CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Forestry and Wood Science

Department of Forest Protection

Bark beetle Outbreak in Honduras in the period of 1970-2010 and the evaluation of vulnerability factors of *pinus ooccarpa and Pinus caribea* Forests.

Bachelor Thesis

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Declaration

I declare that this bachelor thesis was written by me and me Alone, merely using the cited sources. I agree with the loan of my Work and its publication.

In Prague 29.04.2014

Natalí Cruz

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Last, but by no means least, my sincerest love, respect and gratitude goes to my father Cornelio and my mother Veronica, and to all my friends whom I'm honored to call my family.

Figure 1 Pine forest in Honduras

Abstract

Pine forests in Honduras are one of the main natural resources and one of the major economic Sources. Due to the geographic position of this Central American country is susceptible for a set of variations in the climate as the phenomenon (el Niño y la Niña). Between the insects that cause major damages to pine forests, *D. frontalis* has the highest impact. The outbreaks of this pest have become a major risk for these ecosystems causing a high environmental impact and economic losses. In this paper we review some of the aspects of *Dendroctonus.* And we expose a frame of the main factors involved in these outbreaks during the past 50 years, from 1960 to nowadays. The relation of these factors to climate change, and the control methods that are applied. With this, it was pretended to give new approaches for knowledge of the impact that *Dendroctonus frontalis* has on pine forests in Honduras. It was concluded that increases in average temperatures, decrease of precipitation and forest fires are factors that are related with the outbreaks of *D. frontalis* in Honduras. These climatic changes are associated with climate change and wildfires. The relationship with fires and outbreaks leads that to fight against the attacks of *D. frontalis* should be consider a preventive planning to mitigate the effects that climate change cause to these pine forests.

Abstrakt

Borové lesy jsou v Hondurasu jedním z hlavních přírodních a ekonomických zdrojů. Vzhledem k geografické poloze Hondurasu ve Střední Americe jsou místní lesy ovlivňovány klimatickými výkyvy známými pod názvy El Niño a La Niña. Z hmyzích škůdců působí největší škody v borových lesích *Dendroctonus frontalis*. Přemnožení tohoto druhu hmyzu představuje největší hrozbu pro lesní ekosystémy a také mají velký dopad na přírodní prostředí a hospodářský výsledek. V této práci je poskytnut přehled škodlivosti kůrovců rodu *Dendroctonus*. Uvádíme zde příčiny, které vedly ke kalamitám v posledních 50. letech, to znamená od roku 1960 až do dnešní doby, a zmiňujeme vztah těchto vlivů k probíhající klimatické změně, a používané obranné metody proti těmto kůrovcům. Klimatická změna je take důvodem pro uplatnění nových přístupů k výzkumu a uplatnění obranných metod proti *D. frontalis* v lesích Hondurasu. Domníváme se, že zvyšování průměrných teplot a úbytek srážek společně s lesními požáry jsou hlavními příčinami gradací *D. frontalis* v Hondurasu. Klimatické změny totiž zvyšují četnost a rozsah požárů v Hondurasu. Právě souvislost požárů s přemnoženími *D. frontalis* se stává důležitým též plánování obranných aktivit, které by pomohly zmenšit nebezpečí škod, ke kterým může dojít v důsledku klimatických změn.

Table of Contents

List of Figures

List of Tables

1 Introduction

From overall the Central American countries, Honduras is the one with the largest forest area, counting in total with 5.4 million hectares. Of these pine forests are located mainly in the central and western part of the country, covering an area of 2, 7 million hectares (COHDEFOR 2000).

In recent years there has been a reduction in the capacity for pine trees as well as a decrease in the genetic quality of the species of the pine forest. Prolonged periods of drought and forest fires related to pests such as the Dendroctonus frontalis would cause this phenomenon (billings, 2004).

Because Honduras is the country with the highest percentage cover of pine forest in Central America, the country is particularly vulnerable to the consequences of bark beetle attacks that occur every 20 to 30 years as part of the natural dynamics of forest. (Rivera, 2007). This dynamic has serious economic and ecological consequences in forests that are managed or inhabited by humans.

Added to this climate change and El Niño phenomena as average temperature changes and droughts occur, because the occurrence of forest fires related to outbreaks of *Dentroctonus frontalis* (billings, 2004). It is important to relate these factors and make decisions about the management of forests to mitigate the effects that climate change can cause in the pine forests of Honduras.

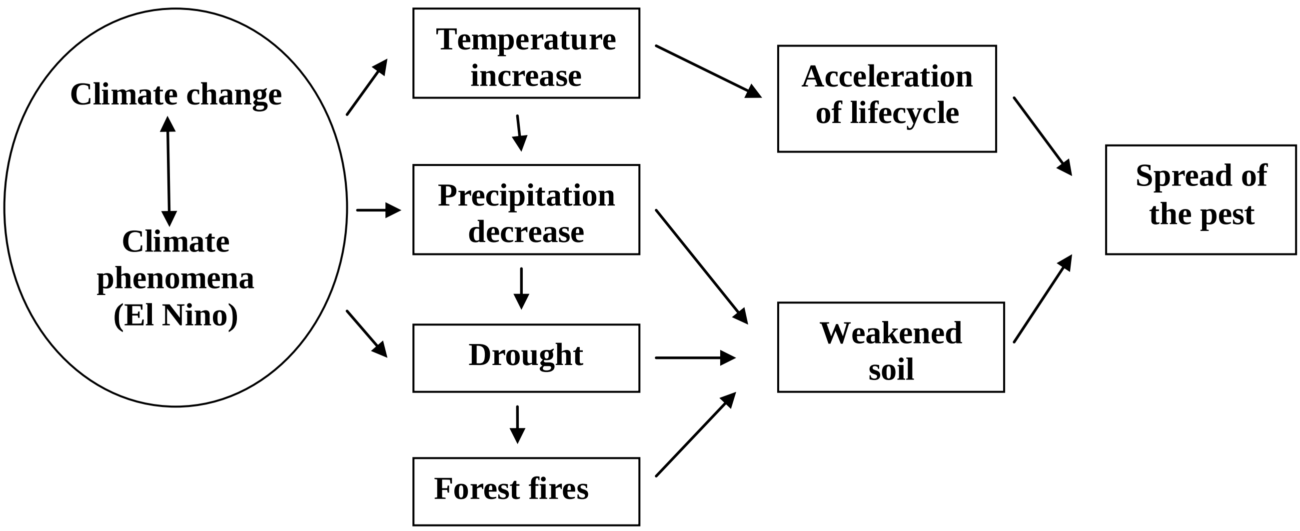
1.1 Aim of thesis

The thesis researches the problematic of *Dentroctonus frontalis* outbreaks in pine forests of Honduras. Specifically, main factors involved in the past 50 years, the relation of these factors to climate change and the implemented control methods. The research aims to make a contribution with possible new approaches of knowledge and control of the pest nowadays.

1.2 Methodology

At first it is exposed the current situation of the pest and pine forests in Honduras. The country's climate and its variability is then analyzed in terms of weather phenomena, climate change and forest fires. Next part consists in a historical record of outbreaks since 1960 and the way that the pest attacks. At the final the methods implemented for pest control are analyzed.

The factors are presented in the different chapters. Factors related to climate change and to each other are: climatic aspects (temperature and precipitation), droughts and forest fires. The concept framework proposed is as follows:



The study will take into consideration the areas of pine forest in Honduras, which have been during the last decades of the twentieth century historically affected by outbreaks of *Dendroctonus frontalis* (specifically, *Pinus occarpa* and *caribbea and D. frontalis Zimm*).

Written sources provide a theoretical framework to evaluate the affectation of the pest from the decade of the 60s. Among these sources are books, scientific articles, research projects and studies regarding the *Dendroctonus frontalis* and pine forests in the region to study. Additionally primary sources will be used. These are offered by various public institutions of the Republic of Honduras, mostly taken from: the Department of Natural Resources and Environment of Honduras (SERNA), the National Forestry Institute (ICF) and the Honduran Corporation for Forest Development (COHDEFOR).

2 Pine forest in Honduras

Pine forests cover about 2,781,500 hectares equivalent to 42% of the roof surface area of forest and are located mainly in the central mountain ranges, on stony ground of hilly slopes and shallow. These pine forests produce 284-358 tons per hectare of biomass and constitute the basis of the primary forest industry. At present, with few pine forests unlogged (COHDEFOR 2000).

2.1 Species and distribution

Pine forests are usually pure stands of *Pinus caribaea* (coastal pine), *Pinus oocarpa* (Ocote pine), *Pinus maximinoi* (weeping pine) *Pinus tecumumanii* (red pine) ; or mixed with some hardwood species among which may be mentioned : several species of Quercus (oaks). In the higher parts of the mountainous interior (rainy forest) grows in pure stands *Pinus ayacahuite* (white pine) ; *Pinus pseudostrobus* (False Weymouth pine) and *Pinus hartwegii* (mountain pine) (SAG, 2006).

The elevation is important factor to consider. There is a preference for certain species to gradients of low elevation and other to high elevation (SAG, 2006). As well the geographical distribution of each specie along the country is related to the altitude of the region where are located (table 1).

Common name	**Scientific name**	**Geographical distribution**
Pino costanero o Caribe	*Pinus caribaea*	It grows in the plains of the Mosquitia and other low areas to 800 m
Pino ocote, ocote	*Pinus oocarpa*	It has a wide distribution in the mountainous regions between 800 and 1200 m
Pinabete, pino triste	*Pinus maximinoii*	It grows in the highest and most mountainous parts between 1200 and 1600 m
Pinabete	*Pinus hartwegi*	Grows between 1400 and 1800 meters above sea level in the mountains of Olancho and West.
Pinabete	*P. tecunumani*	Only grows in mountainous parts of Olancho and West between 1400 and 1600 m
Pino de montaña	*P. ayacahuite*	Mainly located in the Sierra de Omoa
Pino de montaña	*Pinus pseudostrobus*	Western part of the country and has been identified only in the highest mountains of Celaque and Guajiquiro

Table 1 Distribution of the 7 species of pine Honduras. (SAG, 2006)

Pine forests are concentrated in the central area (in the departments of Gracias a Dios, Olancho , El Paraiso, Colon and Atlantida) with 52 % of the total, followed by the eastern region with 19% , western 14 % , and the south has little existence of this type of forest (COHDEFOR, 2000). Also in the area with the largest number of hectares of pines are found a higher density of forests (table 2).

Department	**Sparse pine**	**Dense pine**	**Total**
Atlántida	-	-	-
Colon	-	-	-
Comayagua	54.7	151.0	205.7
Copan	7.7	33.6	41.3
Cortes	4.8	16.0	20.8
Choluteca	7.0	-	7.0
El Paraíso	23.4	150.0	173.4
F. Morazán	61.5	323.6	385.1
G. a Dios	400.8	164.5	565.3
Intibucá	27.7	74.8	102.5
I. Bahía	4.4	-	4.4
La Paz	48.3	35.4	83.7
Lempira	3.1	97.2	100.3
Ocotepeque	-	44.4	44.4
Olancho	149.9	438.6	588.5
Santa. Bárbara	2.8	77.2	80.0
Valle	-	-	-
Yoro	6.2	330.2	336.4
Total	802.3	1936.5	2738.8

Table 2 Distribution of pine forest in departments of Honduras (SAG, 2006)

Another particularity of pine forests to consider is the age of the forest. In the forest yearbook 2005 - 2006 the secretary of agriculture (SAG) by sampling method the quantified size of these succession states in order to exploited, mature, middle, young and recent (Table 3). In the pine forest, mature and middle age forests occupy a larger area with 711.876 ha and 667.146 ha, respectively. (SAG, 2006)

Pine forests	Hectares	Km 2
Exploited	113.236	1.132
Mature	711.876	7,119
Middle	667.146	6.671
Young	141.145	1.412
Recent	46.322	463

Table 3 Succession states of pine forest (SAG, 2006)

3 Pine bark beetles in Central America and Honduras

3.1 Species of Dentroctonus

The pine beetles are bark beetles that attacks pine forests. Pine bark beetles of the genus *Dendroctonus* (Coleoptera: Curculionidae) are the most destructive forest pests in the region where are native pine forests are found. Twelve species of pine bark beetles native to Mexico and portions of Central America can be mentioned. *D. frontalis* and *D. adjunctus* (primarily in Guatemala) are the most destructive. Other species, including *D. mexicanus, D. vitei, D. approximatus, D. parallelicollis* and *D. valens*, are less important (Thunes, 2004).

