CHRONOLOGICAL ASSESSMENT OF SUCCESSION IN THE SEASONAL TROPICAL DRY FOREST:

A CASE STUDY IN THE KAREN MOGENSON RESERVE

by

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ABSTRACT

Chronological Assessment of Succession in the Seasonal Tropical Dry Forest:

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Omar Hernandez

This study examines the forest succession in the tropical dry forests of the Karen Mogenson Reserve (KMR) in Costa Rica's Nicoya Peninsula. Through systematic plot examination and small-scale forest surveys, this study explores tropical succession over time in an area spanning over 900 hectares of dry forest conservation land. The Karen Mogenson reserve presents a unique opportunity to investigate forest succession in a tropical dry environment, encompassing diverse stands ranging from early to mature primary forests. Our findings reveal remarkable tree diversity with both deciduous and evergreen species persisting throughout successional stages.

Over 100 tree species were identified with an expected correlation between tree height and diameter. Changes in forest structure and composition occur as stands age, particularly between middle and late succession stages, leading to alterations in canopy height and forest density. Lianas and dense underbrush are observed to influence early succession, shaping the forest structure towards middle stages. These vines take on configurations that give indication as to how these dry forest progression towards its late succession phases. Late-stage primary dry forests exhibit pronounced canopy height, openness, and a high diversity of tree species occupying specific niches. Efficient allocation and utilization of light and moisture become crucial as competition intensifies. Plot data from middle to late succession stages demonstrate a decrease in forest densities but an increase in overall tree size and diversity. This research provides valuable insights into the complex dynamics of succession in dry forest ecosystems, contributing to our understanding of forest recovery and biodiversity conservation in tropical regions.

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With heartfelt appreciation,

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Introduction

Costa Rica is a treasure of the Mesoamerican region and is known for its diverse landscapes and abundant biodiversity. The Guanacaste province, located along the Western Pacific, showcases a unique blend of temperate environment, tropical weather, and varied topography (Kappelle et al., 2017). The region's cycle of dry and wet conditions has shaped its distinctive plant and animal variations (Helmer, 2000). However, the historical deforestation in the area, driven by industry and colonization over the past 500 years, has had a profound impact on its ecology (Place & Evans, 1999). The conversion of vibrant forest ecosystems into pasture lands, primarily for the cattle industry, has resulted in the loss of plant and animal diversity (Calvo-Alvarado et al., 2009). Fire and chemical use for the clearing of land and the introduction of non-native grasses, have further transformed the landscape (Williams & Baruch, 2000). The repercussions of these practices and the extent of what has been lost continue to be subjects of ongoing research in the area's dry forests (Portillo-Quintero & Sánchez-Azofeifa, 2010).

The tropical dry forests of Costa Rica, as an ecosystem is critically endangered, facing numerous challenges to its stability and long-term preservation (Janzen, 1986). Characterized by distinct seasonal patterns of rainfall and extended periods of drought, these forests harbor unique biodiversity and provide essential ecosystem services (Calvo-Alvarado et al., 2009). However, due to pressure from human activities such as deforestation and agricultural expansion, the tropical dry forests have been significantly fragmented and degraded, jeopardizing their ecological integrity (Place & Evans, 1999). Secondary forest began to return as Costa Rica enacted numerous policies to curb the forest lost.

To address the need for improving conservation and restoration efforts, this research focuses on studying succession in the transitional moist/dry forest located in the Nicoya Peninsula of Costa Rica. Nestled in the Northwestern region of Costa Rica, near the small town of Rio Blanco/San Ramon, lies the captivating Karen Mogensen Reserve (KMR). Spanning an impressive 900+ hectares, this biodiverse haven boasts a captivating altitudinal range of 500 meters. Within its boundaries, a vast tapestry of ecosystems unfolding, showcasing the transition from dry to moist forests, interspersed with pockets of recovering forest as well as the picturesque gallery forests (Figure 1).

Figure 1 Primary Transitional Forest/El Velo De La Novia Waterfall

The Karen Mogensen Reserve provides an ideal setting to investigate forest succession across different stages, from early to late phases, within a single locality. Positioned just 10 kilometers from the Gulf of Nicoya and 15 kilometers from the Pacific Ocean (Figure 2), these bodies of water further enrich its ecological significance. This protected area holds a prestigious status as a National Wildlife Refuge and plays a vital role within the biological corridor of the Nicoya Peninsula. It harmoniously blends with its surroundings, bordering sprawling cattle pastures, as well as other protected and unprotected forests.

The reserve currently contains no permanent forest study plots and most study have been restricted to the rudimentary trail system that extend across the seams of the hills found there. The reserve contains a research station that collects weather data, with onsite domiciles for researchers. These facilities allow quick access into the KMR trail system and forested areas being studied. Trails are few and under constant assault from the elements, fallen trees and occasional landslides. The KMR biological center provides access to dedicated laboratories equipped instruments for analyzing various samples collected from the vast forest zone.

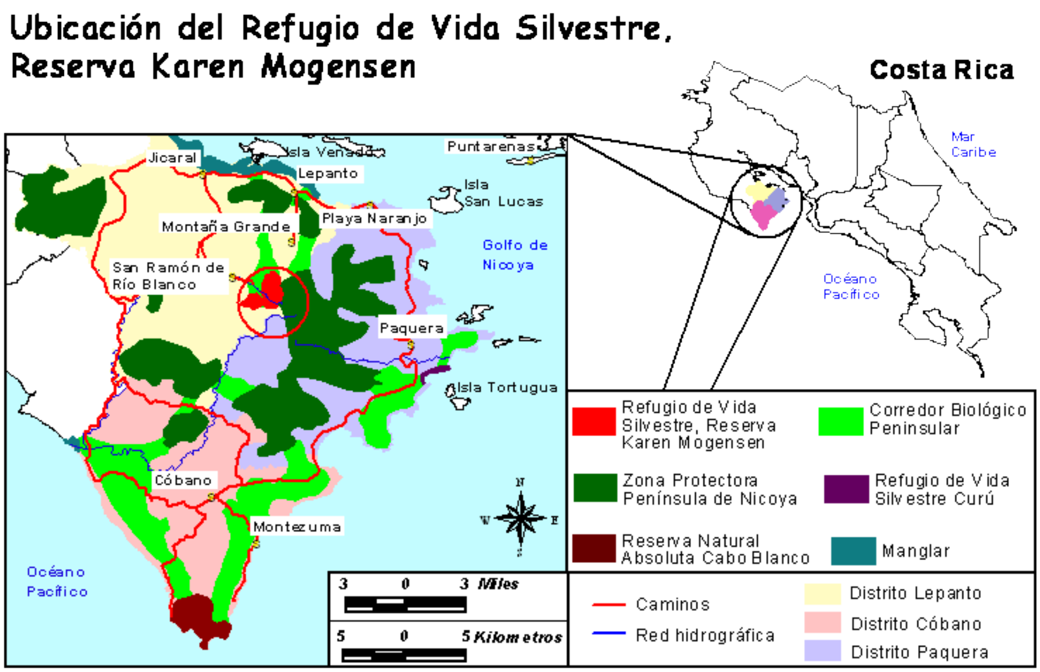

Figure 2 Biological Corridor of the Nicoya Peninsula

<u>Objectives:</u>

As a way to obtain data for further analysis, this study conducted fieldwork that involved performing forest survey plots within the Karen Mogenson reserve. This study of forest succession explores the ways these dry forests express change over time. Its focus is on understanding how, species composition, and ecosystem dynamics develop following pronounced disturbance events. For this region that means cattle ranching, which has been a major force in land change in this area.

This study employed a modified rapid assessment protocol to establish eight distinct chronological sequenced survey plots. The main goal was identifying key aspects of forest succession within this recovering transitional dry forest ecosystem. This survey concentrated on collecting an array of observational data. These data points included the diameter at breast height (DBH) measurements, identification of prevalent native tree species, and observations of shrub and plant assemblages found in varying stages of succession here. Other important elements studied were tree distribution across varying time scales, dominant species within temporal scale, forest density, average plant height, species richness, evenness, and overall composition of these transitioning forest. These characteristics were identified through an in-depth literature reviewed.

The primary forest stands within the reserve, will serve as our control to compare other areas of earlier stage of succession. These stand types are hypothesized to be relatively undisturbed, developing into mature ecosystems with diverse and unpredictable species compositions (Kappelle et al., 2017). This survey will observe areas of secondary forest that, originated from past human activities such as logging, agriculture, or cattle grazing (Buzzard et al., 2016). Based on prior research, it is expected that the species composition in these secondary forests of the reserve will trend towards less diverse and more predictable than in primary forests (Chazdon et al., 2010).

The main objective of this research is to improve the general understanding of seasonal tropical dry forests (TDF) of Costa Rica, often considered an understudied ecosystem (Quesada & Stoner, 2004). A sequential forest examination was a strong way to provide a detailed and systematic analysis of the large numbers of trees found in these tree stands across varying ages. By utilizing chrono-sequencing this kind of data could reveal previously undetermined ecological relationships helping to identify key drivers of biodiversity and ecosystem functions. The research data collected from this project will provide insights into the ecological processes and adaptations that allow these forests to thrive in the face of seasonal variability in the Nicoya Peninsula.

Research Questions

To better understand the dry forest ecosystems of the Karen Mogenson, reserve the following research questions were developed to play a crucial role in guiding this study and highlighting its significance.

- What are the key characteristics driving tropical forest succession within the Karen Mogenson Reserve?
- How is forest succession expressed in terms of tree diversity, forest structure, and management programs within the Karen Mogenson reserve?
- What is the relationship between historical anthropogenic land use and the recovery outcomes of transitional forests in the Karen Mogenson Reserve?
- How is succession expressed through a temporal gradient across the Karen Mogenson reserve?

Literature Review

In recent decades, the study of tropical dry forest succession has gained increasing attention, resulting in a significant body of literature. This literature encompasses research on the drivers and patterns of vegetation change, the impact of disturbance and stress on community dynamics, the interplay between plants and animals, and the effects of global change on TDFs. In this review, this project has as its aim to provide an overview of the current state of knowledge on TDF succession, emphasizing the main research inquiries, methodologies, and discoveries in the field.

The dry forests within this biome play a vital role in upholding the overall well-being and adaptability of the ecology within our research area, while also serving as a significant support system for local livelihoods. Through the literature, we explore the factors that influence forest regeneration, such as seed dispersal, soil fertility, and disturbance history of a region.

In addition to its ecological significance, the region also has a rich cultural and social history that has shaped its current state. This review will also identify and recognize the social and economic pressures that have defined the ecology in this area of Costa Rica. This review uses the presented literature as a lens through which to fuse together an understanding of both the rich history and the unique ecology of Guanacaste Costa Rica. This region is home to some of the last remaining tropical dry forests in the world, and is a critical area for biodiversity conservation. This is a broad assessment of the region, understanding that the area around the Karen Mogenson reserve is in a transitional state, being moist tropical forest. This is an aspect we explore within this review.

Finally, this review addresses the threats that exist to these ecosystems, and what is being done to preserve them. Tropical dry forests are among the most threatened ecosystems in the world, and have been subject to widespread deforestation and degradation due to human activities such as agriculture, logging, and mining. We examine the strategies that have been developed to conserve these forests, including protected area management, community-based conservation, and forest restoration.

A History of Costa Rica

How did Costa Rica stave off many of the pitfall that left the majority of the Central America underprivileged and politicly unstable (Myers & Tucker, 1987), i.e. how is it different from its neighbors across Central America? Costa Rica is a politically stable nation, which is relatively infrequent in the majority Central America (Seligson, 2000). Unlike its neighbors, Costa Rica has not experienced any significant political unrest, civil wars, or military coups since the mid-20th century (Campbell, 2002).

Costa Rica was not "discovered" by Europeans, as the region was already inhabited by indigenous people for thousands of years before the appearance of the Spanish in the early 16th century (Myers & Tucker, 1987). The first recorded European contact with Costa Rica occurred in 1502, when Christopher Columbus sailed along the country's Caribbean coast on his fourth and final voyage to the Americas. However, Columbus did not establish any settlements or claim any territory in Costa Rica, and the region remained largely isolated from European influence for several decades (Wallis, 1911).

In the early 16th century, Spanish conquistadors began to explore and colonize other parts of Central and South America, and by the mid-16th century, they had established a foothold in Costa Rica. The Spanish encountered several indigenous groups in Costa Rica, including the Chorotega, Huetar, and Bribri, among others (Carmack & González, 2006).

The early pre-Colombian history of Costa Rica is a rich mosaic of indigenous tribes that were scattered across the region, engaging in subsistence farming and trade. Estimate of the pre-Colombian populations range between 27,000-400,000, although the precise numbers are a contentious point among anthropologist (Carmack & González, 2006). The use of land by indigenous people in Costa Rica was mainly influenced by the challenging topography of steep hills and thick undergrowth (Place & Evans, 1999). The Spanish initially sought to enslave the indigenous people and extract precious metals from the region, but they soon realized that Costa Rica lacked the gold and silver reserves of other areas in the Americas.

As a result, the Spanish did not establish large-scale settlements in Costa Rica, and the region remained relatively unpopulated and underdeveloped for several centuries. It was not until the late 19th century, when Costa Rica became a hub for coffee cultivation and export, that the country began to experience significant economic growth and development.

This area of the world, over the last five hundred years, has been battered by the expansion of human development (Myers & Tucker, 1987). These authors detail the vast forests and jungles that once stretched across the Mesoamerica landscape from Mexico through into South America. Through this narrative we can also recognize the way the Spanish arrival is connected to the decimation of the local indigenous populations from disease. This event forever changing both social and ecological landscape of the Mesoamerica region. Myers & Tucker go on to discuss that archeologists have identified that most pre-Columbian indigenous land use was sparse and basically constrained to small scale subsistence agricultural. They recount the first serious rounds of deforestation had occurred during the onset of 1500's, across most of Central America. The authors identify the opening of the Americas for its abundance of raw material as the main source of many ecological issues seen across the region.

Although this occurrence of deforestation happened several centuries ago its remnants can still be identified today. Myers & Tucker discuss historic accounts of the ecology in Central America, noting that though forest returned the growth patterns often fell short of the original cover found in these untouched forests. Even at this early stage it was noted by early observations that advanced forms of secondary forest did differ from the true primary type in terms of its biomass, productivity, appearance, species composition, and plant community dynamics.

What is seen as a trend in the hardwood forests of the Central American is cycles of deforestation that spanned years hovering around foreign demand. International influences continued repeating these destructive patterns for both the prime timber and useable agricultural lands (Myers & Tucker, 1987).

How have these cycles of deforestation affected the returning ecology of the greater region? Today, results are fragmented landscapes of remote hills and mountains provide refuge to communities of plants and animals across Central America that have been greatly diminished. Continuing biological research in the last 50 years has distinguished beyond tropical rain forest the distinct ecology of the "dry tropical forest".

The land of the Mesoamerican/Lower Central American was, prior to European colonization a thriving, organized community of indigenous people. Carmack & Gonzalez (2006) argue that the border between Mesoamerica and lower Central Americas was shaped by a complex interplay of political, economic, and ecological factors over many centuries.

The authors argue that the Mayan civilization in the North and the Lenca civilization in the south were both part of a larger regional system that included the exchange of goods, ideas, and people across the border.

The authors also discuss how the arrival of Europeans in the 16th century disrupted this system and led to the exploitation of indigenous populations for labor and resources. The authors conclude that an interdisciplinary approach is necessary to fully understand the long-term processes that have shaped the region and its peoples (Carmack & González, 2006). The main point of understanding here is that there were previous instances of land change that also played a role in how dry forest were distributed in Costa Rica today.

Ecological Policy in Costa Rica

Costa Rica, a Central American country with a population of just over 5 million people, is often regarded as a global leader in ecological policy (Wallis, 1911). This reputation has been earned through a combination of progressive legislation, innovative conservation programs, and a long-standing commitment to protecting the country's natural resources (Boza, 1993). This section of the review attempts to provide a historical outline of Costa Rican ecological policy, tracing the country's journey from a heavily deforested landscape to a global model of sustainable development. What are some of the innovative conservation programs that Costa Rica has implemented to protect its natural resources? How has Costa Rica's reputation as a global leader in ecological policy affected its economy, society, and international relations? What is being protected?

Dan Janzen played a critical part in the development of the Santa Rosa National Park in Costa Rica. In the 1960s and 1970s, Janzen conducted extensive research in the park, studying the interactions between plants, animals, and their environment (Janzen, 1987).

Through his research, Janzen became increasingly concerned about the threats facing the park, including habitat destruction and poaching. To address these threats, Janzen worked closely with the Costa Rican government and other international conservation organizations to develop a plan for the management and protection of the park. He helped to establish a research station in the park, which became a hub for scientific research and conservation activities.

Professor Janzen also worked to raise awareness about the importance of the park and its biodiversity, both locally and internationally. Janzen's efforts helped to establish Santa Rosa National Park as a model for tropical conservation and research. Today, the park is recognized as a UNESCO World Heritage Site and is one of the most important protected areas in Central America. Amongst the many published research of Dan Janzen's article about the future of dry forests "(Janzen, 1986)" is a thought-provoking piece that challenges traditional approaches to studying tropical ecosystems and calls for a more holistic, interdisciplinary approach.

Dr. Janzen argues that many tropical ecologists have focused too narrowly on the study of individual species or specific ecological processes, and have failed to fully appreciate the complexity and interconnectedness of tropical ecosystems. Janzen suggests that future research in tropical ecology should focus on understanding the interactions between organisms and their environments. He calls for greater collaboration between ecologists, conservationists, policymakers, and local communities, and emphasizes the importance of incorporating social and economic factors into conservation planning.

Janzen also highlights the importance of long-term research in tropical ecology, arguing that studies spanning decades or even centuries are necessary to fully understand the dynamics of tropical ecosystems. He suggests in this article that researchers should focus on identifying key ecological processes and understanding how they interact, rather than simply cataloging the species present in a particular ecosystem.

Dr. Janzen's article provides a persuasive vision for the future of tropical ecology, emphasizing the need for interdisciplinary cooperation, long-term research, and a holistic understanding of tropical ecosystems. His call to action is particularly relevant given the ongoing threats facing tropical ecosystems, including deforestation, climate change, and habitat fragmentation.

This research begins to inform our contextual understanding by painting a detailed picture of deforestation in Costa Rica over time. From the review we begin to build an understanding of the different ecologies found across Costa Rica. Through the literature we begin to identify the dry tropical forest found across the breath of Guanacaste and the Nicoya peninsula as a distinct ecology. Costa Rica is one of the countries that has made significant progress in conservation efforts, and one example of this is the Karen Mogensen Reserve.

There is a complex relationship between conservation efforts and local communities in Costa Rica. Campbell (2002) focuses the conflicts and challenges that arise when conservation initiatives are implemented in areas where people rely on natural resources for their livelihoods. It also discusses the various ways in which communities and conservationists can work together to realize a sustainable co-existence (Campbell, 2002). This article stresses how importance of understanding the perspectives and needs of all stakeholders involved in conservation efforts are to promote effective and just conservation practices.

The National Park System in Costa Rica has been successful in preserving the country's rich biodiversity, due in large part to the government's commitment to conservation and the establishment of protected areas across Costa Rica. There are also challenges facing the National Park System, including the need to balance conservation with local economic development in the form of tourism (Boza, 1993).

Ecological Policies in the Nicoya Peninsula and the Karen Mogenson Reserve

The Nicoya Peninsula, located in the northwest region of Costa Rica, is a unique and ecologically diverse area that has been a focal point of the country's ecological policies (Timm et al., 2009). The peninsula is renowned for its pristine beaches, rich biodiversity, and important ecological corridors. Recognizing the significance of preserving this fragile ecosystem, Costa Rica has implemented specific policies and initiatives to protect and restore the natural resources in the region (Place & Evans, 1999).

A prime example of the outcomes of these ecological policies is the Cabo Blanco Absolute Natural Reserve. A nature reserve located on the southern tip of the Nicoya Peninsula near Montezuma-Cabuya and Mal Pais. It is part of the Tempisque Conservation Area and covers an area of 3,140 acres (12.7 km2) on land and 4,420 acres (17.9 km2) in the marine environment. The reserve was established in 1963 as the first major conservation project in Costa Rica, thanks to the efforts of Nils Olof Wessberg and Karen Mogensen. Prior to its establishment, the land was being cleared for agriculture and pasture, with little regard for the preservation of natural habitats. The establishment of the reserve signifies a strategic step in safeguarding biodiversity hotspots and crucial wildlife habitats across the region. It serves as a vital link between different ecosystems and supports the survival of numerous endangered species.

The policies pertaining to the Karen Mogenson reserve emphasize habitat conservation, the prevention of illegal activities such as logging and poaching, and the promotion of scientific research and education (Janzen & Hallwachs, 2016). Over the decades the integration of specific policies tailored to the unique characteristics of the Nicoya Peninsula and the Karen Mogenson reserve exemplifies Costa Rica's comprehensive approach to ecological management.

The Guanacaste Region: Conservation and Dry Tropical Forests

Classification

The Holdridge classification is a method for categorizing ecosystems based on climate, vegetation, and biodiversity using precipitation, bio-temperature, and potential evapotranspiration ratio. It creates life zones categorized by humidity, latitudinal regions, and altitudinal belts, accounting for both abiotic and biotic factors (Holdridge et al., 1971). The Nicoya Peninsula in Costa Rica has a range of life zones, from dry to wet tropical forests, depending on location and climate. By understanding the Holdridge system it demonstrates ways to clearly define the forest of the KMR.

The book by Kappelle et al. (2015) focuses on the Costa Rican ecosystems provides a comprehensive overview of the diverse ecosystems found in Costa Rica, including the Nicoya Peninsula and the area immediate to the Karen Mogenson Reserve (KMR). This book presents detailed information on the ecological characteristics, biodiversity, and conservation status of these ecosystems, and highlights the importance of understanding the complex interactions between natural and human factors in their management and conservation (Kappelle et al., 2015).

In the section on the Nicoya Peninsula, the authors discuss the unique characteristics of the region's dry forest ecosystems, including the effects of climate change, land use change, and other human activities on their ecological integrity. They also highlight the need for effective conservation strategies that prioritize the protection of key habitats and the promotion of ecosystem services such as carbon sequestration and soil conservation.

The book explores the unique ecological characteristics of the tropical dry forest ecosystem and the recovery following extensive deforestation across the Guanacaste region. The authors provide insights into the successional processes that have driven the ecosystem's recovery, and discuss the importance of maintaining functional diversity and promoting the growth of native species in restoration efforts.

What we are provided with is a valuable insight into the ecological characteristics and conservation challenges of ecosystems in Costa Rica, and stresses the importance of understanding the complex interactions between natural and human factors conservation. It also delineates the dry forest and moist forest environments both as something different yet the same as far as long-term trajectories of forest succession.

<u>What Is A Dry Tropical Forest?</u>

Tropical forests are often associated with humid rainforests, but there are also tropical dry forests. These forests have two distinct seasons: a long dry season with high temperatures, followed by a few months of rainfall. The forest canopy changes with the seasons, and during the dry months, trees shed their leaves to allow sunlight to reach the ground. The rainy season brings an end to this period of dormancy, and leaves gradually grow back. Tropical dry forests have alternating cycles of dry heat and rain, but are still rich in biodiversity and are an important ecosystem to protect (Dexter et al., 2018). Water stress is a major factor affecting tree phenology in the dry forest, with seasonal changes in rainfall influencing the timing of leaf drop and flowering in trees (Reich & Borchert, 1984).

Dexter et al. (2018) argue that tropical dry forests have often been overlooked in discussions of biome transitions, despite being an important and distinct ecosystem in their own right. The article looks carefully at the current state of knowledge on tropical dry forests, including their ecology, biogeography, and conservation status. This the importance of including tropical dry forests in discussions of biome transitions in the tropics, and appeals for greater attention and investment in research and conservation efforts to protect these unique and threatened ecosystems (Dexter et al., 2018). Neglecting these ecosystems has led to a lack of understanding and awareness of their ecological importance relative to other parts of the tropics (Schröder et al., 2021). For example, tropical dry forests are crucial in supporting high levels of insect diversity and ecosystem functioning (Janzen, 1987), and in Central America TDFs exhibit high levels of diversity, including many endemic species, specially adapted to harsh condition found in these environments (Gillespie et al., 2000).

Deciduous Forests Of Guanacaste

The Guanacaste region in Costa Rica is known for its dry tropical forest, which is characterized by a mix of deciduous and evergreen trees (Dexter et al., 2018). The deciduous forest in Guanacaste are one of the most biologically diverse and an ecologically important habitats in the Costa Rica. Deciduous forests across Guanacaste are characterized by trees that lose their leaves during a particular season, usually in response to changes in temperature or rainfall (Portillo-Quintero & Sánchez-Azofeifa, 2010). In Guanacaste, the dry season, which runs from December to May, is the time when many of the trees in the deciduous forest lose their leaves (Calvo-Alvarado et al., 2009).

Some of the most common tree species found in the deciduous forest of Guanacaste include the Guanacaste tree (*Enterolobium cyclocarpum*), the pochote tree (*Pachira quinata*), and the teak tree *(Tectona grandis*). These trees provide important habitat for a variety of wildlife, including birds, mammals, and reptiles (Janzen & Hallwachs, 2016).

Gerhardt and Hytteborn (1992) describe the various regeneration strategies of tree species in the deciduous forest of Guanacaste, including sprouting from the root crown or stem, germination from seed, and re-sprouting from epicormic sources. It highlights the importance of animal dispersal of seeds and the role of disturbances in creating gaps that allow for successful seed germination and establishment (Gerhardt & Hytteborn, 1992). A rudimentary understanding of succession we begins to develop through this literature and leads to the questions: 1) What are the specific factors that influence the rate and direction of succession in different ecosystems? 2) To what extent have the human activities such as land use change alter natural patterns of succession? 3) To what extent have the human activities such as land use change alter natural patterns of succession? And, most important to the project overall, 4) How can we balance the need for active management and restoration with the recognition of the value of allowing natural processes of succession to occur?

Laurance et al. (2014) highlight the environmental and social consequences of large-scale agriculture, including deforestation, detailing the great loss of biodiversity, soil degradation, and introduction of invasive grass species. They also discuss the drivers of Costa Rica's agricultural expansion, including the global demand for beef and pharmaceutical plant compounds. The article further explores the potential trade-offs and synergies between agricultural production and conservation efforts (Laurance et al., 2014). This study provides a critical backdrop for understanding the challenges faced by areas such as the Karen Mogenson reserve, particularly with respect to the regeneration of the secondary tropical dry forests (STDF). This reserve, located in the Guanacaste province of Costa Rica, has experienced significant impacts from past agricultural activities, aligning with the large-scale environmental issues discussed in the study.

Agricultural expansion, largely driven by global demand for products such as beef, has led to deforestation, biodiversity loss, and soil degradation in regions like Guanacaste. As the reserve lies in this region, it's reasonable to infer that it has faced similar issues. These historical land use changes, and the environmental impacts associated with them, have initiated the process of secondary succession in the reserve's STDF.

To restore and conserve the STDF in the Karen Mogenson reserve, it is crucial to understand the implications of these land changes and how they have affected forest regeneration. Insights from the Laurance, Sayer, and Cassman study can guide efforts to identify and mitigate ongoing threats to the reserve's forests, such as the potential for invasive grass species to hinder regeneration (Laurance et al., 2014). Furthermore, the study's exploration of the trade-offs and synergies between agricultural production and conservation efforts could inform strategies to sustainably manage land use in and around the reserve, balancing both local economic needs and environmental preservation.

This opens the door to understanding the land changes that lead to secondary succession in more depth, along with many of the issue that are joined with conservation of the dry forest across Guanacaste. For example, Williams & Baruch (2000) focuses on the urgent need for effective management and conservation strategies to address the negative impacts of invasive African grasses on tropical dry forests (Williams & Baruch, 2000). By understanding issues like invasive grasses in Costa Rica we begin to comprehend the overall factors affecting recovery of tropical dry forests and thus tropical forest succession. Invasive species are one of the many stressors that can disrupt the natural patterns of succession and ecological processes in tropical forests, which can have cascading effects on biodiversity.

Moving through this literature review, we pose more questions:

- What is Secondary succession and how is it expressed in a tropical dry forest ecosystem?
- What are the basics of tropical succession in Costa Rica?
- What are the mechanics tropical succession in a recovering dry forest?

McClellan (2014) found that private forests generally had lower species richness and diversity compared to public forests, but had higher tree density and basal area. The private forests also had lower levels of ecosystem functions such as carbon storage and soil fertility. The study suggests that these differences may be due to differences in land use history. This research can develop our understanding of the ecological dynamics of tropical dry forests in Guanacaste, and the role of different land tenure systems in shaping their structure, biodiversity, and ecosystem functions (McClellan, 2014).

Céspedes et al. (2003) studied the restoration of genetic diversity in the *Swietenia macrophylla* (Big-leaf Mahogany) after pasture abandonment. The study deeply analyzes the role of external seed input and survival strategies of species like *Swietenia macrophylla* in forest regeneration. It underscores the necessity of understanding genetic diversity patterns in post-agricultural landscapes for effective restoration strategies (Céspedes et al., 2003).

Through this review we begin to understand what a recovering dry forest environment, as recovery occurs. Griscom and Ashton (2011) reviewed the patterns and processes involved in the restoration of dry tropical forests in Central America. The article discusses various factors that influence the success of restoration efforts, such as the availability of propagules(structure that can become detached from a plant and give rise to a new a plant), soil properties, and disturbance regimes (Griscom & Ashton, 2011). By understanding these factors and implementing effective restoration strategies, we may be able to improve conservation and restoration efforts in the region.

Kapelle et al. (2017) offer an overview of the ecological and conservation status of the Northern Pacific lowland seasonal dry forests in the Guanacaste and Peninsula de Nicoya regions of Costa Rica. The article highlights the high biodiversity and endemism of the region. The research presented also informs on the threats to the ecosystem from staple human activities such as deforestation, cattle ranching, and agriculture. They discuss the conservation efforts undertaken in the region, including protected areas and detail restoration projects in this zone (Kappelle et al., 2017).

Quesada & Stoner (2004) identify various threats to tropical dry forests in Costa Rica, including deforestation, agricultural expansion, hunting, and urbanization. The authors discuss the challenges faced by the conservation efforts in Costa Rica, including insufficient funding, lack of community participation, and limited government support. They close by stressing the need for increased conservation efforts and community involvement to protect tropical dry forests in Costa Rica, and suggest several strategies for achieving this goal (Quesada & Stoner, 2004).

