Another method is to intercrop teak with annual fruit trees. Farmers can implement this technique on a larger scale farm and still yield yearly profits from selling fruit. In addition, a method that works well on a large scale is line planting, where farmers plant different types of crops in rows, however this method tends to be less biodiverse than other options. Furthermore, farmers can plant crops in the understory of a teak farm. This results in the greatest biodiversity but is difficult to maintain on a large scale (Roshetko, 2013).

Enrichment planting is a technique where farmers introduce valuable plant species as a way to rehabilitate underperforming and degraded forests. The biodiversity and economic value of a forest can increase when farmers plant new trees or crops. As farmers establish more variations of plants in the forest, biodiversity increases. If these plants happen to be a valuable species, the economic value of the forest can also increase (Mangueira, 2018). In instances where

the teak plantation itself is underperforming, enrichment from native trees with high value, such as cocobolo (*Dalbergia retusa*) and amarillo (*Terminalia amazonia*), can make the land useful again because artisans and workers commonly use the wood from these native tree species for furniture, musical instruments, boatbuilding and several other amenities (Marshall et. al, 2020; The Wood Database, 2015; The Wood Database, 2015).

4.2.3.6 Native Trees

While larger corporations can invest significant funds into their plantations and get suitable land for teak, that land constitutes very little of the overall land mass in Central America. Most land in Central America does not have the suitable nutrient and physical conditions necessary for efficient teak growth (Personal Communication, Hall, Sept. 18, 2020). Despite the poor soil conditions in Central America, teak continues to be one of the more popular plantation species there, with over 132,770 hectares of teak being planted across the region, primarily in Panama, Costa Rica, and Guatemala (Personal Communication, Hall, Sept. 18, 2020; Sinacore, 2018; Fernandez-Moya et. al, 2015).

The poor quality of Panamanian soils often causes longer rotation times, sometimes requiring 25 years or longer to fully grow the non-native species (Sinacore, 2018). The poor soil conditions in Panama lead to both longer rotation periods and lower quality wood. Research shows that while the average global price for teak plantation logs is around \$350-550/m^3, the value of Panamanian teak is significantly lower, selling for \$175-200/m^3 (Stefanski et al, 2015). The poor soil conditions cause price limiting factors such as knots in the wood, smaller diameters, or shorter heights (Personal Communication, Hall, Sept. 18, 2020).

Thus, another potential land use in Central America that may be both better suited to the land conditions of the region and provide more economic and environmental benefits is the creation of monocultures or mixed plantations of native species. Certain organizations, such as the Forestland Group, have begun experimenting with land that is not conducive to teak growth in Central America by planting patches of native tree species, such as cocobolo (see Figure 4.6), in between their “teak matrix” (Personal Communication, Finkral, Sept. 25, 2020). The group expects the native species to yield higher value and higher quality wood after 40 years (Personal Communication, Finkral, Sept. 25, 2020).

Figure 4.6 – Cocobolo Tree.

Stang, 2008.

The economic feasibility of planting native species in other countries may differ—when asked about the profitability of trees other than teak in Central America, Dr. Finkral informed us that "plantation costs are similar for all species; the big differences are in revenues and investment returns, and those are driven by species' markets and rotation lengths respectively. That's why teak is popular: it's relatively valuable as a species and there is a well-developed global market." When asked about the relative market size of native trees, he continued on, saying, "in general, markets for native species are more localized, domestic. In smaller countries like Belize or Panama, there is not as much domestic demand as in larger countries so that is limiting." (Personal Communication, Finkral, Sept. 25, 2020)

Despite Dr. Finkral's lack of confidence in the native market, recent studies from Panama have found that certain native species either outperform or are competitive with teak in regard to economic and environmental factors. Researchers have increasingly experimented with research on *Terminalia amazonia* (amarillo) and *Dalbergia retusa* (cocobolo) in the past years. Studies have chosen these species for their higher market values, ability to grow on less fertile soil and cultural value (Marshall et. al, 2020; Sinacore 2018). An analysis of the equal annual equivalent (EAE), a measure of how profitable an investment is while also accounting for differences in the length of time it takes to see returns, found that *Dalbergia retusa* monocultures and mixtures with *Terminalia amazonia* significantly outcompeted teak monocultures. At optimal conditions, *Dalbergia retusa* monocultures had an EAE of $23,163/ha while mixtures with *Terminalia amazonia* were close with $23,066/ha; these values are around 27 times larger than teak monoculture's $829/ha (Sinacore, 2018).

Although management practices and site conditions may differ for these native species, further investment into them could be profitable for both the farmer and country that choose to adopt them. With the right amount of government incentive for ecological service payments, native species may become even more competitive with teak. Research found that *Dalbergia retusa* and *Terminalia amazonia* can sequester significantly more carbon in mixes or monocultures in comparison to teak monocultures. While teak can store 17.41 tons of carbon per

hectare, mixtures and monocultures of the aforementioned native species can store 38.68-78.5 tons of carbon per hectare, between 2.2 and 4.5 times higher than teak alone (Sinacore, 2018).

Additionally, increased international environmental group incentives may drive competition as well. The intensification of climate change and lack of meaningful government action may cause concerned citizens to seek out methods to offset their own carbon footprint. Dr. Hall discussed one such program he was involved with which paid farmers $130 per hectare for 20 years for this very purpose (Personal Communication, Hall, Sept. 18, 2020). Increased efficiency and demand could potentially increase international and governmental incentives leading to higher payments to farmers.

Even if landowners choose not to create plantations entirely composed of native species, there is an incredible case for diversification. Diversifying seems to offer more potential advantages than disadvantages, especially in ecological services and economic competitiveness. In addition, diversifying offers a natural defense mechanism for potential threats to farms such as market volatility, which is less likely to affect multiple species at once (Sinacore, 2018). Furthermore, Hall adamantly encouraged the diversification of forests and in future land use (Personal Communication, Hall, Sept. 18, 2020).

4.2.3.7 Cattle Ranching

Cattle ranching is a significant agricultural practice that is not leaving Central America anytime soon. In 2017, Central America used 37% of its land as pastureland (Ritchie, 2013). Experts and farmers often consider the practice of cattle ranching a fallback for when agricultural crops fail. Additionally, it has a significant cultural value as the Spanish and Portuguese ancestry has deep ties to cattle ranching (Murgueitio, 2011). Dr. Hall agreed that cattle ranching is significant to Central America, explaining that the industry is very reliable. When a farmer needs money, they can very easily sell a cow or two (Personal Communication, Hall, Sept. 18, 2020).

Despite cattle ranching being incredibly attractive to farmers, it is incredibly damaging to the environment. In Costa Rica alone cows graze on around 35.5% of the country's land and contribute nearly 30% of their greenhouse gas emissions.

In addition to contributing to climate change through these emissions cattle ranches are also affected by the increased drought and other conditions. In the face of climate change farms see higher rates of heat stress, animal weight loss and mortality from starvation or thirst (Murgueitio, 2011). Furthermore, a large portion of deforestation is driven by the establishment of cattle pastures (Martin, 2017).

4.2.3.8 Silvopastoral Systems

Agroforestry, specifically silvopastoral systems (see Figure 4.7), combines agriculture and forestry in a way that benefits a landowner more than either investment does alone. The Global Silvopastoral Network defines silvopastoral systems as "a type of agroforestry arrangement that allows the intensification of cattle production based on natural processes that are recognized as an integrated approach to sustainable land use" (Global Silvopastoral Network, n.d.). This marriage of cattle farming and forestry can harbor a symbiotic relationship where the vegetation reintroduces nutrients into the soil for the cattle's food source to thrive, subsequently helping the cattle (Personal Communication, Hobbs, Sept. 17, 2020). Silvopastoral systems have

the possibility for a lot of flexibility: both native trees (e.g. Caribbean pine) and teak could grow on cattle farms (Personal Communication, Hall, Sept. 18, 2020; Finkral, Sept. 25, 2020).

Figure 4.7 – Silvopastoral System.

Global Silvopastoral Network, n.d.

Taking all of this information into account, the team came to a conclusion on the future of teak development in Central America. The team subsequently created a list of recommendations for potential landowners or stakeholders in Central America and made a list of recommendations found in the following chapter.

Chapter 5: Conclusion and Recommendations

5.1 Conclusion

Upon analysis and review of the information received from online research and expert interviews, the team concludes that expanding the teak industry in Central America will result in more negative consequences than positive impacts. The environmental impact of teak, poor land conditions in Central America, and current oversaturation of the market are compelling reasons to look into alternate investment opportunities that the team describes in the Results & Analysis chapter. However, if the desired objective of any government or organization is the improvement of current teak production, there are a number of alternative approaches that are more economically and environmentally sustainable. Additionally, plantations that have already invested in teak may currently face a variety of issues regarding teak yield. Some plantations may be struggling to produce a successful final harvest while others may just want to boost their overall productivity. There are improvements for these problems, as well.

Although this report focuses mainly on Panama and Costa Rica, due to the abundance of teak research conducted in those two countries, we believe our recommendations are applicable across Central America.

Ultimately the plans and options that landowners have to consider vary widely depending on their current land use and objectives. Below the team offers financially and environmentally competitive alternatives for stakeholders, as well as ways to incorporate teak into a number of different ventures.

5.2 Recommendations

For established teak plantations that are in need of better results or are located on poor soil:

- *Introduce enrichment planting into the plantation*. By planting more native species that thrive in poor soil conditions, landowners can potentially rehabilitate their sites and increase their profit margins through the addition of valuable native wood.
- *Introduce patches of native monocultures after current rotation of wood*. Native species do not require the same soil conditions as teak and can survive on poorer soil.
- *Invest in fertigation and drip irrigation for the next cycle.* If the financial situation allows, fertilizing and irrigating through the Central American dry season in the next teak growth cycle can boost productivity and reduce the time between teak rotations by years.

For smaller subsistence farmers that may be hoping to earn additional income:

- *Conduct a soil survey to understand the physical and chemical properties of the land*. If the financial situation allows, conducting a soil survey will allow the farmers to determine what will grow well on their land. If the land matches site conditions for teak, one can plant 1-10 hectares of teak.
- *Plant cocobolo*. If the land is relatively unfertile, planting cocobolo and allowing it to grow could be a worthwhile investment. Cocobolo is a tree native to the region used for furniture and musical instruments and outcompeted teak in environmental sustainability studies.

- *Intercrop teak with other crops in the understory or with fruit trees.* These other crops can generate a consistent income while teak matures.

For larger companies seeking to invest in teak:

- *Choose a different investment.* The teak market is already highly saturated and the supply is more than enough for the demand.

or

- *Purchase fertile, nutrient rich land and invest in fertigation and drip irrigation*. This combination can boost productivity during the Central American dry season and reduce rotation time by several years.

For current cattle ranchers seeking to improve productivity and sustainability of their farms:

- *Establish silvopastoral systems*. These systems can enhance ecology of the pasture and introduce a long-term investment if planting a tree for lumber.