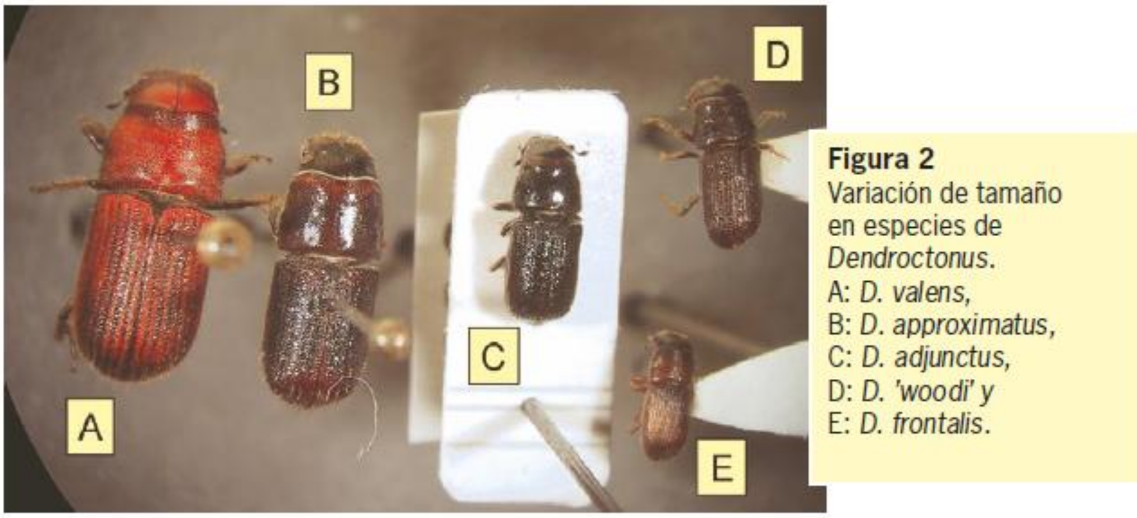


Figure 2 Common species of *Dentroctonus* and their sizes. (Thunes, 2004)

Historically these types of *Dentroctonus* has been credited with the greatest losses of pine forests in Central America in the past 50 years, been considered the most destructive pest of pine forests in Central America, including Honduras (Billings, 2004; Hernandez, 1975). The southern pine beetle is also the most destructive insect pest of pine forests in the southern United States and in parts of Mexico (Payne, 1980).

3.2 Dendroctonus frontalis Zimm

This is the most common type of pine bark beetles in Honduras. Is a native insect that lives mostly in inner bark of pines forest, are small beetles. Length in both sexes is between 2.3 and 4.0 mm. It has a light brown to black, often dark reddish brown. The recently emerged adult beetles in the bark can be a light yellow color (Thunes, 2004).

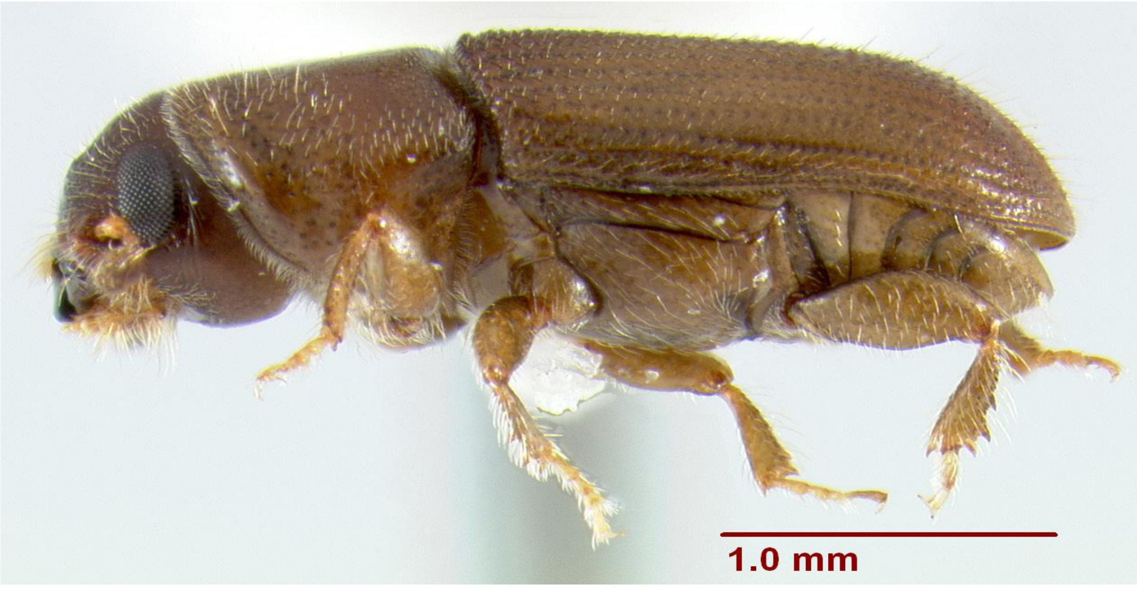


Figure 3 ***Dendroctonus frontalis*** **Zimmermann (Billings, 2005)**

The female lays eggs along shaped galleries constructed in the inner bark interface. The larvae feed in the inner bark and pupate in chambers near the bark surface. Upon completing development, the new adults chew their way out of the bark and fly in search of new trees to attack (Billings, 1982; Hernandez, 1975). Although the beetles do not bore into the wood, they introduce a blue-stain fungus which penetrates into the wood, quickly reducing the marketability of the trees (Billings, 1982).

Figure 4 Galleries of *D. frontalis* (Hernandez, 1975)

They initiate their attacks above on pines weakened by rays, fires, high stand density or other causes. Once 20-30 pines are attacked and if not control will be applied they are able to spread rapidly on forest stand. Under these conditions of outbreak, the bark beetles can kill even healthy pines in sparse stands (Billings, 2005). The bark beetle brood (eggs, larvae, pupae, and new adults) develops within the bark of infested pines. They complete their life cycle in 4 to 6 weeks. Upon emerging from the tree, the new adults fly in search of a new host and the adult beetles only survive a few days outside the host tree (Payne, 1980; Hernandez, 1975).

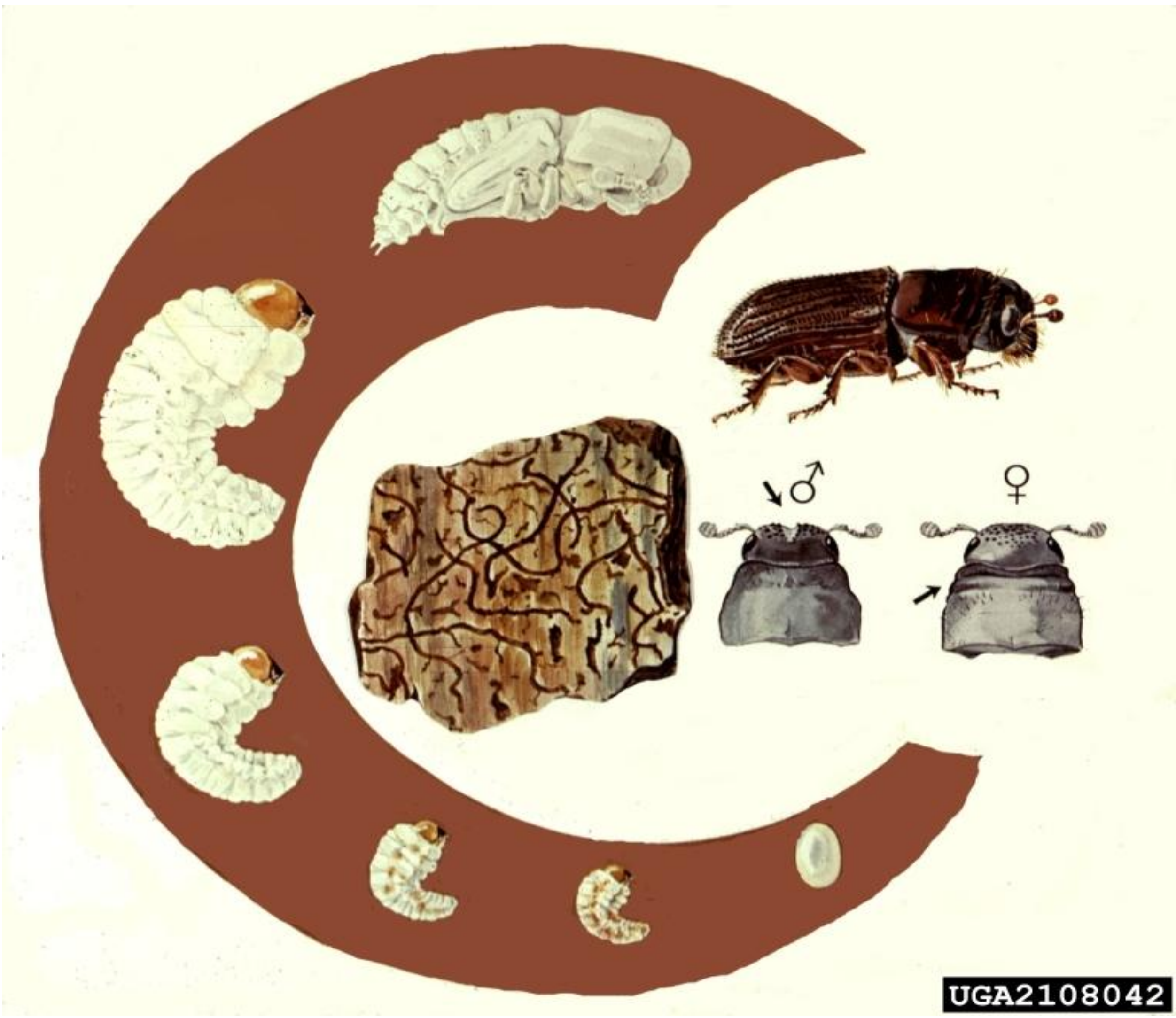


Figure 5 *Dentroctonus* life cycle (Hernandez, 1975)

Other important characteristic of *Dendroctonus frontalis* Zimm. Is that the adult females are responsible for the host selection. And when they locate a suitable host tree, a female beetle will bore through the bark to initiate gallery construction in the inner phloem. Soon after initial attack, females emit an aggregation pheromone (frontalin), this pheromone, attracts other individuals of the same species in order to help them overcome the defenses of the tree. The more bark beetles attack the tree; there is a big probability that the bark beetles will overcome the defense system of the tree and thus will spread and cause a very high damage on the whole forest area (Billings, 2005).

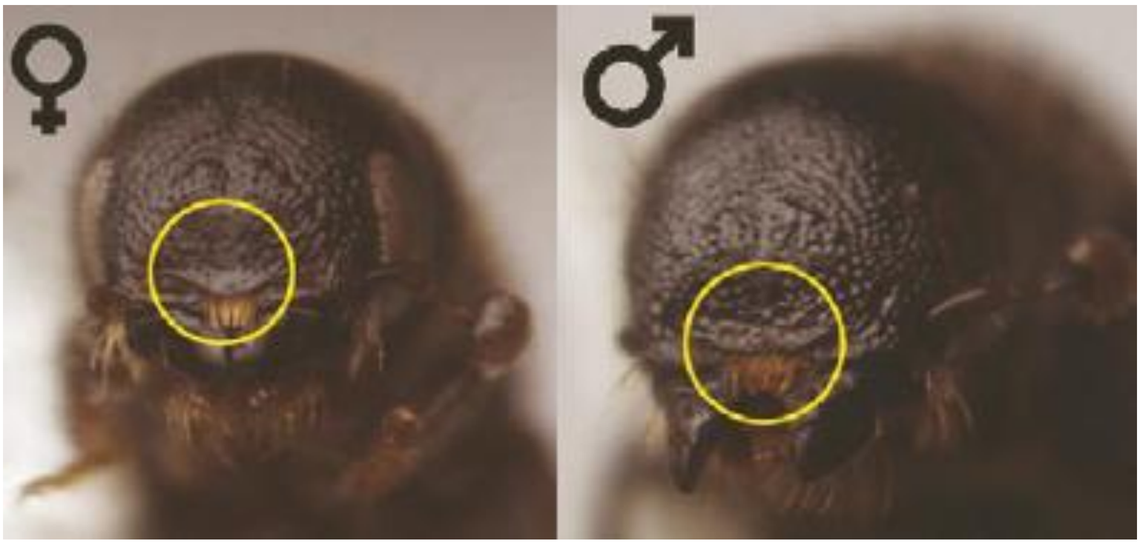


Figure 6 The difference between sexes of *D. frontalis* Zimm. (Thunes, 2004)

4 Climate in Honduras

Due to its geographical location the climate of Honduras have tropical characteristics; however Honduran orography and interaction with the winds that blows over the territory. And the tropical phenomenon's like waves and cyclones generate microclimates that go from the dry tropical to the wet tropical. The orientation of the Honduran mountain range play an important role establishing the regime of precipitation well marked in the Caribbean coast. Most of the Honduran territory, especially inter-mountain areas and coast of the Gulf of Fonseca, have a climate with precipitation regime having two distinct seasons, a rainy and a dry season. During the rainy season (May-October) these regions shows a decrease in precipitation in a period known as Midsummer. In contrast, on the Caribbean coast it rains almost all year with a decrease in precipitation during the months of February to May. The region where more rains is the Caribbean coast and the region where rains the less is the central region (Argueñal, 2010).

