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Master Thesis

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Determination of Native Forest Tree Species Based on Mayan Q'eqchi' Traditional Ecological Knowledge for Tropical Forest Restoration

A case study in the community of Tzalamtun in Alta Verapaz, northeast Guatemala.

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Title and subtitle: Determination of Native Forest Tree Species Based on Mayan Q'eqchi' Traditional Ecological Knowledge for Tropical Forest Restoration: A case study in the community of Tzalamtun in Alta Verapaz, northeast Guatemala.

Topic description: This research explores the Traditional Ecological Knowledge (TEK) from the Maya Q'eqchi' people of Tzalamtun in Alta Verapaz, northeast of Guatemala to document the use of tropical forests species. The study aims to identify important forest species (timber and non-timber) using the Cultural Value Index (CV_e), while considering the status of threatened. As a result, 15 species were identified as priorities for tropical forest restoration: with the most relevant species being *Swietenia macrophylla* (Mahogany), *Cedrela odorata* (Cedar) and *Pimenta dioica* (Allspice).

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Determination of Native Forest Tree Species Based on Mayan Q'eqchi' Traditional Ecological Knowledge for Tropical Forest Restoration: A case study in the community of Tzalamtun in Alta Verapaz, northeast Guatemala.

Abstract

This research explores the Traditional Ecological Knowledge (TEK) from the Maya Q'eqchi' people of Tzalamtun in Alta Verapaz, northeast of Guatemala on the use of tropical forests species. TEK, stemming from generations of indigenous natural resource use, can guide ecological restoration and management strategies, but current conservation initiatives in Guatemala lack TEK-based strategies. Therefore, the study aims were to document tropical forest species based on the Q'eqchi' TEK and identified important forest species for tropical forest restoration using the Cultural Value Index (CV_e). While also prioritizing species for restoration due to their threatened status. Based on these two criteria 15 species were identified and proposed for tropical forest restoration in Tzalamtun. The most relevant species identified were *Swietenia macrophylla* (Mahogany), *Cedrela odorata* (Cedar), *Pimenta dioica* (Allspice), *Dalbergia tucurensis* (Granadillo), *Cojoba arborea* (Cola de Coche), *Inga edulis* (Guama), *Platymiscium dimorphandrum* (Hormigo), Calycophyllum candidissimum (Canela), *Dalbergia stevensonii* (Rosul) and *Tectona grandis* (Teca). Showing species with high cultural importance, economic value and practical use value. The methodology was based on transdisciplinary research by incorporating the participation and collaboration with the Q'eqchi' community to select areas to visit, identify important plant species and describe their knowledge and practices in the natural environment of tropical forest that they inhabit. This information offers potential use in further research on the local indigenous TEK and baseline data to support environmental strategies and social policy.

Keywords: Traditional Ecological Knowledge, Maya Q'eqchi', Tropical Forest, Restoration, Cultural Importance Value (CV*e*), Threatened status.

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I. INTRODUCTION

Human impact on Earth has become so pervasive and significant that the current geological epoch has been dubbed the "Anthropocene" (Steffen *et al*., 2007). One of the forms that humanity's footprint has on Earth is environmental and climate change through the degradation and loss of ecosystems (Thoma *et al*., 2021). Among the ecosystems that are being most affected are the tropical forests around the world, between 1980 and 2012 more than 150 million ha were deforested (Hansen *et al*., 2013a), and the current rate of deforestation is estimated at around 10 million ha per year (FAO, 2022). This despite the numerous and complex beneficial interactions between tropical forests and humans (Edwards *et al*., 2019; Pienkowski *et al*., 2017). Tropical forest ecosystems safeguard and provide essential ecosystem services for human health and well-being (e.g., drinking water, food diversity, medicines, soil fertility, biodiversity, climate stability, and mitigation of climate change and emerging diseases) (Brandon, 2014; Pope *et al*., 2015). In addition, forests are an essential part of the cultural and social identity of diverse peoples around the world and crucial for the alleviation of poverty and extreme poverty in developing countries (McKinnon *et al*., 2016; MEA, 2005). The social-ecological crisis posed by global environmental change demands rethinking the ways in which we as humans relate with each other, biodiversity and the natural environment at many levels and dimensions (Anderson & Barbour, 2003; Hobbs *et al*., 2011; Mantyka-Pringle *et al*., 2017; Uprety et al., 2012). In this context, Traditional Ecological Knowledge (TEK) has been increasingly recognized as a highly relevant approach to forest management and restoration with the aim of sustainable use and natural resource conservation (Covington *et al*. 1998, Berkes *et al*. 2000, Menzies and Butler 2006, Charnley *et al*. 2007, Uprety *et al*. 2011, 2012). TEK is the direct result of a long history of resources being used in an area by indigenous people, where their social structure and belief systems are essential (Berkes, 1999; Berkes *et al*., 2000; Menzies, 2006). Therefore, TEK can complement, supplement, and guide ecological restoration and resource management decision-making through the establishment of “reference communities,” the design and planning of agroforestry systems (diverse multi-crops systems with trees species), based on the selection of suitable species for restoration, and monitoring the success of these strategies (Charnley *et al*., 2007; Menzies, 2006; Parrotta & Agnoletti, 2007; Uprety *et al*., 2012, 2017). The integration of TEK in restoration practice is still very limited (Uprety *et al*., 2012). However, local communities’ involvement is fundamental, particularly in those regions where culture and nature are intertwined, which is typically the case with indigenous societies (Garibaldi & Turner, 2004; Uprety *et al*., 2012). In Guatemala in Central America, there is a high correlation between biological and cultural diversity (Cano & Schuster, 2008). It has also been documented that under these conditions, agroforestry systems based on TEK favor cultural landscape preservation, enable biodiversity conservation and are socioeconomically sustainable because, in part, they incorporate multiple land-uses, management strategies, and resource production practices (Falkowski *et al*., 2016; Toledo *et al*., 2003). Thus, these systems are able to provide subsistence for local people while preserving natural resources for future generations (Falkowski *et al*., 2016).

The Q'eqchi' people represent the largest ethnic group within the Mayan groups in Guatemala and represent around 8.3% of the total population (INE, 2019). They cover an area of 54,242 km^2, distributed mainly in the departments of El Petén, Alta Verapaz and Izabal (Maass, 2008). Among them is a large part of the 3.9 million ha of tropical forest present in the country, with 52% in El Petén, 10% in Alta Verapaz and 7% in Izabal (Food and Agriculture Organization of the United Nations, 2005; Pope *et al*., 2015). Thus, forming the natural environment of the majority of the Q'eqchi' communities, and those who depend on local natural resources and associated ecosystem services for their livelihood, health and well-being. Within these primary and secondary forests they live as subsistence farmers and supplement their livelihoods with forestry through small-scale forest extraction, such as logging, hunting, and the gathering of non-timber products for food, medicine, and shelter (Maass, 2008). This intimate and close relationship of the Q'eqchi' people with their natural environment means that their cultural and spiritual identity is linked to nature, and that in turn governs the way they manage the land and use natural resources. Farmers within traditional Q'eqchi communities ask local deities called *Tz'uultaq'a* for permission to clear and cultivate (Lea, 2018). Thus, taking care to minimize the human impact on the environment, as they recognize the importance of their resources to survive (Carr, 2004; Maass, 2008; Monterroso & Bravo, 2008; Wilson, 1995).

Even though forests represent a fundamental element in the subsistence and cultural identity of indigenous communities in Guatemala, such as the Q'eqchi'. The country faces one of the highest rates of deforestation in Latin America. Forest loss increased from 93,127 ha/year in 1991-2001 to 132,138 ha/year in 2006-2010. Net deforestation for this last period was estimated at about 44,000 ha with an annual net loss rate of 1.0% of forest cover (Sales *et al*., 2016). In the country, the sociopolitical, economic, demographic, and physical landscapes vary by region and, therefore, the factors that contribute to deforestation also differ spatially (Carr, 2004; Pope *et al*., 2015). However, in the last 15 years, this process has been mainly driven by export-oriented monocultures (palm oil, sugar, cardamom and banana), cattle ranching, urban growth and forest fires (Sales *et al*., 2016). Pope *et al*. (2015) mentions that Q'eqchi' communities that live in the cloud forests of the mountains of Alta Verapaz clearly recognize the link between forest loss and the degradation of ecosystem services, since they have seen how agricultural productivity has decreased as the soils they erode and lose organic matter. Although integrated conservation and development projects have been developed in Guatemala, these often take the form of community-based forest management or community-based conservation. Like the example of the forest concessions in the Mayan Biosphere Reserve, in Petén, north of Guatemala (Radachowsky *et al*., 2012). These initiatives do not yet integrate the local TEKs for the design and implementation of strategies for the restoration and regeneration of forests, e.g. agroforestry systems with diversification of timber and non-timber products both for local use and for sale and that also ensure the sustainable development of local communities in its all dimensions. Since they are only focusing on the production of non-timber products and the sale of precious woods (Radachowsky *et al*., 2012). Therefore, the research methodology is based on a transdisciplinary approach by incorporating an active participation and strong cooperation between the Maya Q'eqchi' community of Tzalamtun to document their knowledge and practices on native tropical forest species (timber and non-timber species). This research stands as a preliminary scoping study that explores the recognition of TEKs in on tropical forest species in Tzalamtun, Alta Verapaz, northeast Guatemala. Thus, offer information for potential use in the design and the develop of resilient, sustainable long-term restoration strategies, e.g. agroforestry systems that promote the restoration and conservation of tropical forest while addressing the social, ecological and economic needs (Atangana *et al*., 2014). As well as to offer potential information and baseline data to support environmental and social policy and further research on the local indigenous TEK as an inspiration, and ideas for ecological engineering not only in Guatemala, but also in any tropical forests around the world.

II. PROBLEM STATEMENT

To address the social-ecological crisis posed by tropical forest degradation and loss in Guatemala and the gap of implementing local Traditional Ecological Knowledge on strategies for restoration the research will answer the following question: How the Maya Q'eqchi' Traditional Ecological Knowledge can provide valuable information to select suitable native forest tree species for tropical forest restoration in the Maya Q'eqchi' community of Tzalamtun in Alta Verapaz, Guatemala? To answer this question, the research will explore the Maya Q'eqchi' TEK of tropical forest trees species based on the following objectives.

A. OBJECTIVES

1. GENERAL

Determine relevant forest species based on the Cultural Value Index (CV_e) and their threatened status for the restoration of tropical forest of Tzalamtun, Alta Verapaz.

2. SPECIFIC

(i) Determine the cultural importance of forest species using the CV_e to evaluate their potential in restoration.

(ii) Identify priority forest species for tropical forest restoration based on their threat status.

(iii) Determine a list of important forest species for tropical forest restoration.

III. LITERATURE REVIEW

A. TROPICAL FOREST

Tropical forests begin at the equator and span north to the Tropic of Cancer (23°N) and south to the Tropic of Capricorn (23°S) (see Figure 1). They encompass five major regions: tropical America, Africa, Southeast Asia, Madagascar, and New Guinea; with smaller outliers in Australia, South Asia, and numerous tropical islands (Malhi *et al*., 2014). While the Amazon Basin representing the largest continuous expanse (Thomas & Baltzer, 2002). Together, these regions reach roughly 33% of the world's forests, distributed across a wide range of climates, elevations, and geologies (Thomas & Baltzer, 2002; Torreano, 2004). Although covering only about one-fifth of Earth's terrestrial area (Dinerstein *et al*., 2017), tropical forests are among the most biologically diverse ecosystem (Thomas & Baltzer, 2002). Pillay *et al*. (2022) determined that tropical forests harbor 62% of global terrestrial vertebrate species, more than twice the number found in any other terrestrial ecosystem on Earth. Up to 29% of global vertebrate species are endemic in a to tropical forests, where "endemic" refers to species that are found exclusively in a specific geographic location and nowhere else in the world; with more than 20% of these species at risk of extinction (Pillay *et al*., 2022). Therefore, these ecosystems are highly complex and heterogeneous, comprising diverse ecological networks of interactions between species within communities, and between those communities and the environment (Fayle *et al*., 2015). Furthermore, tropical forest are regulators of climate, providers of food and timber for hundreds of millions of people and bulwarks against poverty and extreme poverty (Brandon, 2014). There is also growing evidence indicates that these forests are a vital part of a suite of nature-base climate solutions that can provide over 30% of the cost-effective climate mitigation strategies needed to stabilize global warming to below the 2 °C target of the Paris Climate Agreement (Griscom *et al*., 2017).

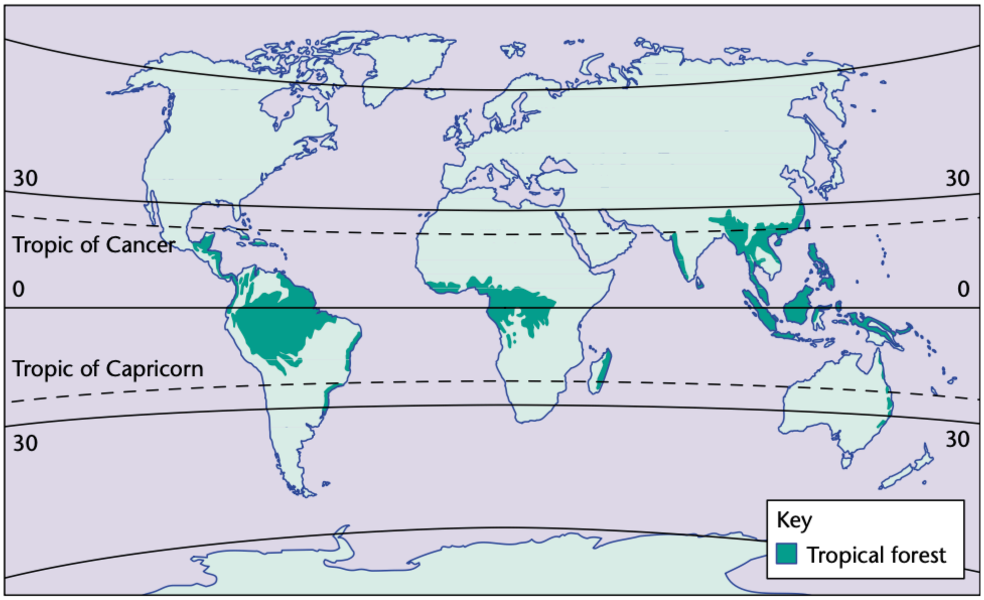

Figure 1. Global distribution of tropical forest. Source: Thomas & Baltzer, 2002.

Tropical forests are diverse and vary in type according to its geographic location, rainfall patterns, elevation, and soil, creating distinctive plant and animal communities, called native species, that are adapted to the specific environmental conditions in their particular geographic location (Thomas & Baltzer, 2002). As a result, tropical forests in each geographic location develop plant community structures shaped by the distinctive local climate, giving rise to unique ecological and biogeographical entities that can be classified using various systems (Atangana *et al*., 2014; Malhi *et al*., 2014; Thomas & Baltzer, 2002). One of the most commonly used systems are the originally described by Holdridge (Holdridge, 1947). In this system, called "Holdridge Life Zones System", rainfall and biotemperature are the main determinants of the vegetation type in a given location, combined with latitude, elevation and humidity, they are used to define a function of distinctive areas known as "life zone" (see Figure 2) (Atangana *et al*., 2014; IARNA-URL, 2018).

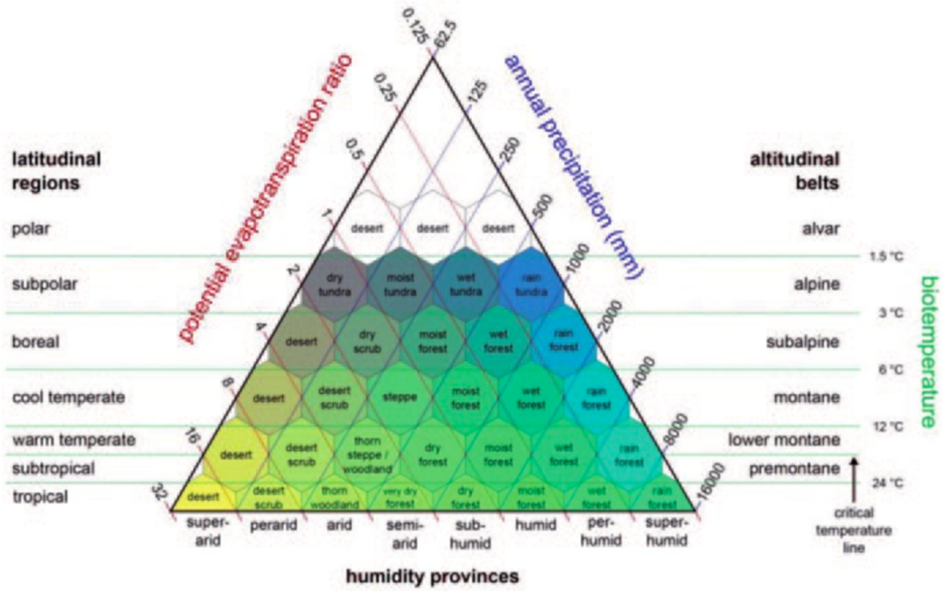

Figure 2. The Holdridge life zone classification scheme. Source: (Atangana *et al*., 2014)

The Holdridge Life Zones System recognizes 38 classes, ranging from polar deserts to tropical rainforests (see Figure 2). In a broad sense, in this system tropical forest classes include tropical very dry forests, tropical dry forests, tropical moist forests, tropical wet forests, and tropical rainforests (Atangana *et al*., 2014). In tropical America, also defined as “neotropical region” (Malhi *et al*., 2014), tropical moist, wet, and rainforests extend from southern Mexico to Bolivia and the Caribbean, with Central American forests predominantly composed of moist deciduous and semi-evergreen seasonal formations (see Figure 3) (Castroviejo-Fisher *et al*., 2014). They are characterized by high rainfall, mean annual temperatures between 21 and 45 °C, and predominantly Oxisol soils (Atangana *et al*., 2014b). Structurally, they are defined by multi-layered canopies, towering emergent trees, and a rich understory (Atangana *et al*., 2014; Thomas & Baltzer, 2002).

