Assessing Fire Risk at Guanacaste Conservation Area, Costa Rica

In Collaboration with the University of Costa Rica

Authors
Corey Alicchio
Lucy Garvey
Winton Parker

Submitted on
May 2nd 2016

Assessing Fire Risk at Guanacaste Conservation Area, Costa Rica

An Interactive Qualifying Project Submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE

In partial fulfillment of the requirements for the Degree of Bachelor of Science

Sponsored by:

Submitted by:
Corey Alicchio, Lucy Garvey, Winton Parker

Submitted to:
Prof. Melissa Belz
Prof. Derren Rosbach

Submitted on May 2nd 2016

Abstract

The Área Conservación de Guanacaste National Park in Costa Rica experiences frequent wildfires that destroy the dry tropical forest. This project, in collaboration with the University of Costa Rica, addresses the duality of wildfire risk by studying vegetation combustion characteristics and social complexities regarding fire usage. We procured plant samples in the National Park to test at the Combustion Laboratory and outlined procedures for further testing to create a more comprehensive wildfire risk assessment. Furthermore we conducted interviews to better understand the consequences of clearing pastures with fire and suggested expanding educational programs to address traditional burning practices with the intent of reducing wildfire risk in Costa Rica.

Acknowledgements

We would like to thank the following individuals and organizations for their support and guidance towards this project:

- The University of Costa Rica for allowing us access to the tools, equipment, and space we needed to complete this project
- The members of the Área de Conservación Guanacaste for allowing us to work in the park and speak with the employees
- Our Sponsors Hennia Cavalinni and Esteban Ramos for their insight and assistance in completing the project
- Students and Staff of the University of Costa Rica: Sergio Vargas, Felipe Gazel, Pablo Molina, Paula Calderon for their generous efforts in teaching, aiding, communicating, translating and helping us throughout the whole project.
- Professors Melissa Belz and Derren Rosbach for their continued support and guidance throughout the entirety of the project
- Worcester Polytechnic Institute for providing us the opportunity to complete our project in Costa Rica

Executive Summary

Figure 1. Map of Costa Rica

Área de Conservación Guanacaste (ACG) is a National Park within the Guanacaste province of Costa Rica. Around 3 percent of all plant and animal species in the world can be found in the ACG's highly diverse ecosystem of 163,000 hectares, including an endangered dry tropical forest (Guanacaste 2016). The Santa Rosa sector of the park contains the majority of the dry tropical forest, which experiences short rainy seasons followed by long dry seasons. The Park Rangers in the ACG deal with frequent wildfires that destroy thousands of hectares a year. Strong winds, prolonged drought, and high temperatures put the dry tropical forest at a much higher fire risk than most other regions in Costa Rica. The vegetation in these forests is highly susceptible to ignition, but the combustion characteristics of the plant species in this region are largely unknown. In addition, the issue of wildfires is exacerbated by the communities surrounding the ACG who set fires as part of their traditional practices. Our sponsor, the University of Costa Rica, recently acquired fire testing equipment, which can assess the previously unattainable combustion characteristics of Santa Rosa's dry tropical forest. Our team was asked by the University of Costa Rica to conduct the first vegetation study in Santa Rosa National Park.

Goal

The goal of this project was to understand human caused fires and set the framework for testing combustion characteristics of plants to begin assessing wildfire risk within the Santa Rosa National Park. In order to complete this goal, we obtained our information through the use of interviews and combustion testing. Four objectives were created to accomplish this project.

1. Learn about the characteristics of vegetation that increase fire risk.
2. Understand the specific vegetation in Santa Rosa National Park and its propensity to burn.
3. Understand the social complexities surrounding the issue of wildfires in Santa Rosa National Park.
4. Examine educational outreach programs provided by the ACG to the surrounding communities.

Investigate Vegetation

Six species of plants were identified for this study, chosen for their abundance and suspected flammability in Santa Rosa National Park (Table 1). To determine the flammability of vegetation in the Santa Rosa National Park we collected plant species and conducted three tests.

Figure 2. Hyparrhenia rufa
Photographed by Corey Alicchio

Plant Collection

Accompanied by two Park Rangers we successfully collected all six species, recording the following information upon collection: GPS coordinates, time and date, species and sample number, description of plant, and observations about the terrain.

Table 1. List of Plant Species

Species	Description
1. Bulbostylis paradoxa	Low level grass
2. Hyparrhenia rufa	Tall grass
3. Quercus oleoides	Oak Tree
4. Curatella americana	Medium Tree
5. Byrsonima crassifolia	Tropical Shrub

Two species, shown in Figure 2 and 3, were selected to complete the range of testing within the timeframe and in accordance with American Society for Testing and Materials (ASTM) Standards. The three tests included:

Figure 3. Quercus oleoides
Photographed by Corey Alicchio

1. Microscale Combustion Calorimeter (MCC)

Measures ignition temperature and how much energy is released as a sample combusts. The more heat it releases the more likely nearby plants are to ignite, which corresponds to a greater intensity wildfire.

2. Optical Smoke Density Chamber

Determines the amount of smoke given off by a piece of wood when heated to smoldering temperatures which is important in understanding its behavior during a fire and in creating mathematical models of forest fires.

Findings

Our team developed four primary findings that are important to the ACG and the community.

3. Flame Spread

The flame spread test measures how fast a flame will advance across a material, which is critical information during a fire, as seconds can make all the difference.

Figure 4. Jaragua in Flame Spread Frame
Photographed by Corey Alicchio

Semi-Structured Interviews

We conducted interviews with Park Rangers in Santa Rosa National Park, a biology teacher from the ACG, and firefighters who have worked both inside and outside of Guanacaste. The topics of the interviews included their experiences with wildfires, what causes wildfires, and how to inform the community about the consequences of starting wildfires. The goal was to obtain information regarding all the aspects of wildfire as it relates to the dry tropical forest and the community.

The ACG Firefighting Program

The ACG firefighting program is well equipped to handle most fires within the park. The equipment, including hand tools, water trucks, and pumps, in addition to the training in the ACG closely matches that of the Costa Rican fire department and other programs from around the world, albeit with fewer personnel. Thirteen Park Rangers act as firefighters on a daily basis and are specially trained to deal with forest fires. Eighty percent of the park is monitored by one member from a lookout point throughout the day with the remaining areas patrolled routinely. In the last 10 years the amount of land affected by wildfire per year has decreased by 70% due to the ACG's firefighting program.

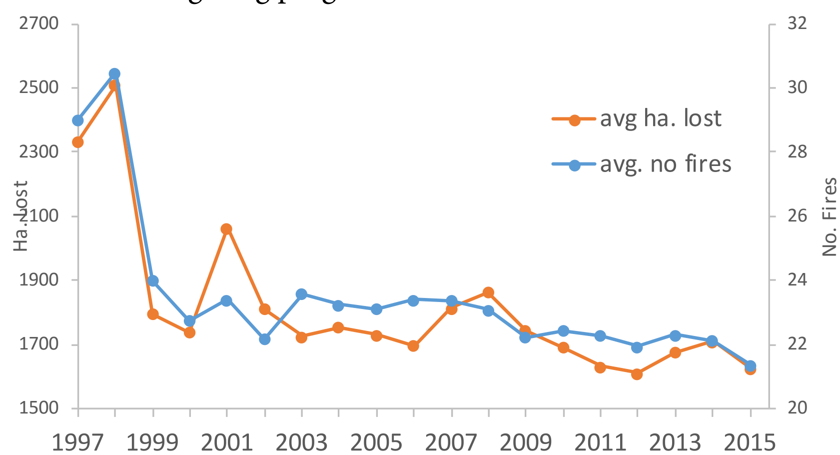


Figure 5. Average fire Damage Done in the ACG
Statistics from Raúl Acevedo's Presentation

Intervening with the Dry Tropical Forest's Natural Growth

Park Rangers limit their forest management to allow the natural regrowth of the dry tropical forest. When left alone, fields of invasive grasses such as Jaragua (Hyparrhenia rufa) are naturally overgrown by the original dry tropical forest vegetation. However, wildfires destroy this restoration, killing trees and facilitating the quick growth of invasive Jaragua to return to the scorched land first rather than the dry tropical forest. Park Rangers choose to intervene during wildfires because almost all fires in the park are human caused.

Educational programs are valuable resources to the initiatives of Santa Rosa

There are several educational programs in the surrounding communities that are highly valuable to the National Park. In fact, all of the park employees we interviewed stated that school programs were the most valuable method to the conservation of the park. Volunteer biologists and scientists teach children in the schools surrounding the ACG about the significance of the park. Excursions into the park add further value, giving students interactive experience in helping to conduct research, observing nature, and learning about the importance of fire breaks. Students also visit the firebreaks in the park to view management techniques. The programs reach out to 53 schools near the ACG. The majority are primary schools. No explicit lesson plans focus on fire education, but teachers emphasize the dangers of fire through the history of wildfire in the park and impart the park's importance to the community.

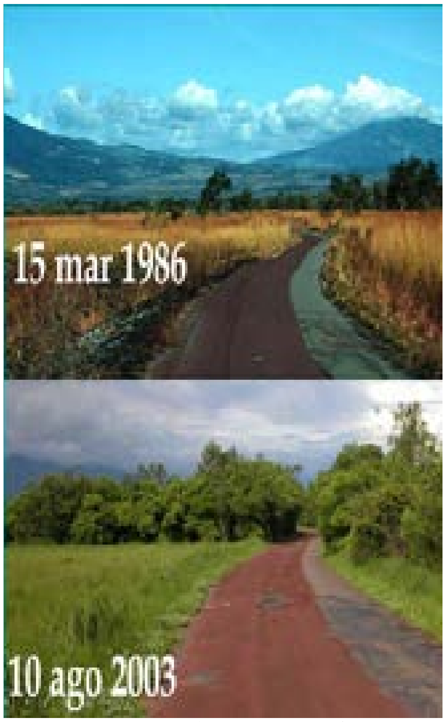


Figure 6. Natural Restoration of Forest
Image from Raúl Acevedo's Presentation

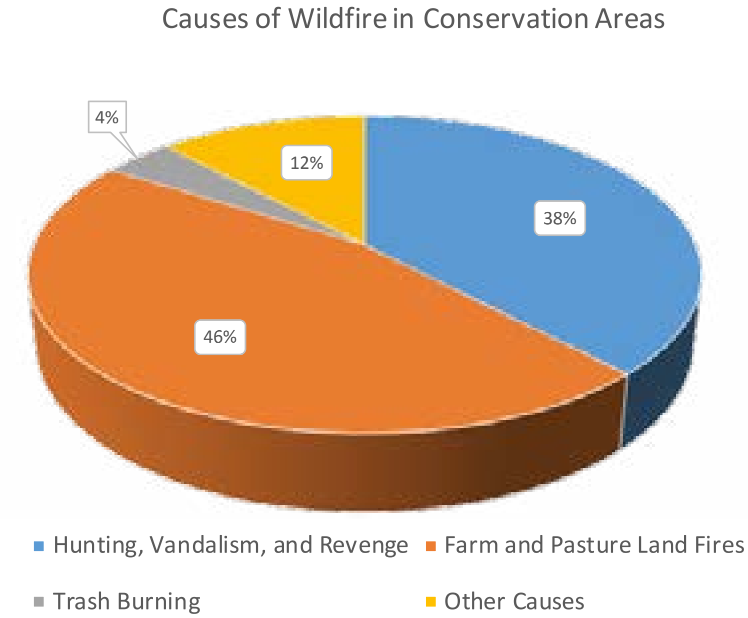


Figure 7. Leading Causes of Wildfire
Statistics from Semanario Universidad Newspaper

Traditional Practices Lead to Wildfires

Of the 376 wildfires recorded in the ACG over the past 20 years, only 4 were naturally caused. Traditional practices of the community are often the cause of wildfires. Burning farmland and trash are common occurrences within Guanacaste. When people disregard the safety precautions and strong winds their traditional burning practices can escalate into wildfires that destroy biodiversity within the ACG. In addition, hunters set fires as a distraction to their hunting activity in other areas. Laws prohibiting trash burning and hunting lack enforcement and urgency. Many people have been released due to a lack of evidence, enabling them to commit further arson. When caught, hunters have set regions of the park on fire in retaliation.

Recommendations

Furthering the Vegetation Study

With the duality presented by our project of both technical data and social complexities, we have developed comprehensive recommendations to address both topics. Our first recommendation is a more thorough study of the vegetation within the park. This requires an investigation of additional species using procedures outlined in our methods chapter. To provide a complete set of data for fire risk evaluation, additional testing equipment will be necessary. The data set would be cataloged and entered into a wildfire simulation model to calculate the danger posed by each species during combustion. Location of the most fire prone vegetation, as determined by these tests, would help the Park Rangers alter their firefighting tactics to improve efficiency and safety.

Increase Educational Efforts

We explored how traditional tendencies of surrounding communities relate to the ignition of wildfires. Park Rangers, the Director of Research in the ACG, and an ACG biologist and teacher felt the most effective method to indirectly reduce the damage caused by wildfires was through the continuation of school programs within the communities. These programs help increase the understanding of fire damage on the biodiversity in the ACG. The target audience is primarily limited to children ages nine to twelve. We recommend expanding the programs to incorporate high schools in order to develop a more complete understanding of the wildfire issue. In addition, we recommend recruiting more volunteers to assist in controlling wildfires within the park. These volunteers are invaluable to their communities, regulating poor farmland and trash burning practices.

Figure 7. Biology Class in the ACG
Image from Raúl Acevedo's Presentation

Conclusion

Our project addresses wildfires within the ACG in distant but connected manners, evaluating fires before and after ignition. Traditional practices including farming, hunting, and trash disposal are the primary causes of fire in the ACG. However once fires start, knowing combustion tendencies is the primary means of properly mitigating the damage. Furthering our efforts to understand how fires are caused and spread allow for a more comprehensive solution to fire risk.

Authorship

The table below describes which aspects of the proposal each team member contributed to outlined by section. Each team member edited all the sections.

Table of Contents

List of Figures

List of Tables

1.0 Introduction Chapter

Costa Rica, located in Central America, is often regarded as a country filled with lush tropical rainforests, however about 10% of the country is considered a dry tropical forest (Holdridge 1971). The dry tropical forest, located mainly within the northwestern province of Guanacaste, is comprised of deciduous trees and grasslands that are prone to forest fires, particularly during the dry seasons which occur between the months of November and May as well as July and August. Forest fires destroy thousands of hectares every year in Costa Rica; 30,000 hectares in Guanacaste alone through the 2015 season (National System of Conservation Areas 2015b). The dry tropical forest sustains the most fire damage in hectares of land throughout all the regions in Costa Rica (National System of Conservation Areas 2015b).

Beyond damage to vegetation, fire results in permanent and unsalvageable devastation to natural resources, animals, and ecosystems (National System of Conservation Areas 2016). Thousands of hectares in Guanacaste have been dedicated to conservation and protection from environmental harm. Valued for its immense biodiversity and ecological importance, this area, known as the Área de Conservación Guanacaste (ACG), is in constant danger from forest fires. Of the 110,000 hectares of protected land within the ACG, 80,000 hectares are filled with treasured dry tropical forest. Despite residing in a protected region, every year this land experiences destruction and the loss of valuable ecosystems consistently started by people living in the surrounding communities.

An important relationship in this region exists between the farmers and their land. Their use of farmland often involves burning to clear and manage brush, which creates the possibility for a wildfire. The traditions of the people surrounding the ACG greatly influence how fire is viewed and used. Many of the communities reside in, or are within close proximity to wildfire prone regions. Despite this, they continue with their traditional practices of fire which puts their homes and livelihood at risk. The traditional burning practices within the community not only jeopardize their own land but the conservation area as well.

To address the issue of forest fires, the University of Costa Rica (UCR) has begun studying combustion characteristics of vegetation within the dry tropical forest in Santa Rosa National Park, a sector of the ACG that has one of the highest wildfire rates each year. The purpose of this project was to better understand fire risk and the effectiveness of fire prevention methods already in place in Santa Rosa. The purpose also included investigating social concerns among the community regarding wildfires which allowed us to understand why wildfires remain an issue. One of the keys to assessing fire risk is understanding the factors that start and enable the spread of wildfires. Prevention becomes more effective when the causes of wildfires are better understood. The University of Costa Rica has asked our team to address the topic of prevention by studying vegetation specific to the park as well as the social aspects that influence wildfire ignition.

This was the first study focused on the combustibility of vegetation conducted by the University of Costa Rica, which included the development of new testing methods. Our team collected a set of samples for six different species that are abundant throughout the park and are known to present a significant fire hazard. We conducted tests on these samples with the intent of uncovering more information about their combustion characteristics. The data from the tests were analyzed and presented to our sponsors to give future researchers the basis to further the vegetation study we started as well as their own personal investigations.

The data we received from our laboratory tests serves as a framework for researchers at UCR and other national colleges to continue our study in other regions of the park and around Costa Rica. We first investigated specific vegetation characteristics that make certain plants more susceptible to ignition and increase fire propagation during wildfires. Learning about the vegetation in the Santa Rosa National Park aided us in the collection and testing of the samples. We also conducted interviews with park employees to understand the social complexities surrounding the issues of wildfires. We inquired about the role fire plays in the lives of those in the surrounding communities and the impact fire has on the park. Based on our findings we recommended possible solutions to help lower fire risk within the park by means of increasing awareness in the surrounding schools and communities.

The next chapter explains the background information pertinent to this project. It introduces the topic of wildfires, discussing fuel and natural phenomena that affect ignition and propagation. Then we apply these general factors to the dry tropical forest in Guanacaste, looking at why this region is particularly threatened by wildfires. Chapter 3, methods, explains in depth the process and equipment we used to reach our final goal. Data and results obtained from testing are provided in our lab results, Chapter 4. Chapter 5, the findings and discussion chapter, presents our team’s observations and interpretations of the interviews conducted. Based on our project work we developed and provided recommendations and conclusions in Chapter 6.

2.0 Background Chapter

Raging fires engulfed the tops of the treetops, setting everything ablaze. In the grasslands the flames traveled faster than an average person can run. It can be ruthless, destroying everything in its path. Plants, animals, and buildings: the fire has no preference. Its only intent is to spread. The fires in California during the 2007 dry season for example, demonstrate this ferocity and danger of wildfires. Throughout that year more than 9000 fires accounted for the destruction of over a million acres of land. As a consequence of these wildfires 900,000 people lost the ability to return to their communities (CAL Fire 2007). It is the largest mass evacuation due to fire in United States history. Along with the damage done to the surrounding environment, the flames destroyed more than 3000 homes (CAL Fire 2007). These fires were so consuming and so intense that they became visible from space. With wildfires negatively impacting people's lives it is apparent with this California 2007 case that there is a need to understand the underlying causes.

We begin this chapter by discussing wildfires in general, focusing on their causes and effects. We then discuss the differences between boreal, temperate, and tropical forests, describing the climate and the types of vegetation within each as it relates to fire risk. From there, we introduce our study area, the Área de Conservación Guanacaste (ACG), Costa Rica. Next we focus specifically on the dry tropical forest in the National Park, which is especially fire prone because of the vegetation and weather. We conclude this chapter discussing the Santa Rosa National Park in Guanacaste where there is concern about the risks posed to the biodiversity by wildfire. There is little information to substantiate the fire risks present in the

Santa Rosa National Park. We intend to address this lack of information with our project investigating combustible vegetation.

2.1 Forest Fires

The destruction caused by wildfires stems from a single ignition event. There are a variety of ways that these devastating fires start. Each event can be categorized into either a natural or unnatural ignition. Investigating primary ignition is the first step in understanding the causes behind wildfires and combustibility of the vegetation. Sources of ignition through natural causes result from lightning, rockslides, and volcanoes, with lightning being the most common (Gazzard 2012). Natural causes only represent a small fraction of all ways ignition of a forest fire can occur. The most damaging fires can usually be traced back to unnatural causes which are a result of human action. Whether accidental or intentional, mankind is responsible for burning tens of millions of acres annually (FAO 2003). Even with the large number of precautions put in place to regulate permissible instances of burning, there are still many cases where people start uncontrollable forest fires unintentionally. These fires are often the result of a person setting a campfire or burning their trash on a dry day with high winds (ICR News 2013). Lighting fires without consideration of the immediate weather conditions can result in an accidental fire spread, creating the possibility for serious damage. There are also many cases where farmers or hunters start fires for their own personal agendas. Some fires are started in retaliation to strict land use conservation laws (Fendt 2015). Overall, intentional fires devastate and destroy a great deal of wildlife habitat and biodiversity.

2.1.1 Benefits of Fire

While fires have the potential to do serious damage, when prescribed and carried out correctly they can increase nutrients in the soil and control fire risk. In fact, there are species of plants that rely on fire to spread their seeds. The Jack Pine tree, native to eastern North America, is known to release its seeds only under high temperatures provided by fire (USDA 2006). A common way for subsistence farmers to manipulate the land is through slash and burn agriculture. Clearing the land through fire and burning the stalks of harvested crops enhances the nutrients of the soil allowing small scale farmers to reuse the same land for many years (Gazzard 2012). Fire is also used to manage forests through prescribed burning. The forest is effectively thinned out by intentionally setting predefined parts of the forest ablaze, greatly lowering the risk of subsequent fires (Gazzard 2012).

2.1.2 Consequences of Fire

Despite the benefits, controlled burns have the potential to become uncontrollable widespread fires even when regulated by experts. The negative aspects of fire usually arise from misconduct surrounding the rules of controlled burns. Stray flames can inflict significant damage on surrounding ecosystems and communities and are often produced by people who disregard precautions or restrictions on burning (Krantz 2015). There are innumerable instances where controlled burns result in unintended large area fires and subsequent damage to communities nearby (Krantz 2015). The chemicals released from burning vegetation are never healthy to breathe. Fires produce a widespread amount of toxins that are absorbed into the atmosphere and into water supplies including, most notably, mercury (Honn 2012). Transforming into methyl mercury, this toxin works its way up the food chain with increasing concentrations, causing a wide range of birth defects in newborns (Honn 2012). Uncontrollable wildfires and the release of toxins are possible with every fire started, even when carefully regulated.

2.1.3 Factors Affecting Wildfires

The chance of a fire becoming uncontrollable or deadly is often determined by wind speeds and weather patterns. Forests that experience strong winds and drought contain the ideal conditions for forest fires (Larjavaara et al. 2004). Winds advance fire by providing oxygen to feed it, while air flow directs the fire up higher towards the tree tops (Larjavaara et al. 2004). Weather patterns, particularly drought, are important aspects to consider in conjunction with fire because the lack of moisture in vegetation greatly increases the chance of combustion (Warnatz 1993). This is due to the fact that more energy is required to dry vegetation with a larger moisture content prior to combustion (Larjavaara, Kuuluvainen et al. 2004). The process of drying technically known as distilling, increases the temperatures of the fuel bed, which assists in the probability of ignition (Warnatz 1993).

Once a fire starts, the fuel present in the immediate area determines the severity with which the fire will spread. Fuel in this case describes a range of vegetation from leaves to needles to individual blades of grass. The range of vegetation is often referred to as small particles, and they tend to have a larger surface area in comparison to their volume compared to other types. The point of ignition is temperature dependent and smaller masses of vegetation reach it at a faster rate (Dibble, et al. 2007). Larger vegetation masses require more energy to ignite thus taking longer to reach combustion (Warnatz 1993). Leaves will burn faster than wood for example, due to its larger surface area and lower mass. The larger surface area of the leaves allows the heat of a fire to affect more of the plant at once. When a plant begins to reach its ignition point, the surrounding flames dry out the plant, removing its water content. The more of the plant that is exposed the faster ignition happens. The difference in water content is often the difference between a large scale wildfire and a smoldering, dying fire (Warnatz 1993). Warnatz, a professor from the Darmstadt University of Technology who specializes in combustible processes, states that the water content in fresh vegetation can be up to 40 times greater than dry or dead vegetation. Therefore, smaller, dry plants have the tendency to burn much faster than larger masses with a higher moisture content.

2.2 Types of Forests and their Fuels

Accordingly, forests with a dry windy climate and a high concentration of small fuel, will be more prone to intense wildfires. This highlights the existence of different categories of forests that contain different fuel types and natural phenomena. The classification of most biomes are by seasonality; temperature, rainfall, and location (Department of Biology and Environmental Science 2008; Pullen 2004). Worldwide there are three main classes of forest; boreal, temperate, and tropical (Pullen 2004).

The boreal forest biome, in comparison to the size of the other two main classes of forests, is enormous. Boreal forests appear in Siberia, Alaska, Canada, and Scandinavia (Pullen 2004). The defining characteristics for boreal forests are low temperatures with moist summers and dry winters (Pullen 2004). Snow is the predominant form of precipitation during the winters (Pullen 2004). Little light permeates through the canopy and the vegetation mainly consists of trees with needles rather than leaves (Pullen 2004). The combination of low temperatures, less sunlight, and moist summers means boreal forests are less likely to harbor massive amounts of dry fuel. A high presence of trees, with a small surface area to volume ratio, means that even if a fire started in the boreal forest, it would spread slowly.

Temperate forests are defined by the occurrence of a winter season with moderate to heavy precipitation. They are common in Asia, America, and Europe (Pullen 2004). Light permeates through the canopy because the foliage is sparse (Pullen 2004). The presence of precipitation and a winter season in the temperate forests indicates moisture, which has the ability to impede the continuation of fires. This forest type, combined with significant moisture content conditions, is not typically associated with high forest or wildfire risk.

Finally, tropical forest vegetation coalesces in areas surrounding the equator that are typically devoid of a winter season, but includes the presence of wet and dry seasons (Pullen 2004). A concentration of precipitation defines the wet season, which sufficiently saturates the vegetation. Light does not reach the ground as a result of the multilayered canopies of broad-leaved trees regularly found in tropical forests (Pullen 2004). A lack of sunlight coupled with high humidity and frequent rainfall causes the forest floor to retain much of its moisture. Within the broad categorization of tropical forest there are several subdivisions with defining characteristics including amount of precipitation and length of the wet season (Pullen 2004). Dry tropical forests in particular are very susceptible to wildfires. In a dry tropical forest nearly all trees are deciduous, shedding their leaves annually. With nothing to shield the ground from the light, leaves dry out on the bed of the forest (CEIBA 2015). Plant shed their leaves during the dry season, which is characterized by drought and strong winds. This season is much longer and more intense compared to other tropical forests, creating the optimal conditions for fire (Pullen 2004). Less moisture due to drought, wind, and sun combined with an abundance of fallen leaves, increases the chances for the dry tropical forest to experience ignition (Gazzard 2012). Dry tropical forests tend to contain a variety of grasses, also considered small particles, which add to the likelihood of large scale wildfires (Warnatz 1993; Ganteaume et al. 2009; Gazzard

2012). From these factors it can be assumed that dry tropical forests are one of the environments most affected by fire. In fact, it is argued that dry tropical forests are the most endangered tropical forest due to their proclivity for fire (Miles et al. 2006). Dry tropical forests, due to their excellent fuel bed, are at greater risk of sustaining damage from fires than other forests.

2.3 Fires in Guanacaste, Costa Rica

Costa Rica, located in Central America, contains vast amounts of dry tropical forests, teeming with wildlife and diversity. These forests are located predominantly in the north western region, in the province of Guanacaste as seen in Figure 2.1. This specific region is subject to more fires than most other regions in Costa Rica due to the types of vegetation and yearly weather trends. In 2015, Guanacaste recorded more fire damaged area than any other province in Costa Rica (Press Release 2015b).

