DISSERTATION

COMMUNITY-BASED FIRE MANAGEMENT AT LA SEPULTURA BIOPSHERE RESERVE, CHIAPAS, MEXICO

Submitted by

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ABSTRACT

COMMUNITY-BASED FIRE MANAGEMENT AT LA SEPULTURA BIOSPHERE RESERVE, CHIAPAS, MEXICO

Within La Sepultura Biosphere Reserve in Chiapas, Mexico, human communities depend upon tropical pine-oak forests for survival. Management of this federally protected natural area is cooperative between government officials and local farmers and ranchers (producers). Producers conduct subsistence milpa agriculture and, by regulation of the reserve, have limited access to timber resources. I used a participatory, interdisciplinary approach to study community-based fire management in two communities within the reserve: Corazón del Valle and Valle de Corzo. Members of these two communities apply extensive traditional ecological knowledge in fire management. Focus groups and interviews revealed that producers integrate 40 environmental and social factors in their traditional burning practices. Frequent, low-intensity controlled burning with hand tools is customary to reduce fuels and to care for the forest.

A shared concern of government managers and producers is reproduction of the dominant tree species, *Pinus oocarpa*. Producers had the opinion that trees grown from seed produce superior timber compared to trees grown from resprouting stems. Analysis of size class distributions of trees, seedlings and resprouts in 37 controlled burn plots confirmed that the density of seedlings is lower than would be expected under a typical reverse-J distribution. Seedling densities in two subjectively located wildfire sites were higher (mean = 3423 ± 2163 seedlings/ha).

Despite very low-intensity fire behavior generated by producers in traditional controlled burning, seedling top-kill was high (82 percent). Because altering burning techniques would be unlikely to calm fire behavior any further, I tested two simple fuel removal treatments to try to reduce seedling top-kill. Removing fuels from a one meter radius around seedlings with a rake or machete reduced seedling top-kill to 52 percent. Removing fuels and covering seedlings with freshly cut green leaves reduced top-kill by 100 percent.

Only by examining the social, ecological and physical aspects of traditional fire management was I able to arrive at practical methods for addressing the shared concern of post-fire pine seedling survival. Continued collaboration by reserve managers, community members and researchers can further refine management of tropical pine-oak ecosystems within the context of protected natural areas in Mesoamerica.

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A seedling of *Pinus oocarpa* that germinated within weeks after a controlled burn.

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- *Pinus oocarpa*
- Seedling survival
- Traditional ecological knowledge (TEK)
- Traditional fire knowledge (TFK)
- Social-ecological system
- La Sepultura Biosphere Reserve
- Protected Area
- Wildland fire
- Indigenous
- Chiapas
- Mexico

Chapter One: Conceptual Framework and Research Objectives

Natural resource managers from the Comisión Nacional de Áreas Naturales Protegidas (CONANP), the Comisión Nacional Forestal (CONAFOR) and The Nature Conservancy contemplate the complexity of fire problems within Protected Natural Areas (PNAs) in Chiapas.

Every fire that takes place on earth is inherently local. Each starts with a single ignition that takes place in a particular location at a point in time. The earliest known evidence that humans controlled fire suggests that people have used fire in Israel for at least 790,000 years (Goren-Inbar et al., 2004). Bird and Cali (1998) found evidence of anthropogenic fire in sub-Saharan Africa dating to 400,000 years ago. While archaeological studies of fire use usually focus on fire evidence related to farming or the hearth (e.g., López-Austin and López-Luján, 2001), biogeochemical evidence focusing on charcoal and ancient vegetation indicates that fire has been a force on earth's biota since terrestrial vegetation developed 420 million years ago (Scott and Glasspool, 2006). Tropical savannas are ecosystems that have evolved with fire, particularly where dry and wet seasons are pronounced (Myers and Rodríguez-Trejo, 2009). Given the moisture conditions where these savannas occur, many would convert to more dense forest types without fire (Bond et al., 2005). Evidence from Belize suggests that fire was burning within the region occupied by *Pinus oocarpa*, the pine species central to this study, 11,210 ± 330 years ago (Kellman, 1975). Rodríguez-Trejo (1999) asserts that in Central Mexico, anthropogenic fire began with settlement, as early as 24,000 years ago. Human involvement with fire in Mexico has been so well established for so long that Pyne (1999, p 181) calls weather, vegetation and people "the great fire triangle of Mexico."

At La Reserva de la Biosfera La Sepultura (La Sepultura) in Chiapas, Mexico, land managers and campesinos (producers) are working together to accomplish community-based fire management (after Ganz et al., 2003). While community-based programs focused on fire prevention are being implemented throughout Mexico and many regions of the globe (Moore et al., 2002, FAO and Asia, 2003, CONAFOR, 2009), only a few incorporate controlled burning (Jurvelius, 2004, McDaniel et al., 2005). The reserve staff at La Sepultura has taken a further step, working collaboratively with producers to develop and implement community-based fire management plans that are driven primarily by local fire knowledge and practices (Cruz-López and Negrete-Paz, 2007, Negrete-Paz, 2004). In doing so, reserve managers legitimize the application of fire by local people as important for accomplishing the reserve's dual goal of biodiversity conservation and “socially just and ecologically viable development” for people living in the region (SEMARNAP, 1999, p 93).

1.1. Three Spheres of Complex Fire Systems: the Conceptual Model of the Project

I designed my study of fire management at La Sepultura to grapple with the multi-scaled, complex social-ecological system (Berkes et al., 2003) of community-based fire management that was taking place in a high-biodiversity protected area. As a conceptual starting point, I used Myers’ (2006) model of integrated fire management (Figure 1.2a), in which fire systems are composed of three legs of a triangle: fire management, fire culture and fire ecology. Two other models in the literature also recognized a combination of social and ecological factors that shape fire systems: one model of fire in Australia by Jackson (1968) (Figure 1.2b.) and another by Mbow et al. (2000) that depicts savanna burning in Senegal (Figure 1.2c.). While each of these models recognizes the interaction of human and ecological systems, none of these models explicitly illustrates the importance of physical fire behavior and its relationships with, and influence upon, the other factors.

With comments from Israél Amezcua-Torrijos, a staff member from Pronatura-Sur, A.C., I developed a conceptual model that elevates the importance of fire’s physical nature and the interaction of fire’s physical properties with the more often cited ecological and social influences. Not only was this model useful at La Sepultura, but I consider it to be more comprehensive and adaptable to many fire situations around the world. Applying some of the terminology used by Mbow et al. (2000, p 562), I call this model “the three spheres of complex fire systems.”

Figure 1.2a. Myers'(2006) model of Integrated Fire Management.

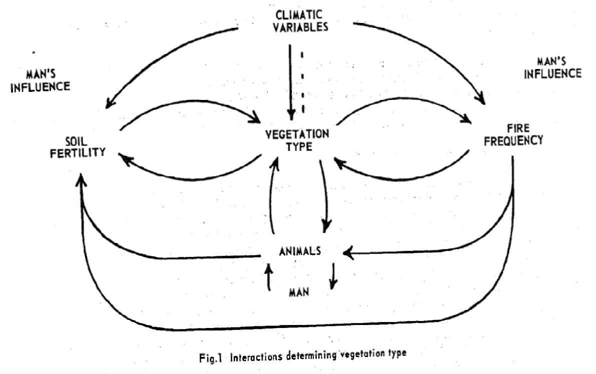


Figure 1.2b. Jackson's (1968) model of the influence of anthropogenic ignition on vegetation type.

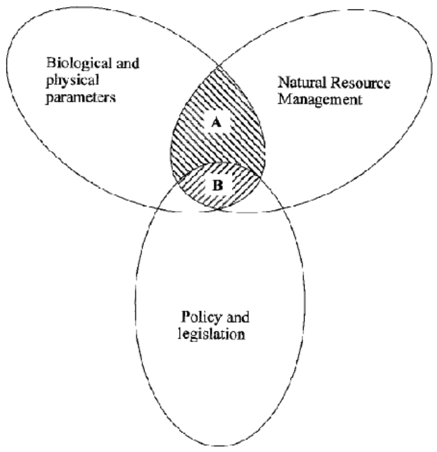


Figure 1.2c. Mbow et al.'s (2000) model emphasizing the social sphere of influence in fire systems.

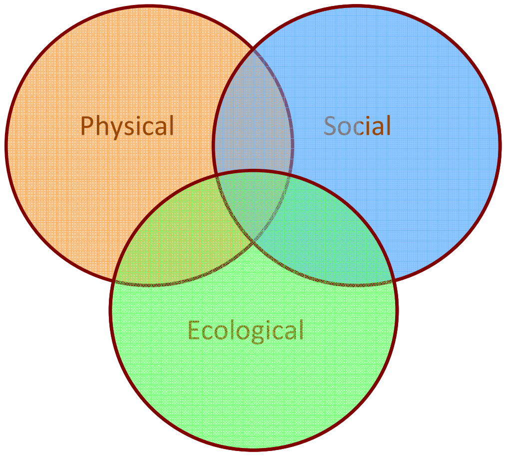


Figure 1.2d. Dissertation model emphasizing social, ecological and physical spheres of fire systems, elevating the importance of fire's physical characteristics.

Figure 1.2. Various models of fire systems and the conceptual model of this study.

To apply this model to any fire situation in the world, one must identify the factors within each sphere that are influential in each situation, at specific spatial and temporal scales. For example, Figure 1.3 shows the factors that apply specifically to the fire situation at La Sepultura during the period of this study. I identified these factors from the literature, scoping interviews and informal conversations with stakeholders, including producers, government and NGO (non-governmental organization) representatives and later, my local advisory committee.