Tropical Dry Forest Succession

Succession in the Karen Mogenson Reserve (KMR) in Costa Rica is a complex and dynamic process that involves the probable changes in plant and tree communities over time following recovery from a disturbance event, such as deforestation from ranching. Tropical dry forests (TDFs) are one of the most threatened and understudied ecosystems in the world (Janzen, 1986). They occur in regions with a seasonal climate and are characterized by a long dry season followed by a shorter rainy season. These forests support high levels of biodiversity and provide important ecosystem services, such as carbon sequestration and water regulation (Janzen, 1988). However, they are under threat from human activities such as logging, agriculture, and urbanization, leading to extensive deforestation and habitat fragmentation (Dimson & Gillespie, 2020).

Chazdon et al. (2010) investigate the patterns of tree functional group composition and dynamics during forest succession in northeastern Costa Rica. The study provides valuable insights into the complex processes that underlie tropical forest succession in this region. It also expands our understanding of how forests transition from open areas to mature ecosystems across the Nicoya peninsula. One important highlight is the critical role that functional diversity plays in driving forest succession in dry tropical forests. These researchers argue that a diverse mix of functional groups is necessary for maintaining ecosystem processes and services, and that restoration efforts should prioritize the promotion of functional diversity in degraded forest areas (Chazdon et al., 2010).

The article by Quesada et al. (2009) provides us with a broad review of the ecological processes that underlie tropical dry forest succession in the Americas, and offers new perspectives on how to manage and restore degraded dry forest ecosystems. This allows us a way to compare different land use recovery scenarios.

These authors identify a number of key factors that influence tropical dry forest succession, and included climate, soil conditions, seed dispersal, and disturbance events such as fire and human activity. Most notably, they highlight how important the understanding of specific dynamics of each stage of succession in order to develop effective management strategies for promoting ecosystem recovery (Quesada et al., 2009). This article emphasizes the importance of considering the complex interactions between ecological processes and human activities in managing and restoring tropical dry forests. It provides valuable insights into the factors that drive forest succession in our area of study of Guanacaste.

Reich and Borchert (1984) investigated the effects of water stress on tree phenology in a tropical dry forest ecosystem in the lowlands of Costa Rica. The study finds that trees in the dry forest are highly sensitive to changes in water availability, with leaf shedding and bud formation occurring in response to periods of water stress. The study also identifies a range of biotic and abiotic factors that influence tree phenology in the ecosystem, including light availability, soil nutrients, and fluctuating temperatures (Reich & Borchert, 1984). This study provides important understandings into the mechanisms underlying tree phenology in tropical dry forests, and underscores the importance of understanding the complex interactions between plant species and environmental factors in these ecosystems. It answers the question how is secession in a TDF expressed over time.

Daubenmire (1972) investigated the phenology and other ecological characteristics of a tropical semi-deciduous forest ecosystem in northwestern Costa Rica. The study identified the key plant species in the ecosystem and describes their phenological patterns, including leafing and flowering times across a number of tree species. This study also provides insights into the environmental factors that influence plant phenology in the tropical semi-deciduous forest ecosystem found across Guanacaste. It stresses the importance of ecological succession in shaping the structure and composition of the ecosystem, with different stages of succession characterized by different plant species and community structures (Daubenmire, 1972). For our study this research provides a basis for further research on the structure and function of tropical semi-deciduous forests that make up the secondary recovery we are directly looking at in our project.

We continue to delve into the existing literature to further elucidate and comprehend the distinct manifestation of tropical forest succession within the specific environments studied in this research. Hertel et al. (2003) examined the size and structure of fine root systems in old-growth and secondary tropical montane forests in Costa Rica. They found that old-growth forests have significantly higher fine root biomass and root length density than secondary forests, showing that they have a more developed root system that is better adapted to nutrient and water uptake (Hertel et al., 2003).

This research offers valuable insights into the processes that drive forest succession in tropical montane forests, and emphasizes the importance of considering the specific environmental conditions that shape these dry ecosystems. The study highlights the unique adaptations of the dry forests, which are capable of thriving even with minor changes in elevation and precipitation. Simililarly, Powers et al. (2009) found that the structure and composition of regenerating forests are strongly influenced by environmental factors such as soil type, topography, and precipitation, and that different regions exhibit distinct patterns of forest regeneration. Understanding the influence of such environmental factors is crucial in the context of the Karen Mogenson Reserve. The reserve features a mix of ecosystems, including both dry and moist forests, which are undoubtedly influenced by these local conditions. By applying the insights from the study (Powers et al., 2009), it can infer how differences in these factors can lead to variations in the patterns of forest regeneration across the reserve.

This study goes on to suggests that effective conservation and restoration strategies should be tailored to local conditions based on historic land usage. Additionally, the study underscores the importance of promoting the growth of native plant species and maintaining functional diversity in forest regeneration efforts. This study provides a good source of information for understanding the complex ecological processes that drive forest regeneration in tropical dry forest ecosystem (Powers et al., 2009).

The life traits of lianas in tropical forest across succession is an important topic as well. Lianas exhibit a range of life history strategies that are influenced by the environmental factors such as light availability, soil nutrients, and plant density that generate competition with other plant species (Letcher & Chazdon, 2012). We learn through this research the importance of considering the role of lianas in these dry forests and how they affect succession, shaping canopy structure and limiting tree species based on its ability to dominate during specific stages of succession.

Wildlife in Tropical Dry Forests

Timm et al. (2009) examined the history, diversity, and conservation of mammals in the Cabo Blanco dry forest ecosystem in Costa Rica, 45 years after a regeneration process was initiated. The study highlights the importance of preserving the ecosystem's biodiversity. The study finds that the Cabo Blanco forest has experienced a significant increase in mammal diversity and abundance over the 45-year period since regeneration efforts began (Timm et al., 2009). Cabo Blanco was a cattle ranch before it was turned into a nature reserve, and the study of mammal diversity in the reserve can provide insights into how the forest has recovered over time (Timm et al., 2009). This study is in the direct region where our study is located and can provide valuable insights into both regional biodiversity and forest succession in a forest study of the Karen Mogenson reserve. This study can also provide a useful reference point for comparing the biodiversity of the Karen Mogenson reserve. Their study compared the mammal diversity in different parts of the reserve, allowing researchers can identify which areas have recovered the most and which ones still show signs of disturbance.

Dal Zotto et al. (2017) identified a diverse and unique avian community in the Karen Mogensen Reserve, including several endangered and threatened species, highlighting the importance of protecting and conserving the reserve's in the face of external environmental threats. This work is a way of directly understanding the reserve's biodiversity and dimensions in preparation for this projects forest survey. The maps in this study were helpful and heavily adapted to our own study since they provided a strong visual representation of the complicated features of the Karen Mogenson Reserve**.**

Deforestation as a Threat to Tropical Dry Forests

Deforestation is a critical environmental issue in Guanacaste, Costa Rica, just as it is in many parts of the world (Laurance et al., 2014). Guanacaste, in particular, has experienced noteworthy changes in land use over the past several decades, which have resulted in the conversion of many of its dry tropical forests into agricultural and urban lands (Calvo-Alvarado et al., 2009). The subject of deforestation is of great importance as laid out in much of this research into the area of conservation and regeneration across this study. Below we explore how deforestation outcomes are expressed.

Ecological Importance:

Guanacaste boasts valuable dry tropical forests with rich biodiversity, including endemic and threatened species (Arroyo-Mora et al., 2005). Converting these forests to agriculture and urban areas disrupts habitats, risking the loss of unique and irreplaceable species.

Environmental Impacts:

Deforestation in Guanacaste has severe environmental consequences (Calvo-Alvarado et al., 2009). It eliminates carbon sinks, worsens climate change, and disrupts ecosystems. The absence of tree cover leads to soil erosion, decreased water quality, altered hydrological cycles, and heightened vulnerability to floods and landslides. These impacts greatly affect the region's ecosystem services, including water and climate regulation.

Socioeconomic Significance:

The deforestation process in Guanacaste has socioeconomic implications for local communities. It often involves the expansion of agribusiness, which can lead to changes in land tenure, livelihoods, and traditional agricultural practices (Sattler & Matzdorf, 2013). The loss of forest resources affects the availability of timber, non-timber forest products, and ecosystem services that communities rely on for their well-being and livelihoods (Matulis, 2013).

<u>Factors Influencing Deforestation and Forest Across the Nicoya Peninsula</u>

This study considers some of the pattern of deforestation and its main drivers in the region including, agriculture, cattle ranching, and the growth in urban development (Boza, 1993). These activities often lead to the fragmentation of forests into isolated patches, which can impact the biodiversity and ecosystem functioning within these patches.

Seed Dispersal:

The patchwork nature of forest recovery in the Nicoya Peninsula is influenced by the process of seed dispersal (Buzzard et al., 2016). The proximity of a recovering patch to a mature forest can significantly influence its recovery rate, as the mature forest serves as a source of seeds. The role of animals, particularly birds and mammals, is also crucial in seed dispersal and, therefore, in forest recovery.

Drivers of Regeneration

Secondary forest regeneration in the Guanacaste/Nicoya region of Costa Rica, like in other seasonal dry tropical forests are often driven by a combination of natural processes and human interventions(Quesada & Stoner, 2004). Research has shown that over the last hundred years, many of these factors or pressures have accelerated, taking their toll on the recovery of areas (Boza, 1993). Through the research of pertinent literature this study identifies the most common drivers of forest regeneration.

Natural Processes:

In seed dispersal animals play a crucial role in seed dispersal, and certain tree species are specifically adapted to take advantage of this (Derroire, 2016a). For instance, some trees produce fruits that are attractive to birds, which eat the fruits and disperse the seeds in their droppings. In Guanacaste, birds, bats, and monkeys are vital seed dispersers (Melin et al., 2020).

Fire:

Fire can be an essential component of SDTFs, influencing the composition and structure of the vegetation (Laurance et al., 2014). Some tree species are adapted to survive or even require fire for germination. Modern use of fire in Seasonal Dry Tropical Forests (SDTFs) include controlled or prescribed burning techniques (Campos-Vargas & Vargas-Sanabria, 2021). These practices mimic natural fire regimes and have specific objectives, such as reducing fuel loads, controlling invasive species, promoting plant diversity, and restoring tree and vegetation structures (Chazdon, 1998).

Human Interventions:

Restoration efforts in Guanacaste, there have been important efforts to restore SDTFs (Boza, 1993). This often involves planting native tree species, controlling invasive species, and managing fire. The Área de Conservación Guanacaste (ACG), a large protected area in the region, has been particularly active in these restoration efforts(Janzen & Hallwachs, 2016). The ACG goes beyond conservation efforts by promoting sustainable land management, community engagement, and environmental education (Janzen & Hallwachs, 2016). Through stewardship programs, they connect people to the land, fostering responsibility and ensuring long-term preservation of the ecosystems. These efforts strengthens the bond between communities and their surroundings, fostering a shared commitment to conservation. Through these comprehensive conservation efforts, the ACG has played a vital role in restoring and protecting the biodiversity and ecological integrity of the Guanacaste region.

Land Use Changes:

Changes in land use, such as the abandonment of agricultural lands, can also drive secondary forest regeneration (Arroyo-Mora et al., 2005). When fields and pastures are no longer encouraged, native vegetation can return. PES programs also help to create incentives to conservation, leading to positive conservation land change from pasture to secondary regrowth (Daniels et al., 2010).

Key Tree Species Of Guanacaste, Their Importance And Adaptations For Recovery.

As dry forests recover and begin to take shape, some particular species play an important parts of this recovery. These tree species that are predominantly found in the regenerating secondary forest seen across the Guanacaste region. Their presence are often due to traits making them more fire-resistant or adapted to hot, dry conditions, of Costa Rica (Gerhardt & Hytteborn, 1992). Trees in the *Fabaceae* family are iconic in this region for both their tenacity to survive and its ability to resist the heat and stand tall. Most prominent: Cenízaro (*Samanea saman*) Palo Verde (*Parkinsonia spp*.) Tempisque (*Senna spp.*) Caro Caro (*Copaifera spp.*) Madre de Cacao (*Gliricidia sepium*), and Guácimo (*Guazuma ulmifolia*).

The trees of the dry forests in Guanacaste, Costa Rica, possess remarkable adaptations to thrive in the region's hot and dry conditions (Reich & Borchert, 1984). They exhibit traits such as deep root systems, drought-tolerant leaves, and fire-resistant characteristics (Kappelle et al., 2017). Dry forests in Guanacaste, dominated by the Fabaceae family, contribute to the enrichment of soil fertility through nitrogen fixation (Kappelle et al., 2017). The patchwork of dry forest, with their spreading canopies, create shade, stabilize soils, and provide habitats for diverse wildlife (Juan-Baeza et al., 2015). The conservation of these trees is crucial to maintain the biodiversity, ecosystem functions, and resilience of Guanacaste's threatened dry forests (Janzen & Hallwachs, 2016). Below is a known list of important tree that play a major role as dry forest recovery (Table 1).

Table 1 Trees that play a major role as dry forests recover

Name (*Scientific Name)*	Notes
Guanacaste Tree (*Enterolobium cyclocarpum*)	Also known as "Elephant Ear" or "Monkey Ear," the Guanacaste tree is an iconic and majestic tree in the region. It has a wide canopy, distinctive round seed pods, and provides valuable shade and habitat for wildlife.
Palo Verde (*Parkinsonia spp.*)	Palo Verde trees are well-adapted to arid environments and have green bark and small, delicate leaves. They are known for their vibrant yellow flowers and play a vital role in the dry forest ecosystem.
Wild Tamarind (*Leucaena leucocephala*)	Wild Tamarind is a fast-growing tree with compound leaves and white flowers. It is valued for its nitrogen-fixing ability and is often used for reforestation and soil improvement projects.
Cenízaro (*Samanea saman*)	Also called rain tree or monkey pod, the cenízaro is a large, spreading tree with a wide canopy. It produces pinkish flowers and characteristic flat seed pods.

Secondary Regeneration In Seasonal Dry Tropical Forests

Secondary regeneration in Seasonal Dry Tropical Forests (SDTFs) often results in forests that exhibit distinct differences from the original, undisturbed forests. These differences encompass various aspects of the ecosystem. In terms of species composition, secondary forests tend to have a different mix of species compared to primary dry forests, with a higher abundance of early successional species and a lower representation of late successional or climax species (Derroire, 2016b) Pioneer species, characterized by their fast growth and opportunistic nature, dominate secondary forests as they quickly colonize open areas after disturbances.

Structurally, secondary forests have lower tree density, reduced vertical stratification, and a simplified canopy structure, in contrast to the well-developed stratification and diverse array of tree heights and sizes found in primary forests (Derroire, 2016a). The overall biomass and tree height may also be lower in early stages of secondary regeneration.

Comparatively, primary dry forests undergo a gradual successional process over an extended period, progressing from early to mature or climax stages, while secondary growth forests often represent early or intermediate successional stages as they recover from disturbances (Chazdon et al., 2010). Subsequently, vegetation structure, species composition, and ecological dynamics differ between primary and secondary forests (Derroire, 2016b).

Primary dry forests have had more time to develop complex ecological processes and provide essential ecosystem services such as carbon storage, nutrient cycling, water regulation, and habitat provision (Kappelle et al., 2015). While secondary forests can gradually regain some of these functions, they may not fully replicate the intricate ecological interactions and services of undisturbed primary forests (Chazdon et al., 2010). Much can be lost in across all composition and function of the forest as they mature.

Primary dry forests also encompass a longer timeframe of uninterrupted growth and development, spanning centuries or even millennia, compared to the relatively recent regeneration of secondary forests. This disparity in timeframe influences the level of ecological maturity and the presence of long-lived, late successional species in primary forests (Gerhardt & Hytteborn, 1992). Due to their high biodiversity, unique species assemblages, and critical ecological roles, primary dry forests hold important conservation value. They often harbor rare, endemic, and threatened species that may be less common or absent in secondary forests, underscoring the importance of protecting and restoring primary dry forests to safeguard these ecological and conservation treasures. Below we present some key distinctions observed between primary and secondary growth in the Guanacaste region.

Species Composition:

Secondary forests often have different species composition compared to primary forests. Early stages of secondary forests are usually dominated by fast-growing, pioneer species that are adapted to high light conditions (Chazdon et al., 2010).. Over time, as the forest matures, you'll see a shift towards more shade-tolerant species, but the specific composition can be influenced by a variety of factors including seed dispersal mechanisms, local seed sources, and disturbances during the recovery process.

Forest Structure:

Secondary forests often have a simpler structure compared to primary forests. They tend to have smaller trees, a lower canopy, and less structural complexity, at least in the early to mid-stages of succession (Chazdon et al., 2010). Over time, the structural complexity may increase as the forest matures.

Biodiversity:

While secondary forests can support high levels of biodiversity, they often have lower biodiversity compared to primary forests, especially in terms of certain groups like specialist or endemic species (Janzen & Hallwachs, 2016).

Soil and Nutrient Cycling:

Disturbances that lead to secondary succession can have a profound impact on soil properties and nutrient cycling (Leiva et al., 2009)). Secondary forests often have different soil characteristics compared to primary forests, which can in turn influence plant growth and species composition.

By developing understanding of these differences in secondary forest regeneration in SDTFs foster essential knowledge for understanding the core of this research study. Through our literature research this study can identify the key ecological processes, to target in a survey and broaden our effort to understand the regenerated forests of the Karen Mogenson reserve.

The secondary forest regeneration in seasonal dry tropical forests (SDTFs) follows a distinct trajectory and exhibits notable differences compared to undisturbed forests. The successional stages, characterized by early, middle, and late successional species, play crucial roles in the recovery of these forests following disturbances. The species composition, structural characteristics, functional traits, and regeneration mechanisms of secondary forests differ from those of undisturbed forests, influenced by factors such as disturbance type, seed availability, soil conditions, and environmental factors unique to SDTFs.

While secondary forests contribute to biodiversity conservation, they may not fully replicate the ecological functions and species diversity of undisturbed forests. Understanding the differences is crucial for effective forest management and restoration strategies. It is also important for assessing the ecological integrity and resilience of the regenerated forests in the Karen Mogenson reserve and other similar dry ecosystems.

<u>Comparative Traits of Primary and Secondary Forests</u>

Secondary forest regeneration in seasonal dry tropical forests (SDTFs) can exhibit several notable differences compared to the original, undisturbed forests (Dimson &

Gillespie, 2020). Here are the key distinctions observed between primary forests and secondary growth in the Guanacaste region.

Successional trajectory:

The secondary regeneration process in SDTFs may follow a different successional trajectory compared to undisturbed forests (Derroire, 2016b). Factors such as the type and intensity of disturbance, seed availability, and soil conditions can influence the composition and structure of the regenerating forest (Lebrija-Trejos et al., 2011). This can result in a different mix of tree species and altered community dynamics.

Species composition:

Secondary forests often have a distinct species composition compared to undisturbed forests (Buzzard et al., 2016). While some original species may recolonize the area, others may be absent or occur in lower abundances. The dominance of pioneer species, which are typically fast-growing and have high seed production, is often observed in early stages of secondary regeneration (McClellan, 2014).

Structural characteristics:

The structural attributes of secondary forests may differ from those of undisturbed forests (Buzzard et al., 2016). Regenerating forests tend to have lower tree density, reduced vertical stratification, and simplified canopy structure. The overall biomass and tree height may also be lower, especially in the early stages of regeneration.

Functional traits:

The functional traits of regenerating trees may differ from those in undisturbed forests. For example, secondary forest species may exhibit higher specific leaf area (SLA) and faster leaf turnover rates, which are traits associated with rapid growth and resource acquisition (Chazdon et al., 2010). These traits can influence ecosystem processes such as nutrient cycling and carbon sequestration. In forest succession, "functional traits" are specific characteristics of plant species that influence their roles and interactions in an ecosystem during different stages (Schwartz et al., 2022). These traits include leaf and root traits, growth rate, reproductive strategies, and response to disturbances. Advantages of different traits vary based on available resources, light, competition, and disturbances during succession.

Regeneration mechanisms:

SDTFs often face specific challenges in regeneration due to the pronounced seasonality, drought, and other environmental factors (Castro et al., 2018). In the absence of specific adaptations, secondary regeneration in SDTFs may rely on mechanisms such as re-sprouting from root or stem fragments, seed dormancy, or seed banks (Buzzard et al., 2016). These mechanisms can influence the species composition and regeneration success of the secondary forests.

Biodiversity conservation:

While secondary forests can contribute to biodiversity conservation, they may not fully replicate the ecological functions and species diversity of undisturbed forests (Kappelle et al., 2017). Some specialized or slow-growing species, including certain rare or endemic species, may struggle to reestablish themselves in secondary forests. So, it is crucial to consider both the ecological and conservation value of secondary regeneration in SDTFs. Regenerating forests represent early or intermediate successional stages, while undisturbed forests encompass mature or climax stages. While secondary forests gradually, over time, recover some ecological functions, they may not fully replicate the complex interactions and species diversity of undisturbed primary forests (McClellan et al., 2018).

The unique challenges of SDTFs, such as intense seasonality and drought, greatly influence the regeneration mechanisms and success of secondary forests. Therefore, the conservation value of secondary regeneration in SDTFs should be considered, recognizing that specialized or slow-growing species might face challenges in reestablishing themselves. Understanding these differences is crucial for the development of effective forest management, restoration strategies, and the general conservation of SDTFs.

Regeneration Process of Secondary Forests in Guanacaste's SDTFs

In the Guanacaste region of Costa Rica, secondary forest regeneration is driven by several factors. One important factor is the presence of a seed source from remnant forests or neighboring areas, which allows for the dispersal of tree seeds into the regenerating areas (Buzzard et al., 2016). Additionally, the role of animals, particularly frugivorous animals such as birds and mammals, this is crucial in the dispersal of seeds and the establishment of new tree species in the regenerating forests (Kappelle et al., 2015).

Certain tree species play a noteworthy role in the process of secondary forest regeneration. Pioneer species, characterized by their ability to quickly colonize disturbed areas, often dominate the early stages of regeneration. Examples of such pioneer species in the Guanacaste region include *Cecropia spp.*, *Vochysia spp.*, and *Trema micrantha*. These trees provide the initial structure and habitat for other plant species to establish and thrive. Invasive have a role but it was not the focus other than an observational context (Chazdon et al., 2010).

The research on forest regeneration processes and the interactions among trees, plants, and animals has revealed valuable insights into the intricate evolutionary relationships and specialized adaptations that have developed between species in response to their environment and each other (Griscom & Ashton, 2011).

Researchers are studying the seed dispersal networks and the specific roles of different animal species in seed dispersal and forest regeneration (Place & Evans, 1999). They are also investigating the dynamics of tree communities in regenerating forests and how these communities change over time. Researchers are employing various techniques such as field surveys, camera trapping, and the use of GPS tracking devices to monitor animal movements and seed dispersal patterns (Quesada et al., 2009).

The valuable insights developed from these research efforts on secondary forest regeneration have not only helped to advance the understanding of ecological processes but also hold implications for environmental policies and conservation initiatives. By informing the development of effective conservation and restoration strategies, including the promotion of specific animal populations and identification of key tree species, this research has played a pivotal role in shaping the history of Costa Rican ecological policy.

What are the characteristics and indicators of dry forest recovery?

What does dry forest recovery look like in the Karen Mogenson reserve? Dry forest recovery encompasses various indicators that demonstrate the restoration and rejuvenation of these ecosystems. As disturbances like fire, logging, or agricultural activities occur, the regrowth of vegetation becomes a primary sign of recovery (Oberleitner et al., 2021). Pioneer species quickly colonize the disturbed areas, paving the way for a succession of plant species, including shade-tolerant and late-successional ones.

Alongside vegetation regrowth, increased biodiversity emerges as more plant species, animals, and insects return to the area, fostering a vibrant and ecologically balanced ecosystem (Derroire, 2016b). The recovering dry forest undergoes canopy closure, characterized by a denser and more closed canopy, as taller trees grow and fill gaps, intensifying competition for light. Simultaneously, the process enhances soil quality by accumulating organic matter, enhancing nutrient cycling, and improving fertility. The return of diverse wildlife species, such as birds, mammals, reptiles, and insects, signifies the restoration of ecological processes and the availability of suitable habitat (Leiva et al., 2009). These observable changes illustrate the remarkable journey of dry forest recovery, influenced by factors such as disturbance type, intensity, climate conditions, and the surrounding landscape context.

Recovery Expressed

How is recovery expressed in the area of Guanacaste/Nicoya's dry forests? Understanding the recovery process in the Guanacaste/Nicoya dry forests is vital for informing effective conservation efforts in the region. As we explore this topic, it is important to consider the various factors that contribute to the unique recovery patterns observed in this area and the implications for how these forests are approached for conservation and future management.

Our definition of recovery is based on our found literature. In the context of forest regeneration, "recovery" typically refers to the process by which a forest ecosystem returns to its original state or develops towards a new ecological state after it has been disturbed or degraded. This process involves the re-establishment of the forest's structure, function, and species composition over time (Dimson & Gillespie, 2020). The "recovery" of tropical dry forests in the Guanacaste and Nicoya regions of Costa Rica is a complex process that is expressed in several observable ways:

Vegetation Changes:

Forest recovery begins with the colonization of pioneering species, which are typically fast-growing plants that can survive in harsh conditions (Daubenmire, 1972). Over time, as the forest matures, these species are replaced by more shade-tolerant species, leading to increased plant diversity (Juan-Baeza et al., 2015). The structure of the forest also changes, with the development of a multi-layered canopy and an increase in the size and density of trees.

Biodiversity Increase:

As the forest structure becomes more complex, the biodiversity of the area also increases (McClellan et al., 2018). This includes not only plant species but also animals, insects, and microorganisms. The return of large mammals, birds, and insects is a significant sign of recovery, as these species play crucial roles in ecosystem functions such as pollination and seed dispersal.

Soil Improvement:

The recovery process also leads to changes in soil composition(Hertel et al., 2003). The presence of vegetation improves soil quality by adding organic matter and preventing soil erosion. Over time, this creates a richer, more fertile soil that can support a wider variety of plant species.

Water Cycle Regulation:

As the forest recovers, it can better regulate the water cycle (Chapman et al., 2020). Trees and plants absorb rainfall, reduce runoff, increase groundwater recharge, and maintain higher levels of humidity within the forest (Gillespie et al., 2000). This can help to mitigate the effects of the dry season.

Carbon Sequestration:

Mature forests are carbon sinks, meaning they absorb more carbon dioxide from the atmosphere than they release (Stan & Sanchez-Azofeifa, 2019). As the forest recovers and more trees grow, the forest's capacity for carbon sequestration increases, contributing to climate change mitigation.

Cultural and Economic Recovery:

Forest recovery also benefits local communities. Forests provide a range of ecosystem services, including provision of food and medicinal plants, water purification, and opportunities for ecotourism (Calvet-Mir et al., 2015). The return of these services is an important aspect of what can be considered robust forest recovery in the Guanacaste/Nicoya regions. This helped to inform the survey in terms of observable criteria that could be included into this study.

The Karen Mogenson reserve is located within the Tempisque conservation zone (ACT Área de Conservación Tempisque). The reserve is a valuable site for observing and studying the recovery process of tropical dry forests in the Guanacaste/Nicoya regions. Its relative isolation from rest of the peninsula has allowed this area to recover with little human intervention over a long period of time. By closely examining the patterns of forest succession and recovery within this reserve, we hope to can gather essential data informing on how these forests recuperate over time.

As we move towards conducting the survey portion of this research in the Karen Mogenson reserve, again the literature and findings of Gillespie on the diversity, composition, and structure of tropical dry forests in Central America have furnished a robust framework to identify and integrate the key characteristics that will guided this survey work (Gillespie et al., 2000).

Succession stages:

By observing and documenting the various stages of forest succession within the reserve, we can identify through the data different recovery process and try to identify patterns or trends in data that may be unique to the region or specific to environmental conditions found in the reserve. Stand age also offers insight into which species are present at different stages of forest development (Gillespie et al., 2000). This would help clarify which stages of succession are currently represented in the Karen Mogenson reserve area.

Species composition:

Identifying and cataloging the plant present in the reserve will help in developing understanding about the changes in species composition over time as the forest here recover at differing rate. This information is crucial cataloging the region's unique biodiversity. Our focus on tree diversity and composition will offer specific details about the tree species present in these transitional forests. This data will also provide a point of comparison for evaluating the immense tree biodiversity of the Karen Mogenson reserve.

Impact of human intervention:

Assessing the role of human activities, both positive and negative, on forest recovery within the Karen Mogenson Reserve can help inform conservation strategies and policies. Understanding the consequences of land use practices, such as agriculture and cattle ranching, as well as the benefits of community engagement and ecotourism, can contribute to the development of sustainable and balanced approaches to managing the region's forests.

By integrating these aspects of forest recovery into the survey work conducted in the Karen Mogenson Reserve, this research can gain a more comprehensive understanding of the complex processes involved in the regeneration of the reserve's unique transitional dry forests.

Conclusion

This research looks to the literature to provide a historic context that fills the gaps in information that allow us to better understand conditions seen in Costa Rica today. This review looks at ecological history of Costa Rica that will provide critical information about its past and present environmental conditions. This in turn informs our understanding regarding the future of conservation of Costa Rica. By studying the unique regional ecological history, this review attempts to identify patterns and trends in ecosystem dynamics, and understand the impacts of human activities regionally.

In addition to understanding the past and present environmental conditions of Costa Rica, studying the ecological history of the greater region can also provide insight into the potential future of conservation efforts across the region of Central America. By analyzing the patterns and trends in ecosystem dynamics, this review can identify areas that may be particularly vulnerable to environmental degradation or that may require special attention in future conservation efforts.

The ecological history of the greater region can provide critical insights into the potential future of conservation efforts in Costa Rica and beyond. By analyzing patterns and trends in ecosystem dynamics and understanding the impacts of human activities regionally, we can identify not only the areas in Costa Rica that require conservation attention but also the broader patterns that may be applicable to other regions facing similar environmental challenges.

This review uses literature to understand the ecological history of Costa Rica, which informs our understanding of its past, present, and future environmental conditions. By studying the unique regional ecological history, it identifies patterns and trends in ecosystem dynamics and the impacts of human activities. This analysis can also provide insight into the potential future of conservation efforts in Central America. By identifying areas that are vulnerable to environmental degradation or require special attention, this review can contribute to more effective conservation strategies in Costa Rica and beyond.

This study having conducted a thorough literature review, has provided a solid base of understanding of the topics surrounding tropical dry forest and its dynamic functions. We defined what is a tropical dry forest and the many characteristics that influence the forests long term development. Building upon this foundation, the goal was to develop a framework or methodology that will enhance overall comprehension of tropical forest succession in the area of Karen Mogenson.