For government or nongovernmental projects seeking to mitigate the effects of climate change, conduct land restoration, or carbon sequestration efforts:

- *Invest in native species*. Various studies proved native species have better water-use efficiency carbon storing properties, contribute more to the sponge effect, and are better suited for the region than teak.

5.3 Limitations

Throughout the seven-week term that the team worked on this project, we had to face and overcome several different challenges. The greatest challenge was dealing with the COVID-19 worldwide pandemic. Originally, we had planned on traveling to Panama to conduct our research in person and cooperate with Oteima University and the Batipa Field Institute. During this time, we would spend two weeks in the city of David, in western Panama, visiting the teak plantation there.

Unfortunately, we did not travel and had to adapt to complete our project remotely. This major problem resulted in the change of our project goal to accommodate the unforeseen loss of contact with Oteima and Batipa. This project redesign allowed the team to continue the project independently by conducting in-depth research and through interviews with experts knowledgeable about our topic.

The COVID-19 pandemic also hindered the team from learning more information from the local farmers. Dr. Hobbs and Dr. Weathers mentioned that one of the most important things to do is talk to the local people (Personal Communication, Hobbs, Sept. 17, 2020; Weathers, Sept. 16, 2020). Unfortunately, the team could not get into contact with any local people that owned small farms in Central America and could not obtain that valuable information.

Another project limitation was the language barrier. Although one member of the team speaks Spanish, the other three have either very little or no fluency at all. This presented a large problem when trying to collect relevant information for the project. The project was unable to capitalize on the abundance of information only available in Spanish, as the team could not identify enough articles or potential researchers to interview that may have given even greater insight towards relevant topics.

5.4 Going Forward

Through the completion of our project, there were many different investigations that the team could have explored but decided against due time constraints. The following is a list of additional investigations not covered in the report that deserve further exploration.

1. *Research factors that affect investment in Central American teak plantations.* Political instability, crime, and other factors present potential problems in the expansion of teak throughout Central America. One potential reason for these problems is a lack of willingness from foreign companies to invest into ventures in these countries. Investigating the specific concerns of foreign businesses may provide a framework for governments or organizations to understand the limitations in the expansion of the lumber industry in their country.

2. *Investigate factors that could convert cattle ranchers to implement sustainable methods.* Currently, cattle ranching is incredibly popular in Central America, but it has disastrous effects on the climate. Investigation of which factors could cause ranchers to switch towards more sustainable practices could reduce the negative impact of cattle ranching on the climate.

3. *Determine incentives needed to promote native tree species growth in Central America*. Past research indicates that although certain native tree species vastly outcompete teak economically, others are too similar in profitability to incentivize farmers switching over. Investigating what types of government incentives, such as larger payments ecological services, could convince farmers to convert teak plantations to plantations consisting of native species could be of interest as future work.

4. *Investigate teak's continued popularity.* Throughout the report, the team discusses the disadvantages that teak presents to the Central American environment, as well as potential alternatives that are more economically enticing. Despite its apparent lack of suitability, farmers continue to plant teak throughout Central America. Thus, it would be insightful to research why this trend has existed and continues to this day: why has teak spread so far in an unsuitable environment despite research suggesting better alternatives?

5. *The effect of crime and violence on potential teak sites.* As noted by Dr. Hall, there is very fertile land in Eastern Panama, but the violence from drug trade introduces severe risks (Personal Communication, Hall, Sept. 18, 2020). Investigating how the drug corridor affects the establishment of potential farms, particularly teak, could reveal interesting information.

6. *Explore smallholder and subsistence farms intercropping with teak.* The method of intercropping teak with annual crops is a common practice in Southeast Asia, as many smaller farmers survive off agricultural crops and save off harvesting their teak until a

large event, such as a wedding or purchasing more land, requires the sale of their teak. This practice is not popular in Central America and may be worth further investigation because intercropping is very beneficial, both environmentally and financially.

7. *Evaluating the viability of teak improving life for small landholders.* With the inability to travel, the team struggled to determine whether or not growing teak is beneficial for small landholders. With interviews, this topic could be investigated further.

8. *Teak disease or insect damage.* The team was unable to find any literature detailing major differences of tree diseases or insect damage between teak and other native tree species. Further research into this or surveys with actual landholders could provide greater information regarding teak sustainability in Central America.

9. *Research government stability and its effects on the expansion of teak/lumber plantations.* The political stability and intricate inner workings of Central American governments differ wildly throughout the region. Although some countries enjoy vibrant democracies with ample resources to use towards self-rehabilitation projects, others are still constrained by past failings, authoritarian governments, and rampant corruption. A stable and trustworthy government is almost certainly a prerequisite for any country to experiment with a new market such as teak. Without proper government support, training, and incentives one can surmise that the industry may be too risky or would fail without resources provided by the government. Additionally, without the trust and consent of the government, countries could find it difficult to convince their citizens what is best for them in the long term. Furthermore, certain countries may have too many prevailing problems that need to be addressed before they can tinker with the more complicated mechanisms required to start up and optimize an entirely new industry. With all this in mind, certain countries in Central America may not be able to expand their current teak growing operations. The potential economic and environmental benefits of the tree may be too risky for certain countries for all of the reasons mentioned above.

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Appendix A: Informed Consent Script

A sample of the script read to every interviewee before any interviews begin.

Hello _____. We are American students from Worcester Polytechnic Institute doing a research project on investigating optimal growth factors for teak. As you are familiar with plants, we would like to interview you on _____. If it's okay with you, could we get your permission to record this interview on our phones to make sure we capture your responses? If you would rather not, it's perfectly fine, we can take notes instead. Any information you share with us is completely confidential and will only be used for research purposes with your permission. Do we have your permission to quote you in our report? You have the option to remain anonymous. We will not identify you by name in any of our writing to make sure the information you share with us is confidential, unless you would like to be quoted.

Our report will analyze various factors affecting teak growth and recommend the optimal conditions. We hope to assist central American farms in finding the ideal properties to grow teak. The report will be available online after we finish writing it, and we can also email it to you if you wish. If we ask a question that you do not want to answer, just let us know and we will move to the next one. If you don’t understand our question, please let us know and we can try to rephrase. Do you have any questions for us before we begin?

Appendix B: Dr. Pamela Weathers Interview Transcript

Team Member: Could you outline your field of expertise/subjects of knowledge

Dr. Weathers: Mostly medicinal plants I am a plant biologist so I know a lot of general information about plants but I work mostly on medicinal plants, particularly one specific plant artemisia annua and a few other, one or two other artemisias like artemisia afra and mainly for the purposes of looking at these as very low cost sustainable approaches for treating infectious diseases. So I'm very keen on sustainability because I think that's very crucial and teak falls into that category certainly because teak is currently harvested in an unsustainable fashion.

Team Member: One thing were looking at is that the teak farms in Central America don't have a lot of money to spend on these teak farms; a lot of them are pretty low income so what we're looking at is how we can most efficiently run those farms at a low cost

Dr. Weathers: Right and then maybe they harvest, I mean teak is a very dense wood and takes a long time to grow but it's also very valuable and so you can understand why teak is an important crop but it's not, it's not managed very sustainably. That's my understanding anyway. It's been one of those concerns.

Team Member: Going off of that, what do you see as the largest problems in its sustainability and the long-term sustainability of the farms

Dr. Weathers: I don't know enough about teak farming to give you that kind of answer. I just know from what I've read about various different kinds of crops that it's a real issue. I mean bananas are really in dire straits. Oil palm is being... it's replacing forests and it's not good because we're losing diversity. There's so many different crops. People need the money. There are also just large conglomerates that take advantage and they're very rich whereas the people doing the work, as usual, do not make much for it. But like bananas as an example are horribly infested with fusarium that's wiping out bananas and so we need ones that are resistant but we also need to grow banana more sustainably... maybe intercropping another species of important commercially useful plant. And then there's coffee, coffee's another one. Man if I lose my coffee in the morning I'm gonna be like a zombie all the rest of my life so I need my coffee. So I'm really worried about some of those things. And they just need much more effective—and teak falls into that but teak is a lumber. It's a high value. It doesn't have the same importance in my mind as some of these food crops. Banana is an important staple in many of these places, as is its cousin plantain. So those, I think, need to have very special focus because they're important food crops and we're gonna run into some very dire situations on food, maybe less so in the United States, but I don't know because you can see what's happening with climate changes that are occurring more and more rapidly. It's going to affect where we get our food from and what kind of food we can use.

Team Member: You mentioned intercropping with the bananas, can you expand on that? What's intercropping?

Dr. Weathers: So intercropping is—right now you have monocultures. It's just banana banana banana banana. It's like going to a corn field—it's all corn. That's done because it allows for easier management. Having another crop that grows in with it usually is much better for the land and it's much better for the individual crops if you choose the right combinations but it makes harvesting much more challenging. So for example if we grew corn and pumpkins and beans together, what a mess! But you get better productivity per acre overall.

Team Member: We read that just growing teak alone seems to erode the land a lot, especially in hilly areas. So maybe integrating something else in would help the production of... and able to sustain the land.

Dr. Weathers: So coffee tends to, coffee might be one, I don't know if it can grow in tolerance with teak but coffee does not need a super lot of sun, so could it be an understory plant with teak—it is a possibility because both are high value and if you could intercrop that way or interplant you make it better sustainability in terms of soil, retention of soil so it doesn't get eroded. But I don't know if the two are tolerant of one another. For example, you've all heard of black walnut, well black walnut, almost nothing grows under black walnut trees because the tree exudes a very toxic compound called jegalone. So if teak does something like that you may not be able to grow something underneath it and it might be better grown in plantations. But then the question is, do we still want to do that because it's causing problems. I don't know how you deal with that. It requires some effort to really study that better. And you might find that somebody has done some little test plot somewhere there's a lot of that kind of work that goes on but you're probably gonna be able to have to read things in Spanish or Portuguese.

Team Member: Just to ask a little bit further about that, I know monocultures are pretty harmful to the soil and they kind of take away a lot of one mineral or resource from the soil because of the high demand for it, how harmful do you think that is in the long term an do you know if it would be easily resolved and if so how do you suggest going about that?

Dr. Weathers: So with annual crops like corn or beans or wheat, you rotate your crops. That's how you avoid that. So corn is a heavy nitrogen feeder—I'm using things were familiar with because I'm not as familiar with tropical plants and teak is a tropical plant, but if you grow corn one year and you grow beans the next year, soybeans is usually what it is, the soybeans are nitrogen fixers and they help to replenish the nitrogen into the soil that corn which is a heavy nitrogen feeder will take out of the soil. And so helps with that. It also helps rotate between the different crops and the pests that attack them so you can use less pesticide to help control it. Because obviously, you can talk about organic farming but I can tell you I've organically farmed for years and it's like just in my own garden and it's a challenge. To do it on a grand scale of massive commodity crop like corn or soybeans it would be extremely difficult. So that's why you see some of these genetically modified versions so that they can use less of a toxin like pesticide but that comes with its political concerns. I don't find anything wrong with the technology of a genetically modified organism because there are enough safeguards that are in place. However, it's politically problematic. Cause we got a lot of people who don't understand science. It's frustrating.