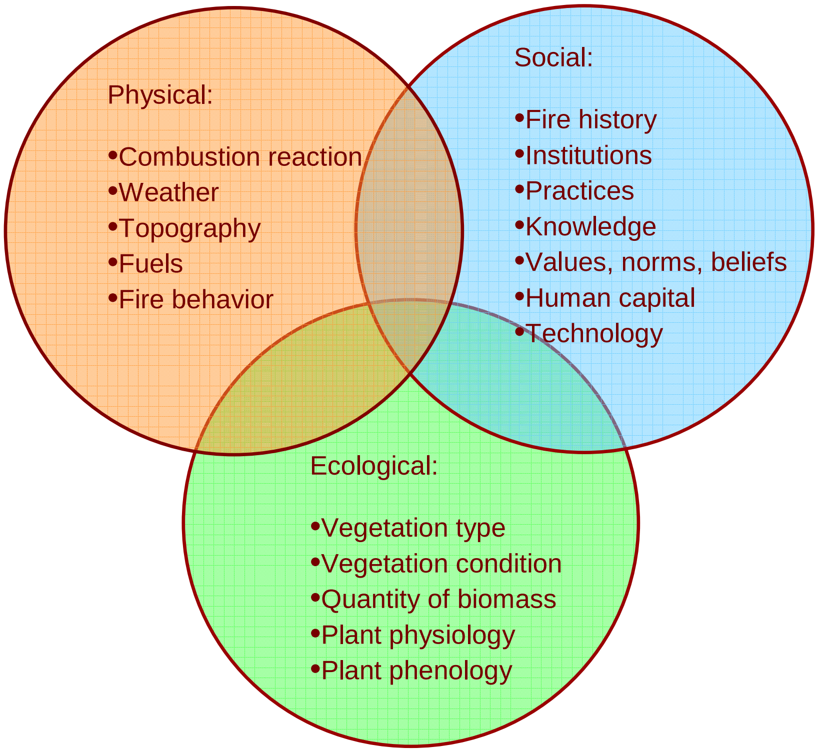
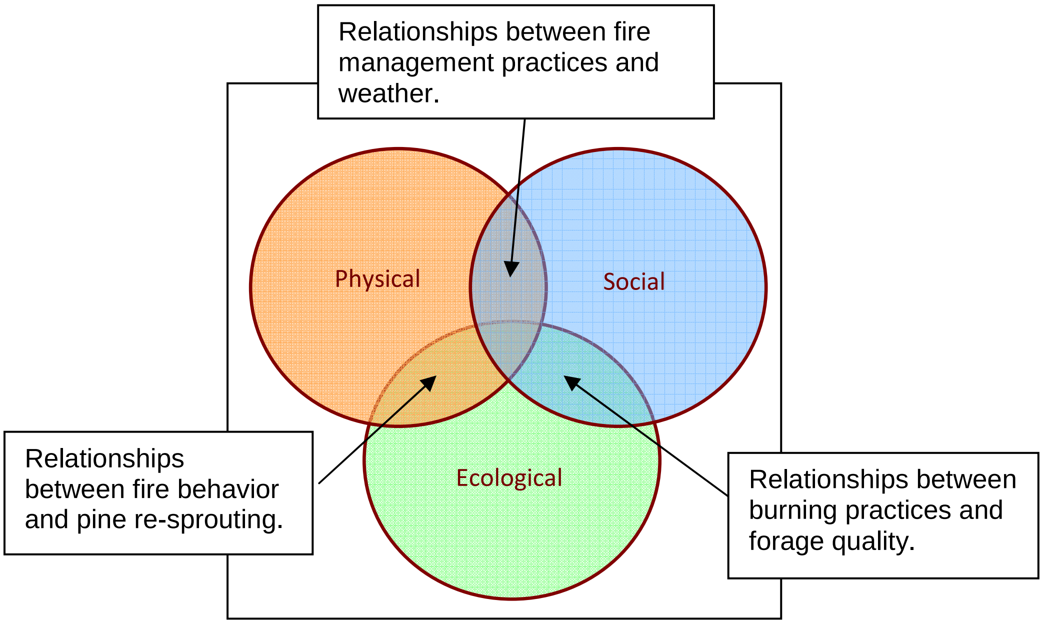


Figure 1.3. Specific components of the three spheres of the complex fire system at La Sepultura Biosphere Reserve.

Using this model I then looked for linkages among these factors within the physical, ecological and social spheres of fire at the study site (Figure 1.4a and 1.4b). In the case of La Sepultura, the triple intersection among all three spheres was the linkage of post-fire pine seedling survival. Personnel from the Comisión Nacional de Áreas Naturales Protegidas (CONANP) and the producers shared a concern about post-fire survival of pine seedlings. Both parties agreed that even low intensity combustion resulting from current burning practices seemed to be limiting this form of pine regeneration (versus pine resprouting).

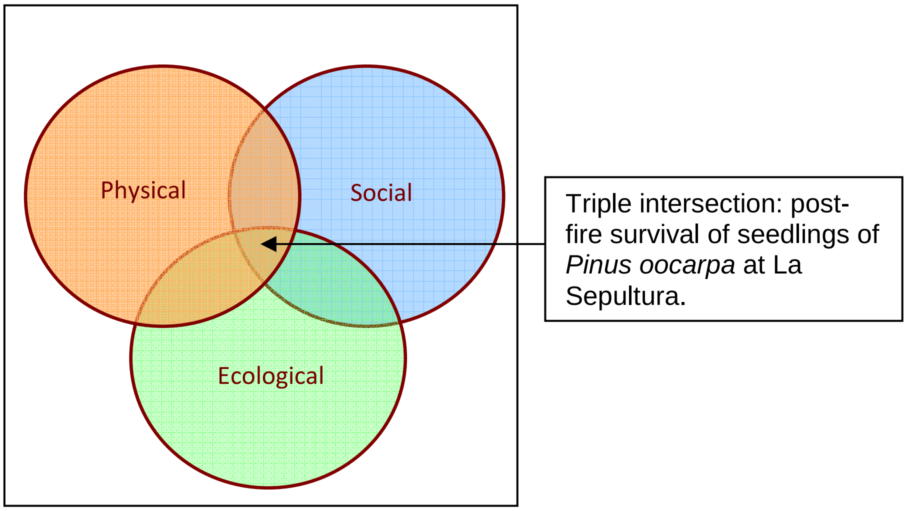


Relationships between fire management practices and weather.

Relationships between fire behavior and pine re-sprouting.

Relationships between burning practices and forage quality.

Figure 1.4a. Examples of linkages that occur in the conceptual space depicted as intersections among the three spheres of the fire system at La Sepultura.



Triple intersection: post-fire survival of seedlings of *Pinus oocarpa* at La Sepultura.

Figure 1.4b. A triple linkage among the physical, social and ecological spheres of fire at La Sepultura: post-fire pine seedling survival.

1.2. Research Objectives, Propositions and Hypotheses

Having explored the conceptual model at the study site and having conducted a preliminary review of the literature, I developed the following research objectives:

> Objective 1. To describe the customary, local burning practices of producers in the two communities, to record the local knowledge used to conduct these practices (traditional burning practices).
>
> Objective 2. To compare the fire knowledge of the two study communities with traditional fire knowledge from around the world.
>
> Objective 3. To characterize the physical fire behavior that producers generate using traditional burning practices (traditional fire behavior).
>
> Objective 4. To elucidate the ecological mechanisms that affect the survival of pine seedlings as a result of traditional fire behavior.
>
> Objective 5. To test the effect of simple fuels treatments on pine seedling survival.

Each of these objectives has one or more associated propositions, tasks or hypotheses, which shaped the specifics of the investigation. The questions to be addressed with qualitative research (Objectives 1 and 2) are expressed as propositions. Objective 3 required the tasks of measuring the weather conditions present during prescribed burns and measuring the fire behavior produced. I accomplished these through participant observation of six controlled burns. Objectives 4 and 5 were accomplished using quantitative field data.

Objective 1. To describe the customary, local burning practices of producers in the two communities and to record the local knowledge used to conduct these practices (traditional burning practices).

> Proposition 1.a. Producers do not burn mindlessly or indiscriminately; they purposely manipulate a variety of fire variables to accomplish specific goals.
>
> Proposition 1.b. Producers do not see fire escapes as unexplainable but rather they have in mind a suite of contributing factors.

Proposition 1.c. Producers do not burn in any kind of weather, but rather they proactively burn on days that have specific weather that they consider conducive to traditional burning. They also choose specific seasons, times of day, and conditions related to moisture.

Proposition 1.d. Producers do not desire just any kind of fire behavior, but rather they manipulate a suite of fire variables in order to produce specific fire characteristics.

Proposition 1.e. Producers not only know what factors they want to select for burning, but they also know in relative terms what quantities of each of these factors they want to use.

Proposition 1.f. Producers have particular field practices they use to accomplish traditional burning.

Objective 2. To compare the fire knowledge of the two study communities with traditional fire knowledge from around the world.

Proposition 2.a. Traditional fire knowledge used by producers shares factors in common with traditional fire knowledge documented from around the world.

Objective 3. To characterize the physical fire behavior and first order fire effects that producers generate using traditional burning practices (traditional fire behavior).

Task 3.a. Measure weather conditions during controlled burns.

Task 3.b. Record fire behavior during controlled burns, including fire type, flame length, rate of spread and direction of spread.

Task 3.c. Measure first and second order fire effects upon pine trees and seedlings, including scorch, char and top-kill.

Objective 4. To elucidate the ecological mechanisms that affect the survival of pine seedlings as a result of traditional fire behavior.

Hypothesis 4.a. The pine forest stands have a variety of size classes, with small size classes well represented.

Hypothesis 4.b. Traditional fire behavior results in significant top-kill of pine seedlings.

Hypothesis 4.c. Greater terminal bud height, low depth and cover of pine needles in the fuel bed, low proportion of needles to grasses in the fuel bed, and low slope will contribute in varying importance to small pine survival.

Objective 5. To test the effect of simple fuels treatments on pine seedling survival.

> Hypothesis 5.a. Simple fuel treatments to remove available fuels from around pine seedlings can reduce their top-kill.

In the next chapter I describe the study site and some historical background that is relevant to fire management at La Sepultura. The subsequent chapters detail the methods, results and discussion related to research regarding each objective. The concluding chapter offers my subjective evaluation of the model, uses the model at a regional scale to evaluate the common perception of fire escapes, and adds a note about the potential of climate change to impact the fire system at La Sepultura.

Chapter Two: Background to the Study Site and the History of Fire in the Region

A father and two sons plant corn in a typical milpa prepared with controlled burning, in La Sepultura Biosphere Reserve. Note the blackened soil and the tropical pine-oak forest in the background.

To prepare to conduct this interdisciplinary study of a complex fire system, I reviewed a variety of literature pertaining to each of the spheres of influence identified in my conceptual model. In this chapter, I provide information from the literature on biophysical and social aspects of the study site and the history of fire in the region. I conclude with a discussion of how this information influences fire management at La Sepultura.

2.1. The Study Site: La Sepultura Biosphere Reserve

La Sepultura is located in the State of Chiapas in southeastern Mexico, which is adjacent to the Guatemala border (Appendix 2.A.). It encompasses 167,310 hectares (Zedillo Ponce de Leon, 1995). The reserve is one of Mexico's Protected Natural Areas (PNAs), administered by CONANP, the Comisión Nacional de Áreas Naturales Protegidas (the National Commission of Protected Natural Areas). The reserve was designed according to the model of the Man and the Biosphere Program of the United Nations Educational, Scientific and Cultural Organization (UNESCO). This program emphasizes nesting critical conservation areas within the context of human society (UNESCO, 2009). Typically, such reserves are designed with a core zone designated strictly for nature preservation, and a series of buffer zones that accommodate increasing levels of human activity. Within La Sepultura, 13,759 ha are designated as the core zone, where, indeed, land use is restricted to preservation purposes (SEMARNAP, 1999).