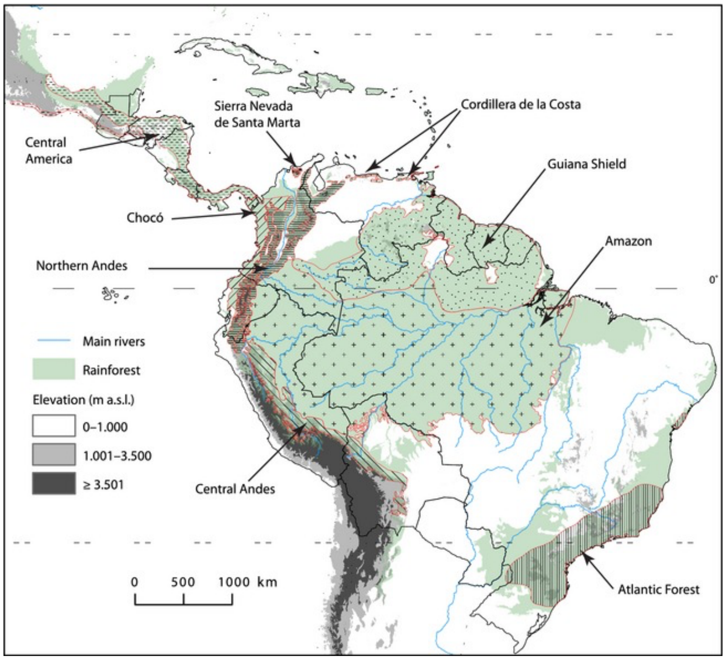

Figure 3. Map of the Neotropical region showing the geographical distribution of rainforest in green. Source: Castroviejo-Fisher *et al*., 2014.

A. DEFORESTATION OF TROPICAL FOREST

For millennia, humans have reshaped the form and process of ecosystems across the terrestrial biosphere, both intentionally and unintentionally (Dearing *et al*., 2006; Ellis *et al*., 2010). Starting with moderately brief practices like hunting and gathering and building towards the increasingly intense and permanent use of land for agriculture and settlements, the widespread and sustained presence of human populations has transformed ecosystems locally, regionally and globally (Ellis *et al*., 2010). This growing scale and intensity of our impact has modified the functioning of the Earth systems, leading to the suggestion that Earth has entered a new geological epoch, the “Anthropocene” (Crutzen, 2002; Steffen *et al*., 2011). Between 1980 and 2012 (see Figure 4a), over 150 million hectares were cleared for agriculture (Gibbs *et al*., 2010; Hansen *et al*., 2013b), with approximately four million hectares subsequently deforested annually (Curtis et al., 2018). This spread of agriculture has fragmented the remaining forests such that, further damaging the landscape-scale connectivity necessary for the persistence of wildlife, especially in the face of climate change (Haddad *et al*., 2015; Senior *et al*., 2019).

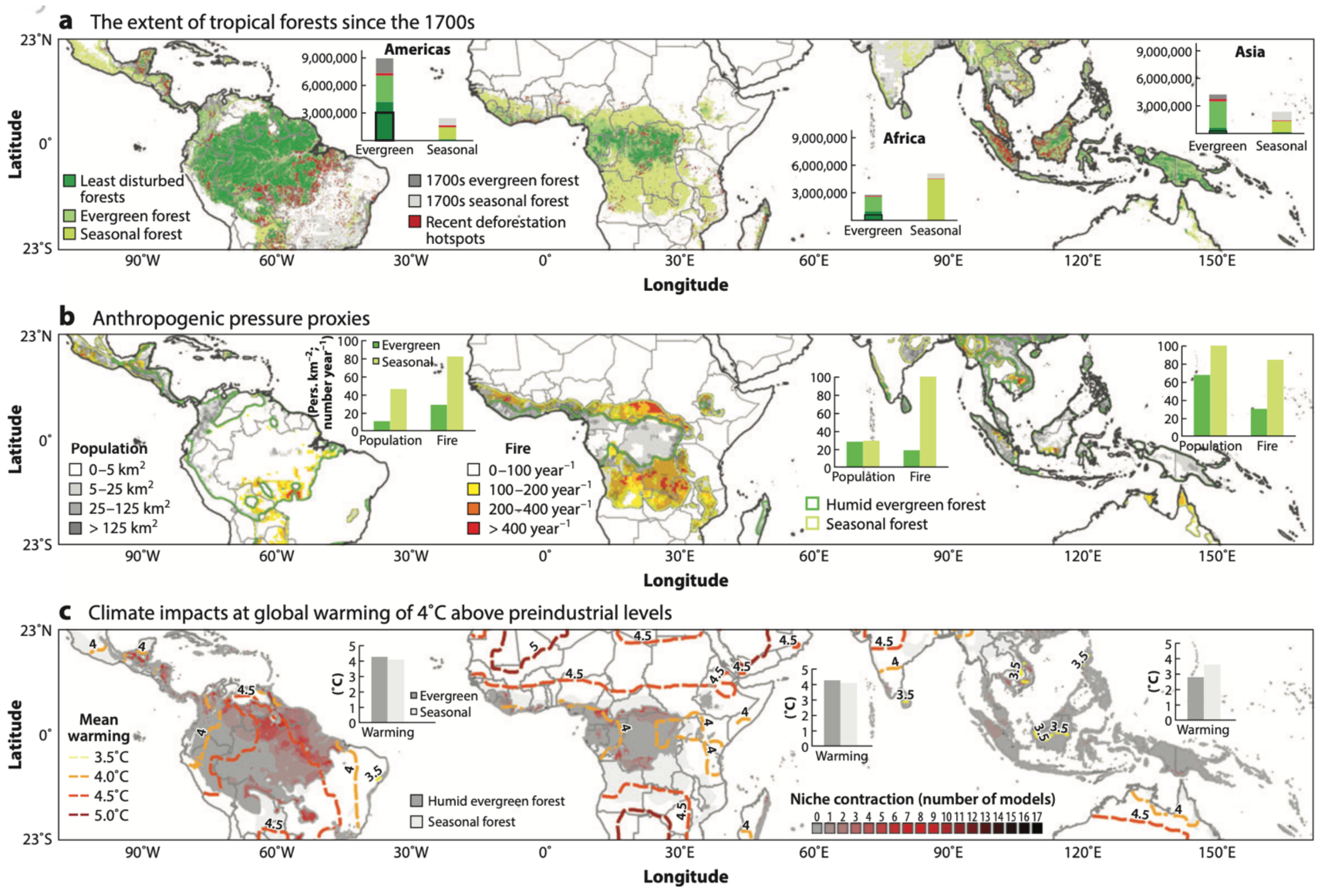

Figure 4. Facets of Anthropocene change in tropical forests. (*a*) Presents the extent of evergreen tropical forests and other dense broadleaf forests within the tropics. Red shading represents the most intense clearance over the period 2000 – 2012 (≥ 10% per 10 km^2), using *Landsat data* (*b*) Human population density (within forest mask only) and fire intensity as two proxies for the overall anthropogenic pressures on tropical forests. (*c*) Potential future impacts of climate change and enhanced CO^2 concentration at 4 °C global warming on humid tropical forests. Source: Malhi *et al*., 2014.

Tropical forests worldwide are undergoing profound changes driven by a diverse array of anthropogenic pressures. These include deforestation, as a long-term or permanent removal (Atangana *et al*., 2014), and fragmentation for agriculture, logging and other resource extraction, unsustainable exploitation and defaunation, increased fire incidence, hunting and wildlife trade, the spread of introduced species and pathogens through global interconnectivity, altered biogeochemical cycles, rising temperatures and carbon dioxide concentrations, and shifting precipitation patterns (Senior *et al*., 2019). The patterns of change are spatially heterogeneous, often characterized by strong interactions among drivers that act in unison and vary in intensity across regions (Edwards *et al*., 2019b; Malhi *et al*., 2014). Such processes can trigger ecological cascades of degradation, that implies changes within the forest which negatively affect the structure and function, over long timescales (Atangana *et al*., 2014b; Malhi *et al*., 2014). As a consequence, most tropical forests are on a trajectory to becoming altered ecosystems, with the degree of alteration dependent on the intensity and duration of the current "bottleneck" of anthropogenic pressures, a bottleneck understood here as a period of acute, concentrated stressors that constrain ecological resilience and threaten long-term forest integrity (see Figure 5) (Malhi *et al*., 2014).

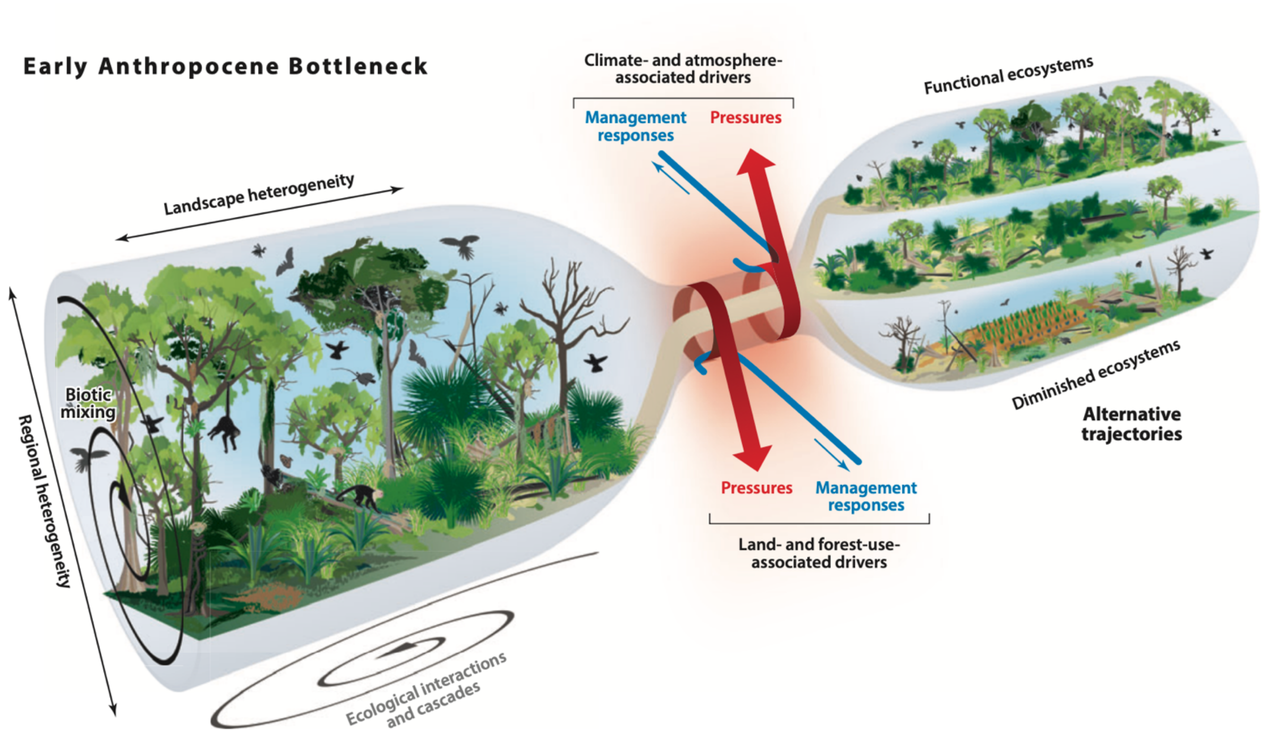

Figure 5. Anthropocene bottleneck of tropical forest: the future composition and dynamics of tropical forests will depend on the severity and duration of the current bottleneck, shaped by forest conditions, ongoing anthropogenic and climate pressures (red belts), and management responses (blue belts); which will determine future state of these ecosystems (functional or degraded/diminished) and the effectiveness of restoration and conservation efforts. Source: Malhi *et al*., 2014.

B. TROPICAL FOREST IN GUATEMALA

Guatemala, located in Central America, is a small country with an area of 108,889 km^2, however presents a great biodiversity of organisms, with around 12,000 plant species (Cano & Schuster, 2008). This is due to a set of factors that have favored the development of multiple life forms, both plant and other taxonomic groups. These factors include its tropical latitudinal position; its Neotropical-Panamanian biogeographic position (Antonelli *et al*., 2018); and its interoceanic position, between the Pacific and Atlantic Oceans. Its topography is also important, presenting a diversity of landforms, soil types, and wide altitude ranges, from 0 to 4,220 m above sea level (IARNA-URL, 2018; Vivero, *et al*., 2006). This results in a diversity of climates with precipitation levels ranging from 400 to 5,000 mm and average annual temperatures ranging from 10 to 30°C (Vivero, *et al*., 2006).

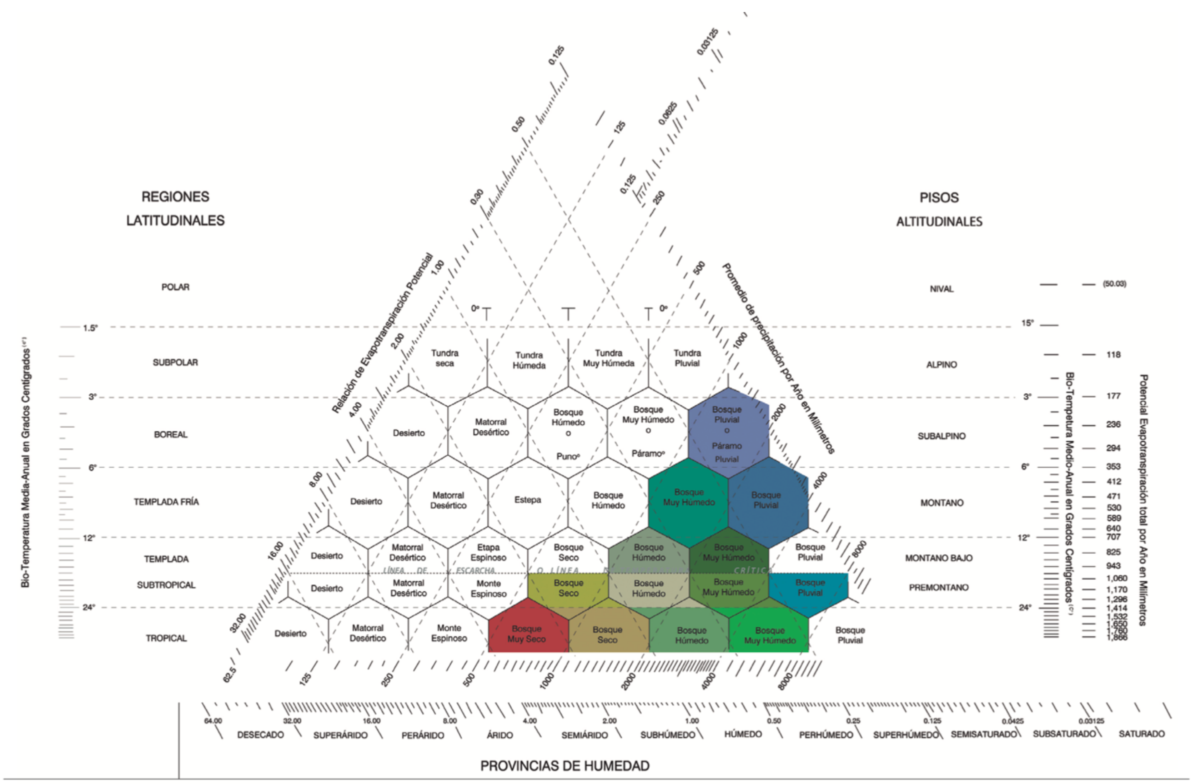

Figure 6. Modification of the hexagons of the Holdridge diagram between the basal and premontane levels for Guatemala. Source: IARNA-URL, 2018.

This combined topographic and climate variation the recent Holdridge System recognize the presence of 13 life zones in Guatemala (see Figure 6), distributed across six altitudinal zones, seven precipitation provinces, and nine humidity provinces (IARNA-URL, 2018). This, in turn, gives rise to a variety of forest types (see map in Figure 7), including tropical forest in the north, mangrove forest on the southern and Caribbean coast, cloud forest in the west and in the Verapaces, dry forest and thornbush in the east, páramo in the top of volcanoes and Cuchumatanes mountain range, montane coniferous forest mixed forest (conifers and broadleaf) in the western highlands of the Altiplano (Vivero, *et al*., 2006).

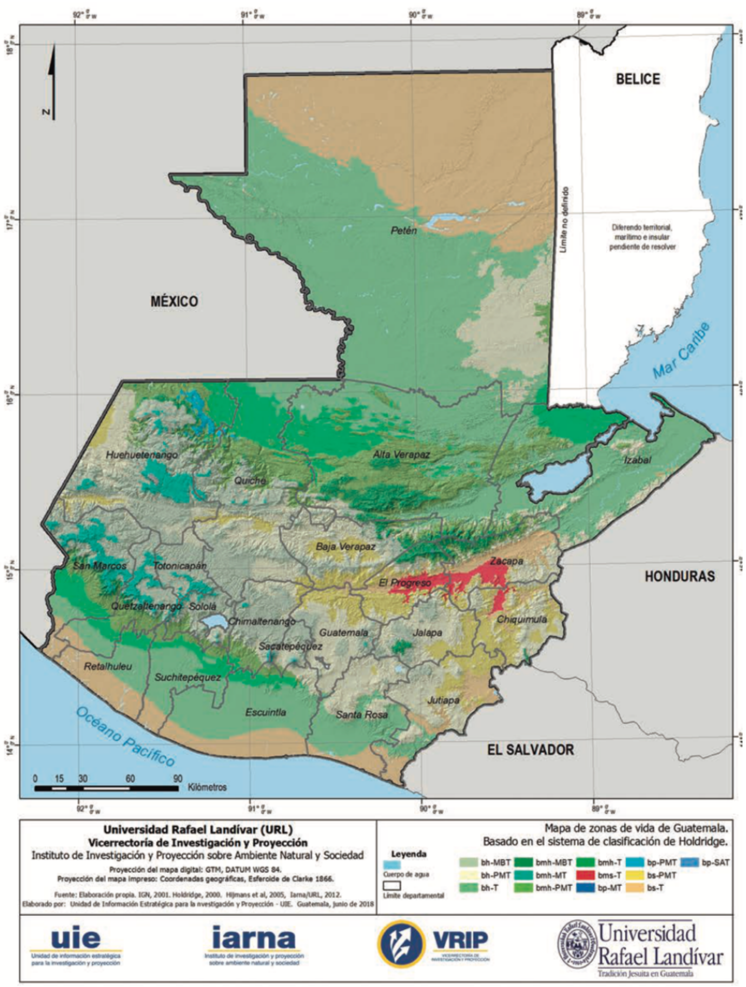

Figure 7. Life zone map of Guatemala based on the Holdridge classification method. Source: IARNA-URL, 2018.