Figure 2.1 Provinces of Costa Rica with Guanacaste Highlighted
Image Modified from
https://upload.wikimedia.org/wikipedia/commons/8/81/Costa_Rica_provinces_blank.png

2.3.1 Guanacaste Conservation Area

Located in the northeastern region of Guanacaste, the Área de Conservación Guanacaste (ACG) (translated to English as Guanacaste Conservation Area) serves as a National Park to tourists, research area for scientists, and a home to thousands of different plant and animal species. As described on the ACG's website, this area spans 163,000 continuous hectares (629 square miles). Marine, dry forest, cloud forest and rainforest ecosystems are all present and interconnected in this region, allowing many species of plants and animals to thrive. An estimated 335,000 species of terrestrial organisms are found in the ACG. This constitutes 2.6% of all animal diversity on the earth (Guanacaste 2016). With such a high level of biodiversity, there is an immense interest in conserving this land.

This unique ecosystem is very rare and valuable to the entire world, with an even greater importance to biologists and researchers. To conserve and protect this land the ACG became a UNESCO World Heritage Site in 2001 (Convention 2016). This right was granted because the ACG shows significant ecological and biological progress, demonstrating on-going processes and also a significant natural habitat for biodiversity. Containing thousands of species in diverse but connected ecosystems allows the ACG to be granted the rights of a World Heritage Site (Convention 2016). These rights include protection from local lawmakers, requiring any laws potentially affecting the ACG to be approved by the World Heritage Committee first. This essentially guarantees the National Park has the necessary legal authority to continue its conservation efforts.

The conservation efforts granted by the World Heritage Site do little to reduce the effects of wildfires in the ACG. Fires within the conservation area deal great harm to the biodiversity, as it destroys the valued dry tropical forest. After a fire occurs, invasive grasses repopulate the burnt land before any other native dry tropical plants or trees**.** Not only does this disrupt the natural process of vegetation growth in the area, but the invasive grass burns more quickly and easily than other plants (Janzen 1988b). This creates a dangerous cycle, where if fires are not controlled, the risk for more fires increases further. Every year the ACG sustains further damage from wildfires.

There are several sectors within the ACG, illustrated in Figure 2.2, each contain different ecosystems from rainforest to cloud forests to dry forests. The Santa Rosa sector, seen colored in purple, mainly consists of a dry tropical forest ecosystem (Guanacaste 2016). Currently in 2016, Santa Rosa has experienced fifteen forest fires and lost around 1700 hectares of land (Guanacaste 2016). To address the issue and presence of fires, the park set regulations that apply to all park visitors. Three of these regulations consist of statements regarding people and fires. Visitors are able to use gas and coal for cooking, but not wood from the National Park (Guanacaste 2016). Beyond the policy considering cooking, the park prohibits all types of fire within its boundaries (Guanacaste 2016). The park is completely tobacco and cigarette free. The reason stated for this regulation by the ACG is that these practices can lead to wildfires (Guanacaste 2016). Wildfires are a problem in Santa Rosa and these measures are in place to keep visitors from causing fires. In addition to mitigating the immediate danger that wildfires present, preventing the return of wildfires also allows previous scorched land in Santa Rosa to develop into a "young regenerating forest". This kind of ecosystem is also known as "secondary dry tropical forest" and does not contain exactly similar vegetation to the area before the wildfire occurred (Janzen 2000). Preventing incidents of fire allows for the natural regrowth of the forest and is part of conserving the biodiversity of Santa Rosa. Focusing efforts on stopping human caused fires is the quickest way to restore the forest in comparison to people expending their energy planting trees while allowing the fires to burn (Janzen 2000). Conserving the land and allowing for the restoration of the forest to occur naturally is the primary focus of the programs and regulations within Santa Rosa.

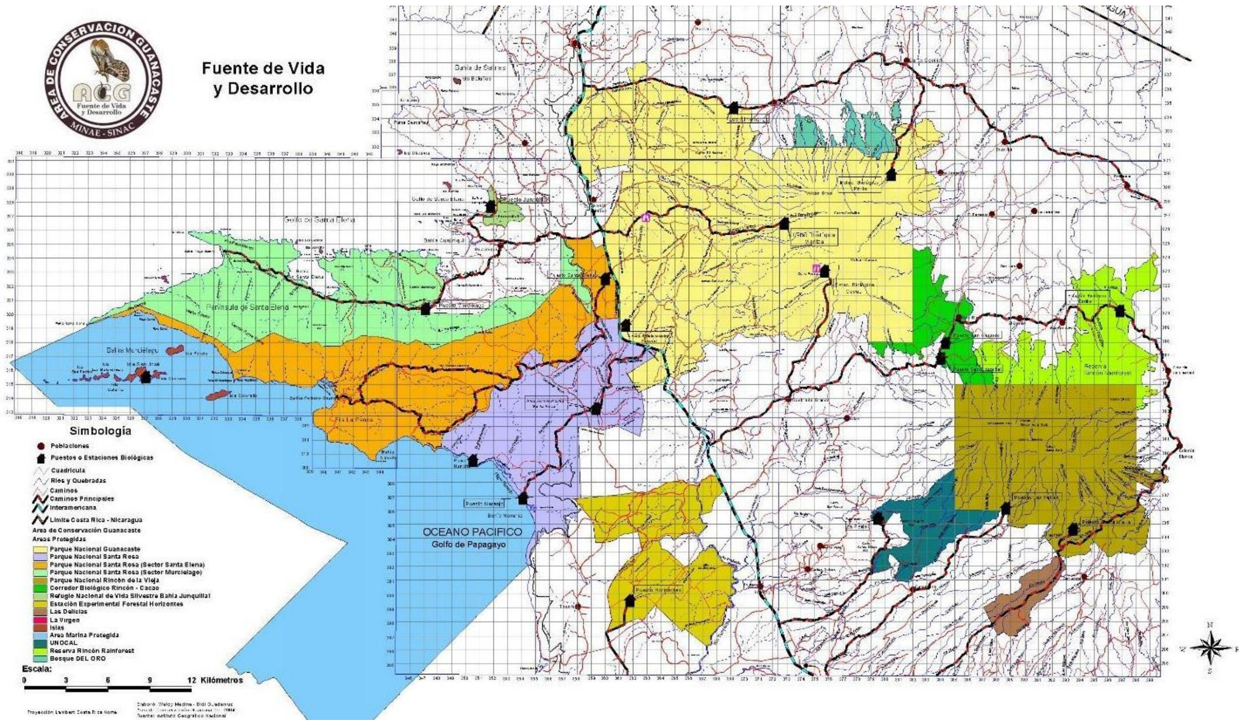


Figure 2.2 Sectors in the ACG
Modified Image From
http://www.acguanacaste.ac.cr/

Preventing fires not only allows for the natural forest to return but also to preserve the historical value of Santa Rosa. La Casona de Santa Rosa holds extensive cultural importance as a museum and monument dedicated to many critical times in Costa Rican history including the Battle of March 20, 1856 when native Costa Ricans defeated Nicaraguan mercenaries who intended to enslave the country. The museum is set in an old cattle ranch that pays respect to the hard work endured by many of their ancestors as they began settling in the area. In 2001 there was an incident in which poachers set fire to the historical museum in retaliation to arrests made by the Park Rangers for hunting on the protected property (Guanacaste 2016). With La Casona placed in an area surrounded by vegetation it is possible that a fire started elsewhere could travel to the museum. Understanding the nearby vegetation could help to prevent losing such a rich cultural site to fire again.

2.3.2 Factors Contributing to Dry Tropical Forest Fire Risk

Understanding the factors that put dry tropical forest at an elevated risk of wildfire is the first step in helping preserve the sector. The vegetation in Costa Rica's dry tropical forest experience four unique seasons that alternate between wet and dry, causing particular months to be more susceptible to forest fires than others (Frankie, Baker et al. 1974). Precipitation defines the first wet season from May to June; the most rain falls during this time period averaging 60.35 inches (Frankie, Baker et al. 1974). The second wet season is from August to November (Frankie, Baker et al. 1974). The longest and most intense dry season occurs from November to May and the second dry season from July to August (Frankie, Baker et al. 1974). The severity of the dry season is a direct result of the scarcity of rainfall, i.e. a drought (National System of Conservation Areas 2016). During a drought, vegetation tends to distill water at a faster rate in comparison to the wet seasons because of the low relative humidity (National System of Conservation Areas 2016). Drought conditions normally combine with strong winds and high temperatures to cause the vegetation to be more susceptible to ignition and the propagation of fire (National System of Conservation Areas 2016). The strong winds Guanacaste experiences are called "Trade Winds". These strong winds are most forceful during the day between the months of December and April. They bring the humidity from the Caribbean Ocean from the East Coast to the West Coast of Costa Rica. The humidity becomes trapped in the centrally located volcanoes and mountains, creating the cloud forests. This results in Guanacaste's dry climate because the humidity does not travel past the volcanoes and mountains. El Niño is a weather event that transpires over the Pacific Ocean in a cyclical manner around every five years with the last occurrence in 2010 (National System of Conservation Areas 2015b; Null 2016). It is the main cause for the severe drought and strong wind conditions currently affecting Guanacaste (National System of Conservation Areas 2015b). This trend occurs because of the increase in Pacific water temperatures (Arias 2015). Scientists in Costa Rica expect the 2016 dry season to have more serious and dangerous forest fires than their 2015 dry season because of El Niño occurring this year (National System of Conservation Areas 2016). During the 2015 season, Costa Rica's province of Guanacaste surpassed the 1977 record of rain shortage, experiencing the most severe drought conditions since then (Arias 2015). The typical weather conditions of the dry tropical forest combine with the forces of El Niño to provide the perfect circumstances for fire ignition and propagation from November to May.

2.3.3 Fires Resulting from Specific Vegetation Types

Because of the dry season in Guanacaste, the vegetation adapts to the harsher conditions by becoming more resilient to drought. The plants develop the ability to minimize the use of resources to avoid wasting what little water is available (Frankie, Baker et al. 1974). This results in vegetation retaining less water, making it more prone to ignition. Each species of plant adapts to drought conditions, resulting in a wide range of plants that have evolved to require less water.

Plants have evolved differently in this region and as a result the ecology in the dry tropical forest is very diverse. Plant and tree growth tends to vary greatly by location even within Guanacaste. A study of Guanacaste's dry tropical forest identified six sub-regions to fully describe the environment; moist deciduous forest, dry deciduous forest, riparian forest, derived savanna, second growth, and seasonal swamp forest (Frankie, Baker et al. 1974). Each of these diverge into their separate sub-regions based on weather patterns and availability of water. The predominant factor varying for each sub-region is the availability of water and the amount of water the plants can retain over several months with little to no rain. Most important to this study is the derived savanna where "the vegetation consists of grasses, occasional shrubs and frequent trees" (Frankie, Baker et al. 1974). This area retains the least amount of water and contains a high amount of fuel, due to the tall grasses. This causes fires to be more common in the derived savanna than any other region throughout the dry tropical forest.

As a result of the diminished moisture, much of the open grassland areas in Guanacaste are highly flammable, especially un-grazed pastures where the grass contains enough fuel to kill above ground plants and damage trees (Janzen 1988b). The types of plants growing and dying in this region greatly influence wildfires. Dried dead leaves coupled with vegetation that has low water content in the dry tropical forest account for much of the risk of wildfire in Costa Rica.

2.4 Vegetation Analysis

To better understand the reason for such a high fire risk in the ACG it is necessary to study the vegetation in the region. Studies of vegetation combustible characteristics have been conducted throughout the world, but not within Costa Rica. It is important to consider previous studies to understand their methods and conclusions.

2.4.1 Previous Studies

Many studies investigate the properties of ignition, including flammability or seasonal differences in the vegetation (Dibble et al. 2007; Weise et al. 2005; Larjavaara, Kuuluvainen et al. 2004). Some studies aim to create descriptive mathematical models of fire based on weather data to illustrate the zones more prone to spread fire (Larjavaara, Kuuluvainen et al. 2004; Dietenberger 2010; Mohammadi, Bavaghar, et al. 2014). Other studies carefully examine information about the characteristics specific to an individual plant. Smoke tests, combustion tests, and others provides insight on the unique attributes of heat release rates and chemical composition to the specific plant (Weise et al. 2005; Dibble et al. 2007; Warnatz 1993). There have also been studies in Costa Rica to determine the differences in dry tropical forest and rainforest vegetation in terms of rainfall amounts (Frankie, Baker et al. 1974). Due to the tremendous impact of wildfire and its propagation on communities, there is an abundance of research to understand wildfire propensities. A study in California used the same equipment as found in the San José fire testing laboratory and their results can be compared despite studying different vegetation in another environment (Weise et al. 2005). Previous studies from other parts of the world provide information on how to conduct studies, validate procedures, and compare results

2.4.2 Furthering Research

Synthesis of results from different studies proves difficult because the wide variety and unique characteristics of vegetation prevents generalizing information to apply to all vegetation (Weise et al. 2005). While many trends emerge from the studies, the ultimate impact these trends have on the severity and likelihood of a fire is not fully understood. In order to understand this data, methods of categorization and the development of set practices for evaluating a location for danger are necessary. The vegetation in the Santa Rosa National Park needs to be investigated to generate ample data for an accurate risk assessment. The properties of specific plants create a greater fire risk to the National Park and the surrounding communities.

Due to the great concern surrounding this topic, the University of Costa Rica has begun a study in hopes of reducing the risk presented by these wildfires. With a large amount of biodiversity at a high fire risk, many species of the dry tropical forest can be conserved and better understood from this study. Our team was asked to conduct this first vegetation study to assess fire risk through testing for combustible characteristics within the Santa Rosa National

Park. We primarily worked with Hennia Cavallini, the head of the Mechanical Engineering Department, and other professors in the Biology and Engineering departments. Esteban Ramos who works for the fire protection company SHPINGENIERIA also assisted us during our project. Through the use of the University's fire testing laboratory we studied a list of six species that are abundant in Guanacaste's dry tropical forest. We began to uncover which of these specific plants have the highest fire risk or if there is a trend associated with the plants. This understanding makes it easier to develop fire prevention solutions in Guanacaste.

In our project, specific characteristics of the vegetation require analysis to determine wildfire risk. There are several variables to consider when comparing the differences between dry grasses, trees, or brush; moisture content, chemical composition, and arrangement of the fuel all affect the flammability of vegetation (Dibble et al. 2007). Each of these aspects leads to faster spreading and more intense wildfires, which is important in identifying and calculating the risk within the Santa Rosa National Park. The next section will discuss the methods we plan to follow in order to complete our project.

3.0 Methods Chapter

The goal of this project was to understand human caused fires and set the framework for testing combustion characteristics of plants to begin assessing wildfire risk within the Santa Rosa National Park. In order to complete this goal, we obtained information through the use of interviews and combustion testing equipment. The results allowed us to determine how to share information with the community in addition to serving as the framework for others to further our research. To attain our goal, we completed the following four objectives:

1. Learn about the characteristics of vegetation that increase fire risk.
2. Understand the specific vegetation in Santa Rosa National Park and its propensity to burn.
3. Understand the social complexities surrounding the issue of wildfires in Santa Rosa National Park.
4. Examine educational outreach programs provided by the ACG to the surrounding communities.

In this chapter we will describe each of the four objectives in detail. Under each objective is the importance of the objective in completing the goal, the method we used to accomplish the objective, and the justification for the methods chosen.

3.1 Objective 1: Learn about the characteristics of vegetation that increase fire risk

This objective helped us understand which plant characteristics increase fire risk so that we can later identify threats and trends of the vegetation in Guanacaste. To accomplish this, we first learned about the possible tests we could conduct and the data that would result.

Discussion with Experts and Content Analysis

One of the most imperative aspects of locating danger zones is determining which combustion characteristics are the most representative of a plant's reaction to wildfire. Our first step was to learn more about the ways vegetation studies have been conducted worldwide in order to provide a basis for understanding which methods to implement in our study. We conducted in depth research focusing on the terminology used to indicate which characteristics they tested for in their methods section. The information we found helped to lay the groundwork for our procedures and gave us a more comprehensive understanding of the theory behind wildfire risk assessment.

Table 3.1 shows a list of six species that were considered for our project. These six species were chosen due to their abundance in the ACG as well as their tendencies to hold less water in comparison to other vegetation. Through our discussion with Esteban Ramos, Sergio Vargas and Felipe Gazel, members working in the fire research laboratory at the University of Costa Rica, we uncovered many of the important characteristics we later tested for. In addition to this we reviewed standards outlined by the American Society for Testing and Materials (ASTM) that gave us insight into these characteristics as well as the necessary sample sizes required for each piece of equipment we used. We used this information to determine the required size for plant collection. The characteristics primarily focused on included the ignition temperature, optical density of smoke released, flame spread velocity, and heat release rate during combustion. These characteristics were crucial to determining how susceptible these specific plants are to ignition and how it propagates fire. Each characteristic influences a specific aspect of how the vegetation burns. The people we chose to talk to had extensive experience with lab work regarding fire properties and were able to answer all questions we had. The ASTM Standards are a universally accepted set of practices to conduct testing, so referencing them allows us to ensure we follow the correct guidelines.

Table 3.1 List of Species and Description

Species	Type of vegetation
Bulbostylis paradoxa	Low level grass
Hyparrhenia rufa	Tall grass
Quercus oleoides	Oak tree
Curatella Americana	Small to medium tree
Byrsonima crassifolia	Tropical shrub or small tree
Enterolobium cyclocarpum	Medium to large tree

Equipment Training

We spent the first week training how to use the fire protection equipment utilized during this study. Becoming familiar with this equipment was imperative to understanding the characteristics we were able to test for. Experts in the laboratory instructed us on the proper procedure and use of each machine. We also read literature on the theory behind each test which provided us a focus for when we were collecting and testing samples.

The three main pieces of equipment we worked with were the Microscale Combustion Calorimeter (MCC), the Smoke Density Chamber, and the Flame Spread Measurement Apparatus. The MCC allowed us to obtain data on the combustion cycle of different species as the temperature is increased from 75 to 750 degrees Celsius. The Optical Smoke Density Chamber measured the optical density of the smoke released from the combustion of wood over a specified period of time. Using the Flame Spread Measurement Apparatus, we observed and recorded the speed at which flames progress through a vegetation sample with the length of 800 millimeters. The data recorded from these tests do not alone correlate to a perfect assessment of fire risk since there are many other factors that influence wildfires. Due to the fact that this new study is still in its infancy, the data we collected merely serves as a baseline for scientists in the future to construct a more comprehensive investigation.

Understanding the vegetation in Guanacaste allowed our team to establish a foundation of fire characteristics relating to fire risk in the Santa Rosa National Park sector. We were the first group to do a study of this type in this area, therefore there was no current data about the combustibility characteristics within this region, which required us to determine and modify procedures for testing. Through our tasks we learned the types of vegetation characteristics that relate to ignition susceptibility and developed trends to share with future researchers and community members surrounding the National Park.

3.2 Objective 2: Understand the specific vegetation in Santa Rosa National Park and its propensity to burn.

This objective allowed us to identify the specific characteristics of the species collected within the Santa Rosa National Park indicating properties associated with fire susceptibility and mechanical properties of the species. Quantitative data analysis leads to the project findings that relate to specific combustion characteristics and their effects.

Field Surveying Procedure

After learning about the characteristics we needed to look for, we procured the six samples listed in the previous objective alongside the fire roads that run through the Santa Rosa National Park. Our team learned how to properly take samples with the help of Rolando Moreira, a graduate student at University of Costa Rica. Mr. Moreira's gathering procedure was validated by two other sample collection manuals describing similar collection techniques and required equipment (Lacey, Short, Mosely 2001; Queensland Herbarium 2013). We followed the procedure specified by Mr. Moreira as closely as possible during our time in Santa Rosa National Park.

We began by gathering the proper materials: cardboard, scissors, plastic bags, markers, GPS, secateurs, and tape. Our team also brought lab notebooks and pencils. During the first week, we created the wooden frames necessary for pressing the samples in the University of Costa Rica's Alajuela wood workshop.

In Santa Rosa, Raúl Acevedo, a Park Ranger, drove and assisted us in collecting samples on March 29th, 2016. A guide was important as we did not know the area well. He was very knowledgeable about the park and was able to quickly identify where the plants were growing. The equipment we brought was unable to cut the tree sizes we required for testing. Because of this, Mr. Acevedo brought his own equipment, a machete and chainsaw, to collect the proper sample sizes. With each sample we collected we gathered any flowers, fruits, or leaves associated with the species. Once we cut down the sample we wrote down the following in the field notebook: the GPS coordinates, a brief description of the species, the date, the collector, and observations about where the species resided. We placed small samples in plastic bags with the species name and GPS coordinates written on tape outside the bag and inside the information was written on a piece of paper in case the tape fell off. As for samples that were too large to place within a plastic bag, we identified it using a piece of tape with the GPS coordinates and species identifier number. All information we recorded was later transposed into a spreadsheet with a picture of the species attached (Appendix A). After collecting the samples, they were transported in the truck to our dormitories in the Santa Rosa National Park and placed in our room until the late afternoon on March 30th. The samples were then transported by bus to a lab in Alajuela on March 31st.

Test Plant Characteristics Tests in the UCR Laboratories

From the tests performed, we were able to understand the heat release trends, flame spread, and optical smoke density. This information was given to our sponsors to include in the vegetation catalog for future research opportunities. Our choices of tests were determined through talking with our Sponsor as to which would provide the most applicable for assessing fire risk. We determined the mechanical characteristics unnecessary for evaluating the species' fire risk and did not perform the corresponding tests. The Microscale Combustion Calorimeter, Optical Smoke Density Chamber, and Flame Spread Apparatus gave us specific data that directly related to fire risk and prioritized performing tests on this equipment. The time for testing was limited so two species were chosen, *Quercus oleoides* and *Hyparrhenia rufa* (Jaragua), to conduct all the tests so we could provide a full set of results on the plants. We chose to follow ASTM Standards because they are universally recognized, reproducible, and make our data comparable to others who have performed similar tests.

Microscale Combustion Calorimetry

Sample Preparation

For the Microscale Combustion Calorimetry test all the species needed a mass between 1-10 mg, with most of ours ranging from 5-9mg as recommended by ASTM Standard D-7309. To acquire the proper mass sizes, we cut pieces of species with scissors and kept measuring it on a mass balance until it fell within the range. Once in the range the species were placed in a chamber to dry. The samples were considered ready for testing once the mass stayed constant, which required checking the samples every half hour until the samples' mass stopped fluctuating between intervals. The samples were then put into small ceramic cups, which had previously been placed in a kiln at 1000^{o}C for 1 hour to burn any excess debris. The total mass of the cup and sample were recorded before placing it into the MCC.

Test Procedures

The combustor within the Microscale Combustion Calorimetry was set to reach 900^{o}C before starting the test. When the combustor was at 900^{o}C the sample moved up into the combustion chamber. Once the sample reached 75^{o}C the test was officially started, the heating rate was set to 1^{o}C/s, and ended when the sample was at 750^{o}C. Although the test ended at 750^{o}C, in order to take the remaining mass, the sample had to return to 75^{o}C. From this test the heat release rate could be determined. We followed ASTM standard D-7309 for the procedure of this test.

Analyzing Data

After the test finished, data was extracted from the Microscale Combustion Calorimeter to a text file. We imported the data into both excel and the MCC curve fit programs to generate graphs displaying heat release rate comparison to temperature. The graphs illustrated how the species reacted to increasing temperature as a visual. In addition to developing graphs we calculated the specific heat release of the sample from equations outlined in the ASTM Standard D-7309. This data shows the total heat released during the course of combustion. All of our calculated values are comparable to values found in previous studies, which allows for us to develop an understanding of how combustible these plants are compared to each other and plants tested in previous studies. We can use this data to approximate how much heat the vegetation is emitting during a wildfire, which translates to fire risk through further analysis, and relate it to necessary amount of water to extinguish the flames. The primary calculations for water needed to extinguish a defined area of burning Jaragua can be seen in Appendix B.

Optical Density of Smoke

Sample preparation

The Optical Density of Smoke test was performed in University of Costa Rica's Alajuela campus' fire lab on samples that were 76.2 mm by 76.2 mm and 25.0 mm thick as recommended by ASTM standard E-662. Only wood samples can be tested in this machine, and the grain direction is important. Six samples of each wood were prepared with the grain running along the 76.2mm dimension and five samples with the grain along the 25mm length. The samples were cut from branches of the trees, which were then processed on the table saw to create identical square samples. Once cut they were dried in an electric furnace. Once dried, the exact thickness was measured and the sample was wrapped in aluminum foil leaving one face exposed. It was then put in a metal frame to hold the wood during the test, and the total mass was recorded.

Test Procedures

We followed ASTM Standard E-662 for the procedure of this test. Each species of tree required at least ten samples; this test required sample sizes too large for the grass species collected. The chamber required about 90 minutes of calibration before inserting the sample. Once calibrated the sample mass, thickness, and duration of test were entered as the test parameters. Next the chamber needed to span and zero the transmissivity of the light. To span the condition, the transmissivity was set to 100 percent. After being spanned the chamber switched to a dark filter to zero the transmissivity to zero percent. With these conditions established the sample was placed in the chamber and the testing began for a duration of forty-five minutes per sample. The test resulted in the specific optical smoke density for the sample. Sergio Vargas, a crucial member of the fire lab equipment, explained how in traditional models for assessing combustibility knowing the specific optical smoke density of the sample allows for an accurate assessment of many factors present during a fire.

Analyzing Data

We extracted the data from all of the smoke test and compiled the information into PDF reports of the samples. These results are important to simulating flame spread in later analysis. This data was then given to our sponsor for them to include in the vegetation catalog.

Fire Spread Test

Sample preparation

The fire spread test was performed in University of Costa Rica's Alajuela campus' fire lab on *Hyparrhenia rufa* (Jaragua) and *Quercus Oleoides* samples sized to fit within a 155 mm by 800 mm by 50 mm metal containment slide as recommended by ASTM standard E-1321. *Quercus Oleoides* samples were stripped of bark and then cut by the shop manager in the woodshop using a bandsaw. The cut samples were then put into a drying chamber for three days to remove moisture from the wood. The mass was then recorded and the wood was then put into a metal frame which holds it in place during the test.

These sample preparation standards however are only intended for wood, therefore we had to make a few modifications when testing the Jaragua since there were no current ASTM standards for this test with grass. Modifications included cutting multiple sections of the Jaragua to a length approximating 800 mm. The slides were placed on a table with the testing face in contact with table. Smaller pieces of Jaragua approximating 200 mm in length were placed vertically or diagonally to the direction of the slide. This technique held the majority of the 800 mm length Jaragua in place that was arranged horizontally into the slide. A fire resistant insulation board was pressed to the back of the slide to keep the sample from moving away from the heat flux generator. The final visual of the Jaragua within the slide before testing can be seen in Figure 3.1. Both thermal and normal visual recordings were taken for each test for later analysis of the flame spread velocity.