Forty-seven human communities, including 35 ejidos (communally held lands with community governance) and 80 ranches occur within the boundaries of the reserve. More than 23,000 people live within the reserve boundaries and three and a half million people live within the reserve's larger Zone of Influence (SEMARNAP, 1999).

People have lived on the land that is now La Sepultura since the Preclassic period of Mesoamerican history. Civilizations have included the Olmecs, Toltecas, Aztecs, Mayas, Chiapanecos and Zoques (SEMARNAP, 1999). Both the Aztec and Maya civilizations utilized a major trade route through Chiapas not far from where La Sepultura is located (Bryant, 1983, Coe et al., 1986). Today, at least eight indigenous languages are spoken in the Zone of Influence, the region surrounding the reserve

(SEMARNAP, 1999). Approximately ten percent of these people do not speak Spanish; however, within the reserve boundaries, 99.9 percent of inhabitants do speak Spanish. Religions practiced within the Zone of Influence include both Catholic and Evangelical Christianity; but Catholicism is the most common (SEMARNAP, 1999).

The current population within the reserve resides in small towns and rural areas, and agriculture is the dominant economic activity. The homes are modest. In the two communities where I stayed, the majority of the houses were constructed of locally made adobe bricks, cement block or a combination of the two. One house was constructed of sticks and mud. As of 1997, 86 percent of the homes throughout the reserve had drainage, 63 percent had electricity and 88 percent had running water (SEMARNAP, 1999).

Many inhabitants depend on natural resources from the reserve for their livelihoods. Private landowners and members of local land cooperatives (ejidos) routinely use fire to manage timber, grazing and traditional agricultural crops such as corn and beans.

2.2. Environmental Characteristics

Physiographically, the reserve landscape is part of the Sierra Madre de Chiapas, a mountainous strip that parallels the Pacific Coast (SEMARNAP, 1999). Characteristic of other Mesoamerican landscapes, the terrain is dissected by small watersheds; and a rich variety of flora and fauna occurs at various elevations. Ecosystems of the reserve are valued locally, nationally and internationally by conservationists for their biodiversity and endemic species (Brooks et al., 2006, Rodríguez-Olivet et al., 2004, Myers et al., 2000b). The vegetation of the reserve includes nine major types, ranging from agricultural areas and well-drained pine-oak forests and savannas to deciduous tropical forests and evergreen cloud forests (SEMARNAP, 1999). Four hundred and six species of terrestrial vertebrates and a rich array of plants that inhabit the reserve are characteristic of the overall biodiversity of the region. One hundred and forty-one of these species are classified in some protected status, such as rare, endangered or special protection (SEMARNAP, 1999).

The dominant vegetation is tropical pine-oak forest, classified by Powel et al. (2001) as Central American pine-oak forests, and more broadly as part of the Tropical and Subtropical Coniferous Forest Ecoregion by Olson et al. (2001). Tropical pine-oak associations also occur in the Old World Tropics (Myers and Rodríguez-Trejo, 2009). At La Sepultura, these flammable forests are located along an elevation gradient between lower elevation gallery forests along rivers and streams, and higher elevation cloud forests. The dominant overstory species is ocote pine *(Pinus oocarpa*). In some places, the density of trees is low appearing more like savannas or woodlands, but for the purposes of this study, I refer to all of these forms as tropical pine-oak ecosystems or tropical pine-oak forests.

2.3. History of Anthropogenic Fire in Mexico and Mesoamerica

To the extent that milpa farming, particularly corn cultivation, has been a cornerstone of Mesoamerican society, so has fire. The uplands located from Southern Mexico through Chiapas and Guatemala were involved in the domestication and breeding of corn (Coe, 1984). MacNeish (1971) dates the domestication of beans and corn in Mexico’s Tehuacán Valley, south of Mexico City, between 5200 and 3400 BCE, although later research dates sedentary farming in Mesoamerica to 2500 BCE (López-Austin and López-Luján, 2001). Further, the ancient trade routes used by the Olmecs, Aztecs and Maya for commerce in obsidian, salt and amber ran through Chiapas (Bryant, 1983, López-Austin and López-Luján, 2001) likely also served as conduits for sharing agricultural knowledge and fire practices.

Further support for the longevity of both anthropogenic fire and corn production in the region is provided by studies of pollen and charcoal in sediments. Rue et al. (2002) examined a 5.3 meter sediment core extracted from a peat bog at the base of rugged hills in the Copan Valley of Honduras. Microscopic fragments of charcoal recorded continuous burning in the region since at least 3750 BCE, the date of the lowest level of the core. Corn pollen was found in sediments dated 2300 BCE and continued throughout the core's sequence. Although lightning caused fires occur naturally in the dry season in western Honduras, Rue et al. (2002) infer that significant peaks in charcoal occurrence found in the sediment core are related to anthropogenic fire. Using updated radiocarbon dates, similar studies of sediments from Guatemala and Belize suggest that corn production could have been initiated as early as 3400 BCE (Rue et al., 2002, Pohl et al., 1996).

Generally speaking, then, fire has been part of the Mesoamerican landscape for roughly 5000 years. Researchers agree that milpa agriculture, and the vegetation burning that is integral to it, continued uninterrupted and independent of influences from outside of the continent until European invasion in 1521 (MacNeish, 1971, Willey, 1989, López-Austin and López-Luján, 2001). Though not specific to Mesoamerica, the words of Stephen Pyne (1995, p 309) are apt, "Eventually fire was itself domesticated no less than land, flora, and fauna. Wildland fire became agricultural fire. Field burning obeyed a new calendar, operated at reduced intensities, and altered the frequency of broadcast fire. For the most part, humans dictated these parameters."

2.3.1. Evidence of Historical Fire Reflected in Mesoamerican Religion

The religious significance of fire appears in the archaeological record in various forms throughout Mesoamerican history. Corn and agriculture played a major role in Preclassic Olmec culture and mythology. The Olmecs personified the earth as a mythical being that had corn sprouting from its head. Corn symbolized royal power and a connection between the sky and the underworld (López-Austin and López-Luján, 2001). Although evidence of fire's association with corn production in Mesoamerica predates the Olmec civilization (Rue et al., 2002), and although the Olmecs practiced milpa agriculture fire imagery is not dominant in Olmec mythology.

To the civilizations of the Classic period, however, expressions of fire played a dominant role in religion. In the Quiché Maya religion, the figure Tohil was revered for bringing the first fire that warmed people (Tedlock, 1996). In addition, the twin brother gods Hunahpu and Xbalanque used a fire drill to make a fire and roast a bird in order to defeat the god, Earthquake. In the Valley of Oaxaca, which is adjacent to Chiapas, the Zapotec civilization worshiped gods of corn, fire and rain, among others (López-Austin and López-Luján, 2001). The Old Fire God, appears in both Maya and Aztec art with various names and forms. In sculptures recovered from various archeological sites, the Old Fire God appears as a wrinkled old man who sits with a brazier on his head (Pyne, 2003). He was a primary deity, giving rise to lesser gods (Pyne, 2003).

Based upon archeological evidence, fire in Mesoamerica achieved the height of its cultural expression in Aztec religion. Both aquatic and fire deities were overwhelmingly represented throughout Teotihuacan; and they are considered among the most important deities(López-Austin and López-Luján, 2001). In the Mexica culture, the god of fire, Xiuhtecuhtli-Huehueteotl, was the center of the house, the temple and the universe (Dehouve, 2001). To the Nahua people, Xiouhtecuhli, the lord of fire and

Huitzilopochtil, the solar god controlled fire and the heavens (López-Austin and López-Luján, 2001). López-Luján (1994) interprets the many different images of Xiuhtecuhtli-Huehuetecuhli in ceramics, stone and pictographs, which have been found across a wide geographic area, as evidence of the importance of fire in Mesoamerican beliefs.

According to López-Austin and López-Luján (2001, p 239), a Postclassic Mexica farmer from Central Mexico would have perceived the agricultural cycle in the following way:

> *During the feminine half of the year, rains and the forces of growth ruled; the other half was ruled by the sun, which toasted the crops to a golden color. At the beginning of the first half, the world of the dead opened, releasing the waters, the powers of germination, and the "hearts of the plants," all of which had been stored during the dry season. When the rainy season was over, everything returned to its subterranean enclosure, where it rested while the sun cooked the food of humans with its rays. The farmer had to act both in the perceptible and the imperceptible realms. He cleared the land, dug into it and collected the ears of maize, but at the same time he ritually propitiated the arrival of the different supernatural beings involved in the process, thanked them for accomplishing their functions, said good-bye to them at the end of the process, and burned the stubble, believing that by doing so he freed (in the smoke) the rainwater that had fallen on the cornfield*."

López-Luján (1994) also notes the frequency with which the Old Fire God was mentioned in texts of the sixteenth and seventeenth centuries, post European contact.

One ritual from the Postclassic period, the New Fire Ceremony, is thought to have been particularly influential throughout the Aztec empire, and widely practiced in northern Mesoamerica (Elson and Smith, 2001). The Mexica, Mixtec and Nahua peoples adopted this ritual of beginning and world renewal, which is based on the juxtaposition of different cycles in the Mayan and Aztec calendars. Grand celebrations were conducted under the auspices of the Aztec empire every 52 years; but the ceremony has also been conducted annually at the local level as recently as 2001 (Dehouve, 2001).

Elson and Smith (2001) provide the following description, arguing that in this ceremony, the Aztec empire used fire to symbolically reinforce local people's subordination to capital. Across the empire, fires in homes were extinguished five days in advance to prepare for the possible end of the world. On the last evening of the 52 year cycle, priests watched the stars from the top of a hill called Huixachtlan in Central Mexico. When the stars aligned in a certain way, the priests declared that the sun would rise the next day to start another cosmic cycle. At that point in the ceremony, the priests used a fire drill to start a fire on the chest of a sacrificial person. The flame from this new fire was used to light torches, which were carried by runners to the people of the villages and towns throughout the empire to rekindle home hearths as well as to light fires in public places (Elson and Smith, 2001).