Due to the great biodiversity present in the country, in October 2010 (International Year of Biological Diversity), the United Nations General Assembly recognized Guatemala as a megadiverse country. This makes it a member of the Group of Like-Minded Megadiverse Countries, a consultation and cooperation mechanism to promote common priorities and interests related to the conservation and sustainable use of biological diversity (CBD, 2025). Furthermore, based on the endemic plant species present in Guatemala, it has been established as a "hotspot" in the heart of Mesoamerica, that is, a region with a representative number of endemic species, and therefore presents an exceptionally high biodiversity of species (Zachos & Habel, 2011).

1. TROPICAL HUMID FOREST (bh-T) & TROPICAL VERY HUMID FOREST (bmh-T)

This research focuses on the tropical forests of Alta Verapaz, in the central-northern region of Guatemala. According to the Holdridge life zone classification, the area comprises two main life zones humid tropical forest (bh-T) and very humid tropical forest (bmh-T) (Holdridge, 1947; IARNA-URL, 2018). Both zones occur in lowland areas (below 500 meters above sea level) in the southern and northern parts of the country, covering a large portion of Alta Verapaz, where this study was conducted. The bh-T life zone occupies about 31.5% of Guatemala’s territory (3.43 million hectares), representing slightly more than a third of the country and constituting the largest life zone. In contrast, the bmh-T life zone covers approximately 5.68% (0.61 million hectares). Average altitudes are 182 meters for bh-T and 321 meters for bmh-T. Climatic conditions are similar: in bmh-T, average annual rainfall reaches 3,583 mm with an average temperature of 25.3 °C, while in bh-T, rainfall averages 2,199 mm and temperature averages 25.65 °C (IARNA-URL, 2018). Together, these two life zones account for 37% of Guatemala’s land area. However, more than two-thirds of their original extent has been degraded, depleted, or polluted, threatening the management of the biological diversity they harbor. Land cover within these zones is distributed as follows: 22.45% forest, 29.12% livestock pasture, 21.20% scrub and bushes, 9.33% basic grains, and 6.21% sugarcane. African palm cultivation is also significant, occupying 2.81% of the area, while the remainder is dedicated to other uses (IARNA-URL, 2018).

In both the tropical humid forest (bh-T) and the very humid tropical forest (bmh-T), a high number of botanical species are shared, reflecting their similar warm lowland tropical conditions (De la

Cruz, 1982). Frequent and widely distributed species in both life zones include *Acoelorrhaphe wrightii, Annona glabra, Aspidosperma cruentum, Astronium graveolens, Attalea cohune, Bactris mexicana, Brosimum alicastrum, Bursera simaruba, Calophyllum brasiliense, Cedrela odorata, Ceiba pentandra, Chrysobalanus icaco, Chrysophyllum mexicanum, Dalbergia ecastaphyllum, Euterpe macrospadix, Grias integrifolia, Guazuma ulmifolia, Pachira aquatica, and Swietenia* macrophylla (Bonham *et al*., 2009; Instituto Nacional de Bosques, 2001). These belong mainly to families such as Fabaceae, Arecaceae, Moraceae, Meliaceae, and Chrysobalanaceae, which dominate the canopy and subcanopy (De la Cruz, 1982). The bmh-T zone also harbors species such as *Alseis yucatanensis and Coccoloba schiediana*, which are adapted to the higher humidity and slightly elevated average rainfall. In contrast, the bh-T zone presents a greater variety of exclusive species, including *Acacia pennatula, Allophylus cominia, Ampelocera hotleii, Astrocaryum mexicanum, Bauhinia divaricata, Bursera diversifolia, and Pouteria campechiana*, many of which are associated with semi-deciduous forest elements and drier microhabitats within the humid forest mosaic (IARNA-URL, 2018; INAB, 2001). Structurally, these forests are characterized by multi-layered canopies exceeding 30 meters in height, abundant lianas and epiphytes, and a diverse understory rich in shrubs and palms, contributing to a complex vertical stratification and high overall biodiversity (see Figure 8) (Atangana *et al*., 2014; Thomas & Baltzer, 2002).

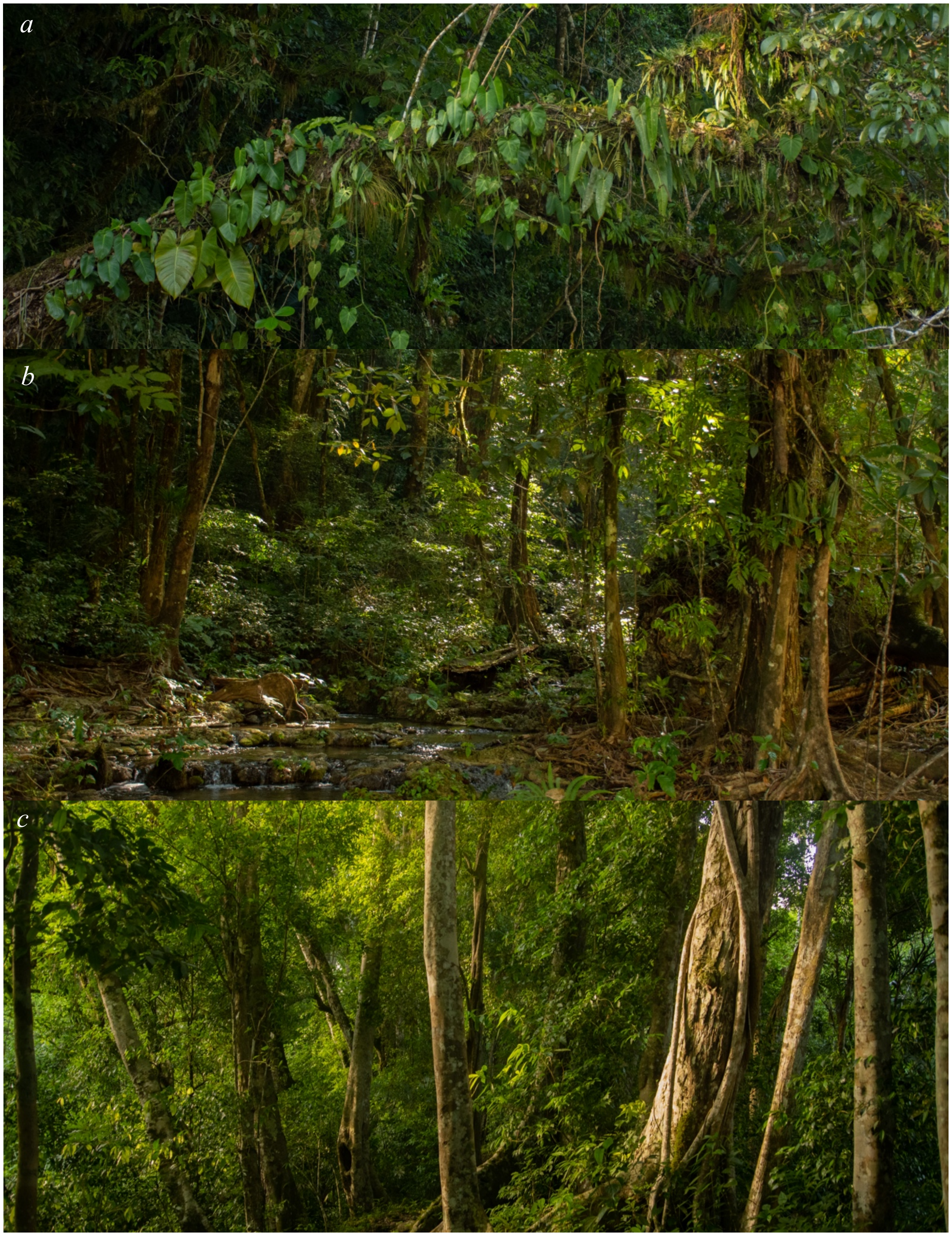

Figure 8. Botanical structure and composition of tropical forest in the central north of Guatemala, showing the great biodiversity in a small area. *a*: Epiphytes composition on a branch; *b* & *c*: Understory structure and composition with different emergent tree size and types. Source: Photos' and author's work.

C. IMPORTANCE OF FOREST AND DEFORESTATION IN GUATEMALA

Beyond their ecological importance, tropical forests in Guatemala provide essential ecosystem services such as soil retention in hillside areas, which helps prevent erosion, and water recharge (IARNA-URL, 2018). Their conservation is particularly relevant given the country's high vulnerability to climate change. According to Germanwatch, Guatemala is among the 10 countries most exposed to its impacts (Kreft, 2014). During the drought caused by the El Niño phenomenon between November 2023 and January 2024, 14% of households in the country reported impacts, in a context where 69% of agricultural producers depend exclusively on rainfall for irrigation (WMO, 2024). According to the FAO, between May and July 2024, 36% of producers experienced production difficulties, and 59% of affected households suffered yield reductions of between 50% and 100% (FAO, 2025). Such droughts, becoming more frequent and intense in recent years, had already caused severe losses in 2016, with $30.8 million in corn and $102.3 million in bean crops lost in the dry corridor (FAO, 2016).

In addition to their ecological functions, these forests hold social and economic value for local communities, providing resources for daily life and cultural traditions (Cano & Schuster, 2008). They also offer significant potential for sustainable tourism, which can generate employment and income in the regions where they occur. Guatemala has a marked forestry vocation: 57.89% of the national territory is unsuitable for agriculture and has the capacity for forest use (Vivero, *et al*., 2006). Timber production is a key economic activity, generating US$91,277,722 in exports in 2016, with an upward trend (SIFGUA, 2018). While logging contributes to deforestation, sustainable management schemes exist, such as the forest concessions in Petén, internationally recognized as a model of sustainable use (Gómez & Méndez, 2007). However, deforestation still remains a serious concern. Between 2006 and 2010, Guatemala lost 146,112 ha of forest, resulting in a remaining forest cover of 3,722,595 ha, with an annual loss rate of 1.00% (INAB, CONAP, UVG, & URL, 2012). These calculations include rubber plantations (30,000 ha in 2010), meaning that the extent of natural forest is even lower. The main drivers of deforestation are agricultural and livestock expansion, urbanization, forest fires, encroachment into protected areas, pests, and natural disasters (INAB *et al*., 2012). Therefore, tropical forest in Guatemala are among the most threatened ecosystems in the country. Their degradation often results in conversion to simpler production systems, which are eventually abandoned when profitability declines (Kappelle, 2008). Key threats include timber and fuelwood extraction, mining, fires from poorly executed slash-and-burn clearing, overharvesting of plants and animals, and agricultural expansion (CECON-USAC, 2002b). Currently, there is limited research, few initiatives, and no established methods for the sustainable use of native species, which often leads to their replacement by commercial plantations or agricultural crops. The primary conservation strategy has been the establishment of protected areas and biological corridors (Jiménez, 2009).

D. ETHNOBIOLOGY

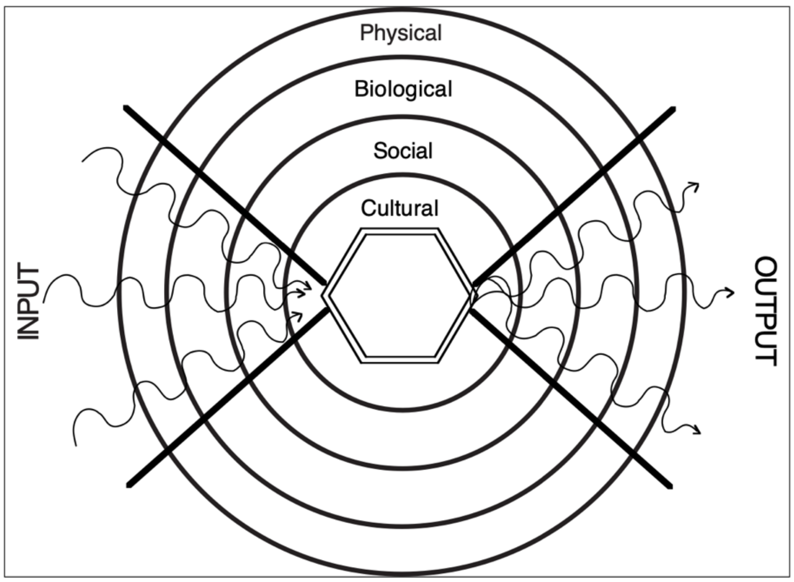

Figure 9. Multiple Environments of Human Ecosystems and the flux of energy and material in different dimensions. Source: (Stepp, 2018).

Ethnobiology has been classically defined as the study of human-environment interactions. Indeed, it is a complex field of knowledge and action that interacts with many scientific disciplines. These interfaces result in different theoretical approaches and challenges. Ethnobiology occupies a privileged position due to its potential to integrate local and global knowledge, connect cultures, academic and scientific approaches, and relate biological and social aspects of human experience with the environment (Stepp, 2018). The term "ethnobiology" refers to a union of competencies that encompasses aspects ranging from the cultural to the biological, encompassing the study of very diverse relationships (Albuquerque & Nóbrega Alves, 2016). Due to the classic definition of ethnobiology, it has been closely associated with human ecology and ethnoecology, the latter being the field of study that describes the interactions of human populations with the local natural environment in all its aspects (see Figure 9), thus achieving a holistic view of the local biological and ecological knowledge of a given community (Martin, 1995).

1. ETHNOBOTANY

Ethnobotany is a subdiscipline within ethnobiology and ethnoecology, but ethnobotany can be considered a science in its own right that seeks to document and understand what humans know about plants over time and in different contexts, how plants are part of their belief system, explanations and conceptions of the world, and how humans use and manage plants to reproduce their cultural, social, as well as to maintain their physical and spiritual life (Ozturk & Hakeem, 2018). Due to its essence of studying the interactions between humans and plants in different cultural and ecological contexts, it is widely used in the documentation of indigenous knowledge, also called Traditional Ecological Knowledge (TEK) about the use of plants, mainly medicinal plants, to provide an inventory of useful plants of the local flora of a community (Lira *et al*., 2016). This indigenous or TEK about the use of plants can be related to human health, history and heritage, both plant genetic inheritance and cultural heritage (Andel, 2016). This field of study is interdisciplinary in nature, encompassing many sciences or branches of study, such as botany, chemistry, medicine, pharmacology, toxicology, nutrition, agronomy, ecology, sociology, anthropology, linguistics, history, archaeology, among others. This allows ethnobotany, like ethnobiology, to be a science with a wide range of approaches and applications (Bermúdez & Oliveira-Miranda, 2005). However, the progress of the science itself and the impact of its studies demand a holistic approach that integrates its different disciplines (Martin, 1995; Prance, 1991).

2. APPLICATIONS

Due to the interdisciplinary nature of ethnobotany, it can encompass many study approaches with very varied applications (Martin, 1995). One of its main applications throughout history is the discovery of new medicines through prospecting programs to investigate the pharmacological activity of the biochemical components of plants used by different human communities, mainly indigenous ones in tropical regions (Bermúdez & Oliveira-Miranda, 2005). However, by addressing theoretical questions about the relationship between humans and their environment within the context of the increasing loss of traditional knowledge about the use of useful plants, as well as in the context of ecosystem degradation and conversion, Ethnobotany has served as a tool for preserving traditional knowledge and biodiversity, while contributing to rural development and the formulation of conservation strategies based on indigenous knowledge regarding the sustainable management of the natural environment (Prance, 1991). Therefore, the two most important applications of ethnobotanical data are economic development through pharmaceuticals and the conservation of cultural and natural resources while promoting community development and local conditions (Martin, 1995).

3. METHODS IN ETHNOBOTANY

Surveys and interviews are useful tools for ethnobotanical studies that should collect data on anthropology, botany, ecology (conservation status), and agronomy (Begossi, 1996). These methos are generally directed to native communities in the region where the study is to be conducted. Depending on the objectives of the study, participants may consist of the general population or key informants, defined as individuals with specialized knowledge and practical experience in the use of the plants being studied (Albuquerque, Cruz Da Cunha, *et al.*, 2014). Surveys are based on a structured questionnaire, also called instruments or ethnobotanical instruments in this context, often deliver to large groups. While interviews are flexible and develops within a conversation with individuals or small groups. These interviews can be either structured or semi-structured, with the latter serving as the primary method for this study. Structured interviews, the stimulus delivered to each respondent must be the same, which means that the already planned questions are posed to each informant (Cunningham, 2001). This style of interview restricts the interviewee's responses, yet it enables the codification/categorization of the answers and provides for speedier production of materials for analysis. In this particular form of interview, it is imperative that the interactions between the interviewer and each interviewee are conducted in a manner that ensures maximum similarity. It is important that any biases caused by factor such as the environment, circumstances, and timing are consistent for all interviewers (Ozturk & Hakeem, 2018). For semi-structured interviews the investigator also prepares some of the questions in advance before conducting field research. However, these questions are mostly adaptable, allowing for greater focus on any issues that may arise during the interview. The investigator may provide an overview of the topics beforehand, and the questionnaire help direct the interview. Semi-structured conversations are the best technique to use if it is not possible to interview the same informant again. This strategy's "open" element allows respondents to answer questions according to their own interpretations (Albuquerque, Cruz Da Cunha, *et al*., 2014).

In any case, it is essential that investigators possess in-depth knowledge of the subject and the key issues to be explored (Andel, 2016). To ensure this, a thorough and comprehensive questionnaire, primarily for surveys and structured interviews, or a detailed guide outlining the specific questions, subjects and issues to be address, mainly for semi-structured interviews, should be developed prior to fieldwork. Questionnaires are highly valuable for conducting surveys and structured interviews, as well as for guiding semi-structured interviews, as they help maintain focus and consistency throughout the process (Albuquerque, Cunha, *et al*., 2014). Therefore, careful attention should be given to the design and formulation of questions to ensure they are simple to use, aligned with the study's objectives, and effective in guiding the discussion (Albuquerque & Nóbrega Alves, 2016). The questions can be open-ended or closed-ended, and their use depends on the research needs and problems. Open-ended questions do not predefine the responses, making them easier to write, but they require more effort and time to analyze. Closed-ended questions have predefined categories or alternative responses (Lira *et al*., 2016). Depending on the number of alternatives, they can be dichotomous or multi-alternative. Response options can be exclusive (e.g., yes or no) or non-exclusive. Closed questions require more time and effort to develop, but their analysis is usually quick and easy. These questions also require less time and effort from the respondent (Cunningham, 2001). It is important to develop easy and manageable questions and take into account the language of the people being surveyed, avoiding specialized language (Albuquerque, Cruz Da Cunha, *et al*., 2014).