The rainfall regime in Honduras is a direct and indirect consequence of following phenomena: Intertropical Convergence Zone (*fig. 6*), climatic depressions in the westerly's midlatitude, tropical waves, systems low altitude atmospheric pressure and surface winds from sea to land, valley breezes from mountains , cold fronts and tropical cyclones (SERNA, 2000). International factors to be taken into consideration are the convergence of humidity and heat flow latent, since these parameters are increased during the rainy season having a positive influence on convection over the region, which is reflected in an increase in the evaporation and humidity (NOAA).

The dry season and the midsummer (July-August) in the south and inter - mountain regions is a consequence of westward movement of the anticyclone North Atlantic, located on the islands Bermuda at this time of year, which causes an increase in the speed of the trade winds (NOAA).

4.1 El Niño and La Niña

The climatic phenomenon El Niño is referred to a warm ocean current that moves toward in the equatorial Pacific Ocean, this phenomenon usually manifests in the Southern Hemisphere during summer, just after Christmas. This phenomenon affects wind flow considerably and ocean currents, temperature, sea surface and precipitation in the Tropical Pacific. Its effects influence the climate of the entire Pacific region and many other parts of the world (SERNA 2000).

The concept of climate variability refers to variations in the mean state of the climate on all spatial and temporal scales. In this oceanographic and atmospheric conditions are also defined. Today it is known that this current warm water is part of a set of interrelations between atmospheric changes and oceanic conditions on a global scale, so to these changes it was added the term Southern Oscillation climate pattern (SERNA 1999).

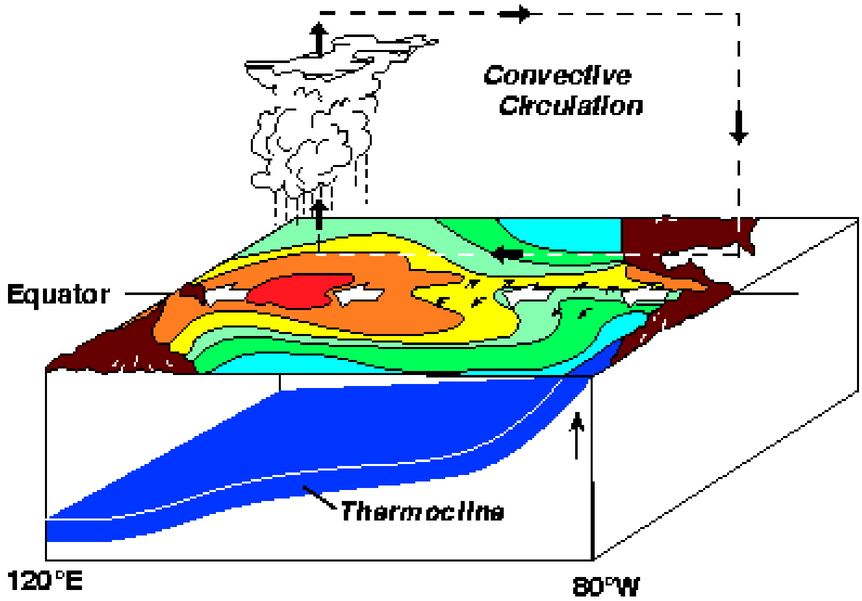


Figure 7 ITCZ Normal conditions (NOAA)

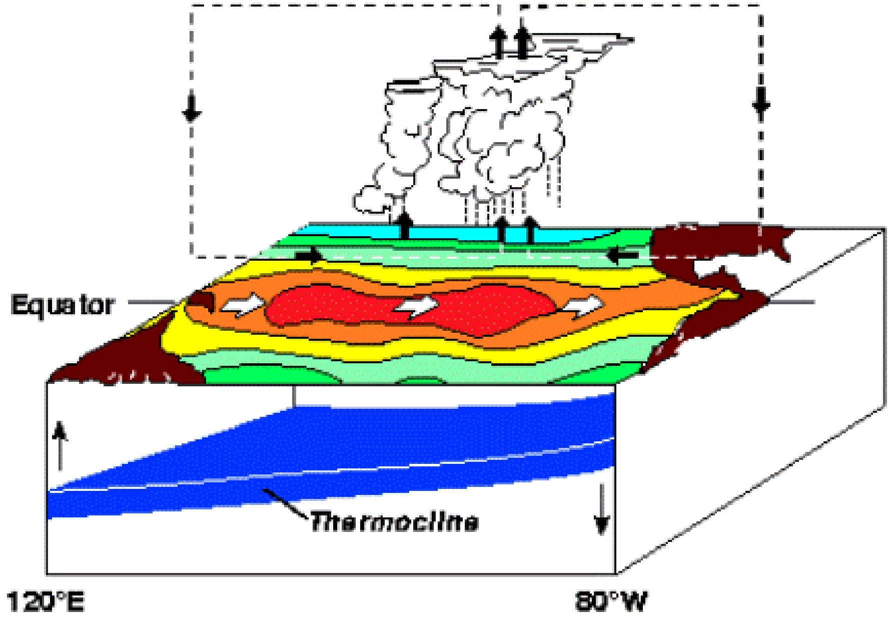


Figure 8 Niño conditions: Warm water pool approaches the South American coast. The absence of cold upwelling increases warming. (NOAA)

The warm phase is called El Niño and some common aspects that characterize El Niño in the equatorial Pacific Ocean are its relation regarding anomalous heating of surface waters and pressure changes at sea level which is usually accompanied by a weakening of the trade winds. This phenomenon occurs repeatedly between 4 and 7 years around Christmas time and usually takes between twelve and eighteen months (Argueñal, 2010).

During the occurrence of El Niño event, the precipitation decreases significantly on Central America and northern South America in the period from July to December. And in the period from April to June it doesn't exist a consistent tendency of a decreasing of the precipitation in Central America (NOAA).

This ocean-atmosphere phenomenon has also a counterpart La Niña, the Cold Phase. The phase is preceded and followed by periods which surface temperatures of the sea during that period are usually lower than normal (3-5 °C) in the central pacific and trade winds are very strong. (NOAA). It is called also anti-El Niño because the effects are the opposite of El Niño.

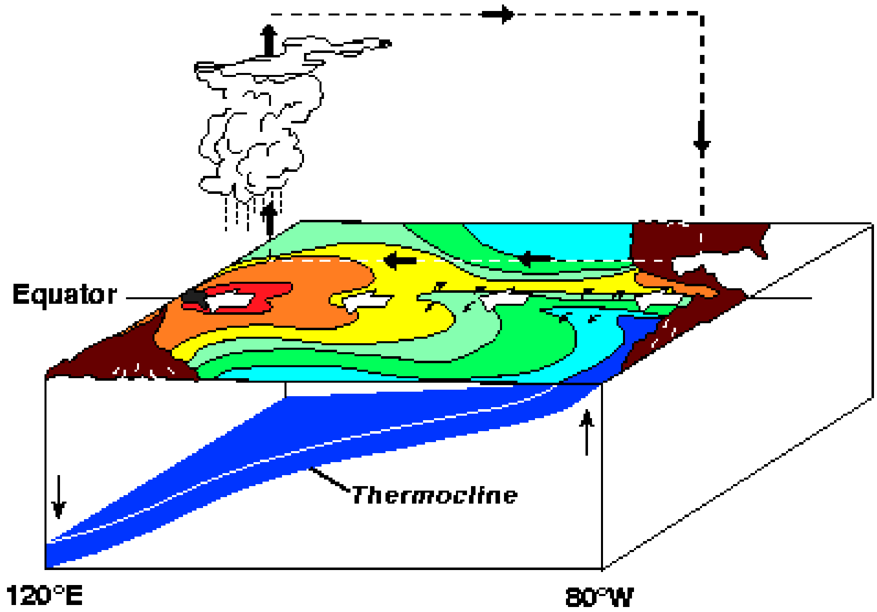


Figure 9 Niña conditions: Warm water is farther west than usual. (NOAA)

The El Niño phenomenon causes decreased rainfall during most of the rainy season, especially from August to October where the rainfall deficit exceeds 60% easily. When the event is weak, early rains in April and May may appear in the south and when it is moderated rains more in June. Then it turns to deficit in regions of the center, south-east and west, where in April temperatures rise by more than 0.6 ° .C. The same happens in August which implies an extension of the period of decreased of usual rainfall occurrence in the rainy season. (Argueñal , 2010)

The precipitation deficit observed between April, May and June in these regions is very important because implies a poor start to the rainy season, which could be related to a shift south of the intertropical convergence zone and crossing waves, very weak on Honduran territory. This anomalous behavior of the precipitation during the onset of the rainy season then La Niña event occurs. The onset of the rainy season in Central America depends on the surface temperature gradient between the Caribbean Sea and the Pacific. If the Pacific is warmer than the Caribbean may occur earlier rains in Central America and the opposite happens if the gradient is reversed.

4.2 Climate change

In the last decades in Honduras has being registered a group of variations in the climate that has not being analyzed in a scientific way , which means that so little progress has being estimated in climatic changes that this territory has being through (SERNA, 2001).

In developed countries have being a big progress about the acknowledge of the climate change however in the tropics countries, like is Honduras case are very little. In this context and in base of the recent events related with the global warming is important to know what are the effects of the hydrometeorology phenomenon's in Honduras with the variability and climate change and if exist a specifically relation between the flooding, droughts, and the increments in the temperature (Argueñal, 2010).

The estimation of how these global warming can affect the regional climates have very low reliability. However is possible to give some information of how the climate change influence ecosystems, human life and economy and which measures can be used to counteract them. And in relation with above said, may be possible to establish how big the impact is that the phenomenon la Niña y el Niño has had.

Weather and climate change is an important factor that influences the stress level of the forest and individual trees (Hicks, 1980). For example: trees that are exposed to wind are more easily attacked. A strong wind breaks the fine roots of the root system and the trees are often stressed due to subsequent water deficiency.

In the future the situation in Honduras could be even worse if we take in consideration other factors at global level of climate change. According to the emission scenarios of greenhouse gases and selected models we would expect changes in precipitation and temperature for the year 2020 are about 6 % decrease in annual precipitation in the departments of Cortes , Santa Barbara Copan , Ocotepeque , Lempira , Intibucá , Comayagua , La Paz, Francisco Morazán , El Paraíso, Choluteca and Valle , and a 0.8 ° C increase in mean annual temperature , specially departments in western and southern part of the country including southern departments of Comayagua, Francisco Morazán and El Paraíso. (Arguenal, 2010)

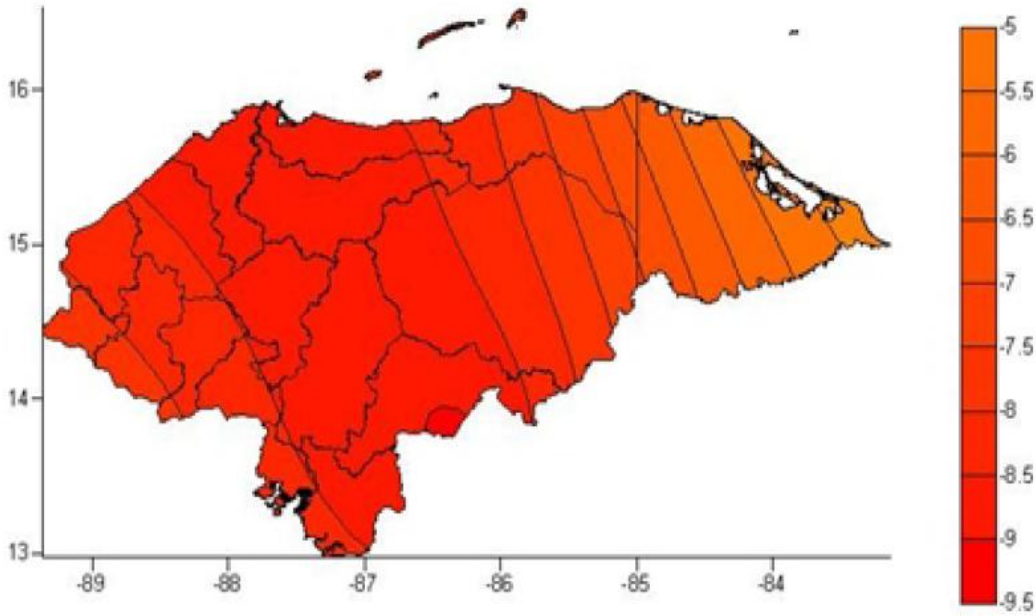


Figure 10 Percentage of deficit rainfall in the rainy season 2020 respect to 2000. (Arguenal, 2010)

4.3 Temperature

The temperatures are determined by the elevation. The lowlands, below 500 m, have an average annual temperature of 24 º C. In areas with elevations between 500 and 2,000 m the average temperature varies between 16 º C and 24 º C, and land above 2,000 m has an average annual temperature of 15 º C or less (SERNA 2001).