The New Fire Ceremony has also been used by different peoples at different times for purposes less dramatic than ushering in a new cosmic era. Mixtec priests or nobles drilled the New Fire as a ritual for founding a new town (Elson and Smith, 2001). The New Fire Ceremonies that were observed by Dehouve in 2000 and 2001 were conducted in January of each year when a new cadre of municipal civil servants was prepared to take charge of its duties (Dehouve, 2001). The timing of the event coincided with the winter solstice, and so the ceremony connected the political cycle with the solar cycle (Dehouve, 2001).

At a specific time in the week long ritual, the religious elders arranged the offerings in prescribed layers within a square log structure. They and the municipal authorities ignited the packed 'Lincoln Log' structure creating a large fire in the center of town as an offering to Señor Lumbre. This fire initiated the responsibilities of the new authorities. On the evening following the ceremony, the town inhabitants put out their home fires and carried fire from the New Fire to re-light their hearths (Dehouve, 2001).

2.4. Influences of Conquest and Independence

2.4.1. The Spanish Conquest, the Mexican War of Independence and the Mexican Revolution

The Spanish Conquest resulted in changes of profound proportions across many Mesoamerican societies. Changes in religion, politics, economics, land ownership and population genetics are some of topics that have received scholarly examination. So, too, the Mexican War of Independence in 1810 was a backlash against domination by the Spanish and the Catholic Church.

Dramatic as these events were, their impact on fire management is less obvious. Milpa agriculture continued to be performed by local farmers, who likely continued traditional practices. According to Reina (1967), farmers did begin to consider particular days in the Catholic calendar as auspicious days for planting crops. To the extent that corn and other traditional crops were planted, we might assume that the use of fire to prepare fields for planting continued also.

Likewise, the Mexican Revolution of 1910 resulted in economic changes, such as who benefited most from the farmers' labor, but milpa agricultural and its associated fire use continued. According to SEMARNAP (1999), the Mexican Revolution of 1910 did not have as dramatic an effect on society in Chiapas as it did in northern Mexico, because local people had already been struggling for local autonomy prior to that national conflict.

What may reside in the psyche of today's producers at La Sepultura as a result of these events are perspectives about government involvement in land management, including fire management. Enabled by political and legal changes brought by the Revolution, several ejidos were registered at La Sepultura during the 1940s (A. Posada, pers. com., July 18, 2008, Corazón del Valle). In contrast to the large landholdings controlled by the Spaniards and the Catholic Church before the Revolution, ejidos are communally held lands controlled for the most part by the people who live and farm there. Most of the agriculture accomplished in the ejidos of La Sepultura is performed for the subsistence of the local community (personal observation).

2.4.2. The Zapatista Uprising of 1994 and the Conflict in the Sierra Madre del Sur

In 1994, indigenous rebels from the highlands of Chiapas conducted an armed rebellion for local autonomy in Mexico. For a time, the Zapatista Army of National Liberation (EJLN) wrestled control of part of Chiapas from the Mexican government. According to Parajuli (2001), the Zapatistas were not seeking to overthrow the Mexican state; rather they were fighting for the following three things, which are relevant to fire management at La Sepultura:

- for land distribution programs that would provide native people with communal landholding in fertile lowland areas with guarantees of secure tenure.
- for community control over agricultural production, including the use of land; and
- for local-level, democratic decision making entrusted to traditional leadership.

Two years after the Zapatista Uprising came a less known armed conflict in the Sierra Madre del Sur, in the low income states of Guerrero and Oaxaca (Weinberg, 1999). These states, one of which is adjacent to Chiapas, have significant populations of indigenous people. According to Weinberg, a Mixtec and Zapotec revival has been underway in the region for the last generation. Like the Zapatista Uprising, the fighting in the Sierra Madre del Sur centered on access to land in order to grow maize under local indigenous rule (Weinberg, 1999).

2.4.3. Establishment of La Sepultura in 1995 by Federal Decree

It was against this extraordinary political backdrop that La Sepultura Biosphere Reserve was established by presidential decree in 1995 (SEMARNAP, 1999, Zedillo Ponce de Leon, 1995).

The overall objective of the reserve is,

> *"To maintain the biological richness and diversity, as well as the ecosystems and essential ecological processes that favor socially just and ecologically viable development for the inhabitants of the region of La Sepultura and its area of influence."* (SEMARNAP, 1999, p 93, translation mine).

Nearly half of the land base at La Sepultura is in buffer zones where farming and ranching are conducted (SEMARNAP, 1999), the reserve's management plan does limit access to natural resources in core conservation areas. Although no one participating in my study said this, I speculate that where reserve regulations have diminished local people's ability to supplement their incomes through hunting and gathering in the reserve, they may harbor some resentment toward the reserve and its managers.

2.4.4. The Extraordinary Fires of 1998

Finally, the numerous and ecologically severe fires of 1998 are likely to influence producers' views of fire management at La Sepultura. As a result of El Niño related drought, extensive areas of southern Mexico and Central America were affected by wildfires. The fires burned in every major vegetation type, including those that are normally too moist to burn (Rodríguez-Trejo et al., 2002, Roman-Cuesta et al., 2003). Southern Mexico experienced more than 14,445 wildfires that encompassed 850,000 has, which is more than twice the annual average (Rodríguez-Trejo et al., 2002). More acres burned in the State of Chiapas than any other state (89,000 ha) (Rodríguez-Trejo and Pyne, 1999), including fire-sensitive tropical vegetation within federal conservation areas.

The fire suppression effort was equally extraordinary and the impacts on daily life in Mexico were significant. Six thousand firefighters, 139,000 soldiers and thousands of volunteers contributed to the fire suppression effort (Rodríguez-Trejo, 1999). Sixty fire fighters died in the control effort (Rodríguez-Trejo and Pyne, 1999). Smoke caused severe air pollution in Mexico City and affected urban areas from Villahermosa to Veracruz; thousands of rural residents living closer to the flames were evacuated (Rodríguez-Trejo and Pyne, 1999). Given a disaster of this magnitude, news of the fires and the consequential emphasis on fire prevention and control likely reached every small community in southern Mexico, including those at La Sepultura.

2.4.5. Community-based Collaborative Fire Management at La Sepultura

In 2005, the sub-director of La Sepultura (now the director), initiated a co-management project called "Manejo Integral y Participativo del Fuego en Comunidades Campesinas de la Reserva de la Biosfera La Sepultura" (Participatory and Integrated Fire Management in Campesino Communities of La Sepultura Biosphere Reserve). Funded by The Nature Conservancy, an international non-governmental organization (NGO) and CONANP, the planning effort engaged a suite of stakeholders, including representatives from the following groups: two ejidos, federal reserve managers, national forestry officials and municipal forestry officials (Negrete-Paz, 2004, The Nature Conservancy, 2005). The collaborative planning process was facilitated by a local facilitator, who lived in a nearby ejido and who worked for a small local NGO. He subsequently became a key informant for my study.

The primary objective of the project was as follows:

> *For organized groups from rural communities of La Sepultura Biosphere Reserve in Chiapas, Mexico to manage and regulate the use of fire with ends for silviculture, ecology and agriculture, within the framework of the law.* (TNC, 2005, p 3, translation mine)

Specific objectives included:

> *Groups of producers of the ejidos plan and agree to regulate the use and fire management zones in the territory of the ejido, through a participatory plan.*
>
> *Organized groups of producers apply a community plan of fire management that includes prescribed burns in forest zones and agriculture in ejido territory, in the legal framework that is in force.*
>
> *They supervise and evaluate the community plan for integrated fire management* (TNC, 2005, p 4, translation mine).

Innovative in its inclusion of prescribed burning, the project has since been completed and it is being replicated in other protected natural areas managed by CONANP (V. Negrete-Paz, pers. com., October 24, 2008, Morelia).

There are many definitions and descriptions of the kinds of cooperative arrangements between public and private stakeholders that are effective for, if not essential to, solving complex social and ecological problems. The spectrum of cooperation runs from mere tolerance of neighbors' opposing viewpoints, to formalized ongoing processes that involve considerable planning, organization, and maintenance (for the latter, see Wondolleck and Yaffee, 2000, Koontz et al., 2004).

Phrases that capture the intent of meaningful collaboration in natural resource management, which are often implemented and studied at the local level, include co-management, collaborative environmental management, community-based natural resource management (CBNRM), and community-based fire management (CBFiM). While none of these terms perfectly describes the current collaborative nature of fire management at La Sepultura, the paragraphs below describe how each of these terms helps to describe the current situation.

Co-management and collaborative environmental management both connote the involvement of the state as well as local stakeholders in some power sharing arrangement (Singleton, 2000, Koontz et al., 2004, Berkes, 2009). At La Sepultura, there is a delicate balance of power between the ejidatarios and the federal reserve managers, due to the rights of ejidatarios to use land for agricultural purposes, the authority of the government to regulate protected natural areas (PNAs), and the reality that producers control day to day land management, including striking the matches that drive the fire regime of the reserve.

Community-based natural resource management (CBNRM) contributes the notion that local populations have particular interest in and knowledge of local natural resources, and that they may be better suited to accomplish effective land management through traditional access and use (Brosius et al., 1998). At La Sepultura, local producers have a vital stake in fire management because of fire's essential role in producing crops, forage and timber. Producers who reside within the reserve and use fire regularly have more fire knowledge and greater experience with controlled burning in the local ecosystems than does the average government reserve manager (pers. obs. May 2006-May 2008).

Community-based fire management (CBFiM) is a subset of CBNRM, which is defined as,

> *a type of land and forest management in which a locally resident community (with or without the collaboration of other stakeholders) has substantial involvement in deciding the objectives and practices involved in preventing, controlling or utilising fires* (Ganz et al., 2003, p 4).

At La Sepultura, producers not only have substantial involvement in deciding how to utilize fires, but with rare exceptions, they also conduct the fires. Local fire use is regulated by federal and state agencies, however, in my observation of the study sites, community governance at the ejido level, both formal and informal, is the most commonly practiced control on local fire management.

Berkes's definition of co-management, "the sharing of power and responsibility between the government and local resource users" (2009, p 1692) is also descriptive of the fire management situation at the reserve. Government agencies at the federal, state and local levels regulate fire management, but the producers are the ones who actually do the controlled burning. The community-based fire planning project that took place during the first two years of this study deepened co-management of fire among the government parties of CONANP and the state and federal fire control agencies and the ejidos. The organizer of the planning project, CONANP, was the most recent (decade long) stakeholder in fire management of the site.

All forms of collaboration are subject to the phenomenon of co-optation or capture, in which one or more participants persuade or overpower others so that the outcome of the collaboration meets their needs, sometimes at the expense of others (Fernandez-Gimenez et al., 2006, Singleton, 2000). At La Sepultura, the participatory fire management planning project begun in 2005 incorporated various elements of exchange that could involve co-optation by both parties: government managers and producers. Most important, these exchanges are not single, simple acts. Rather, they set in motion undulations in types and degrees of power that will be dynamic over time and non-linear in effect.