Team Member: So when changing from corn, is there any modifications that need to be added to the soil to help out the beans grow more or do they just let it happen naturally like you said with the nitrogen

Dr. Weathers: I think usually there are additions to the soil, like nitrogen is getting replenished by the beans if you do it that way. If you don't do that you're gonna probably have to add nitrogen. One very important element, phosphorous, is running in short supply globally. The green revolution that occurred and allowed us to eat much better globally and for less hunger in many places, not everywhere obviously, requires the addition of some of these fertilizers to the soil. So nitrogen, phosphorus, and potassium are the 3 major elements that get added, NPK. Phosphorus, there's no way to really recycle phosphorus. It doesn't have a phosphorus fixing system like we have nitrogen fixers. There's a lot of potassium so that's not as big a problem but with phosphorus we harvest we harvest from the ground, we mine from the ground rock phosphate, and those areas are depleted in probably in about 80 years and they'll be depleted unless new ones are found and that's gonna cause a real serious problem so considering how to recycle phosphorus so that it doesn't all end up in the ocean, which is where it all ends up generally, is very critical. So the phosphorus cycle, and phosphorus is very water soluble if it's slightly acidic with acid rain etc... the water table and yes some of it will get taken back up but it also ends up in our rivers and streams and then that goes right to the ocean. I've taught many years and when I teach my class on plant diversity we talk about why can't we use algae in some of these to capture some of that and then when we bring the algae back in, use them as fertilizer on the soil and it's a slow release phosphorus type of readdition. But phosphorus is really only recycled by bird guano. Sea birds. That's not a lot of phosphorus to harvest. You gotta go and collect it. If you can find places for it. But the algae also take it up and some of them start as polyphosphate so that's a way to think about recycling that particular element. But this requires major efforts—global efforts—to start doing these things cause we are not paying attention to that. That's kind of been totally ignored.

Team Member: Do you think there's any way fertilizer can be used on a teak farm to help grow the teak trees? Cause I've never really heard of it being used in trees

Dr. Weathers: Well sure it's used in some tree farms depends where. I mean our tree farms are things like pines, yellow pine is grown in big plantations in our country and it's harvested for lumber, mainly. Got some relatively hard pine so it makes good lumber. So that is used under those circumstances. Tropically it's very interesting because some of these tropical soils are not very rich to begin with and you get a lot of rain and rain can erode and wash out a lot of minerals. And that's a very interesting possibility, to think about how does one minimize erosion and maximize nutrient readdition to the soil in these areas.

Team Member: Do you think fertilizer is a possibility?

Dr. Weathers: Sure. Animal fertilizers—I don't know what causes or what will stimulate good teak growth and help the soil to maintain a healthy status. Putting inorganic fertilizers on is not a good way to do anything. It's the way it's done because it's easy. It won't be easy in the future cause you're not gonna be able to get things like rock phosphate. So we have to be thinking about that, think about that future, about where do you find these things, how do you think about it from a more sustainable perspective. I suppose you could look at animal waste, for example.

are the teak forests or the teak plantations surrounded by small communities of people who are raising chickens and goats.

Team Member: It's also good cause in these low income communities it's free

Dr Weathers: Well it shouldn't be free cause they're trying to survive and maybe they learn to compost and then their compost is sold back to the plantations so they reap some economic benefit. We can't have people just doing things for free just because it looks like it should be free. They should be paid for what they're doing. Wherever the teak farmer is, he's making a lot of money off of those teak logs.

Team Member: That's what were looking at too, like how can these teak farms affect the communities economically

Dr. Weathers: It has to be a real good balance between the two so nobody's being taken advantage of.

Team Member: Besides fertilizer/animal waste, can you think of anything else that could be used to enhance plant productivity or be used as these natural sources for NPK?

Dr Weathers: The algae like I was saying but that also requires some really good organization and you don't want to harvest algae in such a way that you destroy your, for example, marine coastal areas. But could you set up algal farms along your rivers which are your conduits to the ocean, and we all know that there's all this pollution that goes down and the pollution isn't always necessarily noxious chemicals, it can be things like runoff. So trap those nutrients. That's the only way I've been able to think about how you could trap the nutrients is aglal farms that are used along rivers and tributaries. You want to be able to reuse, for example, teak. I don't know if teak is evergreen? Or does it go through a season? I mean you're down there you are approaching the equator you don't get seasons. It's like pretty consistent weather. You get a little bit of variation in climate so I don't know enough about it.

Team Member: "There's a wet season and a dry season"

Dr. Weathers: "So does the teak lose its leaves? And go dormant during the dry season?"

Team Member: "That's something we do have to look into because...It survives the dry season"

Dr. Weathers: "That doesn't mean it doesn't survive. Our dry season is winter here. Why do we call that a dry season even though we get a lot of snow? Its frozen water. And it's cold. The deciduous trees go dormant and even our pines are growing very slow in winter. They're surviving. And the things like oaks and maples all drop their leaves until spring. And then spring we get the increase in temperature, water becomes more available—it's no longer frozen. And therefore you can grow again. So winter can be a drought season even though you can have a ton, like 10 feet, of snow down there. But until it melts as water it's not available. That's not happening in Panama, but do the trees during the dry season lose their leaves? The reason I'm asking that is because that's a lot of biomass that gets dropped. What do they do with it? Do they just let it accumulate? Do they scoop it up or remove it because they're worried about pests? All those sorts of things should be considered when you're thinking about this because you don't

want to lose that resource. But you might want to make sure you're not having pests that are continuing season to season, if there are truly indeed really a growth season or not with that plant and I don't know enough about teak. I know nothing really about teak other than its utility."

Team Member: "They do lose their leaves during the dry season."

Dr. Weathers: "Ok so it's important to find out what happens to all those leaves. Cause they're ending up on the soil. Leaf litter helps in the retention of soil. It prevents erosion. So if they're getting erosion, then what are they doing with that leaf litter? Is there any way that they can help retain it? To avoid soil erosion if they're on slopes maybe they build little berms, almost like terracing, so that things don't run off—its captured. How many of you go hiking? Ok so if you go down a steep trail, you'll see that its very eroded but occasionally you'll see a little berm of rocks or something in a well-maintained trail and that's to shoot the water off to the side into where the leaf litter is and everything and it minimizes the erosion down the trail. It's the same concept. It's what they're doing when they terrace for rice in Asia, for example, where they grow a lot of rice. The idea is you're berm-ing up to keep the water back but you also prevent erosion that way cause you're growing on the sides of the slope. You will see that also where they're growing tea on the sides of the mountains, that'll often have a slight berm to prevent erosion. So maybe that's what they need to do in the teak forests and that could help hold back that biomass and slowly those minerals that are in the leaf litter can reach back into the soil."

Team Member: "Are there other types of uses for that additional biomass? I know a previous project looked at to do with other waste products of teak which was just excess wood and they used that for biofuel and a couple of other things. Do you think there could be any other uses for that to increase revenue for these small farmers?"

Dr. Weathers: "Any other uses of what?"

Team Member: "Any other uses of the leaves that fall every dry season"

Dr. Weathers: "I would think that the easiest and most effective thing is to keep them there and not lose them and I don't know but I would guess if you're getting erosion then they haven't considered to manage the slope of their terrain a bit. And intercropping. Can you grow coffee underneath? Because that's a good possibility for something. Coffee, like I said, is somewhat shade tolerant so can that grow under teak? That's a high value product too. I don't know about you but I'm paying a lot for my coffee."

Team Member: "Are you familiar with plant spacing and how that would affect productivity of any crop or plant in general?"

Dr. Weathers: "I mean it's different for every species. It's interesting because some of the evidence (studies done years and years ago) suggest that closer planting of a monoculture does not necessarily give you more productivity but the intercropping, in other words diversity of species, gives you better productivity and that's why I suggested the concept of...And it could be something other than coffee that has some value. Maybe it's a crop that is important for the people there for just their own use because it helps alleviate the need to go to market to find food. You can grow some of it there. Or it could be that they can't do that because of the way...That's a whole other issue—commercial management of some of these things that excludes

the local population who will get exploited for the production of the crop but not necessarily derives the major benefit that the plantation owners do. The rich vs. poor."

Team Member: "How much education do you think would be needed for someone to...If someone is living off subsistence farming for example, how much education and time would be needed to get them to a level where they'd be able to have some extra crops or adopt some of these more effective techniques?"

Dr. Weathers: "I think those people who are subsistence farmers are probably very knowledgeable about what their land can or cannot do. So don't ignore that. They have a lot of indigenous knowledge that is important to understand. And that shows respect for them as well as...If they see benefit and they're taught how to cultivate a new crop, I think they would probably take to it quite readily. But you have to also show respect for what they know because they're living off the land. I mean I dare you to do that, it's not easy. That's very important, that it has to be a respect for each other's knowledge. It's a different kind of knowledge base."

Team Member: "I saw that you had some background in Africa, specifically, when you were there did you ever experience or see farmers struggling with lack of access to water? Because in Central America climate change has affected a lot with the rainfall and they've seen less and less rain during their wet season. So have you seen that and have you seen ways that farmers have dealt with that?"

Dr. Weathers: "I wasn't really focused on that as much and where I was, mostly I was either in Egypt—huge deserts, Morocco and Uganda. And Uganda is on the equator. Uganda doesn't have really bad water problems, it's unlike some other areas like Ethiopia is suffering major droughts again and it's just because of the way this climate's been going. And then they might get these absolute monsoon seasons that absolutely washes everything away and destroys everything. And there have been the locusts. So it's been really horrific in terms of what they're trying to deal with. But I have not had personal experience with it. It's what I see in the news and watch what's happening so I can't really comment too much.

I know in a place in Belize, I was there a number of years ago, I've been to Costa Rica too, but in Belize it was really interesting—they capture all their drinking water off their roofs into cisterns, above ground cisterns. We were able to drink all the water in Belize because that's what they do. That works if you get rain but if you don't get the rain then that's a serious problem. And that's what's happening is we're seeing these climate patterns change such that it's hard to plan if you don't know what the climate is going to be like in say 20-30 years. The best thing you can do is conserve water and try to stockpile it in cisterns or lakes or whatever ponds that you can retain it. And then there's two different types of water, potable and much of the water in these countries is not potable meaning you can't drink it. You have to treat it first, unlike I have a well here at my house—I can drink that water. Our water is really clean. But I can't do that in many of the places around the world that are in developing countries. Belize was an unusual exception and it was because they gathered their water off their roofs so it never went to the ground. So you have potable water for drinking and cooking and you need water for agriculture—for your animals, for your crops. And obviously if you have to add your own water and don't depend on or can't depend on the climate then you have to be very judicious on how you deliver that water so that you're not just spraying it out cause you waste a lot that way.

It's drip irrigation or people watering by hand, it's very labor intensive. Trees of course have very deep roots, I don't know about teak cause not all tropical trees have deep roots, at least not that I'm aware of so I don't know what the situation would be like for teak. Nor if you used an undercover crop like coffee for example or something else."

Team Member: "Are there any things that we should look for that are often overlooked for optimizing general plant productivity or tree productivity?"

