Ecosystem Services, Forest Characterization, and Light Diffusion of Tropical Dry Forests

by

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Abstract

The main objective of this thesis was to identify and integrate scientific knowledge of ecosystem characterization and quantification with the goal of assessing ecosystem services (ES) in tropical dry forests (TDFs). By doing so, first I identify main existing gaps and trends on the quantification of ES (provisioning, regulating and supporting) and potential approaches that can be used in TDFs. Overall results showed considerable efforts and research have been increasing in recent decades in the TDFs of America in order to quantify key biophysical variables that support the ES assessment of these forests. Carbon storage and biodiversity are the dominant studied themes, while water and soil lack from studies and methodologies for their services assessment. Most popular methods found to assess ES were literature reviews, remote sensing techniques, and forest and biodiversity inventories.

I also provide an innovative approach to assess a key component of an ES (primary productivity) for different successional stages in a TDF. This study provides a methodology for the estimation of the LAI using the light diffusion through the canopy in two successional stages of a TDF. I demonstrate how vegetation indices derived from measurements obtained from optical phenology towers can be used as a tool for quantifying, monitoring, and detecting changes in canopy structure and primary productivity in secondary TDFs. Quantifying and modeling these ecosystem processes could help us evaluate ES and develop sustainable practices for the appropiate management and conservation of TDFs.

Keywords: ecosystem services, assessment, tropical dry forests, Leaf Area Index.

Preface

This thesis is an original work by Sofia Calvo-Rodriguez. No part of this thesis has been previously published.

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List of symbols and abbreviations

DBH	Diameter at breast height
DOY	Day of the year
ES	Ecosystem Services
EVI	Enhance Vegetation index
H’	Shannon Diversity Index
HCI	Holdridge Complexity index
LAI	Leaf Area Index
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Productivity
PAI	Plant Area Index
PAR	Photosynthetically Active Radiation
RMSE	Root Mean Squared Error
TDF	Tropical dry forest
VI	Vegetation Index
WAI	Wood Area Index
Ω	Clumping index for foliage

Glossary of terms

Assessment: The analysis and review of information for the purpose of helping someone in a position of responsibility to evaluate possible actions or think about a problem. Assessment means assembling, summarising, organising, interpreting, and possibly reconciling pieces of existing knowledge and communicating them so that they are relevant and helpful to an intelligent but inexpert decision-maker (Maes 2013).

Ecosystem function: Subset of the interactions between biophysical structures, biodiversity and ecosystem processes that underpin the capacity of an ecosystem to provide ecosystem services (TEEB 2010).

Ecosystem process: Any change or reaction which occurs within ecosystems, physical, chemical or biological. Ecosystem processes include decomposition, production, nutrient cycling, and fluxes of nutrients and energy (Maes 2013).

Ecosystem service: The benefits that people obtain from ecosystems. The direct and indirect contributions of ecosystems to human wellbeing (TEEB 2010).

Ecosystem: A dynamic complex of plant, animal, and microorganism communities and their non-living environment interacting as a functional unit (Maes 2013).

Functional traits: A feature of an organism that has demonstrable links to the organism’s function (Maes 2013).

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1. Chapter one - Introduction

Tropical dry forests (TDFs) are considered the first frontier for economic development in Latin America. Early Mesoamerican cultures and later Spanish and Portuguese conquerors selected this ecosystem to create their first human settlements (Murphy and Lugo 1986; Sánchez-Azofeifa et al. 2005; Neves et al. 2010; Castillo et al. 2013). Today, the economic and anthropogenic pressures suffered by the TDFs have made them one of the most deforested and the least protected forest ecosystem of the Americas (Janzen, 1988; Sánchez-Azofeifa et al. 2005; Calvo-Alvarado et al. 2009; Neves et al. 2010). TDFs are broadly defined as a vegetation type dominated by deciduous trees (at least 50% of trees present are drought deciduous), with an annual average temperature of at least 25°C or higher, annual precipitation of 700-2000 mm per year, and a dry season (precipitation less than 100 mm) of three or more months (Sánchez-Azofeifa et al. 2005).

According to Miles et al. (2006) TDFs cover 42% of all the tropical forests and have a vast distribution in the Neotropical (from Mexico to Northern Argentina) and the Caribbean region. The original extend of TDFs in the Americas was estimated to be 520,000 km^2 across 18 countries, with less than 40% left of their potential extent (Portillo-Quintero and Sánchez-Azofeifa 2010). Of its total current extension, only 4.5% or 23,417 km^2 are protected by nature reserves (Portillo-Quintero and Sánchez-Azofeifa 2010). Political and economic circumstances have increased anthropogenic pressure in these ecosystems, leading to severe disturbances and extensive clearing (Sánchez-Azofeifa et al. 2005).

TDF suffer from strong anthropogenic forces as a result of their high relative fertile soils, with low rates of nutrient leaching and soil development (Portillo-Quintero et al. 2014). They also possess a marked rainfall seasonality that allows for short cycle crops, limiting the propagation of pathogens and insects. Furthermore, clearing TDF lands is physically easier than other forest types given their low structural complexity (Ewel 1999; Murphy and Lugo 1986; Fajardo et al. 2005; Portillo-Quintero and Sánchez-Azofeifa 2010). This explains why the main threats to TDF in the Neotropics are agricultural development, timber extraction, and expansion of cattle ranching (Fajardo et al. 2005). Today, the remaining TDFs can be found as fragments embedded in matrices of perturbed and heterogeneous land covers (Portillo-Quintero and Sánchez-Azofeifa 2010).

From a biological perspective, TDFs sustain a high biological diversity, including a remarkable amount of endemic species (Linares-Palomino 2011; Mass et al. 2005). In the Americas, endemism levels of TDFs in most regions tend to be higher than in adjacent moist forests (Linares-Palomino et al. 2011). Furthermore, TDFs have important above and below ground carbon reservoirs. The aboveground live biomass for deciduous TDF ranges from 35 to 140 megagrams per hectare and can go up to 225 megagrams per hectare for some TDF (Jaramillo et al. 2011). The root biomass ranges from 17 megagrams per hectare in Chamela-Cuixmala TDF to 66.8 megagrams per hectare in Venezuela TDFs (Jaramillo et al. 2011). Portillo-Quintero et al. (2014) mentions that if TDFs were restored in America, they could potentially add 8 Pg of carbon to the potential total ecosystem carbon stock. They also help with the protection of soils and water. Portillo-Quintero et al. (2014) found that at least 66% of water reservoirs in the neotropics are located within dry forest ecoregions.

TDFs also provide essential ecosystem services that support the means upon which millions of subsistence farmers depend (Mass et al. 2005). For instance, TDFs provide an important source of firewood, medicinal plants, shade, and animals for hunting (Castillo et al.

2005; Balvanera et al. 2011). These timber and non-timber products are critical to the livelihoods and well-being of millions of the world's poorest people (Mass et al. 2005; Blackie et al. 2014). TDF also contribute to human well-being through a wide variety of services including regulation of soil fertility, erosion, water cycle, climate, pollinators, pests, disease vectors, invasive species, and impacts of extreme meteorological events, as well as many cultural services (Balvanera et al. 2011).

It is also recognized that TDFs provide goods and services that differ from those of tropical humid rainforests, consequently requiring different approaches for management and conservation (Blackie et al. 2014). Nevertheless, few efforts have been put towards the conservation and sustainable management of TDFs (Portillo-Quintero et al. 2014). This has translated on a significant gap between research conducted in tropical humid rainforests and TDFs (Trejo and Dirzo 2000; Sánchez-Azofeifa et al. 2005; Portillo-Quintero and Sánchez-Azofeifa 2010). It is also known that most efforts and research addressing ecological and conservation issues of TDFs are not evenly distributed across the Neotropics, focusing only in few countries like Mexico, Brazil and Costa Rica (Gentry 1995; Fajardo et al. 2005; Sánchez-Azofeifa et al. 2005).

It is fundamentally clear that the lack of research, protection and high loss of these forests due to extensive deforestation is causing serious threats to biodiversity and ecosystem services across the Americas. Despite all of this, TDFs are also facing in the new century the great threat of climate change. It has been recognized that droughts will intensify in the 21st century, due to reduced precipitation and/or increased evapotranspiration (IPCC 2012). According to the United Nations World Food Program (WFP), this year, the most severe drought in 30 years, left up 2.81 million people in starvation situations in the called "dry corridor" in Central America. This drought also affected South America and Mexico, causing widespread damage to crops, shortages and rising prices of food and aggravating hunger among the regions poorest (WFP 2014). Although these alarming signs, there is a striking lack of research on how climate change will affect TDFs and how forest management and adaptation should be addressed (Blackie et al. 2014).

Future research in TDFs should be devoted to localized solutions that can be transformed into practical tools and guidance for managers, particularly for smallholders that lack the resources for adaptation (Blackie et al. 2014). Inspired by this reality Tropi-Dry research network was created in 2004 (Sánchez-Azofeifa et al. 2005). *"The fundamental goal of Tropi-Dry is to produce an integrative overview of the human and biophysical dimensions of TDFs that can be used as an objective platform for policy and decision making"* (Sánchez-Azofeifa et al. 2014).

Although a large number of publications and research dealing with TDF have been published in recent years, this knowledge is still inaccessible or ignored by the majority of the parts in which the management and protection of this ecosystem lies. As part of Tropi-Dry research network, this thesis aims to identify and integrate scientific knowledge of TDFs and relate this to ecosystem characterization and quantification in order to assist decision-makers, landholders and government agencies to assess the ecosystem services provided by TDFs. The present thesis compiles 4 chapters, all following the main trend of quantification of ecosystem services in tropical dry forests.

The main objective of Chapter 2 "**Assessing Ecosystem Services in neotropical Dry Forests"** is to develop a meta-analysis of the existing methodologies for evaluating and quantifying the biophysical parameters of the ecosystem services from tropical dry forests in

America. In order to accomplish this I focus only on the ecosystem services established by the Millennium Ecosystem Assessment (MEA 2005) and only on key indicators for the evaluation of water, carbon, soils and biodiversity services. By doing so, I intend to identify existing gaps in the quantification of ecosystem services (provisioning, regulating and supporting) for TDFs. The last objective of this research is to build guidelines that could allow managers, government agencies and stakeholders to quantify the goods provided by their forests following easy, inexpensive and accurate techniques that have been proven in TDFs or other types of ecosystems.

The main objectives of Chapter 3 **"Ecosystem characterization and light diffusion of two Tropical Dry Forests (TDF)"** is to characterize forest structure, composition of species and leaf development using light diffusion through the canopy as a variable associated to the provision of a key ecosystem service (Net Primary Productivity) and analyze the temporal change of this variable in two successional stages in a Costa Rican TDF. With this I provide a new approach to estimate LAI in a continuous base using the relationship between light diffusion through the canopy and spectral vegetation indexes (VI).

Finally Chapter 4 **"Conclusions and future work"** summarizes the challenges for future monitoring of tropical dry forests in the context of ecological succession and remote sensing. In addition, this chapter addresses main recommendations and future work necessary for the evaluation of ecosystem services in TDFs.

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2. Chapter two – Assessing Ecosystem Services in neotropical Dry Forests

2.1. Introduction

Ecosystem Services (ES) are defined as "the benefits people obtain from ecosystems" (Daily 2000; MEA 2005; Mass et al. 2005), or "a function of complex interactions among species and their abiotic environment; complex use and utilization patterns; and various perceptions by beneficiaries" (Fisher et al. 2009). According to De Groot (1992), ES are "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly". In spite of the differences in terminology, for most authors and studies, there is a strong relationship between the maintenance of ecosystem functions and the well-being of humanity (Geneletti 2011; Balvanera et al. 2011; Partidario and Gomes 2013; TEEB 2010).

The origins of the environmental movement and the modern history of ES can be traced back to 1962 when Rachel Carson published her famous book "Silent Spring", putting in the public eye the discussion of the benefits and harms derived from the human-environment relationship. Then in the 70s and 80s ecologists (e.g., Ehrlich and Ehrlich 1970; Westman 1977; De Groot 1987) developed these ideas more deeply and began using the term "services", defining what ES provided to society.

By 2005 these definitions were formalized by the United Nations (UN) in the Millennium Ecosystem Assessment (MEA 2005), thanks to a 4-year study involving more than 1,300 scientists worldwide. They grouped ES into four broad categories: ***provisioning***, such as the production of food and water; ***regulating***, such as the control of climate; ***supporting***, such as nutrient cycles and crop pollination; and ***cultural***, such as spiritual and recreational benefits. Later, between 2007 and 2010 a second international initiative was carried out by the UN and called the Economics of Ecosystems and Biodiversity (TEEB 2010). The TEEB report emphasized on relationship between biodiversity and ES and showed the importance for human well-being. This important report makes the first institutional connection, at the UN level, between economics and ES.

The importance of these conservation strategies has triggered a myriad of schemes and methods to evaluate and classify these services. Many approaches have been proposed and several markets of Ecosystems Services have been created (Bayon 2004; Gómez-Baggethun et al. 2010). In 2004, over 300 Payment for Ecosystem Services (PES) schemes existed in the world (Mayrand and Paquin 2004). Although most of these schemes have not been applied or are in an early stage of experimentation, these schemes have been excellent tools for helping decision-makers realize the importance of sustainable management strategies (Turner et al. 1998; Daily et al. 2000; Mass et al. 2005).

According to de Groot et al. (2012), the global value of ES in 2011 was estimated to be $125 trillion/yr, where the total economic value of tropical forests is approximately $5,264 ha/year (de Groot et al. 2012). But beyond the monetary values and the most obvious benefits we obtain from ecosystems, there are many other intangible ecosystem functions that are essential for human well-being. The value we give these services depends on societal perceptions and preferences for different ES (Balvanera et al. 2012).

In spite of these efforts, there is still a debate amongst the scientific community regarding how these services are considered and valued. Some of the criticisms of these frameworks focus on the use of extrapolated data, where different biomes are sometimes integrated under one classification (Costanza et al. 2014), and the fact that few frameworks evaluate multiple ES (Kinzig et al. 2011). According to Balvanera et al. (2012), there is a lack of information and comparable methods to assess the same ES in Latin America and for inter-country comparisons.

In addition, Latin American research efforts have focused mainly on ES at global and regional scales (e.g., carbon storage), with more localized ES receiving less attention (e.g., microclimatic conditions, floods) (Balvanera et al. 2012).

ES in the tropical dry forests of America

Neotropical dry forests have a distribution of approximately 700,000-km² in the Americas and they account for 67% of the global coverage of this type of ecosystem (Dirzo et al. 2011, Portillo-Quintero and Sánchez-Azofeifa, 2011). Although, TDF are highly fragmented and only a small fraction is on protected areas. In addition, few studies of ES in TDFs have been developed, even though they are "the foundation for the livelihoods of millions of people around the world" (Mass et al. 2005).

TDFs provide a wide variety of ES that are crucial for human well-being (Balvanera et al. 2011). In spite of the fact that water scarcity is the major limiting factor that shapes TDFs, 66% of the reservoirs and dams in tropical regions of America are located in dry ecoregions (Portillo-Quintero et al. 2014), where TDFs have a direct influence on 44% of the major cities. In addition, TDFs sustain a high biological diversity (including many endemic species) (Linares-Palomino 2011), possess important above-ground and below-ground carbon reservoirs, and help with the protection of soil and water, ensuring a higher quality of water (Balvanera et al. 2011).

Maass et al. (2005) identified main services provided by TDFs in Chamela–Cuixmala Biosphere Reserve, Jalisco, Mexico: provides fresh water, provides agricultural and pastoral goods, helps to preserve biodiversity, regulates climate, helps maintain soil fertility, controls floods, and provides scenic beauty. Among the most important provisioning services described by Balvanera et al. (2011) from TDFs are food (from agriculture and cattle ranching), timber, non-timber forest products, biofuels, and germ-plasm (Balvanera et al. 2011). Also, TDFs provide important regulating services such as erosion control, regulation of soil fertility, improves water quality, facilitates the storage of carbon, regulates carbon emissions, and climate (Balvanera et al. 2011). TDFs also hold a well-defined phenological cycle, which makes them potential proxies for the biological response of plants, trees, watersheds, carbon emissions among others, under scenarios of climate change, specifically under drought effects (Barreda-Bautista et al. 2011).

Why is it important to evaluate ES of TDFs in America?

Current governmental land management policies and regulations in the region are still based on the misconception that TDFs are "useless" for biodiversity conservation (Portillo-Quintero et al. 2014). This position results in the absence of explicit policies for its preservation, management, and use (Quesada et al. 2009). Furthermore, this perception is reflected on TDFs having less protection than humid forests (4.5% versus 25%) (Portillo-Quintero and Sánchez-Azofeifa 2009; Scharlemann et al. 2010).

Many of these TDFs regions are also currently under great pressure from population growth, land use, and future climate change (Farrick and Branfireun 2013). According to Miles et al. (2006), more than 30% of the global TDFs are at risk of decline under a climate change scenario of a 2.5°C increase. This scenario has significant implications for the future functioning of their natural and socioeconomic systems (Farrick and Branfireun 2013).

Moreover, frameworks to assess ES in TDFs are scarce, scattered, and sometimes not comparable. Many frameworks to assess ES at a global scale include TDFs under the general category of tropical forest, assuming the services that TDFs provide are the same as those provided by humid forest or rain forest (e.g., Costanza et al. 2014). Little is known still about the ES provided by TDFs (Maass et al. 2005).

Assessing ES is useful for prioritisation and problem identification, especially in relation to interactions and trade-offs among different ecosystem services (Maes et al. 2013). These assessments can also assist decision-makers in identifying priority areas and in constructing relevant policy measures, including the improvement in measuring and demonstrating/evaluating the benefits of ES in relation to costs (Maes et al. 2013). These tools are becoming key instruments to guide decision-making and to quantify their quality. Also, ES experience changes in their demand and supply, which requires evaluation and monitoring of these changes, which results in some urgency to develop standardized methodologies to quantify the biophysical parameters that drive and characterize ES (Martínez-Harms and Balvanera 2012).

Given this context, this study aimed to analyzed schemes and methods for assessing ES in TDFs. In this review, I focused only on the ES established by MEA (2005) and CICES (2013). As such this study focuses on key indicators for evaluating water, soil, carbon, and biodiversity services.

The main questions to be answered in this study were: 1) How can ES be assessed in TDFs?, 2) What are the current existing evaluation frameworks for carbon, soil, water, and biodiversity services?, and 3) Which frameworks have greater potential to be implemented in TDFs in America and why?

With the information collected, I hope to guide stakeholders, government agencies, and NGOs to make more assertive decisions regarding the conservation of TDFs, and to learn how to evaluate the environmental benefits. I hope this summary could help to develop better land use policies, conservation programs, PES schemes (Payments for Ecosystem Services), and to guide further research.

2.2 Methods

Classification of ES

Different ES have been defined for forests ecosystems. For this study, I used the Millennium Ecosystem Assessment (MEA 2005) categories for ES. They recognized four categories of ES, where the “supporting services” represent the foundation for the services of the other categories (Table 2.1).

Data acquisition

To address questions 1 and 2 of this study, a literature review of studies evaluating specific or several ES in TDFs was compiled. For this review, I conducted several systematic web-based searches using keywords and Boolean operators in the Web of Science and Scopus. This research was conducted between January 2014 and April 2015. Keywords used include: tropical dry forest AND ecosystem services OR greenhouse gas regulation OR climate regulation OR carbon storage OR soils OR biodiversity OR carbon stocks OR watersheds OR biomass OR forest productivity OR water quality OR water quantity OR water supply OR fuel-wood OR non-timber forest products OR genetic resources OR flood regulation OR erosion regulation OR medicinal plants OR land use change OR land cover OR phenology OR flowering OR growth rates OR allometric equations OR pollination.

To capture relevant information that could not be tracked in the Web of Science or Scopus, I conducted additional searches for governmental publications, agency reports, non-ISI (Institute for Scientific Information) papers, websites, and databases of ongoing projects, book chapters, synthesis papers, or published manuals or guidelines. I searched within the results for specific TDF terms including: tropical dry forest, dry tropical forest, seasonally tropical dry forest. Once the database with all the studies was built (Appendix 1), I classified each study within the categories of biodiversity, carbon, soils, or water, according to their area of research and the variables measured in the study (Figure 2.1). Subsequently, I classified these same studies within the categories of provisioning, regulating, or supporting services and their subcategories, according to the services analysed in the studies.

Although it is impossible to capture all existing studies involving TDFs, my study tried to capture the main links and trends in the evaluation of ES in TDFs. To address question 3, I analysed the applicability of some of the studies developed in TDFs or other biomes to measure one or several ES. I prepared a synthesis of frameworks that had the most potential to be adapted to TDFs, because they were simple methodologies to follow and could be applied in a short time, were inexpensive but had high reliability, and could measure more than one ecosystem service.

Data analysis

The plots and the geographic distribution of the studies collected for TDFs in America were built using the software for analytics developed by IBM® called Many Eyes (Viégas et al. 2007). I constructed the network analysis using the software Gephi to reveal the general patterns and trends in the data. The main output of this analysis is the sociogram, which provides information about the number and strength of connections in the data. K-core analysis and eigenvector calculations were used to determine stronger connections. K-core analysis is commonly used in network analyses to find core-edge topics (Zhuang et al. 2013). A K-core is a sub graph in which each node is connected to at least a minimum number "K_n" of other nodes in the sub graph. As "K_n" becomes greater, the relationship among the nodes is stronger (Zhuang et al. 2013). Eigenvectors were calculated for each node in the network analysis to assess the centrality of each node. Eigenvectors in matrices are useful as measures of centrality or of status inside the network (Bonacich and Lloyd 2001).

2.3 Results

In total, 531 studies were found evaluating or measuring an ecosystem service in TDFs. From these, 248 studies quantified one or more ecosystem services related to biodiversity, 139 related to carbon, 87 related to soils, and only 57 related to water (Figure 2.2). Studies of biodiversity and carbon focused specifically on provisioning services, studies of water focused on regulating services, and studies of soil focused on supporting services.

In general, the category of supporting services included a greater number of studies quantifying primary production (48.5%). Under regulating services, most studies focused on carbon stocks (39.4%) and water regulation (28.3%). In the provisioning services category, which is the one with the greatest number of studies (n=228), most of them focused on genetic resources (68.1%) and biomass production (27.6%) (Figure 2.3). Regulation of air quality, pests, and erosion were the least studied services in TDFs (n=5).

The locations of the studies included 17 countries in America (Figure 2.4), including Mexico, Costa Rica and Brazil with the highest number of publications (291, 96, and 39 respectively). From all the studies evaluated, 88% focused on secondary TDFs, 7% in old growth tropical dry forests, and 5% in watersheds or streams.

As expected, the number of studies that quantified or measured one or more variables to determine ES in TDFs has been increasing over the years (Figure 2.5) going from 10 studies per decade (1970-1980) to more than 250 per decade (2000-2010). However, the number of studies stops increasing exponentially around 2006, where the trending curve is normalized. Moreover, during the years studies on biodiversity and carbon have been more frequent than studies on water and soil (Figure 2.5). For example, in the decade 2000-2010, from the 276 publications found, 80% of the studies belong to biodiversity and carbon and only 20% belong to water and soil studies. Which could translate as, from every 10 studies evaluating an ecosystem service in TDF, only two consider water and soil services and 8 consider carbon and biodiversity.

Most of the studies (61.4%) were focused at local scales, and reported on one location, usually National Parks, State Parks, or Nature reserves. Fewer studies (38.6%) focused on global, regional, or national scales (Figure 2.6). The most studied locations found in the analysis of the database were Chamela–Cuixmala Biosphere Reserve, in Jalisco, Mexico (n=225); Santa Rosa National Park, in Guanacaste, Costa Rica (n=42); and Mata Seca State Park in Minas Gerais, Brazil (n=18). The most studied regions were the Jalisco state in Mexico (232), and the Guanacaste province in Costa Rica (n=96). The most frequently used words in the titles of the studies were tropical (present in 68% of the studies), dry (56%), forest (73%), Mexico (20%), tree (15%), deciduous (13%) (Figure 2.7).

The authors with the greater number of studies found in the database were Sánchez-Azofeifa (University of Alberta, Canada; 22 studies), Bullock (Universidad Nacional Autonoma de Mexico, Mexico; 17 studies), García-Oliva (Universidad Nacional Autonoma de Mexico, Mexico; 14 studies), Kalacska (McGill University, Canada; 14 studies), Janzen (University of Pennsylvania, United States of America; 14 studies), and Borchert (University of Kansas, United States of America, 10 studies). The most cited studies found in the database are shown in table 2.2.

Network analysis

From the network analysis built, biodiversity and carbon were the variables that had more methodologies developed to assess ES. In contrast to these results, soils and water had fewer methodologies developed for the evaluation of their services (Figure 2.8).

From all the detected methodologies (17 nodes), 7 nodes had higher values of "K_n", which means that these methodologies can be used to assess ES for more than one variable (carbon, water, soils, and biodiversity). These methodologies included forest inventories, biodiversity inventories, soil data collection, meta-analysis, phenology data collection, literature review, and remote sensing techniques. These methodologies were also among the most used in TDFs (75.7%) along with the collection of hydrological data and pollination analyses (5.2%, 5.6% respectively).

Even though there were more studies that quantified biodiversity (more entries in the network, n=248), carbon was the variable with the highest centrality (K_n= 1.00, Table 2.3), meaning that it comprised a higher number of methodologies. Also, water comprised a higher centrality than soils (0.77 versus 6.2). Although there were more studies on soils (87 versus 57), it only possessed 6 methodologies for its quantification.

2.4 Discussion

Main trends and gaps

My study revealed an increase since the 70's in the amount of research dealing with the quantification of ES for biodiversity, carbon, soil, and water in TDFs, going from 10 studies per decade to more than 250 studies in recent decades. Since the 70's several methodologies have been developed, and they have been employed in many countries. Despite this increase this study has detected some important gaps in the evaluation of these ES.

This study has demonstrated that North America, the Caribbean Islands, and Central America were the regions with the highest number of studies, with Mexico and Costa Rica in the lead, followed by Nicaragua, Panama, Puerto Rico, Honduras, Jamaica, Belize, and Cuba. Mexico has the largest extent of TDFs on the continent, comprising 38% of all TDFs in America (Portillo-Quintero and Sánchez-Azofeifa 2009) and several consolidated research groups in, so it is not a surprise that the largest number of studies come from this country. Surprisingly, despite the fact that Costa Rica only possesses 0.4% of the TDFs in America, it produced more studies than countries with much more TDFs, such as Nicaragua (1.6%) and Honduras (1.3%). Other countries that contain TDFs, like El Salvador and Guatemala, had almost no research dealing with TDFs. The main reason for these significant differences between Costa Rica and other countries is probably the presence of the Guanacaste Conservation Area, a region that serves as a magnet for several international research groups.

In South America, Brazil has the most studies that assessed ES in TDFs, followed by Bolivia, and Venezuela. Bolivia and Brazil possess the largest portions of TDFs in South America (25% and 17%, respectively), and are followed by Colombia and Venezuela (6.5% and 6.2% respectively) (Portillo-Quintero and Sánchez-Azofeifa 2009). In spite of this, little research on TDFs was found for Colombia, Peru, and Ecuador.

As expected, most of the studies were conducted in secondary forests, because they cover a greater area than old-growth forests in all regions with TDFs (Sánchez-Azofeifa et al. 2005). Most of the studies also focused on local scales assessments and few worked at global or regional scales. Although generalizations are possible, the functionality and value of an ecosystem is likely to be highly variable, so site-specific assessments are of great importance (Brauman et al. 2007).

This study also revealed some clear trends. Provisioning and supporting services were the most studied services with a great number of methodologies developed for their evaluation. However, regulating services were the least studied, lacking methodologies for their evaluation. Some of the most frequently studied services were genetic resources, primary production, carbon stocks, and biomass production, which is an important finding, because some of them are key ES that are being used for decision-making (Martínez-Harms and Balvanera 2012). For example, in Latin America, existing PES are focused on the provisioning services derived from the protection of forest cover (e.g., Costa Rica, Mexico, Chile, Panama) or biodiversity and carbon sequestration (e.g., Colombia, Bolivia, Brazil) at national scales (Balvanera et al. 2012).

Other ES that are critical for the maintenance of ecosystems and human welfare, such as protection and provision of fresh water, air quality regulation, pest regulation, disease regulation, and erosion regulation were rarely addressed. There is a clear lack of formal research on many of these services. For Balvanera et al. (2012), research on ES supply is still limited to a few services, largely those of global impacts (e.g., carbon storage) and less importance has been placed to regulating services (e.g., regulation of human diseases, microclimatic conditions, floods).

Potential frameworks and methodologies for assessing ES in TDFs

From all the studies analysed in the database, the biophysical variable with the greatest number of studies was biodiversity; however, carbon was the variable with more methodologies developed for the quantification of its services, followed by biodiversity, water, and soils (Table 2.3). Different methods for assessing ES in TDFs can vary in accuracy, precision, verifiability, cost, and scale of application.

For Bagstad et al. (2013) ES assessments need to be quantifiable, replicable, credible, flexible, and affordable. Emerging environmental data sharing, remote sensing techniques, and visualization tools and practices can support ES modeling with high accuracy and lower costs (Bagstad et al. 2013). Maps are also a very powerful tool to process complex data and information from ES quantification on different spatial and temporal scales and thereby support resource and environmental management as well as landscape planning (Crossman et al. 2012).

For carbon quantification, a great number of studies employed remote sensing data, which enables us to acquire data for vast areas (e.g., satellite images, airborne LIDAR) and for continuous periods of time (e.g., carbon flux towers, optical phenology towers). These technologies can be costly and some of them are criticized for not producing accurate results (Gibbs et al. 2007; Sánchez-Azofeifa et al. 2009). However, some studies stress the importance of comparing remote sensing data with ground measurements from forest inventories, permanent plots, or field samples. Forest inventories are the most reliable of all the methodologies, but they can be expensive, slow, and challenging to conduct at a regional or global scale (Gibbs et al. 2007).

The benefit of satellite remote sensing data lies in the potential for systematic and large spatial scale views of the earth at regular intervals (Hesketh and Sánchez-Azofeifa 2013). The most used technologies found for satellite image analysis to obtain land cover of carbon storage were LANDSAT (e.g., Almeida et al. 2014; Arroyo-Mora et al. 2005; Bianchi and Haig 2013; Calvo-Alvarado et al. 2009; Dalle et al. 2011) and MODIS (e.g., Kalacska et al. 2008; Portillo-Quintero et al. 2013; Redo et al. 2013; Rodriguez et al. 2009; Carranza et al. 2014). For Maes et al. (2013) these approaches are appropriate at large scales, for areas where the dominant service relates directly to land use or where data availability is limited, and where the focus is to assess the presence of ES rather than the quantification.

The calculation of biophysical parameters, such as biomass and Leaf Area, can also be assessed using spectral reflectance data derived from remote sensing techniques, like the Leaf Area Index (LAI) (Kalacska et al. 2005), Photosynthetically Active Radiation (PAR) (Van Laake and Sanchez-Azofeifa 2005) or the Normalized Difference Vegetation Index (NDVI) (Hesketh and Sánchez-Azofeifa 2013). These measurements can help to estimate significant ecosystem processes such as transpiration, photosynthesis, potential net primary productivity, and actual net primary productivity that in turn are related to changes in carbon stocks (Sánchez-Azofeifa et al. 2009).

According to the Intergovernmental Panel on Climate Change (IPCC 2001), the variability of carbon stocks (above and below ground) and net greenhouse gas emissions over time can be estimated using some combination of direct measurements, and models based on accepted principles of statistical analysis, forest inventory, remote-sensing techniques, flux measurements, soil sampling, and ecological surveys.

Biodiversity, on the other hand, is a more difficult resource to analyse, given the complexity of species dynamics and all the variables that need to be taken into account. Most of the studies are simple reviews or inventories of flora or fauna focusing on a specific genus (e.g., Quesada et al. 2003; Janzen et al. 2005; Espirito-Santo et al. 2007). Despite the great amount of available data, there is still a lack of consensus about what to analyse and monitor for biodiversity services (Pereira et al. 2013). For Pereira et al. (2013), the most essential biodiversity variables to take into account for ecosystem evaluation are genetic composition, diversity composition, species populations, community composition, ecosystem structure, and ecosystem function. Current available global databases that help to assess genetic resources are: species ranges of mammals (Baillie et al. 2004), birds (BirdLife International 2006), amphibians (IUCN 2006), and threat status according to the IUCN's Red List (IUCN website 2007).

Recent techniques for assessing carbon storage and biodiversity are also based on functional traits of plants (Lavorel et al. 2011). Abiotic variables and plant traits rather than land use alone afford refined representation of relevant ecosystem properties and therefore could be used as functional markers of ES (Lavorel et al. 2011; Ball et al. 2015). Functional traits, such as vegetation height, leaf dry matter content, leaf nitrogen and phosphorus concentration, flowering onset, can be used to map several services Maes et al. (2013). Some efforts in TDFs using this approach are found in Alvarez-Anorve et al. (2008), Hulshof et al. (2013), Mooney et al. (1992), and Powers and Tiffin (2010).

For water services, most of the methodologies used ground measurements to estimate hydrological parameters; only 5 studies used remote sensing data. In most of the studies, the consensus was to conduct long-term studies in watersheds to create more accurate models and to evaluate the behavior of the resources in the long term (e.g., Chapman and Kramer 1991; García-Oliva et al. 1991; Maza-Villalobos et al. 2013; Calvo-Alvarado et al. 2014). However, there is still a poor understanding of key hydrological processes in TDFs, and because of this lack of research, there are few data available for assessing water services in TDFs (Farrick and Branfireun 2013). Research priorities that are required for a more complete understanding of the hydrology in TDFs include those on precipitation, transpiration, and interception, groundwater, runoff and stream flow generation, long-term monitoring projects, and modelling of the resource (Farrick and Branfireun 2013).

Most of the methodologies for assessing ES of soils are focused on soil formation and nutrient cycling analyses using soil samples collected in the field. These methodologies are frequently developed at local scales (e.g., Galicia and García-Oliva 2004; Campo et al. 1998; Powers and Perez-Aviles 2013). Soil erosion is less addressed in the literature and is also often developed for local scales (García-Oliva et al. 1995; Ellingson et al. 2000; Diekmann et al. 2007). Methods used to extrapolate observations of plots or even small watersheds to large regions for determining average annual soil erosion rates are often controversial and criticized (Cotler and Ortega-Larrocea 2006).

Soil carbon fluxes which have significant effects on the global carbon cycle, have less methodologies for TDFs and are subjected to errors in the estimation caused by assumptions about the carbon storage or the effects of forest conversion (Powers et al. 2004; Meir and Pennington 2011). Despite this, some efforts using soil chambers have been conducted to evaluate emissions from TDFs soils (Davidson et al. 1991; Garcia-Mendez et al. 1991; Davidson et al. 1993; Litton et al. 2008). According to Litton et al. (2008), conversion of forests and invasion of plant species in TDFs can lead to long-term decreases in soil carbon storage and increase the release of sequestered carbon into the atmosphere. Furthermore many authors agree that our understanding of the ES soil provides is incomplete, despite a good understanding of soil formation and functioning (Daily et al. 1997; Dominati et al. 2010).

Approaches created to assess multiple ES can be monetary valuations like InVEST (Nelson et al. 2009) or qualitative indexes of people's preferences (Boyd and Wainger 2003). More integrated approaches are based on the application of dynamic process-based ecosystem models (Costanza et al. 1997; Morales et al. 2005; Schröter et al. 2005). These approaches take account of the mechanisms which drive ES delivery and produce more realistic changes in ES supply at the local and global scales, but they require significant investment in terms of data acquisition and expert knowledge (Maes et al. 2013). These integrated approaches have not been applied for TDFs owing to the lack of information, and at the moment there are no integrated approaches for TDFs created to assess and value ES.

Here, I suggest the development of an integrated approach using the available information collected, models created, and methodologies that allow us to assess more than one ES, while the biophysical components and processes associated with ES in TDFs are further studied and analyzed.

Future work and challenges

Given that TDFs regions are most populated and that most land is dedicated to intensive and extensive agricultural activities, the most significant challenge is to improve the physical and economical valuation of less understood provisioning and regulating services. The most urgent in TDFs are soil conservation and water quality availability for human consumption, tourism, agricultural irrigation, environmental flows, and industry use.

There is clear documentation of the value of TDFs for biodiversity conservation and carbon sequestration (Portillo-Quintero et al. 2014). These ES are more commonly studied in TDFs, using a greater number of methodologies for their assessment at local, regional, or global scales and with methods applicable to multiple ecosystems. However, regulation and provisioning services of water and soil are addressed less often. Moreover, interactions between TDFs and these services are not well understood under the scenario of climate change, which will accentuate the crisis of accessibility to water resources. Hence, there is still a need to have better predictions of the impacts of climate change on water resources of TDFs to develop suitable strategies for adapting to this future uncertainty (Ceballos et al. 2009).

It is known that land use change impacts are expected to intensify the effects of climatic warming in TDFs, given that they are already highly disturbed and fragmented (Meir and Pennington 2011). Forest conversion to pasture and agriculture is expected to reduce rainfall through different effects on sensible heat transfer (Costa et al. 2007). An increased regional atmospheric aerosol loading resulting from fire and land use change could also cause reductions in precipitation (IPCC 2007). A higher proportion of TDFs areas are at risk of severe climate change in the Americas than in other regions, which will translate into either a temperature increase of at least 2.5 °C or a precipitation decrease of at least 50 mm year^{-1} by 2055 (Miles et al. 2006). By mid-century, annual average river runoff and water availability are projected to decrease by 10-30% in dry regions at mid-latitudes and in the dry tropics, some of which are presently water stressed areas (IPCC 2001).

Under the scenario of climate change, understanding the relationship of TDFs with conservation of water and soils is of vital importance to meet this challenge. If these interactions are better defined and physically assessed in TDFs, societies will be more willing to preserve these ecosystems by applying different strategies. Unfortunately, my literature review showed that these ES were the least studied. This situation positions these ES in a priority research area, given the high demands by society for fertile soils and availability of fresh water in TDFs areas. It is essential to include water and soils in ES frameworks to develop better environmental and mitigation policies.

2.5 Conclusions

Considerable efforts and research have been increasing in recent decades in the TDFs of America in order to quantify key biophysical variables that support the ES assessment of these forests. Carbon storage and biodiversity have been the subjects of extensive research and methodologies in the region. Most popular methods found to assess ES were literature reviews, remote sensing techniques, and forest and biodiversity inventories. Although there is no consensus among researches on how these variables and methodologies should be addressed, the important amount of information found could help us developed a more integrated approach.

Generally, my review reveals a clear need for an increase research in the following:

- The development of an integrated approach that allows us to assess more than one ES is needed for TDFs.
- Greater research is needed for provisioning and regulating services of water and soil in TDFs regions, given the high demand for these services in the region.
- Studies evaluating and modeling ES in TDFs under climate change scenarios are required.

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2.7 Figures and tables

Table 2.1. Categories, definitions, and subcategories of ES established by MEA (2005).

Category	Subcategory
Supporting services: ES that are necessary for the production of all other services	• Primary production • Nutrient cycling • Water cycling • Pollination • Soil formation
Provisioning services: products obtained from ecosystems	• Biofuels • Biomass • Fresh water • Genetic resources • Biochemicals, natural medicines, and pharmaceuticals
Regulating services: benefits obtained from the regulation of ecosystem processes	• Air quality regulation • Carbon stocks • Water regulation • Erosion regulation • Climate regulation • Water regulation • Disease regulation • Pest regulation • Natural hazard regulation

Table 2.2. Names of studies and references of the most cited studies and the number of times cited.