The Central American region had being over warming the last decades with a positive tendency in the absolute maximum temperatures and a negative tendency in the minimum absolute temperatures. However there has not being a coherent tendency since some regions shown a negative tendency and other a positive (SERNA 2001).

According to SERNA, that participated in a project which in the study frame was elaborated climatic scenarios of medium global temperature and elevation medium of the sea level in 1990 and 2100. However even making several studies and investigation in different ways, it was not enough to know the changes in small scales.

Are several abiotic and biotic factors that explain the development of epidemic outbreaks of *Dendroctonus frontalis*, where the temperature can have large effects on the physiology and behaviour of this insect at different stages of their development, influences from daily activity, nutrition, reproduction and survival of developing them, in temperate areas such as with an average temperature of 10° the life cycle will take around 82 days while in summer temperatures average 30° the life cycle is shortened only 32 days (Payne1980, Hicks, 1980).

4.4 Precipitation

The Caribbean coast receives an average annual precipitation of around 2600 mm of rain. The wettest months are October and November and the driest from March and May. Precipitation decreases in the highlands of the interior, with values close to 1000 mm per year in the near the capital city. On the Pacific coast the periods of high rainfall are one in June and another in September and its average annual precipitation is about 1600 mm of rain. The national average rainfall is between 1400 and 1800 mm per year. (SERNA, 2001)

The average annual precipitation has variations. Values were recorded ranging from 1250 mm as occurred in 1987, to 2750 mm in 1999. During rainy season precipitation ranges between 1200 and 2000 mm for the dry season covers the months from November to April, the average value of rainfall is about 200 mm. Considering projections for the period 2011 to 2025 the average rainfall for the wet season would have reduced and would be established around 1250 mm, while the average station dry would increase to 500 mm. At the end of this period the average precipitation did not submit annual major changes and keep around 1750 mm. (Rivera, 2007).

Periods of drought are may be another risk factor on the stress level of the trees. Prolonged periods of drought will reduce the capacity of trees to resist bark beetle attack. During long periods of dry weather is important to monitor this forest that are susceptible for outbreaks and bark beetles attacks (Billings, 2005).

4.5 Dendroctonus frontalis and wildfires

We can attribute as major risk factor the fires caused by climate change or agricultural purposes, overheating of the soil cause by extremely hot temperatures, or agricultural uses in the rural areas.

The climatic pattern known as El Niño in the mid-1990s produced drought conditions and increased fuels, leading to severe wildfires throughout Mexico and Central America in 1998. In the following years (1999 to 2003), an unprecedented region wide outbreak of pine bark beetles killed some 90 000 ha of pine forests. Efforts to control these outbreaks involved felling infested and adjacent healthy trees over extensive areas. Because of the magnitude of the outbreaks and lack of timber markets, most of the standing dead and felled trees were left on site, drastically increasing fuel loads. In 2003, after most bark beetle outbreaks had terminated, treated areas became the focal point for extensive wildfires (Rivera, 2007).

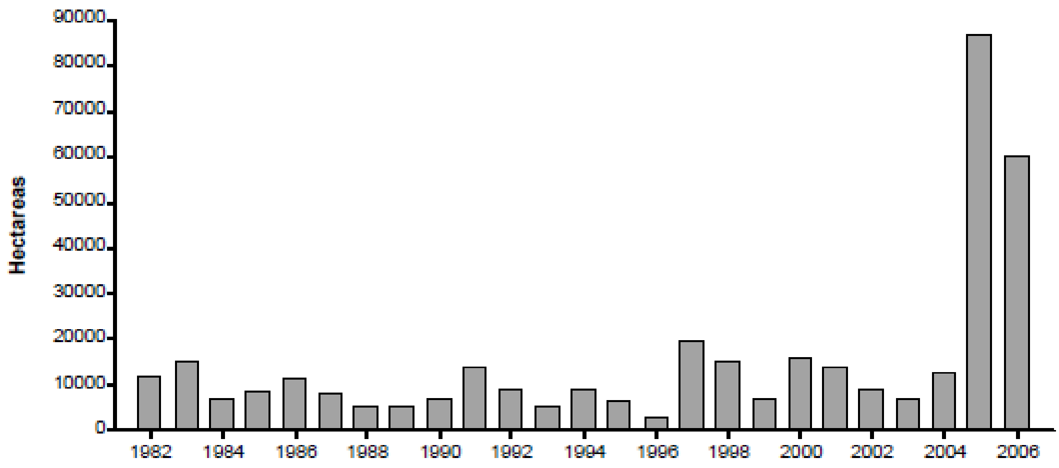


Figure 11 Area hit by forest fires from 1982 to 2006. (Rivera, 2007)

Also the frequent and often indiscriminate use of fire by small farmers in pine-forested areas, combined with lack of thinning to reduce high stand densities, continues to predispose forests to bark beetle outbreaks. Bark beetle problems are usually associated with poor forest management (Billings, 2004).

Traditionally, local residents throughout Central America have set fires in rural areas to extend the agricultural frontier with minimum labour costs or to eliminate old crop residues. Many pine forests are burned annually to provide increased grass cover, used as forage for livestock. Low-intensity, controlled burns in stands of pines ten years of age or older will reduce competition, in turn increasing tree vigour and resistance to bark beetle attack. However, fires that are too hot or too frequent may weaken established pine trees if they do not kill them directly (Billings, 2004).

Weakened pines produce less resin and are less able to defend against initial attacks from primary pest *Dendroctonus frontalis* (This is particularly true for native forests of *Pinus oocarpa* and *Pinus caribaea*). Periodic burning also kills most pine seedlings less than five years of age, effectively preventing the continual in-growth of young seedlings required to obtain stand age diversity (Hicks, 1980).

Fire has become a widely used component of bark beetle control, as sites treated with cut-and-leave may be burned to increase beetle mortality. Fires set following bark beetle treatments kill established regeneration. These sites are often converted to agricultural uses or homesteads, contributing to deforestation (Billings, 2004).

Bark beetle outbreaks also influence wildfire frequency and intensity, as many trees killed by beetles are often left standing or felled and left on site. This abundance of fuel, in turn, increases the threat of wildfires during the annual dry season (December to May) (Billings, 2004). Disgruntled landowners or local residents may also set fire to treated areas in reprisal for having their pines cut down by government control crews.

Several steps are necessary to mitigate the impacts of future bark beetle/fire events. In August 2002, the national fire and forest pest coordinators met in Siquatepeque, Honduras to define common problems and to prepare a regional strategy for fire and pest management (Billings, 2004).The strategy for fire and bark beetles has received approval and support from the Central American Commission on Environment and Development, consisting of the ministers of agriculture from the seven Central American countries.

A recent FAO technical cooperation project has provided training for the pest coordinators and increased awareness of bark beetle prevention and control measures in each country in the region. When the next bark beetle outbreak occurs, detection and direct control responses should be more timely and effective, and Central America should be able to avoid a repetition of recent bark beetle.

5 Outbreaks of Dendroctonus frontalis

Outbreaks are developed in the framework of a number of factors. Among the theories in respect to, we can mention climatic factors and fires in relation with the stress of pine trees (McNulty, 1998; Billings, 2004). Other theories attribute the appearance of outbreaks to factors such as climatic disturbances or variables as insect population dynamics and the high density of trees in unmanaged forests (Hicks, 1980; Payne, 1980).

The outbreak at the beginning or the main first attack occurs on trees that are weak, however, there is also the ability of *D. frontalis* to kill healthy trees that contribute to its pest status. Weakened pines produce less resin and are less able to defend against initial attacks (Rivera, 2010). This is particularly true for native forests of *Pinus oocarpa* and *Pinus caribaea* that are at elevations below 1 000 m, where *D. frontalis* is indigenous. Even more, the *P. caribaea* and *P. oocarpa* forests in Central America are typically composed of even aged stands which are susceptible to bark beetles attacks (COHDEFOR, 2000).

Other attributes that contribute to the destructive potential of *D. frontalis* include: a rapid life cycle with up to ten overlapping generations per year in Central America; the ability of females to establish multiple broods (Payne, 1980); the ability to infest and kill pine hosts of all ages beyond five years as infestations expand, regardless of the tree's physiological condition and infestation cycles that reach peak levels every six to nine years in certain portions of its range (Thunes, 2004).

Every part of the tree can be attacked from the base of large trees to the finer branches. However in most cases the attacks begin around the middle of the trunk in medium sized trees and continue upward. Resin tubes are formed with the size and appearance of roasted corn on the surface of the cortex (Hernandez, 1975).

Figure 12 Resin tubes as a tree response to the penetration of the bark beetle. (Thunes, 2004)

Most of the trees in the forest severely infested with bark beetle resin tubes on the bole of the tree produced as the beetle punctures the bark facilitate the oxidation of the resin produced by the tree in response to physical activity bug. Trees that survive the first attack will have lumps of white resin, while the dead trees have it dark brown. After a number of mites has successfully colonized tree it normally begins to turn yellow and dies. The effect of the attack is given by the obstruction to the passage of water and nutrients within the tree. (Payne 1980).

Attacks can start anywhere in the forest but most of those produced by *D. frontalis* start at the tops of the hills or in the upper parts of the hill, and then descend the slope. Smaller outbreaks usually follow the advance direction and the attack can then predict to some extent. However, as the sprout grows individual attacks and merge, the spread thereof can occur in many directions. The only way to recognize ranged attacks is to see if there is a yellow discoloration of the crown (stage 2). A couple of days after the initial attack, the tree usually begins to turn yellow; then becomes increasingly red, and after a couple of weeks brown (step 3). By then the weevils have completed their development (Thunes, 2004; Billings, 2005).

Figure 13 ***D. frontalis*** **attack. The arrow indicates the direction of the attack. (Thunes, 2004)**

5.1 Historical affectation in the forest

The history in Honduras indicates that from 1962 to 1965 more than two million hectares of forests were attacked by the bark beetle infestation and the rate reached 150,000 hectares per month. This remains the most devastating recorded outbreak of southern pine beetle throughout its range causing heavy economic losses also experienced from a massive outbreaks on pines (*Pinus caribaea, P. Oocarpa)* During outbreaks, trees selected for attack were normally living, standing, and larger than 15 cm of diameter (Billings, 1982).

The most important pest outbreaks in Honduras since 1960 have occurred in the periods 1962-1965, 1982-1984, 1989-1990 and 2001. In this first period of the insect attacks and its biology was not known and therefore the whole country was under an epidemic spread and about 77 000 trees were killed each day, resulting in a 28% mortality of pines forests of the country (COHDEFOR, 2002).

The next outbreaks began in the decade of 1980 in pine stands after natural regeneration developed after the 1960 outbreak. During this time programs were implemented to control the plague thanks to a better knowledge of biology and attack of the *D. Frontali*s from the pasted experience. In 1982 a total of 8,500 hectares were affected, then in 1989 a new event with less intensity, with about 4,000 hectares (Rivera, 2007).

Despite the progress in bark beetle management, a severe *D. frontalis* outbreak appeared again from 2000 to 2003, when 11 650 infestations were detected. The total area affected was the greatest since 1983, amounting to 1 743 ha in 2000, 9 078 ha in 2001 and 13 511 ha in 2002 (COHDEFOR, 2002).