Dr. Weathers: "First I would learn as much as you can about the teak species. You really have to know that inside and out. Then you might learn as much as you can about other crops that work with it. You just have to learn a lot about each of those, really diving into literature that you can find...there's a lot that gets published that's not the general English scientific literature and I think that's very important because you might find some things that someone has tried and you can reach out to them. Usually if they're scientists they'll also be ok with English, especially written. But we're on the downside because we aren't polyglots which is unfortunate, we should be at least in Spanish I would think in North and South America. So that will help I think and you should just learn as much as you can. And then you'll be able to formulate better ideas."

Interview Ends

Appendix C: Dr. Peter Hobbs Interview Transcript

Team Member: To begin can you outline your field of expertise and what you're knowledgeable about in general.

Dr. Hobbs: I did my undergraduate work on agricultural botany and then I did my MS and PHD in the United States in crop physiology. I've spent the last 30 years until 2002 working in south Asia, I was working on, essentially, cropping systems. I was working with local scientists, extension agents, farmers, mainly on the cereal crops; rice, wheat, maize and also some other crops. So my specialization is in this and then I would say that I'm an agronomist, an agronomist is somebody who grows things and so plants grow in soil so I know a little bit about soil, I know a little bit about crop protection and I know a little bit about all of these different aspects of growing items. But mainly food crops as opposed to trees or items like that. Then the last… since 2002 I've been at Cornell as an adjunct professor and adjunct because I couldn't be a tenured professor at my age, until 2015 when I retired. I was teaching quite a number of classes at Cornell and also advising many students. Ok, I would say my specialty in recent years, in the last ten years has been on something called conservation agriculture. This is probably very similar to what you would see in a forest or where you grow trees is where you note hill land keeping permanent soil cover, in a forest it would obviously be leaf droppings but you wouldn't be able to rotate etc. We think that this is a management system that we need to promote in the world where it's feasible to be able to grow food more efficiently with less greenhouse gas, gas emissions, less costs but still maintain production.

Team Member: So when thinking about farming and how we can maximize the efficiency of farming would you say that it's more to do with the upkeep and management of the farm or the soil composition and stuff like that?

Dr. Hobbs: Well I think both of those things, obviously you've got to upkeep the farm and have it, whatever you need tools or machinery, you're using is up to date. Probably if you're growing something like a teak tree, one of the most important things is to maintain the soil health. I think that's one thing we've tended to neglect, we've taken the soil for granted. In fact, Cornell has a very strong program on soil health. And when we talk about soil health, we're talking about essentially improving soil properties, but it doesn't just include chemical, it's the physical properties and also the biological properties. Probably the biological properties are the things that you can't see but are probably vital to maintaining sustainable production of anything on soil. Does that answer your question?

Team Member: Yes, thank you, you mentioned that you worked in southern Asia, so teak actually originated in southern Asia, did you ever work with teak or see any teak farm while you were there?

Dr. Hobbs: I didn't work with teak because I was mainly working on food crops, rice, wheat and these various things, but when I was essentially a Canadian peace corps volunteer in Thailand, Northern Thailand and teak is grown in the hills in that area. They have plantations of teak and you obviously see them when you drive by but I didn't naturally go in and talk to any of the

people, people who were growing the teak. So I don't know very much about teak or the pests and disease issues or management of teak.

Team Member: So one of the big problems with teak actually is that it's grown on hills in hilly areas sometimes, but it deals with problems with erosion of soil when it's not planted with other crops, do you have any ideas of how we can minimize the erosion of soil?

Dr. Hobbs: Once you've got the teak forests established then that should help with erosion but the problem is when you are preparing that sloping land. So there are techniques for doing that, you could terrace, terrace the area, you could put in some sort of thing that would slow down the flow of water. A lot of these areas where teak grows you get heavy rainfall, like we just had with hurricane Sally. You can get 20 inches of rain in one day. So anybody working in the hills you know there are a lot of farmers that are growing crops in hilly areas. One of the traditional techniques that deals with erosion is terracing right, but that takes a lot of labor and time to develop that. Another possibility is to grow some form of crop along the elevation so that you essentially plant something and then you go down a little bit and put another thing and overtime that plant evolves into some form of terrace. I do have a video that I used to show the students that shows you how they do that for cropping, not necessarily for the trees. In other words you grow something on the contour of the hill on the different contour that would essentially act as a barrier for erosion. So that's another way of doing it but if you go there and clear the land and don't do any of these things or some other things that when it rains all the topsoil is going to go downhill and then you're going to be left with the.... topsoil is the best part of the soil is the best where the plants are going to grow best. If you lose that then you're going to go down to subsoil which is not as good as growth for growth. There is a need for that but that is quite a big investment that is needed.

Team Member: And in the areas that we would be working in Central America there's a lot of low-income communities that maybe don't have the funds to do these big projects.

Dr. Hobbs: Some of these local traditional areas for example in part of Mexico where they grow coffee you know they do slowly over time develop a contour system or a terracing system because if they don't they're going to lose that water. I worked in Nepal for 14 years up in the hills. In Nepal terracing is big, you have to terrace in some form it's either having less low so you don't get water running as fast when you put in drainage so the water can drain down through a gullie of some sort but somehow you have to restrict the erosion. Now the other way of doing it would be to plant some sort of cover crop or grasses or something like that and then plant into those terraces. Plant into the vegetation, so the vegetation will hold the soil and prevent it from running down the hill.

Team Member: Yep

Dr. Hobbs: The key there is to stop the erosion right, and so if you can slow it down so the water goes into the subsoil rather than running over the surface and taking the topsoil with it.

Team Member: Are there any properties that vegetation plants need to have or can this be done with most types of agriculture crops?

Dr. Hobbs: You don't actually, you could do it with crops, the advantage doing with crops is that the farmers can harvest anything they're growing. For example, a couple of videos that I have they use some sort of grasses. The grass can be cut for foder and taken and fed to the animals. It depends if you're a commercial farm or a small, smallholder farm and then of course the other problem you have is it needs a community activity you can't do your little piece and the guy above you doesn't know if that water comes down so you have to think in terms of more of a community development rather than an individual. But putting in some vegetation that has a use not only has a use in stabilizing the flow of water but it also can be harvested for some monetary game that would be a plus plus rather than just a plus. So you see some trees, some hedge trees, some plants and a number of different things that can be used to do that. I think if you look in the literature how to manage sloping land you'd probably find all sorts of things and what plants to select depend on what will be available in the place that you wanted to do it you have to get the seed or you have to get the cuttings or you have to get these things there of course you've had to stabilize the land before you actually put those in another words you may have already lost all the topsoil. But good questions.

Team Member: Talking about soil have you dealt with any natural and cheap modifiers that adjust the soil properties to fit a specific crop?

Dr. Hobbs: Yeah I mean this comes down to the chemical properties of the soil. If you were working in some of the areas in South America where for example in the Amazon the soils are, what we called oxisols, they're very leached soils that are very acidic and over time the forest has grown in that area and the problem is like what I'm seeing now the burning of the Amazon for us is to actually come back and replant that forest is going to be a big problem because the soil below the Amazon, the topsoil where the trees are growing is very very acidic so you can use things like lime to adjust the pH. If it's too acidic it's going to have toxicities, aluminum toxicity, because of the acidity of the soil, which may prevent the trees from growing. But that's where you need to do some soil serving of where you want to work and get some of the soil properties. Particularly the chemical properties if you want to adjust the pH. But they need to have a source of some form of alkaline product, dolomite, or some lime or whatever it is that you could add to adjust the pH. You would probably do that in the pit where you planted the trees. You know, dig a hole and adjust the pH so the trees get the chance to establish. So that's just one example of what each has a problem. If you had a phosphorus deficiency or if you have some nutrient deficiency you might have to add some fertilizer or some compost when you plant the trees. Was that what you we're looking for?

Team Member: Yes that was what I was looking for thank you

Dr. Hobbs: So, this all you would do, one of the most important things when you're working, is to work with the local people. They know as much about the local environment than anybody. In the long run they're the ones that are going to have to look after the trees. You're not going to go down there and look after the trees when they take 100 years to mature.

Team Member: That's what we were really trying to do with our original project, go there and work with the local people.

Dr. Hobbs: So it's very important to get a buy-in of the local farmers and get the local buy-in of the scientist that maybe have a soils lab or some sort of expertise in some of the diseases that the teak has and how to control them. One of the most important things is whatever you want to do is... guess who's going to be adopting what you are going to be suggesting. It's going to be the farmer. Include the farmer in the whole discussion from the get-go. They can give you their idea from the local knowledge and you can provide them with some technical knowledge that they may not have or working through the local extension or local scientist that they have there. That's really really key to having any success in an agriculture process so we are having a participatory research and yours is a social science project, social science is talking about people.

Team Member: So we were just looking at how the teak farms could positively affect the communities in the area.

Dr. Hobbs: But They have to have a buy-in, 'oh this is good for us' because they are the ones that are going to manage those and keep them properly managed so they are productive. But remember teak is very slow growing so you were talking about, I forget how many years it is before you can start harvesting, but it might be 40 to 50 years. So you're talking about a long time for this teak forest. In your lifetime me but not mine.

Team Member: So just to kind of take a step back and take a look at the chemical properties, specifically on teak, so we've been doing some research and we found that teak grows best on fertile soil with high values for base cations specifically calcium and magnesium. Can you speak to how you can amend soil conditions to see if it can fit these soil parameters or if you know of any natural things you can amend the soil to specific properties?

Dr. Hobbs: Well the best thing to do is get the soil tested. You want to know what you've got and what you need to do is a survey of the area. Talking to the local soil scientist and the local farmers of well if we're going to grow these trees what's the best place to grow if the farmer has ownership of the teak trees he's maybe going to select some of his better land if you're trying to come in and grow teak, he's going to give you his worst land. I mean this is a human issue but once you've got an idea you can do tests that test for pH, that test for cation exchange capacity, that test for available... They can look at available phosphorus and potassium and calcium and this is a chemical test that can tell you all that information. The only trouble is that some countries don't like you to take their soil samples out of the country. So you may have to find a facility within the country that can do the soil testing for you. Reason for this is by of piracy a lot of people are taking soil samples from the country that are finding interesting bacteria from the soil and patenting it and saying they belong to me, when they belong to the country they came from. So you have to be aware of that. Once you found that you've got a deficiency then you have to look and say what's the best way of overcoming that deficiency. For some of these oxisols, the very acidic soils in the Amazon area, if you put phosphorus in it, it fixes the phosphorus so tightly there's no available anymore so you can put tons of phosphorus in it and it will not make any difference. So you got to find ways of being able to allow the plant to take up that phosphorus. The main nutrients are nitrogen, phosphorus, potassium, calcium, and magnesium and usually if it's a low pH soil you'd be deficient in Calcium and magnesium. If you can increase the pH of the soil then maybe introduce two things what we call the total

amount of phosphorus and calcium in the soil in the available calcium and phosphorus in the soil so you have this soil availability to the plant and they're not equal OK. But you can get that information by doing a soil test.