Figure 3.1 Jaragua within Flame Spread Containment Vessel
Photograph by Winton Parker

Test procedures

To give a short overview of the testing process the equipment must be first calibrated. This calibration requires the use of a heat flux-measuring device. This device is placed at incremental distances along the testing area to determine the heat flux generated by the heater at different positions. The heater is angled 15 degrees from parallel to the sample as seen in Figure 3.2 along with an example of a thermal capture in Figure 3.3, which shows the heat flux along the sample. For our testing purposes, the end closest to the heater was set to approximately 50 kilowatts per square meter and the end furthest from the heat sources was recorded at around 1.7 kilowatts per square meter. The amount of heat flux was changed through the adjustment of the mixture and amount of fuel used by the heater. Once calibrated, the metal slides containing the samples were pushed on a track to a defined location with one face exposed to the heater. A pilot flame was introduced to the hot side of the sample to ignite the wood but not the Jaragua grass. Both thermal and normal visual recordings were taken for each test to record the time and distance the fire spread laterally across the sample. Once the fire reached the other end, or stopped spreading the sample was removed to cool and the final mass was measured. If the flame did not spread the entire length, then the total distance the flame traveled was measured.

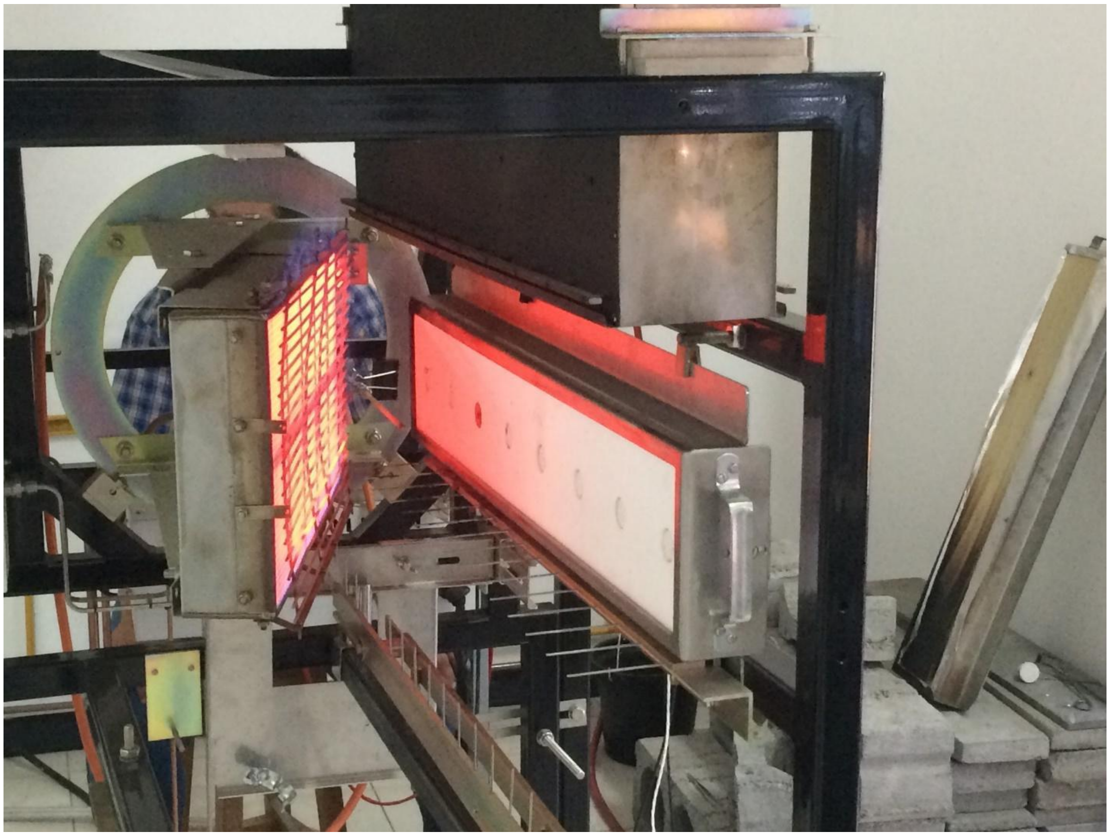


Figure 3.2 Heater Angled 15 Degrees Parallel to Sample
Photograph by Authors

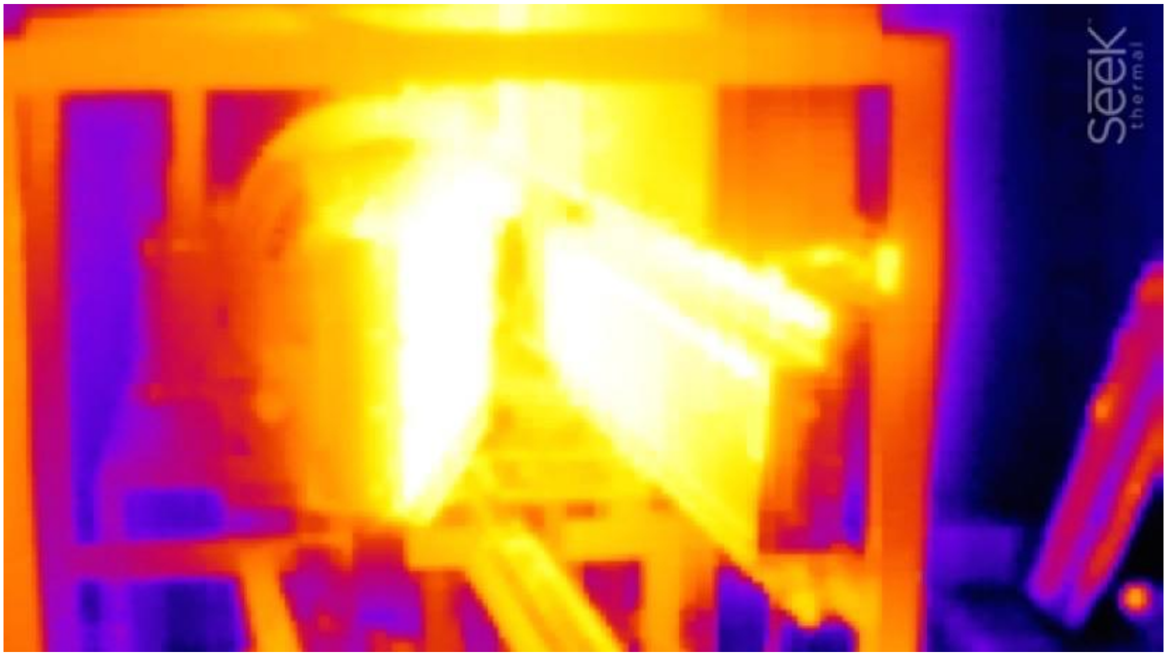


Figure 3.3 Thermal Capture
Photograph by Winton Parker

Analyzing Data

We calculated velocity by comparing the time elapsed in the video recordings to the measured distance the flame travelled. We used an excel spreadsheet to record the data for each trial run. Using a simple calculation of distance travelled over elapsed time gave the flame velocity for the sample. Flame velocity allows for an understanding of how the species will propagate a fire. This information assists in estimating how fast these species will burn, how much time is available to react to the fire, and the projected spread of the flames. Through comparing the flame velocity between species, we determined which species poses a greater fire risk. Firefighters equipped with this knowledge can make more informed decisions as to which fire tactics to follow during wildfires.

Hardness Test

The Hardness test was performed in University of Costa Rica's Alajuela campus' fire lab and required samples with a cross section of 2 inches by 2 inches with a thickness of 2 inches, which was modified from the size recommended for thickness by ASTM standard D-143. The modification was necessary because the test could not be performed on a sample larger than 2 inches. For the rest of the procedure we followed the ASTM standard D-143. Each species of tree required five samples; this test required sample sizes too large for the grass species collected. First we cut the samples according to the proper sample size. Then we placed the samples in a chamber at $20^oC \pm 3^oC$ with a relative humidity of $65\% \pm 5\%$. This ensured that the samples were at 12% moisture content. After being in the chamber, we measured the dimensions of the sample as a precaution to make sure it maintained the proper dimensions required for the test. Then we placed the samples on a mass balance to obtain their mass for later calculations; density and verifying moisture content. The samples were then ready for testing. We used a half an inch ball bearing indenter with a preload of 10 kg and a loading of 100 kg. The test resulted in several indentations in the sample, which were then measured with a microscope's internal dimensioning capabilities. The dimensions of the indent revealed information about the hardness of the species. After testing was complete, we verified that the moisture content was indeed 12% by placing the samples in a heating chamber at 103ºC and checked the mass every hour until the difference between recorded masses was in between .5-1%. This test determined the hardness of the wood, although as previously mentioned we decided that the mechanical tests were unrelated to fire risk assessment and did not continue testing specimens.

3.3 Objective 3: Understand the social complexities surrounding the issue of wildfires in Santa Rosa National Park.

Our third objective was to understand the different viewpoints of people that surround the park and how their perspectives would and actions affect the park. We investigated who was involved both inside and outside of the park and conducted interviews to understand why wildfires are an issue in the community. After talking to these people we developed an understanding of the causes of wildfire and identified their concerns that are not currently being addressed.

Semi-Structured Interviews with Park Rangers/Staff (Julio Diaz, Raúl Acevedo, Roger Blanco, Sergio Cascante and Didi Guadamuz)

We first wanted to understand who fought the fires and how they did this. To achieve this we spoke with several Park Rangers, Raúl Acevedo, Julio Diaz, Sergio Cascante and Didi Guadamuz, along with Roger Seguro, the Director of Research at Santa Rosa National Park. We chose to speak with them because they have first-hand experience putting out fires in the park. They understand the problem the park faces and the reasons for the issues. Interviews were conducted in a semi-structured format to allow us to ask additional questions that we thought of during the interviews. We interviewed Julio Diaz, Sergio Cascante and Didi Guadamuz together over the phone. The remaining interviews were conducted in person. During the interviews we first sought to gain a factual background about fires in the park. This included the primary causes of fire, the impact the fires have on the surrounding biodiversity, and overall effect it has in the National Park (Appendix C). We also inquired about the location of the fires and during what times of the year. Finally, we asked about personal experiences they had along with the issues they felt needed to be addressed including ways they thought were most effective to reduce forest fires.

Semi-Structured Interviews with Firefighters (Jose Pablo Sosa and Gabriel Barboza Gutierriez)

To get the opinion of someone not affiliated with Santa Rosa National Park we talked with two members of the national Costa Rican fire department. Fire Chief of Monteverde, Jose Pablo Sosa, and volunteer firefighter, Garbriel Barboza Gutierriez, were contacted through separate phone calls in a semi-structfappenured interview. This format let us lead with already established questions and then ask further clarifying questions based on their responses. We wanted to understand how the Park Rangers program compared with that of the national firefighters. We asked about how fires are caused along with how they respond to the fires (Appendix C). We also inquired about their experiences in Guanacaste in comparison to other provinces in Costa Rica.

Structured Interview with Maria Chavarría

In order to further our knowledge about the park and the community we talked with a local biologist and teacher, Maria Chavarría. She has been working in the park for 25 years and has close ties to the community, as she teaches many children in surrounding schools. She explained the issue of fire in the National Park and in the community. This included how people use fire in their lives, and the results it can have on the community. We asked about her personal experiences with fire in addition to concerns she currently had (Appendix E). This interview gave us the insight of someone who knew many people in the community while still having a scientific background to understand the importance of the park.

Content Analysis (laws, newspapers, databases of wildfire)

We wanted to find a connection between fire and the community's feelings to understand the personal impact that this issue has as well as understand the way the community as a whole deals with instances of fire. Newspapers are one of the ways people publish and share their stories and ideas about their community. We focused on newspapers articles specifically about Santa Rosa National Park or the surrounding area. This added to our overall understanding of the region and its people. In addition to this we investigated local laws regarding the use of fire to dispose of trash. From this we determined how strict fire regulations were and the penalties for breaking the law. Databases of wildfire history and their causes were also used to determine any trends in wildfires that impact the final recommendations based on the main causes of wildfire.

Justification

Each interview provided a different angle to the problem, and with multiple angles we could see the bigger issue, attempts being made to fix the problem, and where these attempts fell short. Obtaining different perspectives from Park Rangers dealing with the fires, Maria Chavarria as a teacher and biologist, and firefighters not affiliated with the ACG allowed us to triangulate the issues surrounding wildfires. To analyze the interview questions we grouped all the responses with each question we asked. We had few enough interviews that it was possible to compare answers individually. From here we could identify common issues and ideas that gave insight as to why forest fires remain a problem in this area. Understanding the issues allowed us to appreciate the firefighting tactics currently in place and evaluate their effectiveness. Gathering the input of Park Rangers, teachers, and firefighters shaped our final recommendations to help further reduce the problem of forest fires in the Santa Rosa National Park.

3.4 Objective 4: Examine educational outreach programs provided by the ACG to the surrounding communities.

Understanding the methods in which information about fire safety is spread was important to this study as it allowed us to understand what is being done to prevent wildfires from starting. The intent behind spreading knowledge is that the community would understand the reasons for risk and not create situations where fires get out of control. We examined the methods currently in place by the Santa Rosa National Park by talking with directors of these programs and learning about the extent of each program. From here we were able to determine what programs people deemed most valuable and any shortcomings they foresaw.

Semi-Structured Interviews with Park Rangers and Director of Research

In order to examine the current methods used to present fire risk, we asked Park Rangers and the Director of Research in Santa Rosa questions about the programs the ACG currently supported and was involved in (Appendix C). Roger Blanco, the Director of Research, and the Park Ranger are involved in the outreach programs relating to the ACG. We discussed how information is presented, the recipients of the information, and which programs are most valuable to the ACG and the people in the surrounding communities. Understanding these outreach methods was important in identifying any shortcomings and creating recommendations for improvement.

Semi-Structured Interview with Teacher and Biologist (Maria Chavarría)

We sought to understand the National Park's outreach programs to the community. The level of involvement and how well the community knew about the park's programs were important topics to understand how effective their outreach is. To gain this information we interviewed Maria Chavarria, a biologist in Santa Rosa. She has been working in the park for 25 years and also teaches classes for local schools. We first conducted an unstructured interview with her after she gave a presentation about the park in general, and then later a structured interview over the phone for further information to answer additional questions that had come up (Appendix E). Talking with her about the outreach programs in place provided further insight into the curriculum and content of the classes taught. From this we could determine if there was enough of an emphasis on fire safety prevention of wildfires. We also asked about which points seemed to be lacking in the classes and how she thought it could be improved. Another important topic we discussed was the number of schools and students involved in this program, which helped us understand the size of this effort and how many people were being impacted.

Analyze Interviews to Create Recommendations

Upon completing our interviews, we were able to determine the most imperative areas of improvement within the current system through cross reference of responses and further research. To compare the different programs, we considered who the programs reached, what topics were emphasized and the resources dedicated to the particular program. Several ideas were proposed to locals and staff members in the park, and their feedback helped to understand the effectiveness of the programs in place as well as to expose any shortcomings in their educational efforts.

4.0 Lab Results Chapter

Laboratory Testing Overview

We used specialized equipment to test plant samples for specific characteristics in order to approximate fire risk within the Santa Rosa National Park. From the six plant species we collected two were chosen for testing, which allowed us to obtain sufficient results from the fire lab equipment; Microscale Combustion Calorimeter (MCC), Optical Smoke Density Chamber, and Flame Spread. The two chosen species, pictured in Fig. 4.1, were: *Quercus oleoides* (a tall tree) and *Hyparrhenia rufa* (a tall grass). *Hyparrhenia rufa* (Jaragua) was chosen for its suspected high wildfire susceptibility. *Quercus oleoides* was chosen due to its abundance in the park and an adequate sample volume was collected for all three tests. In accordance to ASTM standards D-7309 and E-662, we conducted 4 of each sample type for the MCC and smoke density tests. We also identified 3 separate parts of the *Quercus oleoides* sample: leaves, bark and inner wood. Table 4.1 shows the quantity of tests performed on each piece of equipment.

Table 4.1 Summary of Tests

Equipment	**Species**	**Number of Tests**
Micro Calorimeter	*Hyparrhenia rufa*	8 Samples
	Quercus oleoides	8 Outer Bark
		8 Leaf
		8 Inner Wood
Optical Smoke Density	*Quercus oleoides*	4 Parallel to grain
		4 Perpendicular to grain
Flame Spread	*Quercus oleoides*	3 samples
	Hyparrhenia rufa	4 Samples

4.1 Lab Data

4.1.1 Microscale Combustion Calorimeter

The MCC is shown in Figure 4.2 with a computer on the right to display the testing data. An example of the raw data and the calculations we made are shown in Appendix G and H respectively. Through the MCC testing we determined that the combustion temperature of Jaragua was an average of 328 degrees Celsius, which is lower than any part of the *Quercus oleoides* as seen in table 4.2 The *Quercus oleoides* tree is present in the same regions as the Jaragua dry grass. The peak heat release rate (HRR) tells us how much heat the species emits during the course of combustion and the combustion temperature is the temperature at which the plant creates flames.

In addition, Jaragua grass has a higher peak heat release rate than both the bark and leaves of the *Quercus oleoides* tree shown in Table 4.2. There is a correlation between the heat release rate and the intensity of the wildfire that is consuming vegetation. Generally, the higher the heat release rate, the faster the wildfire spreads and with a higher temperature. Table 4.2 shows the results for the peak heat release rates, averaged over four trial runs. Inner wood of *Quercus oleoides* has the highest HRR value, as wood contains more energy per gram when burning. This testing data was omitted from comparison to our other test analysis due to the fact that the internal hardwood of the tree is not a readily accessible fuel during wildfires and has a high ignition temperature, unlike the bark and leaves of the tree. The wood would be a secondary source of fuel, after the bark and leaves had already been expended. Generally, when the inner wood is available for combustion, the wildfire would have already progressed away from the tree. The dynamic presented here creates the assumption that the high heat release rate from the wood would have little effect on the spread of the wildfire.

Through the analysis of the data we can infer that during the course of a wildfire, **the Jaragua grass would generate a greater fire risk than the *Quercus oleoides* tree.** This data coincides with the information gathered from our interviews with Raúl Acevedo and Roger Blanco in which we were told that the Jaragua grass generally produces the most dangerous wildfires within the Santa Rosa National Park.

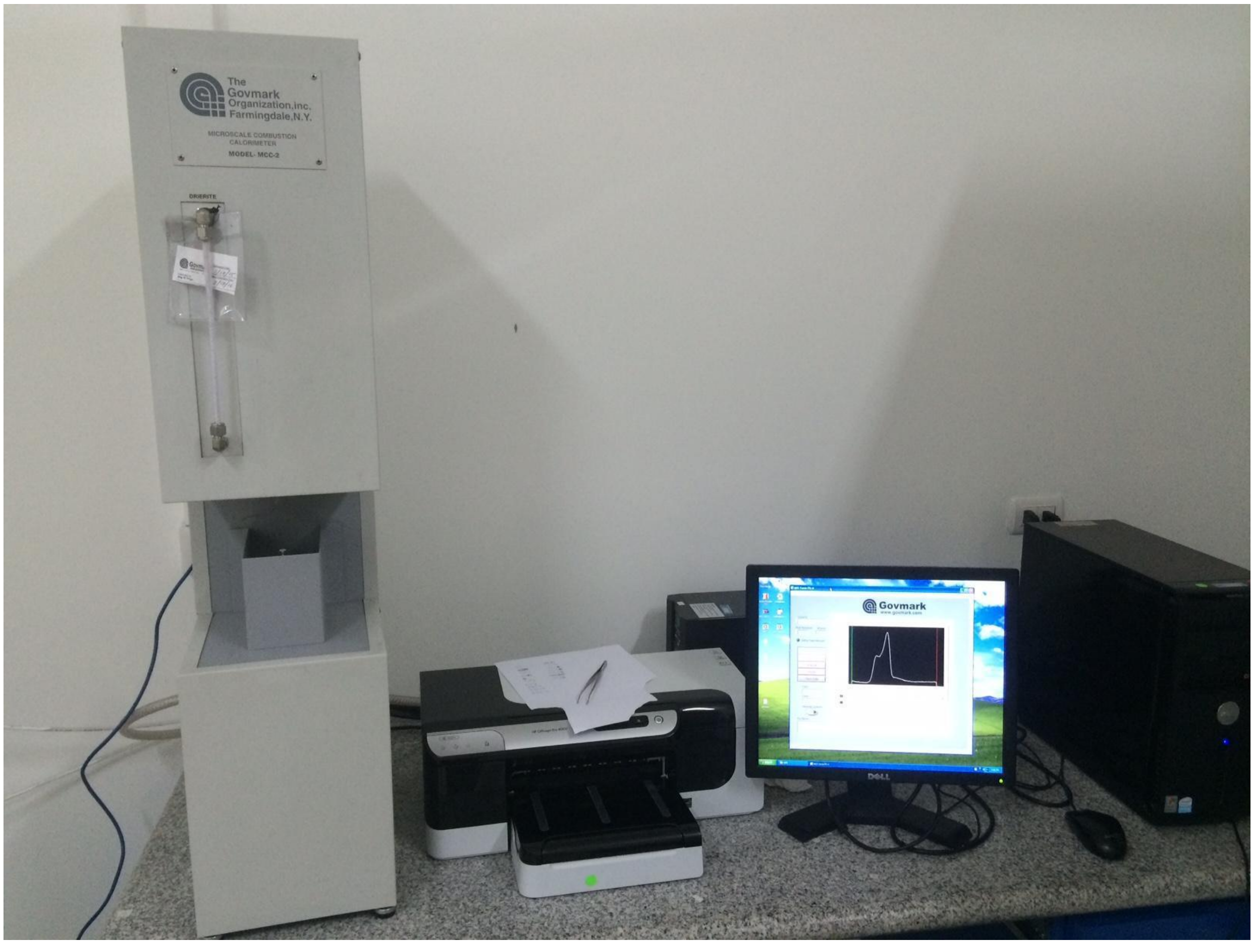


Figure 4.1 Microscale Combustion Calorimeter
Photograph by Winton Parker

Table 4.2 Summary of MCC Test Results

MCC Tests	Species		Average Peak HRR (W/g)
Controlled Thermal	*Quercus*	leaves	100.300

Decomposition (Method A)	*oleoides*	bark	100.561
		inner wood	168.348
	Hyparrhenia rufa (Jaragua)		111.638
Controlled Thermal Oxidative Decomposition (Method B)	*Quercus oleoides*	leaves	180.82
		bark	240.39
		inner wood	191.80
	Hyparrhenia rufa (Jaragua)		140.73

Although there is corresponding information about the combustion tendencies of *Hyparrhenia rufa* and *Quercus oleoides*, there are limitations to comparing these species. From our research we have learned there are many factors that affect wildfires beyond the vegetation's heat release rate. To list a few; **weather patterns, abundance, internal structure and surface area to volume ratio of the vegetation all impact the size, intensity, and spread of wildfire.** Additional testing would be necessary to study other factors and a wider range of species for a comprehensive analysis with more substantial conclusions.

4.1.2 Optical Smoke Density

The wood samples were tested with the heat flux parallel and perpendicular to grain direction. Fig. 4.3 and 4.4 show the graphs of smoke density over time as the specimen was smoldering. Our initial trial runs were not long enough to detect a peak, therefore we extended testing duration to 2600 seconds. Due to only testing one sample with this test, no definitive conclusions can be made with this information alone. However, this data is useful in conjunction with additional types of data to perform simulations of wildfire. The data from all ten tests are provided in Appendix I.

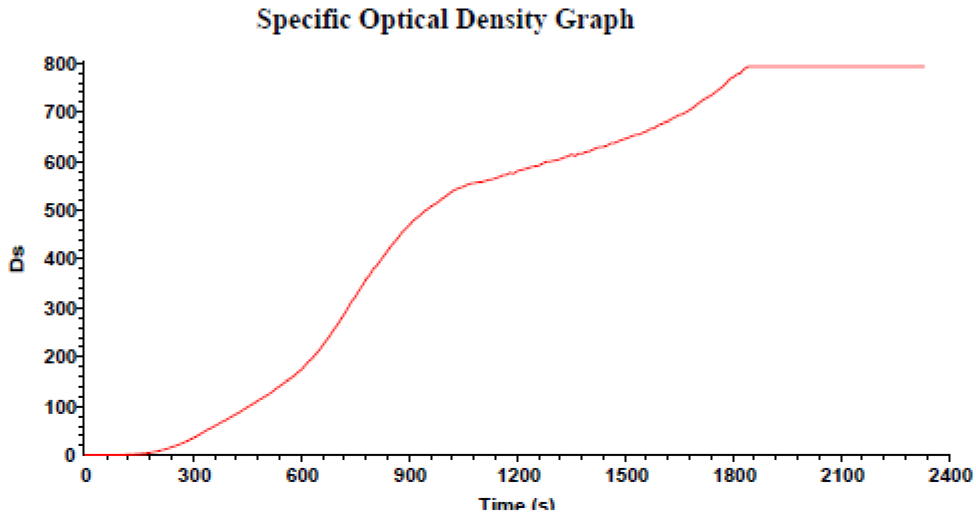
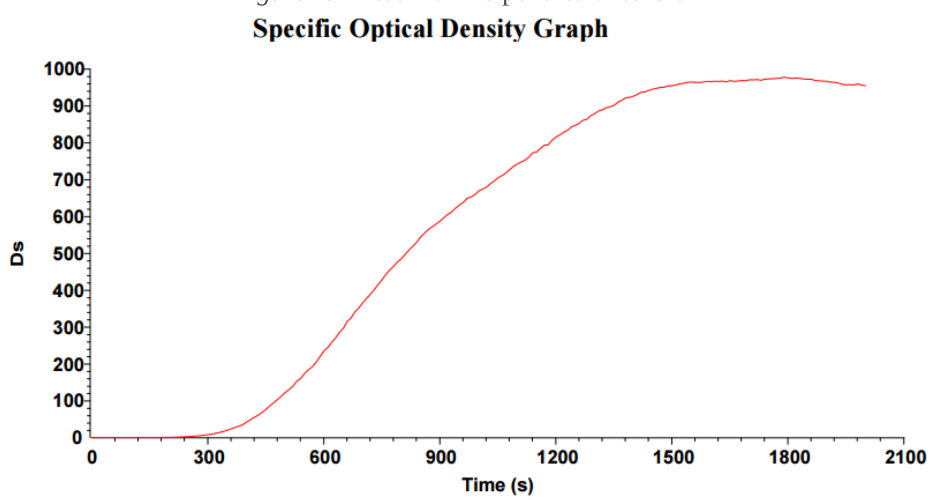


Figure 4.2 Heat Flux Perpendicular to Grain



Test name : Species3-Test2
File name : C:\SMOKEBOX\DATA\Astme662\16040003.SBA

Figure 4.3 Heat Flux Parallel to Grain

4.1.3 Flame Spread

The Flame Spread Apparatus was used to find the speed at which fire travels laterally across vegetation samples. The visual recordings of these tests conducted showed the point of ignition and distance the flame spread across the sample in a certain time. The distance traveled was determined by metal rods incremented at 5 cm from each other that were located next to the sample as seen in the Figure 4.4. The average flame spread velocity was determined using the distance the flame traveled and the time taken to reach that distance. The data for these experiments are shown in Table 4.3 and additional pictures can be seen in Appendix J.