Methods

The Karen Mogensen Reserve

The selection of the Karen Mogensen reserve was driven by its protection and land use history. Its remarkable characteristics offer a unique opportunity to directly observe and study forest succession and its expression within the reserve. In contrast, the Santa Rosa National Park, while also a suitable location for similar surveys, was not chosen due to the presence of many more deliberate scientific human intervention and managed restorative practices. These interventions may have influenced the development of forest characteristics that deviate from those typically observed in more isolated dry forests. By focusing on the Karen Mogensen area, the research environment more closely aligns with the natural dynamics of transitional dry forest ecosystems, providing a robust foundation for accurate and meaningful findings.

Moist and dry tropical forests each have distinct characteristics:

The Karen Mogenson Reserve (KMR) is a diverse location, home to examples of both moist and dry tropical forests. Over time the reserve has growth acquiring adjacent ranches, providing good examples of abandoned pastureland. This mix of ecological habitats presents a remarkable environment for studying forest succession, providing researchers a rare opportunity to analyze the intricate dynamics of forest recovery and regeneration within varying forest types.

Moist and dry tropical forests each have distinct characteristics and succession trajectories, making them intriguing areas of study (Kappelle et al., 2015). The moist forests, with their high rainfall and humidity, support a wide variety of plant and animal species. The succession process here is often marked by complex interactions between various species and the environment, creating a diverse and dynamic ecosystem.

In contrast, dry tropical forests have adapted to survive in regions with marked dry seasons. Despite the challenging conditions, these forests host an impressive variety of flora and fauna, exhibiting distinct adaptive mechanisms (Chazdon et al., 2010). The succession in dry forests provides insights into how species adjust to water stress and how these adaptations shape the progression of the ecosystem over time (Leiva et al., 2009b).

Abandoned Pasturelands

The areas of abandoned pasturelands within the Karen Mogenson serve as a compelling research focus for forest succession. Previously used predominantly for grazing, these lands are now witnessing a transition back to their original state, which affords a unique perspective into the initial stages of forest succession. The investigation into these transitioning lands can illuminate how anthropogenic land alterations influence the pace and path of forest restoration.

While there are other national parks situated in Guanacaste primarily made up of tropical dry forest. these parks tend to have a more uniform ecosystem as Guanacaste spreads north. This constricts the exploration of moist forest dynamics and the metamorphosis of grazing lands into forested areas that are relatively undisturbed by human activities. In contrast, the KMR boasts diverse ecosystems, making it a perfect site for all-encompassing studies on forest succession and a substantial contributor to our comprehension of tropical forest ecology.

A unique facet of the KMR is the existence of temporal gradients of trees in its transitional dry/moist forests ecology. These gradients offer a special opportunity to study forest regeneration dynamics in this specific region of Costa Rica. Our research aims to devise a method to capture and examine the patterns and processes associated with forest regeneration in this unique area. This endeavor can provide deeper insights into the drivers of succession and facilitate a better understanding of the factors catalyzing the transformation of abandoned pasturelands into thriving forests.

By deepening our understanding of the intricate dynamics of tropical forest ecosystems, this research promises to make notable contributions to broader conservation strategies. Additionally, our survey design has been informed and enriched by a careful review of the relevant literature, ensuring a comprehensive and grounded approach to studying forest regeneration in the Karen Mogenson Reserve.

<u>Forest Plots</u>

Forest Research Model: Inventory model

The areas of study in the reserve were chosen for their relative isolation which provides a buffer away from non-natural disturbances. This study's central goal was to design an effective method by which to measure and explore the varying factors that compose secondary forest regeneration within the Karen Mogenson Reserve (KMR). This survey used an inventory model as a baseline for the plot survey in the reserve.

In forest studies, an inventory model refers to a method used to gather and analyze data about a forest's characteristics. These can include various aspects such as tree species, size, age, density, health status, and other structural elements of a studies forest (Henttonen & Kangas, 2015). Inventory models can also capture information about biodiversity, biomass, carbon storage, and the presence of wildlife or other significant ecological features. In the context of forest succession studies, an inventory model can help track changes in the forest over time (USDA Forest Service, 2019). By taking repeated inventories, researchers can observe the progression of succession and understand the factors driving these changes. This can provide valuable insights into how forests recover after disturbances, how they respond to management interventions, and how they might be affected by future changes such as climate change.

These general models allow for the systematic collection of data on the presence and abundance of different species within a defined sampling area (USDA Forest Service, 2019). These standard models use the data from forest inventories as a way to study forest features such as volume, biomass, and overall tree diversity in a more direct way. Inventory models are typically based on statistical sampling theory and can provide a more realistic estimates of forest attributes at different scales, from individual trees to an entire forest ecosystem (Henttonen & Kangas, 2015). The inventory model also helps to understand which species are most common or rare, and how their distribution patterns might be influenced by environmental factors such as natural disturbance or the effect of land changes over time (Henttonen & Kangas, 2015). The use of inventory models offers a window into how and in what ways the regenerative process has been expressed over time within a study area (USDA Forest Service, 2019).

Model Objective:

The objective of the model was to generate a detailed, ground-level portrayal of tropical succession, transitioning from pastureland to mature, late-stage forest within the Karen Mogenson Reserve (KMR). The reserve houses an untouched central area of primary forest that has preserved its original condition since before the establishment of KMR as a nature reserve in the early 1990s.

To enhance overall comprehension, this study applied forest inventory models to measure alterations in tree species composition, structure, and biomass along the successional gradient. By maintaining standardized forest models, this study can more effectively identify the main drivers of succession in the Karen Mogenson Reserve. Utilizing an inventory model in the KMR is a robust method for observing forest dynamics over an extended period. This approach involves conducting repeated surveys to monitor the shifts in forest structure and composition. For instance, by estimating tree growth and mortality rates, the model aids in understanding the forest's responses to environmental factors like climate change or human disturbances.

Maps:

Maps were a useful tool in this project's objective of researching succession across the KMR, providing a visual representation of the reserve's location, its boundaries, and the topography that make research in this area challenging. To gain a comprehensive understanding of the Karen Mogenson Reserve, this project used a combination of resources, including Google Earth/maps, map diagrams from scientific reports, and academic articles to conduct preliminary observation and comparison of the area over time.

Most of the on-site activities conducted in this project within the Karen Mogenson Reserve were informed by information previously gathered from the maps featured (Dal Zotto et al., 2017). They helped to discern tree stand ages and unique terrain challenges this study would be encountering during this study. This made these maps crucial for selecting study locations within the reserve prior to our arrival on-site. The target locations for research plots were determined in advance based on this prior mapping information (Dal Zotto et al., 2017).

In addition to using these maps, this study incorporated Google Earth to track GPS points throughout the project area. This proved to be both cost-effective and time-efficient, allowing us to generate maps using satellite imagery, particularly useful for monitoring changes in the forest over time.

The Plot Survey

The plot surveys were meticulously conducted during the dry season months in the Nicoya Peninsula, functioning as a comprehensive tool to measure a multitude of forest attributes. Through these surveys, we collected data on various parameters like tree height, species distribution, and diameter at breast height. This process not only allowed us to capture a snapshot of the current state of the forest but also provided an avenue to observe and untangle the complex biological processes fundamental in these ecosystems.

As part of a successional study, these plot surveys offer a crucial window into the dynamics of forest recovery and regeneration, and looking at tree species outcomes over time. By comparing these plots across different stages of succession, our study is better able to piece together the trajectory of forest development following disturbances. This, in turn, provides insights into how species composition changes over time, how forest structure evolves, and how biomass accumulates during the process of succession at each stage.

Across this study, research was concentrated on regions within the Karen Mogenson Reserve (KMR) that were in the early to middle stages of abandonment. This focus enabled us to closely examine the specific processes of these particular succession stages. By “dynamics”, this term refer to the array of interrelated biological and ecological processes taking place during forest recovery. This includes, but is not limited to, changes in tree and vegetation composition, alterations in soil quality, shifts in biodiversity, development of canopy structure, and the transformation in the species composition over time. All these processes shape the forest's regeneration trajectory, which is pivotal to understand for effective conservation of these forests (Table 2).

Table 2 Stages of Sucession

Segment of the Reserve	Years of Regeneration	Description
Abandoned Pasture	0-20 years	Areas of the reserve that were previously used for agriculture or grazing but have been abandoned and are now in the early stages of regeneration.
Secondary Forest	20-49 years	Areas of the reserve that have been abandoned for longer periods and are in the mid to advanced stages of regeneration, with a mix of secondary forest and regenerating pasture.
Primary Forest	50+ years	Areas of the reserve that have been abandoned for the longest periods and have fully regenerated into primary forest or advanced secondary forest. These areas are characterized by complex, multi-layered canopies and a high diversity of species.

This field study of the Karen Mogenson reserve (KMR) was conducted by establishing a series of temporary forest plots within its transitional dry forests. This plot-level surveys meticulously recorded a variety of characteristics, such as the reserve'' estimated age, the current stage of succession, and the richness of tree species present. Additional metrics including tree density, the number of tree saplings, tree volumes, and the presence of invasive or exotic vegetation were also noted. The specific criteria for the forest survey were carefully chosen based on feasibility of measurement in a field study context.

Developing A Field Method

This project used the methodology of Condit (1998) as an example of implementing a methodology for a study of the dry tropical forest of Karen Mogenson (Condit, 1998). The study utilized a network of 50 forest census plots, each measuring 50 meters by 50 meters, to collect data on the structure, composition, and dynamics of the forest. By examining the characteristics that compose forest succession in a similar way we allow for the development of forest data that develops a forest level understanding of succession in the KMR. Some key questions the survey sought to answer include:

- What is the character of the forest in each plot?
- Where does each plot fit in terms of progress through the different stages of succession?
- What is the compositional variation for tree of different ages of succession?
- How often are out of place trees for the region encountered?

Plots Methodology

Henttonen & Kangas (2015) demonstrated the effectiveness of this type of proposed plot design using a case study in a Finnish forest. They demonstrate that their inventory plot design is able to provide accurate estimates of a wide range of forest traits, including timber volumes, deadwood volumes, and species richness (Henttonen & Kangas, 2015). This study examined the effect of plot type, plot size, and subsample tree selection strategies on volume, basal area, and stems per hectare in a forest inventory. By adopting this kind of plot model and modifying for the KMR survey it will allow for understanding successional trajectories by comparing the inventory data that is collected from different stages of forest succession found there. The aim of this project is to identify the changes that take place in the structure and composition of dry forests as they progress from pasture to late-stage forest forms.

Modified gentry plot (MGP)

This study identified the modified gentry plot (MGP) was identified to be the most effective plot type for the type of rapid surveys conducted this study (Magnusson et al., 2005) . The MGP is chiefly useful in large areas with one or more biological sector. The (MGP) is a field sampling method used in tropical forest research to study the structure and diversity of the forest. It was developed as a modification of the traditional Gentry plot, which was designed for studying tree species diversity in lowland tropical forests (USDA Forest Service, 2019).

In a Monitored Permanent Plot (MPP) approach, a designated plot within the forest is meticulously studied, with all trees-whether tall or small, shrubs, and saplings- identified, measured, and catalogued (Henttonen & Kangas, 2015). This method gathers vital data about the forest, such as its species composition, diversity, and overall structure. It illuminates details such as the size distribution of trees and the commonness of different species. This technique offers an in-depth understanding of the forest'' current state and potential trajectories of growth.

The modified gentry plot (MGP) method is also useful in tropical forests, where the high levels of biodiversity can make it challenging to obtain a comprehensive understanding of the forest’s structure and diversity using other methods (Henttonen & Kangas, 2015). By using the MGP method inside the forest of the reserve, this study has the best chance to obtain detailed data about the KMR that might only be gathered in a different type study using other more advanced technologies. By combining the Modified Gentry Plot (MGP) method with an a standard inventory model, a base method for the basic plot begins to emerge.

The RAPELD Method:

This project methodology was further informed by combining the procedures found in Magnusson et al. (2005). Methods found in this article explains that the Gentry method, which involves placing transects in a forest and sampling all trees within a certain distance from the transect. This has limitations for use in long-term ecological research sites due to its time-consuming nature (Ciecko et al., 2016).This method deals with this issue by reducing the number of transects needed and increasing the area sampled around each transect with in the plot (Magnusson et al., 2005). By adapting this method with a Gentry plot, we could modify the rectangle shaped sampling area used in RAPELD to match the width of the Gentry plot transect.

To optimize the survey method, this survey employed a rectangular sampling area designed with greater width than length. The chosen dimensions were 20m x 50m, wherein the width of the area corresponded to the distance sampled on either side of the Gentry plot transect. This configuration enhances the representation of spatial diversity and will aid in capturing the heterogeneity within the forest stands.

Rapid Assessment Procedure (RAP)

Rapid Assessment Procedure (RAP) is a method for quickly assessing the biodiversity and ecological status of an ecosystem, such as a forest, through a combination of standardized sampling techniques (Larsen, 2016). RAP is used to provide a quick and relatively low-cost way to evaluate the biodiversity of an area, allowing for conservation and management decisions to be made based on the information gathered. For this forest survey it will quickly provide context, that involves a combination of sampling techniques These techniques are standardized, allowing for data to be collected consistently and accurately across different sites.

As a tool we take portion of methodology for this survey from research that used a rapid assessment tool called FLAT, which is designed to assess forest landscapes for land management purposes (Ciecko et al., 2016). (FLAT) is a method executed in three sequential phases: Forest Cover Type Mapping, Field Assessment, and Management Prioritization (Ciecko et al., 2016). For our survey we adapted this tool to evaluate onsite visual estimation of ecological conditions and as a way to tackle the vast forest of Karen Mogenson.

By adapting a variety of evaluation techniques that are sourced from different proven methodologies, this project wanted to enable a more holistic evaluation of the transitional dry tropical forest of the Karan Mogenson region. Our objective was to unveil a richer, more nuanced portrait of these unique endangered landscapes. This hybrid, rapid-evaluation approach was designed not only to capture the evolving patterns within dry forest ecosystems over time, but also to underpin long-term ecological research and conservation initiatives in this region of Costa Rica.

Chronologically Sequenced Forest Plots

We recognized chronological sequencing as an efficient strategy to assess the Karen Mogenson Reserve. This method enables the exploration of successional changes in tree species composition across tree stands of varying ages (McClellan, 2014). Chronological sequencing of forest plots refer to a field study method where forest plots are established in a chronological sequence, with each plot representing a specific time period.

The application of chronological sequencing methodology shows to be an excellent fit with the design and goals of this forest survey project. This approach, notable for its multiple advantages, stands out for its ability to promote long-term ecological monitoring potential. By allowing for recurrent visits to the same forest plots, it provides opportunities to detect, track, and quantify changes in forest structure, species composition, and ecosystem processes happening over time.

Study Area

Applying a mix of methodologies, drawn from sources such as the US Forest Service standard and various forest field guides, enabled the construction of a comprehensive framework to direct in-field survey. This focused field investigation not only highlighted key forest metrics, but also illuminated the distinct characteristics of various recovering states across the reserve.

Project Data:

This project utilized a condensed version of traditional forest survey techniques within a four-week timeframe to observe various age stands in the Karen Mogenson Reserve (KMR), identifying key metrics crucial and fitting for the survey. The criteria listed below offer a comprehensive framework for understanding and assessing the health, diversity, and future trajectories of these dry forest ecosystem.

Key metrics:

Successional stage: This is determined through the comparison of forest structure and composition observations, which provides insights into the forest'' growth and development over time.

Tree height: Tree height is an essential metric in understanding environmental forest traits. As sunlight competition largely determines the survival and growth of trees, tree height can indicate forest health, volume of tree stands, and competitiveness of certain species.

Diameter at Breast Height (DBH): DBH, the diameter of a tree' trunk measured at 1.3 meters above the ground, is a widely used metric in forestry and ecology to assess tree size and growth. It is used in this project to estimate tree volume, a crucial consideration in timber estimations and forest management.

Basal area: This is the cross-sectional area of trees at breast height, and it is commonly used to describe stand density. The basal area is an essential input in estimating forest biomass using allometric equations.

Species richness: This is the count of different tree species within a plot. Alongside species richness, the dominant tree species within each plot are also identified to comprehend plant biodiversity within the forest better.

Mean plant height: The mean plant height, calculated from all plants within the plot, provides information about the overall growth pattern and health of the vegetation within the plot.

Presence of invasive or exotic vegetation: The existence of invasive or exotic vegetation, such as grasses, is a crucial metric to assess the forest'' health and biodiversity. Evaluating the persistence of cattle grasses and other invasive plants can give an insight into the impact these species have on the forest ecosystem.

Tree saplings presence and count:

The presence and number of tree saplings within our plots are essential to evaluate the forest'' regeneration potential and future growth.

The data gathered through this survey serves as an important resource that can be used by other researchers for further studies of this reserve's incredible nature. Forest ecology is a complex field, and although this survey data is limited in scope, it holds the potential to contribute to the general understanding of these dry ecosystems.

Core Project Method Assessment Procedure

Geographic Positioning System (GPS)

The Geographic Positioning System or (GPS) was essential tool in forest surveying, as it enables the precise determination of the location of forest resources. In the context of this study, GPS technology played a fundamental role in collecting and managing an abundance of essential data.

Plot Location

The exact geographical coordinates of each plot were accurately determined using a GPS device. This precision was essential for the correct classification and tracking of specific plot data, ensuring each plot could be revisited and compared over time.

Forest Stands and Individual Trees Mapping:

The GPS device was employed not only for identifying the general area of the study but also for mapping individual trees and forest stands when necessary. This precise mapping permitted a detailed analysis of forest composition and structure, enhancing our understanding of forest dynamics at a granular level.

Topographic Features Mapping:

This study would have been lost without the GPS capability to map topographic features in the KMR accurately. Features such as streams, trails, ridgelines, and slopes were available on the GPS maps an able to provide a far-reaching view of the study area'’ physical geography. This gave the survey substantial information to understand how the complicated or inaccessible features found here in the KMR influence forest ecology of the reserve.

To ensure the consistency and accuracy of the study, we established a clear procedure for setting up plot locations. Each chosen plot location was marked from the center position, aligned with a North-facing orientation for consistency. The coordinates of these plots were then captured with a Garmin GPS device and meticulously recorded.

Additionally, to further streamline the fieldwork, the GPS device was configured to create a 50-meter x 20-meter survey perimeter. The device was set to trigger an alarm when the researcher exited the designated survey area, serving as a safeguard against inadvertently straying beyond the plot boundaries. This feature proved particularly valuable in the field, especially when navigating through elevated or uneven terrain, which was a frequent characteristic of many of the study plots.

In essence, the use of GPS technology greatly enriched this study, proving indispensable for comprehensive data collection, precise spatial positioning, and efficient management of the field survey work.

Photography

The research plots areas were photographed for reference and further observation. The goal was to capture a thorough photographic record of the tree and plant composition within the differing plots. We wanted to capture, through photo, items that the survey didn't directly tackle, like the abundance of unknown vines, lianas shade, forest canopy, seeds, and soils. Each tree that was not identified onsite was numbered, measured, a picture taken for later identification. All the trees were identified by leaf, bark, and flower if available.

Adjustment and Structuring of the Plot

This survey largely hinged on the adaptation of standardized methodologies, tailored to efficiently navigate the challenging terrain of Costa Rica and optimize the number of survey plots that could be conducted by a solo researcher within a three weeks. Through the application of a rapid assessment procedure and a modified Gentry plot methodology, the survey was able to extended across both tropical dry forests, and the tropical montane forest found in the reserve.

The central design of the modified gentry plot (MGP) employed in this survey is a rectangular plot spanning 20 meters by 50 meters, covering an area of 0.1 ha. The MGP methodology is widely recommended for rapid surveys, particularly across expansive regions displaying one or more ecological gradients, such as humidity, sun exposure, and altitude (Eymann et al. 2010). The compactness of the MGP facilitates a high volume of samples within a limited time frame and affords researchers more time for identifying key plant species compared to methods involving larger plots

This study focused on generating a plot area measuring 50 meters by 20 meters, which is equivalent to 0.5 hectares. The goal was to establish eight of these plots, each of the same dimensions, thereby covering 4 hectares in total. These plots were selected based on their chronological sequence from the oldest to the most recent, with two sample plots being chosen per location. Factors such as the age of the stand and its accessibility were key criteria for selection.

The main grid plot is further divided into ten smaller subplots. Each of these subplots measures 20 meters in length and 5 meters in width and runs parallel to the main plot'' longest dimension. Within these subplots, all trees with a diameter at breast height (DBH) of at least 10 cm are carefully measured, identified, and recorded.

Flags were used to mark the boundaries of each plot, serving as visual guides during plot inspections (Figure 3). The placement of these flags also helped direct research teams as they navigated through the plots, ensuring a thorough examination of each plot. This flagging system was employed throughout different phases of the survey to guarantee complete coverage of the study area.

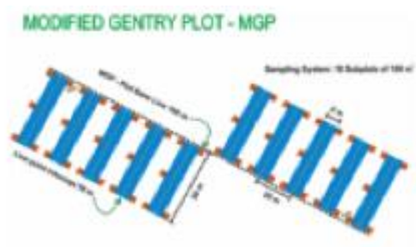

Figure 3 Flagging pattern

Basal Area

To assess the forest density, the basal area was calculated. This is a crucial measurement that shows the portion of forest ground occupied by tree trunks (USDA Forest Service, 2019). This was accomplished using a specialized forestry instrument known as an angle gauge. Foresters commonly use this tool in forest inventories to decide which trees should be measured based on different plot layouts.

In this survey, the angle gauge was deployed to estimate the volume of timber within each plot. The calculation involved measuring the basal area at three separate points within each plot: the front, middle, and back. The average of these measurements was then computed and used to calculate the basal area using the following equation: the number of ‘in’ trees (trees that appear wider than the gauge’s specified angle when viewed through the gauge) multiplied by the basal area factor (BAF) of the gauge, which was five in this case. (5)

This BAF of five meant that each ‘in’ tree represents five square feet of basal area per acre (or a metric equivalent). For this survey this is how the basal area for each plot was calculated using the formula: number of ‘in’ trees times the BAF, yielding the basal area in square feet per Hectare.

Basal area basic formula is

Basal Area (m^2/ha) = Number of 'in' trees x Basal Area Factor (m^2/ha)

Mean plant height

The mean plant height was next taken across all the plots. Using a standard tape measure the plot was crossed and measurement were taken, six per plot location. This was then averaged for later analysis. Each plot was swept for the presence of invasive species or exotic vegetation, such as grasses or bamboos. The goal was to investigate how pervasive the lingering grasses might be from plot to plot. As the forest in the KMR moves up in age into primary or late secondary stages of succession, the study wanted to better understand how the pastures, in these areas, revert back into equilibrium of the jungle forest.

Presence of Tree Saplings

Sampling for the presence of tree saplings in a forest research plot is an important component of forest ecology research. This type of sampling provides valuable information about forest regeneration and the potential for future tree growth and biomass accumulation.

The plots were canvassed for the presence tree saplings and the number of observable saplings found in each plot. Using a hand counter the plot was swept and all saplings above 90cm (3 ft) were counted and added to the plot survey. Sapling species were not identified at this phase due to time restraints. This type of sampling provides valuable information about forest regeneration and the potential for future tree growth and biomass accumulation (Derroire, 2016b).

Diameter at Breast Height

Diameter at breast height or DBH was then take of all trees larger than .5 of a meters. Using a standard forester tape and nails the tree were measured and noted. To measure the DBH of the tree, a forester tape was used. The tape is wrapped around the tree trunk at breast height at a point 1.3 meters (or 4.5 feet) above the ground. This which is a standard method of measuring tree diameter. This is often considered to be the point where the trunk diameter is most stable and indicative of the tree's overall size (USDA Forest Service, 2019). The diameter measurement of the tree taken by reading the tape and noting the corresponding measurement.

Tree Height

The survey used a laser range finder in ascertaining the height of all trees that fell within the survey plot. This portion of the survey took the most time due in part to the height of the trees as they were measured. Tree heights for this project are an important parameter to measure dry forestry recovery in the reserve, as it provides information about tree growth, biomass, and its overall productivity (Powers et al., 2009). In moist tropical forests, where trees can grow very tall, accurate measurement of tree height is particularly important.

Results

In this research project, a chronological plot survey was conducted in the Karen Mogenson Reserve to examine the patterns of change in forest structure, composition, and species richness over time within different stages of forest succession. The aim was to identify the number and species of trees in different successional stages, evaluate forest structure and composition, and understand how forest age and other factors affect successional dynamics in these transitional forest. Research conducted here hopes to provide insights into the processes of forest regeneration, helping to guide forest management and restoration practices, and contribute to the conservation of tropical dry forest ecosystems overall.

Nicoya Peninsula and the Tempisque Basin

Over the last 50 years the area around the reserve zone has undergone enormous change in land use (Guariguata & Sáenz, 2002). The deforestation that has occurred on the Nicoya peninsula, can be linked directly to activities such as ranching and agriculture (Timm et al., 2009). By using map chronologies such as ones presented here we can show the potential for forest regeneration and recovery. By tracking the growth of secondary forests over time, we could gain insights into the conditions that are necessary for successful reforestation across this region. A satellite view of the peninsula provides a better scope of the deforestation and the subsequent recovery of secondary forest between 1984-2020 (a 36-year span, Figure 4).

Figure 4 Nicoya peninsula (Costa Rica), 1984 versus 2020

For much of its history, the Nicoya region was primarily used for subsistence-level activities, including wood gathering, timber harvesting, forest clearing, and agriculture, all of which resulted in deforestation (Arroyo-Mora et al., 2005). Some of the common tree species found in this region include the iconic Guanacaste (*Enterolobium cyclocarpum*), Caro-caro (*Hura crepitans*), and Tempisque (*Sideroxylon capari*). The Guanacaste tree is actually named after the province of Guanacaste, which encompasses the Nicoya Peninsula. The Caro-caro and Tempisque trees are also common in the region, native to the dry tropical forests and other arid habitats found in this part of Costa Rica. These trees provide habitats for a wide variety of animals, such as howler monkeys, iguanas, and armadillos to name just a few found across these forests.

Satellite photos reveal that the areas surrounding the reserve are important for understanding forest preservation, as they demonstrate regional deforestation levels. These photos also show that human activities like agriculture, cattle ranching, and urbanization have caused major loss of dry forests in Nicoya in recent decades (Figure 5).

Figure 5 Karen Mogenson Reserve Forest Recovery 1985 versus 2020

Due to substantial degradation, it is crucial to recognize the growing importance of the areas surrounding the Karen Mogenson Reserve in comprehending the factors that influence the conservation of comparable forests. Across the islands of conservation found here the reserve provided a critical refuge for many of the plants and animals species that have been displaced by the regional deforestation seen over the last 50+ years.

In order to comprehend the factors that contribute to the recovery and restoration of these dry forest biomes, the study takes into account the dynamics of forest age, as well as other factors associated with successional dynamics. This approach aims to gain insights into the regeneration processes of the forest and better understand the mechanisms involved in their recovery and restoration.

Forest Dynamics And The Study of Tropical Forest Succession

To observe the patterns of change in forest structure, composition, and species richness in different stages of forest succession. This project identified a number of tree species and explored their place within different successional stages by assess overall forest structure and its general composition. By exploring the forests characteristics seen across different aged forest plots we can developing a better understanding of the regeneration dynamics seen here.

When referring to "dynamics" in the context of succession in these dry forests we indicate the changes and interactions between different components of the forest ecosystem over time. Important characteristics presented across much of the literature on the topic of forest dynamics of a tropical dry forests incorporate into this study:

Changes in Forest Structure:

In the dense foliage of Karen Mogenson's forests, time brings transformation. The size and distribution of individual trees fluctuate as new species take root and older trees naturally die off or are replaced. The overall canopy structure evolves, reflecting the continuous shift in the transitional forest's makeup.

Species Composition Dynamics:

The rich diversity of flora and fauna within these forests is in constant change. As different plant and animal species migrate in and out, the tree composition subtly shifts, reflecting changes in the distribution of various ecological niches we can see here in the reserve. This dynamic process results in long-term alterations to the forest's biodiversity.

Impact of Environmental Drivers:

Karen Mogenson's tropical dry forests aren't just shaped by their inhabitants, but also by external environmental factors. Weather patterns, periods of drought and near flooding, and even seasonal landslides can all influence the dynamics and structural makeup of these forests as they develop.

Interactions Between Species:

Within these forests, life is intertwined in a complex web of ecological relationships. Competition for resources and interactions between different species contribute greatly to the forest's dynamics. A perfect example is the presence of tropical lianas. These persistent vines influence the forest structure across various stages of forest recovery.

Successional Pathways:

The trajectory of a forest's development, or its successional pathway, can vary greatly in tropical dry forests. These pathways depend on the forest's initial conditions, the species present, and the nature and frequency of disturbance events such in this case it is land abandonment.

By presenting a deeper understanding of what are the expression of these dynamics of dry forest succession, a comprehensive understanding of these and other factors, and how they interact to shape the overall structure and function of the ecosystem over time. Research conducted here hopes to provide insights into the processes of forest regeneration, helping to guide forest management and restoration practices, and contribute to the conservation of tropical dry forest ecosystems overall.

Tree species distribution across the reserve

Here we present the more notable tree species found in the eight plots across Karen Mogenson. We observe a diverse group of species that provide insights into the dynamics of succession in the dry forest of Costa Rica’s Nicoya Peninsula. Numerous trees fall into the category of endemic, endangered or rare.

Bursera simaruba (Indio desnudo)

This species is commonly found in dry forests and can tolerate drought conditions. It is also important for its ecological role as a host plant for many butterfly species. Also indicative of persisting pasture lands common across the reserve.

*Swietenia macrophylla (*Caoba*)*

This species is a valuable timber tree and is very often exploited for its fine quality wood. It presence is an important marker for the ecological health of these threatened forest ecosystem.

Enterolobium cyclocarpum (Ear tree)

This species is known for its large size and distinctive shape, making it a standout tree in the forest. It is also important for its ecological role as a nitrogen fixer and for its edible pods. Along the edge land of pastures, it is valued for its shading seen on the younger sections of the reserve.

Guazuma ulmifolia (Guácimo)

This species is a common tree in dry forests and is important for its ecological role in providing food and habitat for wildlife. Seen in early to middle succession. valued as a cattle supplementation during the dry season when grass was sparce.

Acosmium panamense, *Albizia niopoides*, and *Pseudosamanea guachapele*

These leguminous trees are important for their ecological role as nitrogen fixers, which can help to improve soil fertility in the dry forest ecosystem.