Team Member: With your work with international farms have you seen any techniques used in water deficient farms that don't have a high access to water because as we've seen with climate change the dry seasons are getting a lot longer and the wet seasons are coming with less rain. So that is one problem that we have been kind of looking at is how they can move around that issue or help with that.

Dr. Hobbs: That's a good question. The thing is that you know that climate change, to me, it's the probably number one problem we're going to be facing in the future. And related to climate is rainfall and therefore moisture, we have to make a more efficient use of whatever water we have available to us. I imagine that growing trees may be some sort of drip irrigation system where, and you can get some simpler ones they don't have to be a really sophisticated pumping system to be able to get drip to work, but essentially what you're doing is putting out drip lines so there is a drip for every tree so a small amount of water is going in there overtime. So that is something to look into if water is a big issue. Remember you might have to irrigate those trees if it's dry during the early stages otherwise they will die. You have to make sure they can get themselves established and get the roots into the subsoil. So they can survive at drought and then of course you run into the problem if you have drought and everything is dry and you can have fires like you see in California. I was just watching something on BBC where they have some horrendous fires in Siberia and that's causing a huge problem because that's going to melt the permafrost and release methane as well as carbon dioxide into the atmosphere and you're talking about huge areas affected. So you then have to then protect those trees from fire. Once again you have to have the buy-in of the farmers to make sure people don't slash and burn those areas and then burn all the teak, all the young teak plants that are there. But the most important thing in the future is water, it's going to be one of the factors that will limit crop production. We have a term... essentially want to maximize the crop-per-drop in other words we want to get the maximum amount of production out of every drop of water. So things like drip irrigation or improved irrigation systems is one way to go. It's a little bit more difficult in the forest because you're such a large area so you have to have long drip lines in order to be able to do this. But that might be better than going out with a watering can and water and all these young trees in order to survive the initial years. Once again it's important to collect the climate data and what is the rainfall and does all the rainfall come in one event or is it distributed over the whole year or is it the dry season or the wet season. This is all really important to have that information.

Team Member: In Central America I think they have a five-month dry season which teak can make it through the dry season but I'm sure that's after years of being established.

Dr. Hobbs: You have to establish it first. Now another way of doing this is to not clear the whole forest, don't clear a whole area and then plant teak. Maybe the way to grow teak is to use the existing vegetation as the erosion control and then plant the teak in amongst what's already there so you have kind of a diversified forest. Not the pure stand of teak but you know you can use whatever is there to protect from erosion and that sorts.

Team Member: Do you think that's a big factor in keeping your productivity high in a teak farm?

Dr. Hobbs: The best term that I always use is it all depends...I tell my students all the time it all depends, you got to get this information; soil, water, rain, climate, and vegetation, etc. What grows well? What do you have that could be used to make these vegetative strips? Or what's the labor situation etc.? You need all of that in your planning.

Team Member: It's definitely hard for us right now doing it all remotely, it would be a lot easier if you were there.

Dr. Hobbs: What would be good is to talk to someone that's already there and get in contact with the local researcher to get you that information. I imagine that you're not looking at covering the whole Central America with teak trees but you're looking at a small project area.

Team Member: Originally we were looking at Panama and we actually had a sponsor there that owned a teak farm but throughout this whole pandemic they have seem to have stopped looking at their email and we can't get in contact with them anymore which is unfortunate. So this is why we are reaching out to professors like you and experts like you that might give us more information.

Dr. Hobbs: I think that what you can do is you can actually get information about the soil from the Internet. There are soil programs, FAO or some of these other places, they could tell you what are the types of soils. And then you can look at the properties of these types of different soils, this will be good in a good area to go check and this would not be a good area to go to. And you can also get the climate data the same way. You could do a virtual project and come up with some recommendations on how you control erosion of the terracing or things like this.

Team Member: That is kind of what our goal is right now.

Dr. Hobbs: And whether you do it makes farming systems or whether you do a pure forest you know. You can do that and then maybe sometimes later in life you can go down there and see if it works.

Team Member: Kind of going along with the last comment you made we were curious what you think the advantage of mixed farming such as agroforestry have over straight agriculture or just using tree plantations.

Dr. Hobbs: The problem is, is there is a lot of poor people are chopping down the forest in order to grow crops. So the thing is, can we make the agroforestry we have for us can we make the agriculture in the forest sustainable. Sweden agriculture is probably a sustainable system, slash and burn is what's happening these days is probably not because the ideas in Sweden agriculture is that you clear in area you burn it crop for a few years and then you leave it barren for 20 years and now what's happening is that that land is not being left rejuvenate over 20 years. It's being left to rejuvenate over five years and then we start running into the problem of you lost all the topsoil or you are getting more erosion, you see this in many areas now. So can we introduce

agriculture in that area that would allow the local people to look after their families or have some extra area like growing fruit trees that will allow them to get some income. I have some livestock that could be fed from the forest and at the same time provide milk or some sort of income coming in and some fertilizer from the manure. So there are some projects in the world called alternatives to slash and burn. If you look it up on the Internet you'll see all sorts of things. One of the things is to promote kitchen gardens. you know forest gardens, where people can grow lots of different things that they can either market or barter. But the teak, the problem with teak is that you can't harvest them for the first 50 years or so and most people will die in that time. So maybe they're growing them... so you don't see many smallholders farmers growing teak. They may have one tree or two trees but it's more of a plantation tree.

Team Member: One thing that I know there are a few teak farms currently in Central America, so what do you think are the best ways we can recommend how to improve their farms currently that are not starting from scratch?

Dr. Hobbs: Well I mean this is where to come and possibly do intercropping so you have the teak growing but there's plenty of space between the spacing for each tree. Teak is quite wide so grass and crops can grow in between. That would give you some income, it could be fodder for an animal program you could have silvagro culture is where you have animals that are grazing the fodder crops amongst the timber so you got an animal or a crop or fodder crop or something, some other income being generated while you're waiting for these trees to grow to the size of where you can harvest them. So this is what, if you look there are a lot of programs... There is a forestry program in Kenya one of the CG centers is the world forestry institute… probably were doing a lot of work on the trouble with trees. They take a long time to grow so what can I grow in those areas while they're waiting for the trees to become harvestable. You do some cropping in between so what to grow all depends on where you are and what the people want. But also markets, what do they consume, it's no good going in and planting... let's go to mangoes and grow mango trees and when you get the mangoes you have no market for them. So you got to think about value chains after you got that crop. Are you going to just grow them for some subsistence or are you going to grow them for commercial, some sort of marketing thing or whatever it is. And so as long as you got the proper soil and people to look after them and manage them you probably in some of these tropical areas you are having a whole array of crops to grow along with teak. Not just teak, you can grow some other tree crops that may mature faster. They can also be used for firewood or can be used for, you know, some sort of market value. In other words diversify the teak farms rather than just having teak there. This is why Monocropping is not always a good idea. But have a diversification and turn it into a forest where the teak trees are a part of that forest.

Team Member: That is that is kind of what we've seen as one of the most important things that we can recommend through our research.

Dr. Hobbs: Particularly when you're starting off when you're first establishing that teak farm you've got a lot of space that is not being used so use it for growing something that has a value. And then a course if he got animals then the animals provide manure manure can be collected and use as a fertilizer for the cheek

Team Member: Kind of on the same topic a major part of agricultural land in Panama is currently used for cattle ranching which is in large parts due to less optimal soil conditions in large parts in the Panama Canal watershed. Can you think of any small-scale ways farmers can amend the soil or do you think this has to be done in large scale governmental efforts?

Dr. Hobbs: Well governmental, it could always be cooperatives. You could have some cooperation of a number of smaller scale farmers that work together. If you've got animals there, the animals have to be fed so one of the crops that you might want to include in it there is some sort of fodder crops that could either be grazed by the animal or they can be harvested and fed to those animals and those grass crops can be used for the vegetative strips which is on the contour can be helped with terracing if you have some slope in it so there are some synergies between having livestock and forestry. There are systems out there, the animals produce in the minority helping to feed the grasses and the trees and the animals are also providing some manure to collect and use as some sort of compost. I don't know if the areas have some sort of source of fertilizer. In terms of calcium or magnesium. I mean that manures and composts are usually man made as you have to collect and distribute whereas fertilizer comes in a bag and is more concentrated.

Team Member: Do you think that is also a more expensive option that they might not have access to?

Dr. Hobbs: Well depends on whether they have animals because there is no cost. The only cost you got is the labor involved in collecting it. Now if you actually have them penned into some sort of stockade then the manure can be collected and distributed as a compost whereas if they are free roaming it is kind of difficult to go out collect the manure. The manure is fertilizing the soil wherever they poop.

Interview Ends

Appendix D: Dr. Jefferson Hall Interview Notes (declined recording)

1) Could you please outline your field of expertise and what you're knowledgeable about?
    a) Applied ecology, tropical forestry, ecosystem dynamics
    b) Restoration; forest restoration in plantations
2) Do you have an experience specifically with teak?
    a) Worked with teak for about 14 years
3) What are the main problems that farmers experience when trying to grow and maintain a teak farm?
    a) Soil culture
    b) Fertile, loam, non-acidic pH, high base cations and high phosphorous
        i) Most soils in central America don't meet these conditions
        ii) Offset teak planting—won't grow no matter what happens
        iii) Teak fever 1990's
    c) Plant something else instead of teak
    d) You need to find the correct places***
        i) More wrong places than correct places
4) Are there specific soil conditions that maximizes teak growth?
5) Have you seen intercropping play a role in the growth of teak? If so, is there a preferred crop that compliments teak well?
6) If there is not a lot of money in the budget, what are your suggestions for upkeep of a teak farm
7) What are difficulties the industry faces besides the physical teak growth (i.e. problems getting to market, finding buyers, competition with other plantations)
8) What equipment is needed to grow teak/create a plantation?
    a) Depends on how flat your plantation is
        i) Flatter-more mechanized
            (1) Weed whackers vs machetes
        ii) Hillier-you can't really get lawn mowers
        iii) Fertilize to raise ph in early years-low success rates
        iv) Teak is resistant to burns
            (1) You can set a fire and clean the plantation but you need to know what you're doing
            (2) Fire towers to prevent larger wildfires
        v) Planting-hole diggers
        vi) Fellert bunchers-slice off the tree-only in US
            (1) Big investment
9) What do you think is the most important thing to keep in mind when growing teak?
10) How do you think climate change will affect tree plantations in general, specifically in central America
11) How have you dealt with/how would you deal with a diminishing water supply
    a) Teak uses a lot of water—disrupts the water cycle—water waster
    b) Teak dries out soil first, THEN loses all leaves
    c) Teak creates water shortages basically

d) Drought + growing human population + teak is not the best combination

12) Going off of that, in the paper you sent to us about growing local trees with teak, you discussed the sponge effect. In the paper, teak did not fit the sponge effect. Are there other trees or crops that you are familiar with that do?
13) What can you tell us about the Barro Colorado island area? We were told there was a teak plantation there before.