Service subcategory	Name of the study	Reference	Number of times cited*
Genetic resources	Ten species in one: DNA barcoding reveals cryptic species in the neotropical skipper butterfly *Astraptes fulgerator*	Hebert et al. 2004	1201
Biomass production	Comparative Phenological Studies of Trees in Tropical Wet and Dry Forests in Lowlands of Costa-Rica	Frankie et al. 1974	742
Primary production	Tree Dispersion, Abundance, and Diversity in a tropical Dry Forest	Hubbell 1979	713
Primary production	Ecology of Tropical Dry Forest	Murphy and Lugo 1986	610
Biomass production	Tree allometry and improved estimation of carbon stocks and balance in tropical forests	Chave et al. 2005	578
Biomass production	Biomass Estimation Methods for Tropical Forests with Applications to Forest Inventory Data	Brown et al. 1989	465
Nutrient cycling	Microbial biomass acts as a source of plant nutrients in dry tropical forest and savannah	Singh et al. 1989	426

* The number of times cited was extracted from the Web of Science and takes into account all ISI data bases of citations.

Table 2.3. Nodes in the network analysis with their weight (number of entries) and eigenvector of centrality.

Nodes	Weight	Eigenvector centrality
Carbon	139	1.00
Biodiversity	248	0.95
Water	57	0.77
Bibliography	33	0.65
Meta-analysis	18	0.65
Remote Sensing	46	0.65
Soils	87	0.62
Biodiversity inventory data	93	0.53
Phenology	23	0.53
Forest inventory data	103	0.50
Soil data	86	0.45
Land cover	8	0.38
Climate data	4	0.34
Allometric equations	17	0.32
Destructive samples	8	0.20
Existing maps	3	0.20
Litterfall data	17	0.20
Laboratory experiments	11	0.19
Pollination	28	0.19
Survey	3	0.19

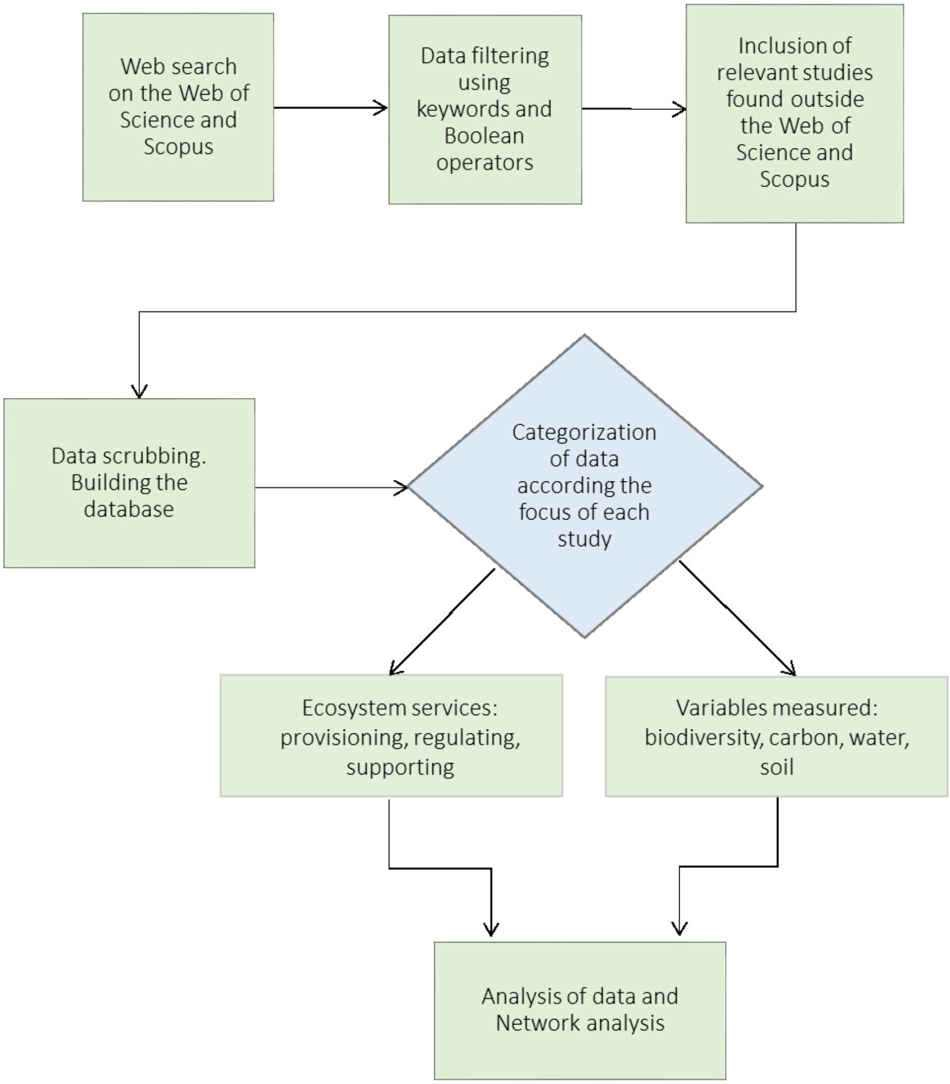

Figure 2.1. Flow chart for the construction of the database and data analysis.

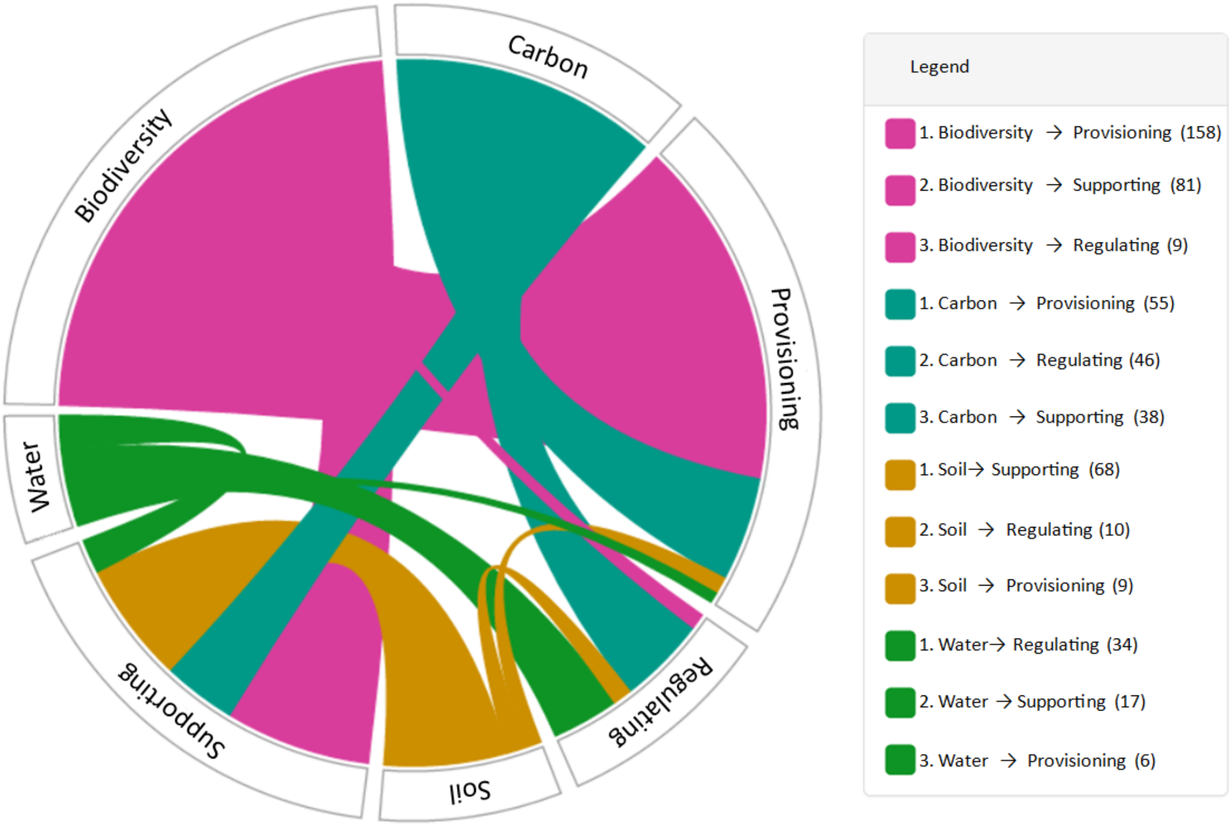

Figure 2.2. Number of studies found for biodiversity, carbon, soils, and water in the categories of supporting, regulating, and provisioning services.

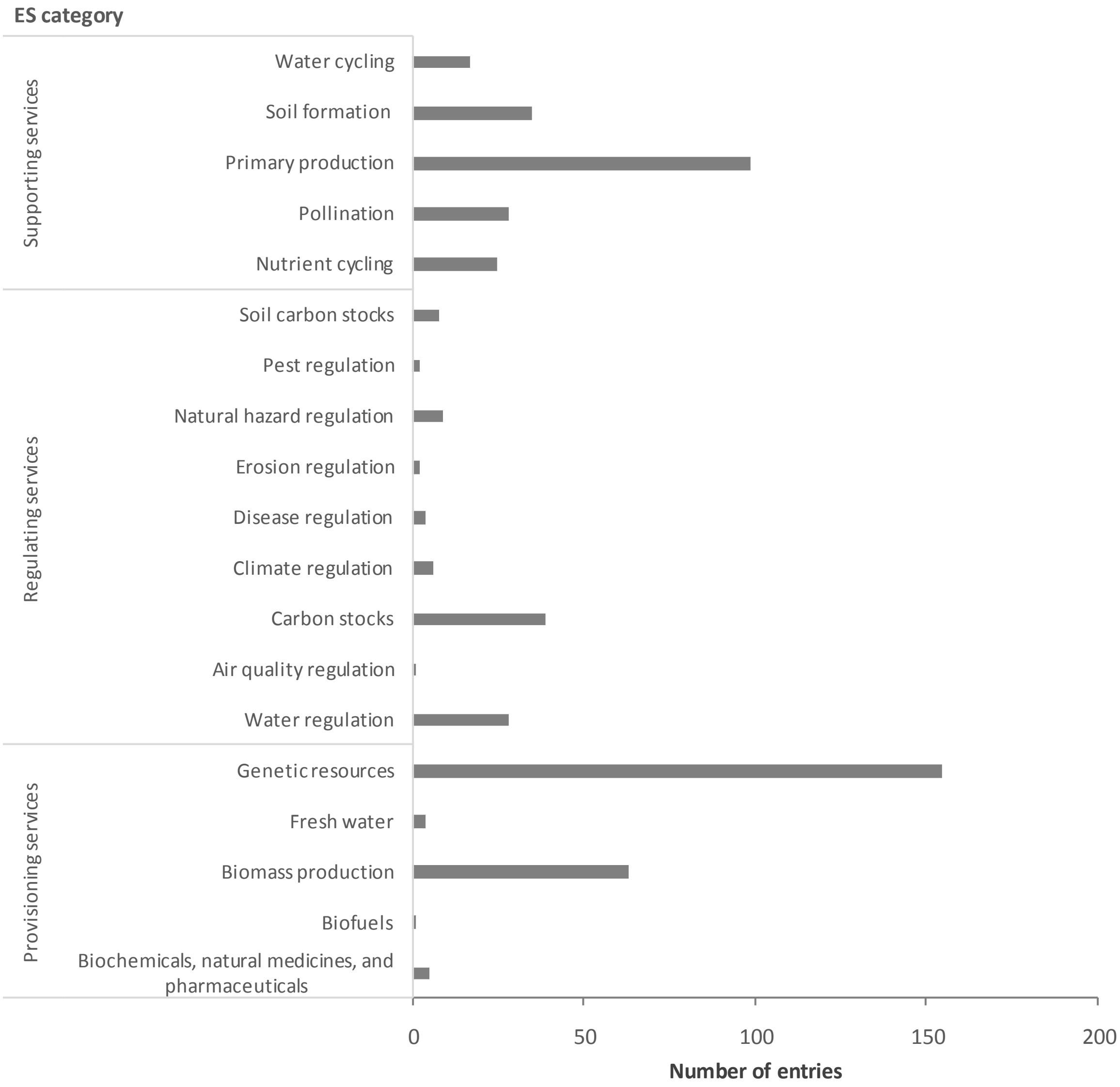

Figure 2.3. Number of studies found in each ES category and subcategories. Primary production is the major subcategory for supporting services, carbon stocks is the major subcategory for regulating services and genetic resources for the provision services category.

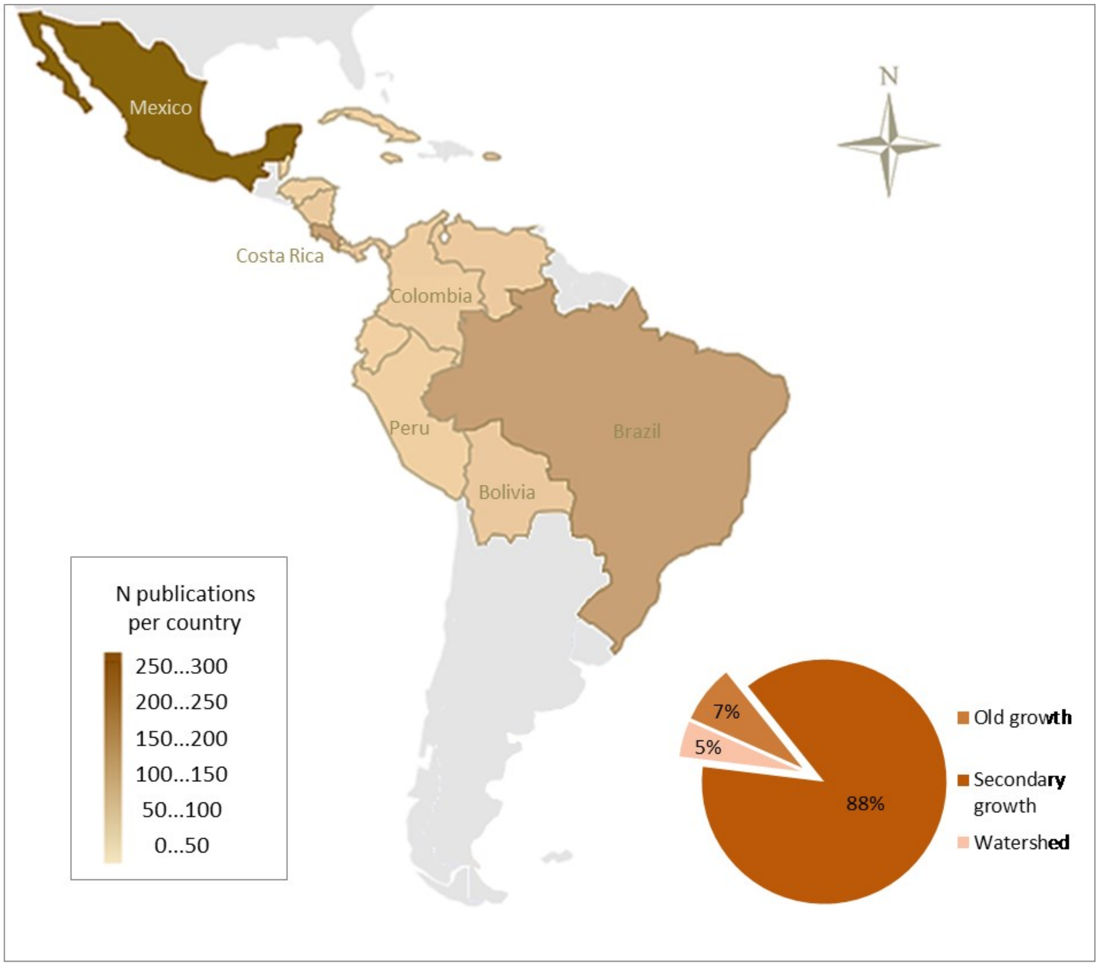

Figure 2.4. Number of publications per country in America evaluating one or more ES in TDFs and percentage of studies conducted in secondary or old growth forests, and watersheds.

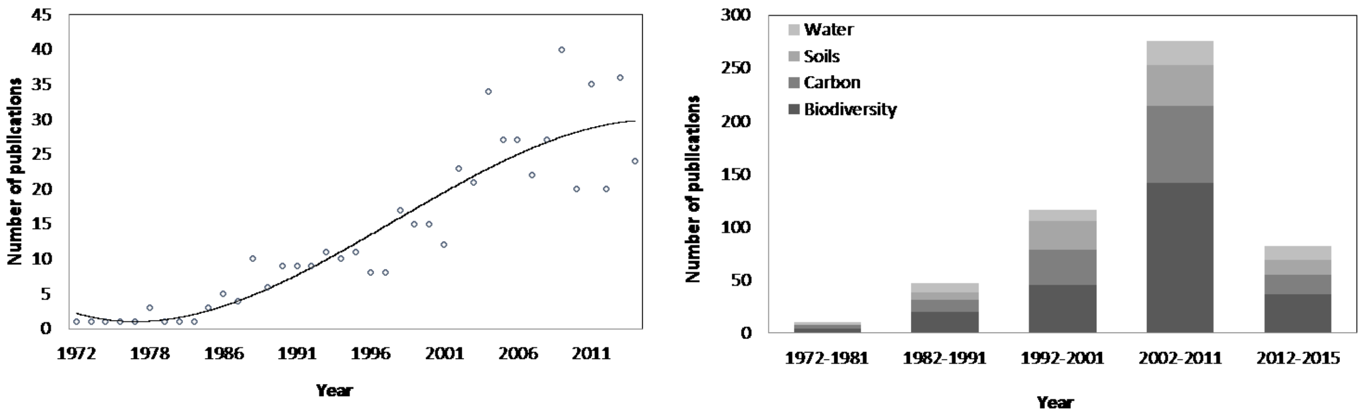

Figure 2.5. Number of studies found per year that evaluated and quantified biodiversity, carbon, soils, or water in TDFs of America.

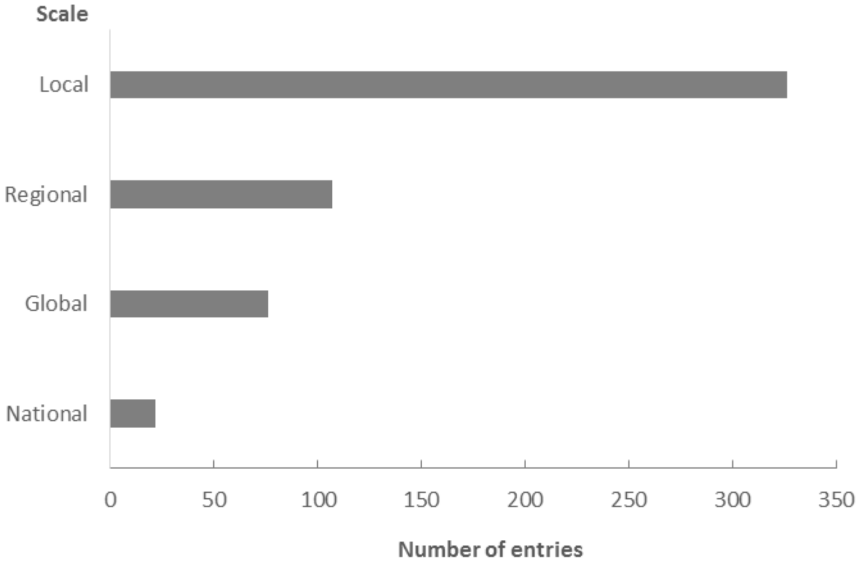

Figure 2.6. Number of studies quantifying ES focused at local, regional, national, and global scales.

Figure 2.7. Word frequency cloud using the titles of the studies found for the TDF in the Neotropics.

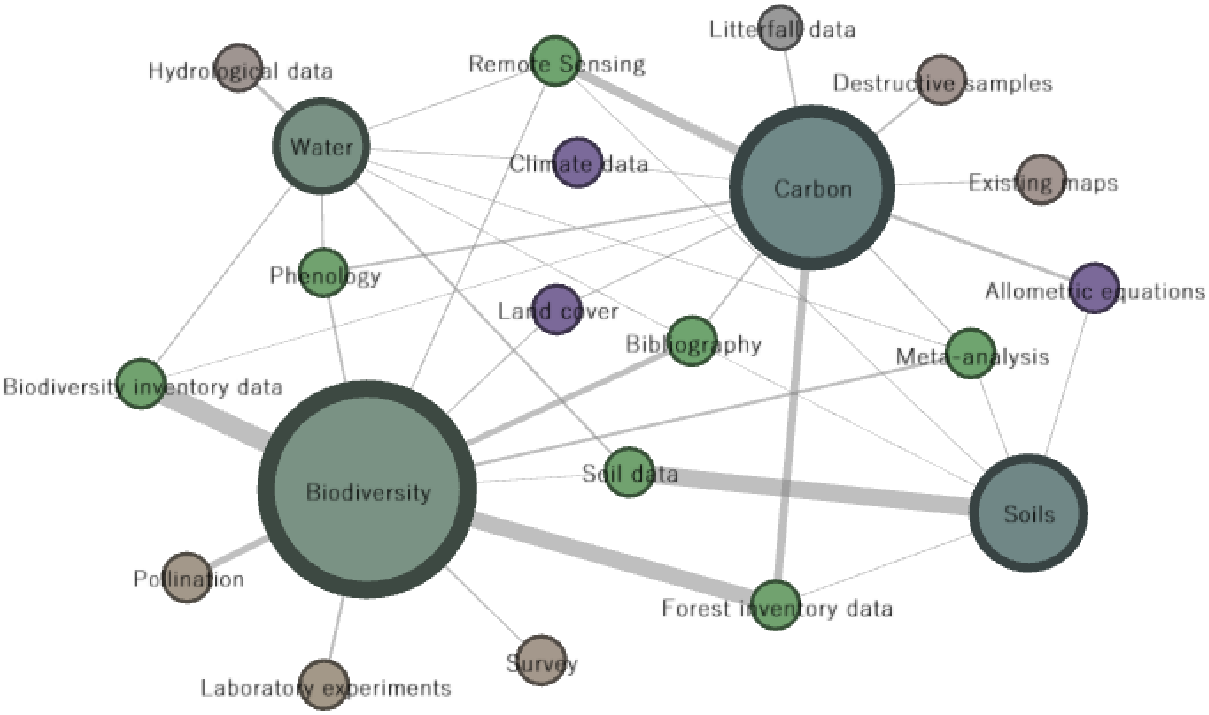

Figure 2.8. Network Analysis of the most used methodologies in TDFs to quantify variables of ES. Green nodes represent the methodologies that are used to quantify 3 or more of the variables, purple nodes are used only to quantify 2 variables and brown nodes are used to quantify only 1 of the variables. Grey lines represent connections among nodes; the wider the line the higher the number of entries.

3. Chapter three - Ecosystem characterization and light diffusion of two Tropical Dry Forests (TDF)

3.1 Introduction

Net primary productivity is defined as the net amount of carbon fixed by plants through photosynthesis over time, which fundamentally influences the carbon cycle (Milesi et al. 2005). Given the need to create a strategy to understand the processes of net primary productivity in TDFs (Tropical Dry Forests), and the forces that drive the carbon cycle as an ecosystem service, it is imperative to characterize the biophysical components of these ecosystems as accurately as possible. Remote sensing is a fundamental tool for such characterization and monitoring, enabling us to study changes in ecosystems through time, and modeling current and future environmental scenarios (Barreda-Bautista et al. 2011).

According to Wilson and Meyers (2007), carbon flux processes are affected mainly by variations in vegetation properties (canopy height, biomass, and leaf area) over the soil surface, with leaf area being one of the key variables in the process of carbon and water exchange. In woody species, the leaf area provides key information on the exchange of energy, mass (e.g., water and CO_2), and momentum flux between the Earth's surface and the atmosphere (Morisette et al. 2006). Leaf area also has an impact on tree growth and recruitment through the interception of light, which in turn affects primary productivity (Gholz 1982; Mass et al. 1995).

The amount of foliage in the canopy is used as an indicator for primary productivity, light availability and other ecosystem processes (Asner et al. 2003; Bréda 2003; Eklundh et al. 2001). This variable can be measured using the Leaf Area Index (LAI), which is defined as the one-sided green leaf area per unit of ground area (Watson 1947; Bréda 2003; Morisette et al. 2006).

Leaves are the primary organs responsible for photosynthesis and transpiration and, as such, LAI is a key biophysical variable that can be linked to several land-atmosphere processes (Cournac et al. 2002). Changes in the LAI (by frost, storm, defoliation, drought, seasonality, and management practices) are accompanied by variations in primary productivity (Bréda 2003). LAI is used in most ecosystem productivity models and global models of climate, hydrology, and biogeochemistry (Morisette et al. 2006), and it is also used by ecophysiologists, managers (farmers and foresters), ecologists, and site and global modelers (Bréda 2003).

In deciduous forests like the TDFs, LAI varies seasonally, having a maximum value during the growing season when water is available and a minimum value at the end of the dry season (Mass et al. 1995; Kalacska et al. 2005a, 2005b). This minimum value of LAI will never reach zero since not all TDFs are 100% deciduous. Quantifying this temporal variation in LAI is important for understanding tropical ecosystem processes (Mass et al. 1995), however, data on temporal LAI variability is rare for TDFs (Kalacska et al. 2005a). Furthermore, LAI estimations in tropical regions are usually collected for old growth forests without considering the differences in canopy structure and the composition found in secondary forests (Lean and Rowntree 1993; Murphy and Lugo 1986; Weaver and Murphy 1990; Kalacska et al. 2005a).

The coefficient "K" for an accurate estimation of the LAI

Although many instruments exist to characterize LAI from the ground, these methods are often laborious and costly. Unlike most flux sensors that are designed to run in all weather conditions, most ground-based instruments to estimate LAI operate largely under conditions of no precipitation (Wilson and Meyers 2007). Measurements of LAI using traditional optical sensors (e.g., LAI-2000) also require multiple visits to the field under very specific sky conditions, making them unsuitable for inaccessible areas and forests with dense vegetation, as well as in areas where persistent sunny conditions are the norm.

Continuous estimations of LAI using remote sensors can be obtained as a function of the spectral Vegetation Indices (VIs), such as the Normalized Differential Vegetation Index (NDVI), or the Enhanced Vegetation Index (EVI). NDVI is currently the most widely used reflectance vegetation index (Pontailler et al. 2003). The NDVI allows us to estimate the amount and vigor of the vegetation that is present on the surface in a specific area (Holbem 1986). NDVI can be a sensitive indicator of the amount and vigor of the vegetation, because the two wavebands used to form this index represent the parts of the solar spectrum in which the Photosynthetically Active Radiation region takes place (PAR, 400nm to 700nm) (Carlson et al. 1994).

Remote sensing satellites (such as MODIS) offer a practical alternative for obtaining a good description of regional and global variation in NDVI. However, the use of MODIS could be improved substantially by calibrating the information using tower-based data that provide the effect of light on vegetation above and below the canopy (Wilson and Meyers 2007).

In this context, Wilson and Meyers (2007) proposed a "K" coefficient to characterize light use efficiency by the canopy, based on NDVI measurements derived from flux towers. This technique uses NDVI information based on solar and PAR fluxes from towers that are designed to measure vegetation indices above the canopy throughout the year (Wilson and Meyers 2007). This method has only been implemented in desert grasslands, temperate grasslands, crops, deciduous forests, and pine forests of North America. At present, estimates of the "K" coefficient do not exist for TDFs or any tropical forest in general. In addition, most studies only utilized a single dataset to establish LAI–NDVI relationships and have not taken the seasonal and year-to-year dynamics into account (Wang et al. 2005). Table 3.1 presents estimation of the "K" value for different vegetation across different ecosystems.

Current wireless sensor networks and optical phenology systems deployed in Costa Rica, Mexico, and Brazil by the Tropi-Dry research network (Pastorello et al. 2011) allow for the collection of information that can be used to estimate the "K" coefficient not only for the ecosystem *per se*, but it can be used also to calculate "K" for a given successional stage (e.g., early, intermediate, and late forest) taking into account the seasonal and year-to-year dynamics of the ecosystem. A successional stage is define here as the phase in which the forest is found during the process of regeneration (functional recovery of the community) depending on the structure, composition of species and functional traits (Quesada et al. 2009).

The systems deployed by Tropi-Dry across the Americas permit estimating a site-specific LAI derived from field measurements and from continuous NDVI tower measurements in real time. The former allows for the possibility of obtaining an accurate time series for the calibration of LAI that is not possible from other ground-based or coarse resolution, remote sensing techniques.

The main objective of this study was to characterize the light diffusion through the canopy as a variable associated with a key ecosystem service (Net Primary Productivity, NPP). In this paper the temporal change of this variable in two successional stages in a Costa Rican TDF is analyzed. The structure and composition of these forests is also studied to determine sensitivity of the "K" coefficient to structural changes during forest succession. I provide a new approach to estimate LAI and the temporal changes during the year, in a secondary TDF using the relationship between light diffusion through the canopy and VIs.

3.2 Methods

3.2.1 Study Area

The study was conducted in the TDF of Santa Rosa National Park in the Guanacaste Conservation Area (ACG) (Figure 3.1) in north-western Costa Rica (10º53' N, 85º38' W). The mean annual temperature is 26.6°C, and the mean annual precipitation is 1,390.8 mm (mean from January 2005 to December 2009) (Sánchez-Azofeifa et al. 2014). The dry season extends for 5 months from December to April, and the monthly water availability during the wet period exceeds 100 mm (Sánchez-Azofeifa et al. 2014). Rainfall seasonality is determined by the effect of the trade winds from the northeast and southwest, and the passing of the Inter Tropical Convergence Zone (Guzman and Calvo-Alvarado 2012).

The soils in Santa Rosa National Park exhibit high heterogeneity due to its volcanic origins (Carvajal-Vanegas and Calvo-Alvarado 2013). Entisols and Vertisols are the most common soil types followed by Mollisols, Alfisols, Inceptisols, and Ultisols (Guzman and Calvo-Alvarado 2012). The topography of the area under study is moderately flat, with an average slope of 7% (Sánchez-Azofeifa et al. 2014).

The park comprises secondary forests in various stages of regeneration with different land-use histories. Kalacska et al. (2004) described the historic land-use change of the successional stages found in Santa Rosa National Park. According to Kalacska et al. (2004), the early-stage forests grew after several intensive pasture fires that took place late in the 1980s; before that the areas were used for cattle pastures and crops. The intermediate-stage forests were never totally cleared. Timber extraction was done regularly from the 1800s to 1940. Between 1975 and 1980 light fires affected the region. No significant land cover changes have been reported since the 1980s.

3.2.2 Field measurements

A.) Forest characterization

I focused my work on two different types of forest succession: early and intermediate succession. In the early successional stage, one permanent plot (50 x 20 m) from the Tropi-Dry project was established in 2006 (10º52'10" N, 85º35'47" W) and a 1 ha permanent plot (100 x 100 m) was deployed in 2013 in the intermediate stage of succession (10º50'29" N, 85º36'56" W). These plots were divided into subplots of 10m x 10m. Field protocols for plot set up in TDFs, defined by the Tropi-Dry network were followed (Alvarez et al. 2008).

In both plots, I identified and measured the diameter at breast height (DBH) of all living woody stems with a DBH equal to or greater than 5 cm. I also measured the height of the tallest trees in each subplot using a telescopic pole (graduated pole). Data were collected in the dry season of March 2014.

The total number of individual trees present in 2014 in both plots was used to describe the structure and composition of the forest. Using these data, I analyzed the density of stems (No/ha), dominant height (m), basal area (m2), number of lianas, and the Shannon Diversity Index (H') (Magurran and McGill 2011). For characterizing ecosystem complexity, I computed the Holdridge Complexity Index (HCI) (Holdridge 1967). For this study, I used the modified version of the HCI, because I sampled trees with DBH > 5 cm (Lugo et al. 1978; Madeira et al. 2009). Species composition was also analyzed by calculating the Importance Value Index (IVI) (Curtis and McIntosh 1951) to determine the most frequent, dominant and abundant species in each successional stage.

B.) Optical phenology towers

The second component of this research involved the deployment of optical phenology towers. In the early successional stage plot, a 15m tower was deployed in 2009 and in the 1 ha plot in the intermediate stage of succession, a 20m tower was deployed in 2013. These optical phenology towers consisted of two solar radiation flux sensors (pyranometers), measuring wavelengths between 300 to 1,100 nm, and two Photosynthetically Active Radiation flux sensors (PAR sensors), which measure wavelengths between 400 to 700 nm (Pastorello et al. 2011). On each tower, one pyranometer and one PAR captured incoming radiation and the other pair captured reflected radiation by the vegetation above the canopy (Figure 3.2). Ratios of these measurements were used to derive vegetation indexes such as the NDVI and the EVI (e.g., Huemmrich et al. 1999; Jenkins et al. 2007; Wilson and Meyers 2007; Rocha and Shaver 2009).

According to Pastorello et al. (2011), these radiation flux sensors have view angles of 85º from the zenith or nadir (when oriented down), with a uniform 360º rotation. Given this, the radius of the field of view was approximately ten times the distance (h) between the sensor position and the surface being monitored (e.g., radius = tan(85º)*h). For the deployment, I had 5m between the top of the canopy and the sensors measuring the reflected radiation, leading to a coverage radius of at least 50m in the monitored area.

Both of these towers were deployed and managed under the standards of the Enviro-Net Project (http://www.enviro-net.org), which addresses a variety of issues related to in-situ (or ground-based) monitoring of ecosystems, from the deployment of sensors to the delivery of processed data products (Pastorello et al. 2011).

C.) Leaf Area Index

For the determination of the LAI, 3 plots (30 x 60 m) were established around each optical phenology tower. The early plots contained 165 points for measuring LAI and the intermediate stage plots contained 84 points (Appendix 4), following the methodology established by Kalacska et al. (2005a). The measurements were collected every month, using a Plant Canopy Analyzer (PCA) LAI-2000 (LI-COR, 1992). The LAI-2000 provided a measurement of the Plant Area Index (PAI) for each plot. The spacing between points of measurement varied between successional stages given that the area sampled by the LAI-2000 was largely dependent on the height of the canopy (Kalacska et al. 2005a). In the dry season, hemispherical photographs in each sampling point were taken, using a camera with a 180º lens (fish-eye) to calculate the Woody Area Index (WAI) (Sánchez-Azofeifa et al. 2009). Photographs and PAI measurements were taken at a height of 1.30 m above the forest floor, under conditions of diffuse light during sunrise or sunset, or on cloudy days to prevent direct incidence of sunlight on the lens. Measurements with the LAI-2000 took place in the early stage plots from March 2009 to May 2011. Measurements in the intermediate stage took place from February 2013 to March 2015.

The specific LAI was calculated for each plot (equation 1) by removing the contribution of WAI from PAI values (Kalacska et al. 2005a). The clumping factor (Ω), which was used in several studies to determine the LAI, was assumed to be 1 for practical reasons in this study, because this factor is significant only in forests with non-random foliage (Sánchez-Azofeifa et al. 2009, Huang et al. 2013).

$$\mathrm{LAI} = \frac{\mathrm{LAI_e}(1 - \mathrm{WAI})}{\Omega} \tag{1}$$

where WAI is the Woody Area Index, $\mathrm{LAI_e}$ is the PAI, and Ω refers to the clumping factor of the foliage at all scales (Leblanc and Chen 2001; Fournier et al. 2003; Huang et al. 2013).

I analyzed differences in WAI and LAI as a function of successional stage with a paired t-test assuming unequal variances (α=0.05). Normality of the data was tested using the

Kolmogorov-Smirnov test (Lilliefors 1967). Using the package e1071 in R (Karatzoglou et al. 2006), I constructed a SVM plot (Support Vector Machine) (Mountrakis et al. 2011; Durbha et al. 2007) to establish differences in LAI between successional stages during different months of the year and differences in LAI between successional stages with the changes of NDVI through the year. SVMs are useful in the remote sensing field due to their ability to successfully handle small training data sets, often producing higher classification accuracy than traditional methods (Mountrakis et al. 2011).

D.) Validation points

To validate my models, I sampled other measurements of PAI during the rainy season of 2014 using the LAI-2000 in different areas of the park within early stage forests and intermediate stage forests (Appendix 5). I collected 15 validation points in each successional stage in areas distant from the optical phenology towers. The LAIs values were collected (Figure 3.3) and calculated for each sampling point by removing the contribution of the WAI that was calculated previously in the early and intermediate plots.

E.) MODIS Data

Data for LAI, NDVI, and EVI derived from the MODIS/TERRA products were obtained for these plots from the ORNL DAAC (2012) using the coordinates of each plot. MODIS provides an 8-day composite LAI (product MOD15A2, collection 5) at a spatial resolution of 1 km x 1 km and a 16-day composite NDVI/EVI (product MOD13Q1, collection 5) at a spatial resolution of 0.25 km x 0.25km. LAI, NDVI, and EVI data were downloaded for each plot where the LAI-2000 was used and also for the validation points. MODIS NDVI/EVI data were downloaded to calculate the "K" coefficient using satellite data. MODIS LAI data were downloaded to compare with the LAI-2000 data and the estimated values of LAI derived from the calculated "K" coefficients.

MODIS data downloaded for the early stage plots were from March 2009 to May 2011 and for the intermediate stage plots from March 2013 to March 2015. The data obtained from MODIS for the validation points were downloaded for the rainy season of 2014.

3.2.3 Data Analysis

Using the information collected by the optical phenology towers in the plots, I calculated the Vegetation Indexes of NDVI and EVI2 for each successional stage using the formulas described in Table 3.2. For this study, only the measurements obtained between 10:00 and 14:00 hours were considered, filtering out cloudy days (including only data records when the measured incoming PAR is more than 900 microEinsteins (micro-mol per m^2/sec), and aggregating the data in daily averages (Pastorello et al. 2011).

Phenometrics (start of the growing season, end of the growing season, length of the growing season and peak of growing season) where calculated in the program TIMESAT (Jönsson and Eklundh 2002; Jönsson and Eklundh 2004; Eklundh and Jönsson 2015) using the Savitzky–Golay smoothing function to fit the NDVI data (Appendix 10). To determine the phenometrics I used only the NDVI data derived from the optical phenology tower deployed in the intermediate stage of succession.

To compare the potential of VI's to estimate the "K" coefficient; I correlated VI's with LAI using least-squares linear regression. Coefficients of determination (R^2) were used to assess their performance. For each site, VIs that showed the highest R^2 were selected for calculating the "K" coefficient.

To calculate "K" I used the VI data derived from the towers and the LAI data derived from the plots to solve equation (2) (Campbell and Norman 1998; Wilson and Meyers 2007):

$$\mathrm{LAI} = -K \log\left(\frac{\mathrm{VI}_{\max} - \mathrm{VI}_{i}}{\mathrm{VI}_{\max} - \mathrm{VI}_{\min}} \right) \tag{2}$$

where $\mathrm{VI}_{\max}$ corresponds to the average of VI values when the vegetation is dense; $\mathrm{VI}_{\min}$ is the average of VI measured during dry seasons, with leaf off; and VI_{i} is the mean of all changes in VI values during the rainy season. The value of the "K" coefficient was determined for each sample by rearranging equation (3):

$$-\frac{\mathrm{LAI}}{\log(\mathrm{b})} = K \tag{3}$$

where log(b) is given by: $\log(\mathrm{VI}_{\max}-\mathrm{VI}_{i})/(\mathrm{VI}_{\max}-\mathrm{VI}_{\min})$.

The "K" values were obtained for different days of the year (DOY) for each successional stage. I used nonlinear regression analysis to assess the variation of the "K" coefficient throughout the year. Using these models, I estimated the LAI using only the "K" values and the NDVI derived from the optical phenology towers, and the MODIS data using equation 4. The performance of the models was evaluated using the coefficient of determination (R^2), residuals analysis and the Root Mean Squared Error (RMSE). The higher the R^2 and the lower the RMSE, the better is the accuracy of the model to estimate LAI. RMSE was calculated using equation (4)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (\mathrm{x}_i - \mathrm{y}_i)^2}{\mathrm{n}}} \tag{4}$$

where x_i is the observed value and y_i is the estimated value of LAI, and n represents the number of observations.