4. ETHNOBOTANY INDICES: IMPORTANCE INDICES

The qualitative nature of the data obtained from ethnobotanical methods makes the application of statistical tests difficult. In response, a diverse of quantitative approaches have been developed using an index that assign numerical scales or calculate a value (non-monetary concept) per folk or biological plant taxon (Hoffman & Gallaher, 2007)1. This trend began in the 1980s with the work of Prance et al. (1977) and Boom (1987), who developed methods to assign importance values to the uses applied to each plant and to measure the percentage of plants used in an area

(Boom, 1987; Prance et al., 1977). Since then, anthropologists and ethnobotanists have developed various indices from different approaches and perspectives, each serving distinct objectives. Some focus on cultural significance, capturing the importance of plants based on factors such as types of uses (Turner, 1988) or the taste of edible species (Pieroni & Pieroni, 2001). Others draw partly from ecological theory, using indices to determine the relative importance of different species or plant families within a society (Begossi, 1996; Cunningham, 2001). A third group has estimated the economic value of forest goods for different ethnic groups (Godoy *et al*., 2002; Hecht *et al*., 1988). More recently, Reyes-García (2006) took the first step toward integrating these approaches, by building an index that considers three dimensions: cultural significance (cultural value), practical daily use (practical value), and economic value. The cultural value (CV_e) of each plant species was calculated based on its potential uses and the number of participants who reported it. The practical value (PV_e) was determined by considering the number of observed uses, the frequency of use, and the potential lifespan of the goods derived from the plant. Finally, the economic value (EV_e) was estimated from the frequency of use and the local market price of the species. The total value index (V_e) of a plant species is the sum of its cultural, practical and economic values: $V_e = CV_e + PV_e + EV_e$. The combination of the three indices offers a more comprehensive valuation of the significance of plants for humans (Reyes-García *et al*., 2006).

E. GUATEMALA AND THE MAYA

An ethnic group is defined as those groups of humans who share common cultural traits such as customs, languages, spiritual beliefs, among others (UNDP, 2005). In Guatemala, 25 ethnic groups coexist (see Figure 10), of which 22 are Mayan, and the other 3 are Xinka, Garifuna, and Ladino, the latter being a heterogeneous Spanish-speaking group of Hispanic and indigenous origin that identifies with Western culture (Hoyler *et al*., 2018). The ethnic groups that are included within the indigenous category, according to the 1996 Peace Accords, are Mayan, Xinka, and Garifuna (Cojtí-Cuxil, 2020). It has been estimated that more than 16 million people live in the country (INE, 2014). According to the Guatemalan National Population Census published in 2019, in which around 15 million people were counted, the percentages of self-identification by community of belonging were calculated as follows: 41.7% as Maya, 1.8% as Xinka, 0.1% as Garifuna, 0.2% as Afro-descendant, 0.2% as foreigner, and 56% as Ladino. Similarly, it is estimated that 43.8% of the population is indigenous (Maya, Xinka, and Garifuna) (INE, 2019). However, estimates by the United Nations Development Program (UNDP) have raised the proportion of the indigenous population to 66% (OPMS/WHO, 2016). This cultural diversity intrinsically represents a wealth of local and indigenous knowledge that each human group has immortalized through their oral history and traditional practices over time (Consejo Mayor de Médicos Maya'ob' por Nacimiento, 2016). Furthermore, the direct coexistence of these mostly indigenous ethnic groups with their natural environment and Guatemala's high biodiversity supports a close and ongoing relationship with nature, on which local and indigenous knowledge is based. This knowledge, which is preserved and transmitted from generation to generation, varies constantly depending on the location and the human group (Albuquerque *et al*., 2015)

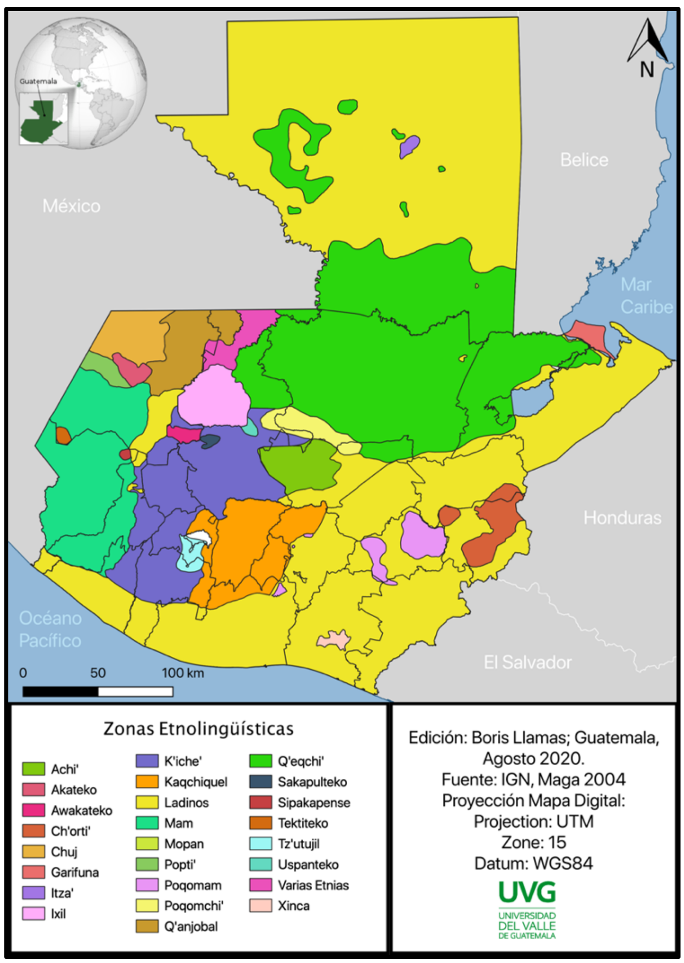

Figure 10. Map showing the distribution of ethnolinguistic zones present in Guatemala. Distribution of the Q'eqchi' ethnic group shown on green. Source: Author's work with *QGIS*.

Although more than half of Guatemala's population is indigenous and this group represents 61.7% of the economically active population (Broch et al., 2017; CADPI, 2017; OPMS/WHO, 2016), indigenous peoples face profound disparities and exclusion from the state. The departments with the highest levels of social exclusion are, for the most part, those inhabited primarily by indigenous populations, characterized by low state investment in services, deficient infrastructure, and limited access to education and healthcare (CBD, 2025; Hoyler *et al*., 2018). According to the 2008 Human Development Report (HDR), 73% of the indigenous population lives in poverty, and of these, 26% in extreme poverty (OPMS/WHO, 2016). Health indicators also reflect this inequality: virtually all health outcomes are considerably worse for the Indigenous population (Bogin et al., 1992). For example, while 49.8% of Guatemalan children under five suffer from malnutrition, this figure is nearly 20% higher in Indigenous areas (UNWFP, 2014). Racism and structural discrimination against Indigenous peoples is a legacy that originated in the Spanish colonization of the 16th century (Grandin *et al*., 2011) and has been reinforced by post-independence Republican governments, abusive policies, political and religious persecution, especially during the Internal Armed Conflict (1960–1996), and processes of ladinization and enculturation, now accelerated by globalization (Consejo Mayor de Médicos Maya'ob' por Nacimiento, 2016; Hoyler *et al*., 2018).

1. THE MAYA Q'EQCHI'

The Q'eqchi' people represent the largest ethnic group within the Mayan groups in Guatemala and represent around 8.3% of the total population (OPMS/WHO, 2016). They cover an area of 54,242 km^2, distributed mainly in the departments of El Petén, Alta Verapaz and Izabal (INE, 2019). Among them is a large part of the 3.9 million ha of tropical forest present in the country, with 52% in El Petén, 10% in Alta Verapaz and 7% in Izabal (Food and Agriculture Organization of the United Nations, 2005; Pope *et al*., 2015). Thus, forming the natural environment of the majority of the Q'eqchi' communities, and those who depend on local natural resources and associated ecosystem services for their livelihood, health and well-being. Within these primary and secondary forests they live as subsistence farmers and supplement their livelihoods with forestry through small-scale forest extraction, such as logging, hunting, and the gathering of non-timber products for food, medicine, and shelter (Maass, 2008). This intimate and close relationship of the Q'eqchi' people with their natural environment means that their cultural and spiritual identity is linked to nature, and that in turn governs the way they manage the land and use natural resources. Farmers within traditional Q'eqchi communities ask local deities called *Tz'uultaq'a* for permission to clear and cultivate (Lea, 2018). Thus, taking care to minimize the human impact on the environment, as they recognize the importance of their resources to survive (Carr, 2004; Maass, 2008; Monterroso & Bravo, 2008; Wilson, 1995).

Figure 11. Photo of the hilly terrain of the Maya Q'eqchi' community of Tzalamtun. Showing the remoteness of the area by the mountains. Source: Author's work.

Due to the remoteness of their settlements (see Figure 11), many older people in particular are monolingual speakers of the Q'eqchi' language. Exposure to the formal education system as well as more frequent interaction with the urban centers and regional markets led to a process of acculturation towards the predominantly urban ladino culture among younger people, who are also more likely to speak Spanish (Maass, 2008). The economic and social life revolves around the milpa system, which consists of the cultivation of maize and will be describe in the next section. Home gardens, called *Li xsutam li rochoch* in Q'eqchi' (*li xsutam*natural: ecosystem or natural environment; *li rochoch*: house; meaning the natural ecosystem next to the house; from author's anecdote in the field) also provide a wide range of crops raised for consumption and for sale at local markets. This is complemented by animal husbandry of chickens, turkeys and pigs on a modest scale, mainly for own consumption. Although the local economy is based on subsistence activities, many households are also linked to the national market economy. They use coffee, cardamom and cacao as their main cash crops. Since the 1970s, coffee has increasingly been replaced by cardamom as a cash crop and as a mainstay of the regional economy (Maass, 2008). Traditionally, land tenure had been governed by a communal management system. Due to the privatization of communal territories since colonial times, which led to the extremely unequal land distribution, temporal wage and migrant labour has become a common source of monetary income. Limited access to enough arable land, the need for immediate income and growing demographic pressure entailed continued clearing of primary forest for agricultural use and led to shorter rotation cycles (Maass, 2008).

a) THE MILPA: *K'al*

The *K'al* in Q'eqchi' or milpa, the latter derived from the Aztec Nahuatl meaning cornfield (Maass, 2008b), is a traditional polyculture (intercropping) system based on maize and with pre-hispanic origin in Mesoamerica (Ford & Nigh, 2009; Teran & Rasmussen, 1995). The milpa consists of the cultivation of maize (see Figure 12) produced through cyclical swidden agriculture, generally carried out by single-family units on small properties (Lea, 2019). While the main crops of the milpa are maize and other basic grains such as beans, the traditional milpa is diversified and can produce more than ten varieties of maize, ranging in color from white, yellow, red, black, and a mixture. Each maize has its own specific maturation, harvest time, and use. Black beans are widely grown within the milpa, along with other varieties called "trepador", "piloy" (*lol* or *nun* in Q'eqchi') or red beans, and six other varieties. This, combined with other crops that include a variety of pumpkins, squash, peppers, yucca, bananas, fruit trees such as papaya, avocado and citrus and other traditional and native herbs such as amaranth and "hierbamora" (*macuy* in Q'eqchi'). This diverse harvest of the milpa are complementary and covering a variety of nutritional needs that supports the balance diet of the Q'eqchi', and is mainly focused for the local people and their families and not for the external market (Ford & Nigh, 2009; Maass, 2008; Teran & Rasmussen, 1995).

The *k'al* is the heart and soul of the Q'eqchi' people, as for the rest of the Maya. It not only produces food for daily sustenance, but also strengthens the connection between people, the environment (*li xsutam*), and the cosmos. For the Maya, every task performed in the *k'al* is a ritual, a resistance and way to remember their identity (author's personal experience in the field). Yishan Lea (2019) describes with powerful words what the *k'al*, or milpa in the following paraph:

"*The Mayas have survived the colonial era, deculturalization, and genocide during internal conflict; their milpa system, corn fields, has sustained the life force that cultivates it. Milpa also nourishes a cultural symbolism with which the people's indigenous identity intertwines. For rural peasants the Maya ways of life that emerged from the subsistence-based economy of milpa provide a stark contrast to the economic model of mono-agriculturalism. Through massive production and market invasion, the technologized economy of neoliberalism engineers for profit, extracts resources, and accumulates wealth while asserting its dominance over the globe.*"

(Lea, 2019)

Figure 12. Milpa or *k'al* system with a standing ceiba (sacred tree of life of the Maya culture *Ceiba petandra*: Malvaceae) in the hills of Tzalamtun. Source: Author's work.

IV. THEORETICAL FRAMEWORK

A. TRADITIONAL ECOLOGICAL KNOWLEDGE

The term Traditional Ecological Knowledge (TEK) came into widespread use in the 1980s, although the practice itself is as old as ancient hunter-gatherer cultures (Berkes, 2012). While there is no universally accepted definition, TEK broadly refers to the body of knowledge held by indigenous and other rural peoples around the world (Falkowski *et al*., 2016); and invites to reflect on how western societies, therefore the western science and academia, can learn from these ways of knowing (Berkes, 2012). However, TEK is not only about knowledge but also about the cultural and political significance it holds for indigenous communities, who often face systemic marginalization and inequality, as previously mentioned. TEK encompasses knowledge, practices, and beliefs about the relationships between humans, local ecosystems, and culture. It includes, among other things, understanding ecosystem functions and natural history (Usher, 2000; White, 2009). TEK also incorporates land and resource management systems, social structures, and indigenous belief systems. This has been evidenced throughout the history of many indigenous people; like the Maya with the use of the milpa, the backbone of the Mayan resource management system, that continues to be widely recognized of its ecological, cultural and economic value until today (Ford & Nigh, 2009). Another notable example also comes from the Maya in the Lacandon tropical forest, who have managed their lands sustainably based on swidden agroforestry systems with evidence of improving soil fertility (Falkowski *et al*., 2016b). These, evidence demonstrates the potential of TEK to serve as a reference for resource management and restoration.

B. TRANSDISCIPLINARITY (TD)

Over the past four decades, transdisciplinarity (TD) has established itself as a distinctive research approach that links science and social practice to address complex and socially relevant problems (Hadorn *et al*., 2008). TD requires not only interdisciplinary collaboration among scientists, but also cooperation between actors from science and society (Jahn *et al*., 2012). Rural development (RD) processes are complex and dynamic, conditioned by the problem addressed, and become particularly challenging in intercultural contexts (Berger-González *et al*., 2016). For example, in Chad, collaboration between pastoralists and public health officials required overcoming differences in interests, worldviews, and communication styles (Zinsstag *et al*., 2011). In such cases, reflexive approaches can facilitate knowledge co-production (Pohl, 2011). A central concept in DT is mutual learning: the equitable exchange, generation, and integration of knowledge from diverse sectors of science and society (Scholz & Steiner, 2015). However, achieving equity requires openly negotiating power relations, and imbalances can persist when resources are concentrated in certain stakeholders (Mobjörk, 2010). A major challenge is achieving integration, defined as the creation of new connections between distinct entities within a given context (Jahn *et al*., 2012). Integration extends beyond knowledge exchange, involving participants as individuals with distinct interests, roles, and communication practices, and can occur at the epistemic, socio-organizational, or communicative levels (Jahn *et al*., 2012). These dimensions have been widely discussed in the TD literature (van Kerkhoff, 2014), and there are ongoing efforts to understand how different epistemes interact to co-produce knowledge (Pohl, 2011).

V. METHODOLOGY

A. STUDY SITE: A CASE OF STUDY IN TZALAMTUN, ALTA VERAPAZ

This research was conducted in Tzalamtun village, located in the municipality of Santa María Cahabón in the department of Alta Verapaz, central north Guatemala, from 1st March to 5th May of 2025 (Fig. 1). The village is located 10 km away from the main town of the municipality, also called Santa María Cahabón. Tzalamtun borders on its northern side the Cahabón River, one of the longest and most voluminous rivers in Guatemala, and is where the town reaches its lowest altitude of ~ 200 m, creating an altitudinal gradient that reaches almost ~ 600 m. The topography of the region is predominantly undulating, with rounded hills and gentle slopes, characterized by clayey rocks. According to the life zones based on Holdridge system for Guatemala, the region is located between the life zones of humid tropical forest (bh-T) and very humid tropical forest (bmh-T) with an average annual rainfall of 2,199 mm (IARNA-URL, 2018), the region is characterize for its warm temperatures that can reach up to 42°C and with a mean temperature of 29°C. The population of Tzalamtun is largely indigenous Maya Q'eqchi', who still strongly maintain their customs, beliefs, traditions, and language. Almost every family is dedicated to agriculture and cultivation of land. The main cash crops in the region are cacao, cardamom, maize, coffee and in low percentage beans and peppers.

(a) Showing Guatemala with the capital Guatemala City and Tzalamtun village shown with blue points.

(b) Tzalamtun village marked with a yellow polygon, the study site in Guatemala

Figure 13. Geographic location of the village Tzalamtun, Alta Verapaz, Guatemala Source: Authors' work with *Google Earth*.

A. TRANSDISCIPLINARY APPROACH: COMMUNITY PARTICIPATION

This methodology was based on a transdisciplinary approach by incorporating the active participation and collaboration with the Q'eqchi' community to select areas to visit, identify important plant species and describe their knowledge and practices in the natural environment of tropical forest that they inhabit in their own way. The latter explained more in detail in the next section. Therefore, the research project was co-designed and co-directed between indigenous Maya Q'eqchi' members of Tzalamtun. Community engagement and active participation was essential at all stages of the research process. A case study approach (Stake, 2008) was selected for this research, given the ability of this framework to explore issues in depth in a locally appropriate manner and its ability to access place-based knowledge and wisdom, an attribute which has been identified as particularly important for environmental change research (Cunsolo-Willox *et al*., 2013).