For the first test conducted on the *Quercus oleoides*, a pilot flame was not used to ignite the sample. Due to the flame resistive properties of this specific species, the sample did not ignite, but rather smoldered and smoked for the duration of the test. The following tests were conducted with the use of a pilot ignition in order to generate a flame that would propagate across the wood. During the second test of the Jaragua, the 200 mm length Jaragua pieces keeping the majority of the sample in place were wrapped in tin foil with the hopes of creating rigid containment of the grass during combustion. This was in reaction to the first test in which the Jaragua grass expanded out of the slide towards the heat flux generator during testing. However, the wrapping of the support samples hindered the progression of the flames as seen in Figure 4.4. The following tests 3 and 4 were conducted without the use of the tinfoil to allow for a more accurate calculation of the flame spread velocity. The thermal recordings of the tests provided information on the temperature of the samples during the course of heating and combustion.

Table 4.3 Flame Spread Test Results

Species	Mass before Test (g)	Flame Spread Distance (cm)	Time (s)	Mass after Test (g)	Calculated Velocity (m/s)	Notes
Quercus Oleoides	1341.7	41.5	N/A	1000	N/A	The mass is only of the wood. Did not catch on fire, just smoldered. There was no pilot light.
Quercus Oleoides	2500	51.5	103	2250	.005m/s	The mass is only of the wood. Caught on fire, but flames stopped at the edge of the heat flux generator. There was a pilot light.
Quercus Oleoides	3500	47	204	3100	.002m/s	The mass is only of the wood. Caught on fire, but flames stopped at the edge of the heat flux generator. There was a pilot light.
Hyparrhenia rufa	7530	55	62	N/A	.009m/s	The mass is the grass and containment vessel. Grass became weak and crumbled, which disbursed its mass making final mass unavailable. The pilot light was on.
Hyparrhenia rufa	7480	40	20	N/A	0.020m/s	The mass is the grass and frame. Grass became weak and crumbled, which disbursed its mass. The pilot light was off. Attempted using pieces of grass wrapped in foil placed perpendicular to the orientation of the testing grass to prevent it from falling out of the containment vessel. Foil prevented the spread of the flames. Discontinued foil after this test.
Hyparrhenia rufa	7600	80	N/A	N/A	N/A	The mass is the grass and frame. Grass became weak and crumbled, which disbursed its mass. The pilot light was off. Due to an error, no video or time.
Hyparrhenia rufa	7400	55	20	N/A	0.027m/s	The mass is the grass and frame. Grass became weak and crumbled, which disbursed its mass. The pilot light was off.

Figure 4.4 Jaragua with Foil After Test
Photograph by Winton Parker

4.2 Limitations

The maximum temperature recorded by the thermal camera (Seek Thermal used with iPhone) is 330 degrees Celsius (626 Fahrenheit). This limitation prevented the observation of the wooden sample's temperature just prior to ignition since the sample burst into flames after the reading from the thermal Camera reached 330 degrees. However, the ignition point of the Jaragua grass occurred shortly after this maximum temperature was reached. We can assume that the ignition point for Jaragua is typically near 330 degrees Celsius, agreeing with the values gathers from the MCC. Additionally, there are no testing procedures for using loose grass in this apparatus, so our flame spread may not be directly comparable to other tests run in this machine.

5.0 Findings and Discussion Chapter

We developed four findings, described in Table 5.1, that focus on the social components of wildfire ignition in Área de Conservación Guanacaste (ACG).

Table 5.1 Findings and Validators

Findings	Validated By:
Finding #1 The ACG firefighting program is well equipped to handle most fires that develop and rarely require outside assistance	Raúl Acevedo, Julio Diaz, Sergio Cascante, Maria Chavarría, Roger Blanco, and Didi Guadamuz
Finding #2 Park Rangers limit their forest management to allow the natural regrowth of the forest.	Roger Blanco, Raúl Acevedo, Julio Diaz, Sergio Cascante, and Didi Guadamuz
Finding #3 Traditional views of trash disposal, farming, and hunting lead to wildfires in the ACG.	Maria Chavarría, Roger Blanco, Raúl Acevedo, Julio Diaz, Sergio Cascante, Didi Guadamuz, and Jose Pablo Sosa
Finding #4 Educational programs emphasize the preservation of Santa Rosa to nearby communities	Maria Chavarría, Roger Blanco, Raúl Acevedo, Julio Diaz, Sergio Cascante, and Didi Guadamuz

Finding #1 The ACG firefighting program is well equipped to handle most fires that develop and rarely requires outside assistance

Overview of the Firefighting Program

We contacted several Park Rangers in person and over the phone, who work in the ACG, to learn about their fire protection program within the park. The Park Rangers stated the fire prevention program in the National Park began in 1985. At that time there were seven members and a very limited toolset for controlling fires, consisting mostly of *machetes*, brooms, and backpack water pumps. Today thirteen members patrol the park everyday acting as both Park

Rangers and firefighters depending on the situation. During the day (8am-5pm) one member is stationed at a viewpoint where nearly 80% of the entire ACG can be monitored. Armed with binoculars and a radio the Park Ranger looks for any signs of smoke and relays to other members if anything is spotted. An additional two towers are occasionally used elsewhere in the ACG. At our time of visiting, one of those towers in the Pocosol sector of the park, as seen in yellow in Figure 2.2, was damaged and out of service. These lookouts allow Park Rangers to quickly locate and respond to fires while they are still manageable. The remainder of the park is regularly patrolled by pickup trucks driving along the 300 km of roads within the ACG. These roads are planned intentionally to double as fire barriers, breaking the land into sections. Park Rangers routinely maintain the roads and paths throughout the ACG. While we were in Santa Rosa National Park collecting plant samples with the Park Rangers they stopped the truck multiple times to clear vegetation growing into the path of the road. Removing the vegetation ensures the borders are maintained and prevents fire from spreading. Wider and longer fire breaks are intentionally burnt annually to further reduce the threat of fire spread.

Responding to a Fire

The Park Rangers explained their strategies for fighting fires and assessing wildfire risk. The list of equipment the Park Rangers use is shown in Table 5.2. Fire severity is first determined by the Park Rangers when responding to a fire. A scale of 1-4 is utilized where level 1 is a small fire capable of being contained by a few members and level 4 is a large, out of control fire and is considered a national emergency (R. Acevedo, personal communication 31 March 2016). Cuerpos de Bomberos de Costa Rica, the fire department of Costa Rica only aides in the largest of fires. The risk scale is illustrated in Table 5.3. The commander determines how to fight the fire through the use of two methods, direct or indirect fire fighting depending on the material burning. Direct tactics include spraying water onto the leading edge of the fire to directly oppose its spread. This method is used against grass fires as long as the flames do not exceed a height of two meters. Three people will go in with water pumps to slow the spread and the rest will use machetes and brooms to smother the flames. Indirect fighting is effective for large fires or if dead leaves and underbrush are burning. This method requires anticipating the path of the flame and creating a barrier by removing any dead leaves and grass from the area so the flames cannot propagate any further. However, estimating where and how quickly the fire spreads is difficult and risky. After a fire is controlled a detailed report is filed for each event. Included in the report is the time and date, cause of fire, location, and amount of land affected (R. Acevedo, personal communication 31 March 2016).

Table 5.2 Available Equipment Description (Appendix K)

Available Equipment	Description
4000L Capacity Water Truck	Slow and difficult to traverse land
400L Capacity Water Tanks for Pickup Trucks	Good to quickly move across the land
20L Backpacks	Used once arriving to scene of the fire
Water Pumps	Pumps water from trucks to the fire
Hand tools	Machetes, brooms, chainsaws (Park Rangers opt to not use additional specialized tools as this is easier for them)

Table 5.3 Fire Assessment Scale and People Required to Address the Fire

Fire Assessment Scale	
1-2 Local	May only require a few Park Rangers to extinguish
2-3 Regional	Help from all available Park Rangers and asking for community volunteers to help as well may be required
3-4 National	A National Emergency. Bomberos are called in to help along with support from the whole country in addition to using all other resources

New Firefighting Technology

Raúl Acevedo stated that in recent years, new technologies have become available to the park and are used to monitor and aid in fire prevention. During peak fire months (March and April) when monitoring from lookout locations becomes insufficient, private helicopters and pilots are hired to patrol from the skies. Satellite imaging is also used (MODIS sensor) to detect critical heat points in the National Park. This is limited in resolution however and can only detect fires with a diameter of at least 25 hectares meaning it does not detect the very beginning of a wildfire. Further discussions with Raúl Acevedo revealed his personal interest in using unmanned aerial drones for surveying, since it would be a cheaper method that requires fewer resources.

Evaluating Effectiveness of Fire Tactics

Overall, with the additional features the fire prevention team has implemented in previous years there has been a decrease in the average number of hectares destroyed per fire (Figure 5.1). Sergio Cascante stated that in the last ten years there has been an average of 22 fires per year, while in the years prior there were over 35 fires a year. More important than the number of fires, is the amount of land affected. As reported by the ACG, the average amount of land affected every year has reduced more than 30% in the past 10 years, as shown in Fig. 5.1. When we asked the Park Rangers and Director what they thought needed to be improved upon, they all agreed it was not the firefighting program, but rather preventing the fires in the first place. The Park Rangers are confident in their ability to fight fires with the resources currently available. The required equipment the ACG uses in addition to actual firefighting strategies (direct and indirect) corresponds with the recommended tactics of the United States Department of Agriculture and the Forest Crises Management program in Europe (National Wildfire

Coordinating Group 1996; Kaulfuß 2010). This illustrates that they have predetermined protocols for fighting fires that correspond with tactics from around the world. Members of Bomberos in Costa Rica stated they share very similar strategies with the Park Rangers. This included their response to fire, methods of fighting fires they use and the equipment they use. In addition, all Park Rangers have completed training in managing fires in the park, enabling them to respond to fires at all times. We found that the small team there is equipped to handle the fires because they are able to minimize the loss of land (Figure 5.1). We also found that their program seems well established and effective.

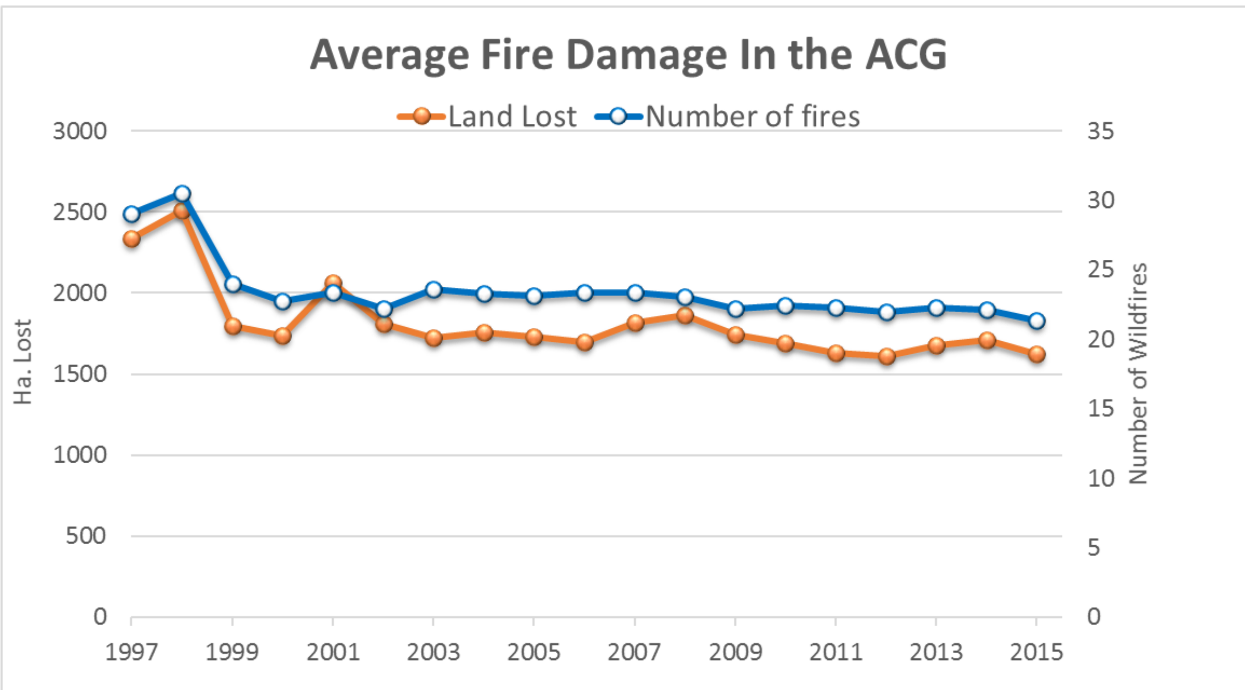


Figure 5.1 Average Fire Impact in the ACG
Generated Graph from Statistics in Raúl Acevedo's Presentation

The Impact of Climate Change

During our interview with Maria Chavarría she argued that climate change has an important impact on the park. She has been collecting data on weather conditions and wind speed for 15 years in the park and noted an increase of extreme conditions that are less predictable. She stated that winds in particular have become stronger. Roger Blanco similarly stated that in years past the rain would be very predictable, to the point that people would place bets on which hour in a specific day the rain would start for the rainy season. He noticed this has changed and now rain doesn't even occur every day during the rainy season, but rather is concentrated in the month of October. High winds and less rain are dangerous conditions that increase the chance for a wildfire to occur. This has both Roger Blanco and María Chavarría concerned that in future years fires could become more severe due to rain occurring less frequently and winds becoming stronger. This fact could make fires more difficult to control and may require additional attention in the future.

Finding #2 Park Rangers limit their forest management to allow the natural regrowth of the forest.

We conducted interviews that helped us to understand the kind of vegetation in the National Park as well as how the Park Rangers manage forest fire risk. During our dialogue with park staff members we found that their forest management practices are as minimal as possible to avoid damaging the dry tropical forest within the Santa Rosa National Park.

Interfering with natural dry tropical forest growth upsets the delicate balance required for such a unique and diverse ecosystem to grow. This was demonstrated in the 1940s when the invasive Jaragua grass was first introduced into Guanacaste. This grass has altered the landscape, converting what once was forest into grasslands. Both Roger Blanco and Raúl Acevedo confirmed that the reason why they intervene during wildfires is because those fires are not natural to the park's dry tropical forest. Wildfires destroy the valuable flora that takes decades to rejuvenate. Some ecosystems around the world have naturally occurring fires that are necessary for some of the vegetation to populate. However nearly 100% of the fires in the ACG have been human caused (R. Blanco, personal communication 31 March 2016). Roger informed us that over the past 40 years there have only been a total of 4 fires that started from natural phenomena such as lightning. Limited intervention can allow dead vegetation to build up, which increase the risk of creating larger intensity fires in the future. Removing this buildup of fuel would decrease fire risk but it would also interrupt the normal development of the dry tropical forest. The Park Rangers also refrain from planting or removing trees, even if the species is common to the area, because it would not be natural to the growth process of the forest.

The majority of the impact the Park Rangers have on the park includes clearing wide roads of most of the vegetation and then burning the remaining low grasses. Despite this practice of destroying vegetation, the benefit far outweighs the destruction because it blocks fires starting in one sector from spreading into another resulting in massive damage. Figure 5.2 shows the Park Rangers in the process of creating a fire road on the left and an aerial view of a completed fire road on the right. In addition, from the ACG website we learned that the Park Rangers cut trails for increased mobility within the sectors. The Park Rangers attempt to maintain a balance between minimal intervention and undertaking measures necessary for the protection of the entire park.

Figure 5.2 Park Rangers in the Process of Creating Fire Barrier (Left), Complete Fire Barrier (Right)
Photograph by and Used with Permission from Raúl Acevedo

Preventing fires within the park and allowing natural regrowth of the forest allows the dry tropical forest to return. The Jaragua grass is typically the first species to dominate an area recently cleared by fire. However, in just a few years without fire, a field full of invasive Jaragua can be overtaken by plants and trees native to dry tropical forests. This restoration process is called succession and can be seen in Figure 5.3. As Roger Blanco stated during our interview, a single fire can easily destroy 10 years of regrowth, and the Jaragua will return to the burnt area first, creating further fire risk.

Figure 5.3 Dry Tropical Forest Growth
Photograph by and Used with Permission from Raúl Acevedo

Finding #3 Traditional practices of trash disposal, farming, and hunting lead to wildfires in the ACG.

During the time our team spent in Guanacaste we observed traditional fire practices. For example, while we were leaving the ACG, we saw a farmer burning his/her land. Visibility was reduced to only a few feet as the entire bus we were traveling in was engulfed in a thick layer of smoke. This is not an uncommon occurrence, we observed people setting fires multiple times in Guanacaste. We inquired through our interviews as to who was causing these fires and found that the community members surrounding the Santa Rosa National Park caused the majority of the wildfires through traditional burning practices. The ACG identifies three categories of fire cause:

intentional, unintentional, and negligent. Intentional implies intent behind the action, in this case a person purposely starts a fire to cause harm. An action performed that has regulations by a person who disregards the precautions and results in harm is defined as negligent. Unintentional is an action that resulted in harm, but not from fault of the person.

Trash Disposal

Maria Chavarría, a biologist and teacher for the ACG for 25 years, brought to our attention some of the social complexities surrounding trash disposal. According to Maria Chavarría, people in the communities surrounding Santa Rosa National Park set fire to their trash as a way to dispose of it, but this burning also follows a long held belief that it protects their homes against snakes. The ACG is concerned with people burning their trash because the strong winds that Guanacaste experiences can potentially carry the fire into the Santa Rosa National Park. Presently there are laws against this practice, for instance the Law for Integral Waste Management numbered Law 8839 Article 49, states that the penalty for burning ordinary waste is up to 80,000 dollars and includes reparation of environmental damage. Maria Chavarría commented how burning trash is ingrained in the people of Guanacaste's culture to the point that even some of the police in the Guanacaste area are unaware of the laws against incinerating waste which results in minimal enforcement of these laws. When Maria Chavarría visits the communities surrounding the ACG, she carries a copy of this law to show those who burn their trash since some are not aware of the regulations. Children, who learned from the educational programs provided by the ACG attempt to convince their parents that burning their trash is hazardous, but the parents tend to ignore them. Roger Blanco, director of research in the ACG, also felt that trash burning was an issue that stemmed from the traditional beliefs and practices of the local people. Park Rangers categorize trash burning as "fires due to negligence", because they are not intentionally meant to cause wildfires but could have been prevented with proper procedures.

Farming

Farmers are legally allowed to set fire to their land, even farmers that live close to the ACG, as long as they have the proper permit. The permit is granted to farmers who agree to follow the listed safety precautions. These precautions include the use of a fire line, possessing sufficient water, and not performing the burn during poor weather conditions such as strong winds (J. Diaz, personal communication 14 April 2016). Despite the precautions outlined by the permits, burning farmland is another source of wildfires that the ACG is concerned about. Julio Diaz, Sergio Cascante, Didi Guadamuz, and Roger Blanco explained that the practice of setting farmland on fire is to quickly clear the land and promote the growth of grass for cattle to graze on. Farmers believe they must clear their farmland with fire to keep the land from becoming unusable (J. Diaz, personal communication 14 April 2016).

With strong winds present within Guanacaste, farmers who neglect the conditions set by the permit while clearing their land with fire, can create an out of control fire that advances into the Santa Rosa National Park. To address this problem the ACG has a community volunteer fire training program that offers time and knowledge to assist farmers in following the precautions outlined by the permit to lower the risk of a wildfire (R. Acevedo, personal communication 31 March 2016). Burning farmland, as Raúl Acevedo a Park Ranger illustrated through a presentation, is socially complex because it is ingrained into the people's culture and is a well-accepted method of managing farmland. Aware of the traditional practices the ACG attempts to protect their land from farmers burning their farmland by constructing a barrier, which does not depend on the farmer properly following the regulations of the permit. As seen in Figure 5.4 this barrier is a pre-burnt plot of land, which serves to prevent the spread of flames from farmland into the ACG. Due to the size of the National Park fire line barriers are not found along the entire perimeter of the park, which leaves several areas vulnerable to wildfires from farmland burning (R. Acevedo, personal communication 31 March 2016). The fire line of burned plots between private property and the ACG are effective because they do not infringe on the traditional practices of the people.

Figure 05.4 ACG Barrier
Photograph by and Used with Permission from Raúl Acevedo

Hunting

Hunting is part of many people's livelihood in Guanacaste. Despite being prohibited within the Santa Rosa National Park there is evidence that it still takes place. Roger Blanco explained that in order to distract and evade Park Rangers, hunters intentionally set fires within the National Park. With the Park Rangers attention on the fire, the hunter is able to hunt in another part of the ACG without detection. In order to prosecute a person for starting a fire, the legal system requires the Park Rangers to personally witness the individual setting the fire, which demonstrates the difficulties in apprehending offenders (R. Blanco, personal communication 31 March 2016). When hunters are caught setting fires they enter a long legal process. The legal proceedings do not immediately put perpetrators in jail. Roger Blanco explained that this creates another motive to start wildfire; revenge. Hunters who are in the process of being sent to jail for starting wildfires often will set fires in retaliation for being caught, which was also confirmed by Julio Diaz, Sergio Cascante, and Didi Guadamuz. The ACG experienced a particular problem with an enraged individual who frequently set fires in the Pocosol Sector, highlighted in yellow within Figure 2.2. However the Park Rangers struggled to convict him, which allowed him to commit further arson. Hunting and revenge fires cause a large portion of the wildfires that affect the ACG (R. Blanco, personal communication 31 March 2016; R. Acevedo, personal communication 31 March 2016, J. Diaz, personal communication 14 April 2016, J.Sosa personal communication 18 April 2016). Costa Rica's National System of Conservation Areas published statistics in the Semanario Universidad newspaper regarding the different causes of fire affecting protected areas, which supports the interview claims and concerns about burning trash, burning farmland, hunting fires, and revenge fires (Figure 5.5). The legal system appears ineffective at stopping people from starting fires. The laws themselves are contradictory to the traditions of the people and the legal system is too slow, which allows for revenge fires.

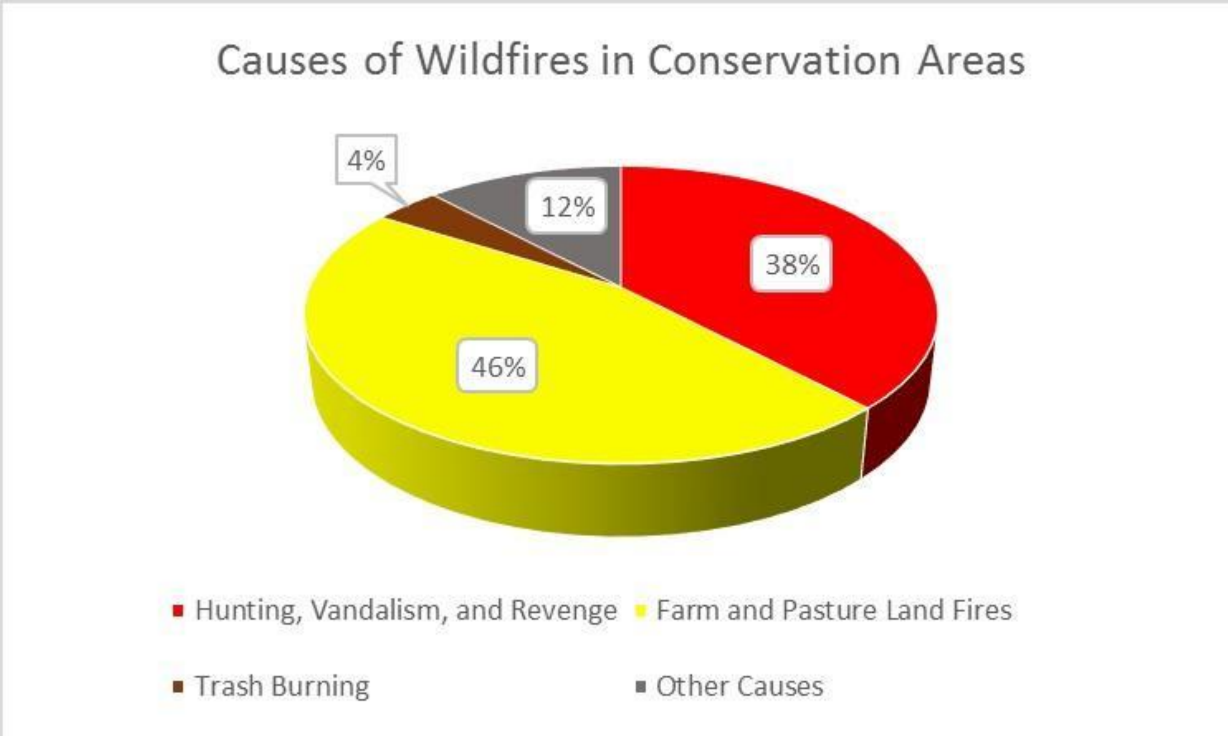


Figure 5.5 Causes of Wildfires in Conservation Areas
Generated Graph from Statistics in Semanario Universidad Newspaper

Finding #4 Educational programs emphasize the preservation of Santa Rosa to nearby communities

In every interview we asked what could be done to further reduce wildfires in the ACG. Unanimously the answer was spreading knowledge about the goals of the park, and importance of fire safety. Specifically, the park employees mentioned two programs already in place, a school outreach program and volunteer training. Maria Chavarría, Roger Blanco and Raúl Acevedo all believe these efforts should be furthered.

Teaching Children

Classrooms throughout Guanacaste are the main target of outreach for the ACG. The schools are centralized around the National Park. Roger Blanco explained that over the last 30 years this program has grown to include more than 50 schools within the surrounding communities. The majority of these schools are public or private elementary schools, with the students typically eight to twelve years old. Seven high schools also participate in the classes. The ACG program is well established with two types of lessons plans; in the class (formal), and field trips into the National Park (informal). In the schools, a teacher or biologist from the park will come and meet with the students in their class and give a presentation about the park to hopefully create a connection between the park and the students. The topics of these lessons include Biological Education, Biosensing Marina, and Environmental Education (Guanacaste 2016). Maria Chavarría is a biologist in the park and has been teaching children about the park for many years. She leads field trips into the park to help work on projects and learn about different areas of the park firsthand. She helps in at least four different programs throughout the park; The Beach Program, Dry Tropical Forest Program, Rain Forest Program and the Cloud Forest Program. All of these programs seek to fascinate and engage the students. For example, the Beach program allows the kids to understand the wildlife found in the ocean and the beach first hand. They are taken snorkeling in the water and given booklets to write observations of the animals they see. All the activities are tied back into the overarching goals of giving the park importance to the children.

Lessons About Fire

While no formal lesson plans about forest fire safety and dangers are in place, it is still a topic stressed by the teachers. Maria explained one such activity she uses in which the kids draw what happens to the aquifers after a fire burns the trees and the roots die. She then explains that without trees the aquifers dry out and many more plants will die as a result of a diminished water supply. She uses this to further explain the repercussions of fire to the environment. Julio Diaz also gives children tours of the fire barriers in place throughout the park to explain their function, and importance. Maria Chavarria believes fire danger should be taught using actual fire history in the ACG, explaining the stories of the Park Rangers and their battles with fire. This would create more of a connection between the children and the issue, increasing the educational value.