To evaluate the estimation capability of the models, I examined the relationship between the observed LAI data using the LAI-2000 and MODIS LAI, against the estimated data of LAI using the "K" coefficients derived from the phenology towers, and from MODIS NDVI using least squares linear regression.

From the 15 validation points of LAI sampled in each successional stage during the rainy season (Appendix 5), I compared ground measurements (LAI-2000), against tower-derived LAI, MODIS NDVI derived LAI, and MODIS LAI values for the same days the sampling was conducted. For this, I compare mean values, variation of data and percentage of difference between the observed LAI values and estimated LAI values.

3.3 Results

Forest structure and composition

Results indicate that the TDF tends to become more complex as we advance through the successional stages and through time as documented by previous studies in this region (Kalacska et al. 2004; Carvajal-Vanegas and Calvo-Alvarado 2013). In the early succession plot, 1,200 stems (> 5cm in DBH) were sampled in 2014 and in the intermediate succession plot 1,136 stems (> 5cm in DBH) were sampled (Table 3.3). Total basal area was 6.9 m^2 in the early stage and 19.3 m^2 in the intermediate stage. The average dominant height was 8.2 in the early stage and 16.2 m in the intermediate stage. No lianas were found in the early stage plots, and 37 individuals of lianas (> 5cm in DBH) were found in the intermediate stage plots.

The most common families found in the early successional plots were Verbenaceae, Cochlospermaceae, and Bignoniaceae, with a total of 5 species (Table 3.4). In the intermediate stage Fabaceae, Malphigiaceae, and Malvaceae were the most common families with a total of 20 species.

The most abundant, dominant and frequent species in the early successional stage plot were *Rehdera trinervis* (Verbenaceae, IVI=113.5), *Cochlospermum vitifolium* (Cochlospermaceae, IVI=61.2), and *Byrsonima crassifolia* (Malphigiaceae, IVI=20.8). In the intermediate stage *Luehea speciosa* (Malvaceae, IVI=48.2), *Lonchocarpus minimiflorus* (Fabaceae, IVI=28.1), and *Guazuma ulmifolia* (Malvaceae, IVI=21.9) were the most abundant, dominant and frequent species.

The Shannon Diversity Index indicates that the early successional plot is a less diverse forest (H'=3.4) compared to the intermediate successional plot (H'=3.4). Moreover, the Holdridge Complexity Index, which integrates both dasometric variables and floristic variables (height, species, basal area, density), showed a forest structure very complex for the intermediate succession (HCI=106.2 ± 37.6), which contrasts with the poorly developed structure found in the early successional stage (HCI=18.6 ± 10.4).

Estimation of Woody Area Index and Leaf Area Index

The Woody Area Index derived from the hemispherical photographs was significantly different between the successional stages ($p<0.05$). The intermediate successional stage was found to have the largest amount of woody material (Appendix 6).

Leaf development exhibited large variations throughout the year for both successional stages according to the LAI (Figure 3.3). In general, LAI indicates a synchronous pattern of leaf production, development, and expansion. The lowest values for indices for both successional stages were observed in the dry season during February-April, and the highest values for the fully expanded phase were observed in the peak of the rainy season during August-October. Overall, LAI values were higher in the intermediate successional stage ($p<0.05$).

From the phenometric analysis (Appendix 10) we determined that the start of the growing season for the year 2013 was the day of the year 148 (May 28th 2013) and the end of the growing season the day 369 (January 4th 2014). The length of the growing season was of 221 days and the peak of the growing season was the day of the year 251 (September 8th 2013).

The SVM analyses (Figure 3.4) classified all the values of LAI in to the different successional stages, differentiating early successional stage from intermediate successional stage according to the month of the year or the average NDVI value for each month. Only for the dry season (from January - May) the SVM analysis did not obtain differences between the early successional stage and the intermediate successional stage.

Estimation of the light diffusion through the canopy

The spectral vegetation indices were correlated with LAI values in each successional stage using MODIS VIs and Optical Phenology Tower VIs. The best correlations with LAI (Figure 3.5) in the early successional stage were NDVI (R^2=0.85) for the tower-based data and MODIS NDVI (R^2=0.87) for satellite data. EVI2 and MODIS EVI produced the worst correlations (R^2=0.78 and R^2=0.58 respectively). In the intermediate successional stage, the best correlations with LAI were NDVI (R^2=0.87) for the tower-based data and MODIS NDVI (R^2=0.73) for satellite data. EVI2 and MODIS EVI were also the worst correlations (R^2=0.33 and R^2=0.67 respectively).

Table 3.5 presents results from the estimation of the "K" coefficient using equation 3. As expected, values of "K" were higher in the intermediate successional stage, lower in the early successional stage, and varied as a function of time (Figure 3.6). Maximum values occurred in September in both successional stages and minimum values occurred during the dry season (January-April). The average "K" coefficient for the growing season (End of May - beginning of December) was higher than 4 in the intermediate stage of succession and approximately 3 in the early stage of succession. Although "K" values using MODIS NDVI tend to be lower, there was no significant difference between the vegetation index (MODIS NDVI or Tower NDVI) used to estimate the "K" coefficient in the early stage (p=0.073) or in the intermediate stage (p=0.416).

For both successional stages, the values of R^2 (Table 3.6) were higher using the "K" coefficient from the phenology towers to determine LAI ($R^{2=}0.89$ in the early stage and $R^{2=}0.93$ in the intermediate stage). RMSE were also lower using the phenology tower data (RMSE=0.20 in the early stage, and RMSE=0.37 in the intermediate stage).

The strength of the relationship of the observed LAI (LAI-2000) and the estimated LAI derived from tower data was strong in the early successional stage and in the intermediate successional stage (R^2=0.89 and R^2=0.93 respectively) (Figure 3.7). This relationship was also strong for the observed LAI (LAI-2000) and the estimated LAI derived from MODIS NDVI in the early successional stage and in the intermediate successional stage (R^2=0.88 and R^2=0.93 respectively).

Moreover, the strength of the relationship of the observed MODIS LAI and the estimated LAI derived from tower data was weak in the early successional stage and in the intermediate successional stage (R^2=0.06 and R^2=0.38 respectively) (Figure 3.8). This relationship was also weak for the observed MODIS LAI and the estimated LAI derived from MODIS NDVI in the early successional stage and in the intermediate successional stage (R^2=0.04 and R^2=0.37 respectively).

Validation of models to estimate LAI

In the early successional stage the median of the ground measurements of LAI using the LAI-2000 (2.38 m2/m2) was close to the median of the tower-derived LAI (2.52 m2/m2) and the estimated LAI from MODIS NDVI (2.31 m2/m2). MODIS LAI, however, overestimated the values of LAI, producing a higher average (3.80 m2/m2) and greater variation in the data range (1.4 - 6.6 m2/m2) (Appendix 8).

The same pattern was revealed for the intermediate successional stage, where the median of the ground measurements of LAI using the LAI-2000 (4.20 m2/m2) was close to the tower-derived LAI (4.20 m2/m2) and the estimated LAI from MODIS NDVI (3.94 m2/m2). MODIS LAI also overestimated values of LAI, with a higher median (5.00 m2/m2) and greater variation in the data range (2.30 - 6.6 m2/m2) (Appendix 9).

There were no significant differences among LAI derived from the LAI-2000, tower-derived LAI, and MODIS NDVI derived LAI ($p>0.05$) for either successional stage. Moreover, the average percentage difference calculated was less than 22% for both successional stages using tower-derived LAI or MODIS NDVI derived LAI compared to the values of LAI-2000 (Figure 3.9). On the contrary, the MODIS LAI had a mean percentage difference of 96% in the early successional stage and a mean difference of 43% in the intermediate successional stage, compared to values for LAI-2000.

3.4 Discussion

Structure and composition of the successional stages

In terms of structure and composition, the plots fit the general description of early and intermediate stages of succession. For example, Carvajal-Vanegas and Calvo-Alvarado (2013), who worked in other permanent plots in Santa Rosa National Park, found the early stage of succession to be dominated by the plant families Verbenaceae and Cochlospermaceae, while the intermediate stage was dominated by the families Fabaceae and Malvaceae. According to Gillespie et al. (2000), Fabaceae is the most dominant family in Central American tropical dry forests, such as in the dry forests of Guanacaste, Costa Rica (Palo Verde, Santa Rosa) and Nicaragua (La Flor, Chacocente, Ometepe Island, Masaya National Park, Cosiguina) (Gillespie et al. 2000).

Carvajal-Vanegas and Calvo-Alvarado (2013) also found the dominant height of the canopy (9.9m in early stages and 17m in intermediate stages) was similar to my results. The basal area found in my study (19.29 m2 in the intermediate stage) was within the range of 17–40 m^2 per hectare found for old-growth TDFs across the world (Murphy and Lugo 1986).

The Shannon Diversity Index and the Holdridge Complexity Index indicated a more dynamic and complex intermediate successional stage in species composition and structure than the early stage, which was less developed structurally and possessed fewer species. Calvo-Rodriguez et al. (2012) documented a similar difference between an early stage and an intermediate stage of succession in a TDF in Brazil. Kalacska et al. (2004) also found a lower Shannon Diversity Index and the Holdridge Complexity Index for early successional stage plots in Santa Rosa National Park, which differed significantly from the intermediate and late stage plots analyzed in her study. It is expected that species diversity and the complexity of the forest increases through plant succession and recovery of the forest. Time since abandonment of the site is a major factor that influences these changes, but it could also be influenced by land use history, landscape (e.g., availability and proximity of seed sources, pollinators), and the biophysical factors specific to each forest stage (Chazdon et al. 2007; Condit et al. 1999). For Quesada et al. (2009) the main mechanisms of succession and regeneration of TDF are still unknown but an important aspect to be considered in the process is the functional response of the community, in which certain plant groups that share specific plant functional traits are more likely to be represented in a particular successional stage (Quesada et al. 2009).

Differences in Woody Area Index and Leaf Area Index among successional stages

Generally, the results of my study indicate that the intermediate stage had the highest values for WAI and LAI compared with the early stage of succession; this was especially true during the rainy season, when LAI values could be significantly different among successional stages. These comparative results of WAI and LAI between successional stages are consistent with other results from TDFs. For instance, Kalacska et al. (2005a) also found the highest LAI values in the intermediate stage during the rainy season (September) and higher values of WAI in the intermediate stage plots in Santa Rosa, Costa Rica. Huang et al. (2013) found highest values for WAI and LAI in the intermediate stage of succession in Chamela–Cuixmala Biosphere Reserve, Mexico, which were significantly different from early and late stages of succession.

Variation in the LAI data was greater in the early stage of succession (Figure 3.5) during all the years of the study, although the variation in the data was less during the seasonal transitional months. On the contrary, I observed less variation in the LAI data during the intermediate stage, except in the transitional months when the variation increased. In these transitional months, trees and lianas began losing leaves (January - February) or leaves started to flush (June - July). Differences in LAI values from successional stages are expected due to dissimilarity in species composition, species richness, species dominance, canopy structure, land use history, seasonality, soil moisture, and microclimate (Kalacska et al. 2005a; Sánchez-Azofeifa et al. 2009; Huang et al. 2013).

Kalacska et al. (2004) noted that the majority of the vegetation in the early stage in Santa Rosa belonged to pioneer tree guilds, with few species from the intermediate guild and, as a result, the majority of the foliage was lost early in the transitional season. In addition, the canopy of the early successional stage is more open and exposed to the effects of wind (Kalacska et al. 2005a; Sánchez-Azofeifa et al. 2009).

The intermediate stage, in contrast, holds a greater number of individuals of trees and lianas per plot with larger diameters and heights (Sánchez-Azofeifa et al. 2009), which creates a more closed canopy. In addition, the intermediate stage contains a mixture of intermediate and some shade-tolerant guilds, with a few species that remains evergreen (Carvajal-Vanegas and Calvo-Alvarado 2013). This might cause a greater variation during the transitional months in the intermediate successional stage, when some tree species lose their leaves early in the dry season and others lose them late in the dry season. The same effect can happen in the transition for the rainy season, when some tree species flush their leaves early and others late in the season.

According to Lopezaraiza-Mikel et al. (2013), the early successional stage in Santa Rosa National Park contained a higher proportion of deciduous individuals and species (which lost their leaves during the dry season), whereas a greater proportion of trees maintained mid-to-full leaf coverage during 7–12 months of the year in the intermediate stage.

In general, average values of LAI for the fully expanded phase of leaves during the peak of the rainy season (LAI=2.49 in the early stage and LAI=4.74 in the intermediate stage) were very close to values reported for other TDFs in the rainy season. Kalacska et al. (2005a) reported values of 2.8 in the early stage and 4.6 in the intermediate stage for other plots in Santa Rosa National Park. Huang et al. (2013) reported values of 2.17 for the early stage and 3.64 for the intermediate successional stage in the TDF of Chamela–Cuixmala Biosphere Reserve.

LAI-VI relationship and light diffusion through the canopy

A strong correlation between vegetation indices and LAI demonstrates that it is possible to obtain accurate LAI values for TDF ecosystems based on spectral features of vegetation derived from optical phenology towers. The LAI data calculated from ground measurements were correlated with tower-based VIs and with MODIS VIs. NDVI (tower-based data) and MODIS NDVI (satellite data) had the highest correlations with ground LAI in the early and intermediate stages. The EVI2 from the tower and the EVI from MODIS had the lowest correlations with the LAI. Wang et al. (2005) also found a better relationship between MODIS NDVI and LAI than between MODIS EVI and EVI in a deciduous forest.

Using the selected best predictors to calculate the "K" coefficient, I obtained values of "K" for the early and intermediate stages. Values were variable throughout the year, and in the rainy season they tended to be higher (3.28 and 2.90 in the early stage, 4.89 and 4.41 in the intermediate stage, using tower NDVI and MODIS NDVI, respectively). The "K" coefficient also varied along the successional gradient, indicating its usefulness in detecting, modeling, and monitoring studies in secondary TDFs. Values of "K" greater than 1 have been detected: Wilson and Meyers (2007), who used an approach similar to that of my study found values of 4.3 in temperate deciduous forest and values of 1.0 to 1.8 in temperate grasslands, Chasmer et al. (2008) found values of "K" of 3.90 in a boreal young pine forests.

Values of "K" derived from the towers were higher than "K" values derived from MODIS. Although there was no statistical difference between these values, variation can be explained by the lower values of NDVI found in MODIS data. Differences between NDVI values measured from the ground, and determined from satellites have been reported in the literature (Wang et al. 2004; Jenkins et al. 2007; Wilson and Meyers 2007). Main variations in satellite NDVI data are due to atmospheric effects, strong effects of temporal sampling, remaining cloud cover, seasonality of vegetation and data processing (Wang et al. 2004). Also Hmimina et al. (2012) emphasize that ground-based NDVI measurements are acquired at constant viewing angles, while MODIS satellite measurements are acquired with different viewing geometries. Moreover, any comparison with spectral-based NDVI must recognize that the wavelength used for the satellite-derived NDVI (Rred: 610nm-680nm, and Rnir: 820nm-900nm) are quite different from those used in broadband NDVI calculations (Rred: 400-700nm, Rnir: 305-2800nm) (Tittebrand et al. 2009). All the mentioned above might cause discrepancies in "K" values derived from ground measurements or satellite data.

From the coefficients "K" determined in this study, I estimated LAI values and compared them with ground measurements. Both tower-derived estimations and MODIS-derived estimations using NDVI had a good correlation with ground LAI. On the contrary, MODIS LAI data overestimated values with a greater variability, resulting in a poor correlation with ground data and the estimated data from LAI. Huang (2013) also found poor correlations in the TDF of Mexico between MODIS-LAI and ground measurements of LAI.

Discrepancies in the MODIS LAI products have been addressed in the literature (Cohen et al. 2003; Douglas et al. 2006; Ahl et al. 2006; Fang et al. 2013; Huang et al. 2013). Subpixel mixture and biome misclassification are the main problems when using MODIS data (Tian et al. 2002; Fang et al. 2013). The MODIS LAI spatial resolution of 1 km x 1 km might represent an issue in secondary forests like Santa Rosa National Park, in which we have small patches of forest from different successional stages close to each other. Moreover, according to the MODIS land cover classification, the TDF of Santa Rosa National Park is classified as "woody savannas" and not as a deciduous forest. This misclassification is often found for TDFs, because leafless forests during the dry season have similar spectral signatures to pastures and savannas (Sanchez-Azofeifa et al. 2003).

The quality of MODIS LAI 8-day product also relies heavily on the weather conditions in tropical areas; it is especially difficult to have completely cloud-free conditions during the rainy season (Wu 2014). These unsolved problems might cause discrepancies in the comparison between MODIS products and tower-derived LAI (Wilson and Meyers 2007).

In contrast to MODIS LAI, numerous studies have reported a good relationship between the MODIS NDVI and ground measurements of phenological parameters (Wang et al. 2005; Fontana et al. 2008; Eklundh et al. 2011). Values of NDVI can differ between similar sites, depending on local environmental factors like understory type, litter amount, soil surface condition, humidity, and roughness (Lacaze et al. 1996). For satellite data, NDVI can also be affected by the presence of cloudy conditions and aerosols in the atmosphere (Wilson and Meyers 2007).

The good correspondence between LAI estimated from the optical towers and MODIS NDVI with the observed LAI was encouraging (Figure 7). Overall, values of "K" obtained from the NDVI of the optical phenology towers seemed to be more accurate for the estimation of LAI. According to Wilson and Meyers (2007), tower-derived NDVI is less affected by cloudy conditions, because continuous 30-min measurements of incoming solar radiation at the flux towers allows the investigator to directly identify and to remove cloudy data points in the derivation of NDVI.

The significance of my study is that I provide for the first time a method to derive continuous LAI measurements from optical phenology towers deployed in different successional stages of the TDF. The treatment of the "K" coefficient and LAI as variables rather than constants over time is an improvement to reduce serious deviations in the LAI estimation in TDFs and, thereby, in estimates of carbon balances and primary productivity. These measurements provide simple and robust estimates of growing season phenology that are useful to productivity models and will greatly improve our understanding of ecosystem processes in TDFs. These data also provide information for validating satellite products and calibrating new algorithms for such products.

3.5 Conclusion

This study provides a methodology for the estimation of the LAI using the light diffusion through the canopy in two successional stages in a TDF. I demonstrate how vegetation indices derived from measurements obtained from optical phenology towers can be used as a tool for quantifying, monitoring, and detecting changes in canopy structure and primary productivity in secondary TDFs. In addition, I demonstrated how data derived from large-scale satellites, such as MODIS, might be limited by local climate conditions and must be used cautiously. However, LAI derived from satellite products can be improved following my methodology.

The models built in this study to estimate LAI can be used to obtain accurate and automated values continuously throughout the year for larger areas in different stages of plant succession in TDFs. These approaches can aid in the development of models for estimating primary productivity, energy, water, and carbon fluxes, in addition to complementing and validating satellite data. Quantifying and modeling these ecosystem processes could help us evaluate ecosystem services and develop sustainable practices for the appropriate management and conservation of TDFs.

3.6 References

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3.7 Figures and Tables

Table 3.1. Values of NDVI and "K" coefficient determined for different ecosystems.

Source	NDVImin	NDVImax	*K*	Ecosystem
Wilson and Meyers (2007)	0.90	0.30	4.30	Deciduous forest
	0.90	0.30	4.30	Deciduous forest
	0.90	0.30	4.30	Deciduous forest
	0.70	0.30	2.50	Pine forest
	0.85	0.25	1.50	Grassland
	0.80	0.25	1.70	Grassland
	0.80	0.25	1.80	Grassland
	0.80	0.30	1.00	Grassland
	0.60	0.15	0.70	Desert grass
	0.90	0.30	2.40	Cropland
	0.90	0.25	2.40	Cropland
Chasmer et al. (2008)	0.37	0.57	0.90	Pine seedlings
	0.31	0.56	3.90	Young pine forest

Table 3.2. Description and formulas of vegetation indices (VI's) used in this study.

VI	Wavebands	Equations	References
NDVI from phenology tower	1,2	(Rnir − Rred)/(Rnir + Rred)	Wilson and Meyers 2007
EVI2 from phenology tower	1,2	2.5(Rnir − Rred)/(1+Rnir+2.4Rred)	Rocha and Shaver 2009
MODIS NDVI	1,2	(Rnir − Rred)/(Rnir + Rred)	ORNL DAAC, 2012
MODIS EVI	1,2,3	2.5(Rnir − Rred)/(1+Rnir+6Rred-7.5Rblue)	ORNL DAAC 2012

Table 3.3. Summary of structure and composition variables found in 1 ha plots in the early and intermediate stages between 2013 and 2014 in Santa Rosa National Park.

Successional stage	**Stand age (years)**	**Dominant height (m)**	**Basal Area (m^2 ha^{-1})**	**Density (stems ha^{-1})**	**No. of lianas >5cm of DBH**	**HCI**	**H'**
Early	30	8.2	6.9	1200	0	18.6	2.0
Intermediate	60	16.2	19.3	1136	37	106.2	3.4

Table 3.4. Families with a composition higher than 5% (of the sampled individuals) and the number of species per family in the successional stages, Santa Rosa National Park.

Stage	Family	Composition (%)	No. Of species
Early	Verbenaceae	57.6	2
	Cochlospermaceae	30.0	1
	Malphigiaceae	12.0	2
Intermediate	Fabaceae	27.8	13
	Malphigiaceae	6.9	1
	Malvaceae	30.5	6

Table 3.5. The maximum, minimum, and seasonal changes in VIs ($NDVI_{max}$, $NDVI_{min}$ and $NDVI_i$) used to find the "K" coefficient in early and intermediate successional plots and the maximum and average "K" values found for the growing season in Santa Rosa National Park, Guanacaste.

Succession	NDVI	NDVImin	NDVImax	$NDVI_i$	K max	$\bar{K}$
Early Stage	**Tower**	0.52	0.69	0.66	3.28	2.84
	MODIS	0.54	0.79	0.77	2.90	2.51
Intermediate Stage	**Tower**	0.72	0.89	0.86	6.31	4.89
	MODIS	0.57	0.84	0.81	5.70	4.41

Table 3.6. Evaluation of the different methods to derive LAI in Santa Rosa National Park, Guanacaste.

Stage	**Method**	**Model to determine "K"**	**R^2**	**RMSE**
Early	Tower NDVI	$4.2+0.059(DOY)-1.15E-4(DOY^2)$	0.89	0.20
Early	MODIS NDVI	$3.41+0.047(DOY)-9.32E-5(DOY^2)$	0.80	0.26
Intermediate	Tower NDVI	$-8.50+0.103(DOY)-1.87E-4(DOY^2)$	0.93	0.37
Intermediate	MODIS NDVI	$-7.05+0.085(DOY)-1.54E-6\ (DOY^2)$	0.92	0.42

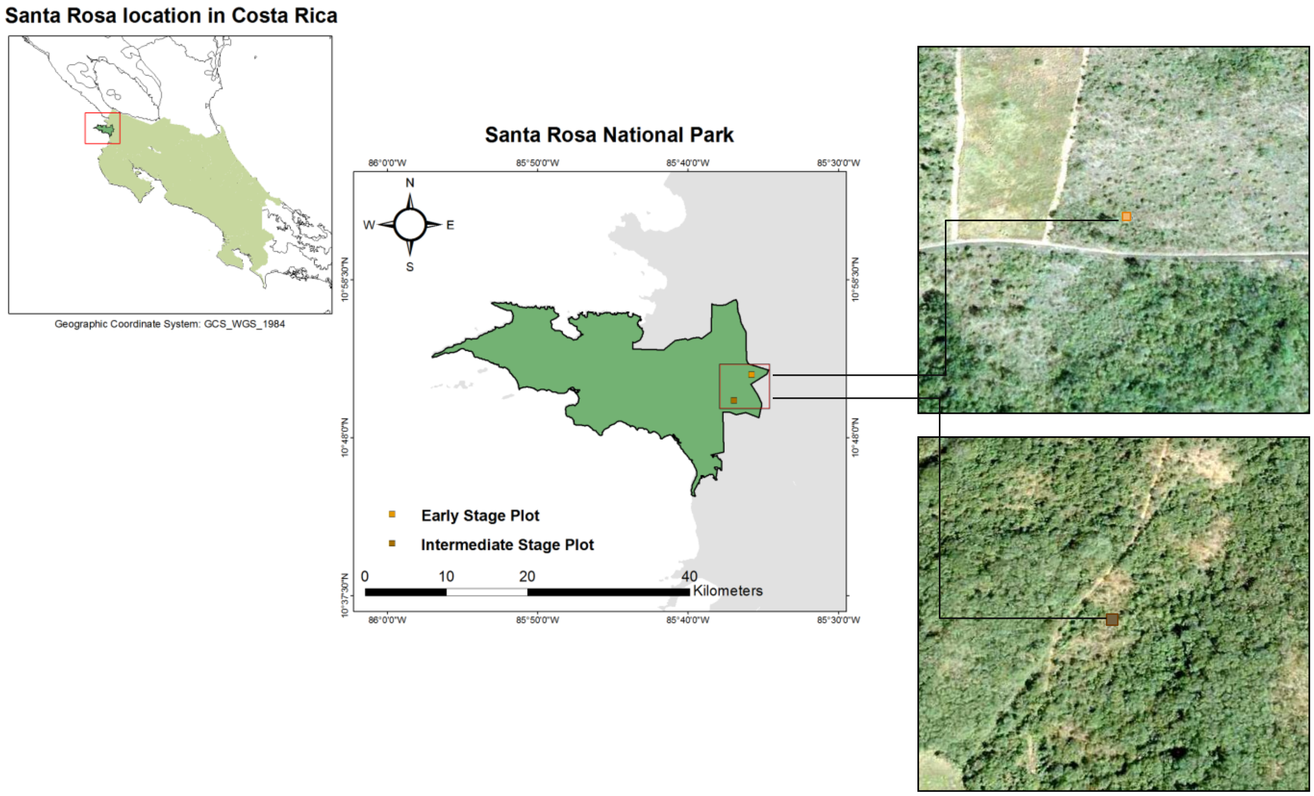

Figure 3.1. Location of Santa Rosa National Park in Costa Rica, and location of the plots used in this study inside the park. Source: Google Earth.

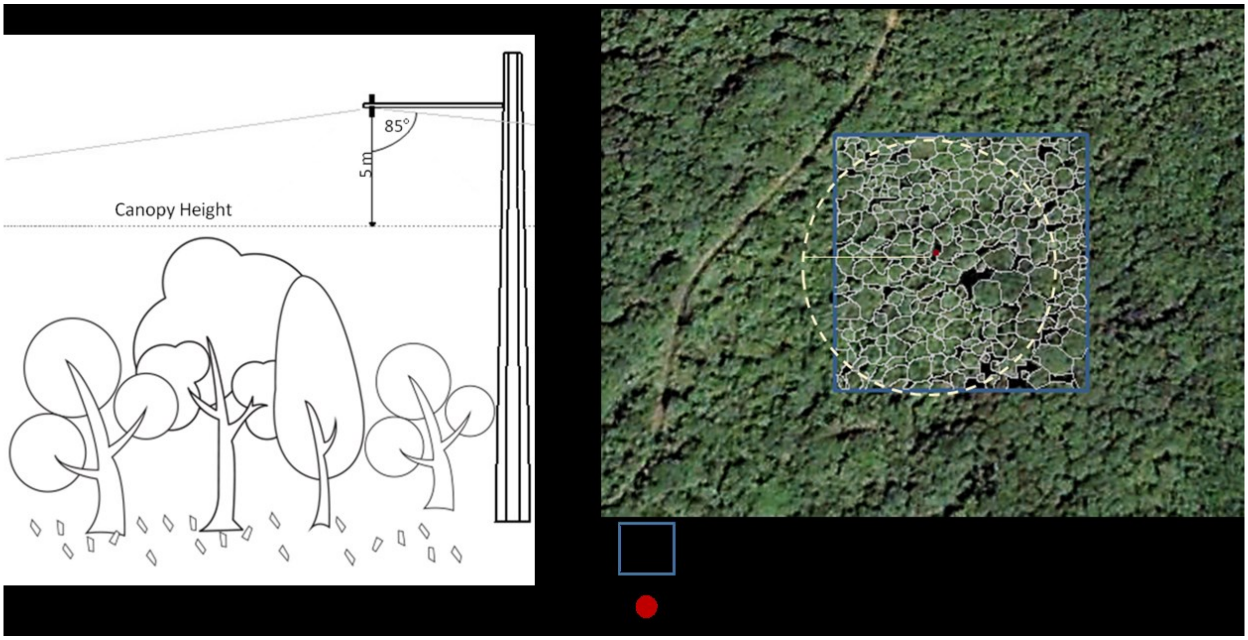

Figure 3.2. A schematic of the optical phenology towers deployment located in Santa Rosa National Park. Left panel is the ground view and right panel is the view from above with the delimitation of the canopy crowns. Source: Google Earth.

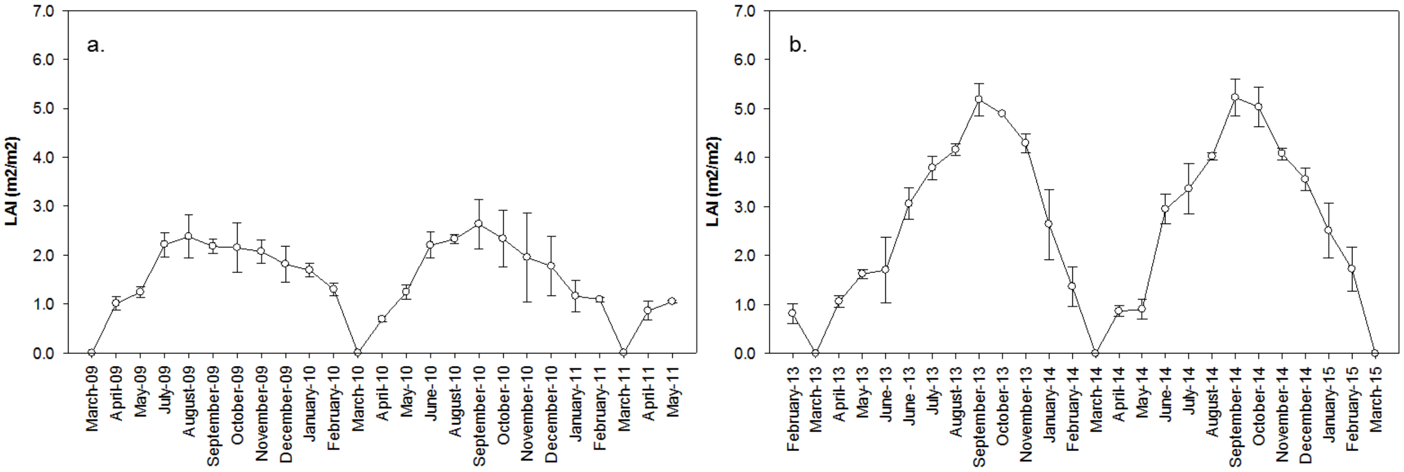

Figure 3.3. Mean values along with standard deviation of (A.) Leaf area index for the early successional stage (March 2009 - May 2011) and (B.) Leaf area index for the intermediate successional stage (February 2013 - March 2015) in Santa Rosa National Park. LAI values include correction for Woody Area Index (WAI).

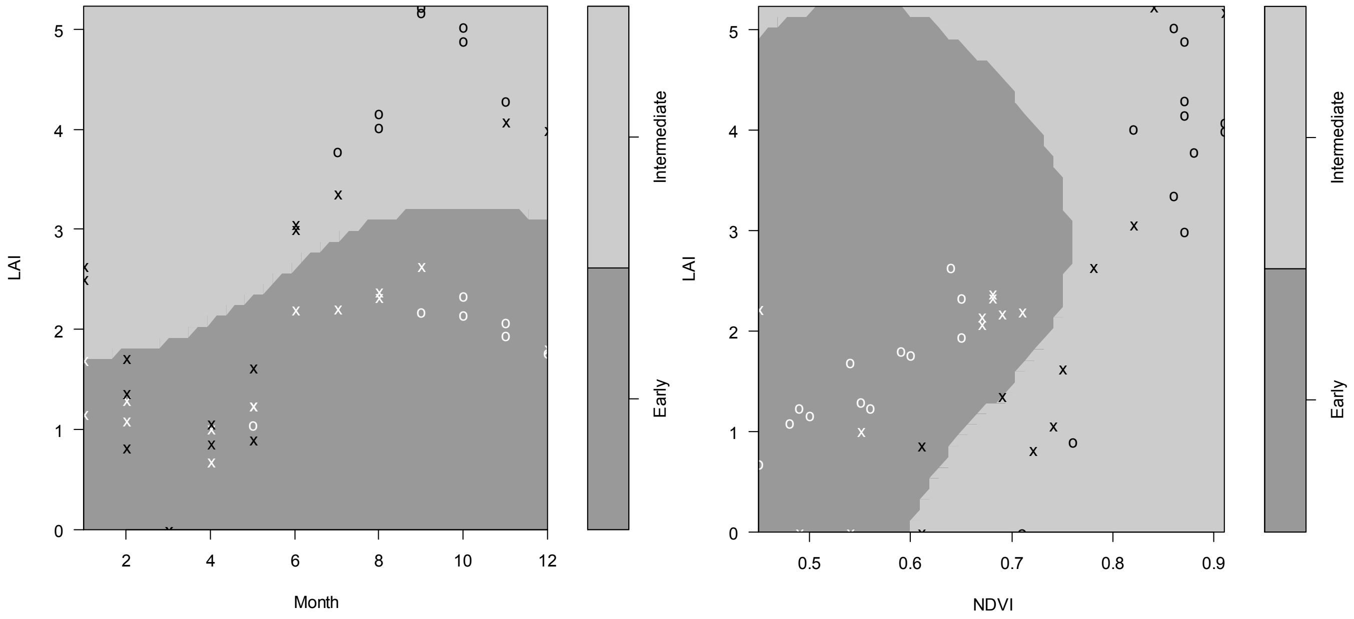

Figure 3.4. SVM analyses for the early successional stage and intermediate successional stage LAI data versus the month of the year (left panel) and LAI data versus the NDVI average values found for each month (right panel) from the optical phenology towers. White symbols represent values of the early successional stage, black symbols represent values of the intermediate successional stage. The dark grey curve represents the boundary found by the SVM algorithm to separate different classes. "X" represents the support vectors used to determine the boundary limits for the classification and "O" represents points not used to determine boundary limits.

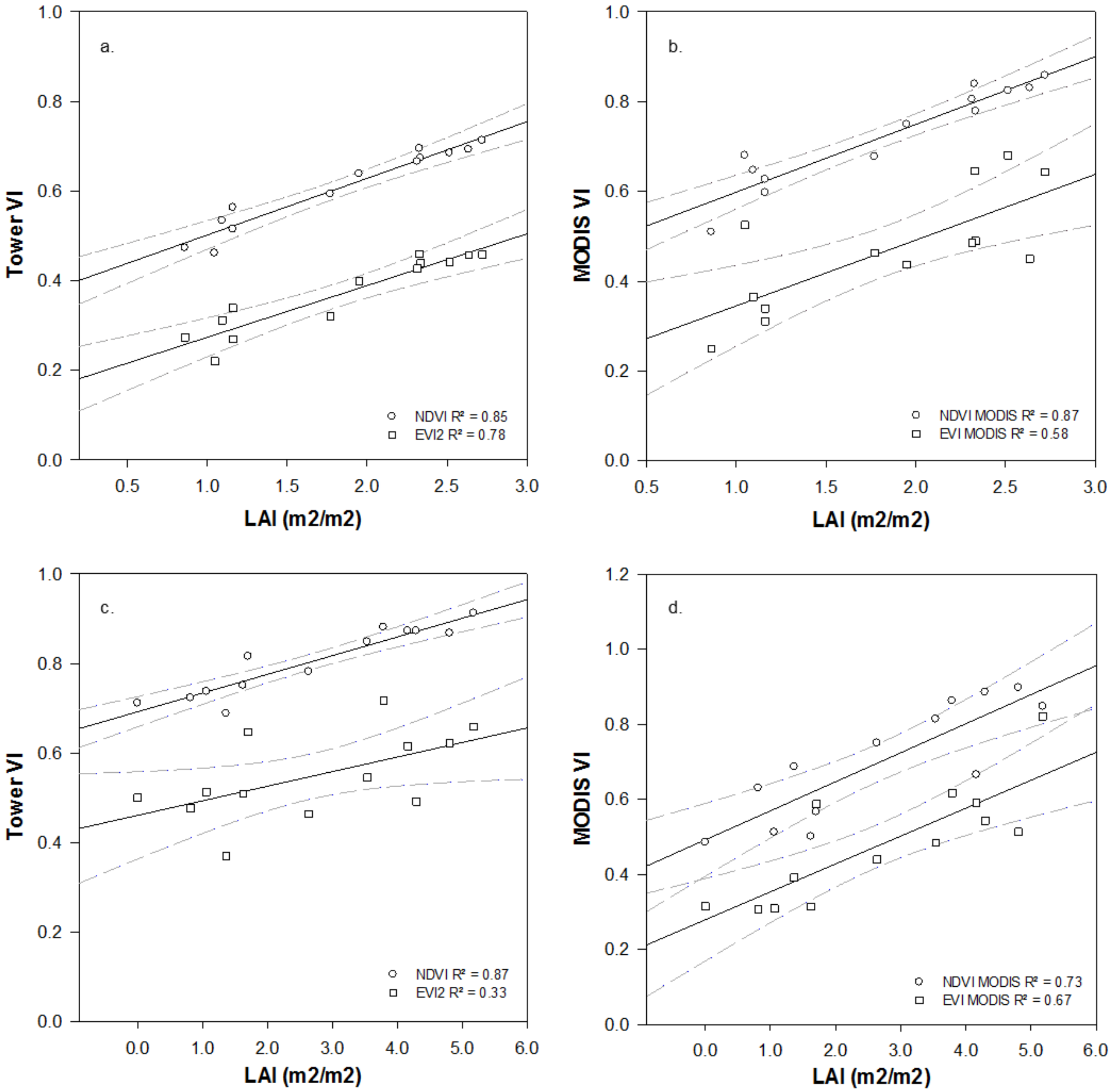

Figure 3.5. Correlations between Leaf Area Index and Vegetation Indices in early (a. and b.) and intermediate successional plots (c. and d.) in the Santa Rosa National Park, Guanacaste. Dashed lines represent the 99% confidence intervals.

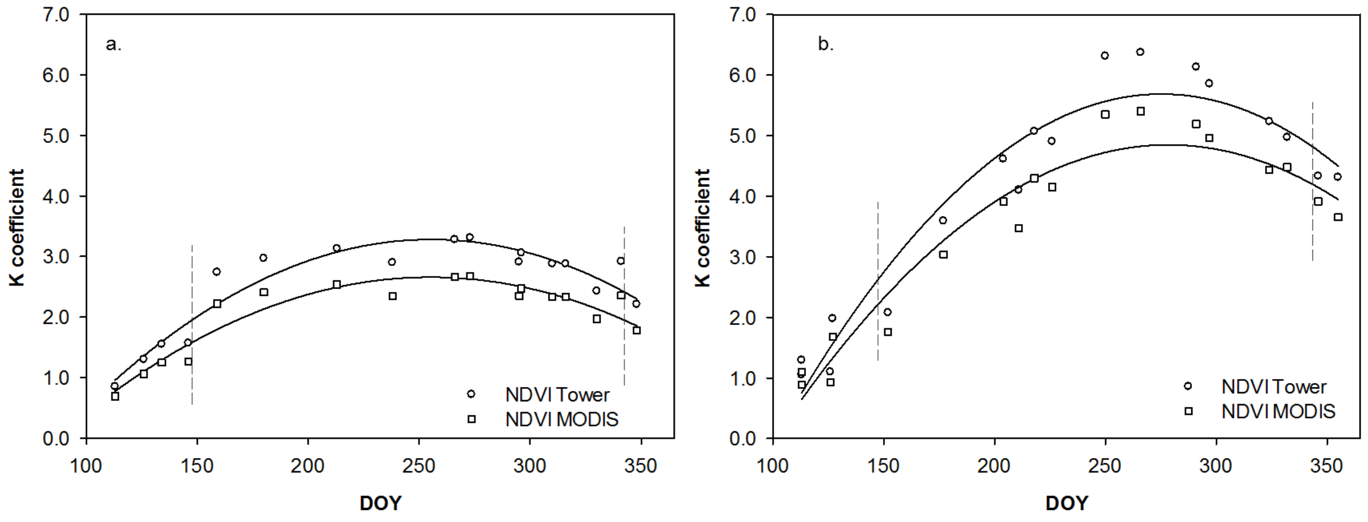

Figure 3.6. Variation of "K" coefficient during leaf growth phase and the fully-expanded leaf phase using the two best predictors from MODIS data and from tower-based data. Early successional plots (a.) and intermediate successional plots (b.) for Santa Rosa National Park, Guanacaste. Dashed lines inside the graphs indicate the start of the growing season and the end of the growing season according to the day of the year (DOY).