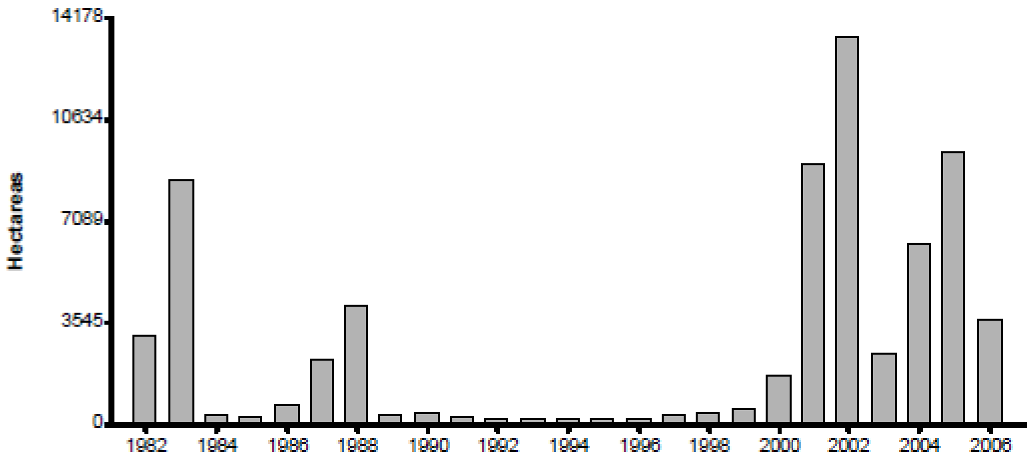


Figure 14Area affected by *D. frontalis* from 1982 to 2006 in hectares. (Rivera, 2007)

For 2001, an increase of *Dendroctonus* populations was observed in the incidence of bark beetles in pine forests from southern Mexico to northern Nicaragua, frontalis that year had increased alarmingly in natural forests and plantations *Pinus caribea* and *P. oocarpa* and throughout Central America. In Guatemala for example, more than 300,000 acres and destroyed reported in Nicaragua there were about 30,000 acres infested by this pest (COHDEFOR, 2002).

Insufficient funding prevented the government forestry agency from responding appropriately, but this outbreak has now been addressed in most regions of the country by means of cut-and-leave and cut-and-remove operations. In 2003, losses were reduced to 2 457 ha. Recently, Honduras has prepared a National Strategy of Forest Protection which covers both bark beetles and fire at the local and national levels. The bark beetles of the species of *Dendroctonus frontalis* Zimmermann are the main pests of the pine forests. Annually thousands of trees die because of these attacks. (COHDEFOR , 2002).

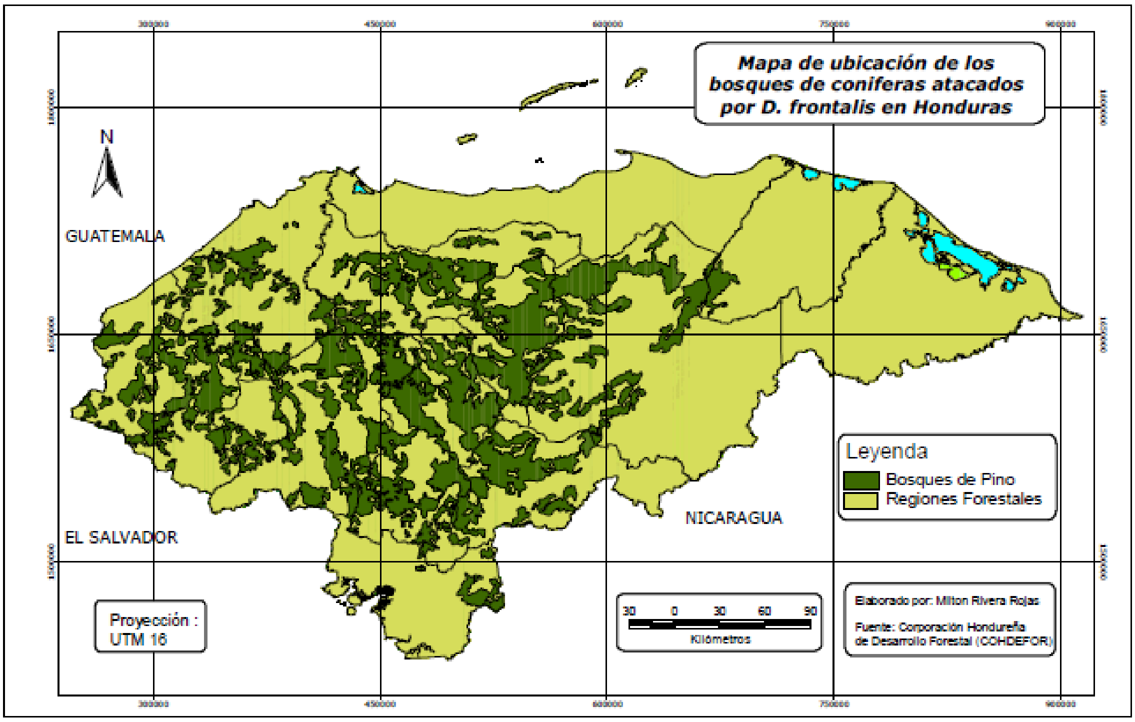


Figure 15 Location map of conifer forests affected by D. Frontalis. (Rivera, 2010)

5.2 Priorities for outbreaks treatments

The infestations of *D. frontalis* should be localized before being treated. Normally the majority of the outbreaks could be detected by air. Or land detection, the observers use as much the red and yellow color in the foliage of the trees, and the number of dying trees. But the land inspections are more to identify the cause of the outbreaks and determine the need of treatment of the forest area (Billings, 1996).

The decision of control depends of a lot of factors, not only of the outbreak, the amount of people that are working in the brigade or team, of the size and number of the trees or the volume of the wood in the outbreak and the conditions of the market for the dead wood damage by the bark beetle. The outbreak with high priority are those who has bigger density of trees infested and should be the first ones that should be marked for the treatment (Thunes, 2004).

Because if let pass the time the other trees will be attacked and if this would happen, we will have to mark the other trees, which is more time and money consuming also. We should not exceed the time of 4 weeks between the marking and the treatment (Thunes, 2004).

As a rule the outbreak with medium priority should not be marked until the outbreaks with high priority had being treated however when for examples one outbreak of medium priority is near one with high priority, we can consider to treat both areas at the same time but this is decision of the person who is managing the control treatments for the forest area. The outbreak with low priority it could be that they would not require any treatment (Thunes, 2004).

5.3 Methods of control

During a long time in Honduras the main strategy was the reduction of the potential of the outbreaks by the treatment of the infested trees with insecticides. Although this treatment might be sometimes effective to control the pest, this strategy was extremely expensive and inadequate to face the outbreaks. Besides there are other harmful side effects (Billings, 2005).

The use of insecticide aggravates the problem, due that in selective form reduce the population of beneficial insects, parasites and predators. Currently with the time and currently more emphasis is given to the reduction of the losses in affected trees than to the elimination of the pest that merely the objective was to kill the pest without thinking taking in account the risks that this will bring to the forest stand, soils, environment and other ecological factors (Billings, 2005).

5.4 Salvage cutting

It is currently the used and recommended control method, which is the extraction of usable infested wood. When performed on time can produce double benefit, because we are able to use the wood before it deteriorates that will reduce in some way economic losses and a proportion of the population of bark beetles is removed and destroyed. To make a good control, we should take in account some cautions: we will extract trees with yellowish- green top with fresh resinous tubes or other evidence of infestation before the bark beetles leave their host.

Depending on the size and activity of the outbreak. We cut a preventive buffer strip 15m. Of healthy trees, to ensure the collapse and dispersion of the pest. Of the dead trees and abandoned by the bark beetles, we extract the usable ones and exploitable trees and the rest is left up to the reproduction of beneficial insects.

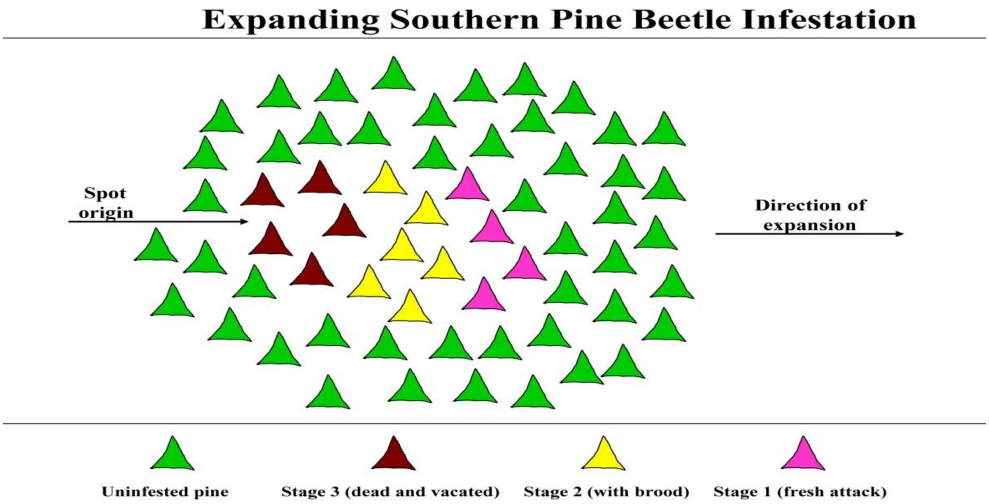
5.3.1 Cut and Leave

This is the most used method for control in Honduras, where expanding spots should be controlled while they are small in order to reduce the economic and ecological losses, As mentioned about cut and leave method it is recommended the most for controlling the outbreaks in expansion of small sizes, less than 10 ha (Billings, 2005).

Used solely for *D. frontalis*, and it should be applied , cut and control the soon as possible after is detected the spot in expansion and before it affects one hectare more, this consists of felling all trees with fresh attacks or bark beetle broods plus a buffer strip of adjacent uninfected trees and leaving them on site.

This procedure reduces beetle survival within infested trees and breaks apart the pheromone production so that the pest doesn't expand to other trees and to the contrary to stop the advance of very large infestations (more than 10 hectares), a buffer strip should be applied, felling all trees in stage 1 and also some healthy pines adjacent of size btw. (20-50 m wide) around the active front of the spot (Billings, 2005).

Once the spot of outbreak is controlled, it is necessary to continue felling trees in stage 2, and finally after this, we should take advantage of those felled trees and utilize them and exploit them for commercial or other purposes. Afterwards in order to not transfer the beetles to uninfected areas, it is recommended to debark all infested logs before transport (Thunes, 2004).



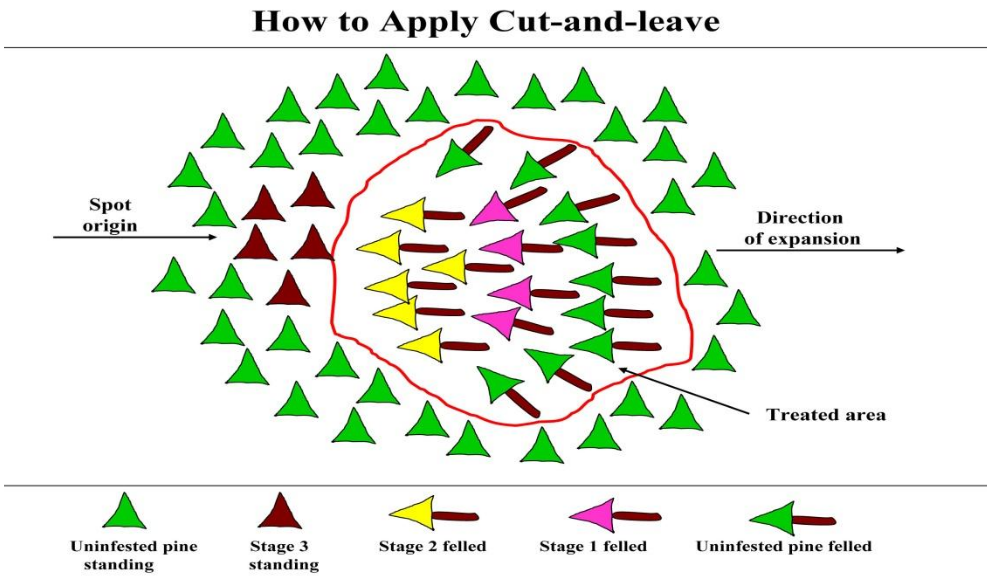


Figure 16 How to apply Cut and leave. (Billings, 2005).

5.3.2 Biological control

The bark beetle has many insects that are parasites, predators and partners, these insects belonging to the orders Himenoptera and Coleoptera, contribute to maintain the natural balance or control of the plague. This balance is maintained, if not broken with improper management practices or natural drastic natural phenomena like irrational cuts, abuse in the use of insecticides, lack of sanitation in the forest, hurricanes, lightning, droughts, etc (Hernandez, 1975). Some of the more important species are the following:

ORDER	FAMILY	SPECIE
Coleptera	Cleridae	*Thanasimus dubius (F.)*
Coleoptera	Histeridae	*Cylistix cilindica (Paykull)*
Coleoptera	Ostomidae	*Tenebroides collaris(Strum)*
Diptera	Dolichopodideae	*Medetera bistrata Parent*
Hemiptera	Aradidae	*Aradus cinnamomeus Panzer*

Table 4 Species to apply biological control. (Hernandez, 1975)

The insects parasites identified they all belong to the order Himenoptera and some of them parasite in immature states (egg, larve, and pupae). And other to the adults and some of them to both (Hernandez, 1975). The most important are:

ORDER	FAMILY	SPECIE
Himenoptera	Braconidae	*Spathius Palidus*
Himenoptera	Braconidae	*Cenocoelius nigrisoma(rohwer)*
Himenoptera	Braconidae	*Coeloides pissodes(Ashmead)*
Himenoptera	Braconidae	*Dendrosoter Sulcatus Muesebeck*
Himenoptera	Braconidae	*Doryctes spp.*

Table 5 Species of order Himenoptera.