Ficus insipida and *Ficus cotinifolia*

These species of fig trees are important for their ecological role as host plants for many fig wasp species. They are also important food sources for a variety of animals.

Terminalia oblonga (Surá, Guayabo de montaña)

This species is important for its ecological role in providing food and habitat for wildlife. A hard wood that reached great height in the forest canopy and valued for is beautiful strong wood. Distributed widely across the tropics and subtropical regions of the American.

These standout species are well-adapted to drought conditions and play important ecological roles in the forest ecosystem. It can be clearly seen how many species provide food and habitat for abundant wildlife here. Other species listed, like Enterolobium cyclocarpum (ear tree), are mid-successional species. These trees can tolerate partial shade and begin to dominate the forest understory as they grow. They provide important habitat for wildlife and contribute to the overall diversity of these forest.

Below, the trees on this list are represented along different stages of succession, from early pioneer species to mature, long-lived trees. Some of the species listed, such as *Acacia cornigera* (Bull acacia) are pioneer species. These trees are adapted to colonizing disturbed areas and can quickly establish themselves in the open spaces like abandoned pasture. Pioneer species play a critical role in the early stages of succession by creating soil conditions that support the growth of other, more shade-tolerant trees.

Early Succession Stage:

These are pioneer species that are first to colonize previously disrupted or damaged ecosystems, beginning a chain of ecological succession that ultimately leads to a more biodiverse steady-state ecosystem. They are often characterized by rapid growth and high tolerance for harsh conditions (Table 3).

Table 3 Tree Species Typical of Early Succession

Bursera simaruba (Indio desnudo)	*Cecropia obtustolia* (Guradumo)
Cecropia peltata (Trumpet tree)	*Inga punctata* (Guaba)
Schizolobium parahyba (Gavilan)	*Vismia baccifera* (Achiotillo)
Zanthoxylum setulosum (Lagarto)	*Trema micrantha*
Hura crepitan (Sandbox tree)	*Acacia cornigera* (Bull Acacia)

Middle Succession Stage:

These are typically hardier than pioneer species, and they start appearing when the conditions have been improved by the pioneer species. They have slower growth rates but longer lifespans (Table 4).

Table 4 Tree Species Typical of Middle Succession

Astronium graveolens (Ronron)	Ficus insipida (Ficus)
Anacardium excelsum (Espavel)	*Guarea Rhopalocarpa* (Cocora)
Pouteria reticulata (Nisparo blanco)	*Terminalia oblonga* (Surá, Guayabón)
Aspidosperma megalocarpon	*Swietenia macrophylla* (Caoba)
Sterculia apetala (Palo de Panama)	*Acrocomia aculeata* (Coyol)

Late Succession Stage:

These species are often larger and require more resources. They are often more shade-tolerant and can out-compete the early and middle successional species in their mature forms (Table 5).

Table 5 Tree Species Typical of Late Sucession

Alchornea costaricensis	*Vachellia collinsii* (Bull Acacia)
Muntingia calabura (Capulín)	*Samanea saman* (Rain tree)
Caryocar costaricense (Ajo/Platano)	*Castilla elasticas* (Hule)
Protium panamense (Copal)	*Quercus oleoide*s
Enterolobium cyclocarpum (Ear tree)	*Brosimum costaricanum*

The list also includes a number of mature, long-lived trees like *Cedrela odorata* and *Swietenia macrophylla* (Caoba). These species require full sunlight and are only able to grow once the canopy has opened up. They play a crucial role in the final stages of succession, helping to create a mature forest ecosystem. The diversity of species found in the survey emphasizes the importance of preserving biodiversity at all stages of recovery to better understand the roles different species play in ecosystem restoration (Figure 6).

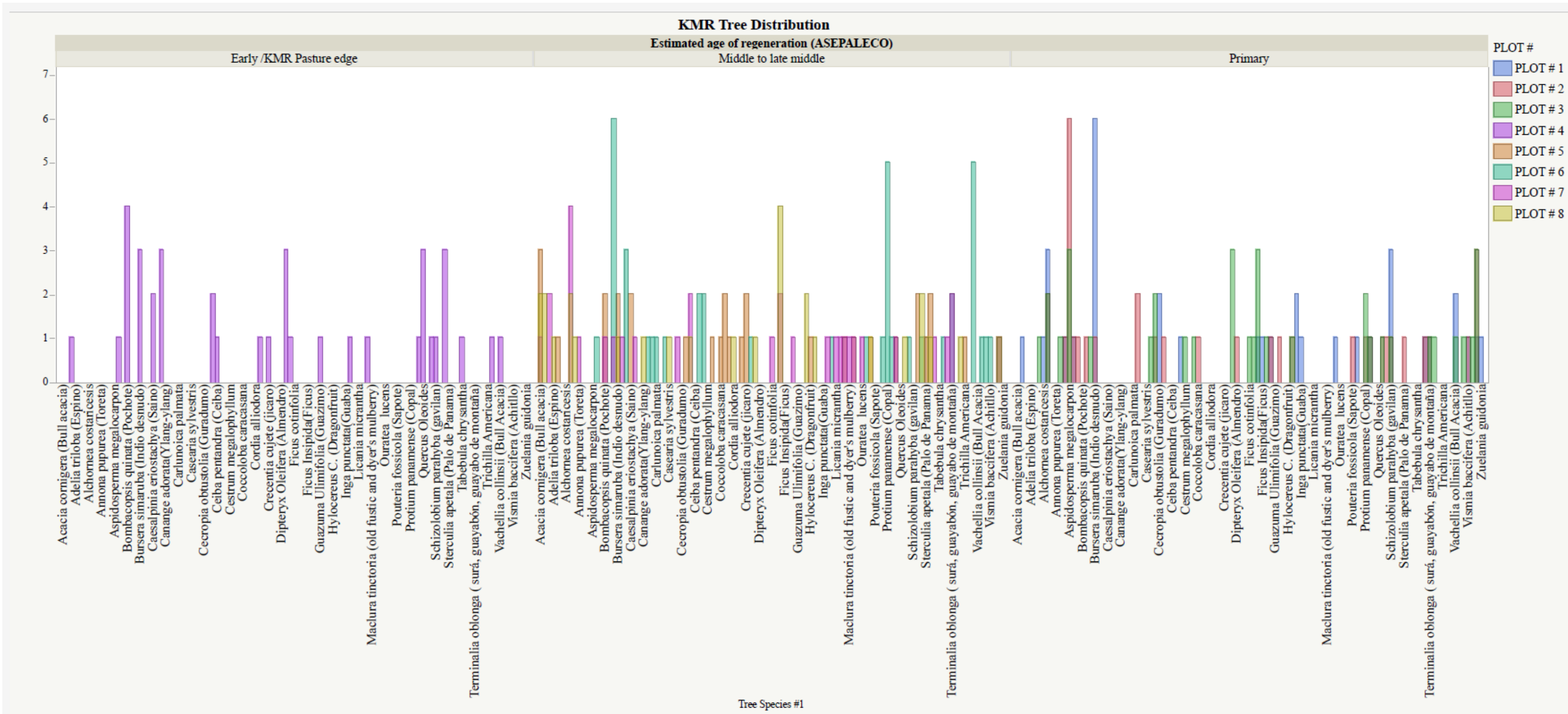

Figure 6 Tree Species Across Successional Age of Plots

Plot Summaries

Plot 1

Location: Latitude: 9.868327° N Longitude: 85.072202° W. Images are presented for Plot 1 (Figures 7-11), as well as my impressions from surveying the plot. Tree species are listed in Table 6.

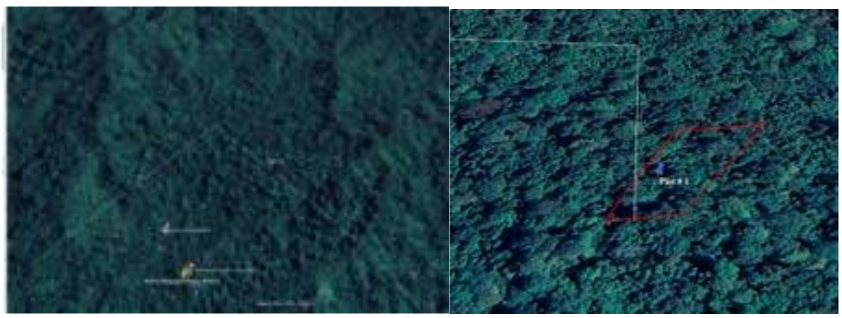

Figure 7 Plot 1 Wide view (L) and close-up (R)

Located at an elevation of 357 meters, Plot 1 is classified as primary forest with a late stage category (greater than 40-60 years) The plot is situated on a sloping hillside, spreading wide by a variety of tall trees and hanging vines. The hillside discharges from several small natural springs that feed water to this area and protentional from other hydrological process that occur here due to the elevated terrain and weather. The higher levels of precipitation found here produce more opportunities for the capture of water that provide various condition for the natural introduction of more adaptive tree species.

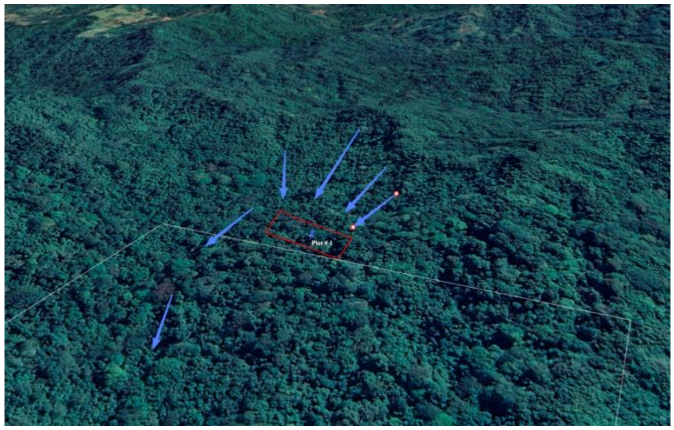

Figure 8 Water Flow Across Plot 1

A uniformity among trees feels real, keeping a straight path is a difficult task. On closer inspection the order disappears, and the randomness of the trees becomes more evident, stretching out like a green maze. The dry leafy ground was thick with leaves, open, with high cathedral like structures. The trees are free from obstruction and our flags could easily be seen across the plot.

Figure 9 Plot 1 Forest Floor/Leaf Litter

Table 6 Tree Species and Measurements of Plot 1

TREE SPECIES	**Count**	**Avg height/m**	**Max height/m**	**Min height/m**	**Avg DBH/m**	**Max DBH/m**	**Avg DBH/m**
Acosmium panamense(Guayacán)	1	9.80	9.80	9.0	0.60	0.60	0.6
Alchornea costaricesis	1	16.30	16.30	16.3	0.59	0.59	0.6
Anacardium excelsum (Espavel)	3	19.13	19.50	18.5	3.41	4.15	3.4
Apeiba tibourbou (Monkey Comb)	1	17.60	17.60	17.6	1.22	1.22	1.2
Astronium graveolens (Ronron)	1	6.90	6.90	6.9	0.46	0.46	0.5
Bursera simaruba (Indio desnudo)	6	13.80	18.70	7.9	1.15	1.74	1.1
Cecropia obtustolia (Guradumo)	2	7.55	8.70	6.4	0.55	0.65	0.5
Celtis schippii (Gavilan)	1	14.80	14.80	14.8	1.09	1.09	1.1
Ficus Insipida (Ficus)	2	17.10	26.10	8.1	2.92	3.74	2.9
Guarea Rhopalocarpa (Cocora)	1	13.80	13.80	13.8	0.94	0.94	0.9
Inga bijuga	2	10.10	10.80	9.4	0.55	0.62	0.5
Inga punctata(Guaba)	1	7.40	7.40	7.4	0.41	0.41	0.4
Muntingia calabura (Capulín)	1	4.10	4.10	4.1	0.66	0.66	0.7
Pouteria reticulata (nisparo blanco)	1	16.40	16.40	16.4	0.87	0.87	0.9
Pseudolmedia spuria	1	2.90	2.90	2.9	0.41	0.41	0.4
Schizolobium parahyba (gavilan)	3	9.53	12.10	7.2	0.59	0.92	0.6
Tabernae montana (Alba/Guijarro)	1	4.50	4.50	4.5	0.37	0.37	0.4
Terminalia oblonga (surá, guayabón, guayabo de montaña)	1	24.40	24.40	24.4	2.81	2.81	2.8
Vachellia collinsii (Bull Acacia)	2	6.10	7.90	4.3	0.26	0.33	0.3
Vismia baccifera (Achitllo)	1	5.60	5.60	5.6	0.35	0.35	0.4
Zanthoxylum setulosum (Lagarto)	1	11.30	11.30	11.3	0.34	0.34	0.3
Zuelania Guidonia	1	16.30	16.30	16.3	1.17	1.17	1.2
Grand Total	**35**	**12.07**	**26.10**	**2.9**	**1.13**	**4.15**	**1.1**

The ground beneath is a layer of fallen leaves, twigs, and branches, creating a natural compost that supports the growth of new plants. The plot has an estimated basal area of 121.7 board m²/ha and an average understory of 8.7 cm.

The mean DBH for the plot is 11.3 cm and the mean height for the plot is 12.1 m. There are 22 tree species present in this plot, with the most common being *Bursera simaruba* (Indio desnudo): with 6 individuals, *Anacardium excelsum* (Espavel): with 3 individuals, and

Schizolobium parahyba (Gavilan) with 3 individuals. The presence of these tree species are indicative of the mix found across the reserve area.

Bursera simaruba (Indio desnudo), for example, is a characteristic species of early successional stages in these dry forests, and its abundance may also indicate that the forest holds on to remnant pioneer species or potentially from nearby pasture lands. Trees are often carried/brought by birds or animals that transverse the entireties of the reserve. As the forest matures, other species may become more abundant and outcompete *Bursera simaruba*. In mature dry forests, certain species may establish long-term footholds that appear somewhat unusual or unexpected.

Anacardium excelsum (Espavel), on the other hand, is a species that tends to dominate in later stages of succession, as it is more shade-tolerant than *Bursera simaruba*. Its presence may suggest that the forest is transitioning to a more mature stage.

Schizolobium parahyba (Gavilan) is also a relatively shade-tolerant species and may be indicative of later successional stages. It is important to note, however, that the presence and abundance of tree species can be influenced by a variety of factors, including disturbances, soil conditions.

Further study would be needed to determine the precise stage of succession in the forest based on these three species alone. Observationally, the *Schizolobium parahyba* is common in the area and seen across the reserve.

Figure 10 Plot 1 Composition

This plot of primary tropical dry forest in KRM is layered ecology, with both well-developed leaf litter on ground, and numerous creeping vines and lianas. Among the common lianas (vines) found in this dry forest included: *Bauhinia monandra, Bauhinia ungulate, Cissus sicyoides and Dolichandra unguis-cati.*

Figure 11 Common Dry Forest Lianas

Plot 2

Latitude: 9.8715° N Longitude: 85.0563° W. Images are presented for Plot 2 (Figures 12-17), as well as my impressions from surveying the plot. Tree species are listed in Table 7.

Figure 12 Plot 2 Wide view (L) and close-up (R)

This plot is a primary forest at an elevation of 287 meters. Another example estimated to be over 40-60 years old forest in the late stage of succession. This plot is a seasonal waterway as well as part of the interior trail system that allow for deeper access to the more isolated areas of the reserve.

The area is mostly flat, but has some unevenness that follows the contours of the deep gullies that channel water away and gradually lead up the hill. The trees in this area have vine-like root systems and small symbiotic epiphytes that grow from the bottom to the upper parts of the foliage.

The transitional nature of this forest means that it is subject to both dry and wet seasons, with fluctuations in rainfall and temperature impacting the growth and survival of plants and animals. This dynamic environment creates a constant state of change, with some species thriving during wetter seasons while others are better adapted to drier conditions.

The tree bark on most of the trees is covered with patches of green mold and various fungus, which indicates high moisture levels. However, being February, the forest is dry and shows no signs of the typical changes in precipitation that occurs in the reserve over the course of a year.

Figure 13 Mature Mixed Dry/Moist Tropical Forest

This area of the reserve is a unique ecosystem that exhibits a high level of biodiversity and dynamic ecological processes. This forest plot is characterized by its mix of both dry and moist forest elements, resulting in a diverse array of plant and animal species observed here. Considering the remarkable diversity present in these forests and the complex dynamics of isolated ecosystems, it is astounding how much we have come to understand about them through scientific exploration and research.

Table 7 Tree Species and Measurements of Plot 2

TREE SPECIES	**Count**	**Avg height/m**	**Max height/m**	**Min height/m**	**Avg DBH/m**	**Max DBH/m**	**Avg DBHm**
Anacardium excelsum (Espavel)	2	30.00	36.90	23.1	2.20	2.45	2.2
Apeiba tibourbou (Monkey Comb)	1	13.80	13.80	13.8	1.41	1.41	1.4
Aspidosperma megalocarpon	6	10.63	14.10	5.5	0.71	1.12	0.7
Astronium graveolens (Ronron)	1	15.30	15.30	15.3	1.27	1.27	1.3
Bactris guineensis (Palm)	1	2.10	2.10	2.1	0.00	0.00	0.0
Bravaisia integerrima	1	19.10	19.10	19.1	1.06	1.06	1.1
Bursera simaruba (Indio desnudo)	1	18.80	18.80	18.8	0.78	0.78	0.8
Caryocar costaricense (Ajo/platano)	2	11.25	17.10	5.4	0.85	1.38	0.9
Castilla elasticas (Hule)	1	10.20	10.20	10.2	0.34	0.34	0.3
Cecropia peltata (Trumpet tree)	1	27.60	27.60	27.6	0.83	0.83	0.8
Coccoloba caracasana	1	11.10	11.10	11.1	0.48	0.48	0.5
Dipteryx Oleifera (Almendro)	1	16.70	16.70	16.7	0.85	0.85	0.9
Guarea Rhopalocarpa (Cocora)	1	31.40	31.40	31.4	1.74	1.74	1.7
Heliocarpus Americanus	1	25.60	25.60	25.6	1.94	1.94	1.9
Hymenaea courbaril (Guapinol)	1	27.30	27.30	27.3	1.27	1.27	1.3
Pouteria fossicola (Sapote)	1	6.60	6.60	6.6	0.28	0.28	0.3
Protium panamense (Copal)	1	24.20	24.20	24.2	0.87	0.87	0.9
Pseudolmedia spuria	1	15.90	15.90	15.9	0.94	0.94	0.9
Raphia taedigera (Palm)	1	3.00	3.00	3	1.69	1.69	1.7
Samanea saman (Rain tree)	1	15.10	15.10	15.1	0.74	0.74	0.7
Schizolobium parahyba (gavilan)	1	3.70	3.70	3.7	0.26	0.26	0.3
Sterculia apetala (Palo de Panama)	1	14.60	14.60	14.6	1.06	1.06	1.1
Tabernae montana (Alba/Guijarro)	1	2.50	2.50	2.5	0.13	0.13	0.1
Terminalia oblonga (surá)	1	27.40	27.40	27.4	2.15	2.15	2.2
Vismia baccifera (Achitllo)	1	7.10	7.10	7.1	0.29	0.29	0.3
Zanthoxylum setulosum (Lagarto)	3	8.00	9.30	6.8	0.39	0.51	0.4
Grand Total	**35**	**14.55**	**36.90**	**2.1**	**0.91**	**2.45**	**0.9**

A deeper shade here with elevated humid condition dominate the area, adding to the complexity of various small plants and shrubs. The “openness” observed across the plot is expressed in the estimated basal area of 60.0 board m²/ha and an average understory of 21.5 m²/ha. The mean DBH for the plot is 9.4 cm and the mean height for the plot is 14.6 m although many large trees were beyond in the general area of study.

A total of 35 tree were surveyed with 22 unique species present across this plot. Trees are thinker and well established here. Leaf litter was thin and scattered measuring 1.4cm or 0.57 inches across the plot with an underbrush that is navigable and open.

Plot 2 also expressed an abundant understory with a scatter of plant and shrubs with a number of palms, many of which are endemic to the region. Palms are a prominent and important component of many tropical dry forest ecosystems in Costa Rica. They are typically found in the understory layer and can be quite diverse, with many species being common to the region.

Figure 14 Plot 2 Leaf Litter

This plot, despite being a primary forest, the area exhibits two characteristics that underscores its overall character and complexity. The plot is located along an internal trail that receives higher levels of foot traffic compared to other areas of the Karen Mogensen Reserve (KMR). Despite this, the area immediately surrounding the trails appears to be relatively undisturbed, with no obvious signs of degradation. A visual observation (Figure 15 Undisturbed Surrounding Trail System) suggests that this plot location and its immediate surroundings have remained relatively intact and free from human-induced disturbance, which is an encouraging sign for the conservation and management of the KMR.

Figure 15 Undisturbed Surrounding Trail System

This plot also had close proximity to the water that channels. This proximity to the water channels may provide many trees and other plants with a more reliable source of water compared to other areas of the forest. These important difference's potentially result in variances in forest structure, such as increased growth or density of certain tree/plant species.

Water access here is an important factor here with obvious influence of the successional dynamics of these old-growth dry forests of the reserve. The variation in composition from area to area in the reserve are hard to capture in just one survey. Here various factors such as differences in moisture levels, topography, tree distribution, and competition between different plant and tree species can come together to form unique ecological niches. These microclimates, which can support a diverse range of specialized trees that have adapted to the specific conditions of this ecosystems. Here (Figure 16 KMR

Unique Ecological Niches) we see a strong mixture of both moist and dry forest trees in mature stages of development.

Figure 16 KMR Unique Ecological Niches

Based on the tree species found present in plot 2, it is possible to connect them to higher levels of water availability in the area. In the case of plot 2, the rapid decay of the mat-like understory suggests that the area is experiencing frequent cycles of growth and deterioration, which may be contributing to the development of the rich diversity of trees seen in the area.

Trees such as *Aspidosperma megalocarpon*, *Zanthoxylum setulosum,* and *Anacardium excelsum* (Espavel) (Figure 17) thrive in areas with the high water availability. It is a dominant tree species in the dry forests of the Pacific coast of Costa Rica, and it is considered an important ecological and economic resource in the region (McClellan et al., 2018) .

Figure 17 *Anacardium excelsum* (Espavel)

The *Anacardium excelsum* (Espavel) tree produces a small, pear-shaped fruit that is edible and highly valued for its sweet, juicy pulp that we find scattered across the undergrowth. The tree's extensive root system sprawl across the forest floor, helping to prevent soil erosion and improve soil fertility over time. The presence of these species within plot 2 suggests that this areas proximity to water generates faster fluctuations between growth and deterioration seen in the trees in this plot.

Additionally, the understory plants of the plot also had a relatively high abundance of species, which further suggests that the area may have adequate moisture to support plant growth. The high abundance of understory plants, the presence of palms and other smaller moisture-loving species observed in the area of plot 2 suggests that the area may be subject to faster and more frequent fluctuations between wet and dry conditions compared to other areas of the forest.

The information collected about plot 2 suggests a unique ecosystem within the study area, exhibiting a high level of biodiversity and dynamic ecological processes that are influenced by water availability and other factors. The presence of moisture-loving species, combined with the high abundance of understory plants, suggests that plot 2 Water here is driving these unique dynamic processes in this area.

Plot 3

Latitude: 9.871171983° N, Longitude: 85.05568204° W. Images are presented for Plot 3 (Figures 18-22), as well as my impressions from surveying the plot. Tree species are listed in Table 8.

Figure 18 Plot 3 Wide view (L) and close-up (R)

Plot 3 is in a primary forest at an elevation of 299 meters. This plot is estimated to be middle to late in the succession stage, with an age of over 60-70 years old, suggesting that it may be relatively undisturbed by human activity. Classified as middle to late succession stage indicates that it has likely undergone growth and development since being established as a forest. Many large trees such as *Ficus Insipida* (Figure 19) can be found across this area.

Figure 19 Mature *Ficus Insipida*(ficus)

This plot was sloped and crossed one of the many interior paths that snake down the large hill to a deeply forested basin. The plot has an estimated basal area of 136.7 board m^2/ha and an average understory of 8.7 cm. The estimated basal area of 136.7 board m^2/ha suggests that this plot area has a relatively high density of trees, which may be indicative of a more mature or advanced stage of succession on observation.

The presence of a thick understory layer suggests that the area has been developing dynamic ecological processes such as recruitment and competition between tree saplings, and other small plant and shrubs. This type of long-term development of forest composition contribute to the overall undercurrents in structure of the forest of Karen Mogenson.

The mean DBH for the plot is 13.6 cm and the mean height for the plot were 16.1 m. Here we find 25 tree species present across this plot, with the most common being Albizia adinocephala, Andira inermis, and Protium panamense. The trees in this plot are of moderate size and height, but vary significantly across individual measurements as seen in Figure 20.

Figure 20 Canopy Structure

The tropical forest in plot 3 has a unique understory with exceptional and complex features. Observationally, the kind of openness seen here can be attributed to the mix of mature trees, saplings, and an abundance of lianas that play an important role in forest structural development (Figure 21).

Figure 21 Varying Forest Structural Development

What is observed in this plot is a stable ecosystem that has reached a level of balance and equilibrium. The forces of tropical ecology at play in the dry forest of the KMR could teach others about the importance of preserving older trees and fostering a diverse and well-developed understory. The mature trees have thick trunks and sprawling canopies that allow dappled sunlight to filter through to the forest floor, creating different amounts of light and shadow all affecting the patterns of growth here. However, the presence of lianas here is heavy and adds an extra layer of complexity to this transitional dry environment.

Lianas and vines

Figure 22 KMR Lianas

In early abandoned pasture lianas would create a tangled network of vines that weave throughout the forest understory, connecting trees and other plants together. This would create a highly interconnected environment, with vines crisscrossing the forest floor and draping from tree branches (Figure 22). Trees warp, fall, and make room for new better adapted trees. This process can be detected across this plot area, varying trees sizes and heights and thick ground vines are indications of the late stage of the development of these dry forest development.

Table 8 Tree Species and Measurements of Plot 3

Tree Species	**Avg height/m**	**Max height/m**	**Min height/m**	**Avg DBH/m**	**Max DBH/m**	**Avg DBH/m²**
Albizia niopoides	19.20	19.20	19.2	1.16	1.16	1.2
Anacardium excelsum (Espavel)	24.15	29.40	18.9	1.38	1.62	1.4
Apeiba tibourbou (Monkey Comb)	27.40	27.40	27.4	1.68	1.68	1.7
Aspidosperma megalocarpon	8.80	12.20	7	0.76	1.03	0.8
Brosimum costaricanum	23.80	23.80	23.8	1.48	1.48	1.5
Cassia grandis	20.30	20.30	20.3	1.71	1.71	1.7
Castilla elasticas (Hule)	13.75	13.80	13.7	1.06	1.46	1.1
Cestrum megalophyllum	12.20	12.20	12.2	0.36	0.36	0.4
Clarisa biflora	8.50	8.50	8.5	0.69	0.69	0.7
Dalbergoia retusa	16.03	22.90	6.5	1.18	1.66	1.2
Ficus cotinfolia	26.60	26.60	26.6	6.75	6.75	6.8
Ficus crassivenosa	4.80	4.80	4.8	0.35	0.35	0.4
Ficus Insipida(Ficus)	28.00	36.50	23.7	4.07	7.49	4.1
Gliricidia sepium (Madero Negro)	7.10	7.10	7.1	0.23	0.23	0.2
Hymenaea courbaril (Guapinol)	37.20	37.20	37.2	1.47	1.47	1.5
Protium panamense (Copal)	8.70	12.20	5.2	0.60	0.74	0.6
Pseudolmedia spuria	6.10	6.10	6.1	0.36	0.36	0.4
Raphia taedigera (Palm)	2.60	2.60	2.6	1.07	1.07	1.1
Schizolobium parahyba (gavilan)	15.90	15.90	15.9	0.67	0.67	0.7
Terminalia oblonga (surá, guayabón, guayabo de montaña)	26.70	26.70	26.7	1.94	1.94	1.9
Trema micrantha	13.10	13.10	13.1	0.76	0.76	0.8

(cont.)

Tree Species	Avg height/m	Max height/m	Min height/m	Avg DBH/m	Max DBH/m	Avg DBH/m^2
Vachellia collinsii (Bull Acacia)	1.90	1.90	1.9	0.09	0.09	0.1
Virola surinamensis (Fruta dorada)	19.10	19.10	19.1	1.14	1.14	1.1
Zanthoxylum rhoifolium	14.60	14.60	14.6	1.02	1.02	1.0
Zanthoxylum setulosum (Lagarto)	13.90	17.40	8.6	0.66	0.75	0.7
Grand Total	**16.13**	**37.20**	**1.9**	**1.36**	**7.49**	**1.4**

The data in plot #3 provides some insights into the process of forest succession. One important aspect of forest succession is the diversity of tree species, which can indicate the stage of succession. In plot #3, the presence of 21 different tree species suggests that the forest is in a mature stage of succession, where multiple species have established themselves and are coexisting.

Another important aspect of forest succession is tree density, which can indicate the stage of succession as well. In plot #3, the total number of trees measured is relatively high, suggesting that the forest may be in a later stage of succession, where the canopy has closed in many instances, and the forest has moved into later stage of maturity.

The data on tree height and diameter can also provide some insights into the successional stage of the forest. The presence of some trees with small DBHs and low heights, such as Vachellia collinsii, suggest that these trees are in the early stages of colonization of the area, while the presence of taller trees with larger DBHs, such as Hymenaea courbaril and Ficus Insipida, could suggest that many large tree might have already been established in this location.

Plot 4

Latitude: 9.880782° N, Longitude: 85.065902° W. Images are presented for Plot 4 (Figures 23-31), as well as my impressions from surveying the plot. Tree species are listed in Table 9.