For example, at the outset of the project, government reserve managers would benefit from establishing a known plan of action for fire management in the two study communities, while producers would benefit from the explicit recognition that they were the implementers and evaluators of the plan. Implicit in the arrangement, however, was the commitment that the plan and its implementation would take place in accordance with the laws in force (Negrete-Paz, 2004). At the time, this entailed producers registering burn authorizations and written records of fires planned and conducted (SEMARNAT and SAGAR, 1997). A future benefit of these records will be documentation of producers' burn practices, such as fire management objectives, burn locations, fire return intervals, burn unit sizes and weather conditions on days when burning takes place. While this will serve to document local fire knowledge and practices for use by future generations, it also signals centralization of information which could also be used to design regulation. Continued cooperation and mutual respect will be necessary to maintain the balance of power for effective collaboration versus regulation and resistance that have resulted elsewhere (Hough, 1993, Kull, 2002).

While some researchers (Bray et al., 2003, Thoms and Betters, 1998) celebrate Mexico's communal lands as an example of successful common pool resource management, others point to cases of local resistance or breaking government rules, especially when ejidos are overlain with protected area boundaries and restrictive regulations (Meridith and Frias, 2004, Cabrera-Garcia and Frias, 2004). My overwhelming impression of the interaction between members of the study communities and reserve managers at La Sepultura was one of commitment to collaboration. However, I did observe the delicate balance of power, cooperation and subtle resistance that producers and reserve managers constantly negotiate through daily actions and participation in government sponsored programs. When to weigh in, when to resist and when to accommodate is the art of the seasoned stakeholder in this setting.

2.4.6. Adoption of NORMA Oficial Mexicana NOM-015-SEMARNAT /SAGARPA-2007, Uso de Fuego.

In 2009, the Mexican government adopted a new national policy for the use of fire, NORMA Oficial Mexicana NOM-015-SEMARNAT/SAGARPA-2007, which affirms the use of controlled burning for both agro-forestry and ecological purposes and sets standards for controlled burning in Mexico (SEMARNAT and SAGARPA, 2009). Remarkably, the policy supports using fire to maintain fire-adapted ecosystems as well as agro-forestry systems, and it prohibits using fire in fire-sensitive ecosystems.

The policy recognizes fire use by local people and specifically acknowledges the importance of fire knowledge in conducting controlled burns. However, it also requires formal notification of intended burns, and authorization of those burns by local, state or federal officials. The performance standards include written controlled burn plans with specific management objectives, fire behavior predictions and specified weather and fuel moisture conditions under which burning will take place, as do controlled burning standards in other national programs. In Mexico, these written requirements may exceed the scope of literacy among some of the adults and elders who currently accomplish controlled burning in rural communities. Nonetheless, the policy is designed to meet the needs of both people and ecosystems in Mexico, an approach that is far superior to many fire policies around the world that prohibit even the purposeful application of fire, including burning for subsistence farming or ecological restoration.

2.5. Synthesis of Historical and Site Factors Relevant to Fire Management at La Sepultura

Across Mesoamerica and within La Sepultura, people light the vast majority of fires, not lightning, lava or spontaneous combustion (Rodríguez-Trejo, 1999). In the State of Chiapas, eighty-three percent of the state's forested land experiences human caused fires (Cedeño, 2001). Reserve managers and fire officials have documented that that from 1997-2005, the annual average of wildfires at La Sepultura that resulted from fires that were started by local people for agro-forestry purposes was 60 percent (Cruz-López, 2006).

Fires at La Sepultura occur in a variety of ecosystems with varying frequency and intensity. Producers conduct subsistence burning annually in tropical pine-oak ecosystems. Fires are used seasonally to stimulate forage production for cattle and to manage the primary timber species, *Pinus oocarpa*. Fire is also used to prepare milpa plots for planting corn, beans and other subsistence crops. The tropical pine-oak forests generally occur at higher elevations than the milpas and the potreros (tame pastures) that are planted for grazing, and fire can move from one vegetation type to another when fuels are receptive to fire ignition and spread.

Community-based fire prevention programs have been developed in tropical zones across the globe, in Africa, Asia and Europe (Moore et al., 2002, FAO and Asia, 2003). They typically involve community fire suppression brigades, the establishment of community firebreaks and fire prevention education programs. Most do not substantively engage traditional ecological knowledge of prescribed burning or the value of controlled burning for local purposes (see Moore et al., 2002, Jurvelius, 2004, Pool et al., 2002).

The length of time that people have been using fire on the Mesoamerican landscape (Figure 2.2), the nearly ubiquitous dependence upon fire for subsistence agriculture, and the legal framework that acknowledges local people's ability to use fire for agricultural and ecological purposes are hallmarks of the fire culture in Mexico. Unlike in other regions where fire prevention and suppression are the primary government perspectives, the Mexican government currently strikes an appropriate balance between promulgating education campaigns to prevent wildfires and respecting local use of fire for agricultural and ecological purposes.

2.6. Rationale for Interdisciplinary Study

Like many other research topics in which humans influence landscapes and vice versa, it is impossible to conduct adequate inquiry into the fire situation at La Sepultura without combining natural science and social science methods (Berkes et al., 2003). World views, cultural history, values, norms, economics and social interactions all play roles in shaping how and why people use fire the way they do. As such, no amount of natural science research alone can adequately characterize these factors and the interaction of these with the environment. Similarly, social science research alone cannot capture the picture. Physical and biological feedback loops, such as the impact of fire upon soils and vegetation shape future fire practices and the ability of people to utilize the natural resources shaped by fire (e.g., timber, livestock forage, and medicinal herbs). For example, high intensity fires (having high heat output and tall flames) may reduce timber supplies but may increase forage. Burning in the right month may increase the reproduction of a medicinal plant. Fires started on low humidity days may be more intense than those started a few days after rain. These linkages among components of the social-ecological system of fire management call for interdisciplinary research, though this approach tends to be challenging (Lele and Norgaard, 2005).

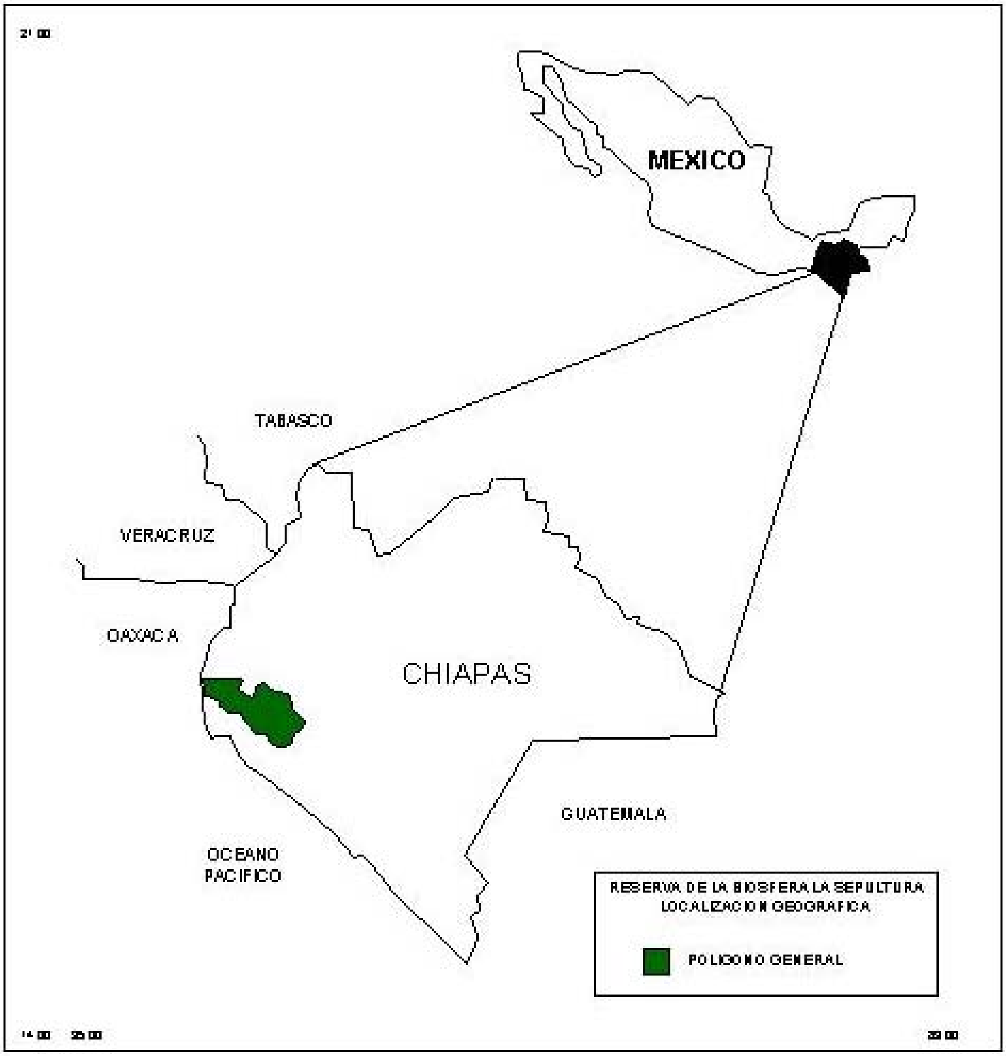
	Paleo-Indian Period: 10,000-3500 BCE
5200-3400 BCE	Corn and beans domesticated in Tehuacán Valley, Central Mexico (MacNeish 1971).
3750 BCE	Charcoal fragments in sediment from Copan Valley, Honduras (Rue et al. 2002).
	Archaic Period: 3 500-1800 BCE
3400 BCE	Corn pollen in sediments from Guatemala and Belize (Pohl et al. 1971).
2500 BCE	Sedentary farming in Mesoamerica (Lopez-Austin and Lopez-Luján 2001).
2300 BCE	Corn in sediments of Copan Valley, Honduras (Rue et al. 2002).
	Preclassic 2000 BCE-250 CE
Preclassic	Corn expressed in mythology of Olmec civilization (Lopez-Austin and Lopez-Luján 2001).
	Classic 250-900 CE
Classic	New Fire Ceremony performed in Aztec and Maya civilizations (Elson and Smith 2001).
	Postclassic 900-1521 CE
Postclassic	Corn expressed in mythology of Olmec civilization (Lopez-Austin and Lopez-Luján 2001).
1521 CE	Spanish invade the Americas, cosmology of corn and fire not emphasized, but milpa agriculture continues.
	Mexican Revolution to the present 1910 CE-present
1910-1921 CE	Mexican Revolution brings agrarian and land ownership reform. Article 27 of the Mexican Constitution allows creation of ejidos (Thoms and Betters 1998).
1934 CE	Agrarian Code of 1934 speeds re-appropriation of hacienda lands to landless peasants (Thoms and Betters 1998).
1940s CE	Ejidos registered in the area of today's La Sepultura Reserve (A. Posada, pers. comm.).
1994 CE	Zapatista uprising in Chiapas, fighting for indigenous control of land, agricultural production and traditional self governance (Parajuli 2001).
1995 CE	La Sepultura established by federal decree (SEMARNAP 1999).
1998 CE	Extensive fires across Mexico driven by El Niño (Cedeño 2001).
2005 CE	Corazón del Valle and Valle de Corzo begin community-based fire planning within La Sepultura (Cruz-López and Negrete-Paz 2007).
2009 CE	Federal Norm 015 adopted, recognizes fire use by local people for agro-forestry and ecological purposes in Mexico. Outlines protocols for controlled burning, acknowledges the importance of fire experience.