5.3.3 Indirect methods

The indirect methods are the good management of a forest area susceptible to the bark beetle attack. In 1984 COHDEFOR implemented one IPM (Integrated pest management programme) in Central America. This programme consists of a national pest coordinator and forest protection coordinators in each forest region to respond to both fires and bark beetle outbreaks.

The way to control the outbreaks of Dendroctonus is to apply prevention and monitoring measures this should be the first approach we have to do, to mitigate losses, an integrated forest management plan such as: thinning to reduce stand density, removing damaged and weakened trees and harvesting before trees become over mature, are primary measures we should apply (COHDEFOR, 2002). Once the outbreaks occur, there should be an immediate attention shifts to the detection and suppression of individual infestations, which can substantially reduce resource loss (Billings, 2005).

Also a permanent record-keeping system to track *D. frontalis* detection and control information, the first in Central America, has been maintained since 1982. When salvage removal is not feasible, cut-and-leave has been commonly and effectively applied for southern pine beetle control in Honduras (Billings, 2005).

6 Conclusion

The *D. frontalis* is a native insect in the pine forests ecosystem, therefore is not possible its eradication as a method of absolute control. It should be considered to execute and plan a good management to control populations of the pest because future outbreaks would have had favorable conditions for its increase. Susceptible areas would increase by weather conditions that would favor stress levels forest and with that the bark beetle population dynamics.

Barker pine beetle *D. frontalis* has been the cause of great losses to the economic forest industry in Honduras and other countries in the region, including even North America. In the case of Honduras, *D. frontalis* attacks have been recorded formally since 1962, but despite the disponibility of data is difficult. It is necessary to improve the quality of registers for thus also improve the analysis of the situation and contribute to the elaboration of management strategies to control the *D. frontalis.*

The effects of climate change appear to be becoming more common and are being Accepted by the international scientific community, however, there is still an atmosphere of speculation on many aspects and it’s until now that climate change is awaking interest. In the case of Honduras and Central America in general, the problematic of Barker pine beetle it been present about 50 years but even that there are just few specific studies that clearly define a relationship between climate change and outbreaks of the pest.

The relationship with fires and outbreak highlights the need for face a problematic together. Adverse weather conditions as prolonged drought would increase the risk of forest fires; this would mean the increased disponibility of forest area exposed for later appearance of outbreaks. This direct relationship leads to the conclusion that efforts to combat the *D. frontalis* should consider the joint of preventive planning and control management activities that would include forest fires and the increase in the total area under forest management.

The climate change scenarios for the area where pine forest in Honduras are located show an increase in temperature and decrease of the precipitation for the period 2011-2020. This will involve a significant change in environmental conditions of the area and thus the interactions between the *D frontalis* and forest.

The outbreaks until now has been concentrated on the pine species *Caribea* and *Oocarpa.* This is because these species do not exceed 1400 m in height, so the average temperatures do not drop below 16 ° C and this favors the lifecycle of *D. frontalis.* In this sense we see that the impacts could reach the pine areas that are currently isolated from attacks by microclimate conditions. Upland areas where currently the *D. frontalis* do not attack could be impacted. It would be adopted an altitudinal shift adaptation as a response to changing weather conditions and other pine species could be affected.

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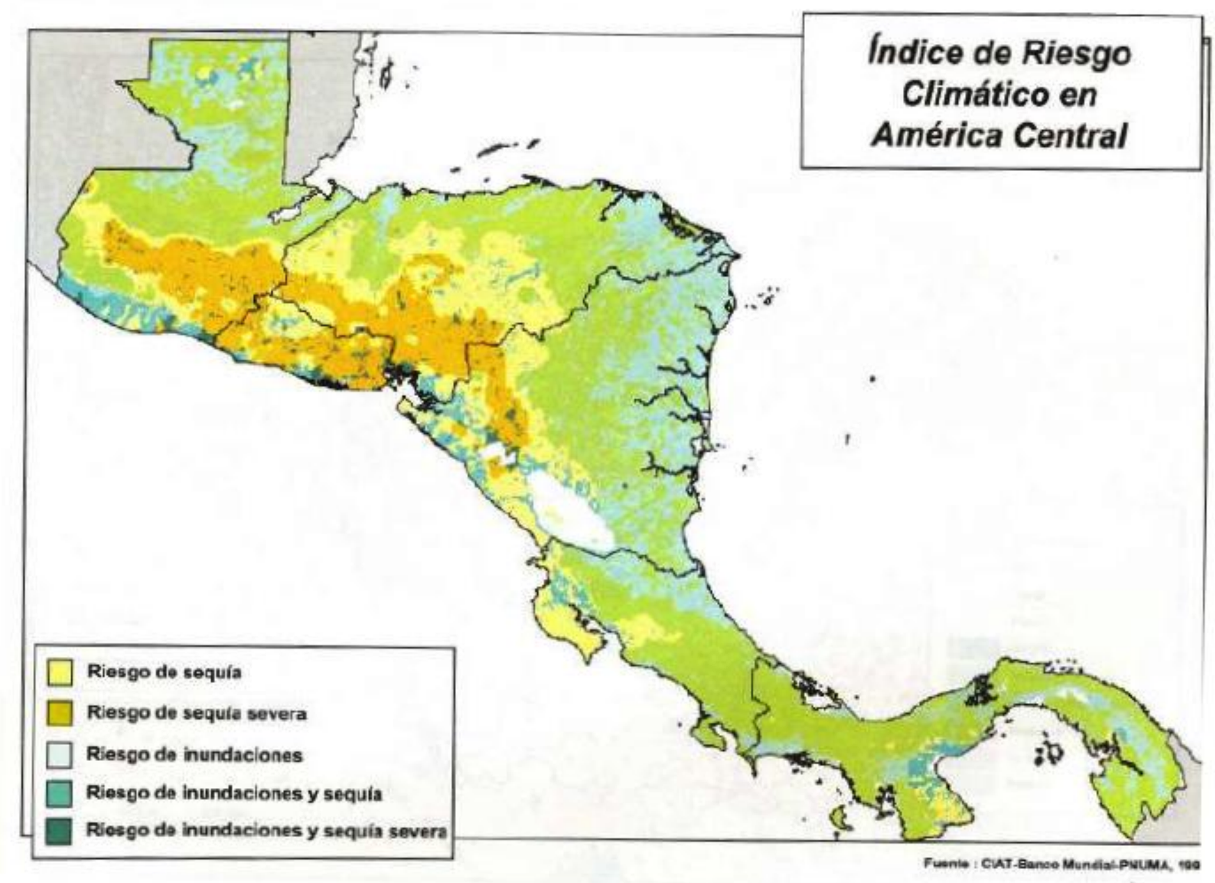
8 Appendix

Land Use and type of forest

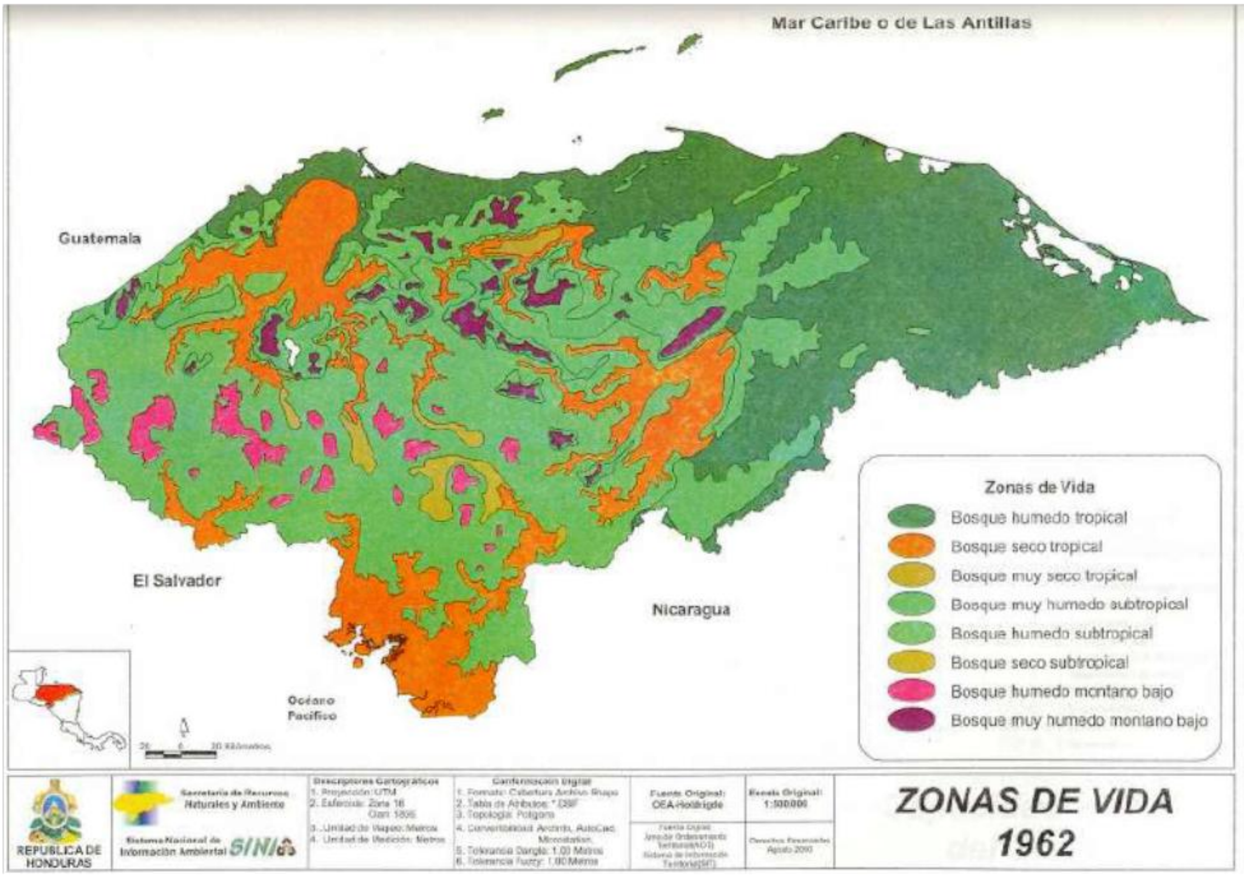
Uso de la tierra y tipo de bosque	Superficie		
	ha	km^2	%
BOSQUE	**4,830,010**	**48,300**	**46.9**
Latifoliado	**2,565,992**	**25,660**	**24.9**
Primario	457,419	4,574	4.4
Maduro	522,012	5,220	5.1
Medio	1,181,995	11,820	11.5
Joven	404,565	4,046	3.9
Coníferas	**1,679,735**	**16,797**	**16.3**
Explotado	113,236	1,132	1.1
Maduro	711,876	7,119	6.9
Medio	667,146	6,671	6.5
Joven	141,145	1,412	1.4
Reciente	46,322	463	0.4
Mixto	**536,601**	**5,366**	**5.2**
Maduro	179,818	1,798	1.7
Medio	328,367	3,284	3.2
Joven	28,417	284	0.3
Manglar	**47,682**	**477**	**0.4**
Maduro	45,692	457	0.4
Medio	1,990	20	0.02
Joven	-	-	0.0
FUERA DE BOSQUE	**5,457,598**	**54,576**	**53.1**
Otras tierras naturales con plantas leñosas	**1,330,843**	**13,308**	**12.9**
Arbustos	897,563	8,976	8.7
Pastos naturales con árboles	358,276	3,583	3.5
Sabana con árboles	75,004	750	0.7
Otras tierras	**3,784,925**	**37,849**	**36.8**
Pasto natural sin árboles	202,133	2,021	2.0
Sabana sin árboles	271,368	2,714	2.6
Humedales	388,981	3,890	3.8
Suelo desnudo	125,869	1,259	1.2
Sistema agroforestal	507,654	5,077	4.9
Cultivo anual sin árboles	933,573	9,336	9.1
Cultivo permanente sin árboles	163,769	1,638	1.6
Ganadería	949,655	9,497	9.2
Infraestructura humana	241,923	2,419	2.4
Cuerpos de agua interior	**341,829**	**3,418**	**3.3**
Total del área muestreada	**10,287,608**	**102,876**	**100.0**
Desconocido	**961,592**	**9,616**	**8.5**
Total área país	**11,249,200**	**112,492**	