Figure 14. Community participation on for the review (bottom) of the plants found and brainstorming ideas for the use of the information (top). Source: Author’s work.

B. SEMI-STRUCUTRED INTERVIEWS: REGISTER OF MAYA Q'EQCHI' TEK

This study was made possible thanks to the outreach that Community Cloud Forest Conservation (CCFC) provided to the community of Tzalamtun. CCFC works with young women between the ages of 16 and 23 from various Q'eqchi' communities, primarily in Alta Verapaz, to provide them with free education during school breaks. This education program allows them to learn and enhance their agroforestry knowledge and techniques, as well as topics related to environmental conservation, ecology, and even personal health. As part of this educational program, CCFC provides small funding so that each participating young woman can develop her own agroforestry plot within her community, utilizing her local knowledge as well as what was learned within the program.

The first contact with the community was with the families of the participating girls in the education program with the help of a research assistants in the community. Who contacted the families by phone or through open houses to invite them to participate in a collective information meeting. An invitation to this meeting was also done to the authorities of the community (*Alcalde* or mayor, *alcalde auxiliar* and community leaders), and also any interest family or person was welcome to join. This meeting had the aim to socialize and explain the whole research, as well as to know their insights and opinions to conduct the research in the community. The explanation and socialization of research took into account the objectives and the methodology that was going to be base, mentioning the semi-structured interviews and the questionnaire (as a guide) that will be used to gather information about their knowledge on trees in their natural environment in the broad sense. At the end, after sharing explaining the research and sharing opinions and ideas, a collective consultation to approve the research with a free, prior and informed consent (FPIC) was done (see Anexes). This was also consulted again in the individual participation with the people that gave them approve to participate. Therefore, the interviews were purely participatory and voluntary in nature; the participants gave their verbal and signed informed consent to participate in this study (see Anexes). Also, they were free to withdraw their information and end the interview at any time. After obtaining their permission and prior consent, we collectively organized a collective schedule to visit each participant, while agreeing to visit areas that participants identified as important and relevant for finding trees. This included the milpa, agroforestry systems of cacao (*cacahuatal*), cardamom (*cardamomal*), coffee (*cafetal*) and other agroforestry plots, like diversified fruits and the ones made by the girls that participated in the education program. The areas also included remnants of tropical forest, water sources, and even areas of a community forest protected by the community itself.

Figure 15. Collective information meeting to socialize the research. Source: Author’s work.

The semi-structured interviews consisted of open-ended questions (see Anexes), conducted in a free-flowing conversational format to allow for participant elaboration, personalization of responses, and emerging themes (Sayrs, 1998). These questions aimed to understand the community's TEKs on native forest species (timber and non-timber use) to latter determine the cultural significance of each plant or tree mentioned. Other information about their knowledge and practices in the management of their communal natural environment consisted of remnants of forest and the agroforestry systems mentioned before. As well as ideas for forest restoration was gather, since several participants not just cited forest species but also mentioned their experiences and insights. However, for this research just the information about the trees is used and explicitly show in result section. The interviews took place in the open air at their agroforestry systems and remanent of tropical forest in and around the community, this to provide visual stimuli that allowed a variety of forest species to be cited. The interview consistent in *ad libitum* walks, meaning walks guided by the participants through areas selected by themselves as they found it important. In total, 26 families participated in the semi-structured interviews, this being the maximum possible number of interviews conducted. The sampling effort was focused on interviewing as many people as possible to ensure a broad sample of voices, experiences, and perspectives. In most cases, the interviews consisted primarily of the parents and participating girls, as well as local guides who also own agroforestry plots in the area. This generated a diverse group of people of different ages and genders in each interview. It is worth mentioning that the parents and local guides were key informants as they had relevant and diverse professions, from subsistence farmers, cacao, cardamom or coffee farmers to ranch builders, wood artisans, carpenters, healers, forest rangers, among others. And was common that they had more than two professions, since everyone were subsistence and cacao farmers and build their own house and by the side they had other diversified work.

Figure 16. Collective information meeting to socialize the research. Left cacao pods and seed on natives' trees found mixed with citrus fruits; right *ad libitum* walks in and around the community. Source: Author's work.

When possible, during or after the semi-structured interview, botanical samples (flowers, fruits, leaves, photos of habit, etc.) of the plants cited where taken based on standardized botanical sampling methodologies. Thus, registering each plant with its common names in Spanish and Q'eqchi', its closest possible taxonomic identification, all the data cited (ethnobotanical, agroforestry, phenological and ecological), and keeping the different parts of each plant on paper and botanical presses. The cited plants where identified to species level (western scientific name) with the use of Flora de Guatemala (Standley & Steyermark, 1946) and Trees of Guatemala

(Parker, 2008). The scientific names and taxonomic family (plant specimens that were able to be identified) was confirmed with https://www.worldfloraonline.org. Later these species with good botanical samples were herborized and then deposited at the UVAL Herbarium of the University of Guatemala, where the voucher specimens were also registered. Plants that were not able to be identified by these western methos were registered just by the local Q'eqchi' and/or Spanish name. The Q'eqchi' and Spanish names were obtained from the local Q'eqchi' participants and then verified (if possible) during interviews and later with literature mentioned above.

C. TRANSCRIPTION AND ANALYSIS OF INTERVIEWS

The interviews were be analyzed descriptively using a rigorous, immersive, constant comparative, multi-step process, which consists of several iterative steps. First, all the transcripts will be read and reread to uncover the main themes, community concerns of agroforestry species, and general findings. Second, the interviews were reread while simultaneously listening to the audio recording to note the cultural value and importance of agroforestry species, their ethnobotanical knowledge and uses, and agroforestry practices. Third, a list of relevant agroforestry species and ethnobotanical knowledge and uses, and agroforestry practices will be created from all transcripts and were discussed with members of the research team to ensure accuracy and authenticity. During the process, the list of agroforestry species and their information were refined to create a final list of relevant species with their ethnobotanical and agroforestry information. Fourth, transcripts were coded according to this list. Finally, a list of preliminary findings and citations were shared with the research team and with local and regional agroforestry professionals to further ensure accuracy, authenticity, and relevance to the research context (Cunsolo Willox et al., 2013).

D. DETERMINATION OF RELEVANT SPECIES

The determination of the relevant agroforestry species was based on the combination of two parameters (1) Cultural Importance and (2) the threaten status. The cultural importance was determined by the *Cultural Value Index* (CV_e) of the species cited in the interviews (Hoffman & Gallaher, 2007; Reyes-García et al., 2006).

1. CULTURAL IMPORTANCE

As reported by Reyes-García *et al*. (2006), the Cultural Value Index (CVe) for each plant species was calculated based on its potential uses and the number of participants who reported it, using the following equations:

$$CV_e = Uc_e * Ic_e * \sum IUc_e$$

where *e* = cited plant. Uc_e = number of uses reported (through free listing) for an cited plant divided by the total number of use categories (5 categories, see results section). Ic_e = Number of participants who listed a species as useful divided by total number of participants. ΣIUc_e = Number of participants who mentioned each use (category) for the cited plant divided by the total number of participants.

2. THREATENED STATUS

The threatened status of each plant was based on the IUCN Red List of Threatened Species, the Guatemalan Red List of Trees (Vivero, *et al*. 2006), the LEA (CONAP, 2009), and species listed in CITES.

3. DATA INTEGRATION

According to the information obtained from both parameters (1) and (2), a data integration table was made. Subsequently, based on fulfilled criteria was used to determine relevant species for agroforestry system design. The criteria are described in the following subsection.

4. SELECTION BASED ON MET CRITERIA

Four criteria were used to determine relevant species. The first was the CV_e index. For this, the lowest CV_e of the 15 most important species were used as the minimum value for a species to meet the criteria. The second criterion were that the species is within one of the threatened categories (Endangered, Vulnerable, or be included in the LEA or CITES). The last criterion used were to have more than 3 uses reported, inferring the practical daily use importance by the people, where the community significance or importance by the people is given by CV_e mention before.

VI. RESULTS

A. IDENTIFICATION OF CITED PLANT SPECIES

The following table shows all the species recorded for Tzalamtun village and its surrounding areas, including their local names in Q’eqchi’ and Spanish, as well as their scientific names. The species were classified as: (A) Fruit trees, (B) Timber trees, (C) Annual/perennial crops.

Table 1. Plant species cited in the interviews and their classification.

No.	Family	Species	Q'eqchi' Name	Local Spanish Name	Classification*
1	**Adoxaceae**	*Sambucus mexicana* C.Presl ex DC.	Tz'oloj	Saúco	C
2	**Amaranthaceae**	*Spinacia oleracea* L.		Espinaca	C
3	**Anacardiaceae**	*Mangifera indica* L.	Mank	Mango	A
4	**Anacardiaceae**	*Spondias mombin* L.	K'ixrum	Jocote	A
5	**Anacardiaceae**	*Spondias radlkoferi* Donn.Sm.	Poc, Pooc, Pook	Ciruela amarilla, jobo	B
6	**Annonaceae**	*Annona purpurea* Moc. & Sessé ex Dunal	Tuk'i, Matakuy	Sincuyá	A
7	**Annonaceae**	*Annona cherimola* Mill.	Tz’uumuy	Anona	A
8	**Apiaceae**	*Eryngium foetidum* L.	Xamat	Cilantro cimarron	C
9	**Apiaceae**	*Coriandrum sativum* L.	Culantro	Cilantro	C
10	**Apocynaceae**	*Tabernaemontana donnell-smithii* Rose	Cocowak	Cojon de Toro	B
11	**Arecaceae**	*Xanthosoma undipes* (K.Koch & C.D.Bouché) K.Koch	Kequeshque, Ox	Malanga	C
12	**Arecaceae**	*Chamaedorea tepejilote* Liebm.	Kiib, Qiib	Pacaya	C
13	**Arecaceae**	*Attalea cohune* Mart.	Mokooch	Corozo	A, B
14	**Arecaceae**	*Cocos nucifera* L.	Kook	Coco	A
15	**Arecaceae**	*Acrocomia aculeata* (Jacq.) Lodd. ex R.Keith	Map	Coyol	A
16	**Arecaceae**	*Spathiphyllum blandum* Schott	Yuk	Cartucho, Anturio	C
17	**Asparagaceae**	*Yucca gigantea* Lem.	K’uuk’iil, k’uuk’il	Izote	C
18	**Asteraceae**	*Perymenium grande* Hemsl.	Tzaj	Tasiscobo	B
19	**Asteraceae**	*Bidens bipontina* Sherff	Xubax		C
20	**Bignoniaceae**	*Roseodendron donnell-smithii* (Rose) Miranda	Saq che'	Palo Blanco	B
21	**Bignoniaceae**	*Crescentia cujete* L.	Joom	Jícara	A
22	**Bixaceae**	*Bixa orellana* L.	Xayaw	Achiote	A
23	**Boraginaceae**	*Cordia alliodora* (Ruiz & Pav.) Oken	Laurel	Laurel	A

No.	Family	Species	Q'eqchi' Name	Local Spanish Name	Classification*
24	**Bromeliaceae**	*Ananas comosus* (L.) Merr.	Ch'op	Piña	C
25	**Burseraceae**	*Protium copal* (Schltdl. & Cham.) Engl.	Copal pom	Copal	A
26	**Burseraceae**	*Bursera simaruba* (L.) Sarg.	Kaqaj	Palo De Jiote	B
27	**Calophyllaceae**	*Calophyllum brasiliense* Cambess.	Leech	Santa María	B
28	**Caricaceae**	*Carica papaya* L.	Putul	Papaya	A
29	**Chrysobalanaceae**	*Moquilea platypus* Hemsl.	Holob'ob, Muxpin, Moxpin	Sunzapote	B
30	**Combretaceae**	*Terminalia amazonia* (J.F.Gmel.) Exell	K'anxan	Naranjo	B
31	**Commelinaceae**	*Tinantia erecta* (Jacq.) Fenzl	Tziton		C
32	**Convolvulaceae**	*Ipomoea batatas* (L.) Lam.	Is	Camote	C
33	**Cucurbitaceae**	*Cucurbita moschata* Duchesne	K'um	Ayote	C
34	**Cucurbitaceae**	*Sicyos edulis* Jacq.	Ch'ima	Güisquil	C
35	**Cucurbitaceae**	*Cucurbita* spp.	Kum	Calabazas	C
36	**Cucurbitaceae**	*Citrullus lanatus* (Thunb.) Matsum. & Nakai		Sandia	C
37	**Cyclanthaceae**	*Carludovica palmata* Ruiz & Pav.	Kala	Junco	C
38	**Euphorbiaceae**	*Manihot esculenta* Crantz	Tzin	Yuca	C
39	**Euphorbiaceae**	*Cnidoscolus aconitifolius* I.M.Johnst.	Chetep, Chetet	Chaya	C
40	**Fabaceae**	*Gliricidia sepium* (Jacq.) Walp.	Kante	Madrecacao	B,
41	**Fabaceae**	*Inga edulis* Mart. ; *Inga vera* subsp. *vera*	Cho'ochoc	Guama, Paterna, Cuje	B, A, C
42	**Fabaceae**	*Diphysa carthagenensis* Jacq.	Q'anpat, Ampat	Guachipilin	B
43	**Fabaceae**	*Cajanus cajan* (L.) Millsp.	Atzum utzuj	Gandul	B, C
44	**Fabaceae**	*Dalbergia tucurensis* Donn.Sm.	Akute'	Granadillo	B
45	**Fabaceae**	*Hymenaea courbaril* L.	Pak, Paks, Paq	Guapinol	B
46	**Fabaceae**	*Cojoba arborea* (L.) Britton & Rose	Tzuj, Suj	Cola de Coche	B, C
47	**Fabaceae**	*Dalbergia stevensonii* Standl.	Kak'che', Keq'che'	Rosul	B
48	**Fabaceae**	*Indigofera suffruticosa* Mill.	Jikiliit, Xiquilite, Ch'oh	Añil, Indigo	B
49	**Fabaceae**	*Inga cookii* Pittier; *Inga jinicuil* Schltdl. & Cham. ex G.Don	Bitz'	Jinicuil	B
50	**Fabaceae**	*Crotalaria longirostrata* Hook. & Arn.	Muuch'	Chipilin	C
51	**Fabaceae**	*Mucuna pruriens* (L.) DC.		Terciopelo	C
52	**Fabaceae**	*Schizolobium parahyba* (Vell.) S.F.Blake	K'olay	Puntero	B
53	**Fabaceae**	*Phaseolus vulgaris* L.	K'enq, Karabans, Qeqnq	Frijol	C

No.	Family	Species	Q'eqchi' Name	Local Spanish Name	Classification*
54	**Fabaceae**	*Platymiscium dimorphandrum* Donn.Sm.	Sankil che'	Hormigo	B
55	**Fagaceae**	*Quercus* spp.	Suj	Encino	B
56	**Lamiaceae**	*Gmelina arborea* Roxb.	Melin	Melina	B
57	**Lamiaceae**	*Tectona grandis* L.f.		Teca	B
58	**Lamiaceae**	*Mentha spicata* L.	Isk'i'j, isk'i'ij	Hierbabuena	C
59	**Lauraceae**	*Persea americana* Mill.	O'	Aguacate	A
60	**Lauraceae**	*Litsea glaucescens* Kunth		Laurel Negro	A
61	**Malpighiaceae**	*Byrsonima crassifolia* (L.) Kunth	Chi'	Nance	A
62	**Malvaceae**	*Theobroma cacao* L.	Kakaw	Cacao	A
63	**Malvaceae**	*Ceiba pentandra* (L.) Gaertn.	Inup	Ceiba	B
64	**Malvaceae**	*Guazuma ulmifolia* Lam.	Ch'ab'ay	Caulote	B
65	**Malvaceae**	*Pachira aquatica* Aubl.	O'okok	Zapotón	B
66	**Malvaceae**	*Trichospermum mexicanum* (DC.) Baill.	Chaib'	Majagua	B
67	**Malvaceae**	*Theobroma bicolor* Bonpl.	Balam	Pataxte	A
68	**Marantaceae**	*Calathea crotalifera* S.Watson	Mox, Maxan	Mox	C
69	**Meliaceae**	*Swietenia macrophylla* King	Sutz' uj	Caoba	B
70	**Meliaceae**	*Cedrela odorata* L.	Yaw	Cedro	B
71	**Moraceae**	*Ficus* spp.	Hu ku'ch	Amate	B
72	**Moraceae**	*Artocarpus altilis* (Parkinson) Fosberg	Mazapan	Mazapan	A
73	**Moraceae**	*Brosimum alicastrum* Sw.	Axl	Ramon	A
74	**Moraceae**	*Ficus* spp.	Sajomte	Amate	B
75	**Musaceae**	*Musa* × *paradisiaca* L.	Tul	Banano, Plátano	C
76	**Myristicaceae**	*Virola koschnyi* Warb.	Q'iqche	Drago, Cacao volador	B
77	**Myrtaceae**	*Pimenta dioica* (L.) Merr.	Peens	Pimienta Gorda	A
78	**Myrtaceae**	*Syzygium aromaticum* (L.) Merr. & L.M.Perry	Klawx, Kalaux	Clavo de Olor	A, B
79	**Myrtaceae**	*Psidium oligospermum* Mart. ex DC.	Pa'ta	Guayaba	A, B
80	**Myrtaceae**	*Syzygium jambos* (L.) Alston	Manzana rosa	Manzana Rosa	B
81	**Oxalidaceae**	*Averrhoa carambola* L.	Carambola	Carambola	A
82	**Passifloraceae**	*Passiflora edulis* Sims	Maracuya	Maracuya	C
83	**Pinaceae**	*Pinus* spp.	Chaj	Pino	B
84	**Piperaceae**	*Piper nigrum* L.	Kaxlan q'een	Pimienta Negra	C
85	**Poaceae**	*Zea mays* L.	Ixim	Maiz, Milpa	C
86	**Poaceae**	*Saccharum officinarum* L.	Utz'ajl, utz'aal, utz'aj	Caña	C
87	**Poaceae**	*Cymbopogon citratus* (DC.) Stapf		Te de Limón	C

No.	Family	Species	Q'eqchi' Name	Local Spanish Name	Classification *
88	**Rosaceae**	*Rubus trilobus* Ser.	Tucan'	Mora	C
89	**Rosaceae**	*Malus domestica* Baumg.	Manzana	Manzana	A
90	**Rosaceae**	*Eriobotrya japonica* (Thunb.) Lindl.		Nispero	A
91	**Rubiaceae**	*Coffea arabica* L.	Kape	Café	A
92	**Rubiaceae**	*Calycophyllum candidissimum* (Vahl) DC.	Kaneel	Canela	A
93	**Rutaceae**	*Citrus × aurantium* L.	Ch'in	Naranja, Mandarina	A
94	**Rutaceae**	*Citrus latifolia* (Yu.Tanaka) Yu.Tanaka	Lamux	Limón	A
95	**Rutaceae**	*Citrus limon* (L.) Osbeck	Lima	Lima	A
96	**Sapindaceae**	*Nephelium lappaceum* L.	Licha	Licha	A
97	**Sapotaceae**	*Pouteria sapota* (Jacq.) H.E.Moore & Stearn	Saltul	Zapote	A
98	**Sapotaceae**	*Chrysophyllum cainito* L.	Xukub'yuk	Caimito	A
99	**Solanaceae**	*Capsicum annuum* L.	Ik	Chile cobanero	C
100	**Solanaceae**	*Solanum americanum* Mill.	Maak'uy	Hierbamora	C
101	**Solanaceae**	*Solanum lycopersicum* L.	Pix	Tomate	C
102	**Urticaceae**	*Cecropia peltata* L.	Xaq Aql	Guarumo	B
103	**Vochysiaceae**	*Vochysia guatemalensis* Donn.Sm.	San Juan	San Juan	B
104	**Zingiberaceae**	*Elettaria cardamomum* (L.) Maton	Tz'i	Cardamomo	C
105			Tzuyuy		B
106			Bilish		B
107			Sac Cho'Oc		B
108			Baro		B
109			Element		B
110			Kaj'Te		B
111			Kak'Oc		B
112			Kisach		B
113			Roj'Colol		B
114				Santo Domingo	B
115			Tz'Imaaj		B
116			Yauch		B
117			Yaxte'		B
118			Chapoc		C
119			Piyac		C
120			Sac Xoc		C
121			Tzib'Tzi		C

*A: Agroforestry type, B: Forest type, C: Conventional annual/perennial classification.