14) Forestry requires understanding about a lot of things
    a) Need a major understanding of plant biology and forestry
15) ITTO
16) Pricing is complicated
    a) India stopped subsidizing buyers (biggest buyer)
    b) Want to wait until financial mechanisms stabilize
    c) You want vineer
    d) Sold based on form and volume
        i) Bad-weaving, knots, insect damage
    e) Minimum long height
        i) If not will be sold for less
    f) Diameter limit
        i) Smaller logs sell for less
        ii) Larger logs-older
    g) You have to find when growing it outweighs cutting it and selling it
17) Pruning+thinning
    a) Optimize growth-choose which ones you want to be sold
        i) Cut trees, leave them on the ground and let them decompose
    b) 1100 trees/hectare
    c) First commercial thinning ~11 years
        i) Costs a lot to get it out of the plantation
18) Usually leaves are left on the ground after they fall
    a) Allelopathic-may inhibit growth of other things
        i) PhD student couldn't find this
    b) At stri they need to whack what mother nature grows back
19) Native species nazis-teak is not native
    a) Teak sequesters a lot of carbon
    b) Teak reduces biodiversity
    c) First thing you do in forestry-find management objective
20) Markets see plantation wood different than wood from a forest
21) Strong lobby for teak plantation in panama
    a) Gov't not really keen on teak
        i) Potential negative consequences compared to other options
    b) Gov't wants to reforest poor soil regions
        i) Teak isn't the best for this
        ii) Green climate fund-encourage reforestation
    c) Gov't wants to help poorer people
        i) Usually helps with farming, not teak forestation
22) Panama being small gives it the 1% from the paper

23) Darian
    a) Wild forest
    b) Pan American highway stops + doesn't go to Columbia
    c) Dangerous—drug trafficking
    d) Most of teak plantations are towards this because of the fertile soil
    e) Very important for biodiversity
    f) ~30k ha over by the Darien
    g) Pressure to connect the road because of this
    h) PBS recording- 2 20 min segments; follow migrants
        i) Walk by skeletons
24) Other barriers:
    a) Cattle near Chiriquí in the highlands have angus beef
    b) Cattle is like a bank acct
    c) Brahman cattle in the lowlands
    d) You need to invest wisely in land
        i) Incentivize and smooth out income streams
        ii) This is difficult
        iii) Payments for ecosystem services
25) Why insecure land rights
    a) You need to have a clear title and you need to pay for this
        i) Ex. indigenous peeps in the US
        ii) So wealthy can get these titles more easily
    b) In panama people have a lot of faith in the squatter rights
        i) People are willing to make long term decisions because they believe in their rights
        ii) Leads to losing land
26) Working with current farmers in panama
    a) Secondary forest
    b) Forest management plan with gov't to let the secondary forest grow
        i) Reinforces land claim
        ii) Allowing forests to regenerate isn't considered a good use of the land but because it's with the gov't, doing the secondary forest thing it's ok
    c) Pay farmers for 20 years so people can offset their carbon footprint
        i) Paid for by people who care about climate change ex. In US
        ii) 130$ per ha for the farmers
    d) Up to individuals to slow climate change
        i) Think globally, act locally
        ii) This is an option for you as an individual to do something about this
        iii) Inertia in climate change-we can stop emissions for a year but it will still get worse
27) Any other trees other than the 2 in the paper
    a) Forestry-part art, part science
    b) Yes
    c) Diversify your types of trees
    d) Testing more all the time
28) Monoculture or nurtured by teak in failed plantations?
    a) Plant native species
29) Establishing new plantation

a) Better to diversify in an uncertain future
30) Tree div net (website)
31) Depends on management objective if you want agroforestry/cattle
32) Other resources
    a) Alex finkral
        i) Forest land group
        ii) Own teak plantations in panama
        iii) Planting cocoa bola
        iv) Managing larger plantation

Appendix E: Dr. Alex Finkral Interview Transcript

Team Member: “Just to get started do you want to just explain your field of expertise and what you’re knowledgeable about in terms of forestry”

Dr. Finkral: “Sure, in the sort of broader world of forestry which may already seem narrow to you, the depth of my training is in silviculture. You’ve probably come across the term already. Silviculture is the sort of science and art of tending forests growing forests usually to achieve some sort of desired goal you know some desired outcome for people. So a lot of times that's making money by growing valuable trees bigger and faster and in a place like Massachusetts where you have mixed hardwood forests dominated by oak species we would manage 40 and 60 and 100 acre kind of ownerships for timber harvests or wildlife habitats or a Quibbling reservoir in the middle of the state would be a good example of...For generating clean drinking water for Boston so that is my I’m a silviculturist so um with probably even a narrower specialization with eastern north American hardwood forests dabbling in the tropics. sorry for the long answer there.”

Team Member: “No no perfect, so more specific to our project how much or how long have you worked specifically with teak.”

Dr. Finkral: “I’ve worked with teak since I believe 19.. I’m sorry 2007 when I began a project in Honduras, which I’ll tell you a little about later, because it’s a pretty interesting twist on everything else you would think about teak growing. We, here, at the forestland group began directly managing teak plantations in 2013. But I’ve been conducting research on teak since I believe 2007.”

Team Member: “So, with our project we’re looking at teak plantations specifically in central American countries. And you mentioned you worked in panama have you worked in any other countries in central America.”

Dr. Finkral: “Belize, Belize and Costa Rica, however, not with teak in those countries. Little bit, little bit of teak I’m sorry a little bit of teak in Costa Rica. Uh we have a little bit there, I’ve looked at teak investment opportunities in Costa Rica. But really when you’re talking about teak in central America, Panama is kind of the most accurate place right now.”

Team Member: “Ok have you seen any teak in Belize because we were looking at that and we may have found something but we couldn’t seem to find a lot about that.”

Finkral: “There is teak in Belize and it does not grow really well but the big issue with teak in Belize is that Belize is in the Yucatan peninsula which is prone to hurricanes and when you get to Honduras and below you have a much greater a much lower risk of hurricanes, like hurricanes don’t come across Costa Rica like really much at all and so when you have a relatively valuable short rotation species like teak you don’t want to put it in a place where once every 10 years you may get a stand replacing storm that would come across the Yucatan peninsula so that would be

probably the greatest reason why you don't see a lot of teak in Belize. But there is some I'd say nation you know in the entire country 2000 hectares."

Team Member: "What do you think are the most important factors to consider when growing teak, like soil conditions or water supply anything like that."

Dr. Finkral: "I think it's probably the right amount of moisture, and by the right amount of moisture I mean, the climate throughout central America is very seasonal with a pronounced rainy time and a very pronounced dry season. You've found that right?"

Team Member: "yeah"

Dr. Finkral: "Ok, and that's one of the important things I'm gonna talk about at some point, the during the drought During the pronounced dry period growth *really* slows down with teak it's what's called, teak is relatively drought tolerant. It doesn't like the drought but it can tolerate it compared to some other species. And then in the wet time of year it does pretty well but if it's in a soil that is poorly drained during the wet time of year it won't grow well at all because it will be in saturated soils that will be kind of be the equivalent of physiological drought so by saying the right amount of moisture I mean some kind of interplay between precipitation or irrigation and well drained soils that still have some you know not sand but a well-drained soil that has some nutrient capital in it. Let me just say, let me say I'm sorry because there's a kind of... I'm always fascinated by the big picture of teak. Teak is from this fairly small part of the world right in Myanmar and kind of south Asia and it's that's its native range but it is now grown all around the globe in the tropics. I mean in every place so central America is one sliver where it is grown successfully but what an adaptable species that it's grown in Fiji and Australia and Indonesia and central Africa and the neotropics, the the thing. So as far as like it's what are the factors that help its growth, it's a widely adaptable species. A real like workhouse right of a species that can be grown in all of those places and in its native range it might grow to 60 or 80 years old before it would be harvested. What we have done is compressed that sort of growth cycle to 18 or 20 years where growing it in a monoculture as fast as we can and and it does that. So I think it's important to keep that in mind for this one valuable species we are growing it now way beyond its native range and at about one fourth the time frame that it would be grown in its native range in natural forest."

Team Member: "Speaking about, you mentioned monocultures is teak usually grown in monocultures and are there any negative effects of having it being in monoculture."

Dr. Finkral: "No, the negative effect of the monoculture is that it's kind of a biological desert, you know you don't have jaguars living in teak plantations because there's not a lot of stratification and brushy cover and kind of diversity of species and fruiting species that animals would eat so it's not very biodiverse, that's the bummer. If you're looking at just teak it grows very well in a monoculture with a very controlled environment where the trees are evenly or uniformly spaced and have access to sort of similar amounts of moisture and nutrients"

Team Member: So kind of on the back end of teak production, have you worked with the processing and selling of teak, like can you speak on that?

Dr. Finkral: “Yep, the important thing to know is that the majority of teak in the world today as a wood product as a you know furniture and lumber and patio furniture and boat decking and things that I’m sure you've already looked through. The majority of that comes from plantations and 96% of plantation teak globally goes to which country.”

Team Member: “India?”

Dr. Finkral: “India, that’s right. India is a gigantic engine of teak consumption so all of our plantation teak from panama and the vast vast majority of plantation teak from central America is shipped in containers to India.”

Team Member: “Do you know why that is?”

Dr. Finkral: “I’m sorry go ahead”

Team Member: “Do you know why India is the number 1 consumer or buyer?”

Dr. Finkral: “Yeah, two big reasons are number one if you go back thousands of years teak is culturally a very important species in India and it is used for all kinds of things in India, moldings and flooring and doors and windows. It's just a much much more common. It's not unlike kind of red oak in Massachusetts. It’s like a standard staple pretty appreciated wood, and it's been that way for a long time. Number two cheap labor, so it is sent in often as round logs you know plantation logs that are I don’t know as small as 15 centimeters in diameter all the way up to 40 and 50 centimeters in diameter. Sent round in these containers, steel shipping containers, then processed in India where labor rates are very very cheap. So you have this kind of established institution there of teak and teak processing and very cheap labor for doing the work for the primary breakdown of the logs cutting into lumber and then building it into things that are then exported, furniture and things like that. But a lot of it is consumed domestically in India. There’s a very big demand in India which I don’t know how many people are in India today. 1 point something billion?”

Team Member: “yeah a lot”

Dr. Finkral: “Yeah but that’s right a significant fraction of the earth’s population and so a lot of teak is consumed there and re-exported to other countries.”

Team Member: “Kind of going back to teak growth, so as climate change becomes a more pressing matter how would you recommend dealing with a low water supply maybe during the dry season or a less of a water supply during the wet season.”

Dr. Finkral: “yeah that's a good question and gosh, I’m sure in your lives you’re beginning to think about. I hope you’re beginning to think about climate change and its impact on a lot of facets of our life. We think about forests quite a bit. Teak is a little… Plantation teak is kind of interesting because, as I said we’re growing it to maybe 18 or 20 years old and that's a relatively short time frame for change in climate. So in any 18 or 20 year span the climates now changing

so rapidly that it's affecting 80-year-old red oak in Massachusetts you know we're thinking a lot more about wow like a small oak tree today, how will that grow and compete with other species in 2060. But with relatively short rotation crops like teak that we're growing we have not talked a lot about that."