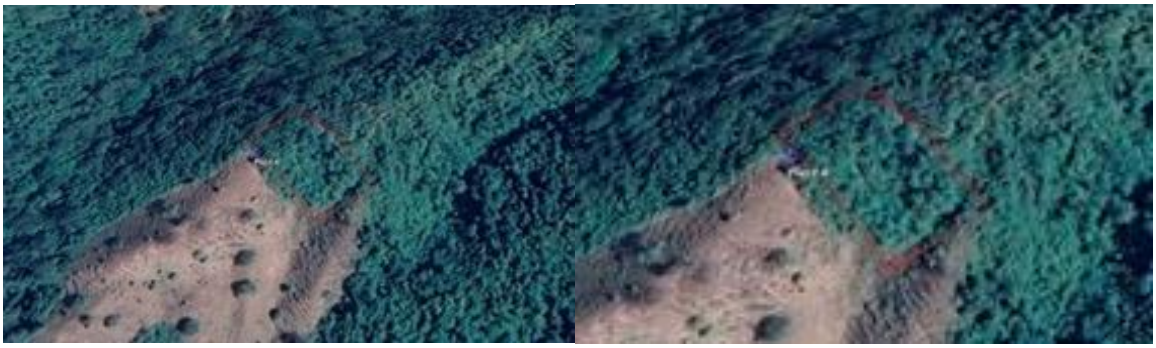

Figure 23 Plot 4 Wide view (L) and close-up (R)

Plot 4 (Figure 23) was an extremely isolated plot at an elevation of 248m, giving this study the opportunity to look at the melding of both degraded pastureland and protected dry forest. Access to plot 4 was through the adjacent ranch to the reserve and is active and home to several herds of Nelore cattle. Nelore are a shy cattle raised across Costa Rica for meat production. Praised for their adaptation to hot and humid climates and are common in the Nicoya region. Below (Figure 24) we can see the low pasture of this ranch through which access was obtained to plot 4.

Figure 24 Adjacent Active Ranch

From this low point I made the steep climb through incline boarders of the reserve. The climb exhausting, and the heat of February only added to the challenge. The contrast between the forest and the field was striking. What must have been years of channeling water has carved large canyons, now filled with dry forest. Below (Figure 25) we see how the only areas not covered by the shrubs and trees is where the water channels deep into the earth.

Figure 25 Plot 4

The degraded pasture offers up the occasional tree, providing a cool and shady break from the sun. The rich green of the reserve and the diverse bird calls made it seem like an entirely different world. These pastures are currently not in practical use so we see many characteristics of early succession. Only the toughest trees do well here, few trees on this landscape can struggling long against the exposure to the harsh sun. Despite the difficulties of the climb, reaching the survey area (Figure 26) was a rewarding experience.

Figure 26 Plot 4.Elevation 248M

Plot 4 is situated at the edge of a pasture in a transitional wet/dry forest. The estimated age of regeneration for this plot is categorized as early with a range of less than 1-20 years. The on-site succession age is categorized as early into middle succession.

Table 9 Tree Species and Measurements of Plot 4

Tree Species	**Count**	**Avg Height/m**	**Max Height/m**	**Min Height/m**	**Avg DBH/m**	**Max DBH/m**	**Avg DBH/m^2**
Acrocomia aculeata (Coyol)	1	19.10	19.10	19.1	1.84	1.84	1.8
Astronium graveolens (Ronron)	1	27.40	27.40	27.4	1.51	1.51	1.5
Bombacopsis quinata (Pochote)	4	14.18	17.50	7.4	1.38	1.71	1.4
Bursera simaruba (Indio desnudo)	3	15.17	17.30	12.4	1.29	1.91	1.3

(cont.)

Tree Species	Count	Avg Height/m	Max Height/m	Min Height/m	Avg DBH/m	Max DBH/m	Avg DBH/m^2
Caesalpinia eriostachya (Saino)	2	11.70	14.70	8.7	1.43	1.75	1.4
Calycophyllum candidissimum (Salmon/conejo)	3	8.77	12.90	5.2	1.25	1.45	1.2
Cedrela odorata	2	22.70	27.10	18.3	1.39	1.63	1.4
Ceiba pentandra (Ceiba)	1	38.60	38.60	38.6	1.37	1.37	1.4
Cordia Alliodora	1	11.70	11.70	11.7	1.39	1.39	1.4
Crecentia cujete (jicaro)	1	2.40	2.40	2.4	0.17	0.17	0.2
Enterolobium cyclocarpum (ear tree)	3	22.20	31.20	8.7	2.22	2.79	2.2
Erythrina berteroana	1	6.30	6.30	6.3	1.03	1.03	1.0
Guazuma ulimifolia (Guácimo)	1	17.70	17.70	17.7	1.51	1.51	1.5
Inga Vera	1	12.50	12.50	12.5	1.17	1.17	1.2
Lysiloma divaricatum (Quebracho)	1	16.90	16.90	16.9	0.91	0.91	0.9
Pseudosamanea guachapele (Guayaquil)	1	14.70	14.70	14.7	0.83	0.83	0.8
Quercus Oleoides	3	8.60	9.30	7.8	1.84	2.43	1.8
Samanea saman (Rain tree)	1	25.80	25.80	25.8	1.21	1.21	1.2
Schizolobium parahyba (gavilan)	1	19.70	19.70	19.7	0.69	0.69	0.7
Spondias mombin (Jobo)	3	10.53	12.50	8.4	0.75	0.96	0.8
Tabebula chrysantha	1	18.30	18.30	18.3	1.25	1.25	1.3
Trichospermun galeattii (capulin)	1	7.60	7.60	7.6	0.26	0.26	0.3
Vachellia collinsii (Bull Acacia)	1	4.20	4.20	4.2	0.31	0.31	0.3
Grand Total	**38**	**14.85**	**38.60**	**2.4**	**1.28**	**2.79**	**1.3**

The estimated basal area for this plot is relatively low at 45.0 m²/ha, indicating that the forest structure is still developing. The average understory cover is 8.9 cm and the mean DBH and height for the plot are 12.8 cm and 14.8 m respectively.

Below (Figure 27) we can see how the strong presence of lianas here drive the forest structure as the vines engulf the small trees all fighting for light and space. This struggle creates the congested appearance of early succession seen in plot 4.

Figure 27 Plot 4 Lianas Dominate Structure/ Lianas thick, tangled mass

The pasture edge appears to have impacted the regeneration of the forest, resulting in the decrease of general canopy height and lower basal area. The energy expended in this general competition produces thicker trees that are defined by their resilience. However, the abundance of specific tree species seen here, such as Inga vera. Inga v., also known as the ice-cream bean tree, is a variable evergreen species of tree in the Fabaceae family. It is typically found in the humid lowland tropics of Nicoya.

The Inga v. has a beneficial symbiotic relationship with soil bacteria that fix atmospheric nitrogen. This species should be noted as restoration marker species, benefiting not only the plant itself but also other plants growing nearby. The presence of tree like Inga v. suggests that these forests are still developing transitioning and adapting, defining the changing landscape here over time. Below(Figure 28) we can observer the varing forest structures of this plot.

Figure 28 Plot 4 Forest Structure

Trees that could not outgrow the vines, suffered incredible distortion to the forest structure in this gradient. The most common tree species found in this plot are *Bombacopsis quinata* (Pochote), *Caesalpinia eriostachya* (Saino), and *Bursera simaruba* (Indo Desnudo) are all important pioneer species in early succession. These tree are markers of the pastures that once spread across the hills. These species are extremely common for this region of Nicoya, often used for fencing. Below (Figure 29) an exsample of a young a *Bombacopsis quinata* (Pochote). It is difficult to evaluate if these trees are long-standing fence boundaries or just naturally seeded trees.

Figure 29 *Bombacopsis quinata* (Pochote)

These species are the first to colonize a disturbed or degraded area such as these edging boarder area and play an important role in soil stabilization. This later creates more favorable conditions for the growth of other plant species.

Numerous species, such as *Bombacopsis quinata* (Pochote), *Caesalpinia eriostachya* (Saino), *Calycophyllum candidissimum* (Salmon/conejo) are common in natural fencing and wood products across this area. As abandoned pastures fade and these pioneer tree species begin to colonize, spreading unrestricted from the remnant of live fences.

Of note, *Calycophyllum candidissimum*, commonly known as "Salmon" or "conejo," is a large beautiful dry zone tree that can grow up to 40 meters tall. This tree’s bark is a grayish-brown and deeply fissured, with a fibrous texture. The leaves are elliptical and dark green, with a glossy texture, and measure about 10-20 cm in length. The below photos (Figure 30) display the small, white flowers that are clustered in panicles, that are then followed by small, round fruits that are about 1 cm in diameter.

Figure 30 *Calycophyllum candidissimum*

The wood of *Calycophyllum candidissimum* is highly valued for its durability and resistance to decay, making it a popular choice for construction and furniture making. It has a light yellow to light brown color, with a fine and uniform texture, and is easy to work with. The presence of these trees (Figure 31) in this area are not uncommon, suggests that the area is undergoing early succession.

Figure 31 Plot 4 General Plot Conditions

The data from plot 4 provides important information about the plant species present in an early successional stage near the Karen Mogenson Reserve in Costa Rica. By identifying and quantifying the abundance of different tree species in the area, we can see the process of forest regeneration and monitor changes over time.

The plot 4 area appears to have a diverse range of tree species, including both hardwood and softwood species indicating a healthy seed transfer across the plot. The mixture of species found here potentially play a role in determining the successional trajectory of the forest. The overwhelming presence of vines and lianas found in Plot 4 observational can be seen here to have a suggestive impact on the overall forest structure of the plot in several ways

Observably, a definite struggle for resource between the vines/lianas that are competing with the many trees for resource's, water, nutrients, space and sunlight.What is seen expressed through the rivalry are drastic changes in forest structure here over time. Many trees have been used as framework for the vines, twisting and warping the trees across these transitional zones.

Variation of successional trajectories are connected to the presence of vines and lianas create natural disturbances. Some vines and lianas are known to be early colonizers of disturbed habitats and may be clear indicators of early successional stages. This differs significantly from lianas that use the more mature trees for support.

Plot 5

Latitude: 9.880782° N, Longitude 85.065902° W. Images are presented for Plot 5 (Figures 32-34), as well as my impressions from surveying the plot. Tree species are listed in Table 10.

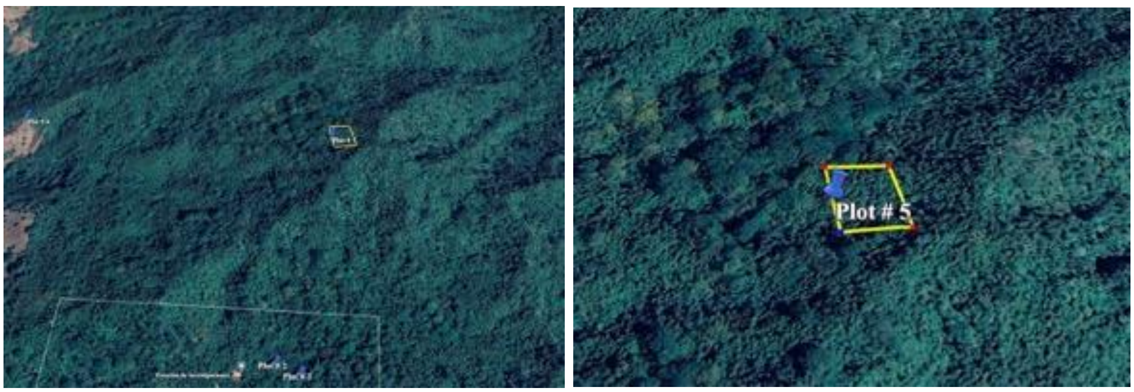

Figure 32 Plot 5 Wide view (L) and close-up (R)

Plot 5 (Figure 32) has an elevation of 433 meters and is categorized as middle to late middle in terms of age and succession, with an estimated age of regeneration between 20-30 years. This plot is again along one of the routes leading to a forest look out of the reserve.

This plot is a shady location with a well-developed canopy with lianas and many smaller shrubs that have given the area a much lower canopy. Trees here have all hallmarks of a dry forest, weighted down from the aggressive vines. Below, many trees here are twisted and warped from being strigulated by the vines.

This transitional zone of a dry/moist tropical forest, portrays a captivating snapshot of a middle succession forest plot. In this shaded area, a well-developed canopy blankets the landscape, offering break from the February sun. The canopy, interwoven with an intricate network of lianas, creates a mesmerizing display of nature's artistry.

Figure 33 Intricate Network of Lianas

The presence of numerous smaller shrubs further contributes to the enchanting scene, rendering the area with a noticeably lower canopy compared to other plots in the vicinity. The trees within this plot bear the unmistakable characteristics of a dry forest. Loaded with the weight of aggressive vines, they exhibit a distinctive appearance. Many of the trees, their growth encumbered by the tenacious embrace of the vines, appear twisted and warped. The relentless struggle for light and resources has left its mark on these resilient arboreal inhabitants.

As this area is further assess it is noted in this plot, a subtle transformation start to unveils itself. The once aggressive vines, though still present, have reached a state of maximized productivity, becoming less prominent in the landscape and canopy. The towering trees, reaching skyward, now embark on divergent successional trajectories. Some trees display the signs of reaching their peak, their branches adorned with the marks of age.

Also seen across the area, other trees that begin to exhibit signs of decline and decay. The density of the forest gradually diminishes, gradually fading back into the text book openness typically associated with late succession dry forests.

Figure 34 Towering Trees Divergent Successional Trajectories

Table 10 Tree Species and Measurements of Plot 5

Tree species	Count	Avg Height/m	Max of Height/m	Min of Height/m	Avg DBH/m	Max of DBH/m	Avg DBH/m^2
Acacia cornigera (Bull acacia)	3	4.07	6.30	2.8	0.47	0.64	0.5
Albizia adinocephala	1	11.90	11.90	11.9	0.73	0.73	0.7
Bombacopsis quinata (Pochote)	2	15.30	16.80	13.8	1.14	1.23	1.1
Bursera simaruba (Indio desnudo)	2	17.25	18.30	16.2	1.29	1.37	1.3
Caesalpinia eriostachya (Saino)	2	12.45	17.60	7.3	1.30	1.37	1.3
Cecropia peltata (Trumpet tree)	1	14.60	14.60	14.6	0.72	0.72	0.7
Chamadorea costa (Palm)	1	1.90	1.90	1.9	0.00	0.00	0.0
Coccoloba caracasana	1	9.80	9.80	9.8	1.43	1.43	1.4
Coccoloba guarcastensis	2	3.20	3.80	2.6	0.30	0.38	0.3
Cochlospermum vitifolium	1	12.40	12.40	12.4	0.51	0.51	0.5
Cordia panamensis	1	6.50	6.50	6.5	0.71	0.71	0.7
Crecentia cujete (jicaro)	2	3.90	5.10	2.7	0.21	0.22	0.2
Hylocereus C. (Dragonfruit)	1				0.00	0.00	0.0
Lysiloma divaricatum (Quebracho)	1	11.10	11.10	11.1	0.61	0.61	0.6
Manikara zapota (Nispero)	1	18.40	18.40	18.4	1.59	1.59	1.6
Plumeria rubra(Flor blanca)	1	10.20	10.20	10.2	0.87	0.87	0.9
Pseudosamanea guachapele (Guayaquil)	1	13.70	13.70	13.7	1.28	1.28	1.3
Spondian radlkoferi	2	14.50	15.60	13.4	0.79	0.84	0.8
Swietenia macrophylla (Caoba)	2	13.00	17.10	8.9	1.20	1.37	1.2
Trichilla Americana	1	14.90	14.90	14.9	0.86	0.86	0.9
Zanthoxylum setulosum (Lagarto)	1	6.70	6.70	6.7	0.34	0.34	0.3
Grand Total	**30**	**10.47**	**18.40**	**1.9**	**0.78**	**1.59**	**0.8**

The estimated basal area for this plot is 110.0 board m²/ha, with an average understory of 6.7cm. The mean DBH for the plot is 10.2 cm and the mean height is 21 m. Plot 5 is an interesting mid-succession plot that showcases a diverse range of vegetation. The remnants of pasture grasses are still evident, providing a glimpse into the plot's history as a cattle pasture. The presence of vines and lianas interwoven throughout the dense lower canopy is a striking feature that hints at the plot's lush and tangled past.

Swietenia macrophylla, commonly known as Caoba or Big-leaf mahogany, is a valuable and rare tree species that grows in tropical forests of Central and South America. In this area we find an example Swietenia m. As a large canopy tree, it plays a critical role in the structure and function of the forest, providing habitat for many other plant and animal species.

Its presence here may suggest that the forests in the reserve have remained relatively undisturbed and that the ecological conditions are suitable for supporting a range of species. The Caoba tree as a rare and valuable species, its presence can provide insight into the ecological health and diversity of these mid aged forests. Plot 5 is a fascinating ecosystem that showcases the resiliency of nature in the reserve.

Plot 6

Latitude: 9.873998025, Longitude: -85.05384497. Images are presented for Plot 6 (Figure 35), as well as my impressions from surveying the plot. Tree species are listed in Table 11.

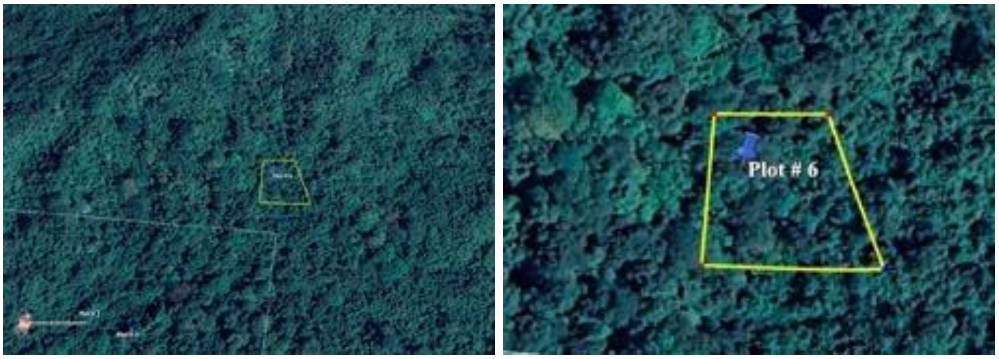

Figure 35 Plot 6 Wide view (L) and close-up (R)

This plot (Figure 35) is categorized as middle to late middle in terms of age and succession, with an estimated age of regeneration between 40-60 years. At an elevation of 325 meters and an estimated basal area of 150.0 board m^2/ha. The average understory is 12.5 cm, the mean DBH is 12.4 cm, and the mean height is 13.2 m.

Plot 6 is another transitional dry forest area, represents a crucial stage in the progression towards late-middle succession. The journey to this plot was not without its challenges, as the area's deep and rugged terrain demanded effort and perseverance. While the nearby hilly areas might have offered more interesting tree samples, they remained inaccessible due to the inherent danger w ith getting in and out of the steep slopes.

Inside the boundaries of Plot 6, a fascinating glimpse into the forest's development unfolds. Here, the plant community is characterized by a prevalence of shrubs and small trees, signaling the ongoing transition from pioneer species to shade-tolerant ones. This shift in dominance is a mark of middle succession, as the ecosystem ages, and becomes more complex and varied.

Amidst this dynamic landscape, several key trees emerge, indicating the progress of succession. One notable species is *Virola surinamensis*, commonly known as "Fruta dorada." With its impressive height and substantial diameter, this tree stands as a evidence to successful competition for vital resources, such as water and sunlight. Another significant presence is *Samanea saman*, aptly named the "Rain tree," which commands attention with its majestic stature and broad canopy, suggesting its role as a dominant species in this particular forest. How many of these are left over cover for cattle or fencing remains?

As the forest progresses towards late-middle succession, the characteristics of plot 6 provide valuable insights into the ongoing dynamics of the transitional nature of these dry forest. The presence of shrubs and small trees, along with the notable individuals such as *Virola surinamensis* and *Samanea saman*, speaks to the resilience and adaptability of the ecosystem as it continues to evolve. This plot serves as a microcosm, encapsulating the intricate processes of succession and the fascinating interplay of species within this remarkable transitional forest.

Table 11 Tree Species and Measurements of Plot 6

Tree species	**Count**	**Avg Height/m**	**Max Height/m**	**Min Height/m**	**Average DBH/m**	**Max DBH/m**	**Avg DBH/m^2**
Astronium graveolens (Ronron)	1	14.50	14.50	14.5	1.42	1.42	1.4
Brosimum costaricanum	6	12.28	17.70	7.4	1.39	2.65	1.4
Byrsonima crossifolia (Nance)	3	14.23	17.40	10.2	1.13	1.31	1.1
Capparis Indica	1	12.70	12.70	12.7	0.94	0.94	0.9
Cardia panamensis	1	19.80	19.80	19.8	1.46	1.46	1.5
Carlunoica palmata	1	1.50	1.50	1.5	0.25	0.25	0.3
Casearia Arguta	1	10.70	10.70	10.7	0.76	0.76	0.8
Celtis schiedeanus (Gavilan)	2	17.30	25.90	8.7	2.26	2.35	2.3
Celtis schippii (Gavilan)	2	16.60	23.30	9.9	2.00	2.48	2.0
Croton schiedeanus	1	7.20	7.20	7.2	0.42	0.42	0.4

(cont.)

Tree species	Count	Avg Height/m	Max Height/m	Min Height/m	Average DBH/m	Max DBH/m	Avg DBH/m^2
Lacnellea panamensis (Lagarto negro)	1	6.10	6.10	6.1	0.67	0.67	0.7
Parkia nitida	1	16.10	16.10	16.1	1.87	1.87	1.9
Pouteria reticulata (nisparo blanco)	1	13.20	13.20	13.2	1.64	1.64	1.6
Protium panamense (Copal)	5	10.88	13.90	6.7	1.18	2.01	1.2
Pseudolmedia spuria	1	6.70	6.70	6.7	0.44	0.44	0.4
Samanea saman (Rain tree)	1	34.20	34.20	34.2	2.34	2.34	2.3
Spondias mombin (Jobo)	1	7.60	7.60	7.6	0.45	0.45	0.5
Tabebula rosea (Roble)	1	15.60	15.60	15.6	1.13	1.13	1.1
Terminalia oblonga (surá, guayabón, guayabo de montaña)	2	22.10	23.10	21.1	1.21	1.53	1.2
Trophis racemosa	5	7.56	12.60	2.7	0.56	0.61	0.6
Vantanea depleta (Chirrino)	1	18.70	18.70	18.7	1.76	1.76	1.8
Virola surinamensis (Fruta dorada)	1	23.90	23.90	23.9	3.42	3.42	3.4
Vismia baccifera (Achitllo)	1	14.10	14.10	14.1	0.91	0.91	0.9
Zanthoxylum setulosum (Lagarto)	1	9.40	9.40	9.4	0.66	0.66	0.7
Grand Total	**42**	**13.16**	**34.20**	**1.5**	**1.24**	**3.42**	**1.2**

The presence here of a wide variety of tree species is a good indicator of a healthy and diverse ecosystem. Additionally, the relatively tall average height of the trees in this plot suggests that there has been sufficient time for these trees to establish and grow to maturity. The presence of trees with larger diameters, such as *V. surinamensis* and *S. saman*, suggests that these species are able to compete successfully for both water and light most likely the dominant tree within this particular forest.

Plot 7

Latitude: 9° 52' 18.214" N, Longitude: 85° 3' 17.853" W. Images are presented for Plot 7 (Figures 36-38), as well as my impressions from surveying the plot. Tree species are listed in Table 12.

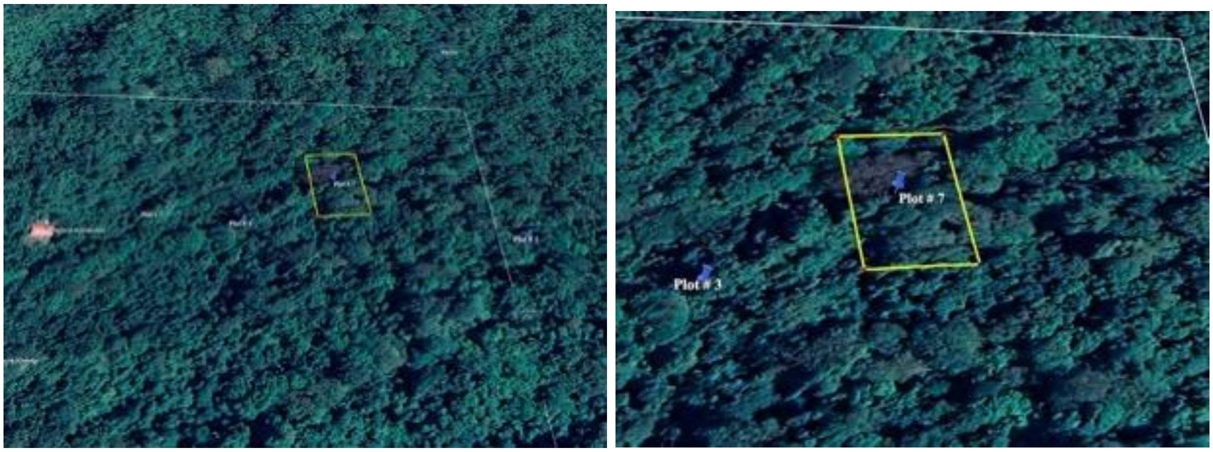

Figure 36 Plot 7 Wide view (L) and close-up (R)

Located in the heart of a dry tropical forest, Plot 7 (Figure 36) stands out as a majestic oasis amidst a landscape of thorny undergrowth and twisted branches. The towering trees that dominate the area create a dense canopy overhead, their branches intertwined with vines that add to the cathedral-like atmosphere. Despite the sweltering heat that characterizes February this region, the forest is teeming with life, and a closer inspection of the vegetation reveals the subtle changes that occur in this middle succession forest.

Figure 37 Cathedral Like Canopy

The deeply wooded dry forest here (Figure 37) are tall and majestic, standing close together, their branches entwined with vines form a dense cathedral like canopy overhead. Animals like the Coati mundi below (Figure 38) casually walked through the study area, their black and white striped tails bobbing as they went. They seemed unfazed by my presence, and I watched in awe as they disappeared into the underbrush.

Figure 38 Coati Mundi

Plot 7, situated in the heart of a dry tropical forest at an elevation of 321m it is splendor amidst the rugged landscape adorned with thorny undergrowth and twisted branches. The high trees, tall and proud, create a dense canopy overhead, their branches intricately entwined with vines, forming awe-inspiring cathedral-like structures. Within this enchanting setting, life thrives abundantly, and every corner of the forest reveals subtle changes characteristic of a vibrant middle succession ecosystem.

Plot 7 contained 33 trees surveyed with a mean height of 18.15 meters. The tallest tree in the plot is the *Anacardium excelsum* (Espavel) which stands at 31.60 meters while the shortest tree is the *Acrocomia aculeata* (Coyol) at 3.1 meters. The plot has a mean DBH of 1.51 meters, with the largest tree being the Ficus Insipida (Ficus) with a DBH of 4.24 meters and the smallest being the *Zanthoxylum setulosum* (Lagarto) with a DBH of 0.37 meters.

Table 12 Tree Species and Measurements of Plot 7

Tree Species	**Count**	**Avg Height/m**	**Max Height/m**	**Min Height/m**	**Avg DBH/m**	**Max DBH/m**	**Average DBH/m²**
Acacia cornigera (Bull acacia)	1	3.70	3.70	3.7	0.41	0.41	0.4
Acrocomia aculeata (Coyol)	2	8.65	14.20	3.1	1.56	2.26	1.6
Anacardium excelsum (Espavel)	4	24.48	31.60	12.9	2.50	3.99	2.5
Annona pupurea (Toreta)	1	6.80	6.80	6.8	0.42	0.42	0.4
Bombacopsis quinata (Pochote)	1	23.40	23.40	23.4	1.85	1.85	1.9
Brosimum costaricanum	1	21.60	21.60	21.6	1.64	1.64	1.6
Bursera simaruba (Indio desnudo)	1	13.20	13.20	13.2	1.08	1.08	1.1
Callicarpa acuminata	1	6.70	6.70	6.7	0.76	0.76	0.8
Castilla elasticas (Hule)	1	19.10	19.10	19.1	1.09	1.09	1.1
Cedrela odorata	2	15.90	19.10	12.7	0.92	1.27	0.9
Ficus cotinfolia	1	18.90	18.90	18.9	2.08	2.08	2.1
Ficus Insipida(Ficus)	2	21.35	27.90	14.8	2.99	4.24	3.0
Guarea Rhopalocarpa (Cocora)	1	15.70	15.70	15.7	1.54	1.54	1.5
Inga Vera	1	17.70	17.70	17.7	0.73	0.73	0.7
Licania micrantha	1	23.70	23.70	23.7	0.74	0.74	0.7
Licania platypus (Sapote)	1	24.30	24.30	24.3	1.58	1.58	1.6
Lysiloma divaricatum (Quebracho)	1	16.40	16.40	16.4	0.69	0.69	0.7
Maclura tinctoria (old fustic and dyer's mulberry)	1	26.80	26.80	26.8	1.37	1.37	1.4
Manikara zapota (Nispero)	1	17.30	17.30	17.3	0.90	0.90	0.9
Ouratea lucens	1	12.20	12.20	12.2	0.68	0.68	0.7

(cont.)

Tree Species	Count	Avg Height/m	Max Height/m	Min Height/m	Avg DBH/m	Max DBH/m	Average DBH/m^2
Pseudosamanea guachapele (Guayaquil)	1	15.70	15.70	15.7	0.82	0.82	0.8
Sterculia apetala (Palo de Panama)	1	16.40	16.40	16.4	1.06	1.06	1.1
Tabebuia ochracea (corteza amarillia)	1	26.60	26.60	26.6	2.43	2.43	2.4
Tabernae montana (Alba/Guijarro)	1	27.70	27.70	27.7	1.94	1.94	1.9
Terminalia oblonga (surá, guayabón, guayabo de montaña)	2	24.50	24.80	24.2	2.36	2.79	2.4
Zanthoxylum setulosum (Lagarto)	1	6.20	6.20	6.2	0.37	0.37	0.4
Grand Total	**33**	**18.15**	**31.60**	**3.1**	**1.51**	**4.24**	**1.5**

A defining feature of this forest is the presence of microclimates generated by the topographical characteristics of the hills and water channels found here. The hills create a range of different elevations, each with its own set of environmental conditions such as temperature, humidity, and wind exposure (Schwartz et al., 2022). As the moisture fans out and down the hills, these microclimates provide a range of habitats for different species, allowing the high levels of biodiversity seen in a relatively small area.

One of the defining features of this forest is the presence of microclimates created by the topographical characteristics of the hills and water channels. These microclimates provide a range of habitats for different species, allowing for the high levels of biodiversity seen in a relatively small area. The plants in the forest have evolved to survive in the arid environment. Many of them have developed deep root systems to access the limited water resources, while others have adapted to store water in their leaves or stems. The result is a vibrant and resilient ecosystem that is able to thrive despite the harsh conditions. The dry forest in the Nicoya peninsula are a testament to the power of evolution.