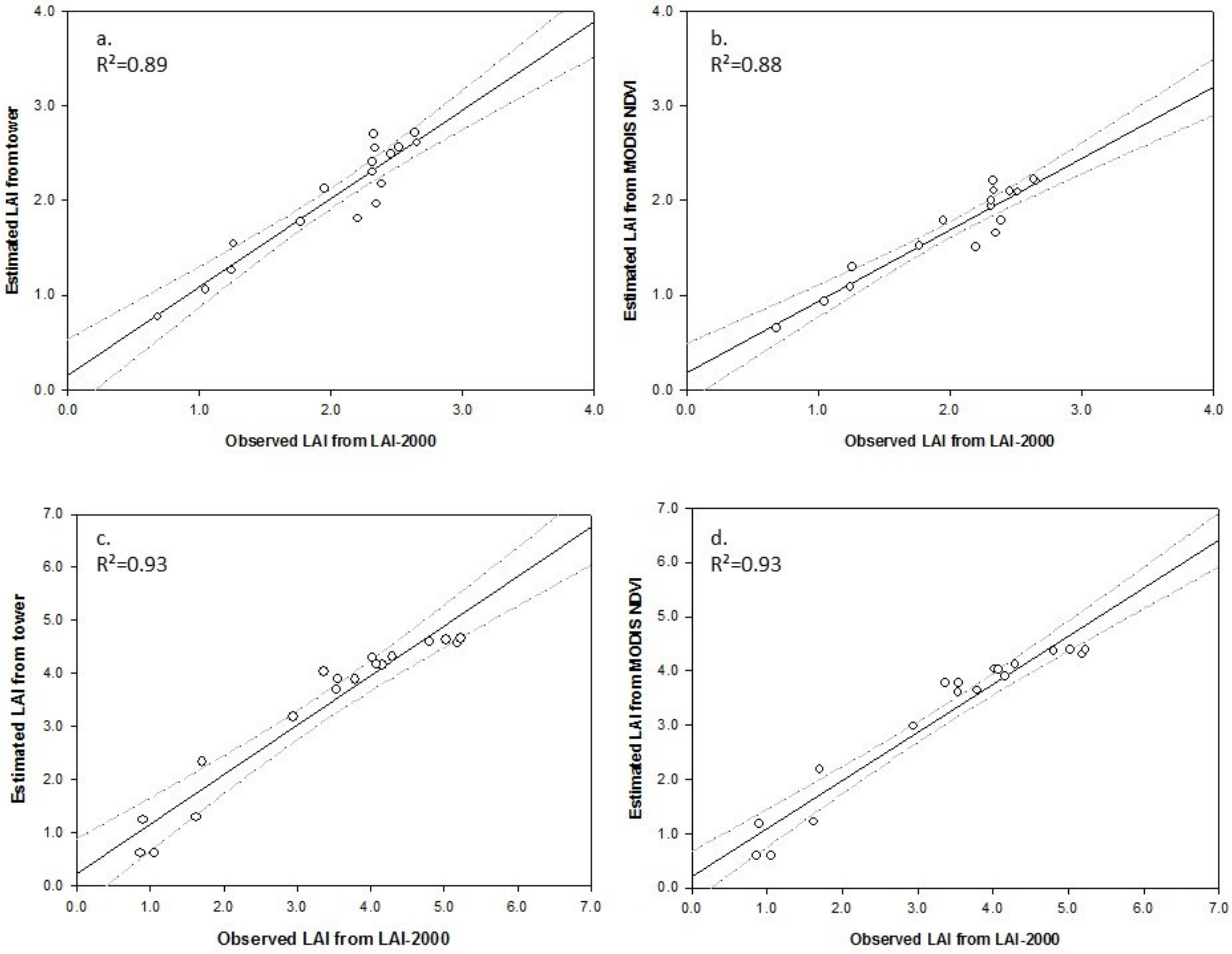

Figure 3.7. Evaluation of models used to estimate LAI versus measurements of LAI-2000 in the early successional stage (a.) and (b.) and in the intermediate successional stage (c.) and (d.). The solid lines represent the relations between estimated and measured values of LAI. Dashed lines represent the 99% confidence intervals. (The regressions where significant, $p<0.05$).

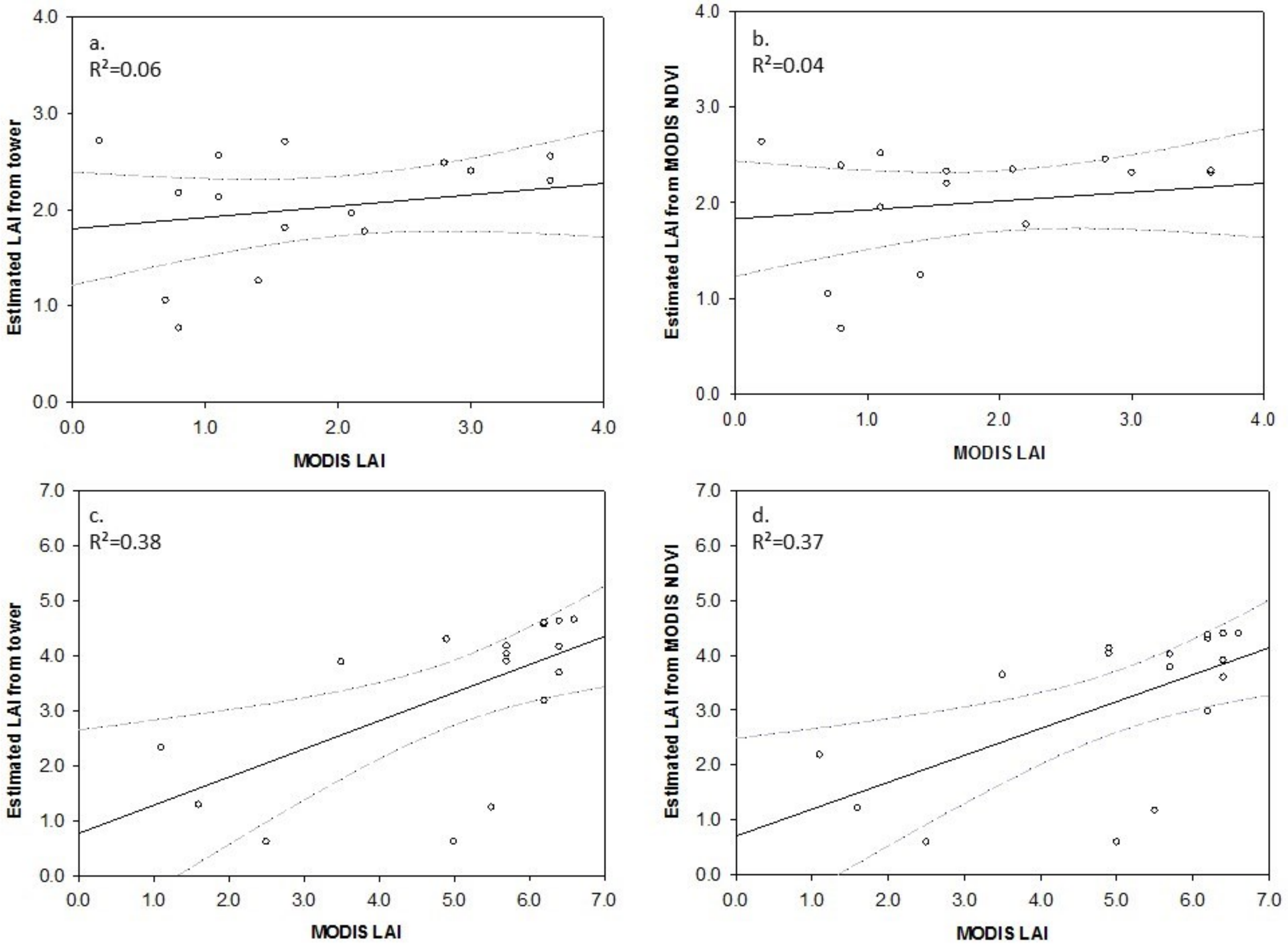

Figure 3.8. Evaluation of models used to estimate LAI versus measurements of MODIS LAI in the early successional stage (a.) and (b.) and in the intermediate successional stage (c.) and (d.). The solid lines represent the relations between estimated and measured values of LAI. Dashed lines represent the 99% confidence intervals. (The regressions where significant, $p<0.05$).

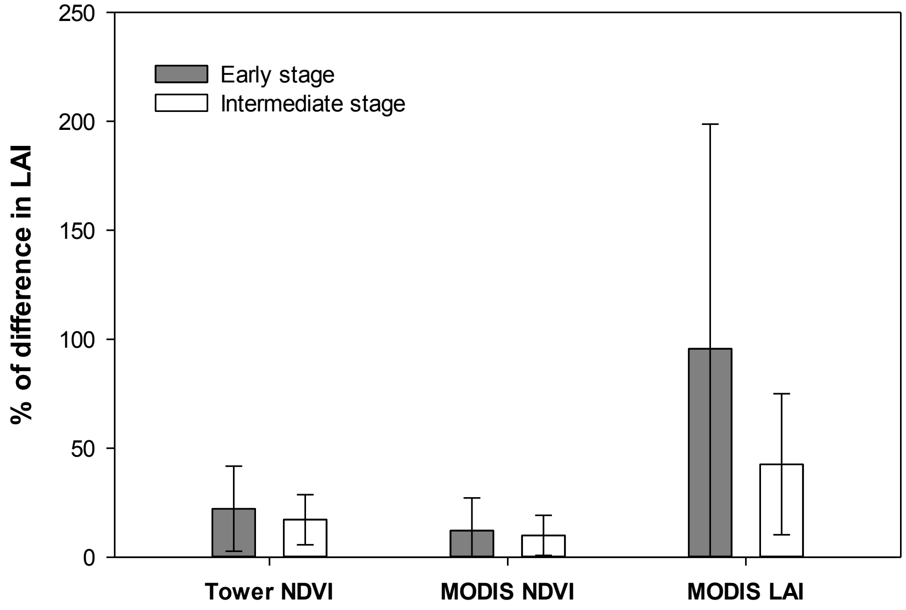

Figure 3.9. Percentage differences among the estimate of LAI using the tower NDVI, MODIS NDVI, and MODIS LAI compared with the ground measurements for the LAI-2000.

4. Chapter four - Conclusions and Future Work

The main objective of this thesis was to identify and integrate scientific knowledge of ecosystem characterization and quantification to assess ecosystem services (ES) in tropical dry forests (TDFs). By doing so, I identify main existing gaps and trends on the quantification of ES (provisioning, regulating and supporting) and potential approaches that can be used in TDFs. I also provide an innovative approach to assess a key ES (primary productivity) of different successional stages in a TDF.

4.1 Synthesis of significant contributions

The results from Chapter 2: "**Assessing Ecosystem Services in neotropical Dry Forests"** demonstrate that considerable efforts and research have been increasing in recent decades in the TDFs of America in order to quantify key biophysical variables that support the ES assessment of these forests.

Main trends in the analysis showed that provisioning and supporting services were the most studied services with a greater number of methodologies developed for their evaluation. Some of the most frequently studied services were genetic resources, primary production, carbon stocks, and biomass production. Other ES that are critical for the maintenance of ecosystems and human welfare, such as protection and provision of fresh water, air quality regulation, pest regulation, disease regulation, and erosion regulation were rarely addressed. There is a clear lack of formal research on many of these services.

Carbon storage and biodiversity have been the subjects of extensive research and methodologies in the region. On the contrary, water and soil lack from studies and methodologies for their services assessment. Most popular methods found to assess ES were literature reviews, remote sensing techniques, and forest and biodiversity inventories. Although there is no consensus among researches on how these variables and methodologies should be addressed, the important amount of information found could helps us developed a more integrated approach. Moreover emerging environmental data sharing, remote sensing techniques, and visualization tools can support ES modeling with high accuracy and lower costs (Bagstad et al. 2013).

Generally, my study reveals a clear need for an increase research in provisioning and regulating services of water and soil in TDFs regions, given the high demand for these services in the region, also the need to develop an integrated approach that allow us to assess more than one ES and studies evaluating and modeling ES in TDFs under climate change scenarios.

The study in Chapter 3: **"Ecosystem characterization and light diffusion of two Tropical Dry Forests (TDF)"** is the first to provide a methodology for the estimation of the LAI using the light diffusion through the canopy and the “K” coefficient in two different successional stages in a TDF. To date such studies were conducted only in temperate or boreal forest (Wilson and Meyers 2007; Chasmer et al. 2008). Existing studies only provided a constant value for this coefficient and not a variable value taking into account the seasonal and year-to-year dynamics of the ecosystem. This is a key element I address in my study, in which I analyzed how this coefficient changes during the year, depending on leaf development during the seasons and the structure and composition of the successional stage.

Moreover, I demonstrate how vegetation indices derived from measurements obtained from optical phenology towers can be used as a tool for quantifying, monitoring, and detecting changes in canopy structure and primary productivity in secondary TDFs. The deployment of these towers permit to estimate a site-specific LAI derived from continuous NDVI tower measurements in real time. The former allows for the possibility of obtaining an accurate time series of LAI that is not possible from other ground-based or coarse resolution, remote sensing techniques.

In addition, I demonstrated how data derived from large-scale satellites, such as MODIS, might be limited by local climate conditions, subpixel mixture and biome misclassification (Tian et al. 2002; Fang et al. 2013; Wu 2014) and must be used cautiously. These limitations can cause a poor estimation of the LAI, especially in the TDF, where the climatic conditions are not favorable during the rainy season (Wu 2014) and the land cover algorithms used in satellites, tends to misclassified this biome, because leafless forests during the dry season have similar spectral signatures to pastures and savannas (Sanchez-Azofeifa et al. 2003). However, in my study I demonstrated how the estimation of the LAI derived from satellite products can be improved for TDF by using the “K” coefficient calculated in this study.

This study represents an important contribution to characterize a key component (LAI) for the assessment of an ecosystem service (Net Primary Productivity, NPP) in TDFs. The models built in this study to estimate LAI can be used to obtain accurate and automated values continuously throughout the year for larger areas in different stages of forest succession in TDFs. This approach is going to be a useful tool in the development of models for estimating primary productivity, energy, water, and carbon fluxes, in addition to complementing and validating satellite data.

4.2 Future work and challenges

It is known that increases in global average temperature exceeding 1.5-2.5°C and in atmospheric carbon dioxide concentrations, will generate major changes in ecosystem structure and function, species ecological interactions, and species geographic ranges, with predominantly negative consequences for biodiversity, and ecosystem goods and services (e.g., water supply) (IPCC 2001). Some countries have made efforts to adapt, particularly through conservation of key ecosystems, early warning systems, risk management in agriculture, strategies for flood drought and coastal management, and disease surveillance systems. However, these efforts are affected in tropic regions by: lack of basic information, observation and monitoring systems; lack of capacity building and appropriate political, institutional and technological frameworks; low income; and settlements in vulnerable areas, among others (IPCC 2001).

For Balvanera et al. (2012) Latin America has a need for more interdisciplinary research on ES to integrate disciplines, communities, and stakeholders. This region still lacks ecological research produced by an unwilling position by academic institutions to address practical environmental problems, and there is an absence of effective bridges between the academic world and decision-makers (Ceballos et al. 2009). This lack of information and significant research dealing with ES in TDF became evident in my analysis and discussion of chapter 2.

Furthermore the assessment of ES is often conducted per service and the cross-sectoral analysis of ES in terms of their synergies and trade-offs needs to be further addressed (Maes et al. 2013). It is important to understand whether interactions are synergistic or competitive and which processes dominate at different scales. There is limited information on the effective management of services; thus it is unclear to what extent trade-offs and win-wins actually occur (Brauman et al. 2007).

There is still a need to create a standard process for quantifying and mapping ES for robust decision making, potential trade on markets and landscape planning (Crossman et al. 2012). From my study overall conclusions, it is clear that TDFs urge the development of an integrated approach using the available information, models created, and methodologies that allow us to assess more than one ES. This could become a powerful tool to assist decision-makers, landholders and government agencies to assess the ES provided by TDFs.

From the remote sensing point of view, addressed in chapter 3, more research in the future using technology as the optical phenology towers used in my study, could helped to improved the modeling and monitoring of TDF ecosystems processes. Ground-based optical sensor networks could provide a very powerful tool for the evaluation of ES provided by TDF with high accuracy, and provide continuous datasets to the public including decision-makers, landholders and government agencies, enabling them to make assertive decisions in real time to mitigate natural disasters and climate change effects. The use of these resources and technologies could help us save and protect not only the important resources and services we obtain from TDF, but it could also help us save ourselves from the environmental, economic and social impacts we might face in the future.

4.3 References

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Appendices

Appendix 1. Database of all collected studies found from the web research for the TDFs.

Measurment	MEA Service	Subcategory	Reference
Biodiversity	Provisioning services	Genetic resources	Aureli, F., Schaffner, C. M., Asensio, N., Lusseau, D. 2012. What is a Subgroup? how Socioecological Factors Influence Interindividual Distance. Behavioral Ecology. 23 (6): 1308-1315.
Soils	Supporting Services	Nutrient cycling	DeLonge, M., D'Odorico, P., Lawrence, D. 2008. Feedbacks between Phosphorus Deposition and Canopy Cover: The Emergence of Multiple Stable States in Tropical Dry Forests. Global Change Biology. 14 (1): 154-160. doi:10.1111/j.1365-2486.2007.01470.x.
Carbon	Regulating services	Carbon stocks	Gallardo-Cruz, J. Meave, A.J.A., González, E.J., Lebrija-Trejos, E.E., Romero-Romero, M.A., Pérez-García, E.A., Gallardo-Cruz, R., Hernández-Stefanoni, J.L., Martorell, C. 2012. Predicting Tropical Dry Forest Successional Attributes from Space: Is the Key Hidden in Image Texture? PloS One 7 (2): e30506.
Carbon	Provisioning services	Biomass production	Litton, C. M., Sandquist, D. R., Cordell, S. 2006. Effects of non-native grass invasion on aboveground carbon pools and tree population structure in a tropical dry forest of Hawaii. Forest ecology and management 231(1): 105-113.
Biodiversity	Supporting services	Primary production	Lugo, A. E., Medina, E., Trejo-Torres, J. C., Helmer, E. 2006. Botanical and Ecological Basis for the Resilience of Antillean Dry Forests. In Pennington, T.B., Ratter, J.A. Neotropical Savannas and Seasonally Dry Forests: Plant Diversity, Biogeography, and Conservation. pp 359.
Carbon	Provisioning services	Biomass production	Merlo, D. S., Harvey, C. A., Grijalva, A., Medina, A., Vilchez, S., Hernandez, B. 2005. Diversity, Composition and Structure of Vegetation in a Fragmented Landscape of Dry Forest in Rivas, Nicaragua. Recursos Naturales y Ambiente (45): 91-104.
Soils	Supporting Services	Soil formation	Restrepo, M. F., Florez, C. P., Osorio, N. W., León, J. D. 2013. Passive and active restoration strategies to activate soil biogeochemical nutrient cycles in a degraded tropical dry land. ISRN Soil Science 2013.
Biodiversity	Provisioning services	Biochemicals, natural medicines, and pharmaceuticals	Rico-Gray, V., Chemas, A., Mandujano, S. 1991. Uses of tropical deciduous forest species by the Yucatecan Maya. Agroforestry systems 14(2): 149-161.
Biodiversity	Provisioning services	Genetic resources	Sanchez-Azofeifa, G.A., Rivard, B., Wright, J., Feng, J., Li, P., Chong, M., Bohlman, S.A. 2011. Estimation of the Distribution of Tabebuia Guayacan (Bignoniaceae) using High-Resolution Remote Sensing Imagery. Sensors 11 (4): 3831-3851.
Biodiversity	Provisioning services	Genetic resources	Achury, R., Chacon de Ulloa, P., Arcila, A. 2012. Effects of the Heterogeneity of the Landscape and the Abundance of Wasmannia Auropunctata on Ground Ant Assemblages in a Colombian Tropical Dry Forest. Psyche (Cambridge). 2012: 1-12.
Biodiversity	Provisioning services	Genetic resources	Adamski, D., Boege, K. 2009. Two new species of Compsolechia meyrick (Lepidoptera: Gelechiidae) associated with Casearia (Flacourtiaceae) in coastal dry-forests of western Mexico. Proceedings Of The Entomological Society Of Washington 111: 305-321.
Biodiversity	Provisioning services	Genetic resources	Adler, G. H., Arboledo, J. J., Travi, B. L. 1997. Diversity and Abundance of Small Mammals in Degraded Tropical Dry Forest of Northern Colombia. Mammalia. 61 (3): 361-370.
Biodiversity	Provisioning services	Genetic resources	Agosta, S. J. 2010. Male Body Size and Mating Success and their Relation to Larval Host Plant History in the Moth Rothschildia Lebeau in Costa Rican Dry Forest. Biotropica. 42 (2): 201-207.
Soils	Supporting Services	Soil formation	Aguilar-Fernandez, M., Jaramillo, V. J., Varela-Fregoso, L., Gavito, M. E. 2009. Short-Term Consequences of Slash-and-Burn Practices on the Arbuscular Mycorrhizal Fungi of a Tropical Dry Forest. Mycorrhiza. 19 (3): 179-186.
Soils	Supporting Services	Primary production	Aguilar, F.M., Jaramillo, V.J., Varela-Fregoso, L., Gavito, M.E. 2009. Short-term consequences of slash-and-burn practices on the arbuscular mycorrhizal fungi of a tropical dry forest. Mycorrhiza 19: 179-186.

Soils	Provisioning services	Biomass production	Allen, M.F., Rincón, E., Allen, E.B., Huante, P., Dunn, J.J. 1993. Observations Of Canopy Bromeliad Roots Compared With Plants Rooted In Soils Of A Seasonal Tropical Forest, Chamela, Jalisco, Mexico. Mycorrhiza 4: 27-28.
Soils	Supporting Services	Primary production	Allen, E.B., Rincón, E., Allen, M.F., Pérez-Jiménez, A., Huante, P. 1998. Disturbance and seasonal dynamics of mycorrhizae in a tropical deciduos forest in Mexico. Biotropica 30: 261-274.
Biodiversity	Supporting services	Primary production	Alvarez-Anorve, M., Quesada, M., de la Barrera, E. 2008. Remote Sensing and Plant Functional Groups. In Kalacska, M., Sanchez-Azofeifa, G.A. (eds.). Physiology, Ecology, and Spectroscopy in Tropical Systems.
Biodiversity	Provisioning services	Genetic resources	Alvarez-Anorve, M. Y., Quesada, M., Sanchez-Azofeifa, G.A, Avila-Cabadilla, L. D., Gamon, J. A. 2012. Functional Regeneration and Spectral Reflectance of Trees during Succession in a Highly Diverse Tropical Dry Forest Ecosystem. American Journal of Botany. 99 (5): 816-826.
Soils	Supporting Services	Primary production	Alvarez-Aquino, C., Barradas-Sanchez, L., Ponce-Gonzalez, O., Williams-Linera, G. 2014. Soil Seed Bank, Seed Removal, and Germination in a Seasonally Dry Tropical Forest in Veracruz, Mexico. Botanical Sciences. 92 (1): 111-121.
Carbon	Provisioning services	Biomass production	Alvarez-Yepiz, J., Martinez-Yrizar, A., Burquez, A., Lindquist, C. 2008. Variation in Vegetation Structure and Soil Properties Related to Land use History of Old-Growth and Secondary Tropical Dry Forests in Northwestern Mexico. Forest Ecology and Management. 256 (3): 355-366.
Carbon	Supporting services	Primary production	Anaya, C. A., Garcia-Oliva, F., Jaramillo, V. J. 2007. Rainfall and Labile Carbon Availability Control Litter Nitrogen Dynamics in a Tropical Dry Forest. Oecologia. 150 (4): 602-610.
Water	Regulating services	Water regulation	Anaya, C. A., Jaramillo, V. J., Martinez-Yrizar, A., Garcia-Oliva, F. 2012. Large Rainfall Pulses Control Litter Decomposition in a Tropical Dry Forest: Evidence from an 8-Year Study. Ecosystems. 15 (4): 652-663.
Biodiversity	Provisioning services	Genetic resources	Andresen, E. 2005. Effects of season and vegetation type on community organization of dung beetles. Biotropica 37: 291-300.
Biodiversity	Provisioning services	Genetic resources	Andresen, E. 2008. Short-term temporal variability in the abundance of tropical dung beetles. Insect Conservation and Diversity 1: 120-124.
Biodiversity	Supporting services	Pollination	Apsit, V.J., Hamrick, J. L., Nason, J. D. 2001. Breeding Population Size of a Fragmented Population of a Costa Rican Dry Forest Tree Species. Journal of Heredity. 92 (5): 415-420. doi:10.1093/jhered/92.5.415.
Biodiversity	Provisioning services	Genetic resources	Arizmendi, M.C., Ornelas, F. 1990. Hummingbirds and their floral resources in a tropical dry forest in México. Biotropica 22: 172-180.
Biodiversity	Supporting services	Pollination	Arreguín-Sánchez, M., Palacios-Chávez, R., Quiroz-García, D.L. 1996. Pollen grain morphology of the family Bignoniaceae from the biological station at Chamela, Jalisco, Mexico. Phytologia 80: 8-22.
Biodiversity	Supporting services	Primary production	Arriaga, L., Leon, J. L. 1989. The Mexican Tropical Deciduous Forest of Baja-California-Sur a Floristic and Structural Approach. Vegetatio. 84 (1): 45-52.
Carbon	Regulating services	Carbon stocks	Arroyo-Mora, J.P., Sanchez-Azofeifa, G.A., Rivard, B., Calvo, J.C., Janzen, D.H. 2005. Dynamics in Landscape Structure and Composition for the Chorotega Region, Costa Rica from 1960 to 2000. Agriculture Ecosystems Environment. 106 (1): 27-39.
Carbon	Regulating services	Carbon stocks	Arroyo-Mora, J. P., Sanchez-Azofeifa, G. A., Kalacska, M., Rivard, B., Calvo-Alvarado, J. C., Janzen, D.H. 2005. Secondary Forest Detection in a Neotropical Dry Forest Landscape using Landsat 7 ETM+ and IKONOS Imagery. Biotropica. 37 (4): 497-507.
Biodiversity	Provisioning services	Genetic resources	Asensio, N., Lusseau, D., Schaffner, C.M., Aureli, F. 2012. Spider Monkeys use High-Quality Core Areas in a Tropical Dry Forest. Journal of Zoology. 287 (4): 250-258.
Biodiversity	Provisioning services	Genetic resources	Avila-Cabadilla, L.D., Stoner, K.S., Henry, M., Alvarez Anorve, M. 2009. Composition, Structure and Diversity of Phyllostomid Bat Assemblages in Different Successional Stages of a Tropical Dry Forest. Forest Ecology and Management. 258 (6): 986-996.

Biodiversity	Provisioning services	Genetic resources	Avila-Cabadilla, L.D, Sanchez-Azofeifa, G.A., Stoner, K.E, Alvarez-Anorve, M., Quesada, M., Portillo-Quintero, C. 2012. Local and Landscape Factors Determining Occurrence of Phyllostomid Bats in Tropical Secondary Forests. Plos One. 7 (4): e35228.
Biodiversity	Provisioning services	Genetic resources	Avila-Cabadilla, L.D., Stoner, K.E., Nassar, J.M., Espirito-Santo, M.M.DO., Alvarez-Anorve, M., Aranguren, C., Henry, M., Gonzalez-Carcacia, J.A., Falcao, L., Sanchez-Azofeifa, G.A. 2014. Phyllostomid Bat Occurrence in Successional Stages of Neotropical Dry Forests. Plos One. 9 (1): e84572.
Biodiversity	Provisioning services	Genetic resources	Ávila-Sakar, G., Domínguez, C. 2000. Parental effects and gender specialization in a tropical Heterostylous shrub. Evolution 54: 866-877.
Biodiversity	Provisioning services	Biochemicals, natural medicines, and pharmaceuticals	Baker, M. 1996. Fur Rubbing: Use of Medicinal Plants by Capuchin Monkeys (Cebus Capucinus). American Journal of Primatology. 38 (3): 263-270.
Carbon	Provisioning services	Biomass production	Balvanera, P., Aguirre, E. 2006. Tree Diversity, Environmental Heterogeneity, and Productivity in a Mexican Tropical Dry Forest. Biotropica. 38 (4): 479-491. doi:10.1111/j.1744-7429.2006.00161.x.
Biodiversity	Supporting services	Primary production	Balvanera, P., Lott, E., Segura, G., Siebe, C., Islas, A. 2002. Patterns of Beta-Diversity in a Mexican Tropical Dry Forest. Journal of Vegetation Science. 13 (2): 145-158. doi:10.1111/j.1654-1103.2002.tb02034.x.
Water	Supporting Services	Water cycling	Balvanera, P., Quijas, S., Pérez-Jiménez, A. 2010. Distribution patterns of tropical dry forest trees along a meso-scale water availability gradient. Biotropica. 43(4): 414-422. 10.1111/j.1744-7429.2010.00712.x.
Carbon	Provisioning services	Biomass production	Barajas-Morales, J. 1987. Wood specific gravity in species from two tropical forests in Mexico. IAWA Bulletin 8: 143-148.
Carbon	Provisioning services	Biomass production	Barajas-Morales, J., Pérez-Jímenez, L.A., Chiang, F. 1997. Seasonal Fluctuations Of Starch In Wood And Bark Of Trees From A Tropical Deciduous Forest In Mexico. Anales del Instituto de Biología (UNAM) serie Botánica 68: 7-19.
Carbon	Regulating services	Climate regulation	Barradas, V. L. 1991. Radiation Regime in a Tropical Dry Deciduous Forest in Western Mexico. Theoretical and Applied Climatology. 44 (1): 57-64.
Water	Supporting Services	Water cycling	Barradas, V., Fanjul, L. 1985. Equilibrio hídrico y evapotranspiración en una selva baja caducifolia de la costa de Jalisco, México. Biotica 10: 199-218.
Carbon	Regulating services	Climate regulation	Barradas, V. L., Adem, J. 1992. Albedo Model for a Tropical Dry Deciduous Forest in Western Mexico. International Journal of Biometeorology. 36 (2): 113-117.
Biodiversity	Provisioning services	Genetic resources	Barrantes, G., Sánchez, J. E. 2003. Geographical distribution, ecology, and conservation status of Costa Rican dry-forest avifauna. Biodiversity conservation in Costa Rica. Learning the lessons in a seasonal dry forest. University of California, Los Angeles, California, EEUU. pp 147-159.
Biodiversity	Provisioning services	Genetic resources	Bawa, K. 2004. Impact of Global Changes on the Reproductive Biology of Trees in Tropical Dry Forests. In Frankie, G.W., Mata, A., Vinson, S.B. (eds.). Potential Impacts of Climate Change on Tropical Forest Ecosystems. pp. 333-345.
Biodiversity	Provisioning services	Genetic resources	Becerra, J.X. 2005. Timing the origin and expansion of the Mexican tropical dry forest. Proceedings of the National Academy of Sciences of the United States of America 102: 10919-10923.
Carbon	Provisioning services	Biomass production	Becknell, J.M., Kissing, L.K., Powers, J. 2012. Aboveground Biomass in Mature and Secondary Seasonally Dry Tropical Forests: A Literature Review and Global Synthesis. Forest Ecology and Management. 276: 88-95. doi:10.1016/j.foreco.2012.03.033.
Soils	Provisioning services	Biomass production	Becknell, J.M. Powers, J. 2014. Stand Age and Soils as Drivers of Plant Functional Traits and Aboveground Biomass in Secondary Tropical Dry Forest. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere. 44 (6): 604-613.

Soils	Supporting Services	Nutrient cycling	Bejarano, M., Etchevers, J., Ruiz-Suarez, G., Campo, J. 2014. The Effects of Increased N Input on Soil C and N Dynamics in Seasonally Dry Tropical Forests: An Experimental Approach. Applied Soil Ecology. 73: 105-115.
Biodiversity	Provisioning services	Genetic resources	Birch, J.C., Newton, A., Alvarez Aquino, C., Cantarello, E., Echeverria, C., Kitzberger, T., Schiappacasse, I., Tejedor Garavito, N. 2010. Cost-Effectiveness of Dryland Forest Restoration Evaluated by Spatial Analysis of Ecosystem Services. Proceedings of the National Academy of Sciences of the United States of America. 107 (50): 21925-21930.
Biodiversity	Supporting services	Primary production	Boege, K. 2004. Induced responses in three tropical dry forest plant species-direct and indirec effects on herbibory. Oikos 107: 541-548.
Biodiversity	Supporting services	Primary production	Boege, K. 2005. Herbivore attack in Casearia nitida influenced by plant ontogenetic variation in foliage quality and plant architecture. Oecologia 143: 117-125.
Biodiversity	Supporting services	Primary production	Boege, K. 2005. Influence of plant ontogeny on compensation to leaf damage. American Journal of Botany 92: 1632-1640.
Biodiversity	Supporting services	Primary production	Boege, K., Marquis, R.J. 2005. Facing herbivory as you grow up: the ontogeny of resistance in plants. Trends in Ecology and Evolution 20: 441-448.
Biodiversity	Supporting services	Primary production	Boege, K., Marquis, R.J. 2006. Plant quality and predation risk mediated by plant ontogeny: consequences for herbivores and plants. Oikos 115: 559-572.
Biodiversity	Provisioning services	Genetic resources	Boom-Urueta, C., Seña-Ramos, L., Vargas-Zapata, M., Martínez-Hernández, N. 2013. Butterflies papilionoidea and hesperioidea (insecta: lepidoptera) in the reserva ecológica luriza (rel), atlantico, Colombia. Boletín Científico. Centro de Museos. Museo de Historia Natural. 17(1): 149-167.
Water	Supporting Services	Water cycling	Borchert, R. 1994. Soil and Stem Water Storage Determine Phenology and Distribution of Tropical Dry Forest Trees. Ecology. 75 (5): 1437-1449.
Water	Supporting Services	Water cycling	Borchert, R. 1994. Induction of Rehydration and Bud Break by Irrigation Or Rain in Deciduous Trees of a Tropical Dry Forest in Costa-Rica. Trees-Structure and Function. 8 (4): 198-204.
Water	Regulating services	Natural hazard regulation	Borchert, R. 1999. Climatic Periodicity, Phenology, and Cambium Activity in Tropical Dry Forest Trees. Iawa Journal. 20 (3): 239-247.
Water	Supporting Services	Water cycling	Borchert, R., Rivera, G., Hagnauer, W. 2002. Modification of Vegetative Phenology in a Tropical Semi-Deciduous Forest by Abnormal Drought and Rain. Biotropica. 34 (1): 27-39. doi:10.1111/j.1744-7429.2002.tb00239.x.
Biodiversity	Supporting services	Pollination	Borchert, R., Meyer, S.A., Felger, R.S Porter-Bolland, L. 2004. Environmental Control of Flowering Periodicity in Costa Rican and Mexican Tropical Dry Forests. Global Ecology and Biogeography. 13 (5): 409-425.
Biodiversity	Provisioning services	Genetic resources	Borrego, A., Skutsch, M. 2014. Estimating the Opportunity Costs of Activities that Cause Degradation in Tropical Dry Forest: Implications for REDD. Ecological Economics. 101: 1-9. doi:10.1016/j.ecolecon.2014.02.005.
Water	Regulating services	Natural hazard regulation	Brenes-Arguedas, T., Coley, P.D., Kursar, T. 2009. Pests Vs. Drought as Determinants of Plant Distribution Along a Tropical Rainfall Gradient. Ecology. 90 (7): 1751-1761. doi:10.1890/08-1271.1.
Biodiversity	Provisioning services	Genetic resources	Briones-Salas, M., Sánchez-Cordero, V., Sánchez-Rojas, G. 2006. Multi-species fruit and seed removal in a tropical deciduos forest in México. Canadian Journal of Botany 84: 433-442.
Water	Supporting Services	Water cycling	Brodribb, T. J., Holbrook, N. M., Gutierrez, M. V. 2002. Hydraulic and photosynthetic co-ordination in seasonally dry tropical forest trees. Plant, Cell Environment. 25(11): 1435-1444.
Biodiversity	Supporting services	Pollination	Bullock, S.H. 1985. Breeding systems in the flora of a tropical deciduous forest in Mexico. Biotropica 17: 287-301.
Carbon	Regulating services	Climate regulation	Bullock, S.H. 1986. Climate Of Chamela, Jalisco, And Trends In The South Coastal Region Of Mexico. Archives for Meteorology Geophysics and Bioclimatology aeries B-Theoretical and Applied Climatology 36: 297-316.