Team Member: "Ok…(inaudible)"

Dr. Finkral: "But, let me interject here, that the experiments we were working on in Honduras were with irrigated teak. Irrigating teak through the dry season and it's expensive because doing all of the site preparation work like plowing the farm field, planting the teak, mowing around it but then installing drip irrigation along these lines. What it does is it enables teak to grow really really fast. While unirrigated teak shuts down in the dry season you're getting nearly 0 kind of wood growth. Irrigated teak just keeps growing year-round at a very high rate. So we can control for drought events with investments in drip irrigation. "

Team Member: "Is drip irrigation common in teak plantations?"

Dr. Finkral: "No, not at all, not at all, not at all. Because it's really expensive and because it's not really recognized as being necessary yet"

Team Member: "How much faster does teak grow with drip irrigation, like does it cut off a couple years in the time it takes to get it to the optimal height?"

Dr. Finkral: "Yeah totally, totally, more than a couple of years. Because again with conventionally grown teak in central America, yeah you may be looking at something as low as 15 or 18 years but on a poorer site maybe 30 years 35 years would be a long rotation for teak in central America. If the dry season is approximately 25-40% of the year, eh 25-35% of the year, by irrigating through that dry period you're increasing growth by 25-35% in kind of big round numbers. And so in our experiments in Honduras we were showing that we could grow teak to a final rotation age of like, you know 12 years, 10, 12 years. That would be kind of the equivalent of 18 year old stands without irrigation. The same thing is done by the way in the US and in other places in growing pine trees like yellow pine trees in the south or pulp and paper and 2x4s and lumber and things. So, every year we're trying to figure out ways to sort of ratchet up the inputs to turbocharge tree growth in plantation settings."

Team Member: "I know another important factor of tree growth is the soil, like teak has to have really rich nutrient soil, so do you do anything to modify the soil at first at least or do you just kind of roll with what you have."

Dr. Finkral: "Yeah we do in the first few years of our plantation establishment we do some nutrient amendments and fertilization with your basic nitrogen, phosphorus, potassium kinds of chemical additives."

Team Member: "Is that expensive to do?"

Dr. Finkral: “It is, yep it is. I mean any time you’re managing, any time you’re spending money on planting the trees, fertilizing the trees, maintaining the trees. You know people with machetes that sort of chop chop chop around your 1 or 2 year old trees so they’re not outcompeted. Those first few years are very expensive to get your crop kind of up and able to compete on its own at year 2 3 4.”

Team Member: “How many employees would you say are required to run a teak plantation maybe daily.”

Dr. Finkral: “Good question, let’s say maybe 1000 hectares, that is what we’ll put this to scale. 1000 hectares of teak I will say you'll need 10 to 15 people.”

Team Member: “And what would you say their jobs include?”

Dr. Finkral: “A lot of it is essentially mowing by hand with machetes. Have you seen that, because I can send you photos if you want of like.”

Team Member: “Yeah that’d be great”

Dr. Finkral: “Ok yeah yeah like of, we’ll have a team of and I’m gonna say men because we don’t have any women who work on these crews, maybe because women are too smart to do this. But, it’s crews of men who just mow through, you know, acres or hectares for weeks and weeks and weeks, swinging the machete that’s kind of just the mechanical mowing but with cheap labor in central America that's a cheap and effective way.”

Team Member: “So, I know that it, I think it differs by country, but I saw that generally the plantations have to be thinned by about 50% at sometimes. Can you speak to what years this is done and if it differs in different countries and why the main purpose of this is?”

Dr. Finkral: “OK, so I’m gonna lay out a basic recipe for a 20-year teak rotation. What’s called a rotation like from planting to final harvest. And you can, you will hear slightly different variations of this by a year or two, but here’s the basic recipe that everyone in Central America is following with teak. You plant the teak, it requires the most maintenance in those early years and then Oh and then you might be planting it at 600-800 trees per hectare. Ok that’s 3 meter by 3 meter or 4 meter by 4 meter spacing. And what happens in plantations or in natural forests is, the trees start spaced out like this but as they get bigger they all start their crowns start to grow together if you’re looking up the crown of the tree begins to grow, you know you start them here, but as they grow they expand and when they start touching each other like this the leaves and branches now they’re competing for light. And when they start competing, growth starts to slow down. So we do what’s called thinning and removing some of the trees if we cut this tree down, now this tree’s crown can expand even further. So at year 4, 5, 6, we’ll do a pre commercial thinning. Meaning the trees aren’t big enough yet to be valuable, so we’ll go through and cut down 20% of the trees in that early phase and just lay them down on the ground. Kill them basically to allow the remaining trees to grow bigger faster. And this is interesting, if you have 800 trees per hectare, not all of them are going to grow straight and tall and nice. You’re going to have an animal that chews on the bark down low over here, you’re gonna have a little windstorm

someday that snaps the top off of this one. And so you're going through and choosing the worst trees, because you're just gonna kill em. You're gonna cut em down and lay em down. Leaving the biggest, straightest trees with the most potential. Then around year 10 maybe 12, you're going to do your first commercial thinning. You're gonna cut out another 20% of the trees and these now you can sell as small diameter, usually maybe a 15 cm minimum diameter, which is like that, for export and you don't get paid a lot but you do get paid for cutting down and selling those trees. And again you're looking for the worst trees there. With every intervention you're trying to grow your biggest, best trees bigger and better. Aiming for that final harvest where everyone's gonna make a ton of money. Then at year 15? You'll do a second thinning, ok and remove another 20% of the trees. And so now you've harvested maybe 60 or 75% of the trees that you planted are now gone. And for those last 4 or 5 years of your 20-year rotation, the best 20-25% of the remaining trees are growing big, fast, tall into, your, you know, 30-50 cm diameters and for those you get paid very high prices. In a final harvest it's a clear cut at the end, and then you'll go back and start over. You'll follow that with a replant. But that's the basic recipe let's say 3 thinnings and a final harvest. So a precommercial thinning, then your first commercial thin, second commercial thin, final harvest in a 20-year time frame. Now keep in mind also that what I'm describing is a fairly intensive kind of industrial model here. Plenty of people in Central America, small farms, have 2 hectares, 5 hectares, 10 hectares, of teak planted here and there. And they may let that go longer periods, they may not final harvest until year 40. But what I'm describing is kind of the dominant investment model for intensively managed plantation teak. Which is pretty common really from Mexico to Panama. Sorry for the long talk there."

Team Member:" No, no don't apologize that was great that was a lot of useful information"

Dr. Finkral: "Yeah, that's the basic gist, think of the 20-year thing with these regularly spaced interventions. And every time you go in and thin the remaining trees go *whoooop*. Like they take off and start growing better. Same is true in natural forests in Massachusetts or Ohio, if you cut some of the trees down, the trees that remain are happy about that. They're like oh my goodness thank you it's a lot less crowded now."

Team Member: "So I'm curious when you do the precommercial thinning, you say you just kill off the trees, but do you mulch them or anything else to kind of get some type of profit from it?"

Dr. Finkral: "Unfortunately you have to pay someone to go and cut them down. But you want to minimize the costs of doing that, so you know the smaller ones are maybe this big you know 5-15 cm in diameter. One person with a machete bang bang bang bang. You know you can hand chop those or for the 10-15 kind of cm size maybe just a quick slice with a chainsaw. But that's just waste, you're just trying to get rid of that. As a funny little nuance, you know, let's say you let your teak stand go into year 6 or 7, growth was slowing because you haven't thinned, but in that time those teak trees may have grown into a merchantable size class. They may have passed that 15 cm kind of minimum diameter sort of size class. Then you might be looking at a commercial thinning for your first thinning. But, it would also represent kind of a slowdown of your eventual crop trees or those best trees, that you'll want to harvest later."

Team Member: “So, talking a bit more about processing the trees and like actually selling when it comes time to commercial thinning as well as the regular harvest, it seems like you just kind of keep them, you just cut them down keep them in logs for the most part but could you speak to how you process the trees on your plantation before they’re sold and how you deal with kind of the smaller shavings or excess wood or less desirable upper properties of the tree?”

Dr. Finkral: “Sure, there is not a lot of what you would call primary processing outside of India. Most of the plantation teak that we’re selling and that is being shipped around the world to India is going in round wood form, so just cut to length basically. And the log lengths are, the standard is about 2 meters. Longer, there are sort of premiums paid for longer logs. But, that sort of a shorter log, you know, a little more than 6 feet is kind of standard. And if it’s helpful I can send you a handful of photos of like teak log decks, with ,you know, hundreds of teak logs laid out, and they’re really pretty too, you can see the cut ends and how pretty the heartwood is of that sort of brown heartwood. So the question is often, well gosh if we could cut the slabs off of these round logs in Panama and square them up, called cutting squares or cutting cants, We could fit a lot more into this rectangular shipping container and get more volume there. So that’s always kind of a thing that’s discussed is. Can we make more money by squaring up the logs before we export or putting them in kind of more raw form, round log form into the containers and then shipping them. And still today, the dominant way of doing that is let the logs get to India, where someone will be paid less than they would be paid in Panama or Honduras or Costa Rica or Mexico to run them through a primary breakdown into the square form. So to come back to part of your original question, we’ll cut a tree down in the plantation, a teak tree, cut from the stump, the lower the log the more valuable. So that first log is called the butt log, it’s the most valuable. It might represent 80% of the value of the whole tree. But then you’ll cut a second log, a third log depending on how high the tree is, until you get to that limiting diameter up on the tree. On a big, mature teak tree you may be able to get 4 or 5 logs, these 2 meter logs out of it, all of which are merchantable. You fell the tree, you cut those to log length starting from the bottom, and you’re cutting all the limbs off the whole way up. All of that material and the top, when you lop the top off, all just stays on the ground in the field. So, not a real sexy story, we’re just extracting logs, leaving leaves and branches and tops in the woods.”

Team Member: “So is it just more expensive and not worth processing any kind of additional benefit like mulching it to make the soil more fertile?”

Dr. Finkral: “Well gosh in the tropics you have such rapid decomposition rates that that stuff starts breaking down real fast. You don’t need to mulch it to get it to decompose fast, and you know branches and tops and things are 1 and 2 centimeter sticks up to 10 and 15 cm top kind of wood that. Gosh you can go back 2 or 3 years and it’s mushy. And it’s not a bad idea to leave some of the nutrient capital that you find in leaves for example on the plantation, on the stump where the tree was just cut. If we were whole tree harvesting, that would require even more fertilization later. So you know leaving some sticks and leaves is actually a good thing for nutrients and for protecting from erosion and the heavy rain. It’s good to have leaf litter and sticks and things to sort of oh what’s the word, make it more diffuse the impact from direct rains on the ground. You guys have good questions by the way these are good.”

Team member: “Thank you, to step away from teak for a second actually, do you grow any other native species on your plantations?”