Figure 2.1. Timeline of significant events related to anthropogenic fire in Mesoamerica and to community-based fire management at La Sepultura.

Furthermore, as the global climate changes, many social-ecological fire systems around the world are poised to undergo crisis after crisis, many on the scale of the extensive fires of 1998 (Rodríguez-Trejo and Pyne, 1999). Such crises of perpetual fire escape and extensive spread typically result from a combination of weather, land management practice, political process, biology, and the physical nature of the combustion reaction. Each of these influences operates at multiple scales in time and space. The ability of this social-ecological system to function in a world of warming climate will require extensive information sharing and collaboration among many parties over time.

In Mexico, where land ownership is dominated by ejidos, positive outcomes, where possible, will likely be the result of local communities sharing their fire practices and working adaptively among multiple stakeholders. It will be important for the Mexican government, which has regulatory authority at various levels, to avoid the pathology of command and control, a management paradigm in which humans respond to ecosystem surprises by trying to increasingly control a process fraught with uncertainty (Holling and Meffe, 1996), such as combustion of vegetation. In the case of fire, the pathology would be trying to prevent and suppress all fires. Not only would this be unlikely to succeed from both the physical and social standpoints, but it might also engender local use of fire as resistance, which has been observed elsewhere when fire use has been prohibited (Kull, 2002, Seijo, 2009). Fortunately, the government's approach to fire management in Mexico is increasingly the collaborative, adaptive approach and not the later recipe for failure (SEMARNAT and SAGARPA, 2009).

Appendix 2.A. Project site map: La Sepultura Biosphere Reserve, Chiapas, Mexico (Courtesy of The Nature Conservancy).



Chapter Three: Local Fire Knowledge and Traditional Burning Practices

Producers stand in a handmade firebreak at the top of a hill, overlooking a parcel to be burned the next May.

This chapter addresses the first two research objectives and the first two tasks within Objective 3. The propositions included in Objectives 1 and 2 suppose three things: 1) that substantial fire knowledge does exist within the two communities, 2) that the existing fire knowledge is applied during controlled burning, and 3) that this knowledge is comparable to traditional fire knowledge elsewhere. The two tasks in Objective 3 were to measure the weather and the fire behavior associated with actual controlled burns at the study site.

Objective 1. To describe the customary, local burning practices of producers in two communities within the reserve and to record the local knowledge used to conduct these practices.

To accomplish this objective, I posed six research questions and investigated six associated propositions, given below.

a. What are the components of fire that producers think about and purposely use in order to accomplish controlled burning?

   Proposition: Producers do not burn mindlessly or indiscriminately; they purposely manipulate a variety of fire variables to accomplish specific goals.

b. What are the components of fire that producers see as contributors to fire escapes?

   Proposition: Producers do not see fire escapes as unexplainable but rather they have in mind a suite of contributing factors.

c. What, if any, weather conditions do producers select for conducting their burns? Which of these conditions, and what combinations of conditions, will produce a desirable fire? An undesirable fire?

   Proposition: Producers do not burn in any kind of weather, but rather they proactively burn on days that have specific weather that they consider conducive. They also choose specific seasons, times of day, and moisture conditions.

d. What kinds of fire behavior, if any, do producers purposely try to produce? Exactly what is desirable fire behavior, undesirable fire behavior?

Proposition: Producers do not desire just any kind of fire behavior, but rather they manipulate a suite of fire variables in order to produce specific fire characteristics.

e. What relative quantities of the most important fire variables do producers choose for controlled burning?

Proposition: Producers not only know what factors they want to select for burning, but they also know in relative terms what quantities of each of these factors they want to use.

f. Operationally, how do producers conduct a controlled burn?

Proposition: Producers have particular field practices they use to accomplish traditional burning.

Objective 2. To compare the fire knowledge of the two study communities with traditional fire knowledge from around the world.

To accomplish this objective, I investigated one research question and its associated proposition.

a. How does traditional fire knowledge at La Sepultura compare to traditional fire knowledge around the world?

Proposition: Traditional fire knowledge used by producers shares factors in common with traditional fire knowledge documented from around the world.

Objective 3. To characterize the physical fire behavior and first order fire effects that producers generate using traditional burning practices (traditional fire behavior).

Task 3.a. Measure weather conditions during controlled burns.

Task 3.b. Record fire behavior during controlled burns, including fire type, flame length, rate of spread and direction of spread.

3.1. Introduction

3.1.1. Traditional Ecological Knowledge

Berkes (1999, p 8) defines traditional ecological knowledge (TEK) as “a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission about the relationship of living beings (including humans) with one another and their environment.” Fernandez-Gimenez (2000) further specifies that TEK is knowledge held by particular groups of people from specific places. Although ethnographic accounts of people’s relationships to their environment have long been included in anthropological and sociological research, TEK gained emphasis as a field of study in the 1980s and 1990s, primarily through case studies of indigenous knowledge in various parts of the world. Berkes’s (1999) study of the Cree hunting practices in sub-Arctic North America, Niamir-Fuller’s (1998) exploration of herders’ decision-making in the African Sahel, Lewis’s (1989) documentation of aboriginal fire knowledge in northern Australia and later Cinner et al.’s (2005) study of traditional coral reef management in Papua, New Guinea demonstrate the variety of geographies and resource management topics of such cases.

In Mesoamerica and Mexico, TEK has been studied in the context of agricultural practices and forest management, particularly in places with indigenous cultures. Among the Rincón Zapotec of Oaxaca, Mexico, subsistence agriculture incorporates concepts including the personification of non-human and supernatural actors, assigning either hot or cold natures to all things, balance of opposing forces, reciprocity, the inevitability of hard physical work, and household and ecological maintenance, concepts that differ from the thinking of visiting agronomists (González, 2001). Modern Itza Maya demonstrate extensive knowledge of useful plants and animals, including most of those recorded for the Cholti-Lacandón Maya prior to European conquest, post-conquest Maya of the Yucatan and three modern Maya groups: the Petén in Guatemala, the Lacandón in Chiapas, and the Yucatec (Atran, 1993). Today, Itza farming includes intercropping 40 food varieties and using more than 100 tree species (Atran, 1993). As in other cultures rich in TEK, knowledge and skills are passed from generation to generation through local teaching and practice (González, 2001).

These and other cases led to the recognition that indigenous knowledge is rich and useful, rather than “inefficient, inferior and an obstacle to development” (Agrawal, 1995, p 413). Scholars called upon scientists and governments to preserve TEK (González, 2001) and, further, to employ it as a useful complement to Western scientific knowledge in natural resource management settings (Pimbert, 1995, Whitehead et al., 2003, Oltremari and Jackson, 2006).

Subsequently, TEK became incorporated into governmental and non-governmental initiatives focused on rural development and establishing indigenous people’s rights (Sillitoe et al., 2002, Grim, 2001, Alcorn, 1993, Brosius et al., 1998). Since then, TEK has gained significant political traction. Consortia such as the Coordinating Body for the Indigenous Peoples’ Organizations of the Amazon Basin (COICA, 2010), and non-profit organizations such as Tebtebba (Indigenous Peoples' International Centre for Policy Research and Education) and the International Work Group for Indigenous Affairs work to ensure indigenous peoples’ rights to self-determination and sustainable development (IWGIA, 2010, Tebtebba, 2010). The General Assembly of the United Nations established the Permanent Forum on Indigenous Issues in 2002, and adopted the Declaration on the Rights of Indigenous Peoples in 2007 (UNPFII, 2010). Recognizing the importance of indigenous peoples to biodiversity conservation, Article 8(J) of the 2007 Convention on Biological Diversity asks signatories to

> *“respect, preserve and maintain knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity and promote their wider application with the approval and involvement of the holders of such knowledge, innovations and practices and encourage the equitable sharing of the benefits arising from the utilization of such knowledge innovations and practices” (Secretariat Convention on Biological Diversity 2007, Article 8(j)).*

In some places, TEK has been used together with western scientific knowledge to inform sustainability and collaborative management of natural resources. For example, the Alaska Beluga Whale Committee has utilized TEK and scientific knowledge in data gathering to guide beluga whale management, in part to guard against formal regulation of beluga whale harvesting by the International Whaling Commission (Fernandez-Gimenez et al., 2006). A more formal example is the statutory arrangement for power sharing in management of Kakadu National Park, Australia, which was established by the Environment Protection and Biodiversity Conservation Act of 1999. The statute provides for the Kakadu Board of Management, which is a primary vehicle for including TEK in park management, through tasks such as preparing park management plans (Commonwealth of Australia 2010). Aboriginal people have majority representation on this board, serving in 10 of the 15 seats, with the remaining seats filled by (national) Parks Australia managers.

Recently, the application of TEK has advanced into the arenas of adaptive management, ecosystem resilience and climate change adaptation (Folke et al., 2005). In 2009, the US Secretary of the Interior’s Order No. 3289 directed the Department of the Interior to support the use of the best available science, including traditional ecological knowledge, in formulating policy pertaining to climate change (Salazar, 2009). Notably, the wording of this order included TEK as part of best available science, blurring the definitional distinctions between the two types of knowledge. Fourteen years earlier, Agrawal (1995) used examples from several studies to argue against a strict division between indigenous knowledge (a subset of traditional knowledge) and Western science.