Biodiversity	Supporting services	Pollination	Bullock, S.H. 1986. Observations and an experiment on synchronous flowering. Madroño 33: 223-224.
Biodiversity	Supporting services	Primary production	Bullock, S.H. 1988. Physical and biological environmental features of chamela jalisco mexico. Folia Entomológica Mexicana 77: 5 - 17.
Carbon	Provisioning services	Biomass production	Bullock, S.H. 1990. Abundance and allometrics of vines and self-supporting plants in a tropical deciduous forest. Biotropica 22: 106-109.
Biodiversity	Supporting services	Pollination	Bullock, S.H. 1994. Wind Pollination Of Neotropical Dioecious Trees. Biotropica 26: 172-179.
Water	Regulating services	Natural hazard regulation	Bullock, S.H. 1997. Effects of seasonal rainfall on radial growth in two tropical tree species. International Journal of Biometeorology 41: 13-16.
Biodiversity	Provisioning services	Genetic resources	Bullock, S.H. 1999. Relationships among body size, wing size and mass in bees from a tropical dry forest in Mexico. Journal of the Kansas Entomological Society 72: 426-439.
Carbon	Provisioning services	Biomass production	Bullock, S.H. 2000. Developmental patterns of tree dimensions in a neotropical deciduous forest. Biotropica 32: 42-52.
Carbon	Provisioning services	Biomass production	Bullock, S.H., Martijena del Río, N.E. 1998. Growth and reproduction in forest trees of the Cactus Opuntia excelsa. Biotropica 30: 553-558.
Carbon	Supporting services	Primary production	Bullock, S.H., Solís-Magallanes, J.A. 1990. Phenology of canopy trees of a tropical deciduous forest in Mexico. Biotropica 22: 22-35.
Biodiversity	Supporting services	Pollination	Bullock, S.H., Martijena del Río, N.E., Ayala, R. 1989. Bee visitation rates to trees of Prockia crucis differing in flower number. Oecologia 78: 389-393.
Biodiversity	Supporting services	Pollination	Bullock, S.H., Ayala, R., Rodríguez González, G., Palacios Chávez, R., Ramos Zamora, D., Quiroz García., D.I., ArreguinSánchez, M.D. 1991. Nest Provision And Pollen Foraging In 3 Mexican Species Of Solitary Bees (Hymenoptera, Apoidea). Pan-Pacific Entomologist 67: 171-176.
Biodiversity	Provisioning services	Genetic resources	Bullock, S.H. 1995. Plant reproduction in neotropical dry forests. In Bullock, S.H., Mooney, H.A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press, New York. pp 277-303.
Biodiversity	Provisioning services	Genetic resources	Burgos, A., Maass, J.M. 2004. Vegetation Change Associated with Land-use in Tropical Dry Forest Areas of Western Mexico. Agriculture Ecosystems Environment. 104 (3): 475-481.
Carbon	Supporting services	Primary production	Burnham, R.J. 1997. Stand Characteristics and Leaf Litter Composition of a Dry Forest Hectare in Santa Rosa National Park, Costa Rica. Biotropica. 29 (4): 384-395.
Biodiversity	Provisioning services	Genetic resources	Burns, J.M., Janzen, D.H., Hajibabaei, M., Hallwachs, W., Hebert, P.D. 2008. DNA Barcodes and Cryptic Species of Skipper Butterflies in the Genus Perichares in Area De Conservacion Guanacaste, Costa Rica. Proceedings of the National Academy of Sciences of the United States of America.105 (17): 6350-6355.
Biodiversity	Supporting services	Primary production	Caetano, S., Naciri, Y. 2011. The Biogeography of Seasonally Dry Tropical Forests in South America. In Dirzo, R. Young, H. S. Mooney, H. A. Ceballos, G. (eds.). Seasonally Dry Tropical Forests. Island Press/Center for Resource Economics. Pp 23-44.
Carbon	Provisioning services	Biomass production	Cairns, M. A., Olmsted, I., Granados, J., Argaez, J. 2003. Composition and Aboveground Tree Biomass of a Dry Semi-Evergreen Forest on Mexico's Yucatan Peninsula. Forest Ecology and Management. 186 (1-3): 125-132.
Biodiversity	Provisioning services	Genetic resources	Calderon-Cortes, N., Quesada, M., Escalera-Vazquez, L.H. 2011. Insects as Stem Engineers: Interactions Mediated by the Twig-Girdler Oncideres Albomarginata Chamela Enhance Arthropod Diversity. Plos One. 6 (4): e19083.
Water	Provisioning services	Fresh water	Calvo, J.C. 1998. Suspended Sediment Yield Prediction Models for Costa Rican Watersheds. Hydrology in the Humid Tropic Environment. 253: 27-32.
Carbon	Regulating services	Carbon stocks	Calvo-Alvarado, J.C., McLennan, B., Sanchez-Azofeifa, G.A., Garvin, T. 2009. Deforestation and Forest Restoration in Guanacaste, Costa Rica: Putting Conservation Policies in Context. Forest Ecology and Management. 258 (6): 931-940.

Water	Regulating services	Water regulation	Calvo-Alvarado, J.C., Jimenez-Rodriguez, C., Jimenez-Salazar, V. 2014. Determining Rainfall Erosivity in Costa Rica: A Practical Approach. Mountain Research and Development 34 (1): 48-55.
Soils	Supporting Services	Nutrient cycling	Campo, J., Jaramillo, V.J., Maass, J.M. 1998. Pulses of Soil Phosphorus Availability in a Mexican Tropical Dry Forest: Effects of Seasonality and Level of Wetting. Oecologia 115 (1-2): 167-172.
Soils	Supporting Services	Nutrient cycling	Campo, J., Maass, J.M., Jaramillo, V.J., Yrizar, A.M. 2000. Calcium, Potassium, and Magnesium Cycling in a Mexican Tropical Dry Forest Ecosystem. Biogeochemistry 49 (1): 21-36.
Soils	Supporting Services	Nutrient cycling	Campo, J., Maass, M., Jaramillo, V.J., Martinez-Yrizar, A., Sarukhan, J. 2001. Phosphorus Cycling in a Mexican Tropical Dry Forest Ecosystem. Biogeochemistry 53 (2): 161-179.
Soils	Supporting Services	Nutrient cycling	Campo, J., Solis, E., Gallardo, J.F. 2012. Effects of Fertilisation on Soil Nutrient Characteristics and the Growth of Tree Stand in Secondary Seasonally Dry Tropical Forests in Mexico. Journal of Tropical Forest Science 24 (3): 408-415.
Soils	Supporting Services	Nutrient cycling	Campo-Alves, J. 2003. Nutrient Availability and Fluxes Along a Toposequence with Tropical Dry Forest in Mexico. Agrociencia 37 (2): 211-219.
Soils	Supporting Services	Soil formation	Campo, J., Vazquez-Yanes, C. 2004. Effects of Nutrient Limitation on Aboveground Carbon Dynamics during Tropical Dry Forest Regeneration in Yucatan, Mexico. Ecosystems 7 (3): 311-319.
Biodiversity	Provisioning services	Genetic resources	Carse, L.E., Fredericksen, T.S., Licona, J.C. 2000. Liana-Tree Species Associations in a Bolivian Dry Forest. Tropical Ecology 41 (1): 1-10.
Carbon	Provisioning services	Biomass production	Carvajal-Vanegas, D., Calvo-Alvarado, J.C. 2013. Chapter 19: Tree diameter growth of three successional stages of tropical dry forests, Santa Rosa National Park, Costa Rica. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 351-366.
Biodiversity	Supporting services	Primary production	Carvalho, F.A., Felfili, J.M. 2011. Temporal Changes in the Tree Community of a Dry Forest on Limestone Outcrops in Central Brazil: Floristic Composition, Structure and Diversity. Acta Botanica Brasilica 25 (1): 203-214.
Biodiversity	Provisioning services	Genetic resources	Carvalho, F.A., Felfili, J.M. 2011. Use of Alpha and Beta Diversity as a Base to Select Priority Areas for Conservation: An Analysis of the Dry Forests on Limestone Outcrops in Parana Valley, Goias State, Brazil. Bioscience Journal 27 (5): 830-838.
Soils	Supporting Services	Nutrient cycling	Pere, C., Romero, J., Rusch, G.M., Ibrahim, M. 2014. Soil Organic C and Nutrient Contents Under Trees with Different Functional Characteristics in Seasonally Dry Tropical Silvopastures. Plant and Soil 374 (1-2): 643-659.
Biodiversity	Provisioning services	Genetic resources	Cascante, A., Quesada, M., Lobo, J.J., Fuchs, E.A. 2002. Effects of Dry Tropical Forest Fragmentation on the Reproductive Success and Genetic Structure of the Tree Samanea Saman. Conservation Biology 16 (1): 137-147.
Biodiversity	Provisioning services	Genetic resources	Castaño-Meneses, G., Palacios-Vargas, J.G. 2003. Effects of fire and agricultural practices on neotropical ant communities. Biodiversity and conservation 12: 1913-1919.
Biodiversity	Provisioning services	Genetic resources	Castaño-Meneses, G., Benrey, B., Palacios-Vargas, J.G. 2009. Diversity and Temporal Variation of Ants (Hymenoptera: Formicidae) From Malaise Traps in a Tropical Deciduous Forest. Sociobiology 54: 633-645.
Carbon	Provisioning services	Biomass production	Castellanos, A., Mooney, H.A., Bullock, S.H., Jones, C., Robichaux, R. 1989. Leaf, stem and metamer characteristics of vines in a tropical deciduous forest in Jalisco, Mexico. Biotropica 21: 41-49.
Soils	Provisioning services	Biomass production	Castellanos, J., Maass, M., Kummerow, J. 1991. Root Biomass of a Dry Deciduous Tropical Forest in Mexico. Plant and Soil 131 (2): 225-228.
Soils	Provisioning services	Biomass production	Castellanos, J., Maass, J.M., Kummerow, J. 1998. Root biomass of a tropical deciduous forest. Plant and Soil 24: 270-274.

Soils	Provisioning services	Biomass production	Castellanos, J., Jaramillo, V., Sanford, Jr. R.L., Kauffman, J.B. 2001. Slash-and-burn effects on fine root biomass and productivity in a tropical dry forest ecosystem in México. Forest Ecology and Management 148: 41-50.
Biodiversity	Provisioning services	Genetic resources	Castillo-Campos, G., Halffter, G., Moreno, C. E. 2008. Primary and secondary vegetation patches as contributors to floristic diversity in a tropical deciduous forest landscape. Biodiversity and Conservation. 17(7): 1701-1714.
Carbon	Regulating services	Carbon stocks	Castillo-Nunez, M., Sanchez-Azofeifa, G.A., Croitoru, A., Rivard, B., Calvo-Alvarado, J.C., Dubayah, R. 2011. Delineation of Secondary Succession Mechanisms for Tropical Dry Forests using LiDAR. Remote Sensing of Environment 115 (9): 2217-2231.
Carbon	Regulating services	Carbon stocks	Castillo, M., Rivard, B., Sanchez-Azofeifa, G.A., Calvo-Alvarado, J.C., Dubayah, R. 2012. LIDAR Remote Sensing for Secondary Tropical Dry Forest Identification. Remote Sensing of Environment 121: 132-143.
Carbon	Provisioning services	Biomass production	Castro Marin, G., Nygard, R., Gonzales Rivas, B., Oden, P.C. 2005. Stand Dynamics and Basal Area Change in a Tropical Dry Forest Reserve in Nicaragua. Forest Ecology and Management 208 (1-3): 63-75.
Carbon	Provisioning services	Biomass production	Castro-Esau, K.L., Sanchez-Azofeifa, G.A., Caelli, T. 2004. Discrimination of Lianas and Trees with Leaf-Level Hyperspectral Data. Remote Sensing of Environment 90 (3): 353-372.
Carbon	Supporting services	Primary production	Castro-Esau, K.L., Sanchez-Azofeifa, G.A., Rivard, B., Wright, S.J., Quesada, M. 2006. Variability in Leaf Optical Properties of Mesoamerican Trees and the Potential for Species Classification. American Journal of Botany 93 (4): 517-530. doi:10.3732/ajb.93.4.517.
Biodiversity	Provisioning services	Genetic resources	Ceballos, G. B., Mooney, H. A., Medina, E. 1995. Vertebrate diversity, ecology, and conservation in neotropical dry forests. In Bullock, S. H., Mooney, H. A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press. pp 215-220.
Biodiversity	Provisioning services	Genetic resources	Ceballos, G.B. 1995. Vertebrate Diversity, Ecology, and Conservation in Neotropical Dry Frosts. In Bullock, S. H., Mooney, H. A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press. pp 215-220.
Biodiversity	Provisioning services	Genetic resources	Ceballos, G.B., Fleming, T. H., Chavez, C., Nassar, J. 1997. Population Dynamics of Leptonycteris Curasoae (Chiroptera: Phyllostomidae) in Jalisco, Mexico. Journal of Mammalogy 78 (4): 1220-1230.
Biodiversity	Provisioning services	Genetic resources	Ceccon, E., Huante, P., Rincon, E. 2006. Abiotic Factors Influencing Tropical Dry Forests Regeneration. Brazilian Archives of Biology and Technology 49 (2): 305-312.
Water	Regulating services	Water regulation	Cervantes, L. 1988. Intercepción de lluvia por el dosel en una comunidad tropical. Ingeniería Hidráulica en México. Segunda época 3: 38-43.
Water	Regulating services	Water regulation	Cervantes, L., Maass, J.M., Domínguez, R. 1988. Relación lluvia-escurrimiento en un sistema pequeño de cuencas de selva baja caducifolia. Ingeniería Hidráulica en México. Segunda época 3: 30-42.
Biodiversity	Provisioning services	Genetic resources	Cespedes, M., Gutierrez, M. V., Holbrook, N. M., Rocha O. J. 2003. Restoration of Genetic Diversity in the Dry Forest Tree Swietenia Macrophylla (Meliaceae) After Pasture Abandonment in Costa Rica. Molecular Ecology 12 (12): 3201-3212.
Biodiversity	Provisioning services	Genetic resources	Chacon, I.A., Janzen, D.H., Hallwachs, W., Bolling Sullivan, J., Hajibabaei, M. 2013. Cryptic Species within Cryptic Moths: New Species of Dunama Schaus (Notodontidae, Nystaleinae) in Costa Rica. Zookeys. (264): 11-45. doi:10.3897/zookeys.264.4440.
Carbon	Regulating services	Climate regulation	Chacon-Leon, M., Harvey, C.A. 2013. The Contribution of Dispersed Trees in Pastures for Biomass Reserve and Climate Change Mitigation. Agronomia Mesoamericana 24 (1): 17-26.
Water	Provisioning services	Fresh water	Chapman, L. J., Kramer, D.L. 1991. Limnological Observations of an Intermittent Tropical Dry Forest Stream. Hydrobiologia 226 (3): 153-166.
Biodiversity	Supporting services	Primary production	Chaves, O.M., Avalos, G. 2006. Is the Inverse Leafing Phenology of the Dry Forest Understory Shrub Jacquinia Nervosa (Theophrastaceae) a Strategy to Escape Herbivory? Revista De Biologia Tropical 54 (3): 951-963.

Biodiversity	Provisioning services	Genetic resources	Chemsak, J.A., Linsley, E.G., Hovore, F. 1988. A concentration site for Cerambycidae in Jalisco, Mexico (Coleoptera). Pan-Pacific Entomologist 64: 291-295.
Water	Regulating services	Water regulation	Cheng, T., Rivard, B., Sanchez-Azofeifa, G.A. 2011. Spectroscopic Determination of Leaf Water Content using Continuous Wavelet Analysis. Remote Sensing of Environment 115 (2): 659-670.
Water	Regulating services	Water regulation	Chilpa-Galvan, N., Tamayo-Chim, M., Andrade, J.L., Reyes-Garcia, C. 2013. Water Table Depth may Influence the Asymmetric Arrangement of Epiphytic Bromeliads in a Tropical Dry Forest. Plant Ecology 214 (8): 1037-1048.
Carbon	Supporting services	Primary production	Clark, D. A., Brown, S., Kicklighter, D. W., Chambers, J. Q., Thomlinson, J. R., Ni, J., Holland, E.A. 2001. Net Primary Production in Tropical Forests: An Evaluation and Synthesis of Existing Field Data. Ecological Applications 11 (2): 371-384.
Biodiversity	Provisioning services	Genetic resources	Cody, M.L. 1986. Distribution and morphology of columnar cacti in tropical deciduous woodland, Jalisco, Mexico. Vegetatio 66: 137-145.
Biodiversity	Supporting services	Primary production	Coelho, M.S., Almada, E.A., Quintino, A., Fernandes, G.W., Santos, R.M., Sanchez-Azofeifa, G.A., Espirito Santo, M.M.DO. 2012. Floristic Composition and Structure of a Tropical Dry Forest at Different Successional Stages in the Espinhaco Mountains, Southeastern Brazil. Interciencia 37 (3): 190-196.
Biodiversity	Supporting services	Primary production	Colleen, K., Bowler, M.G., Pybus, O., Harvey, P.H. 2008. Phylogeny, niches, and relative abundance in natural communities. Ecology 89: 962-970.
Biodiversity	Provisioning services	Genetic resources	Collevatti, R. G., Estolano, R., Ribeiro, M.L., Rabelo, S.G., Lima, E.J., Munhoz, C.B.R. 2014. High Genetic Diversity and Contrasting Fine-Scale Spatial Genetic Structure in Four Seasonally Dry Tropical Forest Tree Species. Plant Systematics and Evolution: 1-11.
Soils	Supporting Services	Nutrient cycling	Corre, M.D., Sueta, J.P., Veldkamp, E. 2014. Nitrogen-Oxide Emissions from Tropical Forest Soils Exposed to Elevated Nitrogen Input Strongly Interact with Rainfall Quantity and Seasonality. Biogeochemistry 118 (1-3): 103-120.
Soils	Regulating services	Soil carbon stocks	Cotler, H., Ortega-Larrocea, M.P. 2006. Effects Of Land Use On Soil Erosion In A Tropical Dry Forest Ecosystem, Chamela Watershed, Mexico. Catena 65: 107-117.
Soils	Regulating services	Soil carbon stocks	Cuevas, R.M., Hidalgo, C., Payan, F., Etchevers, J.D., Campo, J. 2013. Precipitation Influences on Active Fractions of Soil Organic Matter in Seasonally Dry Tropical Forests of the Yucatan: Regional and Seasonal Patterns. European Journal of Forest Research 132 (5-6): 667-677.
Soils	Supporting Services	Nutrient cycling	Cuevas-Reyes, P., Quesada, M., Siebe, C., Oyama, K. 2004. Spatial Patterns of Herbivory by Gall-Forming Insects: A Test of the Soil Fertility Hypothesis in a Mexican Tropical Dry Forest. Oikos 107 (1): 181-189. doi:10.1111/j.0030-1299.2004.13263.x.
Biodiversity	Regulating services	Disease regulation	Cuevas-Reyes, P., Quesada, M., Hanson, P., Dirzo, R., Oyama, K. 2004. Diversity of Gall-Inducing Insects in a Mexican Tropical Dry Forest: The Importance of Plant Species Richness, Life-Forms, Host Plant Age and Plant Density. Journal of Ecology 92 (4): 707-716. doi:10.1111/j.0022-0477.2004.00896.x.
Biodiversity	Regulating services	Disease regulation	Cuevas-Reyes, P., Quesada, M., Oyama, K. 2006. Abundance and Leaf Damage Caused by Gall-Inducing Insects in a Mexican Tropical Dry Forest. Biotropica 38 (1): 107-115. doi:10.1111/j.1744-7429.2006.00115.x.
Biodiversity	Regulating services	Disease regulation	Cuevas-Reyes, P., Quesada, M., Hanson, P., Oyama, K. 2007. Interactions among Three Trophic Levels and Diversity of Parasitoids: A Case of Top-Down Processes in Mexican Tropical Dry Forest. Environmental Entomology 36 (4): 792-800.
Carbon	Regulating services	Carbon stocks	Dai, Z., Birdsey, R.A., Johnson, K.D., Dupuy, J.M., Hernandez-Stefanoni, J.L., Richardson, K. 2014. Modeling Carbon Stocks in a Secondary Tropical Dry Forest in the Yucatan Peninsula, Mexico. Water Air and Soil Pollution 225 (4): 1925.

Carbon	Regulating services	Carbon stocks	Dalle, S.P., Pulido, M.T., de Blois, S. 2011. Balancing Shifting Cultivation and Forest Conservation: Lessons from a Sustainable Landscape in Southeastern Mexico. Ecological Applications 21 (5): 1557-1572.
Water	Provisioning services	Fresh water	Das, R., Lawrence, D., D'Odorico, P., DeLonge, M. 2011. Impact of Land use Change on Atmospheric P Inputs in a Tropical Dry Forest. Journal of Geophysical Research-Biogeosciences 116: G01027.
Soils	Supporting Services	Nutrient cycling	Davidson, E.A., Vitousek, P.M., Matson, P.A., Riley, R.R., García-Méndez, G., Maass, J.M. 1991. Soil emissions of nitric oxide in a seasonally dry tropical forest of Mexico. Journal of Geophysical Research 96: 15439-15445.
Soils	Supporting Services	Nutrient cycling	Davidson, E.A., Matson, P.A., Vitousek, P.M., Riley, R., Dunkin, K., García-Méndez, G., Maass, J.M. 1993. Processes regulating soil emissions of NO and N2O in a seasonally dry tropical forest. Ecology 74: 130-139.
Water	Regulating services	Water regulation	de Araújo, J.C., González Piedra, J.I. 2009. Comparative hydrology: analysis of a semiarid and a humid tropical watershed. Hydrological Processes 23: 1169–1178.
Biodiversity	Regulating services	Pest regulation	de Oliveira, S. H., Negreiros, D., Fernandes, G. W., Barbosa, N. P., Rocha, R., Almeida-Cortez, J. S. 2009. Seedling growth of the invader Calotropis procera in ironstone rupestrian field and seasonally dry forest soils. Neotropical Biology and Conservation. 4(2): 69-76.
Biodiversity	Provisioning services	Genetic resources	De Villa-Meza, A., Martínez-Meyer, E., Martínez-López, C.A. 2002. Ocelot (Leopardus pardalis) Food Habits in Tropical Deciduous Forest of Jalisco, México. The American Midland Naturalist 148: 146-154.
Carbon	Provisioning services	Biomass production	Delaney, M., Brown, S., Lugo, A.E., TorresLezama, A., Quintero, N.B. 1997. The Distribution of Organic Carbon in Major Components of Forests Located in Five Life Zones of Venezuela. Journal of Tropical Ecology 13: 697-708.
Water	Regulating services	Water regulation	DeWalt, S.J., Schnitzer, S.A., Chave, J., Bongers, F., Burnham, R.J., Cai, Z., Chuyong, G. 2010. Annual Rainfall and Seasonality Predict Pan-Tropical Patterns of Liana Density and Basal Area. Biotropica 42 (3): 309-317. doi:10.1111/j.1744-7429.2009.00589.x.
Soils	Supporting Services	Nutrient cycling	Diekmann, L.O., Lawrence, D., Okin, G.S. 2007. Changes in the Spatial Variation of Soil Properties Following Shifting Cultivation in a Mexican Tropical Dry Forest. Biogeochemistry 84 (1): 99-113.
Water	Regulating services	Water regulation	Domínguez, C.A., Dirzo, R. 1995. Rainfall and flowering synchrony in a tropical shrub: variable selection on the flowering time of Erythroxylum havanense. Evolutionary Ecology 9: 204-216.
Biodiversity	Supporting services	Pollination	Domínguez, C.A., Dirzo, R., Bullock, S.H. 1989. On the function of floral nectar in Croton suberosus (Euphorbiaceae). Oikos 56: 109-114.
Biodiversity	Supporting services	Primary production	Durán, E., Meave, J.A., Lott, E.J., Segura, G. 2006. Structure And Tree Diversity Patterns At The Landscape Level In A Mexican Tropical Deciduous Forest. Boletín de la Sociedad Botánica de México 79: 43-60.
Carbon	Provisioning services	Biomass production	Eaton, J. M., Lawrence, D. 2009. Loss of Carbon Sequestration Potential After several Decades of Shifting Cultivation in the Southern Yucatan. Forest Ecology and Management 258 (6): 949-958. doi:10.1016/j.foreco.2008.10.019.
Soils	Supporting Services	Soil formation	Ellingson, L. J., Kauffman, J.B., Cummings, D.L., Sanford, R.L., Jaramillo, V.J. 2000. Soil N Dynamics Associated with Deforestation, Biomass Burning, and Pasture Conversion in a Mexican Tropical Dry Forest. Forest Ecology and Management 137 (1-3): 41-51.
Soils	Supporting Services	Soil formation	Ellingson, L. J., Kauffman, J.B., Cummings, D.L., Sanford, R. L., Jaramillo, V.J. 2000. Soil N Dynamics Associated with Deforestation, Biomass Burning, and Pasture Conversion in a Mexican Tropical Dry Forest. Forest Ecology and Management 137 (1-3): 41-51.
Carbon	Regulating services	Carbon stocks	Ellis, E. A., Porter-Bolland, L. 2008. Is community-based forest management more effective than protected areas?: A comparison of land use/land cover change in two neighboring study areas of the Central Yucatan Peninsula, Mexico. Forest ecology and management 256(11): 1971-1983.

Water	Regulating services	Natural hazard regulation	Enquist, B.J., Enquist, C.A.F. 2011. Long-Term Change within a Neotropical Forest: Assessing Differential Functional and Floristic Responses to Disturbance and Drought. Global Change Biology 17 (3): 1408-1424.
Soils	Supporting Services	Soil formation	Erickson, H., Davidson, E.A., Keller, M. 2002. Former Land-use and Tree Species Affect Nitrogen Oxide Emissions from a Tropical Dry Forest. Oecologia 130 (2): 297-308.
Biodiversity	Regulating services	Disease regulation	Espirito-Santo, M.M.DO., Neves, F., Andrade-Neto, F.R., Fernandes, G.W. 2007. Plant Architecture and Meristem Dynamics as the Mechanisms Determining the Diversity of Gall-Inducing Insects. Oecologia 153 (2): 353-364.
Biodiversity	Provisioning services	Genetic resources	Espirito-Santo, M.M.DO., Sevilha, A., Anaya, F.C., Barbosa, R., Fernandes, G.W., Sanchez-Azofeifa, G.A., Scariot, A., de Noronha, S.E., Sampaio. C.A. 2009. Sustainability of Tropical Dry Forests: Two Case Studies in Southeastern and Central Brazil.Forest Ecology and Management 258 (6): 922-930.
Biodiversity	Supporting services	Primary production	Espírito-Santo, M.M.DO., Olívio-Leite, L., Neves, F., Nunes, Y.R.F., Zazá-Borges, M., Dolabela-Falcão, L.A., Fonseca-Pezzini, F., Louro-Berbara, R., Maia-Valério, H., Fernandes, G.W., Reinaldo-Leite, M., Santos-Clemente, C.M., Esdras-Leite, M. 2013. Chapter 5: Tropical Dry Forests of Northern Minas Gerais, Brazil: Diversity, Conservation Status, and Natural Regeneration. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 69-82.
Water	Supporting Services	Water cycling	Estrada-Medina, H., Santiago, L., Graham, R.C., Allen, M.F., Jimenez-Osornio, J.J. 2013. Source Water, Phenology and Growth of Two Tropical Dry Forest Tree Species Growing on Shallow Karst Soils. Trees-Structure and Function 27 (5): 1297-1307.
Carbon	Provisioning services	Biomass production	Ewel, J. J. 1977. Differences between Wet and Dry Successional Tropical Ecosystems. Geo-Eco-Trop 1 (2): 103-117.
Water	Regulating services	Water regulation	Ewel, J.J., Whitmore, J.L. 1973. The ecological life zones of Puerto Rico and the U.S. Virgin Islands. Forest Service Research Paper. 1–72.
Carbon	Regulating services	Carbon stocks	Fajardo, L., Gonzalez, V., Nassar, J.M., Lacabana, P., Portillo-Quintero, C., Carrasquel, F., Rodriguez, J.P. 2005. Tropical Dry Forests of Venezuela: Characterization and Current Conservation Status. Biotropica 37 (4): 531-546. doi:10.1111/j.1744-7429.2005.00071.x.
Biodiversity	Provisioning services	Genetic resources	Fajardo, L., Rodriguez, J.P., Gonzalez, V., Briceno-Linares, J.M. 2013. Restoration of a Degraded Tropical Dry Forest in Macanao, Venezuela. Journal of Arid Environments 88: 236-243.
Biodiversity	Provisioning services	Genetic resources	Falcao, L. A. D., Espirito-Santo, M.M.DO., Leite, L.O., Garro, R. N.S.L., Avila-Cabadilla, D.L., Stoner, K.E. 2014. Spatiotemporal Variation in Phyllostomid Bat Assemblages Over a Successional Gradient in a Tropical Dry Forest in Southeastern Brazil. Journal of Tropical Ecology 30 (2): 123-132.
Water	Supporting Services	Water cycling	Fanjul, L., Barradas, V.L. 1987. Diurnal and seasonal variation in the water relations of some deciduous and evergreen trees of a deciduous dry forest of the western coast of Mexico. Journal of Applied Ecology 24: 289-303.
Water	Regulating services	Water regulation	Farrick, K.K., Branfireun, B.A. 2013. Left high and dry: a call to action for increased hydrological research in tropical dry forests. Hydrological Processes.
Water	Regulating services	Water regulation	Farrick, K. K., Branfireun, B. A. 2013. Left high and dry: a call to action for increased hydrological research in tropical dry forests. Hydrological Processes, 27(22): 3254-3262.
Water	Regulating services	Water regulation	Farrick, K. K., Branfireun, B.A. 2014. Infiltration and Soil Water Dynamics in a Tropical Dry Forest: It may be Dry but Definitely Not Arid. Hydrological Processes 28 (14): 4377-4387.
Biodiversity	Provisioning services	Genetic resources	Fedigan, L. M., Jack, K. 2001. Neotropical Primates in a Regenerating Costa Rican Dry Forest: A Comparison of Howler and Capuchin Population Patterns. International Journal of Primatology 22 (5): 689-713.

Biodiversity	Supporting services	Primary production	Nunes, Y.R.F., Rodrigues da Luz, G., de Souza, R., Librelon, D., Magalhães-Veloso, M., Espírito-Santo, M.M.DO., dos Santos, R.M. Chapter 18: Floristic, Structural, and Functional Group Variations in Tree Assemblages in a Brazilian Tropical Dry Forest: Effects of Successional Stage and Soil Properties. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 325-350.
Carbon	Regulating services	Carbon stocks	Figueroa, F., Sánchez-Cordero, V. 2008. Effectiveness of natural protected areas to prevent land use and land cover change in Mexico. Biodiversity and conservation 17: 3223-3240.
Carbon	Supporting services	Primary production	Filip, V., Dirzo, R., Maass, J.M., Sarukhán, J. 1995. Within- and among-year variation in the levels of herbivory on the foliage of trees from a Mexican tropical deciduous forest. Biotropica 27: 78-86.
Biodiversity	Supporting services	Pollination	Frankie, G. W., Haber, W.A., Vinson, S.B., Bawa, K.S., Ronchi, P.S., Zamora, N. 2004. Flowering Phenology and Pollination Systems Diversity in the Seasonal Dry Forest. Biodiversity Conservation in Costa Rica. 17-29.
Biodiversity	Provisioning services	Genetic resources	Frankie, G. W., Vinson, S. B., Rizzardi, M. A., Griswold, T. L., Coville, R. E., Grayum, M. H., Martinez, L. E. S., Foltz-Sweat, J., Pawelek, J.C. 2013. Relationships of Bees to Host Ornamental and Weedy Flowers in Urban Northwest Guanacaste Province, Costa Rica. Journal of the Kansas Entomological Society 86 (4): 325-351.
Biodiversity	Provisioning services	Genetic resources	Fuchs, E. J., Lobo, J. A., Quesada, M. 2003. Effects of Forest Fragmentation and Flowering Phenology on the Reproductive Success and Mating Patterns of the Tropical Dry Forest Tree Pachira Quinata. Conservation Biology 17 (1): 149-157. doi:10.1046/j.1523-1739.2003.01140.x.
Soils	Supporting Services	Soil formation	Garcia-Oliva, F., Oliva, M., Sveshtarova, B. 2004. Effect of Soil Macroaggregates Crushing on C Mineralization in a Tropical Deciduous Forest Ecosystem. Plant and Soil 259 (1-2): 297-305.
Soils	Supporting Services	Soil formation	Galicia, L., García-Oliva, F. 2008. Remnant tree effects on soil microbial carbon and nitrogen in tropical seasonal pasture in western Mexico. European Journal of Soil Biology 44: 290-297.
Soils	Supporting Services	Soil formation	Galicia, L., García-Oliva, F. 2011. Litter quality of two remnant tree species affects soil microbial activity in tropical seasonal pastures in western Mexico. Arid Land Research and Management 25 (1): 75-86.
Biodiversity	Provisioning services	Genetic resources	García, A., Cabrera-Reves, A. 2008. Effect of seasonality and vegetation structure on the amphibian and reptile community of the Chamela Biological Station, in Jalisco, Mexico. Acta Zoológica Mexicana Nueva Serie 24: 91-115.
Biodiversity	Provisioning services	Genetic resources	García, A., Ceballos, G. 1994. Field guide to the reptiles and amphibians of the Jalisco coast, Mexico. Fundación Ecológica de Cuixmala and Instituto de Biología, Universidad Nacional Autónoma de México, México, DF.
Biodiversity	Provisioning services	Genetic resources	Garcia, A., Ortega-Huerta, M. A., Martinez-Meyer, E. 2014. Potential distributional changes and conservation priorities of endemic amphibians in western Mexico as a result of climate change. Environmental Conservation 41(01): 1-12.
Carbon	Regulating services	Carbon stocks	Millán, V. G., Sánchez-Azofeifa, A., García, G. M., Rivard, B. 2014. Quantifying tropical dry forest succession in the Americas using CHRIS/PROBA. Remote Sensing of Environment 144: 120-136.
Soils	Supporting Services	Soil formation	García-Méndez, G., Maass, J.M., Matson, P., Vitousek, P. 1991. Nitrogen transformations and nitrous oxide flux in a tropical deciduous forest in México. Oecologia 88: 362-366.
Soils	Supporting Services	Nutrient cycling	García-Méndez, G., Maass, J. M., Matson, P. A., Vitousek, P. M. 1991. Nitrogen transformations and nitrous oxide flux in a tropical deciduous forest in Mexico. Oecologia 88(3): 362-366.
Water	Regulating services	Water regulation	García-Oliva, F., Ezcurra, E., Galicia, L. 1991. Patterns of rainfall distribution in the Central Pacific coast of Mexico. Geografiska Annaler 73A: 179-186.
Soils	Supporting Services	Soil formation	García-Oliva, F., Casar, I., Morales, P., Maass, J.M. 1994. Forest-to-pasture conversion influences on soil organic carbon dynamics in a tropical deciduous forest. Oecologia 99: 392-396.

Soils	Regulating services	Soil carbon stocks	García-Oliva, F., Martínez-Lugo, R., Maass, J.M. 1995. Soil 137Cs activity in a tropical deciduous ecosystem under pasture conversion in Mexico. Journal of Environmental Radiology 26: 37-49.
Soils	Regulating services	Erosion regulation	García-Oliva, F., Martínez-Lugo, R., Maass, J.M. 1995. Long-term net soil erosion as determined by 137Cs redistribution in an undisturbed and perturbed tropical deciduous forest ecosystem. Geoderma 68: 135-147.
Soils	Regulating services	Erosion regulation	García-Oliva, F., Maass J.M., Galicia L. 1995. Rainstorm analysis and rainfall erosivity of a seasonal tropical region with a strong cyclonic influence on the Pacific Coast of Mexico. Journal of Applied Meteorology 34: 2491-2498.
Soils	Supporting Services	Soil formation	García-Oliva, F., Sanford, R.L Jr., Kelly, E. 1999. Effects of slash-and-burn management on soil aggregate organic C and N in a tropical deciduous forest. Geoderma 88: 1-12.
Soils	Supporting Services	Soil formation	García-Oliva, F., Sanford, R.L. Jr., Kelly, E. 1999. Effect of burning of Tropical Deciduous forest soil in Mexico on the microbial degradation of organic matter. Plant and Soil 206: 29-36.
Soils	Regulating services	Soil carbon stocks	García-Oliva, F., Sveshtarova, B., Oliva, M. 2003. Seasonal effects on soil organic carbon dinamics in a tropical deciduous forest ecosystem in western México. Journal of Tropical Ecology 19: 179-188.
Soils	Supporting Services	Soil formation	García-Oliva, F., Oliva, M., Sveshtarova, B. 2004. Effect of soil macroaggregates crushing on C mineralization in a tropical deciduous forest ecosystem. Plant and Soil 259: 297–305.
Soils	Regulating services	Soil carbon stocks	García-Oliva, F., Hernández, G., Lancho J.F.G. 2006. Comparison of ecosystem C pools in three forests in Spain and Latin America. Annals of Forest Science 63: 519-523.
Soils	Supporting Services	Soil formation	García-Oliva, F., Lancho, J. F. G., Montaño, N. M., Islas, P. 2006. Soil carbon and nitrogen dynamics followed by a forest-to-pasture conversion in western Mexico. Agroforestry Systems 66(2): 93-100.
Biodiversity	Supporting services	Primary production	Garcia-Villacorta, R. 2009. Diversity, Composition, and Structure of a Highly Endangered Habitat: The Seasonally Dry Forests of Tarapoto, Peru. Revista Peruana De Biologia 16 (1): 81-92.
Water	Supporting Services	Water cycling	Gartner, B.L., Bullock, S.H., Mooney, H.A., Brown, V.B., Whitbeck, J.L. 1990. Water transport properties of vine and tree stems in a tropical deciduous forest. American Journal of Botany 77: 742-749.
Soils	Supporting Services	Primary production	Gavito, M., Pérez-Castillo, D., González-Monterrubio, C., Vieyra-Hernández, T., Martínez-Trujillo, M. 2008. High compatibility between arbuscular mycorrhizal fungal communities and seedlings of different land use types in a tropical dry ecosystem. Mycorrhiza 19: 47-60.
Soils	Supporting Services	Nutrient cycling	Gei, M., Powers, J. 2013. Nutrient Cycling in Tropical Dry Forests. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 141-156.
Biodiversity	Supporting services	Primary production	Gentry, A. H. 1995. Diversity and Floristic Composition of Neotropical Dry Forests. In Bullock, S.H., Mooney, H.A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press, New York doi:10.1017/CBO9780511753398.007.
Carbon	Regulating services	Carbon stocks	Geoghegan, J., Lawrence, D., Schneider, L.C., Tully, K. 2010. Accounting for Carbon Stocks in Models of Land-use Change: An Application to Southern Yucatan. Regional Environmental Change 10 (3): 247-260.
Carbon	Supporting services	Primary production	Gerhardt, K. 1996. Effects of Root Competition and Canopy Openness on Survival and Growth of Tree Seedlings in a Tropical Seasonal Dry Forest. Forest Ecology and Management 82 (1-3): 33-48.
Carbon	Supporting services	Primary production	Gerhardt, K. 1996. Germination and Development of Sown Mahogany (Swietenia Macrophylla King) in Secondary Tropical Dry Forest Habitats in Costa Rica. Journal of Tropical Ecology 12: 275-289.
Carbon	Provisioning services	Biofuels	Ghilardi, A., Guerrero, G., Masera, O. 2009. A GIS-Based Methodology for Highlighting Fuelwood supply/demand Imbalances at the Local Level: A Case Study for Central Mexico. Biomass Bioenergy 33 (6-7): 957-972.