Uso de la tierra/tipo de bosque	Densidad árbol/ha)	Área basal m^2/ha	Volumen total m^3/ha	Volumen total bosques accesibles millones m^3	Superficie total accesibles ha
Bosque	**226**	**12.7**	**134.8**	**631.2**	**4,681,104**
Coníferas	**174**	**10.1**	**66.0**	**111.4**	**1,686,831**
Maduro	150	12.6	90.4	64.3	711,876
Medio	188	9.2	54.6	36.8	674,242
Joven	337	9.7	46.0	6.5	141,155
Latifoliadas	**262**	**14.0**	**183.1**	**441.3**	**2,409,990**
Primario	237	17.1	278.2	85.8	308,513
Maduro	258	16.9	211.4	110.4	522,012
Medio	270	12.4	143.4	168.4	1,174,900
Joven	216	4.0	29.6	12.0	404,565
Mixtos	**217**	**11.8**	**90.4**	**48.5**	**536,601**
Maduro	179	13.4	111.1	3.2	28,417
Medio	250	11.7	85.6	28.1	328,367
Joven	109	2.7	16.1	2.9	179,818
Fuera de bosque	**34**	**1.7**	**14.1**	**756.2**	**5,378,687**
Otras tierras naturales con plantas leñosas	**52**	**2.2**	**16.3**	**20.4**	**1,251,932**
Arbusto	59	2.0	16.1	13.2	818,652
Pasto natural con árboles	41	2.5	18.2	6.5	358,276
Sabana con árboles	32	1.6	8.1	0.6	75,004
Otras tierras	**28**	**1.6**	**13.4**	**50.7**	**3,784,925**
Sistemas agroforestales	101	5.9	54.6	11.0	202,133
Pasto natural sin árboles	8	0.3	2.5	0.7	271,368
Sabana sin árboles	2	0.1	0.6	0.2	388,981
Humedales	10	0.4	3.7	0.5	125,869
Suelo desnudo	7	0.3	1.6	0.8	507,654
Cultivo anual sin árboles	18	1.1	8.0	7.4	933,573
Cultivo permanente sin árboles	2	0.1	0.7	0.1	163,769
Ganadería	19	0.9	7.3	7.0	949,655
Infraestructura humana	35	2.0	13.6	3.3	241,923

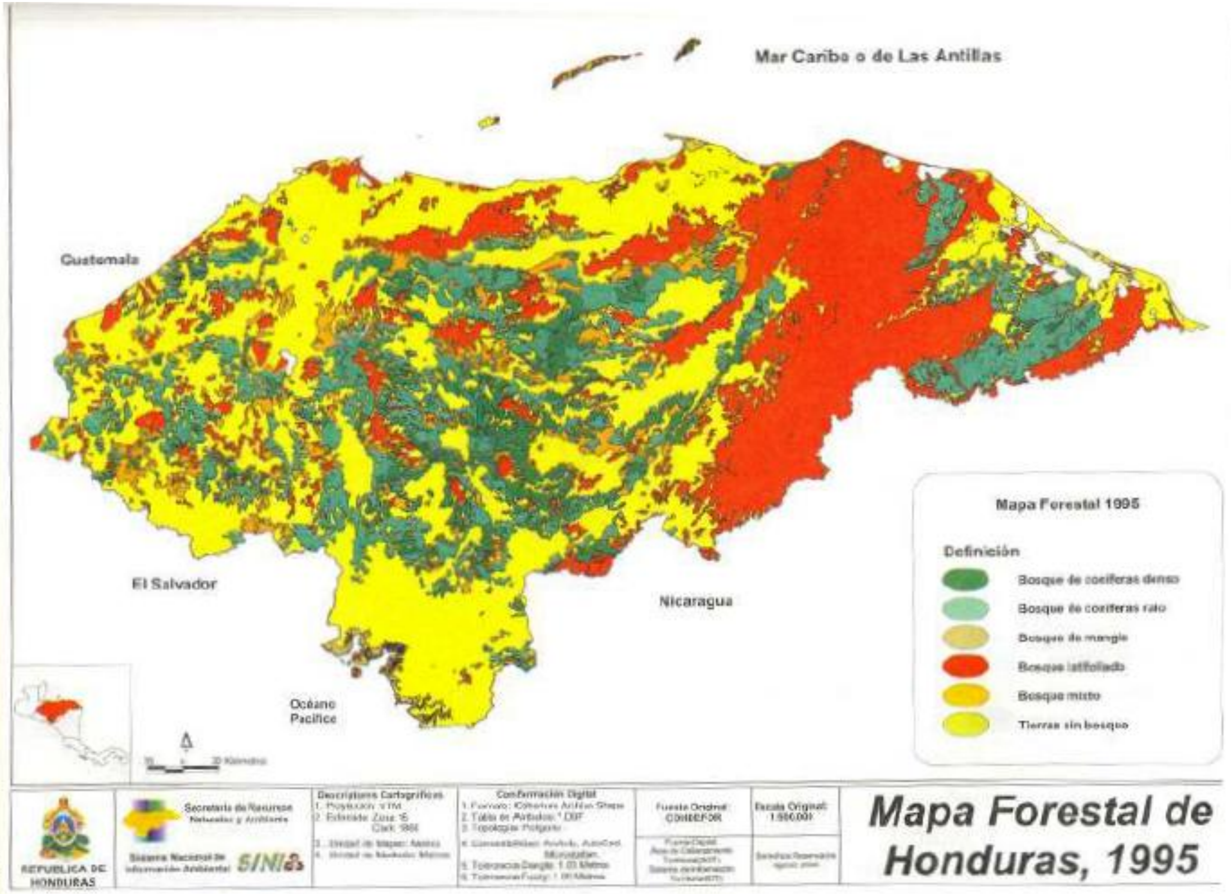
Map of risk of drought in Central America