Dr. Finkral: “Yeah, in Costa Rica we do, we grow other species, including some pine species”

team member loses connection to zoom call

Dr. Finkral: “Oh we lost him”

Team Member: “Yeah that seems to happen a few times when we meet with him”

Dr. Finkral: “Yeah great, this is, we’re trying to become more sophisticated in how we’re growing things. Just to use our example in Panama, and so this may be a little more than you want to know, but you asked so here it is. Take a 100-hectare farm in Panama right, this is not Ohio, it’s not flat, it's not, it’s you know undulating, sometimes steep, but that’s perfect. Teak grows really well in kind of a gently rolling landscape with decent soils. But on that 100 hectares, you’re going to have 5 or 10 hectares that are down in a little valley, or a swale, where it’s a little too wet to be good for teak or kind of a steep slope and a rocky ridgetop. Where the soils are pretty dry and thin and stony. And if you plant teak at a uniform spacing across those 100 hectares, what do you think you’re going to see in 10 years? Plant it, walk away and how’s the teak going to look in ten years? It’s going to look good in the good spots and not good in the bad spots. So that wet valley, the teak’s gonna be kind of short and poorly performing. On the rocky ridgetop, really small and spindly and sad looking, and in the sweet spots on that 100-hectare farm it’s going to be growing really well. So, we’re now entering the second rotations on our farms, and so we have that full 20 years to look at as evidence of why would we replant teak on that 5 hectares of our 100-hectare farm when we know it performs really poorly? What are the native species that would compete better, or perform better on dry sites, wet sites, and that's kind of what we’re looking at are the extremes, the dry and the wet. With maybe 90 hectares of your 100-hectare farm are just fine for teak. They’re pretty well suited, but 10% of that we’re starting to plant with different species and we’re consulting with the Smithsonian in Panama. The Smithsonian Tropical Research Institute or STRI, have you come across them?”

Team Member: “Yeah we actually talked to Dr. Jefferson Hall last week.”

Dr. Finkral: “How’d you find Jeff Hall?”

Team Member: “We were looking up teak research in Panama and his name came up…(inaudible)”

Dr. Finkral: “Jeff and I were in grad school together and he's a close friend and I was just about to say like if you want to know more about native species, Jeff Halls the guy.”

Team Member: “He actually recommended you to us.”

Dr. Finkral: “Oh well, I know probably more about plantation teak than Jeff, and Jeff knows way more than me about most everything else. So Jeff and his team at STRI are helping us

identify native species based on their research that we think will perform well and we're just I'd say starting about two years ago after a final harvest of a teak plantation. We're starting to plant those 2 hectares here, 5 hectares there on our farms with native species. Again in rows, you know like, and in some mixtures like two species planted in rows over here, but it's a little bit experimental and it's a little bit entrepreneurial in that what we think is in 40 years. So in 2 more rotations those marginal sites will have really good, nice, valuable native species timber that can be harvested, along with the sort of teak matrix around it. So you know plenty about the native species story and the restoration work that's going on with STRI"

Team Member: "Yeah we had a good discussion with him last week about a lot about that stuff"

Team Member: "So you said that you kind of waited to see which areas weren't really growing well with teak and which could be supplemented with native species. Were you able to predict any of these areas where you thought that would happen or did you really just have to wait and see what happened after the rotation."

Dr. Finkral: "It would not be hard to predict, based on kind of landform and really the moisture regime across a landscape. If you had a digital elevation model or a topo map you could probably predict with some accuracy where teak would do well and not well. We have the benefit of being able to see teak performance in real time on the landscape because when we planted teak 20 years ago, it was just planted uniformly *zzzzzttt* across everything, like a tapestry laid out on hill and valley and so now it's like look, it's easy to plant the same species in rows again and again and again. But we would be silly to do that across these hectares where we're not seeing reasonable performance at all. Let's carve them out and try something different there and that's why we're going with the native species. And so yeah you could predict it on your own but we have the sort of blinking evidence from actual teak performance that's playing out. And they didn't know that 20 years ago, I mean, 20 years ago these were some of the earliest teak plantations. So, you know, you would think that rotation by rotation by rotation we'll get a little better at this over time you'd think."

Team Member: "So kind of to talk about more of the factors that affect teak growth, are you familiar with the USDA soil taxonomy system?"

Dr. Finkral: "The USDA what taxonomy system?"

Team Member: "Soil taxonomy"

Dr. Finkral: "Yes, I am, I'm not a good soils person though, but go ahead ask something."

Team Member: "Well I was gonna ask if you knew which orders of soil teak…(inaudible)"

Dr. Finkral: "Well shucks, no I can send that to you I mean I have that written down in management plans and documents and things but I could not tell you off the top of my head what kinds of soils they grow in. I mean I would guess inceptisols but I don't know."

Team Member: "And then, so to move into your work in Honduras a bit, you spent some time there performing a case study on investment analysis of Honduran teak plantations, could you speak to your experience and findings during that study?"

Dr. Finkral: "My experience and what in those studies?"

Team Member: "Your experience and findings sorry."

Dr. Finkral: "Oh and findings ok. Yeah it's back to the fertilization and irrigation. What we were trying to see is, ok so we took teak from 80 years to 20 years, what would be stopping us from taking it from 20 years to 10 years, and in kind of a big general statement we found that you can. And what it requires is fertigation. Alright so fertilizer and water through a drip irrigation kind of delivery system that, yeah if you seep kind of nutrients year round into, into the soil around teak trees and irrigate through the drought you can achieve explosive growth and so the investment question is: is it worth significantly higher upfront costs, or kind of a much bigger early investment to then achieve the final harvest revenue stream in half the time or you know 60%, 70% of the time to you know essentially reduce the rotation length by that amount of time. A lot of money in as an investment, you get your money back faster. But from kind of a physiological standpoint the thing that interested me most was wow look at this, that what you will read, here you go, you will read this again and again and again and again and again. That teak needs this dry period, that it needs that pronounced drought period, it's the same in its native range in south Asia. What we found is that no, not only does it not need the dry period to companies grow quality timber, but it strongly prefers to have plenty to drink when it's thirsty year-round, which totally makes sense. So that was the big gee whiz there. Now, the reason that that practice has not been widely adopted is because it's really expensive and so it's already kind of expensive to buy land in Panama and plant teak and manage it for 20 years. To add additional expense when getting your money back is at least 10 years away, that has proven to be a little bit too risky for forest land investors."

Team Member: "So when we were looking into it, it seems like a lot of the land in Panama is currently used for cattle ranching and it's kind of hard to convert those farmers into teak since it's more of a risky investment and cattle are a living bank account for them. Do you think you need to have this kind of significant foreign investment or foreign capital to be able to comfortably start it or do you think that locals in Panama could reasonably start a profitable teak farm?"

Dr. Finkral: "You can do teak on a small scale, as a kind of a supplement to your cattle farm. You know, if you put just a few hectares of teak that will, you know, generate revenue periodically over 20, 30, 40 years. But yeah as a longer, you know a longer-lived crop that has both benefits and disadvantages that more of an annual crop like row crops or cattle would, you know make more sense from a sustenance kind of a standpoint. But yeah, you know from what I have seen I think it's probably a safe statement that to go big and kind of to the 1000-hectare scale and bigger, you need a fairly well funded well financed organization to do that. Not US based necessarily, I mean there are European companies and investment firms that are doing this too. But, a lot of the money is coming from outside Central America and investing in these operations."

Team Member: “So do you think that the majority, I’m not sure if you know, but do you think the majority of kinds of sites in Panama and maybe central America are made from foreign investors or foreign companies rather than local companies?”

Dr. Finkral: “Don’t know, I mean I’m familiar with a lot of the foreign investment including ourselves, but I don’t know how I would characterize that kind of across Panama and across Central America.”

Team Member: “Do you think that the industry should be expanded across Panama, and do you think it will be?”

Dr. Finkral: “One of the problems that we’re grappling with now and everyone’s grappling with now is that a few decades ago everyone saw this as a terrific opportunity and planted a lot of teak. Now we’re kind of in a time where the world is awash with plantation teak and the market is maybe oversupplied, which then suppresses prices right. So if we were the only geniuses planting teak in central America and selling it to India there'd be a great demand for it and we'd be selling it at high prices. But it turns out a lot of people are doing that, we’re competing with Caribbean islands and southeast Asia and central Africa where everyone’s growing teak. So I don't think that we need a lot more of it. I guess that would be my answer to the question. That there’s plenty of teak developed in the world right now I think to meet the world’s demand.”

Team member loses connection to zoom call

Dr. Finkral: “Does that answer your question? Right, Tim are you there? Tim froze for me.”

Team Member: “It looks like he's frozen for us”

Dr. Finkral: “I think that was the answer to the question, that I would say that I would tap the breaks on further teak development right now unless there were some really good opportunities to get in.”

Team Member: “Going in the future with all this climate change, I know teak needs a lot of water to do well. Do you think it's viable that teak will still be a good investment for small farmers because they might not get maybe the same outcome as they would a few years ago.”

Dr. Finkral: “You know I think it is a good investment, and you know it comes back to one of the first things that I said is that teak is like a very adaptable kind of a workhorse of a species. That if you were to plant teak today at a small scale or a big scale, you’re going to have a product in 15 or 20 years that someone will want. It’s not like you’re throwing money into a really risky and strange sort of a business. It’s a well-established species with a well-established demand and maybe you won't get paid as much for it as you'd like. And that’s really what we focus on we’re trying to provide good returns for investors, but it’s worth more than 0. It’s always, your return is almost always better than 0, because teak grows and there’s should always be someone who wants to buy it. So the question is probably, is it the best investment you can make as a smallholder or a farmer versus other things. And I don't know what the other options would be. I

do know that we look at sort of older cattle pasture, pastureland that is kind of expired or been sort of worn down for planting teak. So you can't run cattle on a pasture on central American soils forever, before they kind of grow tired. In that sense teak is a good idea for some of the lower productive parts of your farm, where with some modest nutrient input fertilization you can probably do ok."

Team Member: "When we were talking to Dr. Hall we talked a lot about reforestation and he said how teak is probably not the best option for that because like you said it's a monoculture and there's not a lot of biodiversity in that. So, he just mentioned that maybe letting the native trees grow was a better idea."

Dr. Finkral: "Maybe, no and I'm a fan of natural forests. I mean that's a majority of what we do here, but having a single species and a pretty well-established market for that species is a pretty compelling argument for going that route. I would say that Jeff has a little bit of bias toward the, yeah, I mean really that's what he does. For me personally, if I had 20 hectares in Panama I would love to grow native species, have a little more complexity. But, if you're looking at just sort of a financial model in a spreadsheet, teak is pretty hard to beat as a basic approach. Now keep in mind Jeff's experience, they have grown teak on some poor sites and had relatively poor performance in the Panama Canal Watershed for example. And a lot of people do that, a lot of people in the earliest years of teak development would pitch this investment opportunity. Like, hey look we're gonna go plant teak, it's Panama right? Things are gonna grow well, but things don't always grow well because of what I was describing. You need the right kinds of soils, a well-drained soil and understand the cyclical nature of the rains and there are good spots and not good spots to plant teak in Panama. A lot of people have planted teak in the wrong places and it has been very slow growing. Hey I've gotta go for a lunch meeting here in a minute, but we can follow up with another call, you can follow up with questions. If you wanna email me to remind me to send some photos, I'm happy to do that or just trade emails…"

Interview Ends