Biodiversity	Provisioning services	Genetic resources	Gillespie, T.W. 1999. Life History Characteristics and Rarity of Woody Plants in Tropical Dry Forest Fragments of Central America. Journal of Tropical Ecology 15: 637-649.
Biodiversity	Provisioning services	Genetic resources	Gillespie, T.W., Walter, H. 2001. Distribution of Bird Species Richness at a Regional Scale in Tropical Dry Forest of Central America. Journal of Biogeography 28 (5): 651-662.
Carbon	Provisioning services	Biomass production	Gillespie, T. W., Grijalva, A., Farris, C. N. 2002. Diversity, composition, and structure of tropical dry forests in Central America. Plant ecology 147(1): 37-47.
Carbon	Regulating services	Carbon stocks	Gillespie, T. W., Zutta, B. R., Early, M. K., Saatchi, S. 2006. Predicting and Quantifying the Structure of Tropical Dry Forests in South Florida and the Neotropics using Spaceborne Imagery. Global Ecology and Biogeography 15 (3): 225-236.
Carbon	Provisioning services	Biomass production	Glander, K. E., Nisbett, R.A. 1996. Community Structure and Species Density in Tropical Dry Forest Associations at Hacienda La Pacifica in Guanacaste Province, Costa Rica. Brenesia (45-46): 113-142.
Soils	Supporting Services	Soil formation	Gómez-Anaya, J.A., Palacios-Vargas, J.G. 2004. Structure and composition of litter and soil Poduromorpha assemblages (Hexapoda: Entognatha: Collembola) from a tropical dry forest in Western Mexico. Folia Entomológica Mexicana 43: 215-225.
Soils	Supporting Services	Soil formation	Gonzalez, O., Zak, D. 1994. Geostatistical Analysis of Soil Properties in a Secondary Tropical Dry Forest, St-Lucia, West-Indies. Plant and Soil 163 (1): 45-54.
Soils	Supporting Services	Soil formation	González, R.T., Víctor Jaramillo, J., Peña Cabriales, J., Flores, A. 2008. Nodulation dynamics and nodule activity in leguminous tree species of a Mexican tropical dry forest. Journal of Tropical 24: 107-110.
Biodiversity	Supporting services	Primary production	Gonzalez-Rivas, B., Tigabu, M., Gerhardt, K., Castro-Marin, G., Oden, P. C. 2006. Species Composition, Diversity and Local Uses of Tropical Dry Deciduous and Gallery Forests in Nicaragua. Biodiversity and Conservation 15 (4): 1509-1527.
Biodiversity	Provisioning services	Genetic resources	Gonzalez-Soriano, E., Noguera, F. A., Zaragoza-Caballero, S., Morales-Barrera, M.A., Ayala-Barajas, R., Rodriguez-Palafox, A., Ramirez-Garcia, E. 2008. Odonata Diversity in a Tropical Dry Forest of Mexico, 1. Sierra De Huautla, Morelos. Odonatologica 37 (4): 305-315.
Biodiversity	Provisioning services	Genetic resources	Gordon, J. E., Hawthorne, W. D., Reyes-Garcıa, A., Sandoval, G., Barrance, A. J. 2004. Assessing landscapes: a case study of tree and shrub diversity in the seasonally dry tropical forests of Oaxaca, Mexico and southern Honduras. Biological conservation, 117(4): 429-442.
Water	Regulating services	Water regulation	Govender, Y., Cuevas, E., Sternberg, L. D. S., Jury, M. R. 2013. Temporal Variation in Stable Isotopic Composition of Rainfall and Groundwater in a Tropical Dry Forest in the Northeastern Caribbean. Earth Interactions 17: 27.
Biodiversity	Provisioning services	Genetic resources	Greene, D.F., Quesada, M. 2005. Seed size, dispersal and aerodynamic constraints within the Bombacaceae. American Journal of Botany 92: 998-1005.
Biodiversity	Supporting services	Primary production	Greene, D. F., Quesada, M., Calogeropoulos, C. 2008. Dispersal of Seeds by the Tropical Sea Breeze. Ecology 89 (1): 118-125. doi:10.1890/06-0781.1.
Biodiversity	Provisioning services	Genetic resources	Griscom, H. P., Connelly, A. B., Ashton, M. S., Wishnie, M. H., Deago, J. 2011. The Structure and Composition of a Tropical Dry Forest Landscape After Land Clearance; Azuero Peninsula, Panama. Journal of Sustainable Forestry 30 (8): 756-774.
Carbon	Provisioning services	Biomass production	Griscom, H.P., Ashton, M. 2011. Restoration of Dry Tropical Forests in Central America: A Review of Pattern and Process. Forest Ecology and Management 261 (10): 1564-1579.
Biodiversity	Provisioning services	Genetic resources	Grombone-Guaratini, M.T., Rodrigues, R.R. 2002. Seed Bank and Seed Rain in a Seasonal Semi-Deciduous Forest in South-Eastern Brazil. Journal of Tropical Ecology 18: 759-774.
Biodiversity	Provisioning services	Genetic resources	Gryj, E.O., Domínguez, C.A. 1996. Fruit removal and postdispersal survivorship in the tropical dry forest shrub Erythroxylum havanense: ecológical and evolutionary implications. Oecologia 108: 368-374.

Biodiversity	Supporting services	Pollination	Gryj, E.O., Martínez del Río, C., Baker, H.G., Baker, L. 1990. Avian pollination and nectar use in Combretum fruticosum. Biotropica 22: 266-271.
Biodiversity	Provisioning services	Genetic resources	Guevara-De-Lampe, M., Bergeron, Y., Mcneil, R., Leduc, A. 1992. Seasonal flowering and fruiting patterns in tropical semi-arid vegetation in northeastern Venezuela. Biotropica 24:64-76.
Biodiversity	Supporting services	Pollination	Hamrick, J. L., Apsit, V. J. 2004. Breeding structure of neotropical dry forest tree species in fragmented landscapes. Biodiversity conservation in Costa Rica. Learning the lessons in a seasonal dry forest. University of California Press, Berkley, CA, USA, 30-37.
Biodiversity	Provisioning services	Genetic resources	Hanson, P.E. 2004. Biodiversity inventories in Costa Rica and their application to conservation. Biodiversity.
Biodiversity	Provisioning services	Genetic resources	Hanson, P. E. 2011. Insect diversity in seasonally dry tropical forests. In Bullock, S.H., Mooney, H.A., Medina, E. (eds.). Seasonally Dry Tropical Forests Island Press/Center for Resource Economics. pp. 71-84.
Biodiversity	Provisioning services	Genetic resources	Harvey, C. A., Haber, W. A. 1998. Remnant trees and the conservation of biodiversity in Costa Rican pastures. Agroforestry systems 44(1): 37-68.
Water	Regulating services	Natural hazard regulation	Hayden, B., Greene, D. F., Quesada, M. 2010. A Field Experiment to Determine the Effect of Dry-Season Precipitation on Annual Ring Formation and Leaf Phenology in a Seasonally Dry Tropical Forest. Journal of Tropical Ecology 26: 237-242.
Water	Regulating services	Natural hazard regulation	Hayden, B., Greene, D.F., Quesada, M. 2010. A field experiment to determine the effect of dry-season precipitation on annual ring formation and leaf phenology in a seasonally dry tropical forest. Journal of Tropical Ecology 26:237–242.
Biodiversity	Provisioning services	Genetic resources	Herrerias-Diego, Y., Quesada, M., Stoner, K.E., Lobo, J.A., Hernandez-Flores, Y., Sanchez Montoya, G. 2008. Effect of Forest Fragmentation on Fruit and Seed Predation of the Tropical Dry Forest Tree Ceiba Aesculifolia. Biological Conservation 141 (1): 241-248.
Carbon	Supporting services	Primary production	Hesketh, M., Sanchez-Azofeifa, G.A. 2012. The Effect of Seasonal Spectral Variation on Species Classification in the Panamanian Tropical Forest. Remote Sensing of Environment 118: 73-82. doi:10.1016/j.rse.2011.11.005.
Biodiversity	Provisioning services	Genetic resources	Hidalgo-Mihart, M.G., Cantú-Salazar, L., Carrillo-Percastegui, S.E., C.A. López-González. 2009. Daily activity patterns of coyotes (Canis latrans) in a tropical deciduous forest of western Mexico. Studies on Neotropical Fauna and Environment 44: 77-82.
Biodiversity	Supporting services	Primary production	Huang, Y., Sánchez-Azofeifa, G.A., Rivard, B., Quesada, M. 2013. Linkages among Ecosystem Structure, Composition, and Leaf Area Index along a Tropical Dry Forest Chronosequence in Mexico. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 267-280.
Carbon	Provisioning services	Biomass production	Huante, P., Rincón. E. 1998. Responses to light changes in tropical deciduous woody seedlings with contrasting growth rates. Oecologia 113: 53-66.
Soils	Provisioning services	Biomass production	Huante, P., Rincón, E., Gavito, M. 1992. Root system analysis of seedlings of seven tree species from a tropical dry forest in Mexico. Trees 6: 77-82.
Carbon	Provisioning services	Biomass production	Huante, P., Rincón, E., Allen, E. 1993. Effect of vesicular-arbuscular mycorrhizae on seedling growth of four tree species from the tropical deciduous forest in Mexico. Mycorrhiza 2: 141-145.
Carbon	Provisioning services	Biomass production	Huante, P., Rincón, E., Acosta, I. 1995. Nutrient availability and growth rate of 34 woody species from a tropical deciduous forest in Mexico. Functional Ecology 9: 849-858.
Carbon	Provisioning services	Biomass production	Huante, P., Rincón, E., Chapin, F.S. 1998. Effect of changing light availability on nutrient foraging in tropical deciduos tree-seedlings. Oikos 82: 449-458.
Carbon	Provisioning services	Biomass production	Huante, P., Rincón, E., Chapin, F.S. 1998. Foraging for nutrients, responses to changes in light and competition in tropical deciduos tree-seedlings. Oecologia 117: 209-216.
Biodiversity	Supporting services	Primary production	Hubbell, S. P. 1979. Tree dispersion, abundance, and diversity in a tropical dry forest. Science 203(4387): 1299-1309.

Biodiversity	Supporting services	Primary production	Hulshof, C. M., Martínez-Yrízar, A., Burquez, A., Boyle, B., Enquist, B. J. 2013. Plant functional trait variation in tropical dry forests: a review and synthesis. Tropical dry forests in the Americas: ecology, conservation, and management. CRC Press, Boca Raton, 129-140.
Biodiversity	Provisioning services	Genetic resources	Hutto, R.L. 1989. The effect of habitat alteration on migratory land birds in a west Mexican tropical deciduous forest: a conservation perspective. Conservation Biology 3: 138-148.
Biodiversity	Provisioning services	Genetic resources	Jacobs, J. M., Longino, J. T., Joyce, F. J. 2011. Ants of the Islas Murciélago: an inventory of the ants on tropical dry forest islands in northwest Costa Rica. Tropical Conservation Science 4(2): 149-171.
Biodiversity	Provisioning services	Genetic resources	Janzen, D. H. 1987. Insect Diversity of a Costa Rican Dry Forest - Why Keep it, and how. Biological Journal of the Linnean Society 30 (4): 343-356. doi:10.1111/j.1095-8312.1987.tb00307.x.
Biodiversity	Supporting services	Primary production	Janzen, D. H. 1988. Tropical Dry Forests. The most Endangered Major Tropical Ecosystem. Wilson, E. O. (ed.).
Biodiversity	Provisioning services	Genetic resources	Janzen, D. H. 1988. Management of Habitat Fragments in a Tropical Dry Forest - Growth. Annals of the Missouri Botanical Garden 75 (1): 105-116.
Biodiversity	Provisioning services	Genetic resources	Janzen, D. H. 1993. Caterpillar Seasonality in a Costa Rican Dry Forest. Casey Stamp N.E (ed.).
Biodiversity	Provisioning services	Genetic resources	Janzen, D.H. 2004. Ecology of Dry-Forest Wildland Insects in the Area De Conservacion Guanacaste. Biodiversity Conservation in Costa Rica: 80-96.
Biodiversity	Provisioning services	Genetic resources	Janzen, Daniel H., Hallwachs, W., Blandin, P., Burns, J.M., Cadiou, J.M., Chacon, I., Dapkey, T. 2009. Integration of DNA Barcoding into an Ongoing Inventory of Complex Tropical Biodiversity. Molecular Ecology Resources 9: 1-26. doi:10.1111/j.1755-0998.2009.02628.x.
Biodiversity	Provisioning services	Genetic resources	Janzen, D.H., Hajibabaei, M., Burns, J.M., Hallwachs, W., Remigio, E., Hebert, P.D.N. 2005. Wedding Biodiversity Inventory of a Large and Complex Lepidoptera Fauna with DNA Barcoding. Royal Society Philosophical Transactions Biological Sciences 360 (1462): 1835-1845.
Carbon	Provisioning services	Biomass production	Jaramillo, V. J., Kauffman, J. B., Renteria-Rodriguez, L., Cummings, D. L., Ellingson, L. J. 2003. Biomass, Carbon, and Nitrogen Pools in Mexican Tropical Dry Forest Landscapes. Ecosystems 6 (7): 609-629.
Carbon	Provisioning services	Biomass production	Jaramillo, V. J., Martinez-Yrizar, A., Sanford, R. L. Jr. 2011. Primary Productivity and Biogeochemistry of Seasonally Dry Tropical Forests. In Bullock, S.H., Mooney, H.A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press, New York.
Water	Provisioning services	Genetic resources	Jiménez, J. A. 2004. Mangrove forests under dry seasonal climates in Costa Rica. Biodiversity Conservation in Costa Rica: Learning the Lessons in a Seasonal Dry Forest. University of California Press, California, 136-145.
Soils	Supporting Services	Nutrient cycling	Jimenez, J.J., Lorenz, K., Lal, R. 2011. Organic Carbon and Nitrogen in Soil Particle-Size Aggregates Under Dry Tropical Forests from Guanacaste, Costa Rica - Implications for within-Site Soil Organic Carbon Stabilization. Catena 86 (3): 178-191.
Water	Regulating services	Water regulation	Jimenez-Rodriguez, C., Calvo-Alvarado, J.C. 2013. An Evaluation of Rainfall Interception in Secondary Tropical Dry Forests. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 249-266.
Soils	Supporting Services	Soil formation	Johnson, N. C., Wedin, D. A. 1997. Soil Carbon, Nutrients, and Mycorrhizae during Conversion of Dry Tropical Forest to Grassland. Ecological Applications 7 (1): 171-182.
Biodiversity	Supporting services	Primary production	Kalacska, M., Sanchez-Azofeifa, G. A., Calvo-Alvarado, J. C., Quesada, M., Rivard, B., Janzen, D. H.. 2004. Species Composition, Similarity and Diversity in Three Successional Stages of a Seasonally Dry Tropical Forest. Forest Ecology and Management 200 (1-3): 227-247.

Carbon	Supporting services	Primary production	Kalacska, M., Sanchez-Azofeifa, G. A., Rivard, B., Calvo-Alvarado, J. C., Journet, A. R. P., Arroyo-Mora, J. P., Ortiz-ortiz, D. 2004. Leaf Area Index Measurements in a Tropical Moist Forest: A Case Study from Costa Rica. Remote Sensing of Environment 91 (2): 134-152.
Carbon	Supporting services	Primary production	Kalacska, M., Sanchez-Azofeifa, G.A., Caelli, T., Rivard, B., Boerlage, B. 2005. Estimating Leaf Area Index from Satellite Imagery using Bayesian Networks. IEEE Transactions on Geoscience and Remote Sensing 43 (8): 1866-1873. doi:10.1109/TGRS.2005.848412.
Carbon	Supporting services	Primary production	Kalacska, M., Calvo-Alvarado, J.C, Sanchez-Azofeifa, G.A. 2005. Calibration and Assessment of Seasonal Changes in Leaf Area Index of a Tropical Dry Forest in Different Stages of Succession. Tree Physiology 25 (6): 733-744.
Carbon	Supporting services	Primary production	Kalacska, M., Sanchez-Azofeifa, G.A, Calvo-Alvarado, J.C., Rivard, B., Quesada, M. 2005. Effects of Season and Successional Stage on Leaf Area Index and Spectral Vegetation Indices in Three Mesoamerican Tropical Dry Forests. Biotropica 37 (4): 486-496. doi:10.1111/j.1744-7429.2005.00067.x.
Carbon	Provisioning services	Biomass production	Kalacska, M., Bohman, S., Sanchez-Azofeifa, G. A., Castro-Esau, K., Caelli, T. 2007. Hyperspectral Discrimination of Tropical Dry Forest Lianas and Trees: Comparative Data Reduction Approaches at the Leaf and Canopy Levels. Remote Sensing of Environment 109 (4): 406-415.
Biodiversity	Supporting services	Primary production	Kalacska, M., Sanchez-Azofeifa, G. A., Rivard, B., Caelli, T., Peter White, H., Calvo-Alvarado, J. C.. 2007. Ecological Fingerprinting of Ecosystem Succession: Estimating Secondary Tropical Dry Forest Structure and Diversity using Imaging Spectroscopy. Remote Sensing of Environment 108 (1): 82-96. doi:10.1016/j.rse.2006.11.007.
Carbon	Regulating services	Carbon stocks	Kalacska, M., Sanchez-Azofeifa, G. A., Rivard, B., Calvo-Alvarado, J. C., Quesada, M. 2008. Baseline Assessment for Environmental Services Payments from Satellite Imagery: A Case Study from Costa Rica and Mexico. Journal of Environmental Management 88 (2): 348-359. doi:10.1016/j.jenvman.2007.03.015.
Carbon	Provisioning services	Biomass production	Kauffman, J. B., Steele, M. D., Cummings, D. L., Jaramillo, V. J. 2003. Biomass Dynamics Associated with Deforestation, Fire, and, Conversion to Cattle Pasture in a Mexican Tropical Dry Forest. Forest Ecology and Management 176 (1-3): 1-12. doi:10.1016/S0378-1127(02)00227-X.
Carbon	Regulating services	Carbon stocks	Kauffman, J., Boone, R., Hughes, F., Heider, C. 2009. Carbon Pool and Biomass Dynamics Associated with Deforestation, Land use, and Agricultural Abandonment in the Neotropics. Ecological Applications 19 (5): 1211-1222. doi:10.1890/08-1696.1.
Soils	Provisioning services	Biomass production	Kavanagh, T., Kellman, M. 1992. Seasonal Pattern of Fine Root Proliferation in a Tropical Dry Forest. Biotropica 24 (2): 157-165.
Carbon	Regulating services	Carbon stocks	Keith, H., Mackey, B.G., Lindenmayer, D.B. 2009. Re-Evaluation of Forest Biomass Carbon Stocks and Lessons from the World's most Carbon-Dense Forests. Proceedings of the National Academy of Sciences of the United States of America 106 (28): 11635-11640. doi:10.1073/pnas.0901970106.
Carbon	Supporting services	Primary production	Kellman, M., Delfosse, D. 1993. Effect of the Red Land Crab (Gecarcinus-Lateralis) on Leaf Litter in a Tropical Dry Forest in Veracruz, Mexico. Journal of Tropical Ecology 9: 55-65.
Biodiversity	Supporting services	Primary production	Kelly, C. K., Bowler, M. G. 2009. Temporal niche dynamics, relative abundance and phylogenetic signal of coexisting species. Theoretical Ecology 2: 127-135.
Biodiversity	Supporting services	Primary production	Kelly, C.K., Smith, H.B., Buckley, Y.M., Carter, R., Franco, M., Johnson, W., Jones, T., May, B., Ishiwara, R.P., Pérez-Jiménez, A., Magallanes, A.S., Steers, H.., Waterman, C. 2001. Investigations in commonness and rarity: a comparative analysis of co-occurring, congeneric Mexican trees. Ecology Letters 4: 618-627.
Carbon	Provisioning services	Biomass production	Kissing, L. B., Powers, J. 2010. Coarse Woody Debris Stocks as a Function of Forest Type and Stand Age in Costa Rican Tropical Dry Forest: Long-Lasting Legacies of Previous Land use. Journal of Tropical Ecology 26: 467-471.
Biodiversity	Supporting services	Pollination	Kremen, C., Williams, N.M., Aizen, M.A., Gemmill-Herren, B., LeBuhn, G., Minckley, R., Packer, L. 2007. Pollination and Other Ecosystem Services Produced by Mobile Organisms: A Conceptual Framework for the Effects of Land-use Change. Ecology Letters 10 (4): 299-314.

Soils	Provisioning services	Biomass production	Kummerow, J., Castellanos, J., Maass, J.M., Larigauderie, M. 1990. Production of fine roots and the seasonality of their growth in a Mexican deciduous dry forest. Vegetatio 90: 73-80.
Soils	Supporting Services	Soil formation	Lado, C., Rodríguez-Palma, M., Estrada-Torres, A. 1999. Myxomycetes From A Seasonal Tropical Forest On The Pacific Coast Of Mexico. Mycotaxon 71: 307-321.
Carbon	Supporting services	Primary production	Lambert, J. D. H., Arnason, J. T., Gale, J. L. 1980. Leaf-litter and changing nutrient levels in a seasonally dry tropical hardwood forest, Belize, CA. Plant and Soil, 55(3): 429-443.
Biodiversity	Provisioning services	Genetic resources	LaVal, R. K. 2004. An ultrasonically silent night: The tropical dry forest without bats. Biodiversity conservation in Costa Rica: Learning the lessons in a seasonal dry forest 160-176.
Carbon	Supporting services	Primary production	Lawrence, D. 2005. Regional-Scale Variation in Litter Production and Seasonality in Tropical Dry Forests of Southern Mexico. Biotropica 37 (4): 561-570. doi:10.1111/j.1744-7429.2005.00073.x.
Carbon	Supporting services	Primary production	Lawrence, D., Foster, D. 2002. Changes in Forest Biomass, Litter Dynamics and Soils Following Shifting Cultivation in Southern Mexico: An Overview. Interciencia 27 (8): 400-+.
Soils	Supporting Services	Soil formation	Lawrence, D., D'Odorico, P., Diekmann, L., DeLonge, M., Das, R., Eaton, J. 2007. Ecological Feedbacks Following Deforestation Create the Potential for a Catastrophic Ecosystem Shift in Tropical Dry Forest. Proceedings of the National Academy of Sciences of the United States of America104 (52): 20696-20701. doi:10.1073/pnas.0705005104.
Biodiversity	Provisioning services	Genetic resources	Lebrija-Trejos, E., Bongers, F., Perez Garcia, E., Meave, J. 2008. Successional Change and Resilience of a very Dry Tropical Deciduous Forest Following Shifting Agriculture. Biotropica 40 (4): 422-431. doi:10.1111/j.1744-7429.2008.00398.x.
Carbon	Supporting services	Primary production	Lebrija-Trejos, E., Meave, J.A., Poorter, L., Perez-Garcia, E.A., Bongers, F. 2010. Pathways, Mechanisms and Predictability of Vegetation Change during Tropical Dry Forest Succession. Perspectives in Plant Ecology Evolution and Systematics 12 (4): 267-275. doi:10.1016/j.ppees.2010.09.002.
Carbon	Regulating services	Carbon stocks	Leffler, A.J., Enquist, B.J. 2002. Carbon Isotope Composition of Tree Leaves from Guanacaste, Costa Rica: Comparison Across Tropical Forests and Tree Life History. Journal of Tropical Ecology 18: 151-159.
Soils	Supporting Services	Soil formation	Leiva, J.A., Mata, R., Rocha, O.J., Gutierrez Soto, M.V. 2009. Chronology of Tropical Dry Forest Regeneration in Santa Rosa, Guanacaste, Costa Rica. I. Edaphic Characteristics. Revista De Biologia Tropical 57 (3): 801-815.
Soils	Supporting Services	Soil formation	Leiva, J.A., Rocha, O.J., Mata, R., Gutierrez-Soto, M.V. 2009. Chronology of Tropical Dry Forest Regeneration in Santa Rosa, Guanacaste, Costa Rica. II. Vegetation in Relation to the Soil. Revista De Biologia Tropical 57 (3): 817-836.
Biodiversity	Provisioning services	Genetic resources	Lewis, G. P., Klitgaard, B. B., Schrire, B. D. 2006. Seasonally dry forests of southern Ecuador in a continental context: insights from legumes. Systematics association. 69: 281.
Biodiversity	Provisioning services	Genetic resources	Linares-Palomino, R. 2006. Phytogeography and Floristics of Seasonally Dry Tropical Forests in Peru. In Toby Pennington, R., Lewis, G.P., Ratter, J.A. (eds.). Neotropical Savannas and Seasonally Dry Forests. Plant Diversity, Biogeography, and Conservation. CRC Press.
Biodiversity	Supporting services	Primary production	Linares-Palomino, R., Ponce-Alvarez, S.I. 2009. Structural Patterns and Floristics of a Seasonally Dry Forest in Reserva Ecologica Chaparri, Lambayeque, Peru. Tropical Ecology 50 (2): 305-314.
Biodiversity	Supporting services	Primary production	Linares-Palomino, R., Oliveira Filho, A. T., Pennington, R. T. 2011. Neotropical Seasonally Dry Forests: Diversity, Endemism, and Biogeography of Woody Plants. In Bullock, S.H., Mooney, H.A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press, New York.

Soils	Supporting Services	Nutrient cycling	Litton, C.M., Sandquist, D.R., Cordell, S. 2006. Effects of Non-Native Grass Invasion on Aboveground Carbon Pools and Tree Population Structure in a Tropical Dry Forest of Hawaii. Forest Ecology and Management 231 (1-3): 105-113. doi:10.1016/j.foreco.2006.05.008.
Carbon	Supporting services	Primary production	Lobo, J. A., Quesada, M., Stoner, K. E., Fuchs, E. J., Herrerias-Diego, Y., Rojas, J., Saborio, G. 2003. Factors Affecting Phenological Patterns of Bombacaceous Trees in Seasonal Forests in Costa Rica and Mexico. American Journal of Botany 90 (7): 1054-1063.
Carbon	Supporting services	Primary production	Lobo, J.A., Quesada, M., Stoner, K.E., Fuchs, E.J., Herrerías-Diego, Y., Rojas, J., Saborío, G. 2003. Factors Affecting Phenological Patterns of Bombacaceous Trees in Seasonal Forests in Costa Rica and Mexico. American Journal of Botany 90: 1054-1063.
Biodiversity	Supporting services	Pollination	Lobo, J.A, Quesada, M., Stoner, K.E. 2005. Effects of Pollination by Bats on the Mating System of Ceiba Pentandra (Bombacaceae) Populations in Two Tropical Life Zones in Costa Rica. American Journal of Botany 92 (2): 370-376. doi:10.3732/ajb.92.2.370.
Biodiversity	Provisioning services	Genetic resources	Lohbeck, M., Poorter, L., Lebrija-Trejos, E., Martínez-Ramos, M., Meave, J.A., Paz, H., Pérez-García, E.A., Romero-Pérez, I.E., Tauro, A., Bongers. F. 2013. Successional Changes in Functional Composition Contrast for Dry and Wet Tropical Forest. Ecology 94 (6): 1211-1216.
Biodiversity	Supporting services	Primary production	Lopes, S. de F., Schiavini, I., Oliveira, A. P., Vale, V. S. 2012. An Ecological Comparison of Floristic Composition in Seasonal Semideciduous Forest in Southeast Brazil: Implications for Conservation. International Journal of Forestry Research 2012: 537269-Article ID 537269.
Carbon	Supporting services	Primary production	Lopezaraiza-Mikel, M., Quesada, M., Álvarez-Añorve, M., Ávila-Cabadilla, L., Martén-Rodríguez, S., Calvo-Alvarado, J.C., do Espírito-Santo, M.M., Fernandes, W., Sánchez-Azofeifa, A., Aguilar- Aguilar, M., Balvino-Olvera, F., Brandão, D., Contreras-Sánchez, J.M., Correa-Santos, J., Cristobal-Perez, J., Fernandez, P., Hilje, B., Jacobi, C., Fonseca- Pezzini, F., Rosas, F., Rosas-Guerrero, V., Sánchez-Montoya, G., Sáyago, R., Vázquez-Ramírez, A. 2013. Chapter 7: Phenological Patterns of Tropical Dry Forests along Latitudinal and Successional Gradients in the Neotropics. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 101-128.
Water	Regulating services	Water regulation	López-Blanco, J., Galicia, L., García-Oliva, F. 1999. Hierarchical analysis of relief features in a small watershed in a tropical deciduous forest ecosystem in Mexico. Supplementi di Geografia Fisica e Dinamica Quaternaria 22: 33-40.
Biodiversity	Supporting services	Primary production	Lopez-Olmedo, L. I., Meave, J. A., Perez-Garcia, E. A. 2007. Floristic and Structural Contrasts between Natural Savannas and Anthropogenic Pastures in a Tropical Dry Landscape. Rangeland Journal 29 (2): 181-190.
Soils	Supporting Services	Nutrient cycling	Lorenz, K., Lal, R., Jimenez, J.J. 2009. Soil Organic Carbon Stabilization in Dry Tropical Forests of Costa Rica. Geoderma 152 (1-2): 95-103.
Soils	Regulating services	Soil carbon stocks	Lorenz, K., Lal, R., Jimenez, J.J. 2010. Characterization of Soil Organic Matter and Black Carbon in Dry Tropical Forests of Costa Rica. Geoderma 158 (3-4): 315-321.
Biodiversity	Provisioning services	Genetic resources	Lott, E. J. 1993. Annotated Checklist of the Vascular Flora of the Chamela Bay Region, Jalisco, Mexico. Occasional Papers California Academy of Sciences (148): 1-60.
Biodiversity	Supporting services	Primary production	Lott, E.J., Atkinson, T.H. 2006. Mexican and Central American seasonally dry tropical forests: Chamela-Cuixmala, Jalisco, as a focal point for comparison. Neotropical Savannas and Seasonally Dry Forests: Plant Diversity, Biogeography, and Conservation 315-342.
Biodiversity	Supporting services	Primary production	Lott, E.J., Bullock, S.H., Solís-Magallanes, J.A. 1987. Floristic diversity and structure of upland and arroyo forests in coastal Jalisco. Biotropica 19: 228-235.
Soils	Supporting Services	Primary production	Fernanda, C., Echeverría, H. E., Pagano, M. C. 2012. Arbuscular mycorrhizal fungi: Essential belowground organisms for earth life but sensitive to a changing environment. African Journal of Microbiology Research 6(27): 5523-5535.

Biodiversity	Provisioning services	Biochemicals, natural medicines, and pharmaceuticals	Lucena, R. F., Albuquerque, U. P., Monteiro, J. M., Cecília De Fátima, C. B. R., Florentino, A. T., Ferraz, J. S. F. 2007. Useful plants of the semi-arid northeastern region of Brazil–a look at their conservation and sustainable use. Environmental Monitoring and Assessment 125(1-3): 281-290.
Soils	Supporting Services	Nutrient cycling	Lugo, A. E., Murphy, P. G. 1986. Nutrient Dynamics of a Puerto Rican Subtropical Dry Forest. Journal of Tropical Ecology 2 (1): 55-72.
Carbon	Provisioning services	Biomass production	Lugo, A., Gonzalezliboy, J., Cintron, B., Dugger, K. 1978. Structure, Productivity, and Transpiration of a Sub-Tropical Dry Forest in Puerto-Rico. Biotropica 10 (4): 278-291.
Water	Regulating services	Water regulation	Lugo, A.E., Gonzalez-Liboy, J.A., Cintron, B., Dugger, K. 1978. Structure, Productivity, and Transpiration of a Subtropical Dry Forest in Puerto Rico. Biotropica 10: 278–291
Water	Regulating services	Water regulation	Maass, M., Burgos, A. 2011. Water Dynamics at the Ecosystem Level in Seasonally Dry Tropical Forests. In Bullock, S.H., Mooney, H.A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press, New York.
Carbon	Supporting services	Primary production	Maass, J.M., Vose, J.M., Swank, W.T., Martínez-Yrízar, A. 1995. Seasonal changes of leaf area index (LAI) in a tropical deciduous forest in west Mexico. Forest Ecology and Management 74: 171-180.
Carbon	Provisioning services	Biomass production	Maass, J.M., Martínez-Yrízar, A., Patiño, C., Sarukhán, J. 2002. Distribution and annual net accumulation of above-ground dead phytomass and its influence on throughfall quality in a Mexican tropical deciduous forest ecosystem. . Journal of Tropical Ecology 18: 821-834.
Carbon	Provisioning services	Biomass production	Madeira, B.G., Espirito-Santo, M.M.DO., D'Angelo Neto, S., Nunes, Y.R.F., Sanchez-Azofeifa, G.A., Fernandes, G.W., Quesada, M. 2009. Changes in Tree and Liana Communities Along a Successional Gradient in a Tropical Dry Forest in South-Eastern Brazil. Plant Ecology 201 (1): 291-304.
Biodiversity	Provisioning services	Genetic resources	Madrid-Sotelo, C.A., García, A. 2008. A simple method for externally attaching radio-transmitters to snakes. North-Western Journal of Zoology 4: 335-338.
Biodiversity	Provisioning services	Biochemicals, natural medicines, and pharmaceuticals	Maldonado, B., Caballero, J., Delgado-Salinas, A., Lira, R. 2013. Relationship between use Value and Ecological Importance of Floristic Resources of Seasonally Dry Tropical Forest in the Balsas River Basin, M,Xico. Economic Botany 67 (1): 17-29.
Biodiversity	Provisioning services	Genetic resources	Mandujano, S. 1999. Variation in herd size of collared peccaries in a Mexican tropical forest. Southwestern Naturalist 44: 199-204.
Biodiversity	Provisioning services	Genetic resources	Mandujano, S., Gallina, S., Bullock, S.H. 1994. Frugivory and dispersal of Spondias purpurea (Anacardiaceae) in a tropical deciduous forest in México. Revista de Biología Tropical. International Journal of Tropical Biology and Conservation 42: 107-114.
Biodiversity	Provisioning services	Genetic resources	Marin, G.C, Tigabu, M., Gonzalez-Rivas, B., Christer Oden, P. 2009. A Chronosequence Analysis of Forest Recovery on Abandoned Agricultural Fields in Nicaragua. Journal of Forestry Research (Harbin) 20 (3): 213-222.
Water	Regulating services	Water regulation	Markewitz, D., Resende, J.C.F., Parron, L., Bustamante, M., Klink, C.A., Figueiredo, R., Davidson, E.A. 2006. Dissolved rainfall inputs and streamwater outputs in an undisturbed watershed on highly weathered soils in the Brazilian cerrado. Hydrological Processes 20: 2615–2639.
Biodiversity	Provisioning services	Genetic resources	Marques, T., Schoereder, J. H. 2014. Ant Diversity Partitioning Across Spatial Scales: Ecological Processes and Implications for Conserving Tropical Dry Forests. Austral Ecology 39 (1): 72-82.
Biodiversity	Provisioning services	Biochemicals, natural medicines, and pharmaceuticals	Marshall, E., Newton, A.C. 2003. Non-Timber Forest Products in the Community of El Terrero, Sierra De Manantlan Biosphere Reserve, Mexico: Is their use Sustainable? Economic Botany 57 (2): 262-278.
Soils	Supporting Services	Soil formation	Martijena, N.E. 1998. Soil properties and seedling establishment in soils from monodominant and high-diversity stands of the tropical deciduos forests of México. Journal of Biogeography 25: 707-719.
Biodiversity	Supporting services	Primary production	Martijena, N.E., Bullock, S.H. 1994. Monospecific dominance of a tropical deciduous forest in México. Journal of Biogeography 21: 63-74.
Carbon	Supporting services	Primary production	Martinezyrizar, A., Sarukhan, J. 1990. Litterfall Patterns in a Tropical Deciduous Forest in Mexico Over a 5-Year Period. Journal of Tropical Ecology 6: 433-444.

Carbon	Supporting services	Primary production	Martínez-Yrizar, A., Sarukhan, J. 1990. Litterfall patterns in a tropical decidious forest in Mexico over a five-year period. Journal of Tropical Ecology. 6: 433-444.
Carbon	Provisioning services	Biomass production	Martinez-Yrizar, A., Sarukhan, J., Perez-Jimenez, A., Rincon, E., Maass, J. M., Solis-Magallanes, A., Cervantes, L. 1992. Above-ground phytomass of a tropical deciduous forest on the coast of Jalisco, Mexico. Journal of Tropical Ecology 8(01): 87-96.
Carbon	Supporting services	Primary production	MartinezYrizar, A., Maass, J. M., PerezJimenez, L. A., Sarukhan, J. 1996. Net Primary Productivity of a Tropical Deciduous Forest Ecosystem in Western Mexico. Journal of Tropical Ecology 12: 169-175.
Soils	Supporting Services	Soil formation	Maass, J.M., Jordan, C., Sarukhán, J. 1988. Soil erosion and nutrient losses in a seasonal tropical agroecosystems under various management techniques. Journal of Applied Ecology 25: 595-607.
Water	Regulating services	Water regulation	Mata-Jiménez, A. 2004. Watershed Ecology and Conservation: Hydrological resources in the northwest of Costa Rica. In Frankie, G.W., Mata-Jiménez, A., Vinson, S.B. (eds.). Berkeley, CA University of California Press US. p. 115-125.
Biodiversity	Provisioning services	Genetic resources	Maza-Villalobos, S., Balvanera, P., Martinez-Ramos, M. 2011. Early Regeneration of Tropical Dry Forest from Abandoned Pastures: Contrasting Chronosequence and Dynamic Approaches. Biotropica 43 (6): 666-675. doi:10.1111/j.1744-7429.2011.00755.x.
Soils	Supporting Services	Soil formation	Maza-Villalobos, S., Lemus-Herrera, C., Martinez-Ramos, M. 2011. Successional trends in soil seed banks of abandoned pastures of a Neotropical dry region. Journal of Tropical Ecology 27:35–49.
Water	Regulating services	Water regulation	Maza-Villalobos, S., Poorter, L., Martinez-Ramos, M. 2013. Effects of ENSO and Temporal Rainfall Variation on the Dynamics of Successional Communities in Old-Field Succession of a Tropical Dry Forest. Plos One 8 (12): e82040.
Water	Supporting Services	Water cycling	McLaren, K. P., McDonald, M. A. 2003. The effects of moisture and shade on seed germination and seedling survival in a tropical dry forest in Jamaica. Forest ecology and management 183(1): 61-75.
Biodiversity	Provisioning services	Genetic resources	McLaren, K.P., McDonald, M.A., Hall, J.B., Healey, J.R. 2005. Predicting Species Response to Disturbance from Size Class Distributions of Adults and Saplings in a Jamaican Tropical Dry Forest. Plant Ecology 181 (1): 69-84.
Biodiversity	Provisioning services	Genetic resources	McWhurter, D.W. 1976. Summer birds of Estacion Chamela and vicinity, Jalisco, Mexico. Anales del Instituto de Biología (UNAM) serie Botánica 47: 63-66.
Soils	Supporting Services	Soil formation	Meave, J. A., Flores-Rodríguez, C., Pérez García, E. A., Romero-Romero, M. A. 2012. Edaphic and seasonal heterogeneity of seed banks in agricultural fields of a tropical dry forest region in Southern Mexico. Botanical sciences 90(3): 313-329.
Carbon	Supporting services	Primary production	Medina, E., Zelwer, M. 1972. Soil Respiration in Tropical Plant Communities. Tropical Ecology, Proceedings of the New Delhi Symposium, January 1971: 245-269.
Biodiversity	Supporting services	Primary production	Medina, E., Cuevas, E., Molina, S., Luco, A.E., Ramos, O. 2012. Structural Variability and Species Diversity of a Dwarf Caribbean Dry Forest. Caribbean Journal of Science 46 (2-3): 203-215.
Water	Supporting Services	Water cycling	Meinzer, F. C., Andrade, J. L., Goldstein, G., Holbrook, N. M., Cavelier, J., Wright, S. J. 1999. Partitioning of Soil Water among Canopy Trees in a Seasonally Dry Tropical Forest. Oecologia 121 (3): 293-301.
Carbon	Regulating services	Climate regulation	Meir, P., Pennington, R. T. 2011. Climatic Change and Seasonally Dry Tropical Forests. In Bullock, S.H., Mooney, H.A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press, New York.
Soils	Supporting Services	Soil formation	Mejía-Recamier, B.E., Castaño-Meneses, G. 2007. Community structure of edaphic cunaxids (Acarina) from a lowland dry forest in Chamela, Mexico. Revista de Biología Tropical. International Journal of Tropical Biology and Conservation 55: 911-930.
Water	Supporting Services	Water cycling	Mendez-Alonzo, R., Pineda-Garcia, F., Paz, H., Rosell, J.A., Olson, M.E. 2013. Leaf Phenology is Associated with Soil Water Availability and Xylem Traits in a Tropical Dry Forest. Trees-Structure and Function 27 (3): 745-754.