The goals of the student education programs are very important, increasing the understanding of the community and sharing the value of the conservation. Every member of the park we spoke to believed teaching children was key to spreading this goal. Children of the community will grow up with conservation in mind. Maria Chavarría said that now the program has been in place long enough that she knows parents of children in the program who once went through the same class. New generations continue learning and more people have developed a respect for the forest.

Volunteers

In addition to classroom education the ACG also offers volunteer fire training programs. This program teaches community members about fire safety, how to identify risks in addition to firefighting techniques. Two companies are in charge of this training process but no real timeframe is established for training, because the volunteers often have other occupations. As mentioned in Finding #1 the volunteers are called to assist the Park Rangers when the fire level reaches 2-3. However, the Park Rangers believe they play an even more important role; spreading information to the community. Volunteers “share the science with the neighborhood” (J. Diaz, personal communication, 14 March 2016). They teach others proper fire management for their properties, including assisting them with setting beneficial fires that would otherwise be unsupervised.

Synthesis

The main goal of the ACG is “ensuring the survival of biodiversity in perpetuity” (Guanacaste 2016). In addition to preventing fires, the teachers in the park believe giving value to the park is the most worthwhile investment the park can make. Over the last ten years the average number of fires is decreasing. In 1997 there were an average of 35 fires a year in the National Parks. As of 2015 the average is 22 incidents of fire per year, further illustrated in Figure 5.1. While it is speculative to attribute this to the educational efforts by the ACG, the Park Rangers and Biologists believe continued spread of information is the most important aspect to reducing the issue of wildfires. As mentioned cultural beliefs are strong within the communities, limiting the opportunities for people to change habits. By making use of children's interest in learning, and seeking out volunteers who are dedicated to the park, the ACG staff teaches a small group of people who will share their experiences with others. This effort has been in place for many years, and while fires will not cease to be an issue entirely, the ACG hopes to continue influencing the community.

Limitations

As with any study there remains the possibility that the information gathered was not completely accurate, due to personal opinion of misinformation or misinformation from the interviewees. If our team was able to conduct more interviews our information may have been better triangulated. Our understanding of the cultural practices of the people surrounding Santa Rosa National Park are based primarily on four interviews. It would be beneficial to seek more direct community opinion on the issue of wildfires, trash burning and fire management. Doing so would give additional insight into the views of those who have lived in the region within the culture we investigated. From here, more of an understanding can be gathered by investigating the community's value and involvement in the National Park.

6.0 Recommendations and Conclusion Chapter

Our project focused on the fire risk posed by the vegetation and the causes of wildfire. Our findings from chapters 4 and 5 help to explain the cycle of a wildfire; how and why a wildfire starts, how it spreads, and finally how it is extinguished. From this we created several recommendations to address some of the main concerns we found in addition to recommending future studies for further wildfire testing. Following the recommendations, we give a brief explanation of the data we provided to our sponsors to be used in the creation of a vegetation catalog.

6.1 Further the Educational Programs Already in Place by the ACG.

Because of the value placed on the educational programs already in place, we recommend the ACG continues to invest in and expand this program to reach more of the community. Also the decrease in fires within the ACG over the past several years can be attributed to the educational programs (R. Acevedo, personal communication 31 March). The following recommendations are additions to the pre-existing Biology Education Program involved in fifty-three schools around the ACG.

Reaching out to other areas and making more connections with students is the main goal of the outreach program. Currently there is a large demographic absent from this crucial instruction, teenagers. The majority of the students involved are between eight and twelve years old, only seven high schools are involved in this program. We recommend following the current programs in these few high schools and applying them to additional schools. Colegio Barrio Irvin, Liceo Rural La Garita, Colegio Santa Cecilia, and Liceo Brasilia are four potential high schools to include in the program because they are near the ACG and are surrounded by elementary schools the ACG is already involved with. Expanding to more schools and wider age groups, especially high school, could help reinforce the concepts instilled into the students. The best sources to consult about these options would be Gabriela Gutierrez, the woman in charge of the educational programs provided by the ACG, and the Ministry of Public Education (MEP), because the ACG has formal agreements about educational programs with MEP. Expanding the reach of the program would also benefit the entire community, not just the students. After the program is incorporated in areas around the ACG, other regions in Costa Rica could be included. For example, the Puntarenas province has seen a large number of wildfires in the past years and a similar program could help to reduce the valuable biodiversity lost to fire (Rojas 2016).

We also recommend expanding the topics taught in the primary schools involved in the Biology Education Program. Currently the programs are teaching students to value the National Park, but do not directly address the issue of wildfires. Teachers could be consulted to incorporate specific methods that effectively convey the seriousness of wildfire and its causes. The program would need to synthesize information from the ACG Park Rangers with practical teaching techniques. We recommend that an emphasis of these programs be on fire danger and the impact of wildfire. We suggest incorporating not only the discouragement of traditional burning practices, but also introducing a reason why. For instance, instead of focusing solely on educating children that hunting with fire is “bad”, include that the fire jeopardizes the biodiversity in the park they visit and reduces the amount of available water for the community. Approaching education with this format will resonate because it connects to topics that people value and respect. Some important subjects to include are: why wildfires are hazardous and their potential consequences, how to safely dispose of trash, and who extinguishes the fires and how. Each of these topics could incorporate aspects such as the types of traditional practices that cause wildfires; burning trash, farming, and hunting.

6.2 Increase the Number of Volunteers Through Incentive Programs

To reduce wildfire risk, it is important to create a community where starting wildfires is not socially acceptable. This is achieved by giving importance to preservation and protection. Attempting to change a community's actions through legislation has not worked in this region, since burning land and trash persists. Instead people must be given a reason to change. Volunteer programs seek to accomplish this by allowing community members to learn and understand the value of the ACG. An important support base for the Park Rangers is the team of nearly 40 volunteers that aid in the event of large scale wildfires and assist farmers in safely burning farmland. We recommend a program that would provide incentives for those who join in order to boost recruitment numbers. Currently, there is an insurance program awarded to the volunteers, but more should be available to incentivize other community members to join the program. The proper incentive would need to be determined to balance available resources with the need for volunteers. Giving the volunteers positions, titles, or badges could encourage more people to volunteer because they offer pride based incentives without the ACG incurring a financial cost. Encouraging a sense of pride in service is very important for enlisting more people from the community to spread knowledge about hazardous traditional practices. Giving titles as an incentive worked in the Maasai tribe in Kenya where killing lions was very prestigious. These hunters were trained to become protectors by giving them the title of lion guardians, a title that became highly respected in their community. These guardians were held in such high esteem that the tribe nearly stopped lion hunting, allowing the endangered lions to return (Ham n.d.). This is comparable to expanding volunteer involvement since it not only increases the manpower of the ACG to fight fires, but also spreads knowledge about the importance of the ACG to discourage burning land in general.

Incentives would have to be investigated further, requiring discussion with community members, those already in the volunteer program and others who are not involved. The next priority would be determining the reasons for people joining or choosing not to join. From here additional incentives could be suggested to receive community feedback on the most accepted options.

6.3 Perform a More Comprehensive Study of the Vegetation in the ACG

In order to further understanding of how a fire spreads during a wildfire we recommend continuing vegetation testing. A large range of species should be collected, starting with the most common and abundant within the area being investigated. The three tests our group conducted should also be performed on all distinct features of each sample i.e. bark, leaves, inner wood, flowers. In addition to this, other combustion tests would need to be investigated to create a more conclusive study. Based on our experience we have created an outline of recommended modifications to the testing procedures. The recommendations span our experience with proper sample sizes, effective drying and preparation of samples, and the approximate time required for different procedures. The recommendations we outlined can be seen in greater detail within Appendix L, but main points include:

1. Know required sample size before collection.
2. Cut sample sizes according to specifications and then begin the distilling process.
3. Test grasses in the Flame Spread following special procedures (explained) to contain the grass.
4. Allow for two work weeks to complete the process from collection to results for one species.

Create Simulation Model

In order to get a realistic model of the fire spread in the park, simulations could be investigated. We recommend using the Rothermel model as an initial simulation for the ground spread of flames through vegetation. This is a well-known and extensive model which was recommended for our study by a fire protection Professor in Australia. Using this model would require further research into the variables needed for accurate results. Additional models could be investigated depending on the kinds of data collected during fire testing. The valuable information gathered from models and simulations would help to determine the wildfire risk presented by each species. This would be useful to scientists and Park Rangers for their efforts in investigation and protection. This study could then be expanded beyond the ACG to include other particularly fire prone regions throughout Costa Rica or around the world.

Create a Fire Risk Map

The next step would be to create an integrated map from the location of the studied vegetation within the region being examined. Aerial observation of the vegetation combined with locational information would produce a comprehensive map of the species and the areas they occupy. This map, linked with risk values assigned to each species would highlight regions with the most susceptibility to wildfire that would present the greatest danger if ignited.

6.4 Deliverable: Data for Catalog

Our laboratory tests were part of a bigger effort to provide a comprehensive assessment of fire risk posed by vegetation in the ACG. We completed testing on 32 samples in the Microscale Combustion Calorimeter (MCC), 10 samples in the Smoke Density Chamber, and 7 samples in the Flame Spread Apparatus. Our data, recommendations, and conclusions contributed to the information required for developing catalog entries for the species we tested. The entirety of this data was delivered to our sponsor to create the opportunity for the University and outside researchers to further their related studies. An example of the raw data from the MCC and Smoke Density Chamber are shown in Figure 6.1 and 6.2 respectively. Table 4.3 describes the results from the Flame Spread Test in Chapter 4 and the videos that captured the behavior of the flames are also included with the data. This information is included in Appendix G-K.

File Name: Jaragua1.txt
Date: 28 Jan 2007
Operator:
Test ID:
Sample ID:
Sample Mass (mg): 8.9900
Sample Cup Mass (mg): 170.0000
End Total Mass (mg): 172.5600
Heating Rate (C/s): 1.0
Combuster Temperature (C): 900.0
N2 Flow Rate (cc/min): 80.0
O2 Flow Rate (cc/min): 20.0
Calibration File: Coeff 150318.txt
T Correction Coefficients: 0.000000000 0.000000000 0.000000000
Time Shift (s): 10.0
Pre-Test Comments:
Post-Test Comments:
@

Time (s)Temperature (C) N2 Flow (cc/min) O2 Flow (cc/min) Total Flow (cc/min) Oxygen (%) HRR (W/g) Heating Rate (C/s)

0.000	75.895	83.366	19.896	104.530	18.778	1.573	0.019
0.500	76.091	83.361	19.890	104.532	18.767	1.926	0.019
1.000	76.335	83.351	19.894	104.535	18.756	2.304	0.017
1.500	76.542	83.353	19.896	104.588	18.761	2.157	0.017
2.000	76.817	83.354	19.895	104.665	18.752	2.457	0.018
2.499	77.062	83.358	19.893	104.755	18.743	2.765	0.019
3.000	77.293	83.354	19.892	104.853	18.743	2.759	0.019
3.500	77.526	83.350	19.898	104.952	18.732	3.138	0.018
3.999	77.792	83.349	19.892	105.000	18.734	3.066	0.018

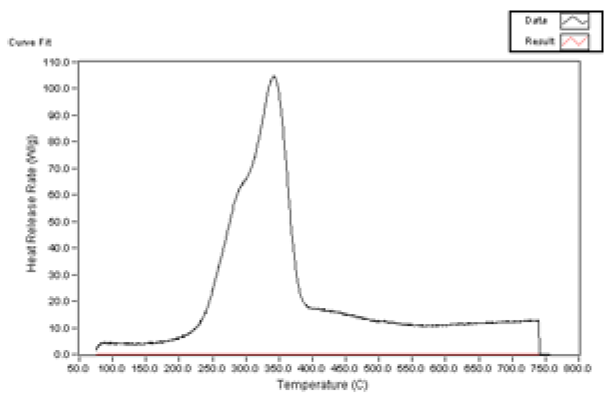
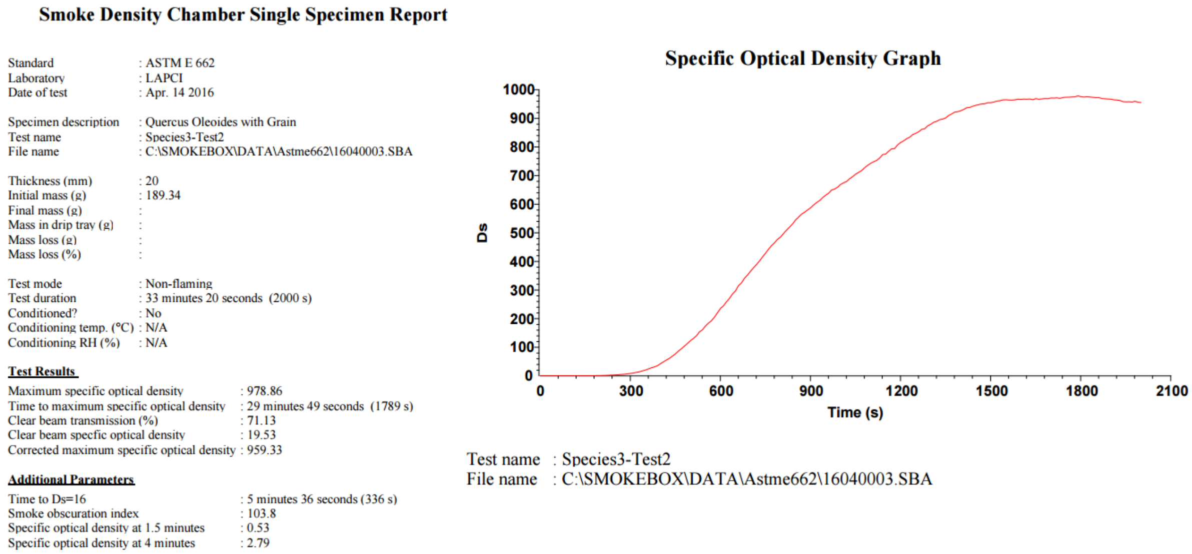


Figure 6.1 MCC Unprocessed Data



Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 14 2016

Specimen description : Quercus Oleoides with Grain
Test name : Species3-Test2
File name : C:\SMOKEBOX\DATA\Astme662\16040003.SBA

Thickness (mm) : 20
Initial mass (g) : 189.34
Final mass (g) :
Mass in drip tray (g) :
Mass loss (g) :
Mass loss (%) :

Test mode : Non-flaming
Test duration : 33 minutes 20 seconds (2000 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

Test Results

Maximum specific optical density : 978.86
Time to maximum specific optical density : 29 minutes 49 seconds (1789 s)
Clear beam transmission (%) : 71.13
Clear beam specfic optical density : 19.53
Corrected maximum specific optical density : 959.33

Additional Parameters

Time to Ds=16 : 5 minutes 36 seconds (336 s)
Smoke obscuration index : 103.8
Specific optical density at 1.5 minutes : 0.53
Specific optical density at 4 minutes : 2.79

Test name : Species3-Test2
File name : C:\SMOKEBOX\DATA\Astme662\16040003.SBA

Figure 6.2 Optical Smoke Density Unprocessed Data

6.5 Conclusion

After coordinating with the UCR and investigating the conservation area in Guanacaste, we tested vegetation and learned about the social concerns still remaining in the community. We began this first vegetation study for the University of Costa Rica, by setting standards for collecting samples, conducting the study, and creating a schedule for testing. From our results we started to understand the cause of the fires, how they spread, and finally how the Park Rangers fight fires. Combining our understanding about the causes of wildfire with the knowledge from several experts in the National Park allowed us to understand why traditional practices continue to create wildfires. Despite the continued efforts of the Park Rangers, fires continue to spread into the park and certain vegetation species pose a great threat. The risk is not going away quickly enough for the community to ignore the problem. Social standpoints can limit community involvement, and changing these norms does not happen quickly but efforts of the ACG continue to create acceptance and support for the park. The community has the ability to eliminate the threat of man-made wildfires in the National Park and this concept can be brought to any park, conservation, or area in the world.

References

Arias, L. (2015, 7/29/2015). El Niño in Costa Rica: We haven't seen the worst of it yet, say experts, *The Tico Times*. Retrieved from http://www.ticotimes.net/2015/07/29/el-nino-effects-costa-ricas-weather-still-growing-experts-say

Berg B., Lune H. (2012). Qualitative Research Methods for Social Science (8 ed.): Pearson.

CAL Fire, OES, U.S. Forest Service. (2007). California Fire Siege 2007. 109.

CEIBA. (2015). Dry Forest Ecology. *Lalo Loor Dry Forest.* Retrieved from http://www.ceiba.org/loorecology.htm#conservation

Comunicado de prensa Incendios Forestales Ultimo. (2015a). [Press release]

Convention, U. N. E. S. a. C. O. W. H. (2016). "UNESCO World Heritage Convention." Retrieved 4/1, 2016.

Costa Rica Registro Mayor Afectacion Por Incendios Forestales Durante La Temporada 2015. (2015b). [Press release]. Retrieved from http://www.sinac.go.cr/noticias/Comunicados%20PrensaSINAC/Comunicado%20de%20Prensa.Informe%20temporada%20de%20incendios%202015.pdf

Department of Biology and Environmental Science. (2008). Biomes of the World. Retrieved 2/9, 2016, from http://w3.marietta.edu/~biol/biomes/biome_main.htm

Diaz, J. M. (2012). Economic Impacts of Wildfire. *Southern Fire Exchange*. Retrieved from http://fireadaptednetwork.org/wp-content/uploads/2014/03/economic_costs_of_wildfires.pdf

Dibble A., Lebow K., White R. (2007). "Combustion characteristics of north-eastern USA vegetation tested in the cone calorimeter: invasive versus non-invasive plants." *International Journal of Wildland Fire*.

Dietenberger, M. A. (2010). Ignition and flame-growth modelling on realistic building and landscape objects in changing environments. *International Journal of Wildland Fire, 19*(2), 228-237. doi: 10.1071/WF07133

Fendt, L. (2015, 4/11/2015). Forest fires burn more than 2,000 hectares in Guanacaste, *The Tico Times*. Retrieved from http://www.ticotimes.net/2015/04/11/forest-fires-burn-more-than-2000-hectares-in-guanacaste.

Frankie, G., Baker, H., & Opler, P. (1974). Comparative Phenological Studies of Trees in Tropical Wet and Dry Forests in the Lowlands of Costa Rica. *Journal of Ecology, 62*(3), 881-919. doi: 10.2307/2258961

Ganteaume, A., Lampin-Maillet, C., Guijarro, M., Hernando, C., Jappiot, M. et al. (2009). Spot fires: fuel bed fammability and capability of firebrands to ignite fuel beds. *International Journal of Wildland Fire, 18*, 18.

Guanacaste, Á. d. C. (2016). "Área de Conservación Guanacaste." Retrieved 4/1, 2016.

Gazzard, R. (2012). Vegetation Fire Risk Management: Toolkit for Practitioners and Advisors. 34.

Ham, A. (n.d.). Guardians of the Lions. Retrieved from http://lionguardians.org/wpi-content/uploads/2012/05/Africa-Geographic-Lion-guardians.pdf

Holdridge L., Genkre. W., Hatheway W.,Liang T. and Tosi. J (1971). "Forest Environments in Tropical Life Zones: A pilot Study."

Honn, M. (2012). Hidden Health Costs of Forest Fires and Control Burns. 2016, Retrieved from http://www.psr.org/environment-and-health/environmental-health-policy-institute/responses/hidden-health-costs-of-forest-fires.html

Inicia Una Posible Activa Y Crítica Temporada De Incendios Forestales En Costa Rica: acciones para atender la nueva temporada de incendios forestales dará inicio desde este 15 de Enero. (2016). [Press release]

Janzen, D. (1988). Tropical Dry Forests: The Most Endangered Major Tropical Ecosystem. *Biodiversity*.

Janzen, D. (2000). Costa Rica's Area de Conservación Guanacaste: A long march to survival through non-damaging biodevelopment, Biodiversity, 1:2, 7-20, DOI: 10.1080/14888386.2000.9712501

Jiménez, J., Lal, R., Leblanc, H. A., Russo, O., & Raut, Y. (2008). The soil C pool in different agroecosystems derived from the dry tropical forest of Guanacaste, Costa Rica. *Ecological Engineering, 34*(4), 289-299. doi: 10.1016/j.ecoleng.2008.04.016

Kaulfuß, S. (2010). Forest Fire Fighting. *Types and Strategies of Forest Fire Fighting*. Retrieved from http://www.waldwissen.net/waldwirtschaft/schaden/brand/fva_waldbrand_wb7_1/fva_waldbrand_wb7_summary_fire_fighting.pdf

Krantz, L. (2015, 6/12/2015). When Prescribed Burns Go Wrong. *Outside Magazine*.

Larjavaara, M., Kuuluvainen, T., Tanskanen, H., & Venäläinen, A. (2004). Variation in forest fire ignition probability in Finland. *Silva Fennica, 38*(3), 253-266. doi: 10.14214/sf.414

Miles, L., Newton, A., DeFries, R. S., Ravilious, C., May, I., Blyth, S., Gordon, J. (2006). A global overview of the conservation status of tropical dry forests. *Journal of Biogeography, 33*(3), 491-505. doi: 10.1111/j.1365-2699.2005.01424.x

Mohammadi, F., Bavaghar, M., & Shabanian, N. (2014). Forest Fire Risk Zone Modeling Using Logistic Regression and GIS: An Iranian Case Study. *Small-Scale Forestry, 13*(1), 117-125. doi: 10.1007/s11842-013-9244-4

Moline, A. (1999). Tropical dry forest restoration in the Guanacaste Conservation Area, Costa Rica. *Student Online Journal Department of Horticultural Science University of Minnesota, 4*(4).

National Wildfire Coordinating Group. (1996). Wildland Fire Suppression Tactics Reference Guide. Retrieved from http://www.coloradofirecamp.com/suppression-tactics/suppression-tactics-guide.pdf

Northoff, E. (2003). Fires are increasingly damaging the world's forests. Retrieved 2/9, 2016, from http://www.fao.org/english/newsroom/news/2003/21962-en.html

Null, J. (2016). "El Niño and La Niña Years and Intensities." 2/2/2016. Retrieved from http://ggweather.com/enso/oni.htm.

Pullen, S. (2004). The World's Biomes. Retrieved 2/9, 2016, Retrieved from http://www.ucmp.berkeley.edu/glossary/gloss5/biome/

Rojas, Jafeth Mora. "Hunting In Protected Wilderness Areas." Semanario Universidad [San Jose] 20 Apr. 2016: 5. Print.

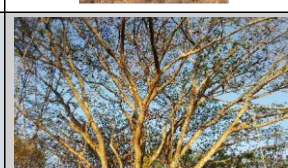
Scott, J., Helmbrecht, D., Thompson, M. (2014). Assessing the Expected Effects of Wildfire on Vegetation Condition on the Bridger-Teton National Forest, Wyoming, USA.

USDA, Moore, L. M. (2006). Plant Guide. Retrieved from http://plants.usda.gov/plantguide/pdf/pg_piba2.pdf

Warnatz, J., Lobert, J. (1993). Emissions from the Combustion Process in Vegetation. *Fire in the Environment: The Ecological, Atmospheric, and Climatic Importance of Vegetation Fires*.

Weise, D. R., White, R. H., Beall, F. C., & Etlinger, M. (2005). Use of the cone calorimeter to detect seasonal differences in selected combustion characteristics of ornamental vegetation. *International Journal of Wildland Fire, 14*(3), 321-338. doi: 10.1071/WF04035

Appendix A. Plant Collection Datasheet

Scientific Nam	ate Collecte		Coordiantes North	West	Notes	No. Samples	Picture
Bulbostylis paradoxa	3/29/2016		10°52'40.1"	85°40'58.1'	Clumps of grass approx. 6" diameteter. Surrounded by jaragua grass and some trees clumps are sperated some distance roots loosley attached in ground, easy to pull up	10 clumps	
Hyparrhenia rufa (Jaragua)	3/29/2016		10°51'10.1'	85°38'36.6"	tall dry grass grows in clumps with many stalks. Approxiamtley 8' tall. Grows densley in large fields of just rufa. Thick bottom growth	3 trash bags full	
Quercus oleoides	3/29/2016		10°52'24.5"	85°36'18.3"	tall tree (40ft) grows straight up vertically with little bend. Few branches, mostly at the top. Surrounding area mostly forrest with	5 large branches 12" diameter and small branches	
Curatella americana	3/29/2016		10°51'36.1"	85°39'17.0"	large bush-like tree (up to 15ft tall? In field with many other plants including tall grass	5 large branches 6" diameter and small brances	
Byrsonima crassifolia	3/29/2016		10°52'40.1"	85°40'58.1"	red outer bark/wood large samples taken with machettes	multiple lage diameter branches	
Enterolobium cyclocarpum	3/29/2016		10°50'28.5"	85°37'38.4"	30-45ft tall, very wide with many branches. Seed pods hanging on branches on edge of fire break with many other surrounding trees	5 large branches 12" diameter and small branches	

Appendix B. Calculations for Amount of Water to Extinguish Jaragua Wildfire

Calculations for water needed to extinguish a Jaragua Wildfire

<u>Constants</u>
Boiling Point of Water = 100 °C

Specific Heat of Water = 1 $\frac{Calorie}{g\ ^\circ C}$ = $4.186\ \frac{Joules}{g\ ^\circ C}$

$1\ Calorie = 4.186\ Joules$

Heat of Vaporization of Water = 540 $\frac{Calories}{g}$ = 2595.32 $\frac{Joules}{g}$

Assuming water used to extinguish fire is approximately 20°C

Energy per mass needed to vaporize 20°C water – E_V

$$E_V = (100^\circ\mathrm{C} - 20^\circ\mathrm{C}) * 4.186\ \frac{Joules}{g\ ^\circ\mathrm{C}} + 2595.32\ \frac{Joules}{g} = 2930.2\ \frac{\mathrm{J}}{\mathrm{g}} = 2930.2\ \frac{\mathrm{kJ}}{\mathrm{kg}}$$

From h_c Results of Microscale Combustion Calorimeter Testing Using Method A

Jaragua 1 – 10735.8 $\frac{\mathrm{J}}{\mathrm{g}}$
Jaragua 2 – 10690.6 $\frac{\mathrm{J}}{\mathrm{g}}$
Jaragua 3 – 9586.5 $\frac{\mathrm{J}}{\mathrm{g}}$
Jaragua 4 – 11666.6 $\frac{\mathrm{J}}{\mathrm{g}}$

Average $h_c = 10669.9\frac{\mathrm{J}}{\mathrm{g}} = 10669.9\frac{\mathrm{kJ}}{\mathrm{kg}}$

Approximating the weight of Jaragua that occupies a square meter of ground space

Average height of Jaragua reaches about 2 meters

Therefore, for every square meter of ground space, the Jaragua occupies 2 cubic meters of volume

For density of Jaragua (based on a 4.3 cm long sample, with diameter of 0.5 cm)

Volume $V = \frac{\pi}{4} * (0.5)^2 * 4.3 = 0.844\ \mathrm{cm}^3$

Approximate mass = 0.1075 grams

Density $D = \frac{0.1075 \text{ g}}{0.844 \text{ cm}^3} = 0.1274 \frac{\text{g}}{\text{cm}^3} = 127.4 \frac{\text{kg}}{\text{m}^3}$

If the Jaragua occupied an entire 2 m^3 solid block, the total mass in the volume would be

$$127.4 \frac{\text{kg}}{\text{m}^3} * 2 \text{ m}^3 = 254.8 \text{ kg}$$

Assuming the actual Jaragua accounts for only 10% of the volume, with 90% comprised of air. We can approximate the total mass of Jaragua per square meter to be

Mass $m = 0.1 * 254.8$ kg = 25.48 kg

If the entirety of this mass were to combust instantaneously it would release about

$$25.48 \text{ kg} * 10669.9 \frac{\text{kJ}}{\text{kg}} = 271869 \text{ kJ}$$

Calculating how much water at 20°C would be evaporated with this amount of thermal energy

$$271869 \text{ kJ} \div 2930.2 \frac{\text{kJ}}{\text{kg}} = 92.78 \text{ kg}$$

92.78 kg of water = 92.78 liters of water needed to extinguish the thermal energy released by a square meter of Jaragua undergoing combustion instantaneously

This calculation is based entirely from the thermal energy released through combustion and the amount of water it would vaporize. It does not take into account the asphyxiation caused by the steam during evaporation, the location in which the water is dispersed, or any other factors that are present during the extinguishing of flames with water. In addition, the accuracy of these calculations is limited by variable densities of the Jaragua, and the results received from the MCC testing. Such factors would need further investigation in order to produce a more precise estimation of the water needed.