The inclusion of TEK in fire management planning at La Sepultura is built upon collaboration that incorporates elements of the following areas of practice and inquiry: management of common pool resources, community-based natural resource management, adaptive management, collaboration, co-management, ecosystem management and recently, community-based collaborative natural resource management (Daniels and Walker, 2001, Ostrom, 1990, Dietz et al., 2003, Berkes et al., 1998, Berkes et al., 2003, Grumbine, 1994, Wagner and Fernandez-Gimenez, 2009, Brosius et al., 1998, Sabatier, 2005). For the purposes of this study, these subjects taken together generally connote shared power and responsibility for sustaining complex social-ecological systems that operate at a variety of spatial and temporal scales (Gunderson and Holling, 2002). This requires stakeholders to work together with flexibility over the long term, balancing access to the resources people need to sustain livelihoods while at the same time building ecosystem resilience in the face of uncertainty and change (Holling, 1973, Galvin, 2009).

3.1.2. Traditional Fire Knowledge around the World

A subset of TEK is Traditional Fire Knowledge (TFK), which I define as fire-related knowledge, beliefs and practices that have been developed and applied on specific landscapes for specific purposes by long time inhabitants. As opposed to lightning ignition or other non-anthropogenic ignition, “burning is the application of fire to particular vegetation areas under specified conditions to achieve select cultural purposes” (Anderson, 2005, p 135).

A review of the TFK literature reveals a range of detail in authors' accounts of local practices and fire knowledge, from general to very specific. The range in specificity of TFK probably relates to four factors: 1) whether such knowledge is currently practiced or is only historical at the time of the research, 2) the depth of the investigation, including the degree of familiarity the researchers have with fire, 3) how comfortable the participants are in sharing detailed fire information (Hill et al., 1999); and 4) whether or not the observer can observe the subjects interacting with live fire on the ground.

The evolution of traditional fire knowledge in the US, for example, is truncated by the historic, purposeful destruction of indigenous peoples and cultures, which resulted in the loss of fire praxis across the landscape. In one of the most thorough treatments of Native American fire, Stewart (2002) provides extensive historical accounts of indigenous burning from coast to coast across North America. However, because the research relies almost entirely upon historical accounts written by European explorers and immigrants, the depth of fire knowledge that may have been possessed by the native peoples who did the burning is largely missing. Lake (2007) provides additional detail from his study of indigenous burning in California. Although most of Lake's subjects did not currently engage in traditional burning, many did recall the former practices of their elders. Other observers (Lewis and Ferguson, 1988, Anderson, 2005) generally noted that Native Americans used fire for a variety of purposes, when and where burning took place, and that Indian burning had a profound influence on the vegetation over large areas (proven in part by open areas reverting to forest following cessation of burning). What is most difficult to find, especially in accounts from the USA and Canada, are records of the nuances in fire knowledge that practitioners use when they are still active fire managers.

The study of TFK in Australia is the most comprehensive in the world (Bowman et al., 2004), due in part to the opportunity to study Aboriginal practices through observation of local fires and by documenting the words of the local people themselves. In an ethnographic dialogue with the Aboriginal people of the Bininj Kunwok tradition, for example, indigenous authors Garde et al. (2009) reveal a local vocabulary of at least 46 words that relate specifically to fire, fire behavior, burning practices and fire effects. Observing people in action working with fire on the land, and providing opportunities for local people to demonstrate their practices and to record their own fire language illuminates the full richness of TFK (Haynes, 1985, Garde et al., 2009).

In several indigenous and local cultures, social influences from the outside have altered the application of traditional burning practices and the evolution of TFK. Government regulation, changes in land tenure, population dynamics including migration, and economic globalization are examples. The most widespread of these are the influences of European colonization and subsequent efforts to exclude local use of fire on the landscape, or at least to restrict it. Attendant demographic shifts included extermination of indigenous peoples through violence and disease (Mann, 2005, Levitus, 2009), movement of peoples from nomadic living to centralized and more sedentary communities (Ross, 2002), and discouraging traditional fire practices through regulation or persuasion (Kull, 2004, Mbow et al., 2000, Cabrera-Garcia and Frias, 2004).

In Australia, for example, changes in fire management began in the late 1800s after extensive die-off of Aboriginal people from introduced diseases including smallpox and influenza (Ritchie, 2009). There were simply less people starting fires in the traditional way to accomplish the traditional landscape effects. Haynes Colonization in Australia resulted in both massacre of local bands of Aboriginal people and the establishment of settlements and outstations to which Aboriginal people were either physically displaced or attracted (Cooke, 2009). By the mid-20th Century, the development of roads brought additional changes in burning patterns, with purposeful fires more likely to be lit along roads rather than on foot deeper into the bush (Cooke, 2009). The cumulative impact of these changes upon fire management in northern Australia was substantial for a time, resulting in fewer, larger, later season fires that both researchers and Aboriginal people considered destructive (Russell-Smith et al., 2009, Haynes, 1991).

In Madagascar, restrictions on burning were legislated at the national level to protect timber and other resources in 1907 and 1913, little more than a decade after French colonization of the country (Kull, 2002). Although the TFK of indigenous people prior to colonization is largely undocumented and so impossible to compare, contemporary burning practices in Madagascar are shaped by a century of regulation and sanctions (Kull, 2004). Fire management is clandestine; fires are lit by individuals operating in secret, often at night, and the initial ignition is often hidden from view. These social factors would shape the resulting fire behavior, fire perimeters and landscape patterns, moderating fire behavior due to nighttime humidities and temperatures, and resulting in patch sizes resulting from free spreading fire that responds to existing fuel breaks.

Fire practitioners in Madagascar are adept at incorporating the current political environment into their decisions, knowing when the government is likely to enforce sanctions and when it is not (Kull, 2002). Local communities protect fire practitioners' identity, resisting government inquiry into who started a particular fire. One can imagine that the skills required for this kind of socially-based navigation and decision-making in Madagascar might be different from what is required to accomplish burning in places where the practice is allowed or encouraged.

Despite these differences, local fire knowledge in Madagascar is quite extensive. As revealed in a combination of interviews conducted by Kull (2004, p 89), local practitioners demonstrate knowledge of several grazing, plant and fire interactions:

> *“With increasing temperatures and the first tentative rains (September or October), pasture grasses begin resprouting. . . . Burning plays several roles at this point. First, it removes the dry stalks of old grass that can impede the access of cattle to the small new shoots. Second, it releases inaccessible nutrients in the old grass back to the soil, fertilizing the new growth. Third, burning overrides the competitive effects of selective grazing, giving favored forage species a better chance. Fourth, by exposing the soil to the sun, in areas of sufficient moisture fire may accelerate the growth of the resprouts. In fact, burning provokes a resprout at any time of year, though the vigor and speed vary.”*

At La Sepultura, local informants pointed to various demographic changes that have affected fire management. They said that globalization of trade, including the National Free Trade Agreement, has negatively affected the economics of small scale farming. This has further encouraged men, who have traditionally been the local fire practitioners, to migrate for extended periods of contract work in the United States (pers. obs., May 2006-May 2008, Valle de Corzo and Corazón del Valle). Local elders also express concern that, as young people take advantage of more educational opportunities and leave the countryside for work in the city, traditional fire knowledge will diminish and fewer people will be available in the community when burning needs to be done. Jardel-Peláez explains that near the protected area of La Reserva de la Biosfera Sierra de Manantlán, in the Mexican states of Jalisco and Colima, some ejidos have only elderly residents who are too old to conduct the burning, and there are no young people in residence to inherit the practice (E. Jardel-Peláez, pers. com., October 24, 2008, Morelia).

3.1.3. Traditional Fire Knowledge and Practice in Chiapas and Mesoamerica

Despite the longstanding importance of fire in Mesoamerica, few studies detail the burning techniques employed by Mesoamerican farmers. Reina (1967) provides a detailed account of milpa agriculture including burning among Maya descendants of the Itzá of Petén in nearby Guatemala. He describes the way in which the milperos (milpa farmers) prepare the fields for burning, including their exquisite analysis of the conditions they want to use for burning, involving winds, the moon and expected rain. Reina also describes how the farmer directs his helpers, the reasons for choosing the particular time for igniting the fire and the meaning of the different colors of smoke (Reina, 1967). In his study, the milperos exhibited additional knowledge of the fire's impact upon the soil, the time for planting after the burn and other information not usually considered by professional fire managers throughout North America. Excerpts from this extraordinary account are included in the Appendix 3.A.

Likewise, Otterstrom (2004) asserts that Mestizo peasants in Nicaragua exhibit complex knowledge of weather, fuels, fire behavior and fire effects. Through participant observation in prescribed burns and a series of interviews, Otterstrom documented that local knowledge was used by the peasants to determine how the land was prepared for burning, how frequently it was burned, the day and season of burning and the lighting methods (Otterstrom, 2004). In their separate studies, both authors, Reina and Otterstrom, noted the farmers' enthusiasm over a good burn.

Tropical pine-oak ecosystems play an important role in Mexican fire management today. Roman-Cuesta et al. (2004) completed a study of wildfire occurrence in the state of Chiapas for the years 1993-1999. During that period, 85 percent of the forest fires (wildfires), covering 65 percent of the area burned, took place in pine-oak communities.

El Niño has a strong influence on the extent of such fires, although the number of fires was less variable. Twenty eight percent of the forest area burned during the severe El Niño episode of 1997-1998 (Roman-Cuesta et al., 2004).

For fires documented between 1993-1999, Roman-Cuesta et al. (2004) found that negligence and deliberate burning were the most common causes. Escapes classified as negligence were responsible for 51 percent of the wildfires and 57 percent of the area burned; intentional fires (arson) were responsible for 33 percent of the fires and 21 percent of the area burned (Roman-Cuesta et al., 2004). Wildfire statistics are similar for the decade 1990-2000. Seventy-four percent of the fires, covering 61 percent of the area burned in Chiapas occurred in pine-oak communities (Roman-Cuesta, 2001). Statewide, 52 percent of the wildfires were attributed to negligence, 29 percent were considered arson and 17 percent were from unknown causes (Roman-Cuesta, 2001).

In years with typical moisture conditions, tropical vegetation outside of the pine-oak ecosystems does not typically burn (Roman-Cuesta, 2001); however during drought when fires in the pine-oak systems are likely to escape, they often have detrimental effects on adjacent fire-sensitive ecosystems (those that are not fire adapted and prone to changes in structure and composition when fires do occur (Myers, 2006). During the drought associated with the El Niño episode of 1997-1998, all vegetation types in Tropical Mexico burned (Roman-Cuesta et al., 2003).