The survey data of Plot 7 further illuminates the grandeur of this middle succession forest. Located at an elevation of 321 meters, the plot comprises a diverse array of 33 surveyed trees, each contributing to the forest's tapestry. The average height of the trees stands at an impressive 18.15 meters, with the *Anacardium excelsum* (Espavel) towering as the tallest individual, reaching an astounding height of 31.60 meters. On the other end of the spectrum, the *Acrocomia aculeata* (Coyol) stands as the shortest tree in the plot, measuring at 3.1 meters. The average diameter at breast height (DBH) is 1.51 meters, with the *Ficus Insipida* (Ficus) claiming the title of the largest tree in terms of DBH, measuring 4.24 meters, while the *Zanthoxylum setulosum* (Lagarto) boasts the smallest DBH at 0.37 meters.

Plot 7 showcases the forest's inherent ability to adapt and thrive within its challenging environment. Microclimates, generated by the topographical variations of hills and water channels, add to the diversity of habitats available to different species within the plot. These microclimates, with their unique combinations of temperature, humidity, and wind exposure, create niches that support the high levels of biodiversity found within this relatively small area.

Plot 8

Latitude: 9.871204002° N, Longitude: 85.05411697° W. Images are presented for Plot 8 (Figure 39), as well as my impressions from surveying the plot. Tree species are listed in Table 13.

Figure 39 Plot 8 Wide view (L) and close-up (R)

Plot 8 is located at an elevation of 346m (Figure 39) in a middle to late succession with an estimated age of regeneration between 40 to 60 years. Plot 8 can be observed to be undergoing middle to late succession with all the characteristics of a transitional dry/moist forest. The forest structure is characterized by a mix of taller trees and shorter shrubs, with a sparse understory of *Cordia alliodora* (Spanish Elm) and *Trichilia martiana*. The presence of canopy gaps and fallen trees implies a natural process of disturbance and regeneration, contributing to the high biodiversity seen across this plot. Despite the presence of some early successional species, the plot appears to be in mid-succession, with a mixture of early and late successional species present.

The estimated basal area of the trees in this plot is 116.7 square board meters per hectare, and the average understory height is 7.7 cm. Plot 8 was a robust and thick forest environment. The mean diameter at breast height (DBH) for the trees in this plot is 12.4 cm, and the mean height is 15.8 meters. Below (Table 13) we show the wide range of tree species and survey results collected.

Table 13 Tree Species and Measurements of Plot 8

Tree species	Count	Avg of Height/m	Max of Height/m	Min of Height/m	Avg DBH/m	Max DBH/m	Avg DBH/m^2
Acacia cornigera (Bull acacia)	2	4.55	5.70	3.4	0.35	0.44	0.3
Acosmium panamense(Guayacán)	2	17.70	19.80	15.6	1.47	1.63	1.5
Adelia triloba (Espino)	1	14.30	14.30	14.3	0.93	0.93	0.9
Anacardium excelsum (Espavel)	2	24.40	27.20	21.6	1.95	2.01	2.0
Andira inermis (Amendro de montana)	1	12.50	12.50	12.5	0.62	0.62	0.6
Bursera simaruba (Indio desnudo)	1	13.60	13.60	13.6	0.91	0.91	0.9
Canange adorata(Ylang-ylang)	1	12.20	12.20	12.2	0.28	0.28	0.3
Casearia sylvestris	1	8.30	8.30	8.3	0.86	0.86	0.9
Cedrela odorata	1	19.40	19.40	19.4	1.49	1.49	1.5
Cordia Alliodora	1	8.10	8.10	8.1	0.47	0.47	0.5
Dalbergoia retusa	1	13.10	13.10	13.1	0.65	0.65	0.7
Ficus Insipida(Ficus)	4	20.83	31.50	16.1	2.11	2.66	2.1
Hura crepitan (Sandbox tree)	2	21.00	24.10	17.9	0.73	0.78	0.7
Hymenaea courbaril (Guapinol)	1	24.60	24.60	24.6	1.78	1.78	1.8
Plumeria rubra(Flor blanca)	1	15.40	15.40	15.4	1.07	1.07	1.1
Raphia taedigera (Palm)	1	1.40	1.40	1.4	1.52	1.52	1.5
Spondias mombin (Jobo)	2	12.95	16.70	9.2	0.98	1.22	1.0
Sterculia apetala (Palo de Panama)	1	19.40	19.40	19.4	2.46	2.46	2.5
Swietenia macrophylla (Caoba)	1	15.10	15.10	15.1	1.37	1.37	1.4
Trichilia martiana	1	26.30	26.30	26.3	1.82	1.82	1.8
Zanthoxylum setulosum (Lagarto)	1	9.80	9.80	9.8	0.36	0.36	0.4
Grand Total	**29**	**15.79**	**31.50**	**1.4**	**1.24**	**2.66**	**1.2**

A total of 29 trees were surveyed, with the tree species richness seeming elevated at 21indiviual species noted. The most abundant species in the plot are *Acacia cornigera* (Bull acacia), *Acosmium panamense* (Guayacán), *Adelia triloba* (Espino), *Albizia niopoides*, and Astronium *graveolens* (Ronron). Other notable species include *Anacardium excelsum* (Espavel), *Bombacopsis quinata* (Pochote), *Bursera simaruba* (Indio desnudo), and *Swietenia macrophylla* (Caoba).

This plot appears to be a varied and vibrant ecosystem undergoing middle to late succession in a transitional dry/moist forest. The growth of the trees seems to be vigorous and robust, and with high diversity in terms of tree species richness, with at least 45 species observed in the survey that this survey were unable to get too due to time constraints and rough terrain.

Chronosequences

Distribution Of Trees Across Time

First examined is the variety of tree species spread across the eight different plots in various phases of ecological succession. Our study discovered an impressive array of species diversity throughout all the plots. From simple observation is might be implied substantial diversity could probably be attributed to a combination of multiple stages of ecological succession present in the surveyed areas and the array of different topographies and microhabitats present within the Karen Mogenson reserve.

A total of 278 trees belonging to 75 distinctive species were recorded in the 8 survey plots were counted in an area equivalent to 0.5 hectares (Figure 40). The density of trees per hectare was calculated as 556 trees/ha overall. The most dominant tree species in the surveyed plots were *Anacardium excelsum* (Espavel), *Bursera simaruba* (Indio desnudo), and *Zanthoxylum setulosum* (Lagarto). Although these species are typically associated with earlier succession stages, the effects of weather and high animal biodiversity contribute greatly to the way seeds are dispersed across the area. The presence of pioneer species is consistent with the preserve growth from land acquisition of adjacent ranches over the last 25 years.

At the earliest stage in Plot 4, these are pasture edges, yet there is a relatively high diversity of species with a total of 29 different species As the succession progresses, there is a decrease in the number of species, with Plot 8 in a middle -late stage succession, having the lowest diversity of species with only 10 different species. Middle succession is a battle ground as deep levels of competition in these isolated regions of Costa Rica. The rapid development of vines across middle succession in these transitional forests is a defining force, shaping the forest structure of the reserve.

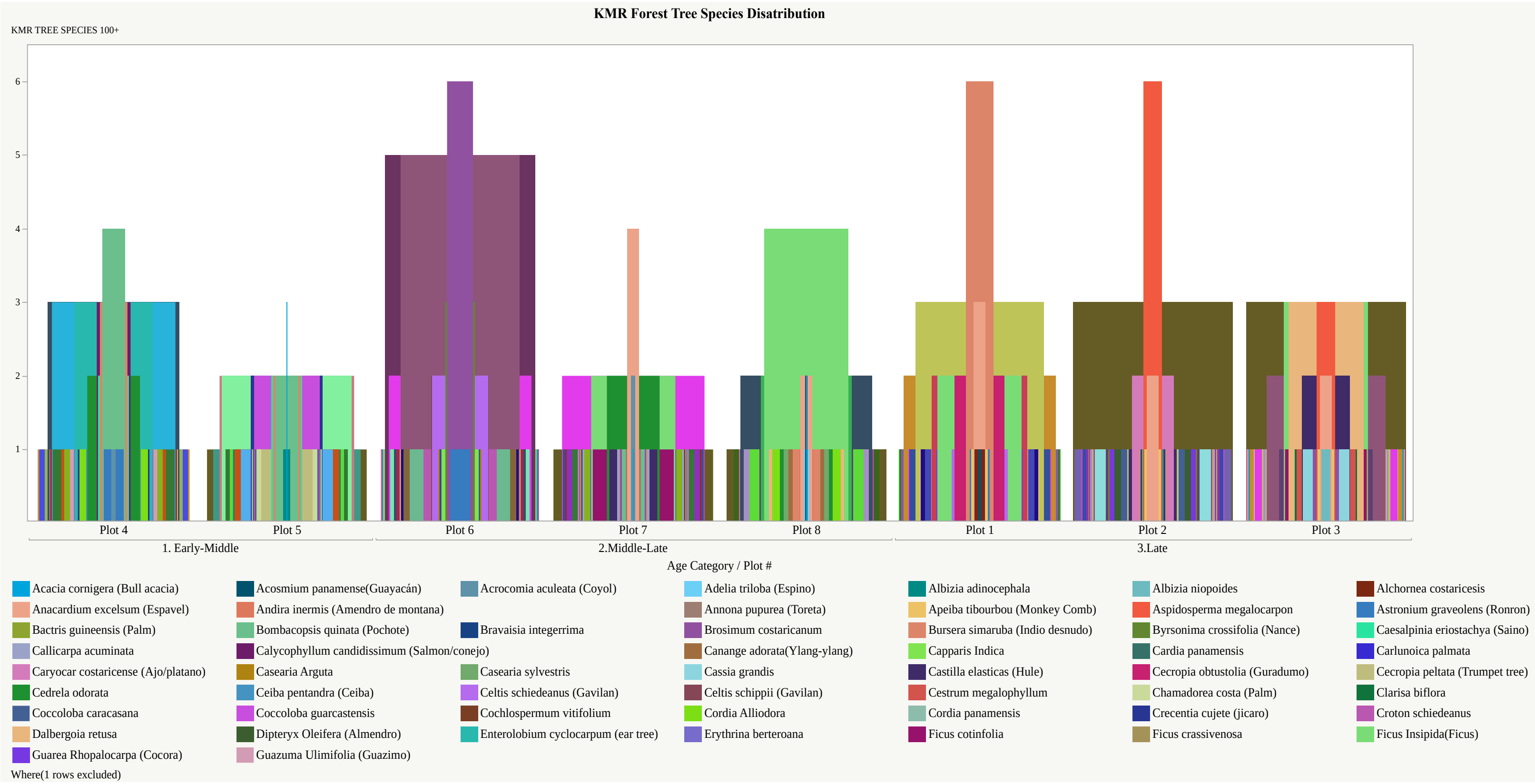

Figure 40 Seventy-five distinctive species were recorded in the 8 survey plots

The most abundant species in the earlier stages of succession are *Alchornea costaricensis*, *Anacardium excelsum*, and *Bursera simaruba*. These species remain dominant throughout most of the succession, with the addition of other species such as *Astronium graveolens* and *Protium panamense* in the later stages that find pockets of sun to grow tall. There is a shift in species composition as succession progresses (Figure 41).

This is typical of forest succession, as certain species are better adapted to environmental conditions and will eventually outcompete other species over time. It is also noteworthy that there is some overlap in tree species composition across the different stages of succession. For instance, some species, such as *Ficus insipida* and *Swietenia macrophylla*, appear in multiple stages of succession. As a way to illustrate the variation observed in the process of succession in the reserve, here the study presents a temporal analysis of the species of the most commonly found trees across all succession stages. This analysis, depicted in Figures 42-44 below, provides evidence of the dynamic nature of ecological succession and highlights the fluctuating patterns of tree species composition over time.

What was observed across all areas of study was the presence of vines and lianas and how they directly play a role in forest development in the region. The long-stemmed, woody vines were a constant presence across different stages of forest succession, including mature phases. Their unique growth strategy enables them to rapidly populate the forest structure, creating complex networks between trees and across the forest canopy.

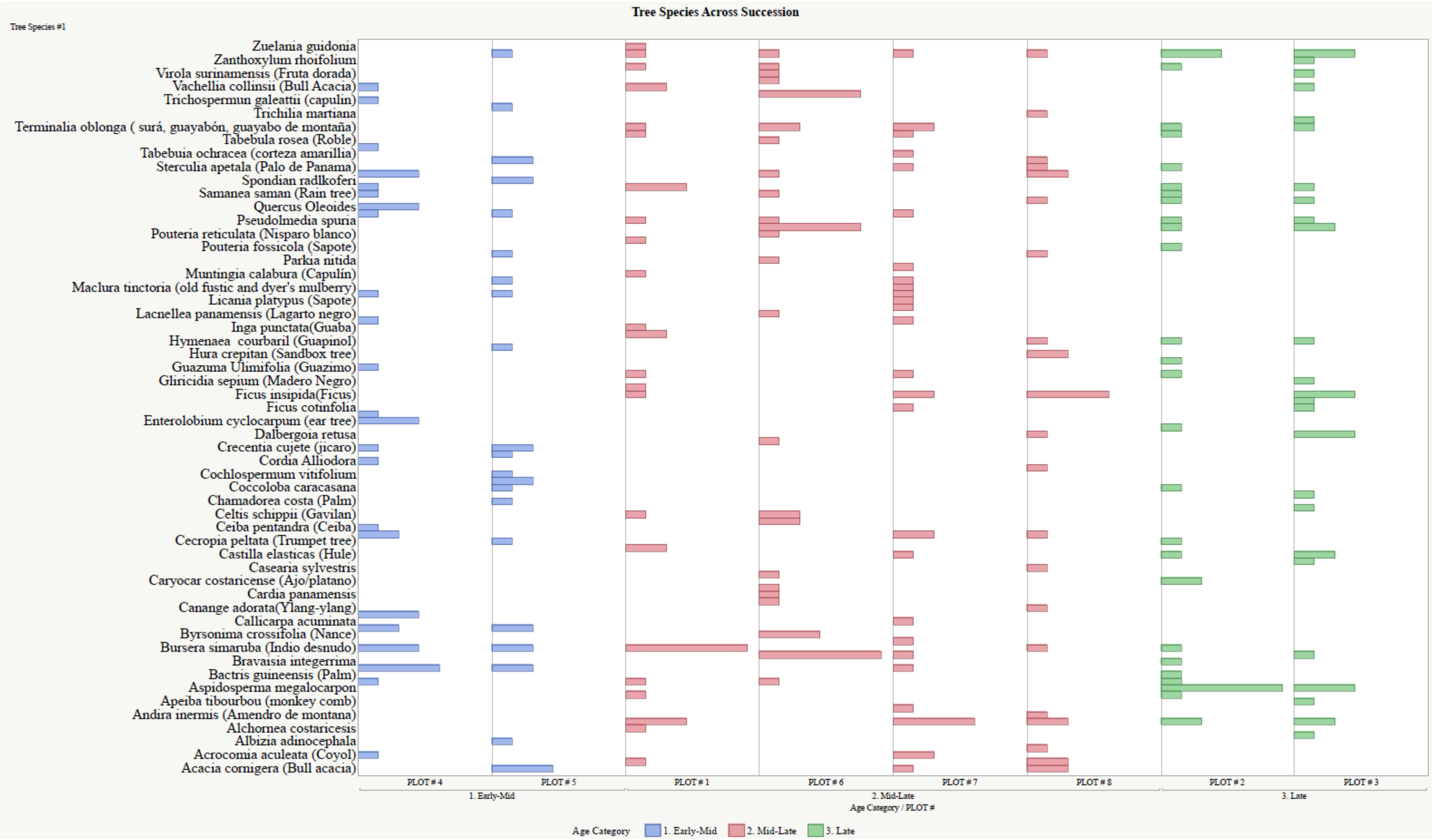

Figure 41 KMR Tree Distribution Across Sucession

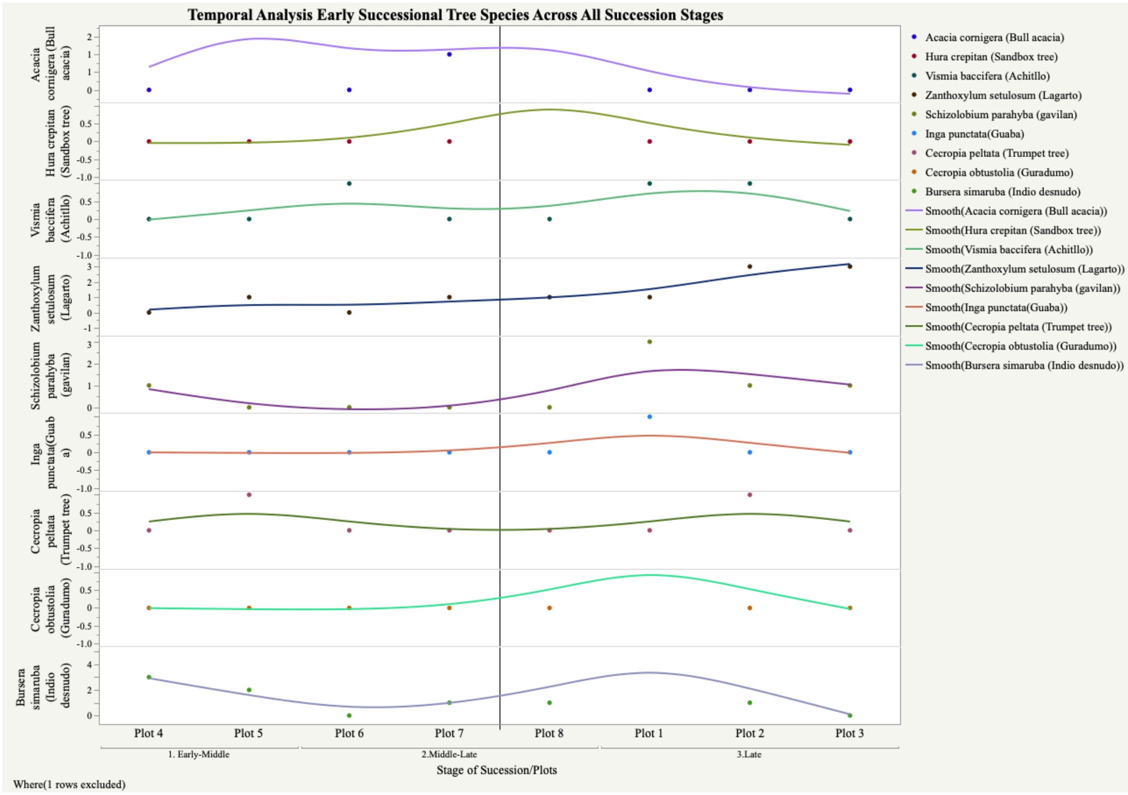

Figure 42 Temporal analysis of early successional tree species

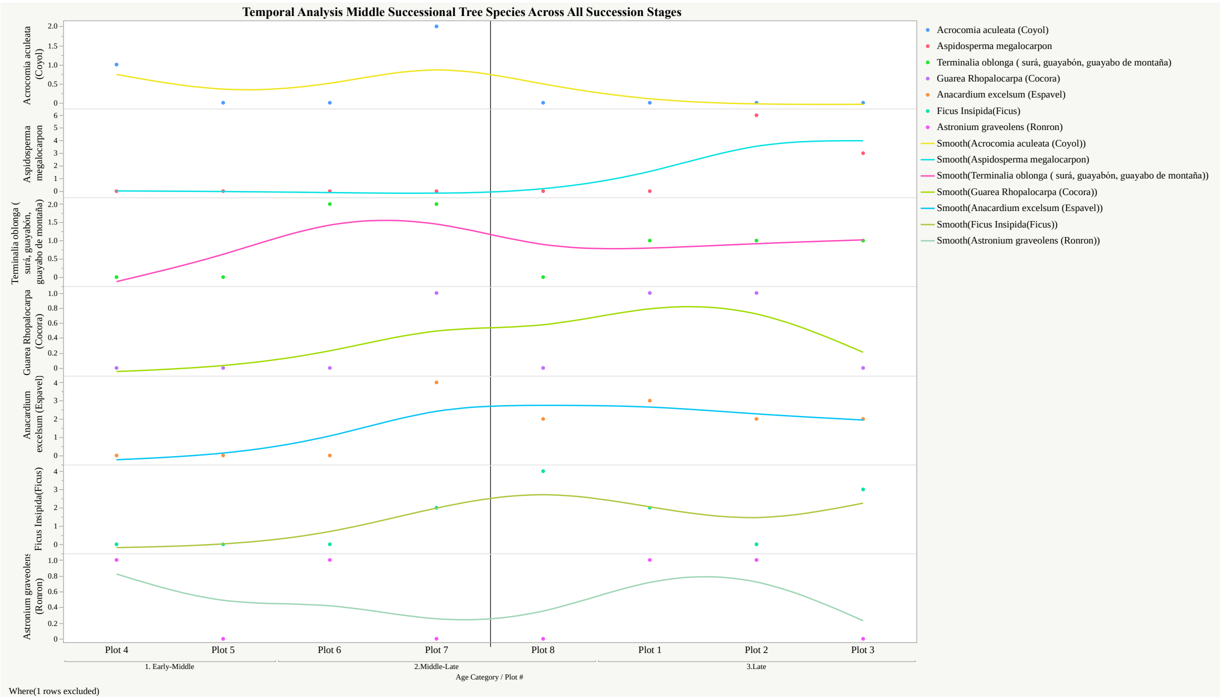

Figure 43 Temporal analysis of middle successional tree species

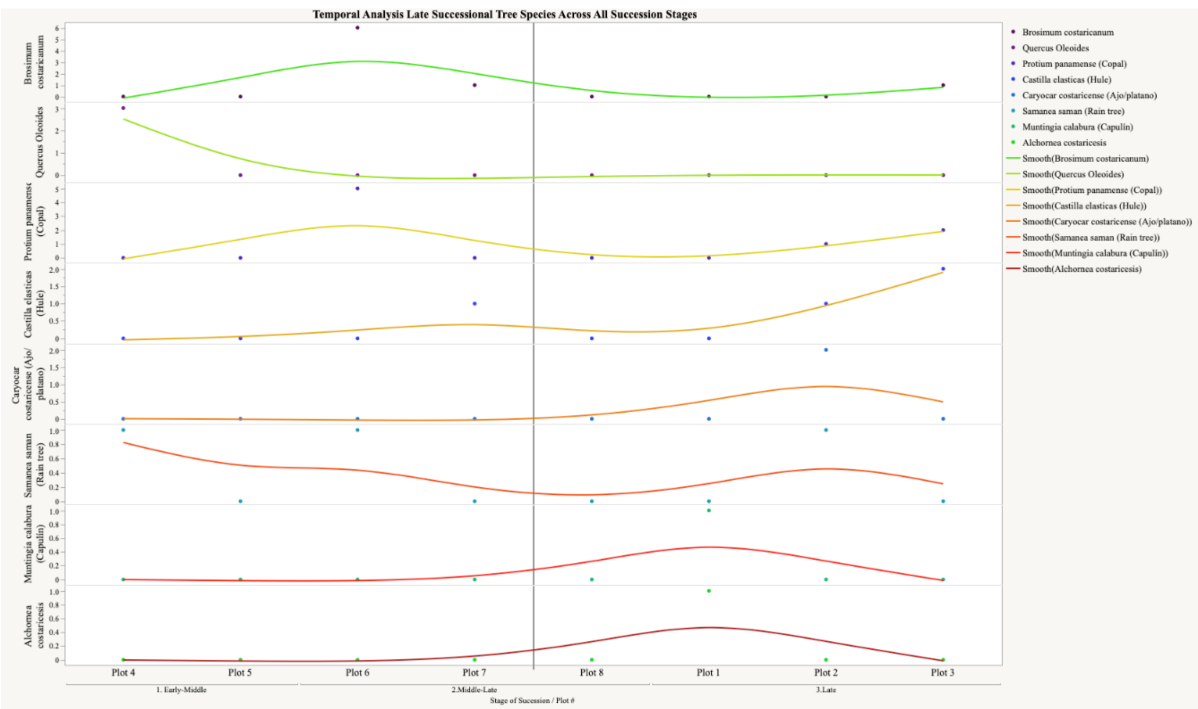

Figure 44 Temporal analysis of late successional tree species

In the reserve’s mature forests, lianas continue to flourish, filling gaps in the canopy and surviving in lower light conditions. Their resilience and adaptability underline their ecological importance in shaping forest ecosystems and maintaining structural complexity, even under conditions where certain tree species may struggle.

The phenomenon of tree species diversity over time here in the reserve often presents a wave-like pattern, much like the undulations of a sine wave. The diversity of tree species in different stages of forest succession in the reserve area can be described as ebbing and flowing, much like the movement of ocean tides over time.

In the reserve early stages of succession is not textbook, diversity flows in with much high number of species found in the edge lands where forest meet pastures. Many of the trees persist and were seen in more mature forms later aged plots. As the forest transitions into middle age, the tree diversity ebbs or recedes, due mainly to competition among species where some outcompete others for the light, water or space. The overwhelming force of the lianas and vines to clog the forest most like reduces the ability of the trees to establish themselves past the early stage of forest development As the forest transitions into a middle-aged phase, the number of species typically diminishes. This drop is often due to the competitive nature of certain species better adapted to the prevailing conditions, eventually outcompeting and supplanting less adapted species.

This data suggests that some tree species may persist and remain dominant across different stages of succession, while others may become less dominant or be replaced by other species over time. More long-term observation would be needed in the form of permanent plots to study tree composition. Though, charts strongly implies that tree species composition changes over time during forest succession, with a general trend towards an increase in the number of species as the forest ages.

Data On Tree Species Richness Across Succession

The data on tree species richness across plots 1-8 shows that there was a wide range of species present in the reserve's forest, with a total of 75 distinctive species recorded. The number of species in each plot varies, with Plot 7 having the highest number of species 27and Plot 5 having the lowest number 25.

Tree species richness fluctuates across the eight plots (Figure 45). This could be some indication that seed beds here persist across longer periods of time. Plot 5, which is in the early stages of succession, has the lowest number of tree species, while all plots in later stages remain consistent well into late stages of forest development.

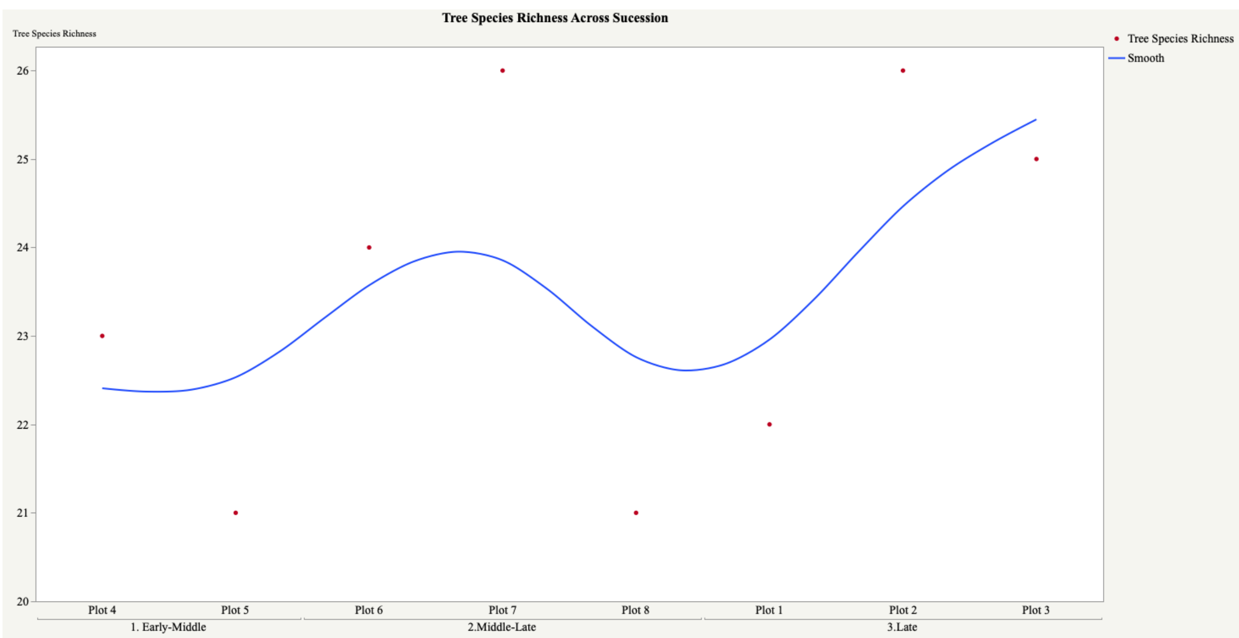

Figure 45 Tree Species Richness Across Plots 1-8

As the forest progresses through succession, the diversity of tree species tends to increase. The graph also show that there is variation in species richness in the middle stages of succession, which could be due to various ecological factors such as competition, environmental stress, or disturbance events.

Species Richness/Mean Understory Across Forest Successional Boundaries

The next plot shows both species richness and the mean understory height across forest successional boundaries (Figure 46). The plots progress from early to late succession, and observation of the data presents a gradual increase in the mean understory plant density as well as in the number of plant species present in each plot. This indicates that the understory is an important component of forest succession, and that as the forest matures, there is an increase in the diversity and density of understory vegetation.

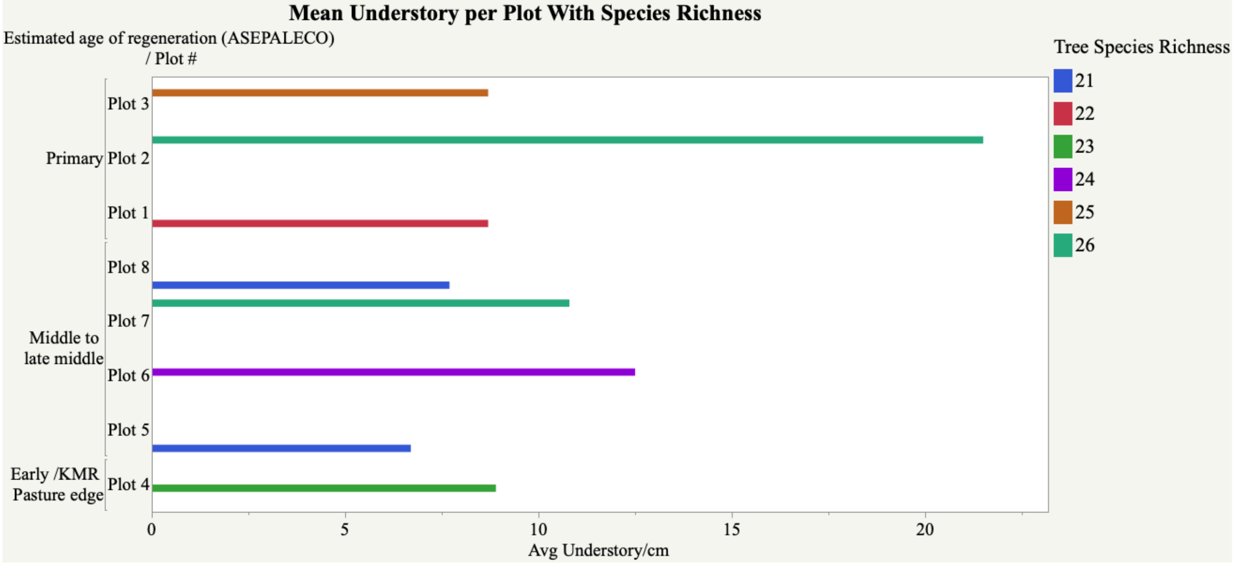

Figure 46 Mean understory density and species richness across succession.