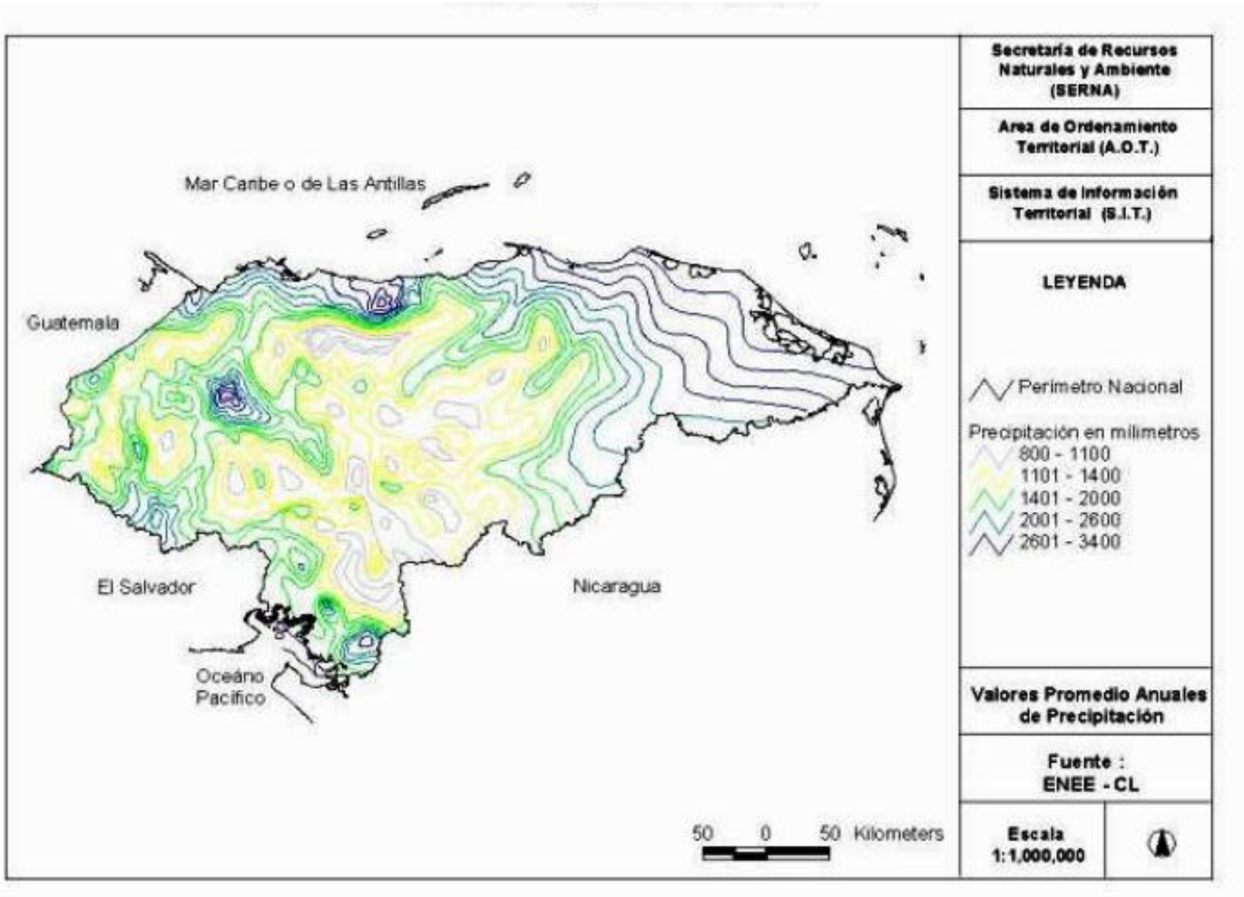
Forest map 1962



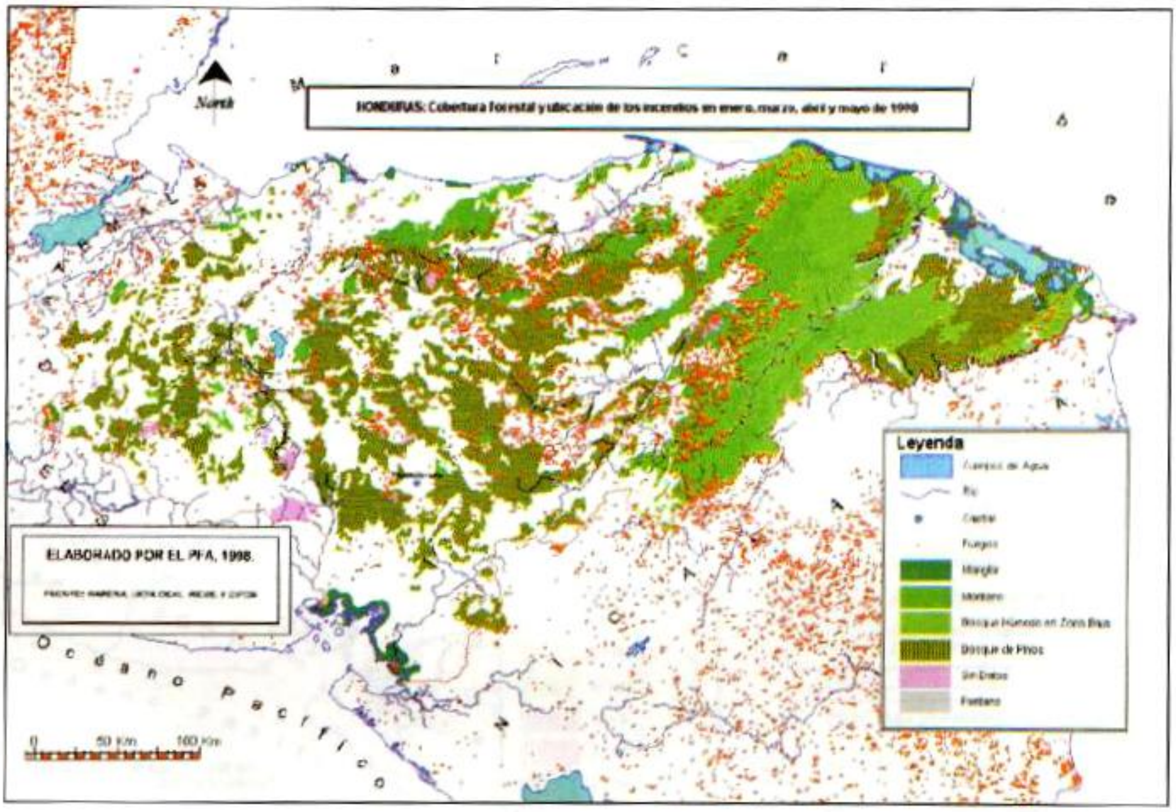
Forest map 1995



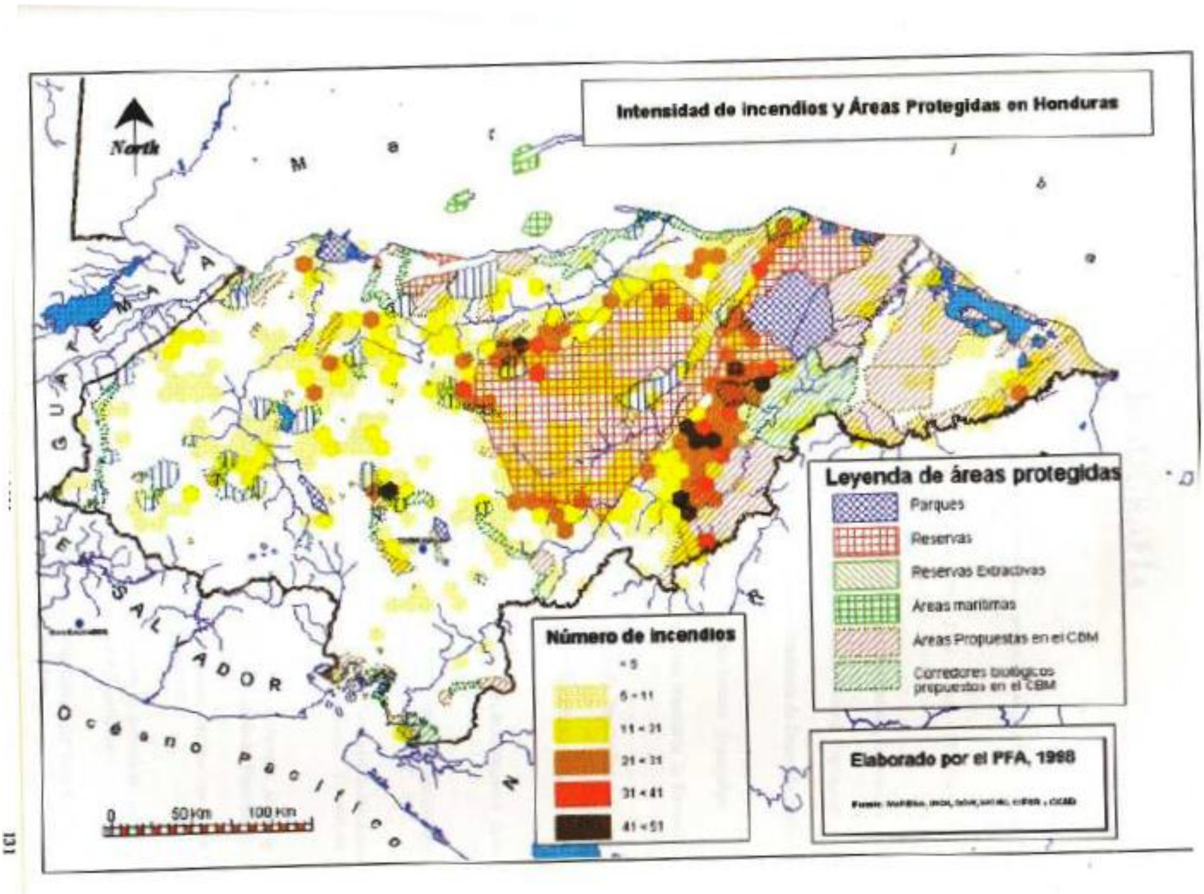
Average annual precipitation values



Fires in forest of Honduras

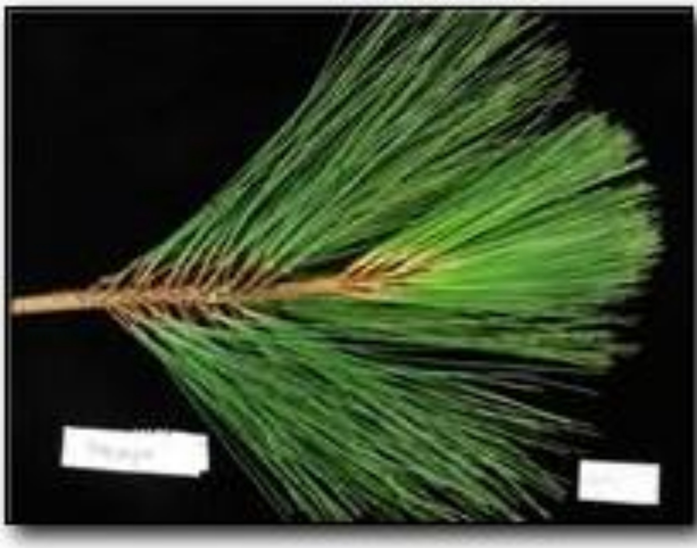


Fires and protected areas



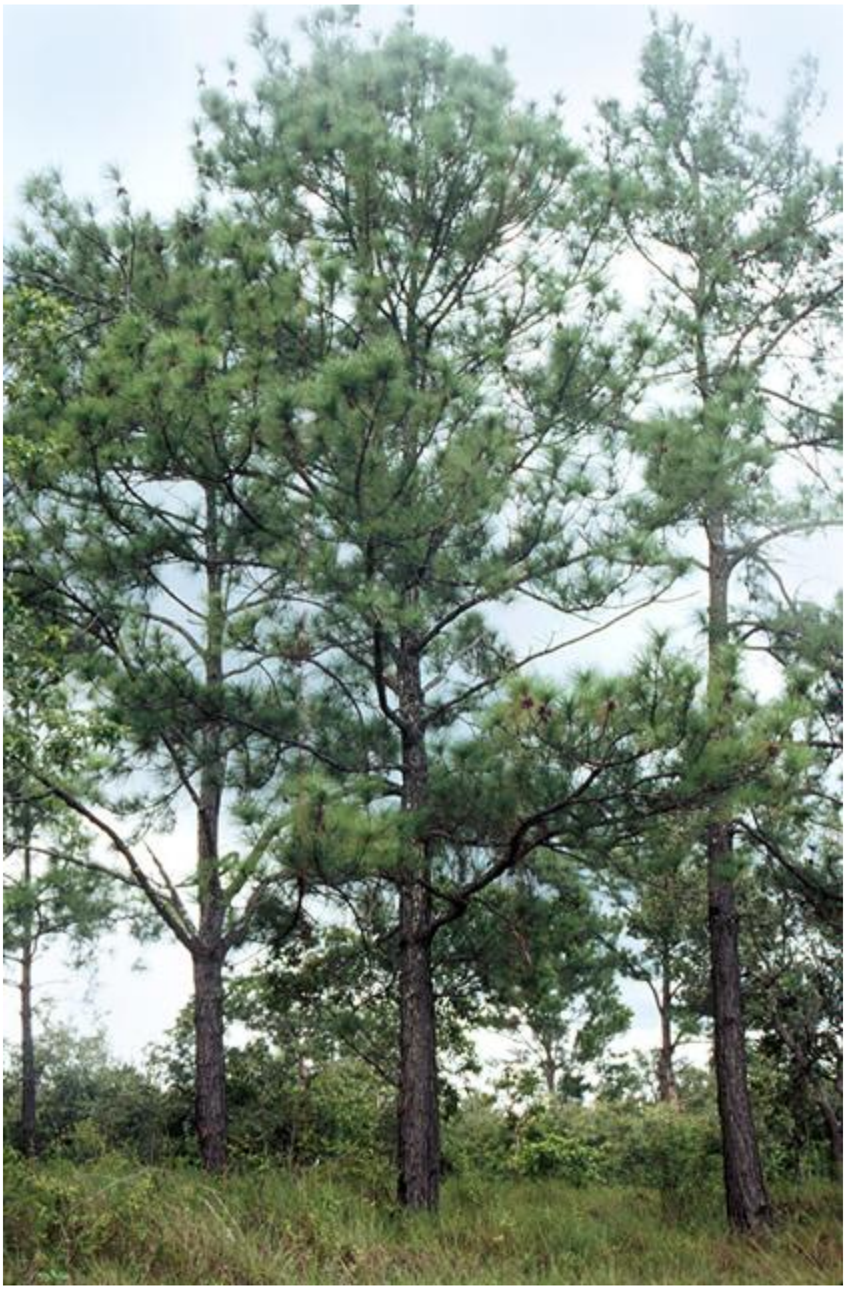
Pinus oocarpa tree

Pinus oocarpa Blanchlet



Pinus oocarpa Cone

Pinus Caribea tree



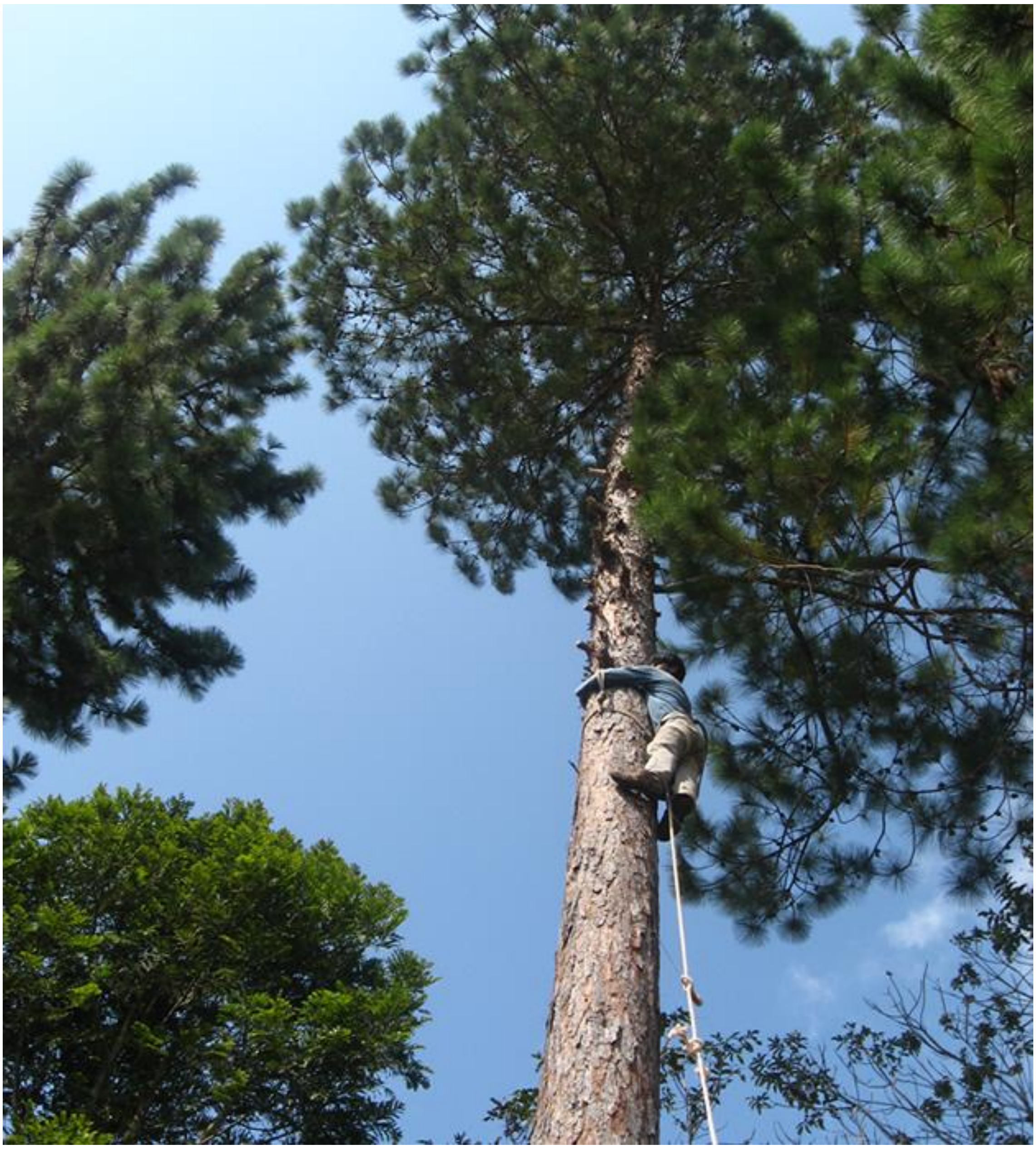
Pinus Caribea Diferent cone sizes

Pinus Caribea blanchet

Pinus Maximinoi

Pinus hartwegi

Pinus tecunumani



Pinus ayacahuite

Pinus pseudostrobus

Biosphere Platano river, pine forest in La Mosquitia.
Pinus (caribea)

Sweet gum *Styraciflua*

Sweetgum *Styraciflua* fruit

Ceiba (The Mayas civilization sacred tree)