Appendix C. Park Ranger Interview Questions Spanish

Hola, somos un grupo de estudiantes universitarios de Worcester Polytechnic Institute de los Estados Unidos que trabajan con la Universidad de Costa Rica. hicimos un estudio de la vegetación para evaluar el riesgo de fuego alrededor de Parque Nacional de Santa Rosa. Nos gustaría entrevistar sobre sus programas educativos y cómo se relacionan con los incendios forestales en el ACG. Nos gustaría utilizar las respuestas dadas a nuestro estudio, que serán publicadas.

Sus respuestas son confidenciales, pero si lo prefiere puede permanecer en el anonimato. Aunque los nombres de nuestro estudio podrían ser útiles para validar la información. Gracias, y su participación es muy apreciada.

1. ¿Cómo se llama?

2. ¿Cuál es su profesión?

3. ¿En su experiencia, cómo ha sido el problema de incendios forestales en la región de Guanacaste?

4. ¿Con qué frecuencia se producen los incendios forestales en el parque (buscala)? En qué época del año se producen con más frecuencia?

5. ¿De qué manera compararía la tendencia de incendios ahora con los de años anteriores? ¿Cuál cree usted que es la razón de esta tendencia?-Guanacaste

6. ¿Cuáles regiones son las de mayor riesgo?

7. ¿Cuáles son las causas más comunes de los incendios forestales?

8. ¿Quién crea la mayor cantidad de los incendios?
   ¿Por qué?

9. ¿Ha tenido alguna experiencia personal frente a los incendios forestales? Si la respuesta es sí, podría explicar el tiempo más reciente o peligrosidad?

10. ¿Se ha hecho algo para ayudar a mitigar estos problemas? Si la respuesta es sí, cuáles son las técnicas de mitigación?

11. ¿Qué tanto funcionan los métodos de prevención de incendios y tácticas de extinción de incendios?

12. ¿En qué áreas necesitan mejorar? Por qué?

13. ¿Puede explicar el protocolo actual para corta fuegos por medio de caminos? ****

14. ¿Puede explicar los niveles del riesgo de incendios? Cómo respondería a cada nivel de fuego?

15. ¿Cómo se siente usted afectando por los incendios forestales?

16. ¿Cómo se afecta el parque nacional por los incendios forestales?

17. ¿Cómo afecta esto a la biodiversidad y el turismo en la región?

18. Si tuviera que elegir sólo uno o dos plantas para estudiar en relación con la susceptibilidad al fuego, cuál de las siguientes escogerías

- Bulbostylis paradoxa
- Hyparrhenia rufa/Jaragua
- Quercus oleoides/Encino Prieto
- Curatella americana/raspa-huacal
- Byrsonima crassifolia/chaparro manteco
- Enterolobium cyclocarpum/Guanacaste Tree
- ¿Piensa que La Casona de Santa Rosa será afectada por un incendio en el futuro? Que se está haciendo actualmente (si es posible) para proteger el monumento?

19. ¿Cómo recluta nuevos voluntarios?

20. ¿Qué es lo que se le enseña a los voluntarios?

21. ¿Por cuánto tiempo se le enseña a los voluntarios?

22. ¿En su experiencia han sido útiles los voluntarios?

23. ¿Cuáles son los programas de extensión comunitaria que están involucrados? (al igual que los programas educativos)

24. Si pudiéramos proporcionar información sobre qué áreas del parque son más susceptibles a los incendios forestales, de cual manera prefiere que se presente la información? (puede escoger más de uno) (Si otra explica por favor):

- Correo Electrónico
- Correo
- Mapa
- Sitio Web
- Conferencia
- Panfelto/Folleto
- Transmisión de Servicio Público
- Reseña
- Catálogo de Vegetación
- Programas Educativos
- Otra

Appendix D. Park Ranger Interview Questions (English)

Hola, somos un grupo de estudiantes universitarios de Worcester Polytechnic Institute de los Estados Unidos que trabajan con la Universidad de Costa Rica. hicimos un estudio de la vegetación para evaluar el riesgo de fuego alrededor de Parque Nacional de Santa Rosa. Nos gustaría entrevistar sobre sus programas educativos y cómo se relacionan con los incendios forestales en el ACG. Nos gustaría utilizar las respuestas dadas a nuestro estudio, que serán publicadas.

Sus respuestas son confidenciales, pero si lo prefiere puede permanecer en el anonimato. Aunque los nombres de nuestro estudio podrían ser útiles para validar la información. Gracias, y su participación es muy apreciada.

1. What is your name?

2. What is your profession?

3. In your experience how have wildfires been an issue to the Park?

4. How frequently do wildfires occur in the forest? In what time of the year are they most frequent?

5. How do the trends of fire compare to years past? What do you think is the reason for this trend?

6. What regions are most at risk?

7. What are the most common causes of wildfires?

8. Who starts the most fires? Why?

9. Do you have any personal experience with forest fires? If yes could you describe the most recent, or dangerous time?

10. What has been done to help mitigate these problems? What are the techniques used to put out the fires?

11. What methods of fire preventino work the best? Why?

12. What areas need to be improved the most? Why?

13. Can you explain the protocols for creating firebreaks and fireroads?

14. Can you explain the levels of fire risk? How do you respond to each level?

15. How are you personally affected by forest fires?

16. How is the park affected by forest fires?

17. What is the effect to the biodiversity and tourism in the area?

18. If you could pick only one or two plants to study from the following list, which would you choose?

- Bulbostylis paradoxa
- Hyparrhenia rufa/Jaragua
- Quercus oleoides/Encino Prieto
- Curatella americana/raspa-huacal
- Byrsonima crassifolia/chaparro manteco
- Enterolobium cyclocarpum/Guanacaste Tree

19. Do you think the La Casona House is in danger of fires again? What is currently done to protect the monument?

19. How do you recruit new volunteers?

20. What are the volunteers taught?

21. How long are the volunteers trained?

22. How are the volunteers helpful?

23. What community outreach programs is the park involved in? (like educational programs)

24. If we could provide information about which areas in the park are more susceptible to forest fires, what would be the preferred way to present the information?

- Email
- Letter
- Map
- Website
- Conference
- Pamphlet
- PSA
- Catalog of vegetation
- Education programs
- other

Appendix E. Interview Questions with Teachers (Spanish)

Hola, somos un grupo de estudiantes universitarios de Worcester Polytechnic Institute de los Estados Unidos que trabajan con la Universidad de Costa Rica. hicimos un estudio de la vegetación para evaluar el riesgo de fuego alrededor de Parque Nacional de Santa Rosa. Nos gustaría entrevistar sobre sus programas educativos y cómo se relacionan con los incendios forestales en el ACG. Nos gustaría utilizar las respuestas dadas a nuestro estudio, que serán publicadas.

Sus respuestas son confidenciales, pero si lo prefiere puede permanecer en el anonimato. Aunque los nombres de nuestro estudio podrían ser útiles para validar la información. Gracias, y su participación es muy apreciada.

1. ¿Cuál es su nombre?
2. ¿Cuál es su ocupación?
3. ¿Dónde enseña?
4. ¿Hace cuanto que enseñas?
5. ¿Cuanto tiempo enseñas en Guanacaste?
6. what do the lesson plans look like (what is taught in the programs) → ¿En los clases cuál es el plan de estudios?
7. What are the most important ideas students should get from a class → ¿Cuáles son los temas más importantes para los estudiantes?
8. ¿Qué le enseñan sobre incendios forestales en Costa Rica?
9. ¿Hay usos culturales del fuego?
10. ¿Cómo utiliza el fuego en su vida y casa?
11. ¿Qué sabe usted acerca de los cazadores en las áreas protegidas?
12. ¿Sabe usted cómo afectan los incendios forestales a su comunidad? Cómo, ejemplos?
13. ¿Cómo usaría un plan en una clase normal con sus estudiantes?-general, on any given day
14. ¿Cómo usaría un plan de incendio en una clase normal con sus estudiantes?
15. ¿Hay días en los que ha visitado los parques nacionales con los estudiantes?

16. ¿Cree que algo se podría hacer para mejorar la educación de prevención de incendios?

17. ¿Por qué cree que es importante enseñar sobre los incendios forestales y la prevención?

18. ¿Cuantos estudiantes hay en sus clases?

Appendix F. Interview Questions with Teachers (English)

Hola, somos un grupo de estudiantes universitarios de Worcester Polytechnic Institute de los Estados Unidos que trabajan con la Universidad de Costa Rica. hicimos un estudio de la vegetación para evaluar el riesgo de fuego alrededor de Parque Nacional de Santa Rosa. Nos gustaría entrevistar sobre sus programas educativos y cómo se relacionan con los incendios forestales en el ACG. Nos gustaría utilizar las respuestas dadas a nuestro estudio, que serán publicadas.

Sus respuestas son confidenciales, pero si lo prefiere puede permanecer en el anonimato. Aunque los nombres de nuestro estudio podrían ser útiles para validar la información. Gracias, y su participación es muy apreciada.

1. What is your name?

2. What is your occupation

3. Where do you teach?

4. When did you start teaching?

5. How long have you been teaching in Guanacaste?

6. What is a typical lesson plan like?

7. What are the most important concepts for the student to learn?

8. What is taught about wildfires in the classes

9. Are there cultural reasons behind the use of fire?

10. How do you use fire in you day to day life?

11. What do you know about hunting in protected areas?

12. How do wildfires affect the community? (examples?)

13. On a given day could you describe the lesson plan in the class?

14. How is fire taught about in a regular lesson plan?

15. Are there days when the students visit the National Park?

16. Can something be done to improve fire education in the classes?

17. What is important to teach about wildfires?

18. How many students are in the classes?

Appendix G. Example MCC Raw Data

File Name:	Quercus Oleodies bark B1.txt						
Date:	4-Feb-07						
Operator:							
Test ID:							
Sample ID:							
Sample Mass (mg):	5.77						
Sample Cup Mass (mg):	167.3						
End Total Mass (mg):	167.36						
Heating Rate (C/s):	1						
Combuster Temperature (C):	900						
N2 Flow Rate (cc/min):	80						
O2 Flow Rate (cc/min):	20						
Calibration File:	Coeff 150318.txt						
T Correction Coefficients:	0	0	0				
Time Shift (s):	10						
Pre-Test Comments:							
Post-Test Comments:							
@							
Time (s)	Temperature (C)	N2 Flow (cc/min)	O2 Flow (cc/min)	Total Flow (cc/min)	Oxygen (%)	HRR (W/g)	Heating Rate (C/s)
0	75.846	86.344	19.943	107.492	18.73	-0.106	0.316
0.5	76.135	86.343	19.94	107.489	18.723	0.267	0.35

0.985	76.36	86.341	19.94	107.485	18.728	-0.036	0.383
1.486	76.637	86.337	19.938	107.514	18.725	0.128	0.379
1.986	76.857	86.341	19.94	107.569	18.726	0.072	0.372
2.486	77.081	86.335	19.937	107.643	18.727	0.034	0.35
2.985	77.327	86.329	19.934	107.729	18.722	0.316	0.341
3.485	77.602	86.341	19.935	107.826	18.718	0.525	0.37
3.985	77.798	86.336	19.939	107.896	18.72	0.421	0.37
4.485	78.033	86.339	19.938	107.938	18.724	0.173	0.336
4.985	78.308	86.334	19.938	107.966	18.722	0.303	0.35
5.485	78.6	86.34	19.938	107.991	18.721	0.375	0.402
5.986	78.853	86.34	19.938	108.01	18.722	0.303	0.415
6.486	79.121	86.337	19.939	108.026	18.72	0.394	0.397
6.986	79.429	86.338	19.939	108.045	18.723	0.279	0.408
7.486	79.686	86.34	19.941	108.057	18.723	0.231	0.425
7.986	79.98	86.34	19.936	108.063	18.722	0.291	0.416
8.486	80.27	86.343	19.94	108.068	18.723	0.246	0.423
8.985	80.541	86.346	19.938	108.074	18.725	0.137	0.426
9.485	80.868	86.341	19.941	108.071	18.727	0.06	0.432
9.985	81.146	86.338	19.941	108.071	18.721	0.361	0.448
10.485	81.429	86.339	19.939	108.076	18.728	-0.027	0.435
10.985	81.741	86.337	19.94	108.079	18.717	0.568	0.431
11.485	82.082	86.345	19.939	108.085	18.72	0.409	0.464
11.985	82.387	86.336	19.941	108.093	18.711	0.894	0.484
12.485	82.715	86.34	19.94	108.102	18.725	0.151	0.477
12.985	82.99	86.345	19.941	108.104	18.719	0.483	0.461
13.485	83.324	86.342	19.944	108.113	18.723	0.262	0.451
13.985	83.688	86.346	19.94	108.117	18.723	0.272	0.487
14.485	84.03	86.351	19.937	108.119	18.722	0.289	0.523

Appendix H. Equations for MCC and Corresponding Values for Method A and Method B

Equations for MCC results:

Specific Heat Release Rate Q(t) W/g

$$Q(t) = \frac{E\rho F}{m_o}\Delta[O_2]$$

Heat release capacity

$$\eta_c = \frac{Q_{max}}{\beta}$$

Pyrolysis residue

$$Y_p = \frac{m_p}{m_o}$$

Specific heat of combustion

$$h_{c,\ gas} = \frac{h_c}{1 - Y_p}$$

Combustion Residue

$$Y_c = \frac{m_c}{m_o}$$

Method A:

Sample	Qmax	Bavg	nc	mo	mp	Yp	hc	hcgas		Qmax avg
Jaragua 1	104.648	0.0493	2123.3	8.99	2.54	0.2825	10735.8	14963.5		
Jaragua 2	121.891	0.5882	207.2	8.01	1.7	0.212	10690.6	13570.8		
Jaragua 3	90.138	0.9303	96.89	5.87	1.63	0.277	9586.5	13271.8		
Jaragua 4	129.875	0.9474	137.08	4.95	1.34	0.271	11666.6	15997.1		111.638
QO Bark 1	126.785	0.9344	135.68	5.17	0.98	0.189	15068.6	18593		
QO Bark 2	81.61	0.9362	87.17	9.96	2.75	0.276	12170.5	16812.5		
QO Bark 3	115.25	0.9339	123.41	8.5	1.76	0.207	12038.9	15182.6		
QO Bark 4	78.6	0.2337	336.32	6.19	1.52	0.246	12233.7	16215.6		100.56125
QO Wood 1	146.66	0.8962	163.64	7.64	1.47	0.192	11058	13692.6		
QO Wood 2	167.75	0.9362	179.18	7.67	1.51	0.197	11374.4	14162.6		
QO Wood 3	170.58	0.9511	179.35	6.79	1.42	0.209	11203.4	14165.9		
QO Wood 4	188.4	0.9531	197.67	7.29	1.4	0.192	12703.4	15722.9		168.3475
QO Leaf 1	100.24	0.5481	182.9	4.48	0.95	0.212	13336.2	16925.2		
QO Leaf 2	100.56	0.9382	107.18	4.33	0.88	0.203	12806.4	16072.9		
QO Leaf 3	95.43	0.9474	100.72	4.34	1.05	0.242	13232.5	17455.6		
QO Leaf 4	104.97	0.9413	111.51	3.9	1.12	0.287	12318.1	17280.8		100.3

Method B:

Species	Trial Number	Qmax	Net Calorific Heat	Combustion Temp (C)
Quercus Oleoides Bark	4	227.90	17748.89	333.517
	3	117.79	19412.23	476.859
	2	8.19	455.45	
	1	375.49	23046.30	284.87
	avg	**182.34**	**15165.72**	**273.81**
Quercus Oleoides wood	4	161.82	17305.05	343.502
	3	188.67	18789.66	341.684
	2	222.40	17943.45	404.005
	1	194.32	18495.41	330.15
	avg	**191.80**	**18133.39**	**354.84**
Quercus Oleoides leaf	4	191.66	16970.64	435.462
	3	172.79	15684.31	413.698
	2	180.51	15758.84	446.847
	1	178.31	17208.81	436.523
	avg	**180.82**	**16405.65**	**433.13**
jaragua	4	647.44	16865.04	289.857
	3	146.32	14709.95	312.598
	2	149.02	14526.19	382.642
	1	126.84	13737.50	326.825
	avg	**267.41**	**14959.67**	**327.98**

Appendix I. Optical Smoke Density Data

Smoke Density Chamber Single Specimen Report

Standard	: ASTM E 662
Laboratory	: LAPCI
Date of test	: Apr. 14 2016
Specimen description	: Quercus Oleoides with Grain
Test name	: Species3-Test2
File name	: C:\SMOKEBOX\DATA\Astme662\16040003.SBA
Thickness (mm)	: 20
Initial mass (g)	: 189.34
Final mass (g)	:
Mass in drip tray (g)	:
Mass loss (g)	:
Mass loss (%)	:
Test mode	: Non-flaming
Test duration	: 33 minutes 20 seconds (2000 s)
Conditioned?	: No
Conditioning temp. (°C)	: N/A
Conditioning RH (%)	: N/A

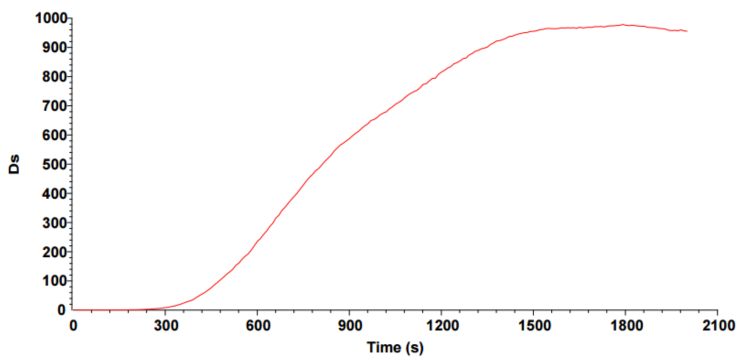
Test Results

Maximum specific optical density	: 978.86
Time to maximum specific optical density	: 29 minutes 49 seconds (1789 s)
Clear beam transmission (%)	: 71.13
Clear beam specfic optical density	: 19.53
Corrected maximum specific optical density	: 959.33

Additional Parameters

Time to Ds=16	: 5 minutes 36 seconds (336 s)
Smoke obscuration index	: 103.8
Specific optical density at 1.5 minutes	: 0.53
Specific optical density at 4 minutes	: 2.79

Specific Optical Density Graph



Test name : Species3-Test2
File name : C:\SMOKEBOX\DATA\Astme662\16040003.SBA

Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	99.4	0.3702	1230	4.79E-05	834.2
60	99.2	0.4566	1260	3.43E-05	853.4
90	99.1	0.5258	1290	2.38E-05	874.2
120	99	0.596	1320	1.82E-05	889.8
150	98.8	0.6673	1350	1.48E-05	901.6
180	98.3	0.9649	1380	1.04E-05	921.9
210	97.4	1.525	1410	8.78E-06	931.4
240	95.3	2.788	1440	7.25E-06	942.4
270	91.5	5.077	1470	6.31E-06	950.4
300	86.3	8.448	1500	5.83E-06	954.9
330	78.1	14.2	1530	5.19E-06	961.6
360	65.6	24.18	1560	4.97E-06	964
390	54	35.33	1590	4.72E-06	967.1
420	38.1	55.38	1620	4.75E-06	966.6
450	26.1	76.92	1650	4.56E-06	969
480	16.3	104	1680	4.53E-06	969.3
510	10.2	131.1	1710	4.42E-06	970.8
540	6.04	160.9	1740	4.26E-06	972.9
570	3.47	192.8	1770	4.12E-06	974.8
600	1.64	235.5	1800	4.02E-06	976.2
630	0.886	270.9	1830	4.1E-06	975.1
660	0.411	315	1860	4.28E-06	972.7
690	0.214	352.5	1890	4.68E-06	967.5
720	0.113	389.2	1920	4.96E-06	964.2
750	0.0567	428.5	1950	5.56E-06	957.6
780	0.0299	465.1	1980	5.34E-06	960
810	0.017	497.5			
840	0.00952	530.8			
870	0.00523	565.2			
900	0.00354	587.6			
930	0.00229	612.5			
960	0.00145	638.6			
990	0.00101	659.6			
1020	0.000712	679.5			
1050	0.000455	705.2			
1080	0.000309	727.4			
1110	0.000214	748.4			
1140	0.000139	773.1			
1170	9.71E-05	793.7			
1200	6.62E-05	815.6			

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 15 2016

Specimen description : Quercus Oleoides against Grain
Test name : Specieas3-Test3
File name : C:\SMOKEBOX\DATA\Astme662\16040004.SBA

Thickness (mm) : 19.5
Initial mass (g) : 193.61
Final mass (g) : 132.93
Mass in drip tray (g) : 0
Mass loss (g) : 60.68
Mass loss (%) : 31.3

Test mode : Non-flaming
Test duration : 43 minutes 50 seconds (2630 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

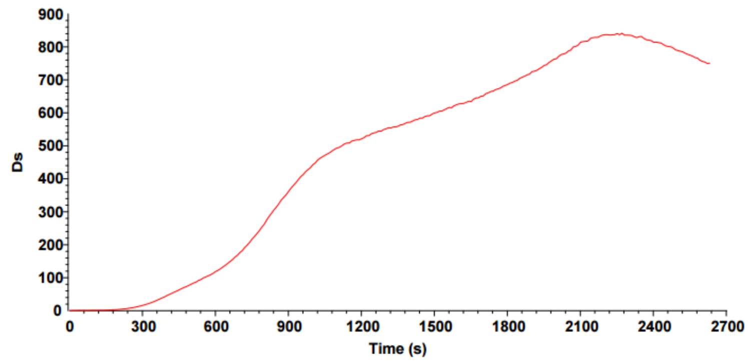
Test Results

Maximum specific optical density : 841.36
Time to maximum specific optical density : 37 minutes 50 seconds (2270 s)
Clear beam transmission (%) : 85.83
Clear beam specfic optical density : 8.76
Corrected maximum specific optical density : 832.6

Additional Parameters

Time to Ds=16 : 4 minutes 60 seconds (300 s)
Smoke obscuration index : 55.7
Specific optical density at 1.5 minutes : 1.17
Specific optical density at 4 minutes : 7.02

Specific Optical Density Graph



Test name : Specieas3-Test3
File name : C:\SMOKEBOX\DATA\Astme662\16040004.SBA

Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	98.5	0.8429	1830	0.000533	696.1
60	98.2	1.065	1860	0.000434	707.9
90	98	1.168	1890	0.000366	717.6
120	97.7	1.34	1920	0.000301	728.9
150	96.9	1.808	1950	0.000233	743.5
180	95.4	2.727	1980	0.000182	757.5
210	92.7	4.363	2010	0.000143	771.4
240	88.5	7.023	2040	0.000121	781.3
270	82.8	10.82	2070	8.7E-05	800
300	75.6	16.03	2100	6.77E-05	814.3
330	67.1	22.89	2130	6.39E-05	817.7
360	57.1	32.12	2160	5.26E-05	828.9
390	48.4	41.55	2190	4.66E-05	835.7
420	40	52.46	2220	4.65E-05	835.9
450	33.3	63.08	2250	4.3E-05	840.3
480	27.9	73.16	2280	4.67E-05	835.7
510	23.1	84.02	2310	4.78E-05	834.4
540	19.3	94.45	2340	5.09E-05	830.7
570	15.8	105.9	2370	5.98E-05	821.5
600	12.7	118.5	2400	6.79E-05	814.2
630	9.88	132.7	2430	7.09E-05	811.7
660	7.4	149.3	2460	8.49E-05	801.4
690	5.32	168.2	2490	0.000102	791
720	3.54	191.5	2520	0.000113	785
750	2.26	217.3	2550	0.000135	774.6
780	1.45	242.6	2580	0.000158	765.8
810	0.824	275.1	2610	0.000195	753.8
840	0.483	305.7			
870	0.287	335.6			
900	0.182	361.6			
930	0.116	387.7			
960	0.0745	412.9			
990	0.0517	433.8			
1020	0.0344	457.1			
1050	0.0267	471.6			
1080	0.0211	485.2			
1110	0.0176	495.5			
1140	0.014	508.6			
1170	0.0123	516.3			
1200	0.0112	521.6			
1230	0.00952	530.8			
1260	0.00805	540.4			
1290	0.00693	549.1			
1320	0.00635	554.1			
1350	0.0058	559.2			
1380	0.00495	568.4			
1410	0.00439	575.2			
1440	0.00378	583.7			
1470	0.00334	590.9			
1500	0.00286	599.8			
1530	0.0026	605.3			
1560	0.00214	616.5			
1590	0.00186	624.5			
1620	0.00172	628.8			
1650	0.00157	634.2			
1680	0.00129	645.5			
1710	0.00104	658			
1740	0.000904	665.8			
1770	0.000767	675.2			
1800	0.000637	685.8			

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 16 2016

Specimen description : Quercus Oleoides Perpendicular to the grain
Test name : Species3-Test4
File name : C:\SMOKEBOX\DATA\Astme662\16040005.SBA

Thickness (mm) : 19
Initial mass (g) : 190.168
Final mass (g) : 124.99
Mass in drip tray (g) : 0
Mass loss (g) : 65.178
Mass loss (%) : 34.3

Test mode : Non-flaming
Test duration : 50 minutes (3000 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

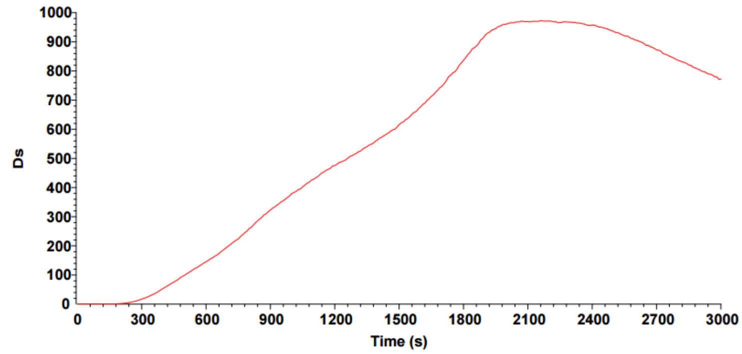
Test Results

Maximum specific optical density : 972.7
Time to maximum specific optical density : 36 minutes (2160 s)
Clear beam transmission (%) : 83.42
Clear beam specfic optical density : 10.39
Corrected maximum specific optical density : 962.3