Carbon	Regulating services	Carbon stocks	Miles, L., Newton, A. C., DeFries, R. S., Ravilious, C., May, I., Blyth, S., Kapos, V., Gordon, J. E. 2005. A Global Overview of the Conservation Status of Tropical Dry Forests. Journal of Biogeography 33 (3): 491-505.
Soils	Supporting Services	Soil formation	Miller, P.M. 1999. Coppice shoot and foliar crown growth after disturbance of a tropical deciduous forest in Mexico. Forest Ecology and Management 116: 163-173.
Soils	Supporting Services	Soil formation	Miller, P.M. 1999. Effects of deforestation on seed banks in a tropical deciduous forest of western Mexico. Journal of Tropical Ecology 15: 179-188.
Biodiversity	Provisioning services	Genetic resources	Miller, P.M., Kauffman, J.B. 1998. Effects of slash and burn agriculture on species abundance and composition of a tropical deciduous forest. Forest Ecology and Management 103: 191-201.
Soils	Supporting Services	Soil formation	Miller, P.M., Kauffman, J.B. 1998. Seedling sprout response to flash-and-burn agriculture in tropical deciduous forest. Biotropica 30: 538-546.
Soils	Supporting Services	Primary production	Mohamed, A., Reich, R. M., Khosla, R., Aguirre-Bravo, C., Briseño, M. M. 2014. Influence of Climatic Conditions, Topography and Soil Attributes on the Spatial Distribution of Site Productivity Index of the Species Rich Forests of Jalisco, Mexico. Journal of Forestry Research 25 (1): 87-95.
Biodiversity	Provisioning services	Genetic resources	Mohamed, A., Reich, R.M., Khosla, R., Aguirre-Bravo, C., Mendoza Briseno, M. 2014. Influence of Climatic Conditions, Topography and Soil Attributes on the Spatial Distribution of Site Productivity Index of the Species Rich Forests of Jalisco, Mexico. Journal of Forestry Research 25 (1): 87-95.
Soils	Supporting Services	Nutrient cycling	Montaño, N.M., García-Oliva, F., Jaramillo, V. 2007. Dissolved organic carbon affects soil microbial activity and nitrogen dinamics in a Mexican tropical deciduous forest. Plant and Soil 295: 265-277.
Soils	Supporting Services	Nutrient cycling	Montaño, N.M., Sandoval-Pérez, A.L., García-Oliva, F., Larsen, J., Gavito, M.E. 2009. Microbial activity in contrasting conditions of soil C and N availability in a tropical dry forest. Journal of Tropical Ecology 25: 401-413.
Water	Regulating services	Water regulation	Montenegro, A., Ragab, R. 2010. Hydrological response of a Brazilian semi-arid catchment to different land use and climate change scenarios: a modelling study. Hydrological Processes 24: 2705–2723.
Carbon	Regulating services	Carbon stocks	Mooney, H.A., Bullock, S.H., Ehileringer, J. 1989. Carbon isotope ratios of plants of a tropical deciduous forest in Mexico. Functional Ecology 3: 137-142.
Biodiversity	Supporting services	Primary production	Mooney, H.A., Chu, C., Bullock, S.H., Robichaux, R. 1992. Carbohydrate, water and nitrogen storage in vines of a Tropical Deciduous Forest. Biotropica 24: 134-139.
Carbon	Regulating services	Carbon stocks	Mora, F., Martinez-Ramos, M., Ibarra-Manriquez, G., Perez-Jimenez, A., Trilleras, J., Balvanera, P. 2015. Testing Chronosequences through Dynamic Approaches: Time and Site Effects on Tropical Dry Forest Succession. Biotropica 47 (1): 38-48.
Carbon	Regulating services	Carbon stocks	Morales, R.M., Tomoaki, M., Idol, T. 2008. An Assessment of Hawaiian Dry Forest Condition with Fine Resolution Remote Sensing. Forest Ecology and Management 255 (7): 2524-2532.
Biodiversity	Provisioning services	Genetic resources	Morales-Garza, M.R., Arizmendi, M. del C., Campos, J.E., Martínez-García, M., Valiente-Banuet, A. 2007. Evidences on the migratory movements of the nectar-feeding bat Leptonycteris curasoae in Mexico using random amplified polymorphic DNA (RAPD). Journal of Arid Environments 68: 248-259.
Biodiversity	Provisioning services	Genetic resources	Moreira, P. A., Fernandes, G. W., Collevatti, R. G. 2009. Fragmentation and Spatial Genetic Structure in Tabebuia Ochracea (Bignoniaceae) a Seasonally Dry Neotropical Tree. Forest Ecology and Management 258 (12): 2690-2695.
Carbon	Supporting services	Primary production	Morellato, L.P.C. 1992. Nutrient Cycling in 2 South-East Brazilian Forests .1. Litterfall and Litter Standing Crop. Journal of Tropical Ecology 8: 205-215.
Biodiversity	Provisioning services	Genetic resources	Morón, M.A., Deloya, C., Ramírez-Campos, A., Hernández-Rodríguez, S. 1998. Coleoptera fauna lamellicornia from Tepic region, Nayarit, Mexico. Acta Zoológica Mexicana Nueva Serie 75: 73-116.

Biodiversity	Provisioning services	Genetic resources	Morrison, D.W. 1978. Influence of habitat on the foraging distances of the fruit bat Artibeus jamaicensis. Journal of Mammalogy 59: 622-624.
Biodiversity	Provisioning services	Genetic resources	Muenchow, J., von Wehrden, H., Rodríguez, E. F., Rodríguez, R. A., Bayer, F., Richter, M. 2013. Woody vegetation of a peruvian tropical dry forest along a climatic gradient depends more on soil than annual precipitation. Erdkunde, 241-248.
Biodiversity	Supporting services	Primary production	Murphy, P. G., Lugo, A. E. 1986. Ecology of tropical dry forest. Annual review of ecology and systematics 67-88.
Carbon	Provisioning services	Biomass production	Nassar, J. M., Rodriguez, J. P., Sanchez-Azofeifa, G.A., Garvin, T., Quesada, M. 2008. Manual of Methods: Human, Ecological and Biophysical Dimensions of Tropical Dry Forests. Caracas, Venezuela: Instituto Venezolano de Investigaciones Cientificas.
Biodiversity	Provisioning services	Genetic resources	Nassar, J., Stoner, K. E., Ávila-Cabadilla, L., do Espírito-Santo, M. M., Aranguren, C. I., González-Carcacía, J. A. Rodríguez, J. P. 2013. Fruit-Eating Bats and Birds of Three Seasonal Tropical Dry Forests in the Americas. Tropical Dry Forests in the Americas: Ecology, Conservation, and Management pp 173.
Biodiversity	Provisioning services	Genetic resources	Nava-Cruz, Y., Maass-Moreno, M., Briones-Villareal, O., Mendez-Ramírez, I. 2007. Evaluation of the edge effect on two arboreal species of the tropical dry forest of Jalisco, Mexico. Agrociencia 41: 111-120.
Soils	Supporting Services	Soil formation	Nava-Mendoza, M., Galicia, L., García-Oliva, F. 2000. Efecto de dos especies de árboles remanentes y de un pasto en la capacidad amortiguadora del pH del suelo en un ecosistema tropical estacional. Boletín de la Sociedad Botánica de México 67: 17-24.
Carbon	Provisioning services	Biomass production	Návar, J. 2009. Allometric equations for tree species and carbon stocks for forests of northwestern Mexico. Forest Ecology and Management 257(2): 427-434.
Biodiversity	Provisioning services	Genetic resources	Neves, F., Fonseca Oliveira, V.H., Espirito-Santo, M.M.DO., Zagury Vaz-de-Mello, F., Louzada, J., Sanchez-Azofeifa, G.A., Fernandes, G.W. 2010. Successional and Seasonal Changes in a Community of Dung Beetles (Coleoptera: Scarabaeinae) in a Brazilian Tropical Dry Forest. Natureza Conservacao 8 (2): 160-164. doi:10.4322/natcon.00802009.
Biodiversity	Provisioning services	Genetic resources	Neves, F.S., Araujo, L., Espirito-Santo, M.M.DO., Fagundes, M., Fernandes, G.W., Sanchez-Azofeifa, G.A., Quesada, M. 2010. Canopy Herbivory and Insect Herbivore Diversity in a Dry Forest-Savanna Transition in Brazil. Biotropica 42 (1): 112-118. doi:10.1111/j.1744-7429.2009.00541.x.
Biodiversity	Provisioning services	Genetic resources	Neves, F., Silva, J. O., Marques, T., Mota-Souza, J. G., Madeira, B., Espirito-Santo, M.M.DO. 2013. Spatiotemporal Dynamics of Insects in a Brazilian Tropical Dry Forest. Tropical Dry Forests in the Americas: Ecology, Conservation, and Management, 221.
Soils	Supporting Services	Soil formation	Niemeyer, R. J., Fremier, A. K., Heinse, R., Chávez, W., Declerck, F.A.J. 2014. Woody Vegetation Increases Saturated Hydraulic Conductivity in Dry Tropical Nicaragua. Vadose Zone Journal 13 (1).
Biodiversity	Provisioning services	Genetic resources	Noguera, F. A., Zaragoza-Caballero, S., Rodriguez-Palafox, A., Gonzalez-Soriano, E., Ramirez-Garcia, E., Ayala, R., Ortega-Huerta, M.A. 2012. Cerambycids (Coleoptera: Cerambycidae) from a Tropical Dry Forest in Santiago Dominguillo, Oaxaca, Mexico. Revista Mexicana De Biodiversidad 83 (3): 611-622. doi:10.7550/rmb.25088.
Soils	Supporting Services	Soil formation	Noguez, A.M., Escalante, H.A., Forney, L., García-Oliva, F., Souza, V. 2005. Microbial macroecology: highly structured prokaryotic soil assemblages in a tropical deciduous forest. Global Ecology Biogeography 14: 241-248.
Soils	Supporting Services	Soil formation	Noguez, A.M., Escalante, A., Forney, L., Nava-Mendoza, M., Rosas, I., Souza, V., García-Oliva, F. 2008. Soil aggregates in a tropical deciduous forest: effects on C and N dynamics, and microbial communities as determined by t-RFLPs. Biogeochemistry 89: 209-220.
Biodiversity	Provisioning services	Genetic resources	Odegaard, F. 2003. Taxonomic Composition and Host Specificity of Phytophagous Beetles in a Dry Forest in Panama. Arthropods of Tropical Forests: 220-236.
Biodiversity	Provisioning services	Genetic resources	Oliveira-Filho, A. T., Jarenkow, J. A., Rodal, M. N. 2006. Floristic relationships of seasonally dry forests of eastern South America based on tree species distribution patterns. Systematics association. 69: 159.

Biodiversity	Supporting services	Primary production	Oliveras de Ita, A., Rojas-Soto, O.R. 2006. Ant presence in acacias: an association that maximizes nesting success in birds? Wilson Journal Of Ornithology 118: 563-566.
Biodiversity	Provisioning services	Genetic resources	Ornelas, J. F., Arizmendi, M. D., Marquezvaldelamar, L., Navarijo, M. D., Berlanga, H. A. 1993. Variability Profiles for Line Transect Bird Censuses in a Tropical Dry Forest in Mexico. Condor 95 (2): 422-441.
Biodiversity	Provisioning services	Genetic resources	Osorio Beristain, M., Domínguez, C.A., Eguiarte, L.E., Benrey, B. 1997. Pollination efficiency of native and invading Africanized bees in the tropical dry forest annual plant, Kallstroemia grandiflora Torr ex Gray. Apidologie 28: 11-16.
Biodiversity	Provisioning services	Genetic resources	Pacheco F., Deloya, C., Cortes, P. G. 2006. Phytophagous scarab beetles from the Central Region of Guerrero, Mexico (Coleoptera: Scarabaeidae: Melolonthinae, Rutelinae, Dynastinae, Cetoniinae). Revista Colombiana de Entomologia 32: 191-199.
Biodiversity	Provisioning services	Genetic resources	Padilla-Gil, D.N., Halffter, G. 2007. Biogeography of the areas and Canthonini (Coleoptera: Scarabaeidae) of dry tropical forests in Mesoamerica and Colombia. Acta Zoológica Mexicana Nueva Serie 23: 73-108.
Biodiversity	Supporting services	Pollination	Palacios, C.R. 1985. Lluvias de polen moderno en el bosque tropical caducifolio de la Estación de Biología Chamela, Jal. (México). Anales de la Escuela Nacional de Ciencias Biológicas, México 29: 43-55.
Carbon	Provisioning services	Biomass production	Palacios-Vargas, J.G., Castaño-Meneses, G., Rubio, A.P. 1999. Phenology Of Canopy Arthropods Of A Tropical Deciduous Forest In Western Mexico. Pan-Pacific Entomologist 75: 200-211.
Biodiversity	Supporting services	Primary production	Palacios-Vargas, J.G., Castaño-Meneses, G., Gómez-Anaya, J.A., Martínez-Yrízar, A., Mejía Recamier, B.E., Marínez-Sánchez, J. 2007. Litter and soil arthropods Diversity and density in a tropical dry forest ecosystem in Western Mexico. Biodiversity and conservation 16: 3703-3717.
Carbon	Provisioning services	Biomass production	Paredes-Villanueva, K., Sánchez-Salguero, R., Manzanedo, R. D., Sopepi, R. Q., Palacios, G., Navarro-Cerrillo, R. M. 2013. Growth rate and climatic response of Machaerium scleroxylon in a dry tropical forest in southeastern Santa Cruz, Bolivia. Tree-Ring Research 69(2): 63-79.
Carbon	Supporting services	Primary production	Parker, G., Tinoco-Ojanguren, C., Martínez-Yrízar, A., Maass, M. 2005. Seasonal balance and vertical pattern of photosynthetically active radiation within canopies of a tropical dry deciduous forest ecosystem in Mexico. Journal of Tropical Ecology 21: 283-295.
Biodiversity	Supporting services	Pollination	Parra-Tabla, V., Bullock, S.H. 1998. Factors limiting fecundity of the tropical tree Ipomoea wolcottiana (Convolvulaceae) in a Mexican tropical dry forest. Journal of Tropical Ecology 14: 615-627.
Biodiversity	Supporting services	Pollination	Parra-Tabla, V., Bullock, S.H. 2000. Phenotypic natural selection on flower biomass allocation in the tropical tree Ipomoea wolcottiana Rose (Convolvulaceae). Plant Systematics and Evolution 221: 167-177.
Biodiversity	Supporting services	Primary production	Pascual-Alvarado, E., Cuevas-Reyes, P., Quesada, M., Oyama, K. 2008. Interactions between galling insects and leaf-feeding insects: the role of plant phenolic compounds and their possible interference with herbivores. Journal of Tropical Ecology 24: 329-336.
Biodiversity	Provisioning services	Genetic resources	Pau, S., Gillespie, T.W., Price, J.P. 2009. Natural History, Biogeography, and Endangerment of Hawaiian Dry Forest Trees. Biodiversity and Conservation 18 (12): 3167-3182.
Biodiversity	Regulating services	Natural hazard regulation	Peguero, G., Espelta, J.M. 2014. Endozoochory and Fire as Germination Triggers in Neotropical Dry Forests: An Experimental Test. Biotropica 46 (1): 83-89.
Biodiversity	Provisioning services	Genetic resources	Pennington, R.T., Lewis, G.P., Ratter, J.A. 2006. An Overview of the Plant Diversity, Biogeography and Conservation of Neotropical Savannas and Seasonally Dry Forests. Systematics Association Special Volume Series. Pennington, R.T., Lewis, G.P., Ratter, J.A (eds.). CRC Press-Taylor Francis Group. Boca Raton.
Biodiversity	Supporting services	Primary production	Pennington, R.T, Lavin, M., Oliveira-Filho, A. 2009. Woody Plant Diversity, Evolution, and Ecology in the Tropics: Perspectives from Seasonally Dry Tropical Forests. Annual Review of Ecology Evolution and Systematics 40: 437-457.

Biodiversity	Provisioning services	Genetic resources	Pescador-Rubio, A. 1993. The effects of a multispecies sequential diet on the growth and survival of a tropical polyphagous caterpillar. Entomologia Experimentalis et Applicata 67: 15-24.
Carbon	Supporting services	Primary production	Pezzini, F. F., Ranieri, B. D., Brandão, D. O., Fernandes, G. W., Quesada, M., Espírito-Santo, M. M.DO., Jacobi, C.M. 2014. Changes in Tree Phenology Along Natural Regeneration in a Seasonally Dry Tropical Forest. Plant Biosystems.
Carbon	Regulating services	Carbon stocks	Pfaff, A.S., Kerr, S., Hughes, R.F., Liu, S., Sanchez–Azofeifa, G.A., Schimel, D., Tosi, J. And Watson, V., 2000. The Kyoto Protocol and Payments for Tropical Forest: An Interdisciplinary Method for Estimating Carbon-Offset Supply and Increasing the Feasibility of a Carbon Market Under the CDM. Ecological Economics 35 (2): 203-221.
Biodiversity	Supporting services	Primary production	Pirie, C.D., Walmsley, S., Ingle, R., Jiménez, A.P., Magallanes, A.S., Kelly, C.K. 2000. Investigations in plant commonness and rarity: a comparison of seed removal patterns in the widespread Jatropha standleyi and the endemic J-chamelensis (Euphorbiaceae). Biological Journal of the Linnean Society 71: 501-512.
Biodiversity	Regulating services	Natural hazard regulation	Poorter, L., Mcneil, A., Hurtado, V.H., Prins, H. H. T., Putz, F. E. 2014. Bark Traits and Life-History Strategies of Tropical Dry- and Moist Forest Trees. Functional Ecology 28 (1): 232-242.
Carbon	Regulating services	Carbon stocks	Portillo-Quintero, C. A., Sanchez-Azofeifa, G. A. 2010. Extent and Conservation of Tropical Dry Forests in the Americas. Biological Conservation 143 (1): 144-155. doi:10.1016/j.biocon.2009.09.020.
Carbon	Regulating services	Carbon stocks	Portillo-Quintero, C.A., Sanchez-Azofeifa, G.A., Espirito-Santo, M.M.DO. 2013. Monitoring Deforestation with MODIS Active Fires in Neotropical Dry Forests: An Analysis of Local-Scale Assessments in Mexico, Brazil and Bolivia. Journal of Arid Environments 97: 150-159. doi:10.1016/j.jaridenv.2013.06.002.
Carbon	Supporting services	Primary production	Portillo-Quintero, C., Sánchez-Azofeifa, G.A., Espírito-Santo, M.M.DO. 2013. Chapter 10: Edge Influence on Canopy Openness and Understory Microclimate in Two Neotropical Dry Forest Fragments. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 157-172.
Biodiversity	Supporting services	Primary production	Pounden, E., Greene, D.F., Quesada, M., Contreras Sánchez J.M. 2008. The effect of collisions with vegetation elements on the dispersal of winged and plumed seeds. Journal of Ecology 96: 591-598.
Soils	Provisioning services	Biomass production	Powers, J. S., Peréz-Aviles, D. 2013. Edaphic factors are a more important control on surface fine roots than stand age in secondary tropical dry forests. Biotropica 45(1): 1-9.
Biodiversity	Supporting services	Primary production	Powers, J.S., Tiffin, P. 2010. Plant Functional Type Classifications in Tropical Dry Forests in Costa Rica: Leaf Habit Versus Taxonomic Approaches. Functional Ecology 24 (4): 927-936. doi:10.1111/j.1365-2435.2010.01701.x.
Biodiversity	Provisioning services	Genetic resources	Powers, J.S., Becknell, J.M., Irving, J., Perez-Aviles, D. 2009. Diversity and Structure of Regenerating Tropical Dry Forests in Costa Rica: Geographic Patterns and Environmental Drivers. Forest Ecology and Management 258 (6): 959-970.
Soils	Regulating services	Soil carbon stocks	Powers, J.S., Corre, M.D., Twine, T., Veldkamp, E. 2011. Geographic Bias of Field Observations of Soil Carbon Stocks with Tropical Land-use Changes Precludes Spatial Extrapolation. Proceedings of the National Academy of Sciences of the United States of America 108 (15): 6318-6322.
Carbon	Regulating services	Carbon stocks	Prado, D. E. 2000. Seasonally Dry Forests of Tropical South America: From Forgotten Ecosystems to a New Phytogeographic Unit. Edinburgh Journal of Botany 57 (3): 437-461.
Biodiversity	Provisioning services	Genetic resources	Prado, D., Gibbs, P. 1993. Patterns of Species Distributions in the Dry Seasonal Forests of South-America. Annals of the Missouri Botanical Garden 80 (4): 902-927.
Biodiversity	Supporting services	Primary production	Pringle, E.G., Adams, R.I., Broadbent, E., Busby, P., Donatti, C.I., Kurten, E.L., Renton, K., Dirzo, R. 2011. Distinct Leaf-Trait Syndromes of Evergreen and Deciduous Trees in a Seasonally Dry Tropical Forest. Biotropica 43 (3): 299-308. doi:10.1111/j.1744-7429.2010.00697.x.
Biodiversity	Provisioning services	Genetic resources	Pyritz, L.W., Buentge, A.B.S., Herzog, S.K., Kessler, M. 2010. Effects of Habitat Structure and Fragmentation on Diversity and Abundance of Primates in Tropical Deciduous Forests in Bolivia. International Journal of Primatology 31 (5): 796-812.

Biodiversity	Supporting services	Pollination	Quesada, M., Fuchs, E. J., Lobo, J.A. 2001. Pollen Load Size, Reproductive Success, and Progeny Kinship of Naturally Pollinated Flowers of the Tropical Dry Forest Tree Pachira Quinata (Bombacaceae). American Journal of Botany 88 (11): 2113-2118. doi:10.2307/3558436.
Biodiversity	Supporting services	Pollination	Quesada, M., Stoner, K.E., Rosas-Guerrero, V., Palacios-Guevara, C., Lobo, J.A. 2003. Effects of habitat disruption on the activity of nectarivorous bats (Chiroptera : Phyllostomidae) in a dry tropical forest: implications for the reproductive success of the neotropical tree Ceiba grandiflora. Oecologia 135: 400-406.
Biodiversity	Supporting services	Pollination	Quesada, M., Stoner, K. E., Lobo, J. A., Herrerias-Diego, Y., Palacios-Guevara, C., Munguia-Rosas, M. A., Salazar, K. A., Rosas-Guerrero, V. 2004. Effects of Forest Fragmentation on Pollinator Activity and Consequences for Plant Reproductive Success and Mating Patterns in Bat-Pollinated Bombacaceous Trees.Biotropica 36 (2): 131-138. doi:10.1111/j.1744-7429.2004.tb00305.x.
Biodiversity	Provisioning services	Genetic resources	Quesada, M., Sanchez-Azofeifa, G.A., Alvarez-Anorve, M., Stoner, K.E., Avila-Cabadilla, L., Calvo-Alvarado, J.C., Castillo, A., Espirito-Santo, M.M., Fagundes, M., Fernandes, G.W., Gamon, J., Lopezaraiza-Mikel, M., Lawrence, D., Cerdeira Morellato, L.P., Powers, J.S., Neves, F.D.S., Rosas-Guerrero, V., Sayago, R., Sanchez-Montoya, G. 2009. Succession and Management of Tropical Dry Forests in the Americas: Review and New Perspectives. Forest Ecology and Management 258 (6): 1014-1024. doi:10.1016/j.foreco.2009.06.023.
Biodiversity	Supporting services	Pollination	Quesada, M., Rosas, F., Aguilar, R., Ashworth, L., Rosas-Guerrero, V. M., Sayago, R., Lobo, J. A., Herrerias-Diego, Y., Sanchez-Montoya, G. 2011. Human Impacts on Pollination, Reproduction, and Breeding Systems in Tropical Forest Plants. In Bullock, S.H., Mooney, H.A., Medina, E. (eds.). Seasonally dry tropical forests. Cambridge University Press, New York.
Biodiversity	Supporting services	Pollination	Quiroz-García, D.L., Palacios-Chávez, R., Arreguín-Sánchez, M. 1994. Flora polinica de Chamela, Jalisco (Familias Amaranthaceae, Combretaceae, Loasaceae, Martyniaceae, Papaveraceae, Tiliaceae y Violaceae). Acta Botánica Mexicana 29: 61-81.
Biodiversity	Supporting services	Pollination	Quiroz-García, D.L., Martínez-Hernández, E., Palacios-Chávez, R., Galindo-Miranda, N.E. 2001. Nest Provisions And Pollen Foraging In Three Species Of Solitary Bees (Hymenoptera : Apidae) From Jalisco, Mexico. Journal of the Kansas Entomological Society 74: 61-69.
Carbon	Supporting services	Primary production	Ragusa-Netto, J., Silva, R. R. 2007. Canopy Phenology of a Dry Forest in Western Brazil. Brazilian Journal of Biology 67 (3): 569-575.
Biodiversity	Supporting services	Pollination	Raine, N.E., Willmer, P., Stone, G.N. 2002. Spatial Structuring And Floral Avoidance Behavior Prevent Ant-Pollinator Conflict In A Mexican Ant-Acacia. Ecology 83: 3086-3096.
Biodiversity	Supporting services	Pollination	Raine, N.E., Pierson, A.S., Stone, G.N. 2007. Plant–pollinator interactions in a Mexican Acacia community. Arthropod-Plant Interactions 1: 1872-8855.
Carbon	Regulating services	Carbon stocks	Ravera, F., Tarrasón, D., Espelta, J. 2014. Land use change trajectories, conservation status and social importance of dry forests in Nicaragua. Environmental Conservation 1-11.
Carbon	Provisioning services	Biomass production	Read, L. Lawrence, D. 2003. Litter Nutrient Dynamics during Succession in Dry Tropical Forests of the Yucatan: Regional and Seasonal Effects. Ecosystems 6 (8): 747-761.
Carbon	Supporting services	Primary production	Read, L. Lawrence, D. 2003. Recovery of Biomass Following Shifting Cultivation in Dry Tropical Forests of the Yucatan. Ecological Applications 13 (1): 85-97.
Water	Supporting Services	Water cycling	Reich, P.B., Borchert, R. 1984. Water-Stress and Tree Phenology in a Tropical Dry Forest in the Lowlands of Costa-Rica. Journal of Ecology 72 (1): 61-74.
Water	Supporting Services	Water cycling	Rentería, L.Y., Jaramillo, V. J. 2011. Rainfall drives leaf traits and leaf nutrient resorption in a tropical dry forest in Mexico. Oecologia 165: 201-211.
Soils	Supporting Services	Nutrient cycling	Renteria, L., Jaramillo, V. J., Martinez-Yrizar, A., Perez-Jimenez, A. 2005. Nitrogen and Phosphorus Resorption in Trees of a Mexican Tropical Dry Forest. Trees-Structure and Function 19 (4): 431-441.

Biodiversity	Supporting services	Primary production	Lucas, R. M., Mitchell, A., Bunting, P. 2008. Hyperspectral data for assessing carbon dynamics and biodiversity of forests. In Kalacska, M., Sanchez-Azofeifa, G.A. (eds.). Hyperspectral Remote Sensing of Tropical and Subtropical Forests. CRC Press, Boca Raton, FL. 47-86.
Soils	Supporting Services	Primary production	Rico-gray, V., Garciafranco, J. G. 1992. Vegetation and Soil Seed Bank of Successional Stages in Tropical Lowland Deciduous Forest. Journal of Vegetation Science 3 (5): 617-624.
Carbon	Provisioning services	Biomass production	Rincón, E., Huante, P. 1988. Análisis de crecimiento de plántulas de Apoplanesia paniculata y Celaenodendron mexicanum. Phytologia 65: 174-183.
Carbon	Provisioning services	Biomass production	Rincón, E., Huante, P. 1993. Growth responses of tropical deciduous tree seedlings to contrasting light conditions. Trees 7: 202-207.
Carbon	Provisioning services	Biomass production	Rincón, E., Huante, P. 1994. Influence of mineral nutrient availability on growth of tree seedlings from the tropical deciduous forest. Trees 9: 93-97.
Carbon	Provisioning services	Biomass production	Rincón, E., Huante, P., Ramírez, Y. 1993. Influence of vesicular-arbuscular mycorrhizae on biomass production by the cactus Pachycereus pecten-aboriginum. Mycorrhiza 3: 79-81.
Water	Supporting Services	Water cycling	Rincón, E., Huante, P., Álvarez-Añorve, M. 1999. Respuestas de plantas y ecosistemas al cambio climático: un enfoque ecofisiológico. Ciencia 50: 5-15.
Carbon	Provisioning services	Biomass production	Rincón, E., Huante, P., Álvarez-Añorve, M. 2000. Análisis de crecimiento de tres especies de Caesalpinia (Leguminosae) de la selva baja caducifolia de Chamela, Jalisco. Boletín de la Sociedad Botánica de México 66: 5-13..
Carbon	Provisioning services	Biomass production	Roa-Fuentes, L., Julio Campo, L., Parra-Tabla, V. 2012. Plant Biomass Allocation Across a Precipitation Gradient: An Approach to Seasonally Dry Tropical Forest at Yucatan, Mexico. Ecosystems 15 (8): 1234-1244.
Biodiversity	Supporting services	Primary production	Rodrigues da Luz, G., Nunes, Y.R.F. 2013. Seed Germination of Arboreal–Shrub Species with Different Dispersal Mechanisms in a Brazilian Tropical Dry Forest. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 281-300.
Carbon	Regulating services	Carbon stocks	Rodríguez, J. P., Nassar, J. M., Rodríguez-Clark, K. M., Zager, I., Portillo-Quintero, C. A., Carrasquel, F., Zambrano, S. 2008. Tropical dry forests in Venezuela: assessing status, threats and future prospects. Environmental Conservation 35 (04): 311-318.
Water	Regulating services	Water regulation	Rojas-Jimenez, K., Holbrook, N.M., Gutierrez-Soto, M.V. 2007. Dry-Season Leaf Flushing of Enterolobium Cyclocarpum (Ear-Pod Tree): Above- and Belowground Phenology and Water Relations. Tree Physiology 27 (11): 1561-1568.
Biodiversity	Provisioning services	Genetic resources	Romero-Duque, L.P., Jaramillo, V., Pérez-Jiménez, A. 2007. Structure and diversity of secondary tropical dry forests in Mexico, differing in their prior land-use history. Forest Ecology and Management 253: 38-47.
Biodiversity	Provisioning services	Genetic resources	Rosell, J.A., Olson, M.E., Weeks, A., De-Nova, J. A., Medina Lemos, R., Pérez Camacho, J., Feria, T. P., Gómez-Bermejo, R., Montero, J.C., Eguiarte, L.E. 2010. Diversification in species complexes: Tests of species origin and delimitation in the Bursera simaruba clade of tropical trees (Burseraceae). Molecular Phylogenetics and Evolution57:798–811.
Biodiversity	Provisioning services	Genetic resources	Ruiz, J., Fandino, M. C., Chazdon, R. L. 2005. Vegetation Structure, Composition, and Species Richness Across a 56-Year Chronosequence of Dry Tropical Forest on Providencia Island, Colombia. Biotropica 37 (4): 520-530. doi:10.1111/j.1744-7429.2005.00070.x.
Carbon	Regulating services	Carbon stocks	Saatchi, S.S., Harris, N.L., Brown, S., Lefsky, M., Mitchard, E.T.A., Salas, W., Zutta, B.R., Buermann, W., Lewis, S.L., Hagen, S., Petrova, S., White, L., Silman, M., Morel, A. 2011. Benchmark Map of Forest Carbon Stocks in Tropical Regions Across Three Continents. Proceedings of the National Academy of Sciences of the United States of America 108 (24): 9899-9904. doi:10.1073/pnas.1019576108.
Biodiversity	Provisioning services	Genetic resources	Sabogal, C. 1992. Regeneration of Tropical Dry Forests in Central-America, with Examples from Nicaragua. Journal of Vegetation Science 3 (3): 407-416.
Carbon	Provisioning services	Biomass production	Sampaio, A.B., Scariot, A. 2011. Edge Effect on Tree Diversity, Composition and Structure in a Deciduous Dry Forest in Central Brazil. Revista Arvore 35 (5): 1121-1134.

Carbon	Supporting services	Primary production	Sanchez-Azofeifa, G.A., Castro-Esau, K. 2006. Canopy Observations on the Hyperspectral Properties of a Community of Tropical Dry Forest Lianas and their Host Trees. International Journal of Remote Sensing 27 (9-10): 2101-2109.
Carbon	Regulating services	Carbon stocks	Sanchez-Azofeifa, G., Harriss, R.C, Skole, D.L. 2001. Deforestation in Costa Rica: A Quantitative Analysis using Remote Sensing Imagery. Biotropica 33 (3): 378-384.
Water	Provisioning services	Fresh water	Sanchez-Azofeifa, G.A., Harriss, R.C., Storrier, A.L., Camino-Beck, T. De. 2002. Water Resources and Regional Land Cover Change in Costa Rica: Impacts and Economics. International Journal of Water Resources Development 18 (3): 409-424.
Carbon	Regulating services	Carbon stocks	Sanchez-Azofeifa, G. A., Daily, G. C., Pfaff, A.S.P., Busch, C. 2003. Integrity and Isolation of Costa Rica's National Parks and Biological Reserves: Examining the Dynamics of Land-Cover Change. Biological Conservation 109 (1): 123-135.
Carbon	Regulating services	Carbon stocks	Sanchez-Azofeifa, G. A., Quesada, M., Cuevas-Reyes, P., Castillo, A., Sanchez-Montoya, G. 2009. Land Cover and Conservation in the Area of Influence of the Chamela-Cuixmala Biosphere Reserve, Mexico. Forest Ecology and Management 258 (6): 907-912.
Carbon	Supporting services	Primary production	Sánchez-Azofeifa, G.A, Castro, K., Wright, J., Gamon, J., Kalacska, M., Rivard, B., Schnitzer, S.A., Lu Feng, J. 2009. Differences in Leaf Traits, Leaf Internal Structure, and Spectral Reflectance between Two Communities of Lianas and Trees: Implications for Remote Sensing in Tropical Environments. Remote Sensing of Environment 113 (10): 2076-2088.
Carbon	Provisioning services	Biomass production	Sanchez-Azofeifa, G.A, Kalacska, M., Espirito-Santo, M.M.DO., Fernandes, G.W., Schnitzer, S. 2009. Tropical Dry Forest Succession and the Contribution of Lianas to Wood Area Index (WAI). Forest Ecology and Management 258 (6): 941-948.
Carbon	Regulating services	Carbon stocks	Sanchez-Azofeifa, G. A., Portillo-Quintero, C. 2011. Extent and Drivers of Change of Neotropical Seasonally Dry Tropical Forests., edited by Dirzo, R. Young, H. S. Mooney, H. A. Ceballos,G.
Biodiversity	Provisioning services	Genetic resources	Sánchez-Cordero, V., Stockwell, D., Sarkar,S., Liu, H., Stephens, C. R., Giménez, J. 2008. Competitive interactions between felid species may limit the southern distribution of bobcats Lynx rufus. Ecography 31: 757-764.
Biodiversity	Provisioning services	Genetic resources	Sánchez-Rojas, G., Sánchez-Cordero, V., Briones, M. 2004. Effect of plant species, fruit density and habitat on post-dispersal fruit and seed removal by spiny pocket mice (Liomys pictus, Heteromyidae) in a tropical dry forest in Mexico. Studies on Neotropical Fauna and Environment 39: 1-6.
Soils	Supporting Services	Nutrient cycling	Sandoval-Pérez, A.L., Gavito, M.E., García-Oliva, F., Jaramillo, V.J. 2009. Carbon, nitrogen, phosphorus and enzymatic activity under different land uses in a tropical dry ecosystem. Soil Use and Management 25: 419–426.
Biodiversity	Regulating services	Pest regulation	Santos, B. A., Quesada, M., Rosas, F., Benitez-Malvido, J. 2011. Potential Effects of Host Height and Phenology on Adult Susceptibility to Foliar Attack in Tropical Dry Forest Grass. ISRN Ecology 2011: 730801-Article ID 730801.
Biodiversity	Provisioning services	Genetic resources	Sasa, M., Bolaños, F. 2004. Biodiversity and conservation of Mesoamerican dryforest herpetofauna. Biodiversity conservation in Costa Rica: Learning the lessons in a seasonal dry forest. Frankie, GW, A. Mata and SB Vinson (Eds.). University of California Press, Berkeley 177-193.
Soils	Supporting Services	Nutrient cycling	Sayer, Emma J., Sutcliffe, L.M.E., Ross, R.I.C., Tanner, E.V.J. 2010. Arthropod Abundance and Diversity in a Lowland Tropical Forest Floor in Panama: The Role of Habitat Space Vs. Nutrient Concentrations. Biotropica 42 (2): 194-200.
Soils	Regulating services	Soil carbon stocks	Saynes, V., Hidalgo, C., Etchevers, J.D., Campo, J.E. 2005. Soil C and N Dynamics in Primary and Secondary Seasonally Dry Tropical Forests in Mexico. Applied Soil Ecology 29 (3): 282-289.
Water	Regulating services	Water regulation	Schulze, A., Jansen, M., Koehler, G. 2009. Diversity and Ecology of Anuran Communities in San Sebastian (Chiquitano Region, Bolivia). Salamandra 45 (2): 75-90.
Water	Supporting Services	Water cycling	Segura, G., Balvanera, P., Duran, E., Perez, A. 2003. Tree Community Structure and Stem Mortality Along a Water Availability Gradient in a Mexican Tropical Dry Forest. Plant Ecology 169 (2): 259-271.

Carbon	Regulating services	Carbon stocks	Silva, J. F., Fariñas, M. R., Felfili, J. M., Klink, C. A. 2006. Spatial heterogeneity, land use and conservation in the cerrado region of Brazil. Journal of Biogeography 33(3): 536-548.
Carbon	Regulating services	Carbon stocks	Silver, W.L., Ostertag, R., Lugo, A.E. 2000. The Potential for Carbon Sequestration through Reforestation of Abandoned Tropical Agricultural and Pasture Lands. Restoration Ecology 8 (4): 394-407.
Carbon	Supporting services	Primary production	Smith, C. K., Gholz, H. L., Oliveira, F. D. 1998. Fine Litter Chemistry, Early-Stage Decay, and Nitrogen Dynamics Under Plantations and Primary Forest in Lowland Amazonia. Soil Biology Biochemistry 30 (14): 2159-2169.
Soils	Supporting Services	Nutrient cycling	Solis, E., Campo, J. 2004. Soil N and P Dynamics in Two Secondary Tropical Dry Forests After Fertilization. Forest Ecology and Management 195 (3): 409-418.
Biodiversity	Provisioning services	Genetic resources	Solórzano, S., Ibarra-Manriquez, G., Oyama, K. 2002. Liana diversity and reproductive attributes in two tropical forests in Mexico. Biodiversity and conservation 11: 197-212.
Carbon	Regulating services	Carbon stocks	Southworth, J. 2004. An Assessment of Landsat TM Band 6 Thermal Data for Analysing Land Cover in Tropical Dry Forest Regions. International Journal of Remote Sensing 25 (4): 689-706.
Carbon	Provisioning services	Biomass production	Stegen, J. C., Swenson, N. G., Valencia, R., Enquist, B. J., Thompson, J. 2009. Above-ground forest biomass is not consistently related to wood density in tropical forests. Global ecology and biogeography 18(5): 617-625.
Carbon	Provisioning services	Biomass production	Stegen, J.C., Swenson, N.G., Enquist, B.J., White, E.P., Phillips, O.L., Jorgensen, P.M., Weiser, M.D., Monteagudo Mendoza, A., Nuez Vargas, P. 2011. Variation in Above-Ground Forest Biomass Across Broad Climatic Gradients. Global Ecology and Biogeography 20 (5): 744-754.
Carbon	Regulating services	Carbon stocks	Steininger, M. K., Tucker, C. J., Ersts, P., Killeen, T. J., Villegas, Z., Hecht, S. B. 2001. Clearance and Fragmentation of Tropical Deciduous Forest in the Tierras Bajas, Santa Cruz, Bolivia. Conservation Biology 15 (4): 856-866.
Biodiversity	Supporting services	Primary production	Stern, M., Quesada, M., Stoner, K. E. 2002. Changes in Composition and Structure of a Tropical Dry Forest Following Intermittent Cattle Grazing. Revista De Biologia Tropical 50 (3-4): 1021-1034.
Biodiversity	Provisioning services	Genetic resources	Stoner, K. E., Quesada, M., Rosas-Guerrero, V., Lobo, J. A. 2002. Effects of Forest Fragmentation on the Colima Long-Nosed Bat (Musonycteris Harrisoni) Foraging in Tropical Dry Forest of Jalisco, Mexico. Biotropica 34 (3): 462-467.
Biodiversity	Provisioning services	Genetic resources	Stoner, K. E., Sanchez-Azofeifa, G. A. 2009. Ecology and Regeneration of Tropical Dry Forests in the Americas: Implications for Management. Forest Ecology and Management 258 (6): 903-906.
Biodiversity	Provisioning services	Genetic resources	Stoner, K. E., Timm, R. M. 2004. Tropical Dry-Forest Mammals of Palo Verde - Ecology and Conservation in a Changing Landscape. Biodiversity Conservation in Costa Rica: 48-66.
Biodiversity	Provisioning services	Genetic resources	Stoner, K. E., Timm, R. M. 2004. Tropical Dry-Forest Mammals of Palo Verde - Ecology and Conservation in a Changing Landscape. Biodiversity Conservation in Costa Rica: 48-66.
Biodiversity	Provisioning services	Genetic resources	Stoner, K. E., Timm, R. M. 2011. Seasonally Dry Tropical Forest Mammals: Adaptations and Seasonal Patterns., edited by Dirzo, Rodolfo Young, Hillary S. Mooney, Harold A. Ceballos,Gerardo.
Biodiversity	Provisioning services	Genetic resources	Stoner, K. E., Quesada, M., Rosas-Guerrero, V., Lobo, J. A. 2002. Effects of Forest Fragmentation on the Colima Long-Nosed Bat (Musonycteris Harrisoni) Foraging in Tropical Dry Forest of Jalisco, Mexico. Biotropica 34 (3): 462-467.
Biodiversity	Provisioning services	Genetic resources	Stoner, K. E., Salazar, K. A. O., Fernandez, R. C. R., Quesada, M. 2003. Population Dynamics, Reproduction, and Diet of the Lesser Long-Nosed Bat (Leptonycteris Curasoae) in Jalisco, Mexico: Implications for Conservation. Biodiversity and Conservation 12 (2): 357-373.
Biodiversity	Provisioning services	Genetic resources	Suarez, A., Williams-Linera, G., Trejo, C., Valdez-Hernandez, J.I., Cetina-Alcala, V.M., Vibrans, H. 2012. Local Knowledge Helps Select Species for Forest Restoration in a Tropical Dry Forest of Central Veracruz, Mexico. Agroforestry Systems 85 (1): 35-55.
Biodiversity	Provisioning services	Genetic resources	Suazo-Ortuño, I., Alvarado-Díaz, J., Martínez-Ramos, M. 2008. Effects of Conversion of Dry Tropical Forest to Agricultural Mosaic on Herpetofaunal Assemblages. Conservation Biology 22: 362-374.