A total of 121 plant species were identified in Tzalamtun village and its surrounding area, of which 70 are forest species (Fruit and Timber trees). This list includes species found in agroforestry systems and secondary succession forests and other type plantations like house gardens. During the interviews there were cases in which a single name is used to identify a group of species (e.g., Cho'ochoc for *Inga edulis* Mart. & *Inga vera* subsp. *vera*; Suj for *Quercus* spp.). Similarly, some informants mentioned that they have several names to identify some trees (e.g., Hu ku'ch and Sajomte for *Ficus* spp.). A difference in information provided depending on age was noted, with older informants showing knowledge of more species and their uses, primarily forest species, while younger informants focused more on basic knowledge such as timber and food. However, on some occasions, the participating women were able to provide names and diverse uses, such as medicinal uses, demonstrating knowledge of some local trees.

The following figure shows the 5 most frequent taxonomic family from the species cited in the interviews by the participants of Tzalamtun.

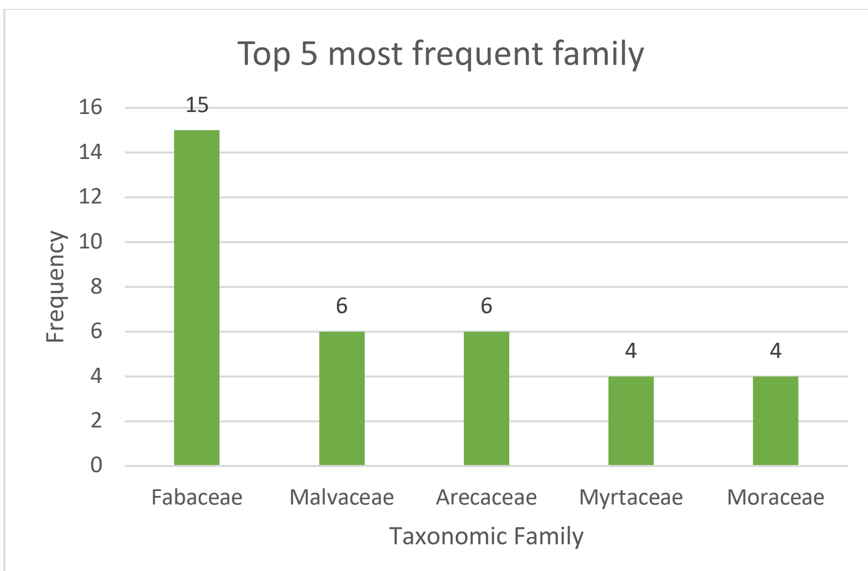

Figure 17. The five most frequent taxonomic families from the species cited in the interviews.

Figure 17 shows that the five most frequently cited taxonomic families are Fabaceae, Malvaceae, Arecaceae, Myrtaceae, and Moraceae. These families infer diversity of plant habitats like palms (Arecaceae) to threes (Fabaceae, Malvaceae, Myrtaceae and Moraceae). However, we need to consider that 17 specimens (14%) could not be identified, which may have changed the above frequencies if identified. The Fabaceae family is the most frequently cited family of all, with 15 occurrences (12.3%) with the main classification of crop as timber and fruit trees.

B. CULTURAL IMPORTANCE

1. CULTURAL IMPORTANCE INDEX

The following figure shows the 15 most culturally important tree species (Fruit and Timber trees) with the highest *Cultural Value Index* (CV_e) in Tzalamtun.

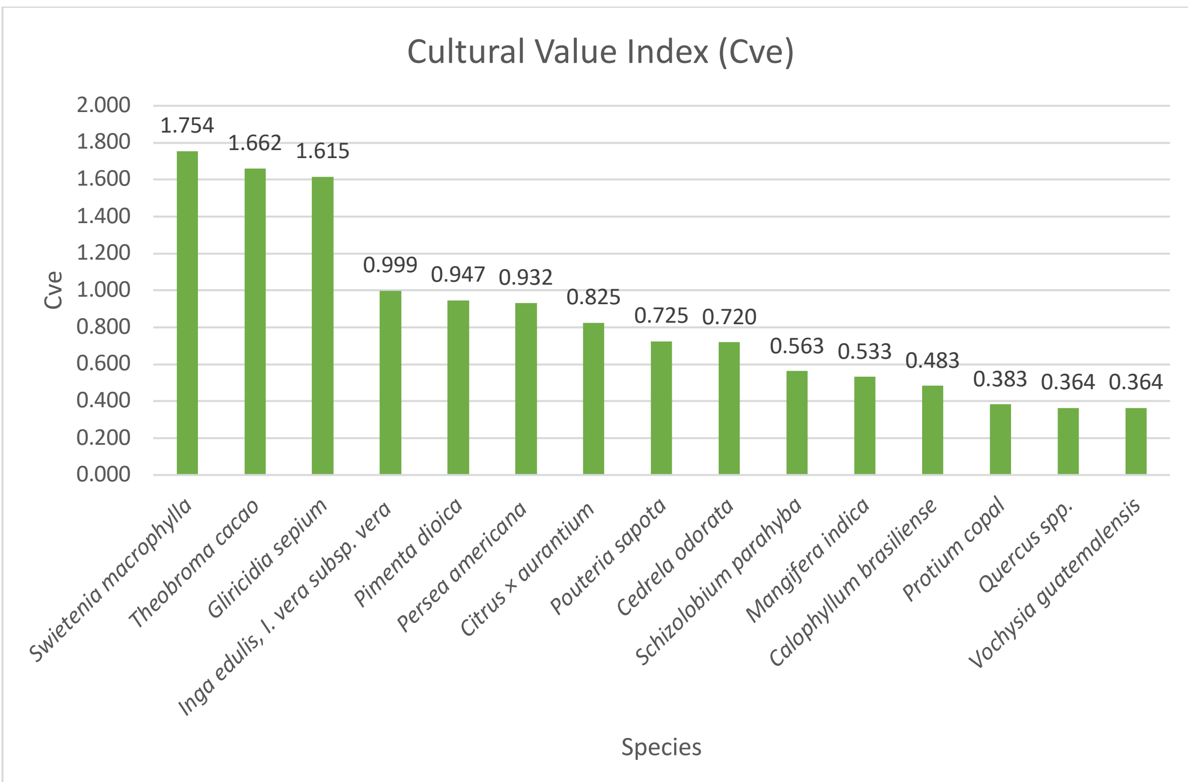

Figure 18. Cultural Value Index of the 15 species of greatest cultural importance to the people of Tzalamtun.

All the 103 identified plant species, of which 70 are tree species, were being used in any kind of form as timber, shade, medicinal, etc, for the local Q'eqchi' people. The most important species was *Swietenia macrophylla* King. with a cultural value index of 1.754, while *Theobroma cacao* L. was the species with the highest number of uses citations (72).

2. CATEGORY OF USES

The following table shows the different categories of uses recorded during the interviews and the total number of species and citations for each.

Table 2. Category of uses cited in the interviews.

Code	Description of Category Use	No of Species	Frequency*
E	Edible as food or spices	77	777
W	Wood for construction of houses and equipment	50	483
M	Medicinal for human and animal diseases	61	389
P	Shade and soil erosion protection	53	473
L	Ceremonial, crafts, dyes and musical instruments	51	295

*Frequency refers to the total number of times the category was cited, calculated as the sum of citations for each species plus the citations from all interviews (sum of all mentions across species and interviews).

The uses mentioned by key informants during the interviews were grouped into 5 categories. Of these, edible use was the category with the largest number of species recorded (77). General use for wood had 483 mentions, making it the most frequently cited category after edible. This, followed by shade (473 mentions) and soil erosion protection, as were mention the fallen leaves and canopy protects against direct sunlight and also for the heavy rains in winter season.

C. DETERMINATION OF RELEVANT SPECIES FOR RESTORATION

1. THREATENED STATUS

The following figure shows the number of species found for each threatened status according to the IUCN Red List of Threatened Species, the Guatemalan Red List of Trees (Vivero, *et al*. 2006), the LEA (CONAP, 2009), and species listed in CITES.

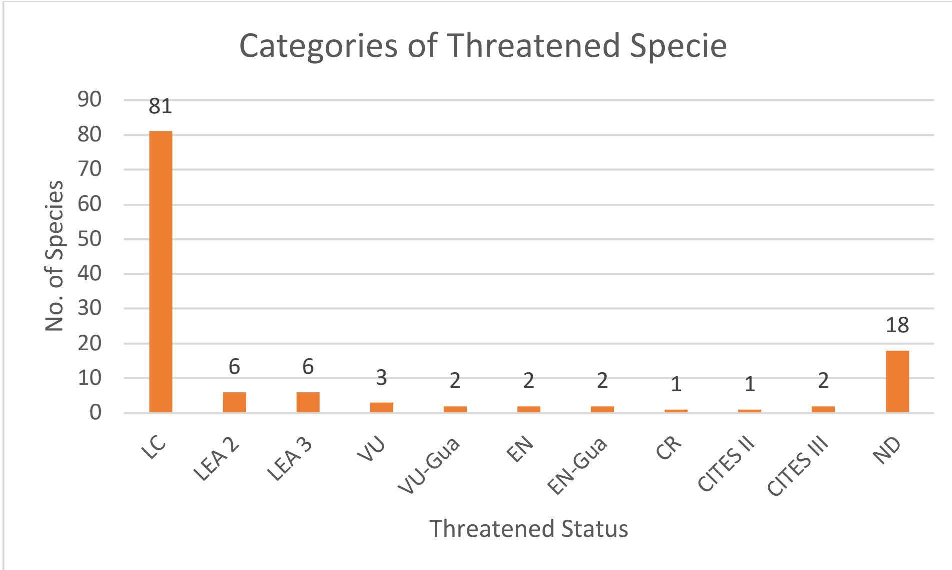

Figure 19. Number of species found for each category of threatened.

UCN Status: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, LC = Least Concern, ND = No Data. The endings Gua in each criterion indicate that the information was obtained from the Guatemala specific red list of trees.

The List of Threatened Species of Guatemala (LEA): LEA 2 = restricted distribution and LEA 3 = threatened if its use is not regulated.

Some of the species were evaluated on more than one of the red lists (see Table 3). Sixteen species were found to be evaluated on one of the three red lists of threatened species, of which only four were evaluated for Guatemala and nine were in some threat category (CR, EN and VU). Twelve of the species found during the study were included in the LEA. One species (*Dalbergia tucurensis*) is listed in CITES Category II, EN and LEA 2 category due to the inclusion of the entire genus. Thirteen species were found not evaluated in any of the sources used to determine their threatened status.

2. DATA INTEGRATION AND SELECTION BASED ON MET CRITERIA: DETERMINATION OF RELEVANT SPECIES FOR RESTORATION AND AGROFORESTRY SYSTEMS.

The following table shows the species found during the sampling of cultural importance, the criteria used of threatened status for their selection, and the species selected as relevant for tropical forest restoration in the area.

Table 3. Species selected as relevant for restoration according to the integration of data of cultural importance (CV_e) and threatened status.

No.	Specie	Family	Use Category	Threatened Status	CV*e*
1	*Swietenia macrophylla*	Meliaceae	W, M, S	EN, VU_{Gua}, LEA 3, CITES II	1.754
2	*Inga edulis*; *I. vera* subsp. *vera*	Fabaceae	F, W, M, S, A	LC, LEA 3	0.999
3	*Pimenta dioica*	Myrtaceae	F, M, S, A	LC, LEA 3	0.947
4	*Cedrela odorata*	Meliaceae	W, M, S, A	VU, LEA 2	0.720
5	*Quercus* spp.	Fagaceae	W, M, S, A	VU	0.364
6	*Ceiba pentandra*	Malvaceae	W, M, S, A	LC, LEA 3	0.142
7	*Ficus* spp. **(Hu ku'ch)**	Moraceae	W, M, S, A	VU	0.047
8	*Dalbergia tucurensis*	Fabaceae	W, S, A	EN, EN_{Gua}, LEA 2, CITES III	0.036
9	*Bursera simaruba*	Burseraceae	W, M, S, A	LC, LEA 2	0.017
10	*Calycophyllum candidissimum*	Rubiaceae	F, M, S, A	LC, LEA 2	0.017
11	*Cojoba arborea*	Fabaceae	W, M, S, A	LC, LEA 3	0.014
12	*Dalbergia stevensonii*	Fabaceae	W, M, S, A	CR, EN_{Gua}, LEA 2, CITES III	0.014
13	*Platymiscium dimorphandrum*	Fabaceae	W, M, S, A	LC, LEA 3	0.014
14	*Tectona grandis*	Lamiaceae	W, S, A	EN	0.009
15	*Inga cookii; I. jinicuil*	Fabaceae	F, W, S	LC, VU_{Gua}, LEA 2	0.007
16	*Ficus* spp. **(Sajomte)**	Moraceae	W, M, S , A	VU	0.005
17	Tzuyuy		W, S	ND	0.005
18	Bilish		W, S	ND	0.004
19	Sac Cho'Oc		W, S	ND	0.002
20	Baro		W, S	ND	0.001
21	Element		W, S	ND	0.001
22	Kaj'Te		W, S	ND	0.001
23	Kak'Oc		W, S	ND	0.001
24	Kisach		W, S	ND	0.001
25	Roj'Colol		W, S	ND	0.001
26	Santo Domingo		W, S	ND	0.001
27	Tz'Imaaj		W, S	ND	0.001
28	Yauch		W, S	ND	0.001
29	Yaxte'		W, S	ND	0.001

Use Category: F = Food or spice, W = Wood for construction, M = Medicinal, S = Shade and soil protection, A = Ceremonial, crafts, dyes or musical instruments.
UCN Status: CR = Critically Endangered, EN = Endangered, VU = Vulnerable, LC = Least Concern, ND = No Data. The endings Gua in each criterion indicate that the information was obtained from the Guatemala specific red list of trees.
The List of Threatened Species of Guatemala (LEA): LEA 2 = restricted distribution and LEA 3 = threatened if its use is not regulated.

Species that meet 3 or more selection criteria.

Twentynine species were evaluated for inclusion in the list of species relevant for forest restoration. These represent all species obtained during forest sampling and interviews. For non-identified species, local names were used instead of species and family names. Blank cells in the table represent data that were not generated by this study, are unavailable, or do not apply to trees that were not identified to species level. Fifteen species were found to meet three or more of the evaluation criteria. The criteria used to determine the relevance of each species for restoration were: CV_e greater than 0.005, being in a threatened status and having three or more uses. For a description of each use category, see Table 2.

D. FOREST SPECIES IN AGROFORESTRY SYSTEMS

The following table shows the forest species cited in their respective agroforestry systems, here as multi-crop systems based on a main crop and the use of diverse trees and plant, that were present. That agroforestry systems consisted of five types: milpa, cacao, cardamom, coffee and diversified fruit trees. In the *ad libitum* walks it was noticed that there was a selection of trees depending on the base crop and purpose of the agroforestry system. Were the participants mentioned important characteristics based mainly on the need of the base crop. For the milpa or maiz (*Zea mays*), an annual crop that is light demanding, meaning that big and tall trees are not suitable, and the species listed in the Table are mainly herbaceous, medium size and small crowns if it is a tree. Meanwhile, for the cacao (*Theobroma cacao*), cardamom (*Elettaria cardamomum*), coffee (*Coffea arabica*) are perennial crops that requires shade requiring or are shade adapted like in the case off coffee. Meaning that in these agroforestry systems the presence forest tree species are suitable, for its characteristics of high, big crowns and broadleaf.

Table 4. Plant species present in the five agroforestry systems.