The data gives a strong indications that the way understory develops plays a vital role in forest succession across the reserve. As the succession progresses in this plot, the count of developing saplings shows an increase that becomes more prominent in the middle to late stages of maturity. The data also suggests that as these transitional forests matures, there is a suggestive increase in both diversity and density of understory vegetation over time.

The number of saplings varies with the estimated age of regeneration (Figure 47). In general, there are more saplings present in areas with younger estimated regeneration age. This could suggest that the forest has a more dynamic regeneration process, with new growth occurring regularly as forest mature. This is consistent with the rapid growth seen here of sapling in middle to late succession. Additionally, the data can inform us about the potential future composition of the forest, as saplings are the future trees of the forest. The presence of a large number of saplings in a particular stage suggests that in the future, the forest composition may be dominated by those species.

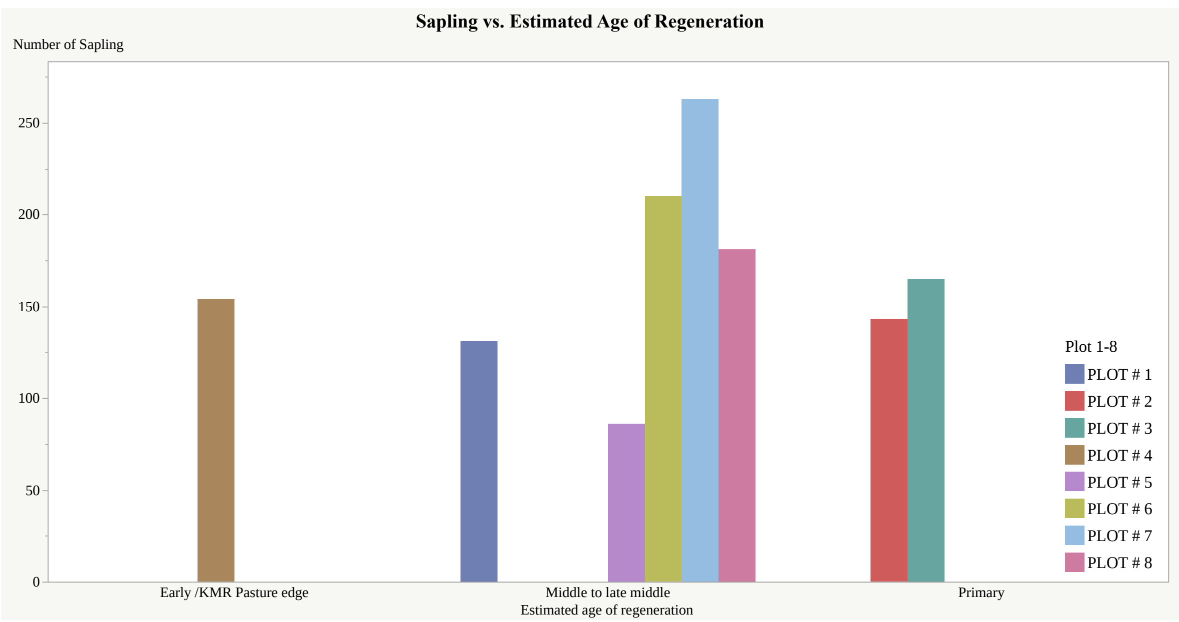

Figure 47 Saplings present across the forest plots/across time

This data also reveals that there is a strong persistence across all plots of tree species as succession progresses over the varying time frames. It is worth noting the high levels of diversity found here, that even in the later successional stages, there is still a considerable amount of species diversity present in these dry forests. This provides some indication that the forest is still able to support a range of species, even as it matures and becomes more stable. possibly due to the fact that earlier successional stages provide more niches for different species to coexist and thrive.

This data also suggests that there is a dynamic relationship between tree species richness and forest composition, with earlier successional stages supporting higher levels of species diversity well into late stages of development. This data also can provide a deeper understandings into the regeneration dynamics and future composition of the forests here in the reserve.

Forest Densities in the Karen Mogenson

To estimate the basal area for each of the 8 plots, we can use the mean basal area per plot (in square feet) and convert it to square meters or board meters. Plot size = 20 m x 50 m = 1000 m^2 = 0.1 hectares. These results are rough estimates of the basal area for each of the 8 plots in a the KMR (Table 14, Figure 48). Basal area is often a measure of the cross-sectional area of a tree trunk at breast height, typically measured in square feet per acre or square meters per hectare. In this case, the basal area has been measured in square feet and then converted to both square meters and board meters.

Variations in tree densities observed across the reserve are a strong indication of different stages of forest succession. Plot 4, for instance, appears to be in an early stage of succession, with a considerable density of thick, twisted trees and a low canopy height due to the overwhelming presence of lianas within the forest structure.

Table 14. Calculation of Basal Area for each Plot

Plot number	Mean Basal Area (sq. ft.)	Basal Area (sq. meters)	Basal Area (board meters)
1	121.7	11.29	51.53
2	60.0	5.57	25.42
3	136.7	12.68	57.89
4	45.0	4.18	19.07
5	110.0	10.21	46.61
6	150.0	13.93	63.56
7	110.0	10.21	46.61
8	116.7	10.83	49.00

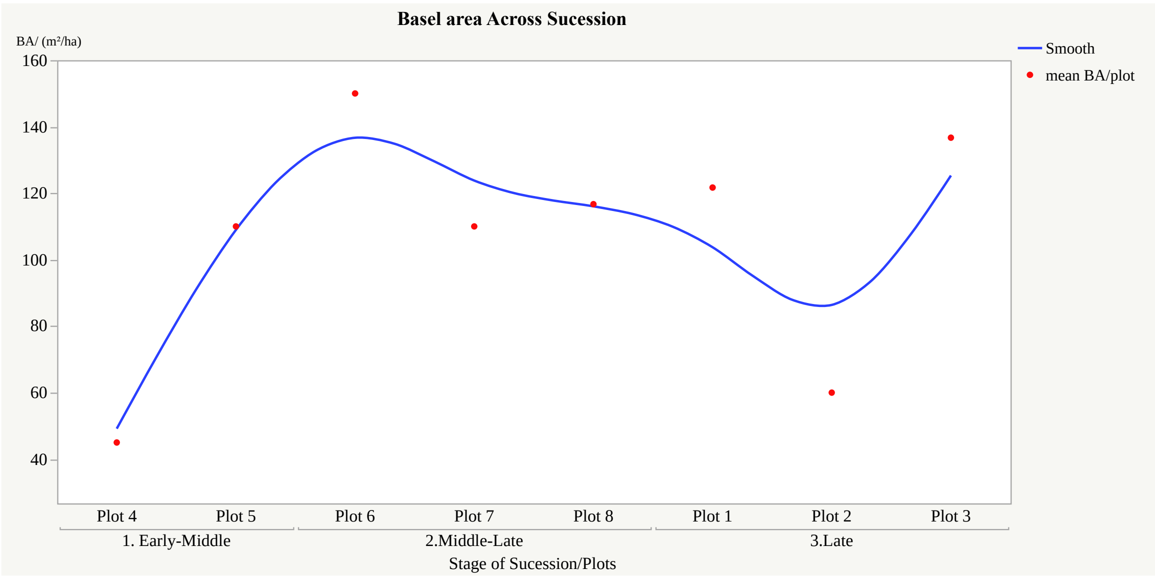

Figure 48 Tree densities across successional order of plots.

The values of mean basal area across the different stages of succession increase in as the forest matures and moves through late succession (Figure 49). This data suggests that as the dry forest becomes denser and wetter, with larger and more diverse trees, the overall biomass of the forest seem to increases.

Forest understory

The pattern with forest understory is varied. In the late successional plots, the plot with the lowest mean basal area (Plot 2) has the highest mean understory (Figure 49). The amount of light that reaches the forest floor helps determine the amount of understory.

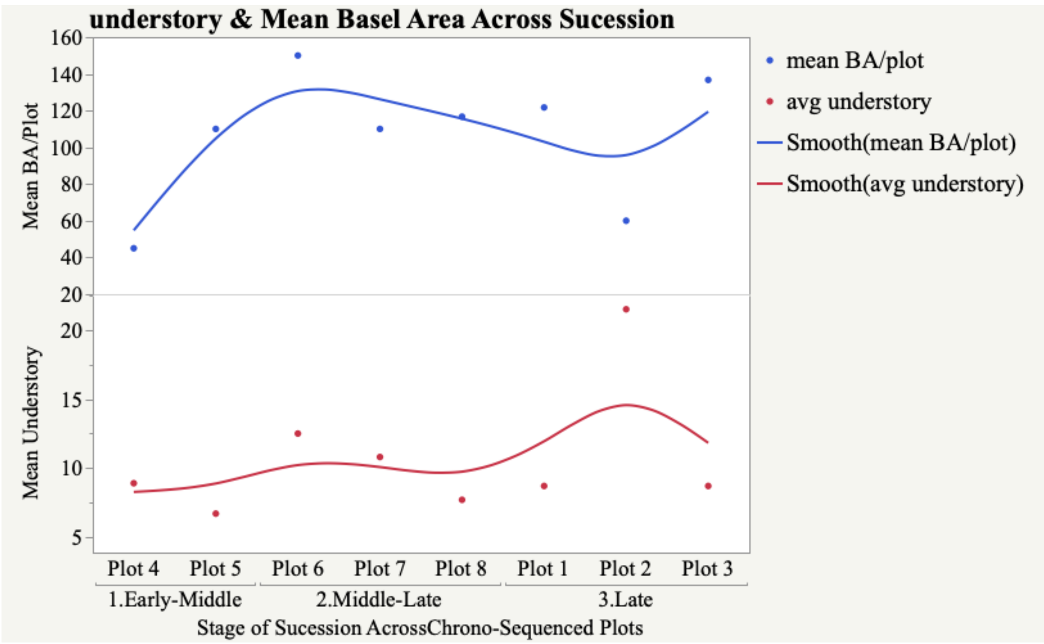

Figure 49 Understory and Mean Basal Area Across Sucessional Order of Plots

Basal area is an important way to measure of forest productivity and health. It also gives some indication of the amount of wood that can be utilized for carbon uptake or sequestration from forested area. Higher basal areas generally indicate a greater density of trees and greater productivity within the forest ecosystem.

Lianas contribute notably to the forest structure of the reserve by creating connections between trees and across the forest canopy. Their unique growth strategy allows them to reach sunlight with less investment in supportive tissue compared to trees, enabling them to spread rapidly across the forest structure (Letcher & Chazdon, 2012). These woody vines are therefore a vital component of the structural complexity, serving as bridges and creating networks that influence the movement and habitation patterns of certain animals and insects within the forest ecosystem. In many parts of the reserve a cathedral like structure begins to take form as ages vines cross the gulf between great trees (Figure 50).

Figure 50 Cathedral-like dry forest structure

In the more mature stages of forest succession, the role of lianas becomes increasingly prominent. Their ability to survive in lower light conditions, combined with their capacity to quickly colonize gaps in the canopy caused by falling trees or branches, allows lianas to persist and even thrive in mature forests. This adaptability, along with their structural role, makes lianas a constant feature in the ever-changing tapestry of the forest.

The overall resilience and structural contribution of the lianas throughout various stages of forest succession, particularly into the mature phases, underscore their ecological importance in shaping forest in this reserve. Their persistent presence suggests a level of adaptability and resilience that allows them to thrive in conditions where certain tree species may struggle. Understanding the role of these adaptable climbers in forest dynamics was worth noting in this survey.

The observed differences in tree densities across the Karen Mogenson Reserve are indicative of varying stages of tropical forest succession, with higher densities representing more mature ecosystems and lower densities indicating earlier stages. Lianas play a critical role in shaping these forest ecosystems, as they can add complexity to the process of tropical forest succession across the reserve. They have multiple impacts on forest dynamics, influencing the relationship between tree densities and succession stages.

Height And DBH

The relationship between height and diameter at breast height (DBH) across succession is shown in Figure 51. Highlighted are areas of positive relationship, where major growth and structure start to transition from phase to phase of maturity. The data points for each plot are color-coded, with green representing the earliest stage of succession (Plot 4) and green representing the latest stage (Plots 1-3). The graph indicates that as trees grow taller, their DBH also tends to increase, indicating that taller trees tend to have thicker trunks. Shaded area distinguish hotspots where some rudimentary correlation exists between trees heights and DBH. Additionally, there appears to be an increase in the variability of height and DBH as succession progresses, with more scattered data points in later plots. This suggests that the forest becomes more diverse in terms of tree size and structure as it matures.

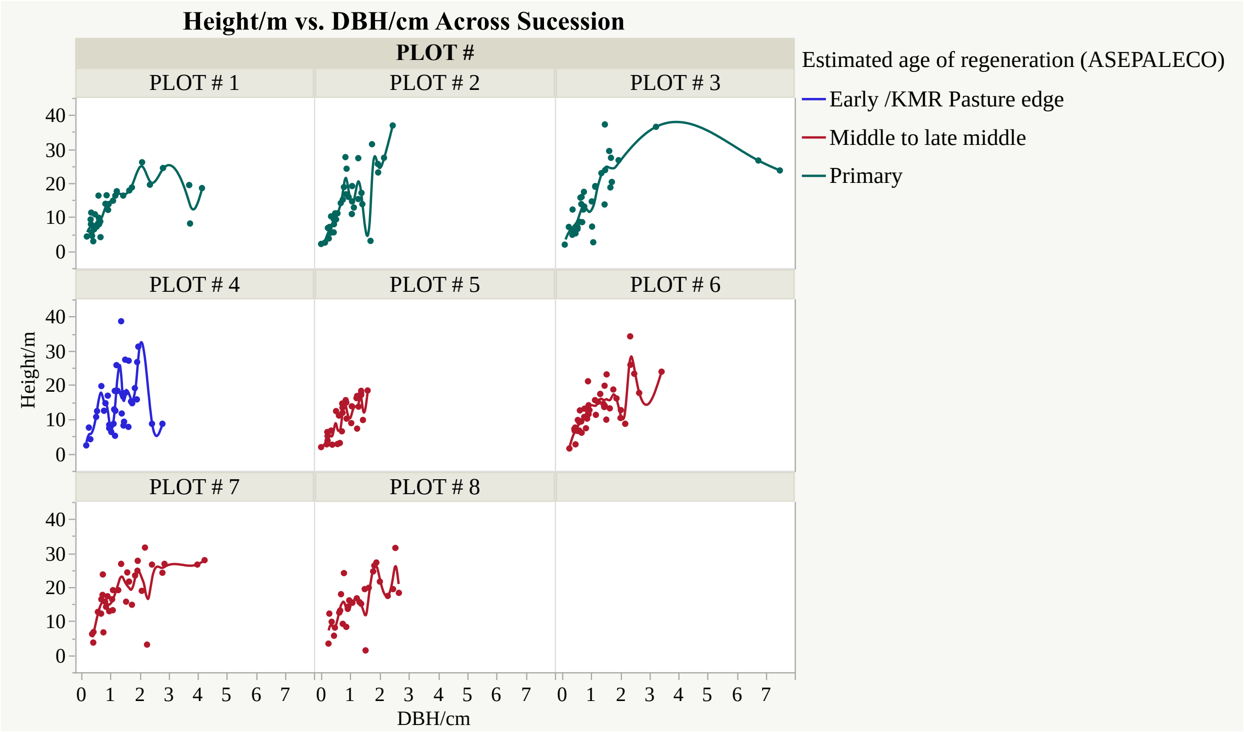

Figure 51 Relationship between tree height and (DBH) across succession

As more light reaches the lower levels of the forest canopy, we can observe a significant growth spurt from a diverse range of tree species. The graph offers valuable insights into how height and DBH are related across different stages of succession and how the forest becomes increasingly diverse over time.

How is Height And Diameter at Breast Height Expressed Across Succession?

Height and diameter at breast height (DBH) of trees from the eight different plots vary across the stage of succession similarly. This suggests the expected positive correlation between height and DBH (Figure 52).

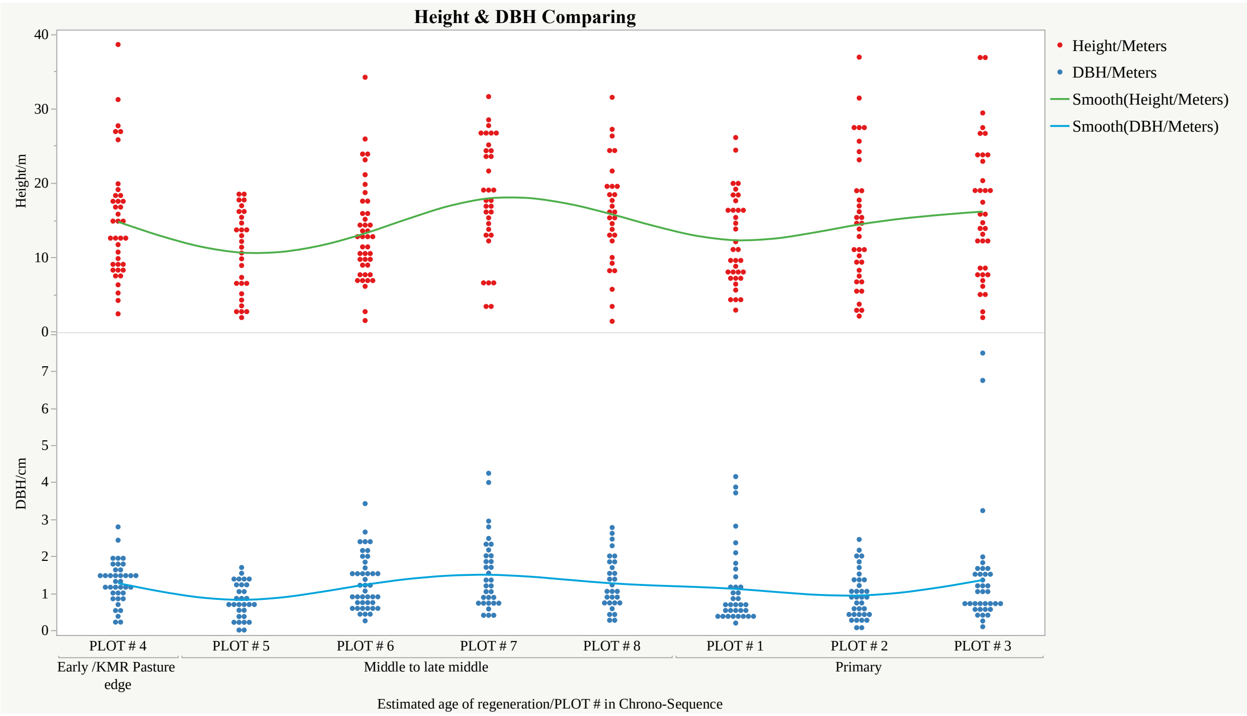

Figure 52 Tree height and diameter at breast height (DBH) across successional stages

Areas of the forest with high DBH and high height values indicate healthy, mature trees that have had access to ample resources for growth over an extended period. In contrast, areas with low DBH and low height values may indicate young or area where trees have experienced more limited access to resources. The ground observations indicate that between early and middle succession the vines have significant influence over both forest structure, height, and width over time.

As we further looking at the relationship between height/DBH and species richness, we can see that as these forests matures and moves through succession, there is an increase in both tree height and DBH, as well as an increase in tree species richness. This suggests that as the forest becomes older and more mature, it can support larger and more diverse tree communities (Figure 53).

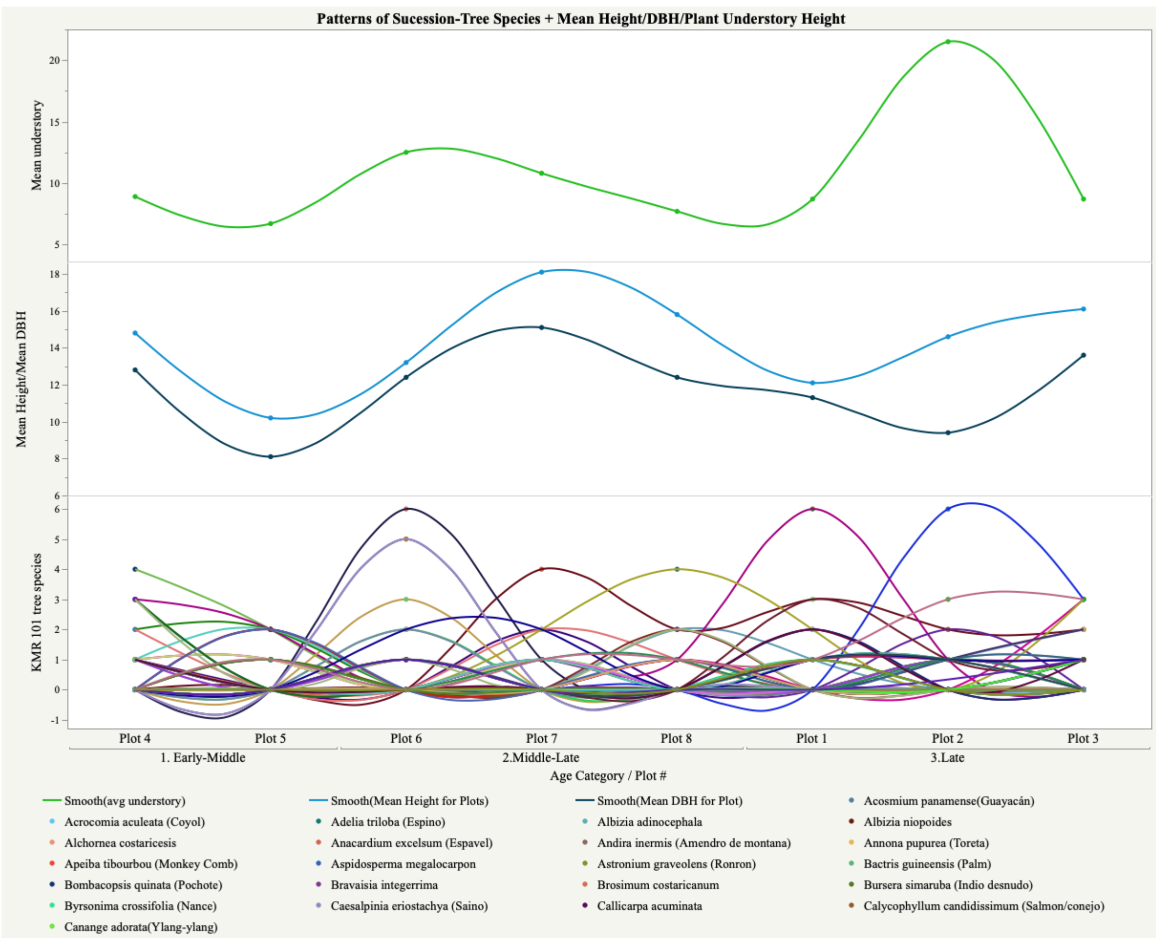

Figure 53 Comparative patterns of tree species across successional order of plots

These comparative findings suggest that there may be differences across the successional stages that paint a better picture overall health of the forest in each of the surveyed plots. We find many places where the forest characteristic overlap.

The higher sapling densities in plots 1-3 may indicate a more recent stage of forest succession, but these areas are actually far older, with saplings here similar to those found in middle successional areas. This could suggests recent tree recruitment from previously abandoned ranchland. The differences in height and DBH measurements between the different plots may also reflect differences in successional stage, with plot 5 potentially being in a more advanced stage of succession than the other plots. Although there were no significant differences in leaf litter accumulation between the plots, this does not necessarily imply that nutrient cycling and soil health are consistent across the surveyed forest. Further studies would be needed to confirm this and to investigate the factors that may be influencing the observed differences in sapling characteristics and density between the different plots.

Discussion

Walking through the forests in the Karen Mogensen Reserve makes clear the massive scale of a tropical forest, where I felt at times much like the ants that dwell across the forest floor. The undertaking of this survey was to better understand the KMR as these dry forests move through succession. These transitional tropical forests represent the margins where topography and geography meet to preserve a biome that is hardly recognized for its importance. The Nicoya Peninsula's unique climate produces some of the most majestic biological assemblies that the planet has to offer. This dry ecology offers home to migrating birds, rare mammals, plants and trees. The proof of policy is unmistakable in both photographic evidence and on the ground as regeneration is seen and preservation of these lands can be seen.

The Karen Mogenson Reserve (KMR), a biological outpost nestled in the heart of the Nicoya Peninsula, uniquely encapsulates the interplay between dry and moist forest ecosystems. It's an intricate tapestry woven with a multitude of threads representing diverse flora and fauna. This contrast of biomes is not a battle of the fittest, but rather a harmonious symbiosis that creates a complex, yet functional, mosaic of life across the reserve.

The KMR stands as an ideal illustration of this balance, with its transition zones being an ecological marvel. The seemingly endless stretches of pasture and dry forests trees gradually give way to moist tall, green canopies, fostering a variety of species adapted to thrive in these hybrid environments. This diverse habitat witnesses the ebb and flow of the seasons, with the pronounced dry spell followed by an abundant wet season. It's a magical transformation; a mosaic painted in shades of burnt yellows during the dry months gradually changing to vivid emerald as the rains arrive.

The diverse composition of species is striking. From deciduous trees that shed leaves in the dry season to reduce water loss, to epiphytic plants in the moist forests, soaking up the abundant humidity in the air. Migratory birds flock from the Northern regions to breed in the dry warmth, while elusive mammals and countless invertebrates have carved out niches in both the parched undergrowth and the lush canopy. Many species are yet to be fully cataloged or studied.

This initial dataset from the Karen Mogensen Reserve has provided some fascinating insights into the characteristics of forest plots at various stages of succession and at different elevations. These results are preliminary and represent a snapshot of the forest dynamics in this specific area. A more in-depth and continuous study would undoubtedly reveal richer, more nuanced information about the ecosystem's dynamics and help us understand the various processes at play in greater detail.

Successional Trajectories:

The data clearly shows a progression in tree growth metrics (tree height, DBH, and basal area) from the early to late succession stages. The general increase in these measurements indicates that the forest is maturing as the succession stage progresses, which aligns with what is known about forest succession. This pattern suggests that different processes such as colonization, growth, competition, and possibly disturbances are driving the forest's development. However, a long-term study tracking these plots over time would provide a more accurate picture of the successional trajectories in the Karen Mogensen Reserve. Understanding these trajectories would be invaluable for predicting future forest dynamics and managing conservation efforts.

Species Richness:

Interestingly, the data indicates a similar number of tree species across the different succession stages. This suggests that species richness in this forest may not be tightly linked to the successional stage. However, this preliminary data set does not provide information on the relative abundance of each species, which is a crucial aspect of biodiversity. An in-depth study focusing on species distribution and abundance across the reserve would give a more nuanced understanding of biodiversity patterns and their relationship with succession and elevation.

Understory Density:

The understory height data could indicate the level of light penetration and competition in the understory. However, a more detailed survey of the understory, considering factors such as the density and species of shrubs and saplings, would give a better understanding of understory dynamics and how they relate to the forest's successional stage and overall structure.

Elevation and Moisture Levels:

Elevation appears to vary across the plots, and it could be influencing the forest characteristics through its effects on the local climate, particularly moisture levels. Higher elevations are typically cooler and receive more rainfall than lower areas, which can affect tree growth and the rate of forest succession. A comprehensive study that includes measurements of temperature, rainfall, and soil moisture across the reserve would shed light on how these climatic variables interact with elevation to influence the forest's characteristics.

In conclusion, while the preliminary data from the Karen Mogensen offers valuable insights into the forest's characteristics, there is much more to learn about this ecosystem. A more detailed and long-term study would reveal deeper insights into the complex interplay of successional processes, species interactions, and the influence of elevation and climate. Such a study could provide essential knowledge for forest conservation and management in the reserve and other similar ecosystems.

What is the Character of Succession in KMR?

The survey examined the early pasture with its savanna like condition, choked with vines as the light loving saplings weave through the climbers that tamp down the forest's enthusiasm. Even though the young forests were often cluttered with vines and lianas, it was actively regenerating and teeming with burgeoning life.

The explosion of middle succession in the forest of the KMR were full of species in conflict, competing for light, moisture, and space in this stage. The trees push off the yoke of vines and break off in fast growth, both height and girth. Developing understories retain the moisture more readily and develop the complex soil found across the all the survey areas. Not as congested as early succession, the ongoing process of forest development produces a lower canopy ceiling and an observable delineation of the shade tolerant trees and those that prefer the sun.

Going deeper into places within the reserve that were designated secondary forests in a state of middle succession, were in areas of long retired ranches. These places contained mixes of trees often used for fencing and shade for cattle in the hot summer months. The remaining trees continue to mature, contributing to the variety of recovering species. These species begin to increase in number during the later stages of middle succession across these abandoned pasturelands.

This study was initiated in the primary forests as a way to examine a baseline for basic understanding. These protected areas are a true treasure of ecological significance. The pristine nature of these areas provides a base template to compare other recovering areas too. These primary forest have only the smallest traces dry characteristics. The forest has an open feeling, tall mature trees are high and spread out filtering sunlight down across the ground.

The symmetry of the trees here are patterned almost even if not for the rises and dips of the rugged topography. Leaf litter thick on the ground, home to a multitude of insect life, creates the bottom of the vast food chain. The transitional nature of these dry forest accentuates the biodiversity of trees and animals in the reserve, even amplifying it to the untrained eye. The mix of moist and dry forest trees produce a litany species that have made their way into the reserve producing a unique composition that over time will serve to energize the regenerative process.

Factors that drive succession in this reserve are not simple or even clear. Over the course of this study, various characteristics that frame recovery were noted, those most noteworthy being the presence of microclimate and Liana's.