Additional Parameters

Time to Ds=16 : 4 minutes 55 seconds (295 s)
Smoke obscuration index : 71.4
Specific optical density at 1.5 minutes : 0.11
Specific optical density at 4 minutes : 5.46

Specific Optical Density Graph



Test name : Species3-Test4
File name : C:\SMOKEBOX\DATA\Astme662\16040005.SBA

Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	100	0	1830	2.86E-05	863.8
60	100	0	1860	1.96E-05	885.4
90	99.8	0.1	1890	1.24E-05	911.7
120	99.6	0.2	1920	8.63E-06	932.4
150	99.2	0.5	1950	6.89E-06	945.3
180	98.4	0.9	1980	5.54E-06	957.8
210	95.9	2.4	2010	5.03E-06	963.3
240	90.9	5.5	2040	4.74E-06	966.8
270	83.8	10.1	2070	4.38E-06	971.3
300	73.9	17.3	2100	4.52E-06	969.5
330	64.3	25.3	2130	4.45E-06	970.4
360	53.8	35.5	2160	4.28E-06	972.7
390	42.1	49.5	2190	4.39E-06	971.2
420	33.5	62.8	2220	4.57E-06	968.9
450	26.7	75.6	2250	4.81E-06	966
480	20.5	90.9	2280	4.63E-06	968.2
510	16.2	104.3	2310	4.77E-06	966.4
540	12.6	118.8	2340	4.92E-06	964.7
570	10.1	131.6	2370	5.48E-06	958.5
600	7.92	145.4	2400	5.52E-06	958
630	6.27	158.8	2430	6.28E-06	950.6
660	4.86	173.4	2460	6.79E-06	946.2
690	3.54	191.5	2490	7.76E-06	938.6
720	2.64	208.3	2520	8.8E-06	931.4
750	2.02	223.7	2550	1.07E-05	920.1
780	1.39	245.1	2580	1.24E-05	911.7
810	1	263.9	2610	1.4E-05	904.8
840	0.68	286.1	2640	1.67E-05	894.7
870	0.477	306.4	2670	2.04E-05	883.1
900	0.357	323.1	2700	2.48E-05	871.9
930	0.267	339.7	2730	3.07E-05	859.6
960	0.205	354.9	2760	3.59E-05	850.8
990	0.152	371.8	2790	4.33E-05	840
1020	0.117	387.1	2820	5.07E-05	830.9
1050	0.0889	402.7	2850	6.11E-05	820.2
1080	0.0686	417.6	2880	7.26E-05	810.4
1110	0.0523	433.1	2910	8.82E-05	799.2
1140	0.0387	450.4	2940	0.000104	789.8
1170	0.0312	462.8	2970	0.000123	780.1
1200	0.025	475.5	3000	0.000142	772.1
1230	0.0201	488			
1260	0.0162	500.3			
1290	0.0128	513.8			
1320	0.0105	525.4			
1350	0.00807	540.3			
1380	0.00651	552.6			
1410	0.00483	569.7			
1440	0.00383	583			
1470	0.00296	597.9			
1500	0.00216	615.8			
1530	0.00161	632.9			
1560	0.00115	652.2			
1590	0.00083	670.7			
1620	0.000595	689.8			
1650	0.000398	712.8			
1680	0.000273	734.5			
1710	0.000185	756.9			
1740	0.000113	785.2			
1770	7.72E-05	806.9			
1800	4.59E-05	836.7			

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 16 2016

Specimen description : Quercus Oleoides Perpendicular to Grain
Test name : Quercus Oleoides Perpendicular Test 6
File name : C:\SMOKEBOX\DATA\Astme662\16040008.SBA

Thickness (mm) : 20
Initial mass (g) : 194.178
Final mass (g) : 138.2
Mass in drip tray (g) : 0
Mass loss (g) : 55.978
Mass loss (%) : 28.8

Test mode : Non-flaming
Test duration : 38 minutes 50 seconds (2330 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

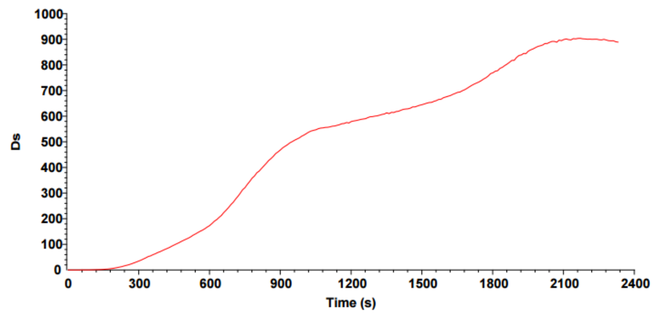
Test Results

Maximum specific optical density : 905.03
Time to maximum specific optical density : 36 minutes 01 seconds (2161 s)
Clear beam transmission (%) : 91.66
Clear beam specfic optical density : 4.99
Corrected maximum specific optical density : 900.04

Additional Parameters

Time to Ds=16 : 3 minutes 60 seconds (240 s)
Smoke obscuration index : 83.4
Specific optical density at 1.5 minutes : 0.4
Specific optical density at 4 minutes : 16.22

Specific Optical Density Graph



Test name : Quercus Oleoides Perpendicular Test 6
File name : C:\SMOKEBOX\DATA\Astme662\16040008.SBA

Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	100	0	1230	0.00371	584.8
60	99.6	0.2	1260	0.00338	590.2
90	99.3	0.4	1290	0.00294	598.3
120	98.2	1	1320	0.00266	603.9
150	96	2.3	1350	0.00227	613.1
180	91.9	4.8	1380	0.00222	614.2
210	84.9	9.4	1410	0.00191	623
240	75.4	16.2	1440	0.00173	628.7
270	65.5	24.2	1470	0.00152	636.1
300	54.5	34.8	1500	0.0013	645.1
330	43.9	47.2	1530	0.00113	653.2
360	35.5	59.4	1560	0.00099	660.6
390	28.9	71.2	1590	0.000809	672.2
420	23.2	83.8	1620	0.0007	680.5
450	18.3	97.4	1650	0.000564	692.9
480	14.4	111	1680	0.000472	703.1
510	11.4	124.3	1710	0.00035	720.1
540	8.62	140.5	1740	0.000279	733.2
570	6.66	155.3	1770	0.000209	749.8
600	4.9	172.9	1800	0.000148	769.6
630	3.26	196.2	1830	0.00011	786.6
660	2.01	223.9	1860	8.21E-05	803.3
690	1.18	254.7	1890	6.37E-05	817.9
720	0.663	287.6	1920	4.41E-05	838.9
750	0.367	321.5	1950	3.38E-05	854.2
780	0.194	358	1980	2.68E-05	867.6
810	0.119	385.8	2010	2.25E-05	877.4
840	0.0701	416.3	2040	1.86E-05	888.3
870	0.0436	443.6	2070	1.85E-05	888.6
900	0.0283	468.4	2100	1.55E-05	899.1
930	0.0197	489	2130	1.58E-05	897.8
960	0.0146	506.4	2160	1.43E-05	903.5
990	0.0111	522	2190	1.48E-05	901.5
1020	0.00841	537.9	2220	1.52E-05	900
1050	0.00717	547.1	2250	1.56E-05	898.4
1080	0.0063	554.5	2280	1.6E-05	897
1110	0.00587	558.5	2310	1.68E-05	894.4
1140	0.0053	564.4			
1170	0.00469	571.4			
1200	0.00409	579.2			

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 16 2016

Specimen description : Oleoides Quercus against Grain
Test name : Species3-Test5
File name : C:\SMOKEBOX\DATA\Astme662\16040006.SBA

Thickness (mm) : 19
Initial mass (g) : 183.21
Final mass (g) : 120.121
Mass in drip tray (g) : 0
Mass loss (g) : 63.089
Mass loss (%) : 34.4

Test mode : Non-flaming
Test duration : 36 minutes 40 seconds (2200 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

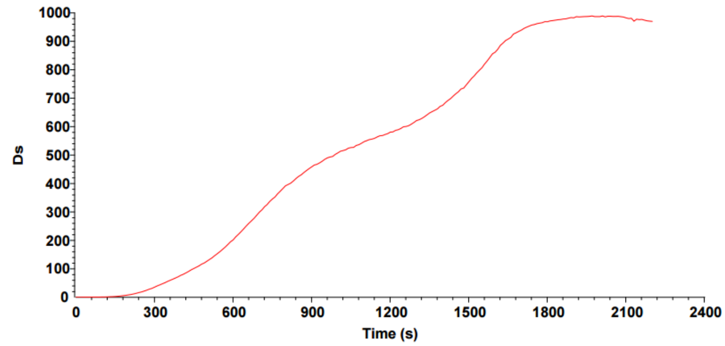
Test Results

Maximum specific optical density : 990.09
Time to maximum specific optical density : 33 minutes 35 seconds (2015 s)
Clear beam transmission (%) : 88.92
Clear beam specfic optical density : 6.73
Corrected maximum specific optical density : 983.35

Additional Parameters

Time to Ds=16 : 3 minutes 59 seconds (239 s)
Smoke obscuration index : 108.2
Specific optical density at 1.5 minutes : 0.99
Specific optical density at 4 minutes : 16.42

Specific Optical Density Graph



Test name : Species3-Test5
File name : C:\SMOKEBOX\DATA\Astme662\16040006.SBA

Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	99.1	0.5076	1230	0.00345	589.1
60	98.8	0.6825	1260	0.00283	600.4
90	98.3	0.9884	1290	0.00222	614.4
120	97.4	1.502	1320	0.00173	628.7
150	95.1	2.901	1350	0.00123	648.2
180	90.7	5.61	1380	0.000956	662.6
210	84.3	9.809	1410	0.000655	684.3
240	75.1	16.42	1440	0.000437	707.4
270	65.1	24.65	1470	0.000283	732.4
300	53.6	35.72	1500	0.00018	758.2
330	43.6	47.57	1530	0.000105	789.2
360	35.3	59.76	1560	6.11E-05	820.3
390	28.4	72.17	1590	3.27E-05	856.1
420	22.5	85.61	1620	1.95E-05	885.8
450	17.1	101.2	1650	1.32E-05	907.9
480	13.1	116.7	1680	9.02E-06	929.9
510	9.81	133.1	1710	6.91E-06	945.2
540	6.86	153.6	1740	5.6E-06	957.2
570	4.59	176.6	1770	4.99E-06	963.9
600	2.97	201.5	1800	4.55E-06	969.1
630	1.79	230.6	1830	4.16E-06	974.2
660	1.07	260.2	1860	3.87E-06	978.5
690	0.655	288.2	1890	3.55E-06	983.4
720	0.386	318.6	1920	3.4E-06	985.8
750	0.241	345.5	1950	3.32E-06	987.2
780	0.149	373	1980	3.34E-06	986.9
810	0.0989	396.7	2010	3.21E-06	989.1
840	0.0686	417.6	2040	3.27E-06	988.1
870	0.0477	438.5	2070	3.29E-06	987.7
900	0.0335	458.8	2100	3.62E-06	982.3
930	0.0262	472.7	2130	4.42E-06	970.9
960	0.0193	490.4	2160	3.97E-06	977
990	0.0156	502.6	2190	4.4E-06	971.1
1020	0.0123	516			
1050	0.0103	526.4			
1080	0.00861	536.6			
1110	0.00674	550.6			
1140	0.00583	559			
1170	0.00492	568.6			
1200	0.00398	580.7			

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 16 2016

Specimen description : Quercus Oleoides Perpendicular to the Grain
Test name : Quercus Perpendicular Test 5
File name : C:\SMOKEBOX\DATA\Astme662\16040007.SBA

Thickness (mm) : 20
Initial mass (g) : 184.22
Final mass (g) : 122.3
Mass in drip tray (g) : 0
Mass loss (g) : 61.92
Mass loss (%) : 33.6

Test mode : Non-flaming
Test duration : 35 minutes 20 seconds (2120 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

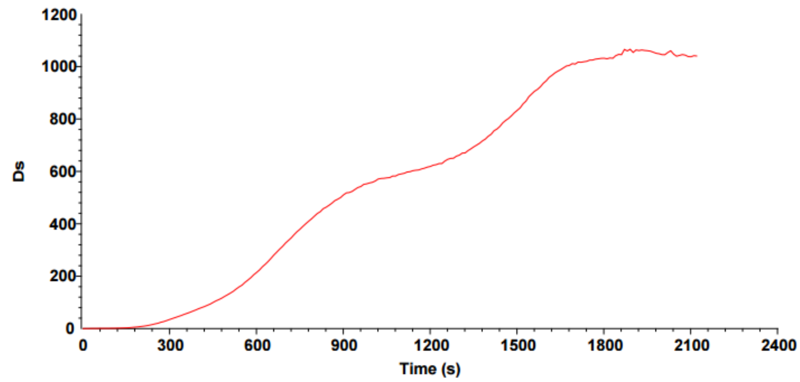
Test Results

Maximum specific optical density : 1070.11
Time to maximum specific optical density : 31 minutes 13 seconds (1873 s)
Clear beam transmission (%) : 89.84
Clear beam specfic optical density : 6.14
Corrected maximum specific optical density : 1063.97

Additional Parameters

Time to Ds=16 : 4 minutes 03 seconds (243 s)
Smoke obscuration index : 131.3
Specific optical density at 1.5 minutes : 1.16
Specific optical density at 4 minutes : 15.37

Specific Optical Density Graph



Test name : Quercus Perpendicular Test 5
File name : C:\SMOKEBOX\DATA\Astme662\16040007.SBA

Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	99	0.6013	1230	0.00169	629.8
60	98.5	0.8744	1260	0.00127	646.2
90	98	1.156	1290	0.00104	658
120	97.2	1.625	1320	0.000833	670.5
150	95.2	2.83	1350	0.000556	693.7
180	90.7	5.592	1380	0.000372	716.7
210	85	9.3	1410	0.000239	741.9
240	76.5	15.37	1440	0.000143	771.5
270	65.4	24.3	1470	8.39E-05	802.1
300	54.4	34.95	1500	4.88E-05	833.1
330	44.8	46.04	1530	2.66E-05	868
360	36.2	58.24	1560	1.37E-05	905.8
390	28.9	71.21	1590	8.04E-06	936.5
420	23	84.24	1620	4.74E-06	966.8
450	17.6	99.67	1650	3.25E-06	988.3
480	13.1	116.4	1680	2.46E-06	1004
510	9.34	135.9	1710	1.97E-06	1017
540	6.19	159.5	1740	1.87E-06	1020
570	3.96	185.1	1770	1.62E-06	1028
600	2.4	213.9	1800	1.53E-06	1032
630	1.38	245.5	1830	1.53E-06	1032
660	0.745	280.9	1860	1.2E-06	1046
690	0.418	314	1890	8.4E-07	1066
720	0.237	346.6	1920	9.13E-07	1061
750	0.134	379.4	1950	9.23E-07	1061
780	0.0783	410	1980	1.1E-06	1051
810	0.0471	439.2	2010	1.2E-06	1046
840	0.031	463.1	2040	1.17E-06	1047
870	0.02	488.3	2070	1.2E-06	1046
900	0.0136	510.2	2100	1.38E-06	1038
930	0.0107	523.9			
960	0.00779	542.3			
990	0.00615	555.9			
1020	0.00473	570.9			
1050	0.00436	575.5			
1080	0.00389	582.1			
1110	0.00323	592.8			
1140	0.00272	602.6			
1170	0.00241	609.7			
1200	0.00205	618.9			

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 19 2016

Specimen description : Quercus Oleoides Perpendicular to Grain
Test name : Quercus Oleoides Perpendicular Test 7
File name : C:\SMOKEBOX\DATA\Astme662\16040009.SBA

Thickness (mm) : 18.5
Initial mass (g) : 174.03
Final mass (g) : 105.27
Mass in drip tray (g) : 0
Mass loss (g) : 68.76
Mass loss (%) : 39.5

Test mode : Non-flaming
Test duration : 43 minutes 20 seconds (2600 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

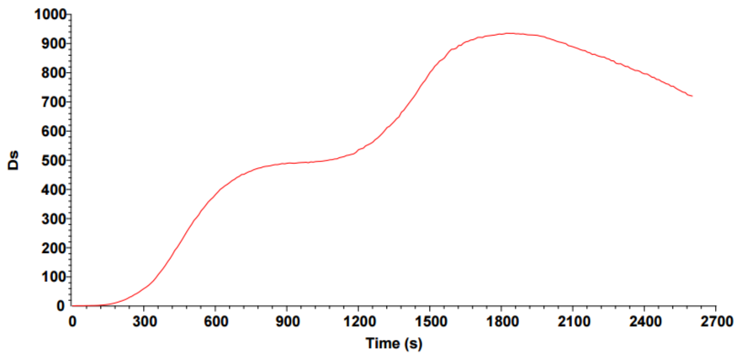
Test Results

Maximum specific optical density : 936.34
Time to maximum specific optical density : 30 minutes 35 seconds (1835 s)
Clear beam transmission (%) : 82.23
Clear beam specfic optical density : 11.21
Corrected maximum specific optical density : 925.13

Additional Parameters

Time to Ds=16 : 3 minutes 20 seconds (200 s)
Smoke obscuration index : 141.7
Specific optical density at 1.5 minutes : 1.83
Specific optical density at 4 minutes : 30.08

Specific Optical Density Graph



Test name : Quercus Oleoides Perpendicular Test 7
File name : C:\SMOKEBOX\DATA\Astme662\16040009.SBA

Tabulated Results

Time (s)	T (%)	Ds
0	100.0	0.0
30	98.1	1.095
60	97.6	1.375
90	96.9	1.828
120	94.9	3.013
150	90.4	5.787
180	82.7	10.91
210	72.5	18.42
240	59.2	30.08
270	47.3	42.97
300	35.2	59.79
330	25.4	78.51
360	15.3	107.6
390	8.8	139.3
420	4.58	176.7
450	2.38	214.3
480	1.18	254.7
510	0.597	293.6
540	0.338	326.1
570	0.197	357.1
600	0.128	381.9
630	0.0845	405.7
660	0.062	423.4
690	0.0459	440.6
720	0.0378	451.7
750	0.0312	462.8
780	0.0263	472.6
810	0.0236	478.8
840	0.0218	483.2
870	0.0206	486.5
900	0.0196	489.5
930	0.0196	489.5
960	0.0188	492
990	0.0189	491.6
1020	0.0177	495.3
1050	0.0173	496.7
1080	0.0159	501.4
1110	0.015	504.9
1140	0.0131	512.7
1170	0.0115	519.8
1200	0.00867	536.2
1230	0.00689	549.4
1260	0.0055	562.2
1290	0.00378	583.8
1320	0.0023	612.2
1350	0.0016	633
1380	0.000926	664.4
1410	0.000555	693.7
1440	0.000314	726.4
1470	0.00016	765.1
1500	8.54E-05	801
1530	5.17E-05	829.8
1560	3.6E-05	850.5
1590	2.14E-05	880.5
1620	1.7E-05	893.5
1650	1.37E-05	905.9
1680	1.21E-05	913.1
1710	1.05E-05	921.5
1740	9.61E-06	926.3
1770	9.16E-06	929.1
1800	8.71E-06	931.9

Time (s)	T (%)	Ds
1830	8.27E-06	934.9
1860	8.48E-06	933.4
1890	8.52E-06	933.2
1920	9.06E-06	929.6
1950	9.3E-06	928.1
1980	1.02E-05	923.1
2010	1.18E-05	914.3
2040	1.37E-05	905.8
2070	1.53E-05	899.6
2100	1.85E-05	888.7
2130	2.19E-05	879.1
2160	2.55E-05	870.3
2190	2.89E-05	863.2
2220	3.38E-05	854.2
2250	3.85E-05	846.7
2280	4.94E-05	832.4
2310	5.57E-05	825.5
2340	6.69E-05	815
2370	7.66E-05	807.3
2400	9.34E-05	795.9
2430	0.000113	785
2460	0.000132	776
2490	0.000167	762.5
2520	0.000196	753.5
2550	0.000255	738.3
2580	0.000326	724.2

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 19 2016

Specimen description : Quercus Oleoides Parallel to Gran
Test name : Quercus Oleoides Parallel Test 8
File name : C:\SMOKEBOX\DATA\Astme662\16040010.SBA

Thickness (mm) : 22
Initial mass (g) : 202.53
Final mass (g) : 113.11
Mass in drip tray (g) : 0
Mass loss (g) : 89.42
Mass loss (%) : 44.2

Test mode : Non-flaming
Test duration : 41 minutes 50 seconds (2510 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

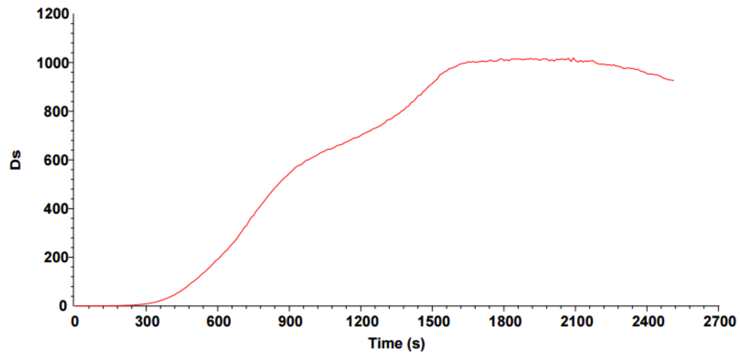
Test Results

Maximum specific optical density : 1022.81
Time to maximum specific optical density : 32 minutes 42 seconds (1962 s)
Clear beam transmission (%) : 86.25
Clear beam specfic optical density : 8.48
Corrected maximum specific optical density : 1014.33

Additional Parameters

Time to Ds=16 : 5 minutes 39 seconds (339 s)
Smoke obscuration index : 97.3
Specific optical density at 1.5 minutes : 0.97
Specific optical density at 4 minutes : 3.55

Specific Optical Density Graph



Test name : Quercus Oleoides Parallel Test 8
File name : C:\SMOKEBOX\DATA\Astme662\16040010.SBA

Tabulated Results

Time (s)	T (%)	Ds
0	100.0	0.0
30	98.9	0.648
60	98.6	0.8029
90	98.3	0.9658
120	98.2	1.058
150	97.9	1.216
180	97.4	1.534
210	96.1	2.278
240	94	3.549
270	90.1	5.957
300	85.1	9.219
330	78.5	13.89
360	67.7	22.32
390	56.1	33.13
420	44.2	46.83
450	31.8	65.76
480	21.8	87.3
510	14.5	110.7
540	9.3	136.2
570	5.73	163.9
600	3.49	192.3
630	2.03	223.5
660	1.17	255
690	0.607	292.7
720	0.317	330
750	0.149	373.1
780	0.075	412.5
810	0.0379	451.6
840	0.0206	486.5
870	0.0118	518.4
900	0.0074	545.2
930	0.00461	572.4
960	0.00343	589.3
990	0.00253	606.9
1020	0.00192	622.5
1050	0.00148	637.6
1080	0.00125	647.2
1110	0.000971	661.7
1140	0.000774	674.7
1170	0.000592	690.1
1200	0.000487	701.2
1230	0.000375	716.2
1260	0.000292	730.5
1290	0.000221	746.6
1320	0.000156	766.6
1350	0.000113	785.2
1380	7.88E-05	805.6
1410	4.68E-05	835.5
1440	2.83E-05	864.4
1470	1.89E-05	887.6
1500	1.17E-05	915.2
1530	6.4E-06	949.6
1560	4.81E-06	966
1590	3.71E-06	980.9
1620	2.91E-06	994.7
1650	2.49E-06	1004
1680	2.63E-06	1001
1710	2.4E-06	1006
1740	2.25E-06	1010
1770	2.36E-06	1007
1800	2.32E-06	1008
1830	2.05E-06	1015
1860	2.05E-06	1015
1890	2.07E-06	1014
1920	2.08E-06	1014
1950	2.27E-06	1009
1980	2.11E-06	1013
2010	2.42E-06	1005
2040	2.04E-06	1015
2070	1.98E-06	1017
2100	2.36E-06	1007
2130	2.55E-06	1002
2160	2.38E-06	1006
2190	2.83E-06	996.4
2220	3.02E-06	992.6
2250	3.27E-06	988
2280	3.49E-06	984.4
2310	4.04E-06	975.9
2340	4.07E-06	975.5
2370	4.84E-06	965.6
2400	5.97E-06	953.5
2430	6.37E-06	949.9
2460	7.49E-06	940.6
2490	9.18E-06	928.9

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 20 2016

Specimen description : Quercus Oleoides Parallel to Grain
Test name : Quercus Oleoides Parallel Test 9
File name : C:\SMOKEBOX\DATA\Astme662\16040011.SBA

Thickness (mm) : 21
Initial mass (g) : 191.299
Final mass (g) : 132.57
Mass in drip tray (g) : 0
Mass loss (g) : 58.729
Mass loss (%) : 30.7

Test mode : Non-flaming
Test duration : 37 minutes 50 seconds (2270 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

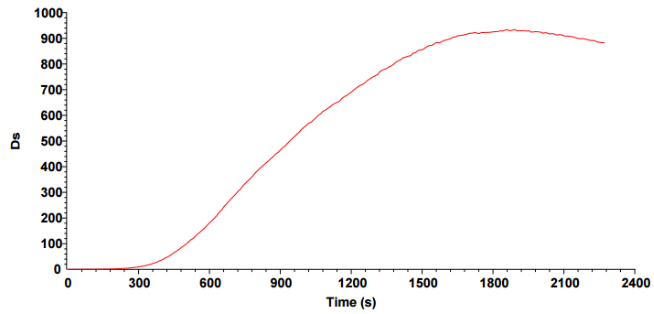
Test Results

Maximum specific optical density : 933.61
Time to maximum specific optical density : 31 minutes 30 seconds (1890 s)
Clear beam transmission (%) : 92.07
Clear beam specfic optical density : 4.74
Corrected maximum specific optical density : 928.88

Additional Parameters

Time to Ds=16 : 5 minutes 32 seconds (332 s)
Smoke obscuration index : 80.9
Specific optical density at 1.5 minutes : 0.51
Specific optical density at 4 minutes : 3.82

Specific Optical Density Graph



Test name : Quercus Oleoides Parallel Test 9
File name : C:\SMOKEBOX\DATA\Astme662\16040011.SBA

Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	99.5	0.2958	1230	0.000398	712.9
60	99.2	0.4624	1260	0.000294	730.2
90	99.1	0.5128	1290	0.000213	748.6
120	98.8	0.6914	1320	0.000146	770.3
150	98.4	0.9131	1350	0.000117	783.1
180	97.6	1.405	1380	8.7E-05	800
210	96.2	2.249	1410	6.35E-05	818
240	93.6	3.818	1440	5.11E-05	830.5
270	89.8	6.167	1470	4.05E-05	843.8
300	84.4	9.704	1500	3.31E-05	855.3
330	76.9	15.08	1530	2.49E-05	871.8
360	67.1	22.91	1560	2E-05	884.3
390	55.6	33.66	1590	1.77E-05	891.3
420	43.6	47.58	1620	1.54E-05	899.1
450	32.3	64.86	1650	1.27E-05	910.1
480	22.6	85.25	1680	1.18E-05	914.5
510	15.9	105.6	1710	1.08E-05	919.8
540	10.4	129.6	1740	1.1E-05	918.7
570	6.81	154	1770	1.02E-05	922.8
600	4.21	181.6	1800	9.81E-06	925.1
630	2.59	209.4	1830	9.12E-06	929.3
660	1.43	243.7	1860	8.5E-06	933.3
690	0.843	273.8	1890	8.46E-06	933.6
720	0.503	303.3	1920	9.1E-06	929.4
750	0.296	333.8	1950	9.14E-06	929.2
780	0.186	360.3	1980	9.66E-06	926
810	0.109	390.9	2010	1.08E-05	919.9
840	0.0712	415.5	2040	1.14E-05	916.4
870	0.0465	439.9	2070	1.23E-05	912.2
900	0.0298	465.3	2100	1.3E-05	908.8
930	0.0189	491.5	2130	1.34E-05	907.2
960	0.0118	518.3	2160	1.54E-05	899.3
990	0.0072	546.8	2190	1.62E-05	896.4
1020	0.00481	570	2220	1.75E-05	892
1050	0.00335	590.7	2250	2E-05	884.3
1080	0.00215	616.2			
1110	0.00159	633.4			
1140	0.00118	650.6			
1170	0.000799	672.8			
1200	0.000587	690.5			

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : LAPCI
Date of test : Apr. 20 2016

Specimen description : Parallel to grain
Test name : Quecus Oldeidis
File name : C:\SMOKEBOX\DATA\Astme662\16040012.SBA

Thickness (mm) : 16
Initial mass (g) : 171.78
Final mass (g) : 105.117
Mass in drip tray (g) : 0
Mass loss (g) : 66.663
Mass loss (%) : 38.8

Test mode : Non-flaming
Test duration : 45 minutes (2700 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

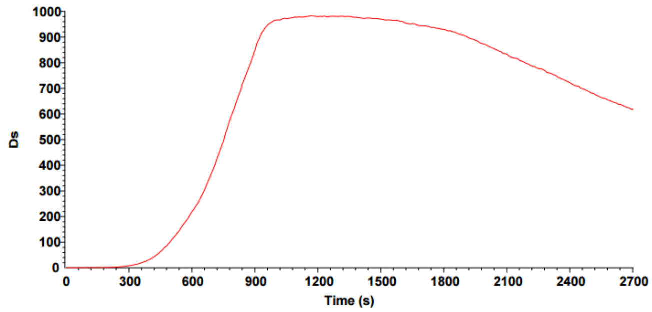
Test Results

Maximum specific optical density : 983.78
Time to maximum specific optical density : 19 minutes 28 seconds (1168 s)
Clear beam transmission (%) : 72.33
Clear beam specfic optical density : 18.57
Corrected maximum specific optical density : 965.21

Additional Parameters

Time to Ds=16 : 5 minutes 45 seconds (345 s)
Smoke obscuration index : 207.8
Specific optical density at 1.5 minutes : 0.34
Specific optical density at 4 minutes : 2.89

Specific Optical Density Graph



Test name : Quecus Oldeidis
File name : C:\SMOKEBOX\DATA\Astme662\16040012.SBA

Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	99.8	0.09754	1830	9.93E-06	924.4
60	99.6	0.2489	1860	1.16E-05	915.7
90	99.4	0.3395	1890	1.33E-05	907.7
120	99.1	0.5172	1920	1.65E-05	895.5
150	98.8	0.7165	1950	1.9E-05	887.1
180	98.2	1.036	1980	2.37E-05	874.6
210	97.1	1.687	2010	2.8E-05	865
240	95.1	2.891	2040	3.42E-05	853.4
270	91.8	4.93	2070	4.06E-05	843.7
300	86.8	8.135	2100	4.9E-05	832.8
330	80.1	12.71	2130	6.34E-05	818.1
360	70.7	19.89	2160	7.48E-05	808.7
390	59.6	29.65	2190	9.06E-05	797.7
420	46.8	43.54	2220	0.00011	786.6
450	33.2	63.27	2250	0.00013	777
480	22.3	86.14	2280	0.000149	769.1
510	13.2	116.1	2310	0.000181	758.1
540	7.94	145.2	2340	0.000231	743.9
570	4.27	180.8	2370	0.000275	733.9
600	2.2	218.9	2400	0.000342	721.5
630	1.16	255.4	2430	0.000426	709
660	0.497	304.1	2460	0.000514	698.1
690	0.174	364.1	2490	0.000623	687.1
720	0.0561	429.1	2520	0.000758	675.9
750	0.018	494.2	2550	0.000942	663.4
780	0.00424	577.2	2580	0.0011	654.5
810	0.00129	645.3	2610	0.0013	645
840	0.00037	717	2640	0.00149	637
870	0.000121	781	2670	0.00182	625.8
900	3.68E-05	849.2	2700	0.00209	617.8
930	1.19E-05	913.9			
960	6.66E-06	947.3			
990	4.97E-06	964.1			
1020	4.79E-06	966.2			
1050	4.34E-06	971.9			
1080	4.05E-06	975.8			
1110	3.83E-06	979			
1140	3.8E-06	979.4			
1170	3.56E-06	983.3			
1200	3.8E-06	979.4			
1230	3.62E-06	982.3			
1260	3.69E-06	981.2			
1290	3.73E-06	980.6			
1320	3.68E-06	981.3			
1350	3.74E-06	980.4			
1380	3.96E-06	977.1			
1410	4.21E-06	973.5			
1440	4.16E-06	974.3			
1470	4.31E-06	972.3			
1500	4.5E-06	969.8			
1530	4.76E-06	966.6			
1560	4.93E-06	964.6			
1590	5.2E-06	961.5			
1620	5.96E-06	953.6			
1650	6.06E-06	952.7			
1680	6.93E-06	945			
1710	7.11E-06	943.6			
1740	7.98E-06	936.9			
1770	8.41E-06	933.9			
1800	9.06E-06	929.7			

Smoke Density Chamber Single Specimen Report

Standard : ASTM E 662
Laboratory : Quercus Oleodis parallel to grain test 11
Date of test : Apr. 20 2016

Specimen description :
Test name : Quercus Oleodis
File name : C:\SMOKEBOX\DATA\Astme662\16040013.SBA

Thickness (mm) : 18.5
Initial mass (g) : 185.377
Final mass (g) : 102.49
Mass in drip tray (g) : 0
Mass loss (g) : 82.887
Mass loss (%) : 44.7

Test mode : Non-flaming
Test duration : 43 minutes 20 seconds (2600 s)
Conditioned? : No
Conditioning temp. (°C) : N/A
Conditioning RH (%) : N/A

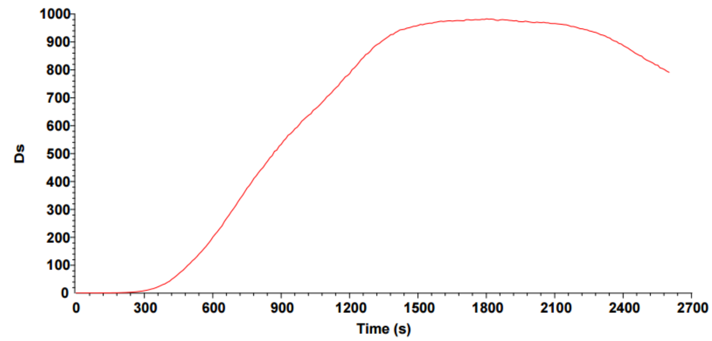
Test Results

Maximum specific optical density : 983.17
Time to maximum specific optical density : 29 minutes 57 seconds (1797 s)
Clear beam transmission (%) : 78.81
Clear beam specfic optical density : 13.65
Corrected maximum specific optical density : 969.52

Additional Parameters

Time to Ds=16 : 5 minutes 37 seconds (337 s)
Smoke obscuration index : 101.6
Specific optical density at 1.5 minutes : 0.71
Specific optical density at 4 minutes : 3.37

Specific Optical Density Graph



Test name : Quercus Oleodis
File name : C:\SMOKEBOX\DATA\Astme662\16040013.SBA

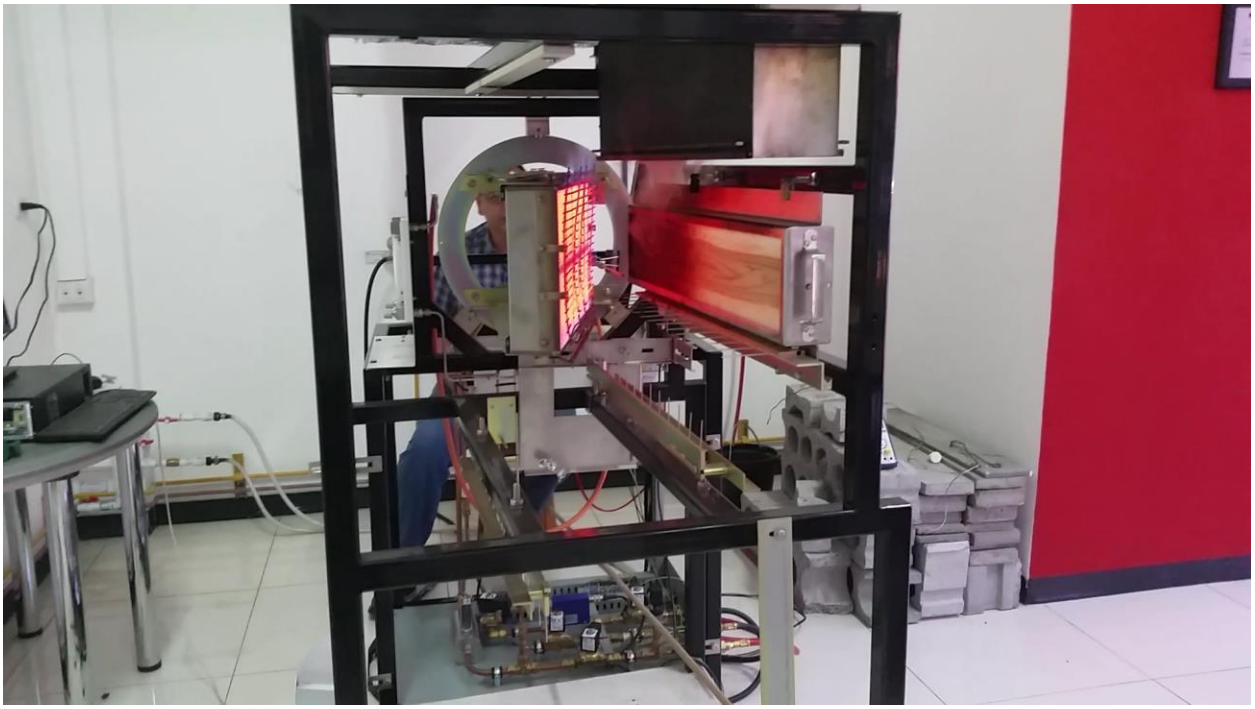
Tabulated Results

Time (s)	T (%)	Ds	Time (s)	T (%)	Ds
0	100.0	0.0			
30	99.2	0.4672	1830	3.69E-06	981.2
60	99	0.5929	1860	3.83E-06	979.1
90	98.8	0.7078	1890	3.86E-06	978.6
120	98.6	0.8311	1920	4.09E-06	975.3
150	98.4	0.9361	1950	4.29E-06	972.5
180	97.9	1.233	1980	4.26E-06	972.9
210	96.6	1.966	2010	4.55E-06	969.1
240	94.3	3.366	2040	4.55E-06	969.2
270	90.9	5.457	2070	4.6E-06	968.5
300	85.8	8.803	2100	4.82E-06	965.8
330	77.7	14.5	2130	5.07E-06	963
360	67.3	22.67	2160	5.47E-06	958.6
390	55.8	33.43	2190	6.01E-06	953.2
420	41.9	49.93	2220	6.7E-06	947
450	29.8	69.46	2250	7.6E-06	939.7
480	20.5	90.88	2280	8.46E-06	933.6
510	13.2	115.9	2310	9.95E-06	924.3
540	8.58	140.8	2340	1.19E-05	914.1
570	5.37	167.6	2370	1.49E-05	901.1
600	3.02	200.7	2400	1.92E-05	886.5
630	1.77	231.3	2430	2.48E-05	871.9
660	0.937	267.7	2460	3.26E-05	856.2
690	0.514	302.1	2490	4.28E-05	840.7
720	0.268	339.5	2520	5.31E-05	828.3
750	0.14	376.7	2550	6.48E-05	816.9
780	0.0769	411.1	2580	8.56E-05	800.9
810	0.0446	442.3			
840	0.026	473.3			
870	0.0141	508.2			
900	0.00909	533.5			
930	0.00517	565.8			
960	0.00344	589.1			
990	0.00214	616.4			
1020	0.00148	637.5			
1050	0.000986	660.8			
1080	0.000651	684.6			
1110	0.000417	710.1			
1140	0.000265	736.1			
1170	0.000163	764			
1200	0.00011	786.8			
1230	6.63E-05	815.5			
1260	4.01E-05	844.4			
1290	2.71E-05	866.8			
1320	1.78E-05	890.9			
1350	1.31E-05	908.3			
1380	9.62E-06	926.2			
1410	7.86E-06	937.8			
1440	6.86E-06	945.6			
1470	6.02E-06	953.1			
1500	5.41E-06	959.2			
1530	4.95E-06	964.3			
1560	4.73E-06	967			
1590	4.25E-06	973			
1620	4.15E-06	974.4			
1650	4.13E-06	974.7			
1680	4.02E-06	976.2			
1710	3.77E-06	979.9			
1740	3.86E-06	978.6			
1770	3.79E-06	979.6			
1800	3.58E-06	982.9			

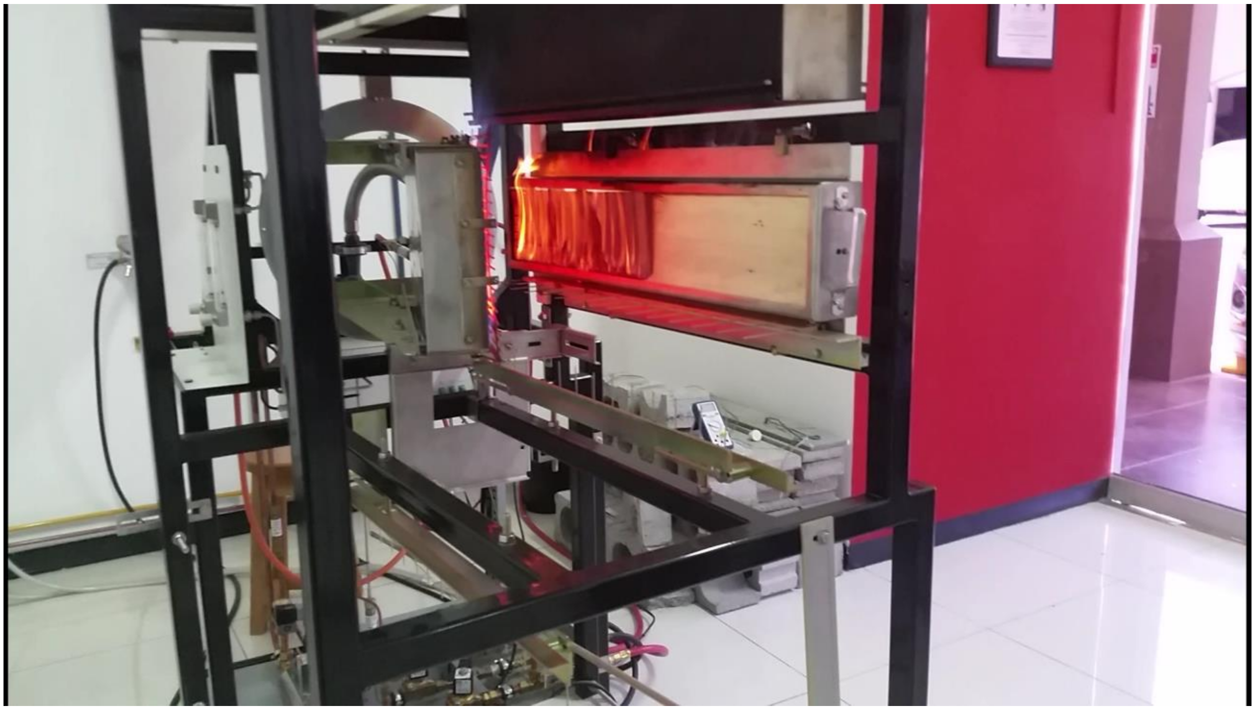
Appendix J. Flame Spread Test Pictures

These images show the sample as it is burning. The flame starts at the left side of the wood and progresses to the right.

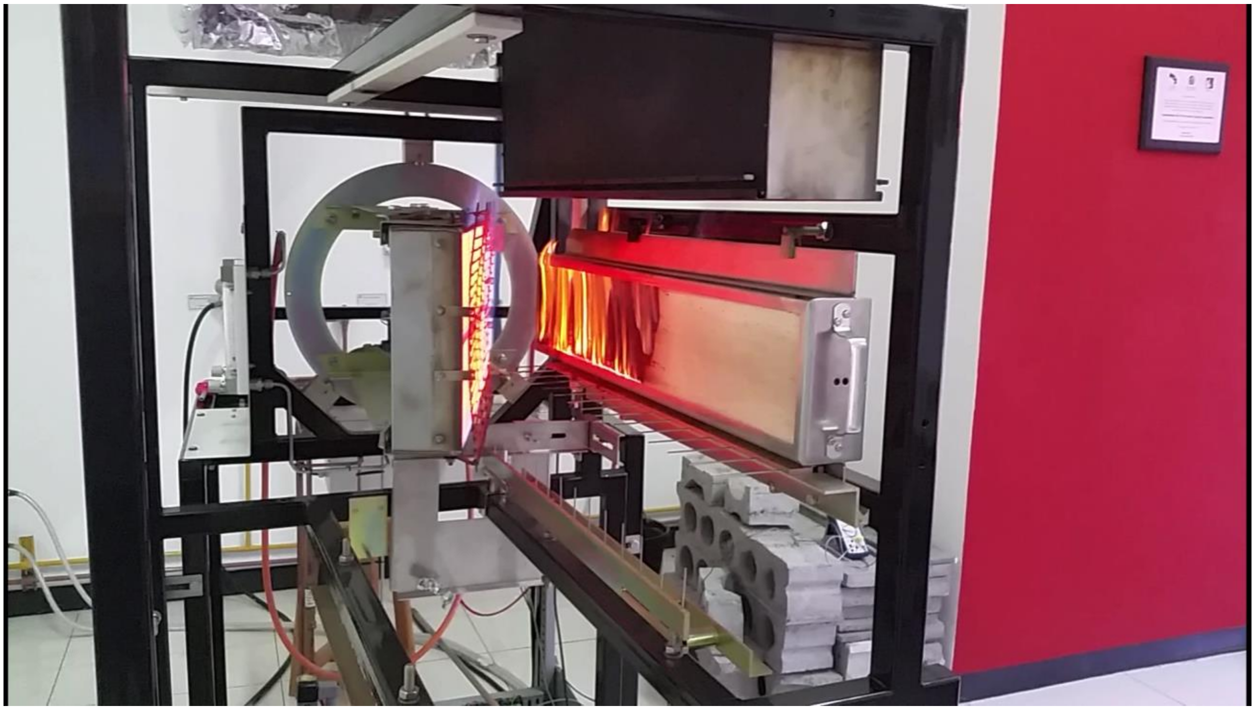
Quercus oleoides Test 1:



Quercus oleoides Test 2:



Quercus oleoides Test 3:



Quercus oleoides Samples After Tests from Left to Right Test 3, Test 2, Test 1:

While testing the *Hyparrhenia rufa*, the grass kept falling out of the fixture after some of the plant had burnt.

Hyparrhenia rufa Test 1:

Hyparrhenia rufa Test 2:

Hyparrhenia rufa Test 3: No Data available

Hyparrhenia rufa Test 4:

Appendix K. Equipment Used by Park Rangers

Appendix L. Sample Collection Procedures

Sample Collection

After performing the processes of sample collection, sample preparation, sample testing, and data analysis we have recommendations for researchers who plan to continue our project. When collecting samples it is important to know ahead of time what size samples are required for the tests to be performed in order to gather enough large samples. One test that needs particularly large sized samples is the flame spread test, there were some tree species that were not large enough to perform this test and resulted in unusable samples. Another aspect of the samples we did not account for during collection was the shape of the samples collected. A twisted branch will be difficult to prepare as most tests require defined rectangular shapes. We recommend the collection of as many straight branches as possible.

Lengthy Drying Times

Preparing samples is a protracted process and distilling the samples collected requires extra preparation time depending on the size of the sample. Larger samples take longer to distill, but a heating chamber assists in this issue by both making the process occur faster and keeping the sample sterile. It is recommended to cut the species to the desired sample size and then allow it to distill; the drying process will occur faster because the size is smaller.

Hardness Testing Sample Modification

Through testing for the hardness values of different wood samples we noticed it was necessary to make alterations to the procedures listed in the ASTM standards. The equipment for testing hardness in wood was not large enough to accommodate for the sample sizes prescribed by the ASTM standards. Therefore, we suggest changing the sample size from 2x2x4 inches to 2x2x2 inches. We also recommend future studies to follow the modified sample size to allow the data gathered to be comparable.

Grass Flame Spread Sample Preparation

In order to perform the flame spread test for grass, we developed a way for the apparatus to hold our collected Jaragua since grass has not been a material tested in this manner before. Future studies should perform their grass flame spread tests with the grass oriented horizontally along the direction of the slide. It is sufficient to pack many 800 mm lengths of grass within the sliding sample container. The same insulating back plate and spine press used in the flame spread testing of wooden planks should be used for the grass. For grass, an issue arises in the front of the slide that faces the heater during testing. As the grass ignites it expands outwards, creating the potential for errors in the results. To resolve this issue, we recommend the use of a thin grate between the slide and the grass sample for containment purposes. The thickness and material of the bars would have to be as minimal as possible as to not interfere with the natural combustion of the grass but still provide enough support to keep the sample in place.

Increased Sample Containers for Rapid Testing

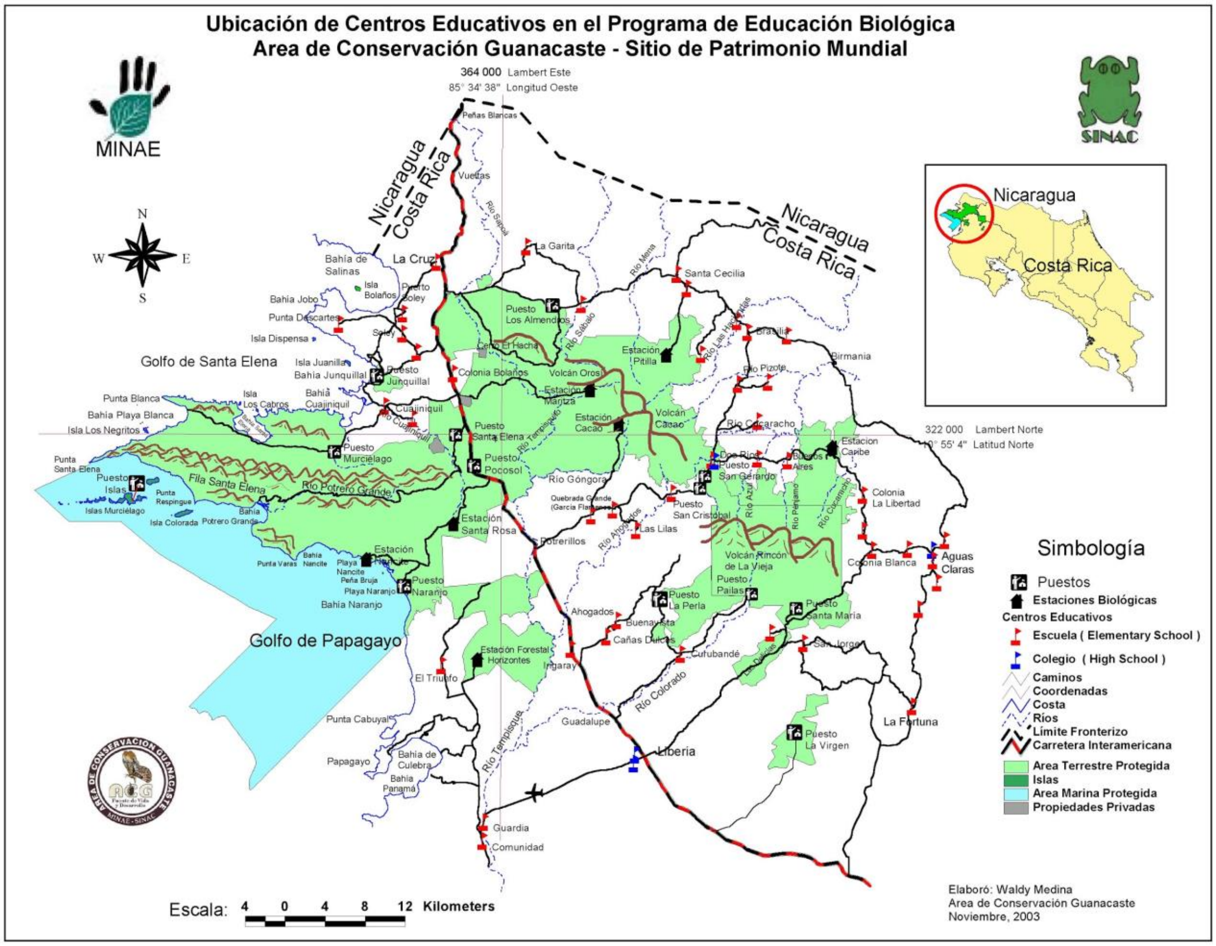
With both the MCC and the Smoke Density Chamber there was a lack of available equipment which increased the down time between trials. Capsules for the MCC were limited due to time required to clean capsule after testing. There were two metal containers for the Smoke Density Chamber that needed to cool and be cleaned before the next sample could be loaded, inhibiting testing progress. In order to streamline testing, we recommend several capsules for the MCC pre-prepared to perform all the projected tests for the day and to obtain more Smoke Density Chamber containers.

Time Evaluation

The last recommendation addresses the time that should be allotted to complete testing for each species. Collecting all the samples necessary for one species is possible to complete within one day. Preparing samples in terms of cutting to the proper size can take up to three days depending on the availability of equipment. The distilling process is dependent on the sample size, but often can range from 24 hours to a week. Approximating the time necessary for all testing is difficult due to common complications including losing samples, repeating tests due to errors in performance, mishandling of samples, lack of available equipment, and necessary calibration time. In addition, the number of tests desired for a credible average for each species characteristic greatly affects the time required. Based on our experience we recommend a full four days of testing, ten hours per day, if the researchers are familiar with the testing procedures. If not, we recommend five days to allow one day for learning and practicing the procedures. Altogether, one should expect a maximum of 2 work weeks to complete the process from collection to results for one species. This time may be reduced if samples are collected and tested simultaneously.

Appendix M. Additional Maps of the ACG

Location of ACG in Costa Rica



Location of Schools participating in the ACG class programs

Location and size of fires within the ACG 1997-2015