Milpa (*Zea mays*) Annual – Light demanding	**Cacao** (*Theobroma cacao*) Perennial – Shade requiring	**Cardamom** (*Elettaria cardamomum*) Perennial – Shade requiring	**Coffee** (*Coffea arabica*) Perennial - Shade adapted	**Diversified** (Fruit trees forest) Perennial - Light demanding
1. *Bidens bipontina*	**1. *Bursera simaruba***	**1. *Bursera simaruba***	**1. *Bursera simaruba***	1. *Acrocomia aculeata*
2. *Calathea crotalifera*	2. *Calophyllum brasiliense*	2. *Cajanus cajan*	2. *Cajanus cajan*	2. *Annona cherimola*
3. *Carludovica palmata*	3. *Cecropia peltata*	**3. *Cojoba arborea***	3. *Citrus latifolia*	3. *Annona purpurea*
4. *Carica papaya*	4. *Cedrela odorata*	4. *Cordia alliodora*	4. *Citrus × aurantium*	4. *Artocarpus altilis*
5. *Chamaedorea tepejilote*	5. *Ceiba pentandra*	5. *Hymenaea courbaril*	**5. *Cojoba arborea***	5. *Attalea cohune*
6. *Cnidoscolus aconitifolius*	6. *Cordia alliodora*	**6. *Inga cookie***	6. *Cordia alliodora*	6. *Averrhoa carambola*
7. *Crotalaria longirostrata*	7. *Dalbergia stevensonii*	**7. *Inga jinicuil***	7. *Gliricidia sepium*	7. *Bixa orellana*
8. *Cucurbita moschata*	8. *Dalbergia tucurensis*	8. *Musa × paradisiaca*	8. *Hymenaea courbaril*	8. *Brosimum alicastrum*
9. *Cucurbita* spp.	9. *Diphysa carthagenensis*	**9. *Pimenta dioica***	**9. *Inga cookie***	9. *Byrsonima crassifolia*
10. *Ipomoea batatas*	10. *Ficus* spp. (Hu ku'uch & Sajomte)	10. *Protium copal*	**10. *Inga jinicuil***	10. *Cajanus cajan*
11. *Manihot esculenta*	11. *Gliricidia sepium*	11. *Roseodendron donnell-smithii*	11. *Musa × paradisiaca*	11. *Calycophyllum candidissimum*
12. *Musa × paradisiaca*	12. *Gmelina arborea*		**12. *Pimenta dioica***	12. *Carica papaya*
13. *Phaseolus vulgaris*	13. *Guazuma ulmifolia*		13. *Protium copal*	13. *Chrysophyllum caimito*
14. *Sicyos edulis*	14. *Hymenaea courbaril*		14. *Psidium oligospermum*	14. *Citrus × aurantium*
15. *Solanum americanum*	15. *Indigofera suffruticosa*		15. *Roseodendron donnell-smithii*	15. *Citrus latifolia*
16. *Spathiphyllum blandum*	**16. *Inga cookii***			16. *Citrus limon*
17. *Xanthosoma undipes*	**17. *Inga edulis***			17. *Cocos nucifera*
18. *Yucca gigantea*	**18. *Inga jinicuil***			18. *Cordia alliodora*
	19. *Inga vera* subsp. *vera*			19. *Crescentia cujete*

	20. Litsea glaucescens *21. Moquilea platypus* *22. Pachira aquatica* *23. Perymenium grande* ***24. Pimenta dioica*** *25. Pouteria sapota* ***26. Platymiscium dimorphandrum*** ***27. Quercus* spp.** *28. Roseodendron donnell-smithii* *29. Schizolobium parahyba* *30. Spondias mombin* *31. Spondias radlkoferi* ***32. Swietenia macrophylla*** *33. Syzygium aromaticum* *34. Syzygium jambos* *35. Tabernaemontana donnell-smithii* ***36. Tectona grandis*** *37. Terminalia amazonia* *38. Theobroma bicolor* *39. Trichospermum mexicanum* *40. Virola koschnyi*			*20. Eriobotrya japonica* ***21. Inga edulis*** ***22. Inga vera* subsp. *vera*** *23. Litsea glaucescens* *24. Malus domestica* *25. Mangifera indica* *26. Nephelium lappaceum* *27. Persea americana* ***28. Pimenta dioica*** *29. Piper nigrum* *30. Pouteria sapota* *31. Psidium oligospermum* *32. Spondias mombin* *33. Syzygium aromaticum* *34. Theobroma bicolor* *35. Theobroma cacao*

	41. Vochysia guatemalensis 42. Tzuyuy 43. Bilish 44. Sac cho'oc 45. Baro 46. Element 47. Kaj'te 48. Kak'oc 49. Kisach 50. Roj' colol 51. Santo Domingo 52. Tz'imaaj 53. Yauch *54.* Yaxte'			

VII. DISCUSSION

A. FOREST SPECIES IDENTIFICATION

Since the survey was based on *ad libitum* walks in and around the agroforestry systems in the village of Tzalamtun, the general list includes species from all environments present in the area, from crops to forest (mostly remnant patches of forest). This was the first study to focus on forest species identification with the help of local Q'eqchi' agroforestry farm owners in the village of Tzalamtun. This study also covers several sampling areas, including sites within the ecosystem that had not been sampled previously. Surely there are remanent of forest areas with species that have not been reported for the site. Subsequent surveys and monitoring could undoubtably expand the list of botanical species for the area.

Table 1 represent the first guide to local names in Q'eqchi and Spanish of local trees in the hilly landscape and in the agroforestry systems of Tzalamtun, Guatemala. This table may be helpful when working with forest species in other Q'eqchi' regions and Q'eqchi' communities of the country (Lanquín, Cahabón, Senahú, etc.). However, is necessary to evaluate which species and names are compatible between different areas and also in different scales like at communities, villages or regions scales. This, since is common that one same name is used for related species in different sites and is highly probably that there exist other names used for certain trees. For example, *Inga edulis* Mart. & *Inga vera* subsp. *vera* that both were identify by the name Cho'ochoc or Suj for all the *Quercus* spp. It was also found that there is a variation in the names for certain species depending on the interviewed person, resulting in various reported names for only one taxa. For example, that was the case for related trees species that with the available botanical material (leaves) were identified to genus level: *Ficus* spp., and that some informants identified by two names: Huku'uch and Sajomte. Therefore, it is necessary to sample fruits and flowers to accurately identify to species level and see they are different or the same species.

B. CULTURAL IMPORTANCE

Based on the responses obtained during the interviews regarding traditional knowledge of the aforementioned plants, their uses were divided into 5 categories, which are described in Table 2.

Category E = "Edible as food or spice" contains the most species. This is because the most frequently visited landscapes were agroforestry systems primarily growing milpa (maiz), cacao, coffee, cardamom, or various fruit trees. Many of the shade trees (Category P = Crop shade and soil erosion protection) or timber trees (Category W = Wood for construction in houses and equipment) also bear edible fruit or are used as spices, like *Calycophyllum candidissimum*, *Pouteria sapota, Inga edulis, Bixa orellana, Pimienta dioica*, among others. These two categories of shade and timber trees will be discussed in depth in the section D of discussion. It is worth mentioning that although is not used in these categories, many of the edible, timber, shade, and medicinal (Category M = Medicinal for human and animal diseases) trees are also used as fodder to feed farm animal, which helps the family economy. The medicinal (M) category, despite not having the highest frequency of citations, is the second with the highest number of species present. This is consistent with previous studies on medicinal ethnobotany and TEK of medicinal plants of the Mayan people (Hitziger *et al*., 2016), and especially of the Q'eqchi' people, on the great diversity of biocultural resources that they safeguard as part of their ancestral knowledge (Pesek et al., 2010; Thiel & Quinlan, 2020; Zarger, 2002). This is partly due to the great biological diversity present in Guatemala, being a biodiversity hotspot (Zachos & Habel, 2011), as well as the cultural legacy of the Mayan civilization in the region, which still survives today (Maass, 2008a). On the other hand, home remedies, often homegarden medicinal plants, are the first choice for health care, especially in rural, impoverished areas (Geck et al., 2020). Among the trees registered in this study with medicinal uses are *Pimienta dioica* (allspice), *Persea americana* (avocado), *Citrus x aurantium* (orange), *Pouteria sapota* (sapote), *Mangifera indica* (mango), *Psidium oligospermum* (guava), *Bursera simaruba* (palo de jiote), *Crescentia cujete* (jicaro), *Brosimum alicastrum* (ramon), among others. Some of these trees have also been recorded as medicinal by previous studies, Thiel & Quinlan (2020), also records *C. x aurantium* to relieve fever, cough and headache, *M. indica* to relieve fever and aches, *P. americana* to relieve diarrhea, stomach pain and skin problems. Also, in the book “Raxnaq’il Nuk’aslemal: Medicina Maya en Guatemala” which was the result of an extensive study on the knowledge and practices of traditional Mayan medicine with great participation of Q’eqchi’ healers, report several species of trees with medicinal uses that were also registered in this study such as *B. simaruba, B. crassifolia, Cedrela odorata, Chamaedorea* spp., *Diphysa* spp., *Ficus* spp., *M. indica, P. americana, Quercus* spp., among others (Consejo Mayor de Médicos Maya’ob’ por Nacimiento, 2016).

The last category, L, includes all species used for ceremonial purposes, such as making handicrafts, dyes, or musical instruments. These species are often the same wood or food species mentioned above, along with other trees exclusively used for these purposes. This is the case with the *Platymiscium dimorphandrum* tree, which is used to make drums and marimbas (a traditional xylophone-like instrument made entirely of wood) and is also used as timber in construction. Another tree frequently cited in this category, and whose use was considered very important within the Q'eqchi' culture, is the *Protium copal* tree, or "Copal pom" in Q'eqchi'. Copal is widely harvested for the production of copal, the dried and hardened resin that is subsequently burned exclusively within rituals and ceremonies to purify and sanctify any space by expelling evil spirits. The central ceremony in this context is called *mayejak*, which means offering or sacrifice. This ceremony is performed primarily at the beginning of the planting cycle, during the clearing of the land and planting, to ask for protection and a good harvest, as well as to give thanks for the elements that allow the growth of crops and life itself. The *mayejak* is directed toward the four cardinal points, along with the elements that each cardinal point represents, which within the ceremony are represented by four colors: red for east and fire, white for north and wind, yellow for south and water, and black for west and earth. The ceremony is also dedicated to the guardian spirit of the hills and valleys, called *Tzuul Taq'a*. *Tzuul* literally means hill or mountain and *Taq'a* means valley in the Q'eqchi language. The *mayejak* takes place around a fire, decorated with colored candles, each color representing the aforementioned deities and elements. In the center, where the copal fire is lit, blue and green candles are placed, representing the heart of the sky and the heart of the earth, respectively. These candles represent *Tzuul Taq'a*, the entire Earth and the cosmos that allow existence. Candles in the colors of each cardinal point are grouped together and placed in the direction of their respective cardinal points. This creates a square cross with the four cardinal points, adorned with various offerings, including cacao beans, corn, sugar, flowers, and traditional foods such as tamales. After starting in the center, the fire grows and spreads to the sides, burning the candles of the cardinal points as well as the offerings placed there. Around this fire, prayers and songs are said, and people walk around the fire counterclockwise, where they offer more elements to the fire, such as copal, sesame seeds, incense, and fermented beverages like *boj*, which is made from fermented corn.

The difference in information provided in relation to age suggests a loss of interest in traditional tree uses, giving them importance only as fuel and a source of income through the sale of wood. This, in turn, increases the vulnerability of the species, since these uses generally involve felling the trees. This contrasts with other forms of non-timber utilization that utilize only parts of the tree without the need to cut it down completely. Applied ethnobotanical studies on transdisciplinary approach are recommended to prevent the loss of information on the uses and properties of trees and other plant species at the site (Caneva et al., 2017; Geck et al., 2020).

Regarding the medicinal knowledge, a difference in the information provided was noted based on gender, with female participants being more likely to cite medicinal uses, thus providing new information. Torrez-Avilez *et al*. (2016) conducted a systematic review to determine whether there are gender-based patterns in medicinal plant knowledge on different scales (national, continental, and global). They found significant gender differences only at the national and continental levels, with women in the Americas knowing more, but no differences observed at the global level. This suggests that the assumption that women always possess greater knowledge due to their domestic and caregiving roles does not hold across cultures, reflecting the heterogeneity in labor division among communities. Such variation in labor allocation also influences knowledge of other resources, such as firewood. (Torres-Avilez *et al*., 2016). Based on the observation in the field and complemented with the ethnography of the Q'eqchi' division along gender lines made by Maass (2008); a difference of labour exist where most agricultural production is related to men. Whereas household work and food processing are completed by women, who also cultivate home gardens and tend domestic animals. However, women also take part in agricultural and forest gathering, meaning that there is a flexibility on the division of labour. Therefore, male and female roles are perceived as complementary and accorded equal value for the Q'eqchi' people. Therefore, is recommended to include a diverse group with different gender since the gender can influence specific areas of knowledge depending on scales and the degree of flexibility or division of labour.

C. NATIVE TROPICAL FOREST SPECIES: FOREST REMANTS

During the field survey in the region of Tzalamtun there was not found any primary forest in or around the village, but a mixture of remanent forest and agroforestry systems with native forest species focused on different crop productions that were mainly milpa (maize), cacao, cardamom, coffee and diversified fruit trees (see Table 4). Therefore, the best way to restore the ecosystem is actively by using remanent of forest and the native forest species present in the agroforestry systems as references for choosing species to plant in combination with culturally and economically important species that ensure long-term sustainability in the strategies of forest restoration.

Indicator species were found for the life zones present in the region that are Humid Tropical Forest (bh-T) and Very Humid Tropical Forest (bmh-T) described by IARN-URL 2018 based on De la Cruz (1982) work, among them: *Annona* spp., *Attalea cohune, Brosimum alicastrum, Bursera simaruba, Byrsonima crassifolia, Calophyllum brasiliense, Cedrela odorata, Ceiba pentandra, Cordia aliodora, Dalbergia* spp*., Guazuma ulmifolia, Manikara zapota, Pachira aquatica, Pimienta dioica, Potrium copal, Spondias mombin, Swietenia macrophylla, Terminalia amazonia* and *Vochysia guatemalensis*. Indicator species generally represent late successional stages, especially tree species since they have long life cycles and are generally harvested for timber. The fact that mature individuals of these species were found in the study site indicates that these remnants of forest and native trees are suitable for used as tropical forest and native forest (Carpenter et al., 2004). Sixteen species (13% of all registered species) were found to fall within some category of threat or risk of extinction. Of these, twelve have been assessed for Guatemala, while the remaining four lack available information regarding their conservation status in the country (see Figure 19). In addition, thirteen species were recorded exclusively by their Q'eqchi' names, with the help of Q'eqchi' landowners and farmers. Due to challenges in accessing adequate specimens and the limitations this posed for proper herbarium identification, these species could not be classified at any taxonomic level. Nevertheless, tree names in Q'eqchi' hold deep significance, even when they cannot be identified through Western taxonomic methods. These names reflect ancestral ecological knowledge accumulated over generations, often describing morphological traits, medicinal uses, or specific ecological relationships. Hitziger *et al*. (2016) (Chapter 7, in: *Raxnaq'il Nik'aslemal*, Medicina Maya en Guatemala) found that common Q'eqchi' names for medicinal plants used specifically in the treatment of snakebites have Q'eqchi' linguistic roots that refer to venomous snakes or animals. The most common is *Xkwa Ixul* meaning "snake food", but also *B'olay* and *Kanti*, which refer respectively to a type of venomous snake and the generic name for the garter snake. This observation could exemplify the use of mnemonic resources (meaning the name of the plant directly indicates its use). In the Q'eqchi' region, there are numerous similar cases in which, through a linguistic analysis of the plant name, it is possible to infer its local use (Consejo Mayor de Médicos Maya'ob' por Nacimiento, 2016).

Since these cited plants could not be identified by western scientific methos and due to environmental circumstances and limitations, they still hold important knowledge since they are used by the community. Also, like the other identified species they are locally unique variants, or culturally distinct classification systems. As such, they offer a valuable starting point for botanical research and highlight the importance of preserving and respecting Indigenous knowledge systems that enrich our global understanding of biodiversity. This demonstrates the information gap in Guatemala regarding the conservation status of its forest species. This information can be valuable for decision-making and prioritizing species in reforestation and restoration programs (Berkes, 2012).

D. SYNERGIES BETWEEN CULTURAL AND NATIVE TROPICAL FOREST SPECIES

Due to the characteristics of timber and shade species, their importance will be discussed in this section to finish with the determination of relevant species for reforestation. Most informants noted a prioritization of the use of trees for timber (50 species, see Table 2), which are primarily used in the construction of their homes. This makes sense considering that most homes in the area are built partly or entirely of wood. It was also found that the species most frequently mentioned first were those considered high-quality woods, such as mahogany (*Swietenia macrophylla*) and cedar (*Cedrela odorata*) (see Figure 18). Shade tree species were mentioned in numbers similar to timber species, reflecting the fact that many timber trees also serve as shade providers in agroforestry systems. These trees are often maintained for long periods to attain the height and trunk diameter required for construction or carpentry, making them particularly well-suited to dual functions in such systems. In the present study, timber species were recorded exclusively within agroforestry plots, likely due to the heavy pressure from selective logging that has reduced their abundance near populated areas. Accessing areas with high densities of these species often requires walking long distances into the forest, and even in locations two hours or more from settlements, signs of past extraction were occasionally observed. Some other of most frequent high-quality timber species, that are also use for shade, are *Dalbergia* spp., *Schizolobium parahyba, Calophyllum* *brasiliense, Platymiscium dimorphandrum, Tectona grandis, Vochysia guatemalensis, Roseodendron donnell-smithii, Diphysa carthagenensis, Cojoba arborea*, among others that can be found in Table 1 with category B in Type of Crop. (Ramírez-Argueta et al., 2022) recommend promoting timber species as part of the shade component in cacao plantations, given their productive potential and the absence of negative effects on cacao yields. This approach has long been practiced by many Q'eqchi' owners of cacao agroforestry systems (see Table 4), where shade trees are often timber species. In fact, many of these agroforestry plots have been established for more than a decade, demonstrating the sustained integration of timber production with cacao cultivation.