Microclimates:

Microclimates in Guanacaste, refers to the unique climate conditions that exist in small, localized areas within the larger regional climate. These microclimates can be influenced by a variety of factors, such as elevation, topography, vegetation, and even human activities. Across Nicoya, microclimates can vary depending on the location, but some examples this study encountered fall under the following. Montane microclimates with the higher elevations within the reserve have a cooler, moister climate than the surrounding lowlands and abandoned pastures.

These microclimates are influenced by the cooling effect of the elevation and the presence of moist forests retaining more available moisture. Further are the many Canyon microclimates seen across the area, many with their own microclimates, which can be influenced by the shape of the land and the presence of biomass.

Lianas:

Lianas and vines can be seen to have a suggestive impact on succession in dry tropical forests here in the reserve. These climbing plants modify the structure and composition of the forest by the following observations:

Competition for resources: Lianas and vines are seen to directly compete with other plants and trees here for light, water, and nutrients, this potentially affecting their normal growth and survival patterns.

Altering tree growth and mortality:

Lianas can also be observed here to physically impact trees by strangling them or weighing down branches, altering tree growth patterns and increasing tree mortality. The warping trees over time become overwhelmed and drop the overall canopy height here in the reserve.

Changing forest structure:

The presence of lianas and vines in the reserve can be observed to alter the overall structure of the forest by generating a dense understory and modifying light availability for other species. This undergrowth of vines is noted across middle succession plots we surveyed.

This study observed both positive and negative impacts on the successional trajectories. Lianas in the KMR were observed to be a hub of biodiversity in many ways, providing additional food and habitat for the wildlife in the forest. This was beneficial to the many migrating birds seen nesting in the protection of the reserve. In contrast negative impacts can also be ascribed to the rapid spreading of the liana's here.

The competition with trees for light, water, and nutrients, can be seen to slow tree growth and potentially altering the successional trajectory of the forest. This often leads to tree mortality that physically can damage or kill trees. These kinds of disturbance are slow and exert pressure over years. This will often lead to shifts in forest structure and tree composition over time. The heavy presence of lianas can reduce the amount of light available to trees, potentially lowering overall forest productivity.

Overall, the impact of lianas on secondary succession in dry forests in this reserve is complex and can vary depending on the specific conditions or species involved. Further research would be needed to fully understand the role of lianas in the regenerative process of the reserve.

As the we further think about the results of this survey we examine the details that have come to the surface of this reserve.

Tree height and diameter:

In general, as the succession stage progresses, the mean height and diameter at breast height (DBH) of trees tend to increase. This is expected, as trees grow taller and thicker over time. Still, it's important to note that this relationship may not be strictly linear, as various factors such as competition, disturbances, and species-specific growth rates can influence these measurements we have collected. As the stages of succession advance in the reserve, there's a general increase in the mean height and diameter at breast height (DBH) of trees.

This progression mirrors what the literature underscores about the natural growth trajectory of tropical trees here.

Dominant tree species:

The data shows that different tree species dominate different plots. This indicates that different species have unique ecological roles and may be more suited to particular stages of succession. For instance, some species are known to be pioneer species, which are the first to colonize an area, while others are late-successional species that become more abundant as the forest matures. It is some indication of the potential of climate adaptation regionally. Taken in conjunction with the understory data we get a clear indication of how the understory changes across time. The data presents some insights into the forest structure and the amount of light penetration in different plots.

The higher understory height values can be positively associated with more the more open canopies of the primary forest, while lower values indicate denser canopies developing. The average understory height varies significantly across the plots, suggesting heavy competition. This variation further supports the idea that different stages of succession are present here operating and developing in different ways within the reserve across time.

Reserve Management

The management of the Karen Mogenson Reserve (KMR) stands as an evidence to the power of minimal human intervention. The reserve thrives with a small staff and limited interference in natural processes. This hands-off approach has fostered remarkable outcomes in the reserve, as witnessed in its uninhibited forest regeneration.

The reserve's relative isolation in the center of the Nicoya region plays a crucial role in its success. This remoteness not only drives unhindered natural succession but also provides a unique attraction for tourists. With its blend of biodiversity and the allure of untouched wilderness, KMR attracts nature enthusiasts and researchers alike. This form of eco-tourism, coupled with direct donations, forms the backbone of the reserve's revenue, ensuring its continued conservation.

Analysis of data from the KMR shows how the limited human interference enables the area to follow the most natural paths of ecological succession. The reserve is a live showcase of varying stages of forest succession, teeming with diverse tree species of different heights and diameters. This diversity underscores the complexity of ecological succession, illustrating how it is shaped by a multitude of factors.

One such factor is elevation, which contributes to the forest succession dynamics within the reserve. In the higher elevations often provide cooler temperatures and greater precipitation, fostering different species assemblages compared to lower, often drier, areas found in the greater Guanacaste region. These variations in species composition further enhance the ecological complexity and richness of the KMR.

By understanding the mechanisms of forest succession in the KMR we offer valuable insights into the workings of this natural ecosystems, as STDF areas are increasingly rare. The management of KMR highlights how passive restoration, paired with limited, sustainable tourism, can work in tandem to conserve biodiversity and ecosystem functions. Its success story offers a real model that could potentially be replicated in other reserves globally, helping to preserve these wonderful dry forests.

<u>How is succession expressed in the Karen Mogenson reserve?</u>

This preliminary survey of the Karen Mogenson Reserve (KMR) has shed light on the critical ecological function of forest succession in a transitional tropical forest. The observed variations in tree height, diameter, species richness, and understory composition across different stages of succession, indicate a dynamic and complex ecosystem at work in the reserve. The survey illustrates the undeniable regenerative power of nature, given the right circumstances. The varying stages of succession, from early-stage pastures; transforming into dense, tangled undergrowth to then mature forests have many lessons. These dry forest demonstrating the continuous cycle of growth, competition, and adaptation that characterizes this dry forest ecosystems.

This collected data show the importance of each successional stage as it shapes these forests, underscoring the complexity of ecological interactions bursting from this reserve. What the data fails to show in any substantial way is the influence of microclimates, as dictated by elevation and available water across the zone. These features have a profound impact on forest structures and long-term forest outcomes. Alongside this, the distinct roles of lianas in these successional stages were noted and not accounted for during this survey. Their impact, both positive and negative, on forest dynamics is a compelling area that merits further research. More in-depth, longitudinal studies would shed more light on the intricate interplay between these components.

Connecting what was observed directly in the plot surveys to what is understood about forest succession, based on the reviewed literature, provided a deeper understanding of how tropical forest succession is expressed.

Fundamental to this study, was understanding and investigating the long-term changes in forest structure and composition. Studies like Arroyo-Mora et al. (2005), Gillespie et al. (2000), and McClellan et al. (2018) provide valuable insights into the dynamics of forest structure and composition over time. These papers analyze changes in tree density, species richness, and community assembly during different stages of forest succession.

Ample consideration of the literature was given to the topics of the ecological mechanisms underlying succession in Karen Mogenson. Research by Chazdon (1998), Chazdon et al. (2010), and Lebrija-Trejos et al. (2011) helped to clarifies the ecological processes that govern forest succession, such as the role of functional groups, plant traits, and interactions between different life forms during the regeneration process. All this research proved to be of great importance when exsamining features on the ground during this survey.

Additionally the tree biodiversity and ecosystem functions was vital for placing into context the large amount of diversity seen across the study area. Several studies, including Hertel et al. (2003), Magnusson et al. (2005), and Oberleitner et al. (2021), placed great focus on the relationship between biodiversity and ecosystem functions in tropical dry forests. This research provided a source of valuable information on the importance of species richness and functional diversity for ecosystem resilience and services with in this ecology. The litriture brought this research full circle, providing a base of understanding that framed this study with sound scientific approach.

In terms of management, the KMR stands as a testament to the viability of passive restoration paired with sustainable tourism. It provides a model that not only preserves biodiversity but also ensures that such the reserves are economically sustainable. The reserve managers are a highly trained and dedicated team, producing solid conservation results and facilitating tremendous educational opportunities to the community and larger world.

All these observations, while fascinating, serve to underscore one fundamental fact: we are just scratching the surface of the rich, complex ecological tapestry that is the KMR. This reserve holds a trove of untapped knowledge and offers immense opportunities for further research into forest succession and its underlying mechanisms. Future studies could explore in more detail the drivers of succession, impacts of climate variations, the role of animal species in shaping the vegetation, and the specific ecological requirements of individual tree species.

As we advance our understanding of forest ecosystems like the KMR, we are not only documenting the natural world, but we're also learning valuable lessons about conservation, restoration, and sustainable management that could inform future efforts to preserve and restore TDF ecosystems across the world. The Karen Mogenson Reserve is, indeed, an ecological beacon that can guide on the quest to understand and preserve our planet's priceless biodiversity.

Conclusion

Based on the data collected during this wide-ranging forest survey in the Karen Mogenson reserve, it can be established that the forest has undergone considerable changes in composition and structure as we examine it chronologically. The number of tree species increased from 42 in the early succession plots to 75 in the mature primary forest plots. Additionally, we noted an increase in species richness over time, with the highest number of species found in the mature forest plots 1, 2, and 3.

There were variations in tree density and basal area across the plots, which indicated different stages of forest succession. The early succession plots had lower tree density and basal area, while the mature forest plots had higher values. The sapling data also showed that regeneration was occurring, and there was a potential for continued forest growth.

The intricate understory had a positive relationship with species richness, with the highest number of species found in the areas with the highest understory biomass. Higher moisture in these plots contributed to the fast breakdown of the leaf litter, producing fertile beds for the large number of saplings found across the 8 plots.

Across succession boundaries 240 saplings in early/mid-succession plots. 1093 in mid/late-succession plots, indicating a higher density of young trees in the mid/late-succession stage. This could suggest ongoing regeneration and recruitment of new individuals into the competitive forest community.

This variance in sapling count across succession boundaries is an important indicator of the current state of forests. What can be observer directly is the forest process of regeneration and recruitment of new trees into the different forest age groups. The higher density of young trees in the middle to late stage of maturity suggests more light availability reaching to the lower levels of the forest. In this later stage of forest development, we begin to see the opening up canopies and fast-growing species spring up to and drop seed.

An observable decline in liana and vine behaviors starting in middle succession here begins compositional shift in the overall make-up of the forest across the reserve A connected factor that can be observed is how the old fallen vines become pockets of decomposed leaf and rigid fibrous ground cover. This provides perfect footholds for the large sapling development seen across all the plots in the KMR.

Other important results of the forest survey is a noticeable pattern of an undulating diversity emerged as the different age plots within the dry forest matured. It became evident that previous ranching activities played a noteworthy role in driving land change dynamics in the reserve. Remnant trees from these abandoned pastures were found to be pervasive, particularly in the late successional plots.

The term "waves of undulating diversity" can be used to describe the fluctuating pattern of species composition and abundance observed across the various age plots. As the plots progressed in age, there was a noticeable wave-like pattern in the diversity of plant species, indicating dynamic ecological processes at play.

The influence of previous ranching activities on land change was evident, as these practices had a lasting impact on the forest ecosystem. The remnant trees from abandoned pastures persisted and were found to be present in significant numbers, even in the later successional plots. This highlights the resilience and adaptability of these trees and their ability to establish themselves in the forest ecosystem despite the transition towards later successional stages.

This survey results revealed a complex interplay between land use history, forest succession, and the persistence of remnant trees from past disturbances, contributing to the observed undulating diversity in the dry forest.

These observations are consistent with the general understanding of tropical dry forest succession, where early-succession dry forests typically have lower sapling counts due to the competition for resources and limited availability of suitable microhabitats for regeneration. One prime example was detected in plot 4, where little sapling activates was registered. In plot 4, liana and vine proliferation dominate, saturating the ground cover, leaving little room for saplings to grow.

<u>Key Findings</u>

- There is a strong relationship between the age of forest regeneration and various forest characteristics, such as mean basal area (BA) per plot, average understory, mean diameter at breast height (DBH) for the plot, mean height for plots, and tree species richness.
- As forest succession progresses quickly, the mean BA per plot tends to increase, indicating that the forest is becoming denser and more structurally complex. This is evident when comparing early/middle-aged plots (Plot 4 and Plot 5) to middle/late-aged plots (Plot 6, Plot 7, and Plot 8) and late-aged plots (Plot 1, Plot 2, and Plot 3).
- Tree species richness also appears to be positively associated with forest succession. Late-aged plots (Plot 1, Plot 2, and Plot 3) have a higher number of tree species compared to early/middle-aged plots (Plot 4 and Plot 5). This

indicates increased biodiversity as the forest progresses through succession stages.

- The mean DBH and mean height for plots generally increase with forest age, suggesting that the trees become larger and taller as the forest matures. This can be observed by comparing early/middle-aged plots to middle/late and late-aged plots.
- The average understory cover varies among the plots, with some early/middle-aged plots showing higher understory cover than some late-aged plots. This suggests that factors other than forest age may influence understory development.

The results of this forest survey in the Karen Mogenson Reserve's dry forest demonstrate that forest succession is expressed in the transitional forest through changes in forest structure, tree size, and species richness. As forests mature, they tend to become denser, more structurally complex, and support a higher number of tree species.

In general, the forest in the Karen Mogenson Reserve is highly diverse and has undergone noteworthy changes over time. The data collected from the survey provides valuable information for understanding the dynamics of tropical forest succession and the importance of conservation efforts in maintaining the biodiversity of these ecosystems.

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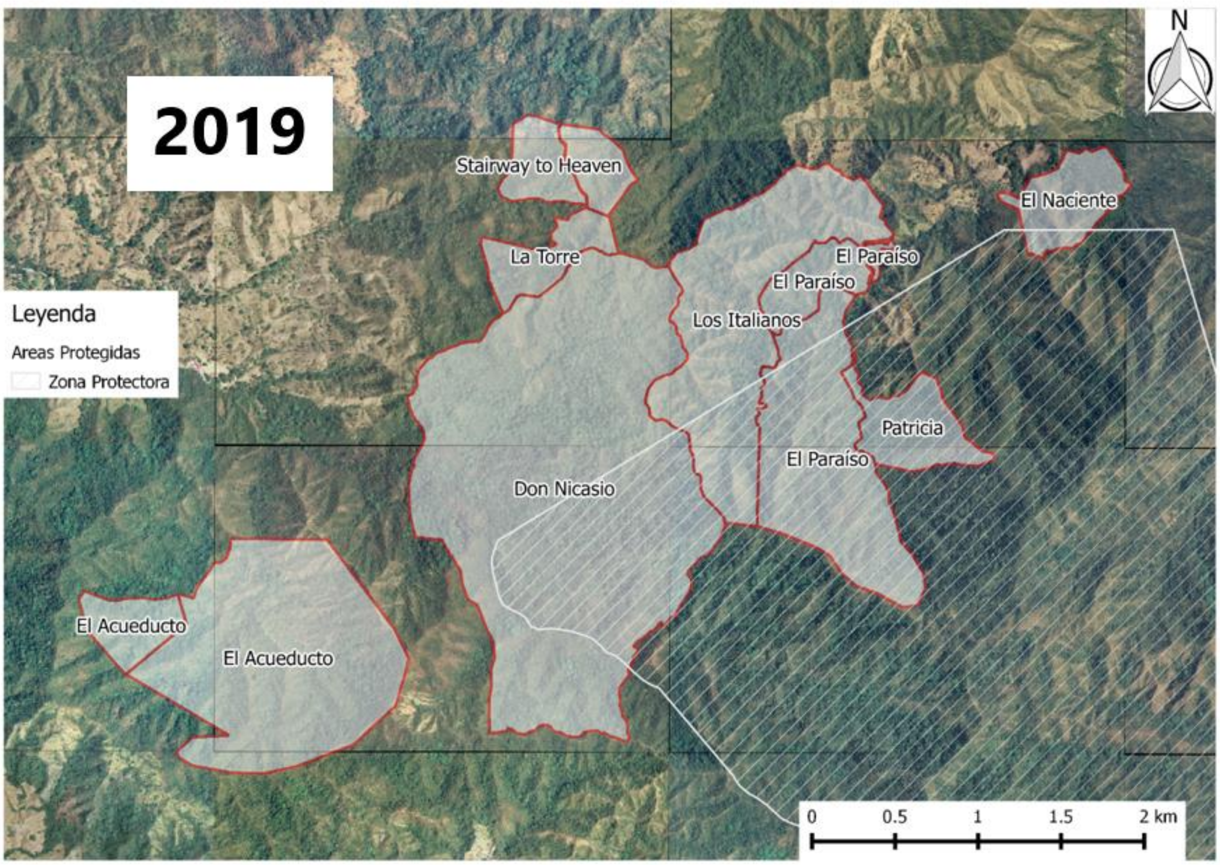
Appendices



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El Paraíso
El Paraíso
Los Italianos
Leyenda
Areas Protegidas
Zona Protectora
Patricia
El Paraíso
Don Nicasio
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El Acueducto
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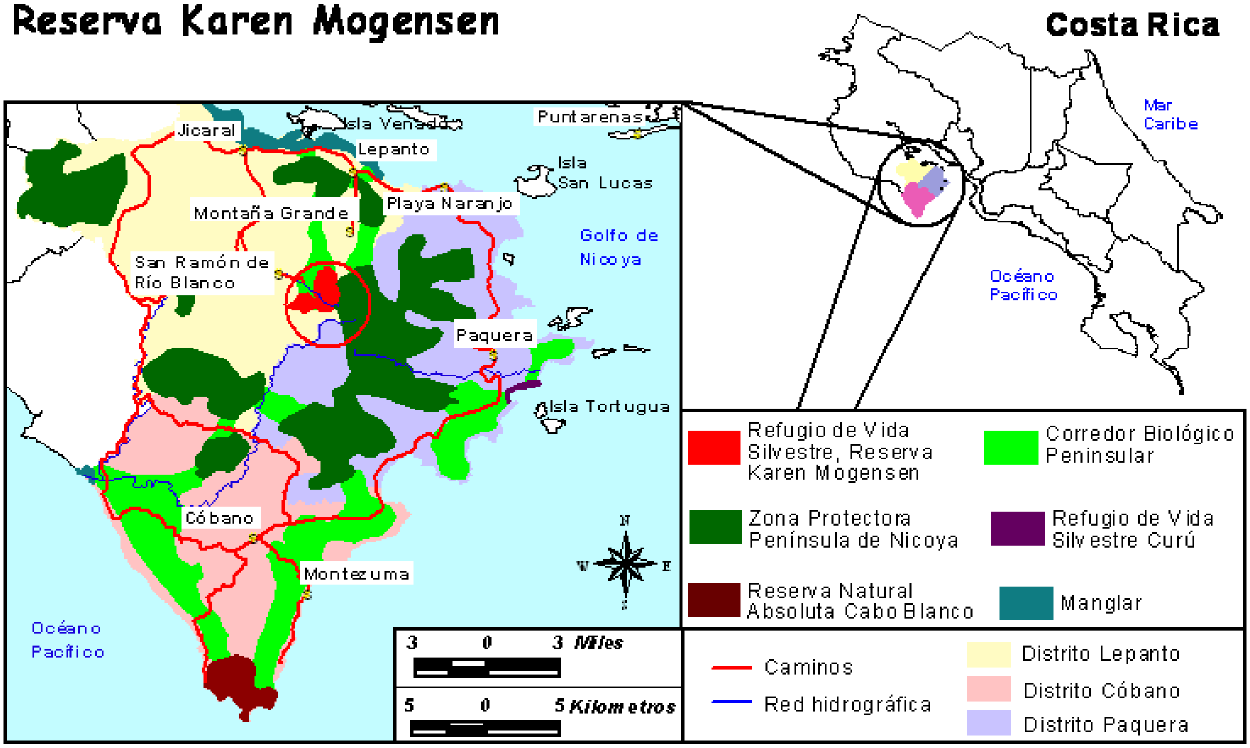
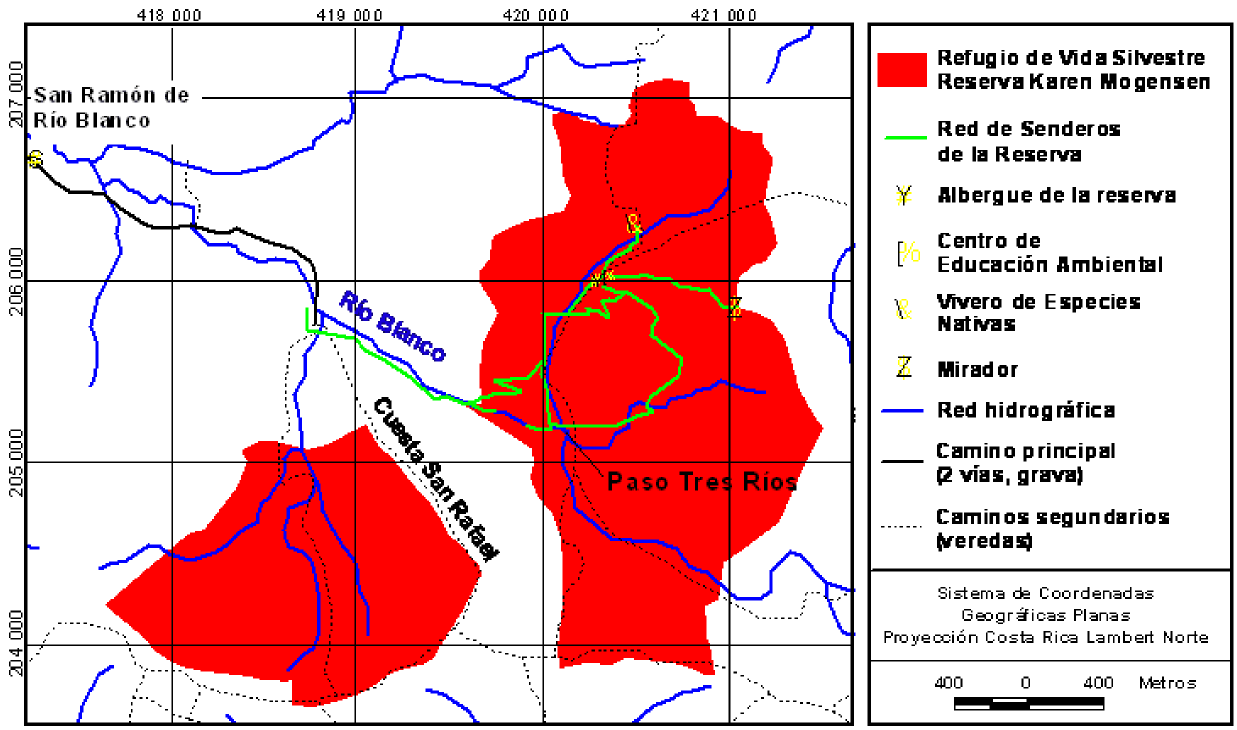
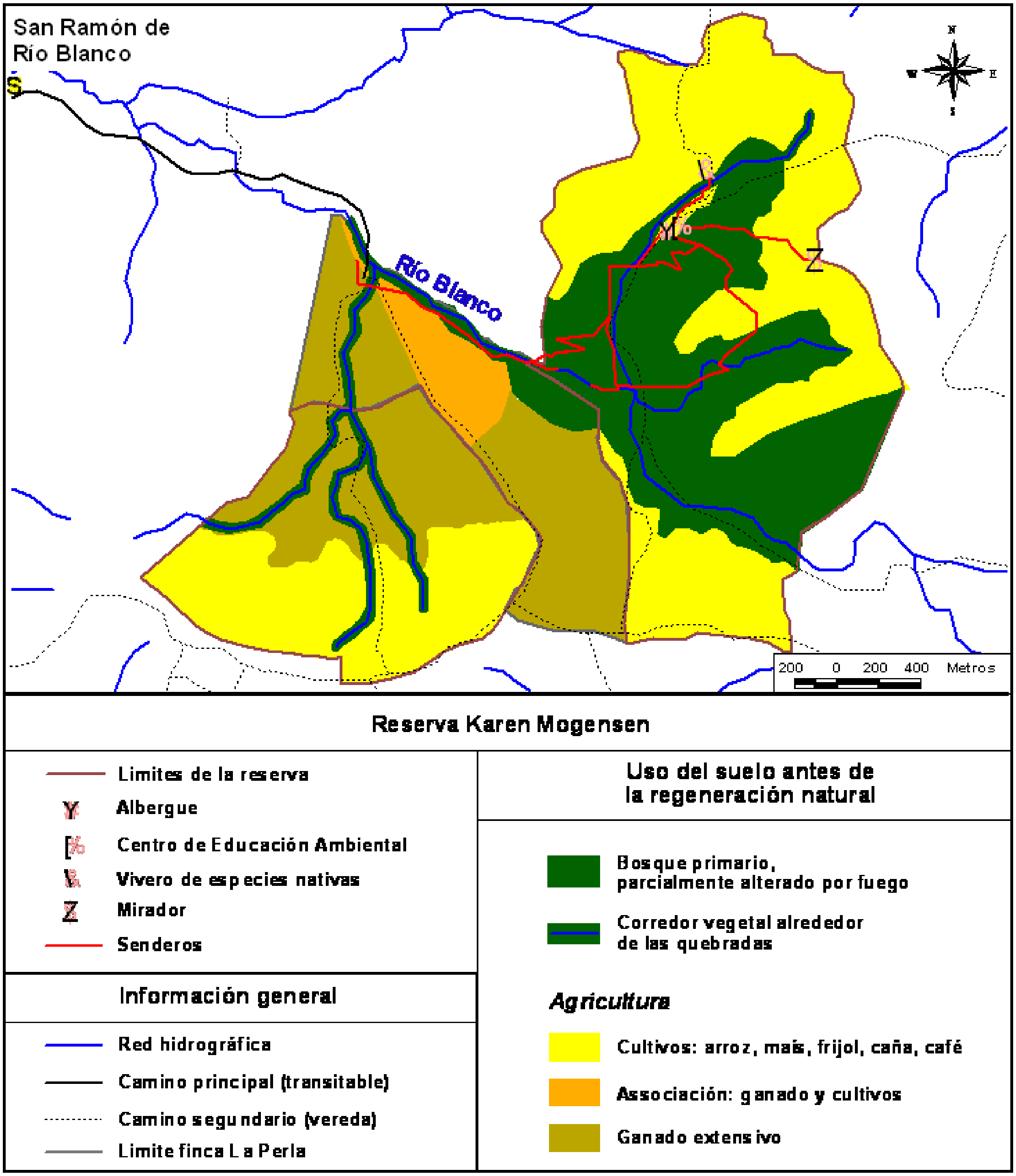
Ubicación del Refugio de Vida Silvestre, Reserva Karen Mogensen





Fuente: Muestreos de campo (abril del 2002) -- Hojas cartográficas (1/50 000 Isla Venado - 1/25 000 Montaña Grande)
Elaboración: Grégoire Ferrer - ASEPALECO - 2002

Refugio de vida Silvestre, Reserva Karen Mogensen
Mapa de Uso del Suelo Anterior al Proceso de Regeneración Natural



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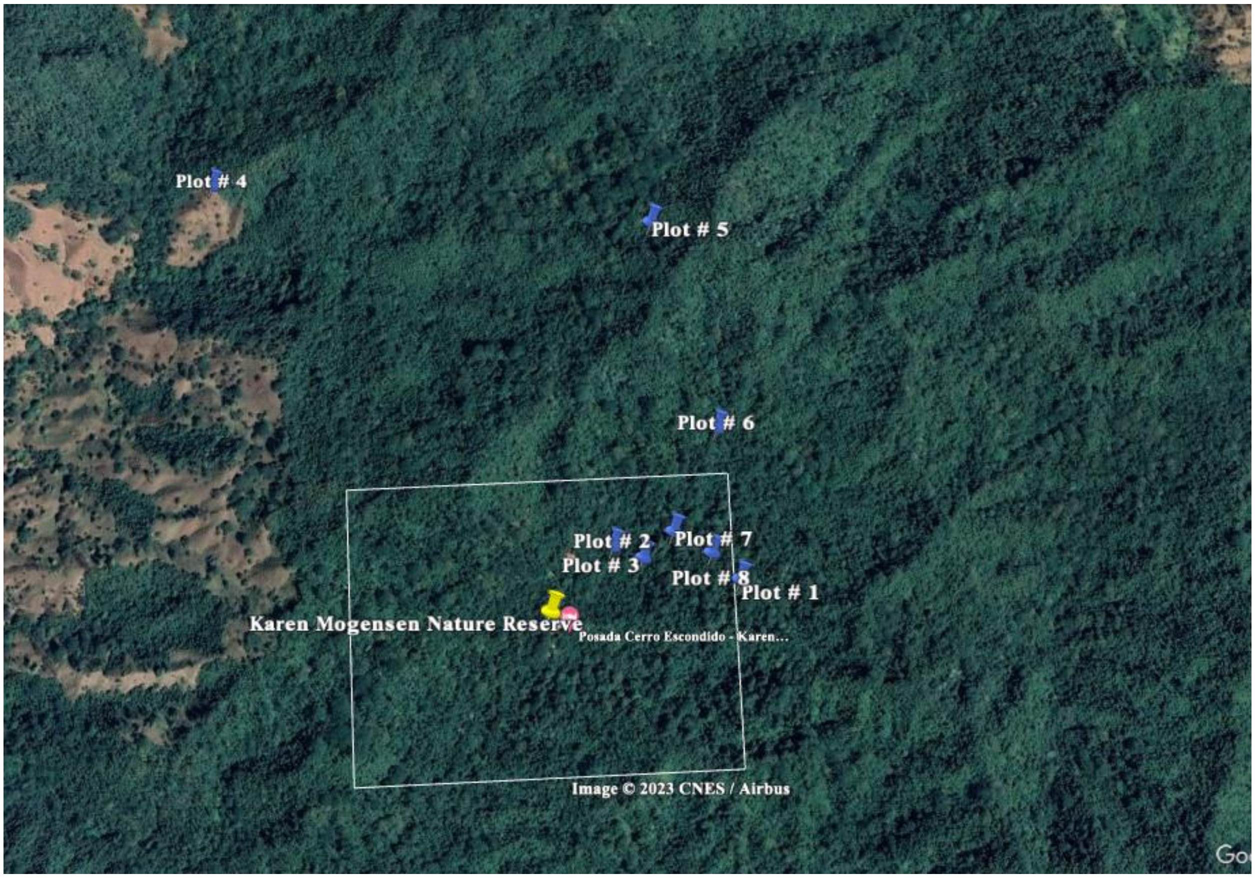
Elaboración: Grégoire Ferrer - ASEPALECO - 2002


Plot # 4
Plot # 5
Plot # 6
Plot # 2
Plot # 7
Plot # 3
Plot # 8
Plot # 1
Karen Mogensen Nature Reserve
Posada Cerro Escondido - Karen…
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