Water	Provisioning services	Genetic resources	Suazo-Ortuno, I., Alvarado-Diaz, J., Martinez-Ramos, M. 2011. Riparian Areas and Conservation of Herpetofauna in a Tropical Dry Forest in Western Mexico. Biotropica 43 (2): 237-245. doi:10.1111/j.1744-7429.2010.00677.x.
Carbon	Regulating services	Carbon stocks	Tarrason, D., Urrutia, J.T., Ravera, F., Herrera, E., Andres, P., Espelta, J.M. 2010. Conservation Status of Tropical Dry Forest Remnants in Nicaragua: Do Ecological Indicators and Social Perception Tally? Biodiversity and Conservation 19 (3): 813-827.
Biodiversity	Provisioning services	Genetic resources	Thompson, I.D., Ferreira, J., Gardner, T., Guariguata, M., Lian Pin Koh, Okabe, K., Pan Yude, Schmitt, C.B., Tylianakis, J., Barlow, J., Kapos, V., Kurz, W.A., Parrotta, J.A., Spalding, M.D., Vliet, N.V. 2012. Forest Biodiversity, Carbon and Other Ecosystem Services: Relationships and Impacts of Deforestation and Forest Degradation. IUFRO World Series 31: 21-50.
Biodiversity	Provisioning services	Genetic resources	Thompson, C.L., Williams, S.H., Glander, K.E., Teaford, M.F., Vinyard, C.J. 2014. Body Temperature and Thermal Environment in a Generalized Arboreal Anthropoid, Wild Mantled Howling Monkeys (Alouatta Palliata). American Journal of Physical Anthropology 154 (1): 1-10.
Carbon	Regulating services	Air quality regulation	Tiessen, H., Feller, C., Sampaio, E. V. S. B., Garin, P. 1998. Carbon Sequestration and Turnover in Semiarid Savannas and Dry Forest. Climatic Change 40 (1): 105-117.
Biodiversity	Provisioning services	Genetic resources	Timm, R. M., McLearn, D.K. 2007. The Bat Fauna of Costa Rica's Reserva Natural Absoluta Cabo Blanco and its Implications for Bat Conservation. University of California Publications in Zoology 134: 303-352.
Biodiversity	Provisioning services	Genetic resources	Timm, R.M., Lieberman, D., Lieberman, M., McClearn, D. 2009. Mammals of Cabo Blanco: History, Diversity, and Conservation After 45 Years of Regrowth of a Costa Rican Dry Forest. Forest Ecology and Management 258 (6): 997-1013.
Biodiversity	Provisioning services	Genetic resources	Toledo, V.H., Noguera, F.A., Chemsak, J.A., Hovore, F.T., Giesbert, E.F. 2002. The Cerambycid fauna of the tropical dry forest of El Aguacero, Chiapas, Mexico (Coleoptera : Cerambycidae). Coleopterists Bulletin 56: 515-532.
Biodiversity	Provisioning services	Genetic resources	Travi, B. L., Adler, G. H., Lozano, M., Cadena, H., Montoya-Lerma, J. 2002. Impact of Habitat Degradation on Phlebotominae (Diptera : Psychodidae) of Tropical Dry Forests in Northern Colombia. Journal of Medical Entomology 39 (3): 451-456.
Biodiversity	Supporting services	Primary production	Trejo, I., Dirzo, R. 2002. Floristic diversity of Mexican seasonally dry tropical forests. Biodiversity and conservation 11: 2063–2084.
Carbon	Regulating services	Carbon stocks	Trejo, I., Dirzo, R. 2000. Deforestation of Seasonally Dry Tropical Forest: A National and Local Analysis in Mexico. Biological Conservation 94 (2): 133-142.
Carbon	Provisioning services	Biomass production	Urquiza-Haas, T., Dolman, P.M., Peres, C.A. 2007. Regional Scale Variation in Forest Structure and Biomass in the Yucatan Peninsula, Mexico: Effects of Forest Disturbance. Forest Ecology and Management 247 (1-3): 80-90. doi:10.1016/j.foreco.2007.04.015.
Biodiversity	Provisioning services	Genetic resources	Valdivia-Hoeflich, T., Vega-Rivera, J.H., Stoner, K.E. 2005. The Citreoline Trogon as an ecosystem engineer. Biotropica 37: 465-467.
Biodiversity	Provisioning services	Genetic resources	Valenzuela, D., Macdonald, D.W. 2002. Home-range use by white-nosed coatis (Nasua narica): limited water and a test of the resource dispersión hypothesis. The Zoological Society of London 258: 247-256.
Biodiversity	Provisioning services	Genetic resources	Valenzuela, D., Ceballos, G. 2000. Habitat Selection, Home Range, and Activity of the White-Nosed Coati (Nasua Narica) in a Mexican Tropical Dry Forest. Journal of Mammalogy 81 (3): 810-819.
Biodiversity	Supporting services	Pollination	Valiente-Banuet, A., Molina-Freaner, F., Torres, A., Del Coro Arizmendi, A., Casas, A. 2004. Geographic differentiation in the pollination system of the columnar cactus Pachycereus pecten-aboriginum. American Journal of Botany 91: 850-855.
Carbon	Provisioning services	Biomass production	Van Bloem, S.J., Lugo, A.E, Murphy, P.G. 2006. Structural Response of Caribbean Dry Forests to Hurricane Winds: A Case Study from Guanica Forest, Puerto Rico. Journal of Biogeography 33 (3): 517-523.
Biodiversity	Provisioning services	Genetic resources	Van Groendael, J.M., Bullock, S.H., Pérez-Jiménez, L.A. 1996. Aspects of the population biology of the gregarious tree Cordia eleagnoides in Mexican tropical deciduous forest. Journal of Tropical Ecology 12: 11-24.
Carbon	Supporting services	Primary production	Van Laake, P.E., Sanchez-Azofeifa, G.A. 2005. Mapping PAR using MODIS Atmosphere Products. Remote Sensing of Environment 94 (4): 554-563.

Water	Regulating services	Water regulation	Vargas, J.A., Mata, A. 2004. Where the Dry Forest Feeds the Sea - the Gulf of Nicoya Estuary. Biodiversity Conservation in Costa Rica: 126-135.
Carbon	Provisioning services	Biomass production	Vargas, R., Allen, M.F., Allen, E.B. 2008. Biomass and Carbon Accumulation in a Fire Chronosequence of a Seasonally Dry Tropical Forest. Global Change Biology 14 (1): 109-124.
Carbon	Regulating services	Climate regulation	Vargas, R., Yépez, E.A., Andrade, J.L., Ángeles, G., Arredondo, T., Castellanos, A.E., Delgado-Balbuena, J., Garatuza-Payán, J., González Del Castillo, E., Oechel, W., Rodríguez, J.C., Sánchez-Azofeifa, A., Velasco, E., Vivoni, E.R., Watts, C. 2013. Progress and Opportunities for Monitoring Greenhouse Gases Fluxes in Mexican Ecosystems: The MexFlux Network. Atmósfera 26 (3): 326-336.
Biodiversity	Provisioning services	Genetic resources	Vázquez-Domínguez, E., Piñero, D., Ceballos, G. 1998. Heterozygosity patterning and its relation to fitness components in experimental populations of Liomys pictus from tropical forests in western México. Biological Journal of the Linnean Society 65: 501-514.
Biodiversity	Provisioning services	Genetic resources	Vázquez-Domínguez, E., Piñero, D., Ceballos, G. 1999. Linking heterozigocity, demography and fitness of tropical populations of Liomys pictus. Journal of Mammalogy 80: 810-822.
Biodiversity	Provisioning services	Genetic resources	Vázquez-Domínguez, E., Ceballos, G., Piñero, D. 2002. Exploring the relation between genetic structure and habitat heterogeneity in the rodent Liomys pictus From Chamela, Jalisco. Acta Zoológica Mexicana 86: 17-28.
Biodiversity	Provisioning services	Genetic resources	Vega-Rivera, J.H., Ayala D., Haas, C.A. 2003. Home-range size, habitat use, and reproduction of the Ivory-billed Woodcreeper (Xiphorhynchus flavigaster) in dry forest of western Mexico. Journal of Field Ornithology 74: 141-151.
Biodiversity	Provisioning services	Genetic resources	Vega-Rivera, J.H., Alvarado, F., Lobato, J.M., Escalante, P. 2004. Phenology, Habitat Use, And Nesting Of The Red-Breasted Chat (Granatellus Venustus). Wilson Bulletin 116: 89-93.
Biodiversity	Provisioning services	Genetic resources	Vieira, D.L.M., Scariot, A. 2006. Principles of Natural Regeneration of Tropical Dry Forests for Restoration. Restoration Ecology 14 (1): 11-20.
Carbon	Supporting services	Primary production	Villalobos, S.C., González-Carcacía, J.A., Rodríguez, J.P., Nassar, J. 2013. Interspecific and Interannual Variation in Foliar Phenological Patterns in a Successional Mosaic of a Dry Forest in the Central Llanos of Venezuela. In: Sánchez-Azofeifa GA and Powers J (eds.) Tropical Dry Forests in the Americas: Ecology, Conservation and Management. CRC Press. pp 301-324.
Biodiversity	Provisioning services	Genetic resources	Villaseñor-Sánchez, E.I., Dirzo, R., Renton, K. 2010. Importance of the lilac-crowned parrot in pre-dispersal seed predation of Astronium graveolens in a Mexican tropical dry forest. Journal of Tropical Ecology 26: 227-236.
Biodiversity	Provisioning services	Genetic resources	Vinson, S. B., Mata, A., Frankie, G.W. 2004. Biodiversity Conservation in Costa Rica: Learning the Lessons in a Seasonal Dry Forest. Berkeley: University of California Press. http://login.ezproxy.library.ualberta.ca/login?url=http://search.ebscohost.com/login.aspx?direct=truedb=nlebkAN=108461site=ehost-livescope=site
Water	Regulating services	Water regulation	Vose, J. M., Maass, M. 1999. A Comparative Analysis of Hydrologic Responses of Tropical Deciduous and Temperate Deciduous Watershed Ecosystems to Climatic Change. Usda Forest Service Rocky Mountain Research Station Proceedings., edited by C. Franco AguirreBravo CR.
Soils	Supporting Services	Primary production	Wall, D. H., Gonzalez, G., Simmons, B.L. 2011. Seasonally Dry Tropical Forest Soil Diversity and Functioning, edited by Dirzo, Rodolfo Young, Hillary S. Mooney, Harold A. Ceballos, Gerardo.
Biodiversity	Provisioning services	Genetic resources	Watkins, II. J.F. 1988. The Army Ants Formicidae Ecitoninae Of The Chamela Biological Station In Jalisco Mexico. Folia Entomológica Mexicana 77: 379-394.
Carbon	Provisioning services	Biomass production	de Souza Werneck, M., Franceschinelli, E. V. 2004. Dynamics of a dry forest fragment after the exclusion of human disturbance in southeastern Brazil. Plant Ecology 174(2): 339-348.
Carbon	Supporting services	Primary production	Whigham, D. F., Towle, P. Z., Cano, E.C. 1990. The Effect of Annual Variation in Precipitation on Growth and Litter Production in a Tropical Dry Forest in the Yucatan of Mexico. Tropical Ecology 31 (2): 23-34.
Biodiversity	Supporting services	Pollination	White, G. M., Boshier, D. H., Powell, W. 2002. Increased Pollen Flow Counteracts Fragmentation in a Tropical Dry Forest: An Example from Swietenia Humilis Zuccarini. Proceedings of the National Academy of Sciences of the United States of America 99 (4): 2038-2042. doi:10.1073/pnas.042649999.

Biodiversity	Supporting services	Pollination	White, G. M., Boshier, D. H., Powell, W. 2002. Increased Pollen Flow Counteracts Fragmentation in a Tropical Dry Forest: An Example from Swietenia Humilis Zuccarini. Proceedings of the National Academy of Sciences of the United States of America 99 (4): 2038-2042. doi:10.1073/pnas.042649999.
Water	Regulating services	Water regulation	Whitney, B. S., Mayle, F. E., Burn, M. J., Guillén, R., Chavez, E., Pennington, R.T. 2014. Sensitivity of Bolivian Seasonally-Dry Tropical Forest to Precipitation and Temperature Changes Over Glacial-Interglacial Timescales. Vegetation History and Archaeobotany 23 (1): 1-14.
Biodiversity	Supporting services	Primary production	Williams-Linera, G., Alvarez-Aquino, C., Hernandez-Ascencion, E., Toledo, M. 2011. Early Successional Sites and the Recovery of Vegetation Structure and Tree Species of the Tropical Dry Forest in Veracruz, Mexico. New Forests 42 (2): 131-148.
Biodiversity	Regulating services	Natural hazard regulation	Wolfe, B. T., Saldaña Diaz, G.E., Van Bloem, S.J. 2014. Fire Resistance in a Caribbean Dry Forest: Inferences from the Allometry of Bark Thickness. Journal of Tropical Ecology 30 (2): 133-142.
Water	Supporting Services	Water cycling	Worbes, M., Blanchart, S., Fichtler, E. 2013. Relations between Water Balance, Wood Traits and Phenological Behavior of Tree Species from a Tropical Dry Forest in Costa Rica-a Multifactorial Study. Tree Physiology 33 (5): 527-536. doi:10.1093/treephys/tpt028.
Biodiversity	Provisioning services	Genetic resources	Yara O, C., Reinoso, G.F. 2012. Hunting Ants (Ectatomminae y Ponerinae) in Dry Forest Fragments and their Matrix (Tolima, Colombia). Revista Colombiana De Entomologia 38 (2): 329-337.

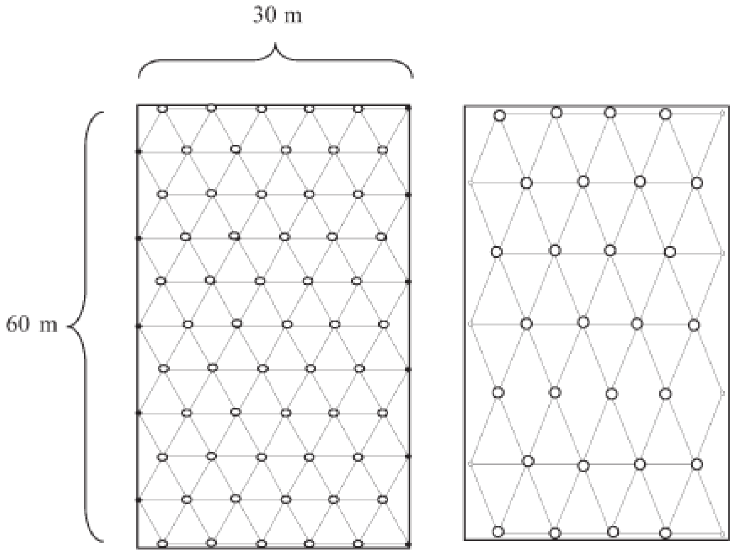
Appendix 2. Values of LAI obtained from LAI-2000 and calculated values of "K" derived from tower measurements and MODIS NDVI, for the early and the intermediate successional stages and different days of the year.

Successional stage	Year	DOY	LAI	K derived from tower	K derived from MODIS
Early	2009	273	2.65	3.31	2.92
Early	2009	296	2.45	3.06	2.70
Early	2009	316	2.31	2.88	2.54
Early	2009	341	2.35	2.92	2.58
Early	2010	29	1.69	2.11	1.86
Early	2010	56	1.30	1.62	1.43
Early	2010	85	0.00	0.00	0.00
Early	2010	99	1.39	1.74	1.53
Early	2010	113	0.68	0.85	0.75
Early	2010	134	1.24	1.55	1.37
Early	2010	146	1.26	1.57	1.39
Early	2010	159	2.20	2.74	2.42
Early	2010	180	2.39	2.97	2.62
Early	2010	213	2.52	3.13	2.77
Early	2010	238	2.33	2.90	2.56
Early	2010	266	2.64	3.28	2.90
Early	2010	295	2.33	2.91	2.57
Early	2010	310	2.31	2.88	2.54
Early	2010	330	1.95	2.43	2.14
Early	2010	350	1.77	2.21	1.95
Early	2011	26	1.16	1.45	1.28
Early	2011	40	1.16	1.45	1.28
Early	2011	57	1.09	1.36	1.20
Early	2011	70	0.00	0.00	0.00
Early	2011	70	0.00	0.00	0.00
Early	2011	91	0.86	1.07	0.95
Early	2011	126	1.05	1.30	1.15
Intermediate	2013	55	0.82	0.99	0.90
Intermediate	2013	79	0.00	0.00	0.00
Intermediate	2013	113	1.06	1.29	1.17
Intermediate	2013	127	1.63	1.98	1.79
Intermediate	2013	152	1.71	2.08	1.87
Intermediate	2013	204	3.79	4.61	4.16
Intermediate	2013	218	4.16	5.07	4.58
Intermediate	2013	250	5.18	6.31	5.70
Intermediate	2013	297	4.81	5.85	5.28

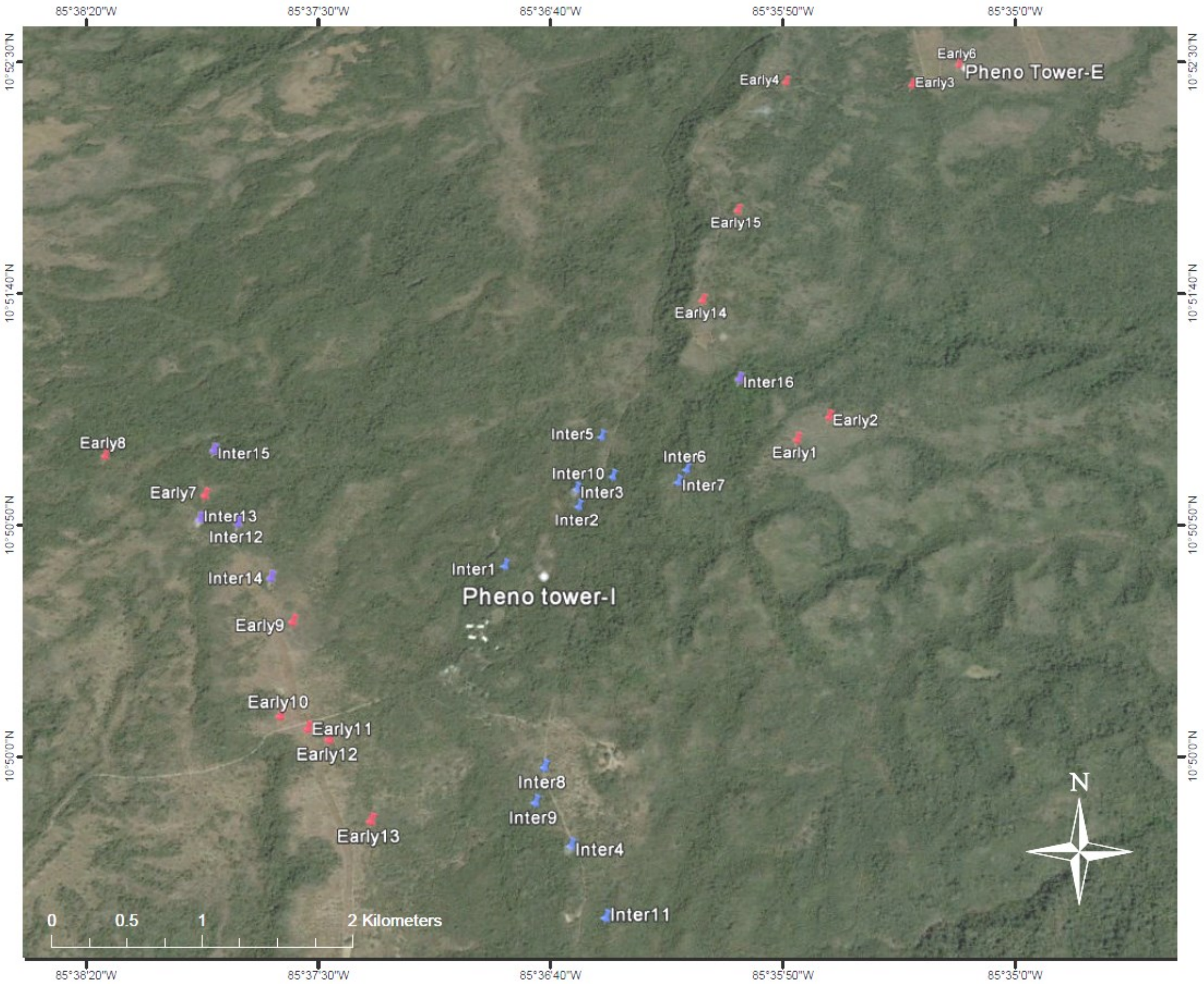
Intermediate	2013	324	4.30	5.23	4.72
Intermediate	2013	355	3.54	4.31	3.89
Intermediate	2014	22	2.64	3.21	2.90
Intermediate	2014	55	1.36	1.66	1.50
Intermediate	2014	87	0.00	0.00	0.00
Intermediate	2014	113	0.86	1.05	0.95
Intermediate	2014	126	0.90	1.10	0.99
Intermediate	2014	177	2.95	3.59	3.24
Intermediate	2014	211	3.36	4.10	3.70
Intermediate	2014	226	4.02	4.90	4.42
Intermediate	2014	266	5.23	6.37	5.75
Intermediate	2014	291	5.03	6.13	5.53
Intermediate	2014	332	4.08	4.97	4.48
Intermediate	2014	346	3.55	4.33	3.91
Intermediate	2015	28	2.51	3.05	2.76
Intermediate	2015	46	1.72	2.10	1.89
Intermediate	2015	61	0.00	0.00	0.00

Appendix 3. Values of LAI from LAI-2000, LAI derived from tower, LAI derived from MODIS, and MODIS LAI with their percentage differences compared to the ground measurements of LAI-2000.

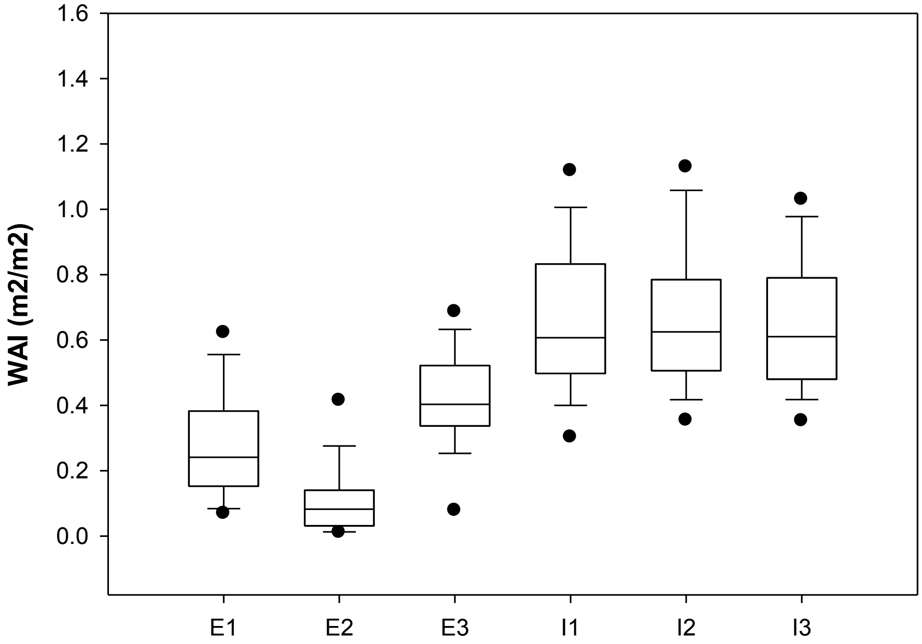
Successional stage	LAI-2000	LAI derived from tower NDVI	% Difference	LAI derived from MODIS NDVI	% Difference	MODIS LAI	% Difference
Early1	1.50	2.47	65	2.27	51	6.50	333
Early2	1.74	2.48	42	2.27	30	6.20	255
Early3	2.55	2.48	3	2.28	11	3.80	49
Early4	2.10	2.49	18	2.29	9	3.80	81
Early5	1.88	2.50	33	2.30	22	1.40	26
Early6	1.69	2.51	48	2.30	36	3.80	124
Early7	2.53	2.51	1	2.31	9	5.40	113
Early8	3.16	2.52	20	2.31	27	5.40	71
Early9	1.78	2.53	42	2.32	30	2.30	29
Early10	2.21	2.53	14	2.33	5	2.30	4
Early11	1.85	2.54	37	2.33	26	2.30	24
Early12	2.25	2.54	13	2.34	4	2.30	2
Early13	2.35	2.55	8	2.34	1	2.60	10
Early14	1.66	2.56	54	2.35	41	5.80	249
Early15	3.05	2.56	16	2.35	23	6.60	116
Average	**2.16**	**2.52**	**22**	**2.31**	**12**	**4.03**	**96**
Intermediate1	3.85	4.07	6	3.82	1	4.30	12
Intermediate2	3.30	4.09	24	3.84	16	6.60	100
Intermediate3	3.43	4.11	20	3.85	12	4.30	25
Intermediate4	3.60	4.13	15	3.87	8	4.80	33
Intermediate5	3.35	4.14	24	3.89	16	4.30	28
Intermediate6	3.10	4.16	34	3.91	26	6.50	110
Intermediate7	3.12	4.18	34	3.92	26	5.00	60
Intermediate8	4.11	4.20	2	3.94	4	4.80	17
Intermediate9	3.52	4.21	20	3.96	12	5.20	48
Intermediate10	3.16	4.23	34	3.97	26	6.60	109
Intermediate11	3.71	4.25	14	3.99	7	4.80	29
Intermediate12	3.83	4.26	11	4.00	4	5.30	38
Intermediate13	3.64	4.28	18	4.02	10	5.40	48
Intermediate14	4.20	4.29	2	4.03	4	2.30	45
Intermediate15	4.27	4.31	1	4.05	5	5.40	26
Average	**3.61**	**4.19**	**17**	**3.94**	**10**	**5.04**	**43**



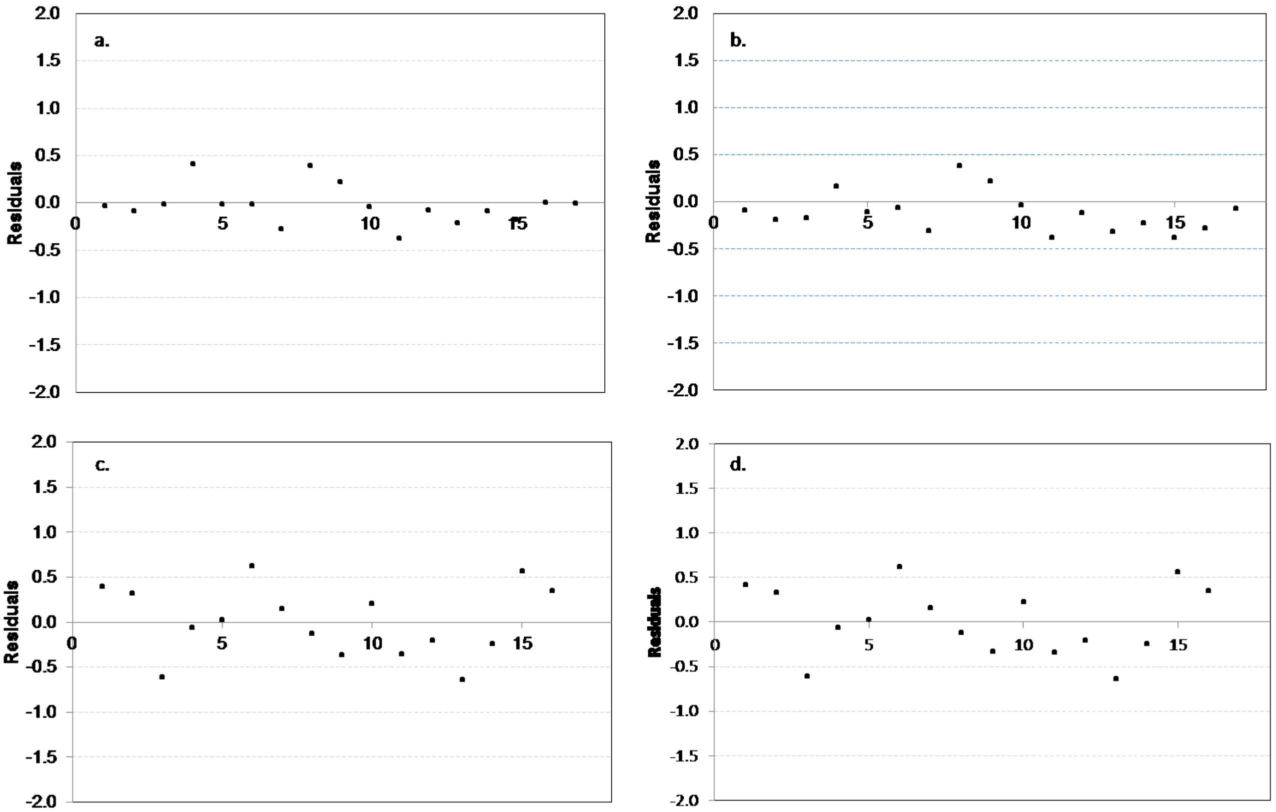
Appendix 4. Early stage plot for LAI measurements with sampling points for early stage (left) and intermediate stage plots (right) (After Kalacska et al. 2005a).



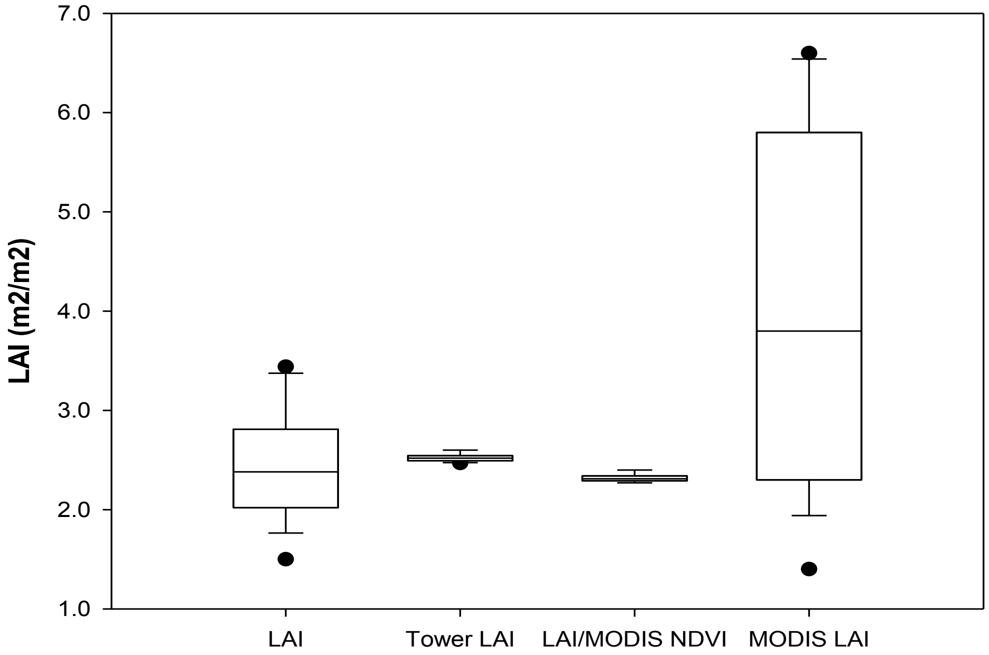
Appendix 5. Location inside Santa Rosa National Park of the optical phenology towers in the early stage (Pheno tower-E) and in the intermediate stage of succession (Pheno tower-I). The validation points where LAI was measured in the early stage are in red and the validation points in the intermediate stage of succession are in blue.



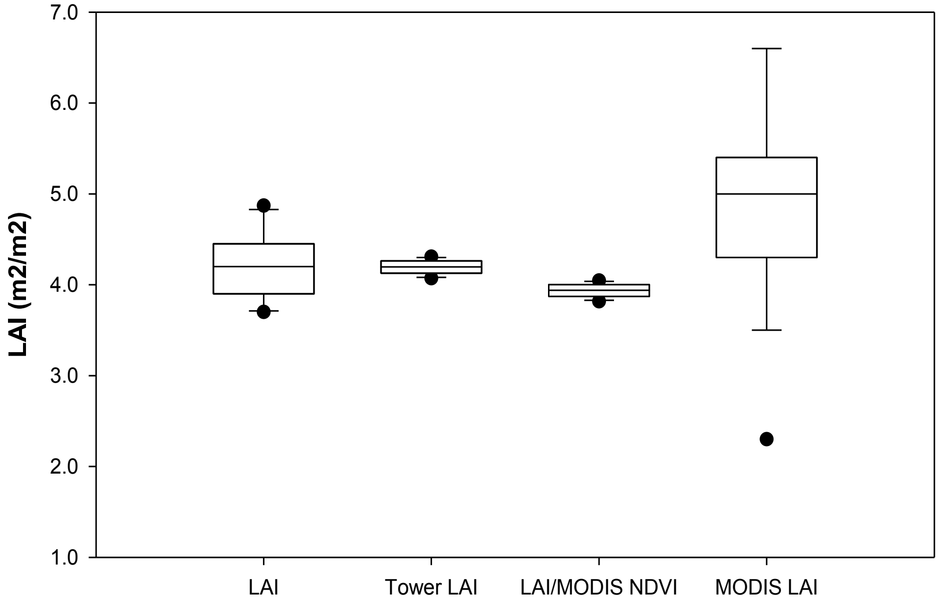
Appendix 6. Woody Area Index in the early successional stage plots (E1, E2, and E3) and in the intermediate successional stage of succession plots (I1, I2 and I3) in Santa Rosa National Park. The median of the WAI is indicated by a solid line inside the boxes. The boundaries of the boxes indicate the 25th and 75th percentiles. The whiskers above and below the boxes indicate the 90th and 10th percentiles and the dots the 5th and 95th percentile outliers.



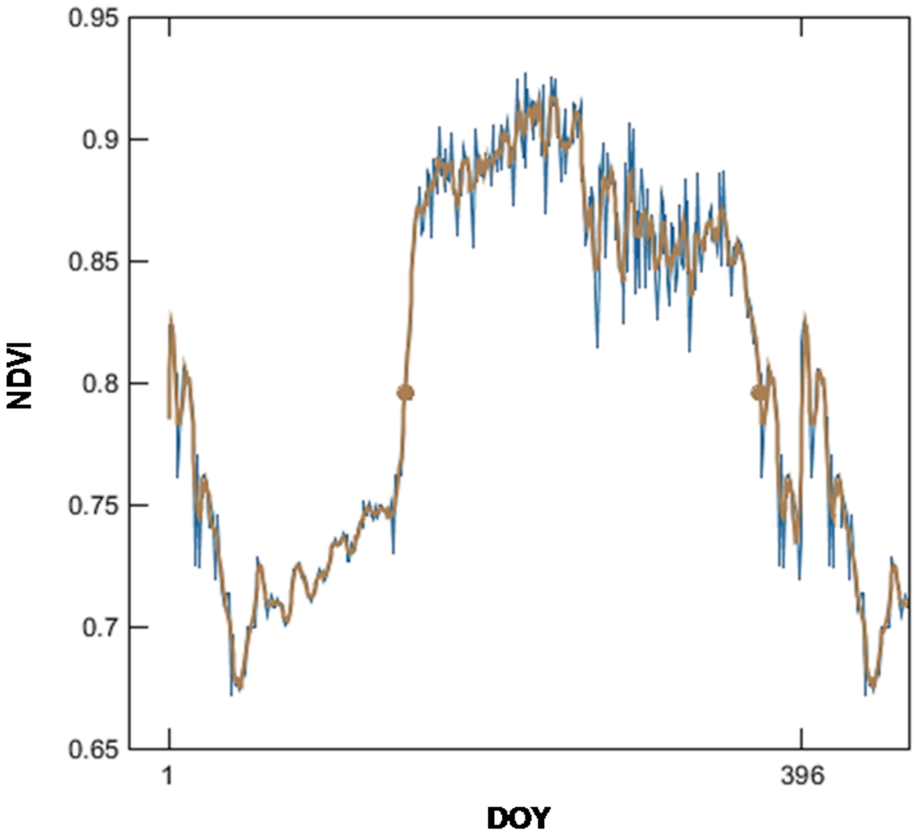
Appendix 7. Residuals from the evaluation of the estimation capability of the models for estimating the LAI in the early stage (a.) using tower-derived LAI versus LAI-2000 and (b.) using MODIS NDVI derived LAI versus LAI-2000. In the intermediate stage (c.) using tower-derived LAI versus LAI-2000 and (d.) using MODIS NDVI derived LAI versus LAI-2000.



Appendix 8. Values of LAI measured in 15 early successional stage validation points using the LAI-2000, MODIS LAI, and estimated values of LAI using the "K" coefficients developed in this study. The median of the LAI is indicated by a solid line inside the boxes. The boundaries of the boxes indicate the 25th and 75th percentiles. The whiskers above and below the boxes indicate the 90th and 10th percentiles and the dots the 5th and 95th percentile outliers.



Appendix 9. Values of LAI measured in 15 intermediate successional stage validation points using the LAI-2000, MODIS LAI, and estimated values of LAI using the "K" coefficients developed in this study. The median of the LAI is indicated by a solid line inside the boxes. The boundaries of the boxes indicate the 25th and 75th percentiles. The whiskers above and below the boxes indicate the 90th and 10th percentiles and the dots the 5th and 95th percentile outliers.



Appendix 10. NDVI data for the intermediate successional stage with the Savitzky–Golay smoothing function and the points for the start of the growing season and the end of the growing season of year 2013.