In turn, informants also prioritized trees for the shade of economically important and widely used agroforestry systems-based crops mainly cacao, cardamom and coffee. One of the most mentioned tree for shade was Madrecacao (*Gliricidia sepium*) (See Figure 3), as well as other species of the Fabaceae (Legume) family, which made it the most cited taxonomic family in the interviews which is consistent with the theory of being the most prominent family in the plant world (See Figure 2) (Alamu et al., 2023). Among the most frequently cited species from the legume family were *Cajanus cajan, Cojoba arborea, Dalbergia stevensonii, D. tucurensis, Diphysa carthagenensis, Hymenaea courbaril, Inga cookii, I. jinicuil, I. edulis, Inga vera subsp. vera, Platymiscium dimorphandrum* and *Schizolobium parahyba* (see Table 1). However, a wide variety of species from other taxonomic families, used for timber, fruit, and other purposes, were also mentioned as shade providers (see Table 4). Leguminous species are well known for their ability to fix atmospheric nitrogen (N) through symbiotic associations with nitrogen-fixing bacteria known collectively as "rhizobia", which inhabit root nodules and convert inert atmospheric N into biologically available forms in a process called "biological nitrogen fixation" (BNF) (Iannetta et al., 2016; Sprent & Sprent, 1990). This process not only facilitates N availability to companion plant species (Singh et al., 2023), but also represents the largest natural source of nitrogen cycled to sustain ecosystems (Vitousek et al., 2002). It is estimated that legumes can fix more than 200 kg of N per hectares in both tropical and temperate landscapes (Iannetta et al., 2016). Meanwhile, along with water, soil mineral N is a major factor that limits the productivity of any agricultural systems (Louarn et al., 2021), where natural nutrient cycle is disrupted because of the low plant biomass, nutrient export in crop harvest and disturbance to soil microbiota by cultivation (reduced nutrient recycling) (Lal, 2004; Nair et al., 1999). This is especially important in humid tropical forest ecosystems where the soils are generally poor, and the high plant productivity depends on rapid recycling of nutrients between the plant community and the soil (Martinelli et al., 1999). In humid tropical agroforestry, as show on this research, legume trees that form dinitrogen-fixing symbiosis with rhizobia are common, and (Nygren et al., 2012) have shown that are also the main N source in low-input systems. (Alamu et al., 2023) conducted a comprehensive review on the applications of *Gliricidia sepium* for enhancing soil fertility and crop nutritional quality, highlighting the extensive body of research on its beneficial effects when used in intercropping systems. The study shows *G. sepium*'s significant role in fixing atmospheric nitrogen, increasing soil organic carbon, and mitigating the adverse effects of heavy metals on soil fertility, contributing to improved crop growth and productivity. Furthermore, *G. sepium* have shown to offer economic advantages to low-income farmers by reducing the need for costly mineral fertilizers, thereby making sustainable agriculture more accessible and financially viable.

Inga edulis is another legume tree traditionally used to shade perennial crops in agroforestry systems (Alvarado Aguayo et al., 2020; Lojka et al., 2010). In Tzalamtun, its presence was frequently observed during the field visits and *ad libitum* walks at the agroforestry systems mainly of cacao and coffee, as seen in many other tropical regions like the Amazon (Lojka et al., 2010). It was also one of the most frequently cited species during interviews (see Figure 3). *I. edulis*, *and* the genus *Inga* spp. in general, is well-known to improve soil fertility through N-fixation (Leblanc et al., 2005). *I. edulis* provides multiple ecosystem services, including firewood and charcoal production, as well as a sweet, edible pulp suitable for human consumption (Pennington & Fernandes, 1998). Its high biomass makes it valuable as green manure, contributing to soil fertility, weed suppression, and erosion control, particularly in alley cropping and other agroforestry systems (Leblanc et al., 2005; Lojka et al., 2010). Due to these characteristics, *I. edulis* holds strong potential for restoring degraded soils in tropical forest ecosystems (Weber et al., 2001). (Carpenter et al., 2004b; Nichols et al., 2001) demonstrated that *I. edulis* can significantly enhance the growth of *Terminalia amazonia* seedlings by increasing foliar nitrogen content, biomass, and basal diameter in intercropping systems, further supporting their role in promoting regeneration and biodiversity in tropical agroecosystems. This finding is particularly relevant to this study, as T.

Amazonia, a native timber species, was also commonly observed in the cacao-based agroforestry systems visited during field surveys.

E. DETERMINATION OF SPECIES RELEVANT FOR RESTORATION

The main objective of this research was to identify species relevant for forest restoration in the tropical forest of Tzalamtun, Alta Verapaz. To achieve this, both the cultural and threatened status of each species found in the visited agroforestry systems were considered. Determining the overall importance of each species is inherently complex, as it depends on the multiple and overlapping interactions between cultural and ecological dimensions, and especially on how these two spheres intersect, as discussed in the previous section. For example, the cultural importance index reflects how much a species is used by people, whether for timber, food, or other purposes. However, many non-cultivated but widely used forest species have low ecological index scores because overexploitation has rendered them threatened. As a result, they are scarce in natural areas, particularly near towns, making them difficult to find, study, or register. Conversely, a high cultural importance score can also correspond to widely cultivated species, such as edible non-forest plants, that are abundant and not under threat and therefore have limited relevance for reforestation. Due the above, prioritizing species for restoration requires, for this research to focus mainly on forest species that meet multiple criteria, while considering their natural history, threatened status, and cultural uses (de Almeida et al., 2024). It is equally important to integrate additional factors such as economic potential, key ecological functions (e.g., soil restoration), and propagation methods, although in many cases, such information is scarce or unavailable (Carpenter et al., 2004a; Falkowski et al., 2016b).

Figure 3 presents the 15 species with the highest cultural value in the study, including several with significant economic potential. The top two species are *Swietenia macrophylla* (Mahogany) with a cultural importance value of 1.75, and *Theobroma cacao* (Cacao) with 1.66. Although both are culturally important, mahogany stands out as the more suitable species for reforestation when threat status is considered. This, since mahogany is a high-quality timber species classified as endangered, whereas cacao is a widely cultivated crop with no conservation concern. This is why threat categories were combined with cultural importance values to identify forest species with restoration potential. At first glance, Figure 4 shows that relatively few species meet these criteria, largely because a substantial proportion of recorded species (35%) are cultivated crops (Type C = Conventional annual/perennial crop). By integrating threat status with cultural importance, Table 3 was generated, producing a markedly different ranking from Figure 4. Some species, such as mahogany, cedar (*Cedrela odorata*), and allspice (*Pimenta dioica*), remained highly ranked, while others with strong economic potential emerged, such as *Dalbergia tucurensis* and *Dalbergia stevensonii*. These species, belonging to the rosewood group, is highly valued internationally for fine furniture and musical instruments. Notably, the genus *Dalbergia* spp. is the most heavily trafficked group of living organisms worldwide in terms of both volume and economic value (Rakotonirina et al., 2024), underscoring its conservation and restoration relevance. Another relevant species is *Cojoba arborea*, recommended for ecosystem restoration due to its ease of propagation, broad altitudinal range, and wide geographic distribution (Martínez-Garza et al., 2016).

There is no doubt that oaks (*Quercus* spp.) must be included in any restoration effort in the area. They are under constant threat from the extraction of firewood, timber, and charcoal production (Montes-Hernández & López-Barrera, 2013). In addition to being culturally important species, they represent the main component of the upper stratum of forest remnants and provide a large number of ecosystem services, such as soil retention, hosting other plant species, providing refuge, and providing food for animals. For these reasons, it is necessary to conduct studies to identify which oak species are found in the area and subsequently, to investigate methods of reproduction and establishment (Smith et al., 2020).

Other species may be relevant due to their relationships with other crops. As previously discussed, with species from the Fabaceae family, such as those from the genus *Inga* spp., we can also add *Platymiscium dimorphandrum, Cojoba arborea*, and species from the genus *Dalbergia* spp., that since belong to the same family they also have nitrogen-fixing properties. Another example of this is the Lauraceae family, which in itself represents an important species as a source of animal food within the ecosystem. Local avocado varieties (*Persea americana, Litsea glauscens*) represent important genetic resources that are under pressure from displacement of more commercial varieties. A similar case is that of the Sapotaceae family, which is relevant for various products acquired from it, such as fruits, chewing gum, and wood. *Pouteria sapota* is highly valued for its fruits, which are commonly considered to be a good source of nutritious fruit. Although the species is cultivated in several places in Central America, Parker (2008) recognizes the lowlands of Alta Verapaz as the center of origin for this species, making the conservation of the species in the area a priority.

In some cases, Q'eqchi' participants mentioned their desire to plant native species. However, once the seeds are collected, they do not know what to do with them. They also mentioned that they extract seedlings of several timber species from their family and friends agroforestry systems to try and experiment to plant them on their own agroforestry systems for a future harvest and to provide more shade. This interest could facilitate the implementation of restoration strategies. Therefore, once the species relevant for restoration have been identified, it is necessary to begin breeding and research programs for those that require pre-germination treatments or special conditions (Montes-Hernández & López-Barrera, 2013). It is also important to include nurse species that facilitate the establishment of the others (Carpenter et al., 2004). It is also important to evaluate the appropriate successional stages to determine the sites and times for planting each species (Buisson et al., 2017; Morellato et al., 2016). This study presents a practical method applicable to different ecosystems for the selection of forest species for restoration, taking into account their endangered status and cultural importance. It is recommended that this procedure be applied to other tropical forests to create a guide for ecosystem restoration in Guatemala, with notes and species specific to each region. The same can be done in the various tropical ecosystems. The information generated by this methodology can also serve as a basis for further research in ecology and ethnobiology. As the method is applied in different sites, it can be adapted to different conditions and integrate other factors and recommendations that arise from each experience. Additionally, the results will be used to create a forest nursery within the community of Tzalamtun, which will focus on the reproduction of the species prioritized in the study. This nursery will use the forest remnants in and around the community of Tzalamtu as a source of germplasm and will provide seedlings for the restoration of degraded areas within the community, as well as for residents who wish to plant these species.

VIII.LIMITATIONS

The identifications of forest plant species presented some difficulties in obtaining specimens for identification due to the canopy height and understory density. Resulting in 17 individuals of the 121 plant specimens identified just by the Q'eqchi' or Spanish name. However, the identification of forest species by the local Q'eqchi' owners of the agroforestry systems with local names in Q'eqchi' and/or in Spanish, was a great starting point to identify many of the forest species.

IX. CONCLUSIONS

1. A general list of 121 plant species is available for Tzalamtun village and surrounding areas, of which 70 are forest species (A and B classification).

2. The three species with the highest cultural importance value index (CV*e*) in the agrofrorestry systems and remanent of forest are *Swietenia macrophylla* (1.75), *Theobroma cacao* (1.66), *Gliricidia sepium* (1.62), *Inga edulis*, *I. vera* subsp. *vera* (0.99) and *Pimenta dioica* (0.95).

3. Sixteen species (13% of all registered species) were found to fall within some category of threat or risk of extinction, among them *Tectona grandis* (EN) and the genus *Quercus* spp. (VU). Of these, twelve have been assessed for Guatemala, among them *Inga edulis* (LEA 3), *Pimienta dioica* (LEA 3), *Cedrela odorata* (LEA 2), *Ceiba petandra* (LEA 3), *Bursera simaruba* (LEA 2), *Calycophyllum candidissimum* (LEA 2), *Cojoba arborea* (LEA 3) and *Platymiscium dimorphandrum* (LEA 3); and 3 have been included in CITES *Swietenia macrophylla* (EN, VU-Gua, LEA 3, CITES II), *Dalbergia tucurensis* (EN, EN-Gua, LEA 2, CITES III) and *D. stevensonii* (CR, EN-Gua, LEA 2, CITES III).

4. The category of use with the greatest number of species and citation was “Edible ad food or spice” (E) with 77 species and 777 citations. Using citation number, the following categories were “Wood for construction in houses and equipment” (W) and “Crop shade and soil erosion protection” (P) with 50 species and 483 citations and 53 species and 473 citations. The next category was “Medicinal for human and animal diseases” (M) with 61 species and 389 citations, and the last one was “Ceremonial, Crafts, Dyes and Musical Instruments” with 51 species and 295 citations.

5. The species proposed for tropical forest restoration in Tzalamtun are those that meet the criteria; with the most relevant species being *Swietenia macrophylla* (Mahogany), *Cedrela odorata* (Cedar), and *Pimenta dioica* (Allspice), *Dalbergia tucurensis* (Granadillo), *Cojoba arborea* (Cola de Coche), *Inga edulis* (Guama), *Platymiscium dimorphandrum* (Hormigo), Calycophyllum candidissimum (Canela), *Dalbergia stevensonii* (Rosul), *Tectona grandis* (Teca).

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XI. APPENDICES

A. RESEARCH MATRIX

Question	Objective	Variables	Methods
¿What are the Maya Q'eqchi' Traditional Ecological Knowledge on timber and non-timber species in the tropical forests of Petén, Alta Verapaz and Izabal that can be useful for forest restoration and food security?	Identify relevant forest species for food security based on cultural importance using the *Use Value Index* (IVU). Identify relevant forest species for tropical forest restoration based on ecological importance using the *Importance Value Index* (IVI).	• Tree and plant species • Knowledge and uses of tree and plant species	• Semi structured interviews • Botanical and forestry survey • Botanical identification
¿Which are the relevant and most important species based on cultural and ecological importance?	Establish a list of the most important native plant species based on IVI and IVU for potential use in agroforestry systems for restoration and food security.	• Tree and plant species • Cultural Value • Ecological Value	• IVU • IVI • Met criteria (endangered, native, etc.)
¿What is the suitable design of an agroforestry plot based on Maya Q’eqchi’ TEK and modern agroforestry practices?	Co-design a agroforestry systems with the Q’eqchi’ community using the plant species identify and incorporating their local and traditional crops.	• Agroforestry plot design	• Transdisciplinary tables and workshop

B. PLANTS SPECIES IN EACH AGROFORESTRY SYTEM FOUND

C. TIMELINE

The schedule of the research project is divided into five main parts: socialization, interviews, transcription and qualitative data analysis, writing and finally socialization of results and thesis dissertation.

Description	2025																															
	February					March				April					May				June					July				August				September
	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36
Traveling and Fieldwork preparation																																
Socialization																																
Interviews and Agroforestry Survey																																
Transcription and Data Review																																
Data analysis																																
Writing																																
Socialization of results																																
Thesis dissertation																																

D. INFORMED CONSENT

Traditional indigenous Q'eqchi' Mayan knowledge as a tool in agroecological and agroforestry systems for natural forest restoration and food sovereignty in Guatemala

Informed Consent

Dear,

I hope you are doing well today. My name is **Boris Llamas Menchú** , and I'm from the capital of Guatemala. I have a degree in Biology from the Universidad del Valle de Guatemala (UVG) and am currently completing my master's degree in Forest Management at the University of Copenhagen, Denmark.

This graduation project seeks to document the traditional indigenous knowledge and practices of the Q'eqchi Maya people regarding the natural forest and native (indigenous) trees they use in their milpa (milpa) and agroforestry plots or systems. This is done with the goal of preserving, valuing, and disseminating the Q'eqchi people's knowledge of forests, trees, and agriculture, and also promoting reforestation and restoration of Guatemala's natural forests. The information obtained will be shared with each participant and the community of Tzalamtun.

This documentation will be conducted through interviews with Q'eqchi people with knowledge or experience with natural forests, native trees, and traditional agriculture. Therefore, you have been invited to participate in an interview about Q'eqchi knowledge of natural forests, native trees, and traditional agriculture. This interview is entirely voluntary and free of charge.

In this interview, all data and information you provide: (1) will not be appropriated by me, my institution, or any other entity; (2) will be used professionally, based on your prior consultation and consent; (3) you will be given all the cultural, intellectual, and personal recognition and respect that you deserve; (4) and finally, you may end the interview at any time you wish, as well as revoke the entire interview even if you have previously participated. In the interview, you can give your name or do it anonymously. Although your name is not used, the interview is completely confidential. The estimated time for the interview is approximately 1 hour. During the interview, you will be asked for permission to record it using a cell phone and take photographs, this in order to save all the information you provide.

Finally, you can let me know any questions you may have right now or contact me at my cell phone number **4739-2500** , which has WhatsApp.

If you are interested in participating, please answer the following questions to **obtain your approval and complete the survey with your consent.**

Do you accept? participate in the interview ? But:____

Do you agree to take photographs and record videos? Yes:____ No:____

Name and/or Signature: ________________ Mr. Boris Llamas Menchú

Thank you for your valuable time and interest in participating!

E. SEMI-STRUCTURED INTERVIEW

Interview instructions

You will be asked a series of questions that you can answer freely. Within each question, additional questions can be developed to better understand your opinion.

Questionnaire

1. How important is natural forest to you? *Clarify what natural forest is* .
2. How do you think the natural forest is related to the Mayan worldview?
3. How do you think native trees are related to the Mayan worldview?
4. What are the most important trees for you?
    a. Because?
    b. What is your name in Q'eqchi'?
        i. What is its meaning in Q'eqchi'?
        ii. What is your name in Spanish?
    c. What uses does the tree have for you? / What do you use the tree for?
        i. What parts does it use?
        ii. Is it used fresh or dried?
        iii. How do you prepare it?
    d. What importance does the tree have in the natural forest?
        i. Floor
        ii. Water
        iii. Climate
        iv. Animals (Food, shelter, etc.)
        v. Other plants (Shade, protection, etc.)
    e. Where is it found or grown?
        i. Milpa
        ii. Natural Forest
        iii. Other
        iv. What role does the tree play in that place?
    f. Is the tree scarce? / Do you think it is in danger of disappearing?
    g. When is it harvested?
    h. Does the plant have times when it can be used?
        i. Moon phase
        ii. Winter/Summer
        iii. Day/Night
    i. Should we be careful with her?
    j. What importance does the tree have in the Q'eqchi' Mayan culture?
5. How did you learn this knowledge?
6. Do you see that your knowledge and practices from the forest and trees are disappearing ?
7. Do future generations continue to learn these knowledge and practices ? If not, why?

F. BUDGET

Category	Cost (Eur)	Justification
Traveling from Copenhagen	1,000	Round flight from Copenhagen to Guatemala
Local Traveling in Guatemala	500	Local transportation to Field work area
Materials	100	Notebooks, pens
Equipment	500	Recorders, laptops
Compensation	600	Rent of communal areas
Food & Accomodation	300	In field work area
Other expenses	100	
Total	3,100	