In addition to degrading fire-sensitive ecosystems, escaped fires and the accompanying smoke can risk citizens’ respiratory health, contaminate local water supplies (through erosion) and in some cases interfere with commerce and tourism. During the extensive fires of 1998, smoke covered the sky for a month; citizens throughout the state experienced severe respiratory difficulties and airports were closed due to limited visibility (Roman-Cuesta, 2001). To complicate the matter, scientists predict an increase in the frequency and severity of El Niño-driven droughts in the region as a result of global climate change (Magrin et al., 2007). This will almost certainly increase the extent of wildfires in southern Mexico in the future.

Around the world, governments have sought to restrict fire use through regulation, policy and educational campaigns. Kull's intensive studies of fire use by local people in Madagascar have shown that regulatory and punitive approaches to fire management can be ineffective and even counterproductive (Kull, 2002, Kull, 2004). In a study of decision-making by farmers in the tropical savannas of central Brazil, Mistry (1998) found that farmers made their decisions about fire management based upon agricultural economics (forage conditions, income stability) and that although there were a suite of regulations relating to government approvals to burn, these played little role in farmers' decisions. Assuming the presence of sufficient heat and fuel to support combustion, fire's ability to spread unattended makes it easy to use, in secret if necessary, for both livelihood and protest purposes (Kull, 2002, Kull, 2004, Cottrell, 1989). In essence, where people rely on fire for survival, such as for subsistence agriculture, they will use it as they see fit.

In Chiapas, as it is throughout much of Mexico and Central America, fire is an integral part of milpa agriculture and grazing systems upon which producers depend for survival. There is some concern that unrecorded local knowledge about fire that is kept in the minds of local community members may be lost as elders pass away and as young people move from the countryside to the cities. Such in-depth knowledge, passed from generation to generation, is undoubtedly needed to help restore ecological fire regimes and to prepare for the challenges of fire management within this and other reserves in the future.

3.2. Methods

3.2.1. The Two Study Communities

I selected two small communities within La Sepultura for this study: Corazón del Valle and Valle de Corzo (Figure 3.1). Both of these communities enjoy good relations with CONANP staff members and they are used to cooperating with the government on various projects. In addition, I had met the leadership in both communities during previous visits, having participated in fire-related work there as an employee of The Nature Conservancy.

Land tenure in both communities is cooperative. Corazón del Valle was founded in 1981 (Cruz-López, 2006) whereas Valle de Corzo was founded approximately 15 years ago (S. Pinacho, pers. com., May 18, 2006, Corazón del Valle). Both ejidos were formerly ranches.

Members of both ejidos considered Corazón del Valle as further developed than Valle de Corzo. During the study period, inhabitants of Valle de Corzo were still actively building or improving their homes. Fewer homes had indoor plumbing and several homes had neither indoor nor outdoor bathrooms. Corazón del Valle had a secure source of water piped from a higher elevation watershed within the reserve, but Valle de Corzo did not.

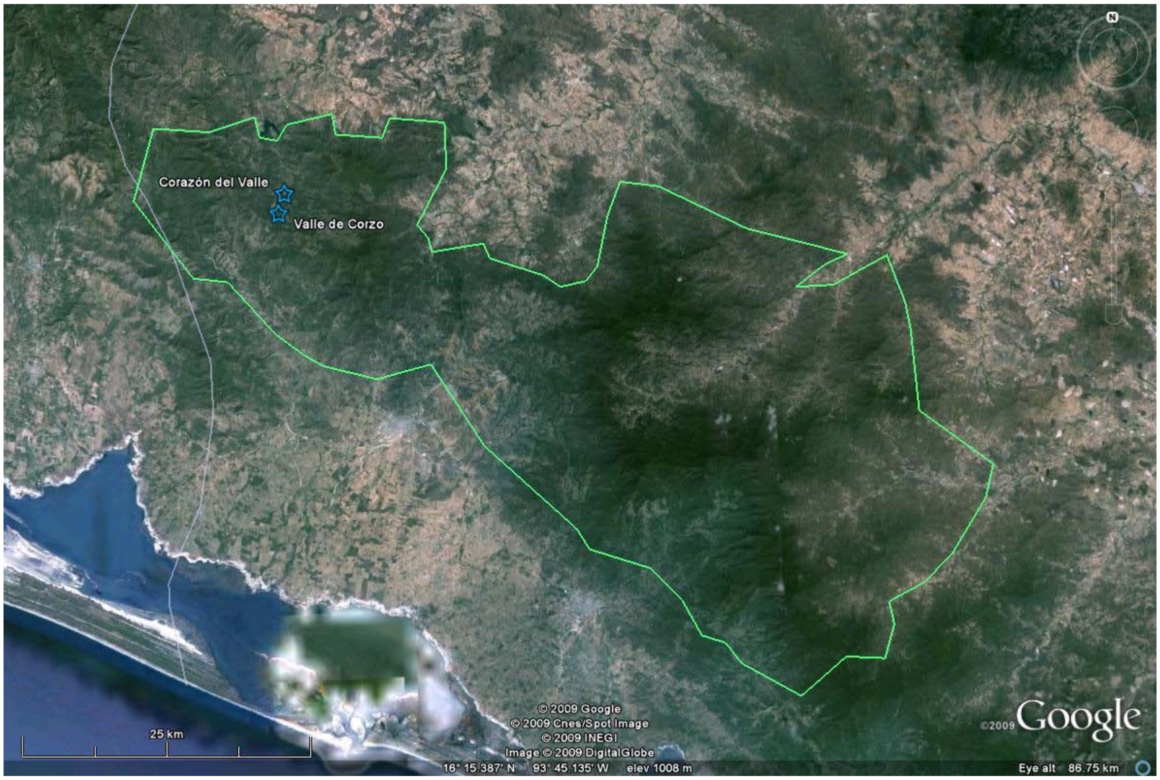


Figure 3.1. Location of the two study sites, Corazón del Valle and Valle de Corzo, within the boundary of La Sepultura Biosphere Reserve (Google, 2010; reserve boundary courtesy of Pronatura-Sur 2008).

Several of the inhabitants of Valle de Corzo had moved either from the state capitol of Tuxtla Gutiérrez, a city of more than a 500,000 people (INEGI 2008), or from the coast. Some of the community members commuted weekly to the city for work, although my interviews focused on members who lived and worked on the land full time.

Typically, the individuals registered as *ejidatarios* control individual parcels of land, while *pobladores* live in the community but do not have land. Typically the founders of the ejido selected and have rights to use the highest quality parcels while ejidatarios who joined the coop later have rights to use lesser quality or smaller parcels.

Both communities have one-room primary schools. Some children who graduate from sixth grade travel into town approximately 10 km to attend secondary school.

Although both are accessible by dirt road to the small town of Rosendo Salazar, and from there by paved road to the Municipality of Cintalapa (roughly equivalent to a county seat in the US), Valle de Corzo is approximately four kilometers farther up into the hills. This made it impractical for children from Valle de Corzo to travel on foot to the secondary school in Rosendo Salazar.

The population sizes of Corazón del Valle and Valle de Corzo are small, consisting of 29 households and 111 inhabitants in Corazón del Valle and 27 households and 99 inhabitants in Valle de Corzo. The general layout of each community is shown in Figures 3.2a and 3.2b. I asked two key informants to help define age groups that would be meaningful to the study of local fire practices. They recommended using the following age groups: young = 15-29 years old, mature = 30-49 years old, and seniors = 50+ years old.

Table 3.1 summarizes the population sizes of the two communities. Figures 3.3a. and 3.3b. show the basic demographics of age and gender of each community. Because I had been told that the men usually conduct the burning, I also noted the number of men in these three age groups. This serves as a crude estimate of the number of men potentially involved in fire management in each community. Thirty-four men in Corazón del Valle and 35 men in Valle de Corzo fell in the age groups that are commonly involved in fire management.

Figure 3.2a. Satellite image of the study community, Corazón del Valle (Google, 2010).

Figure 3.2b. Satellite view of the study community, Valle de Corzo (Google, 2010)

Table 3.1. Numbers of households and inhabitants of the ejidos Corazón del Valle and Valle de Corzo, as of January 2008. The number of men included in the young, mature and senior age groups provides a rough estimate of the number of men potentially involved in fire management. Age groups: Young = 15-29 years old, Mature = 30-49 years old, and Senior = 50+ years old.

Community	Households	Inhabitants	Men in the fire age groups: young, mature and senior.
Corazón del Valle	29	111	34
Valle de Corzo	27	99	35

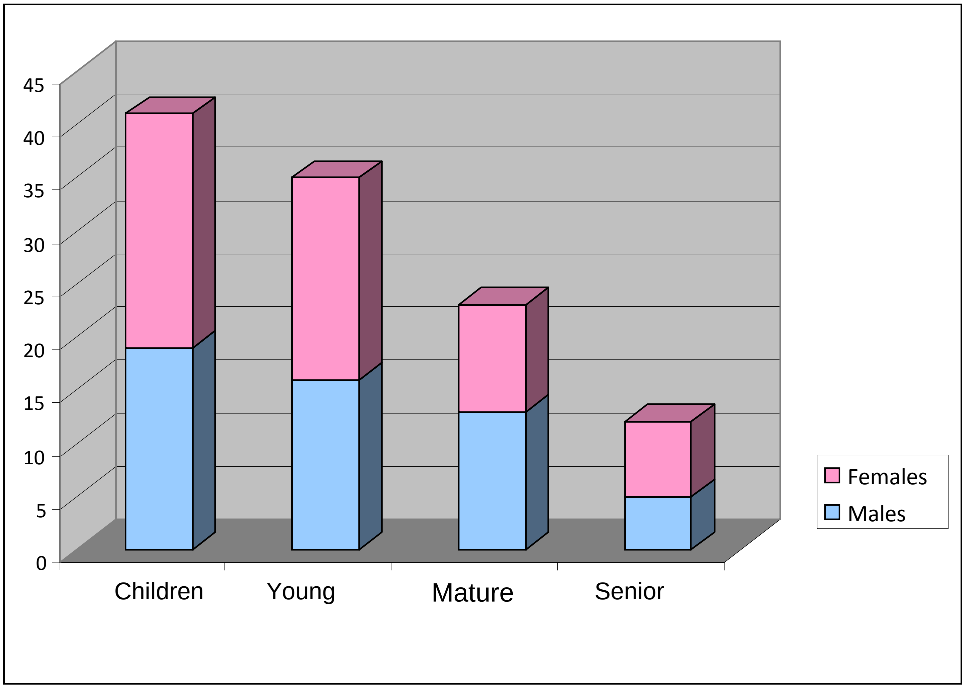


Figure 3.3a. Population of the ejido Corazón del Valle in each age group, by gender, as of January 2008. Age groups: Children = 0-14 years of age; Young = 15-29 years of age; Mature = 30-49 years of age; and Senior = 50+ years of age. (n=111.)

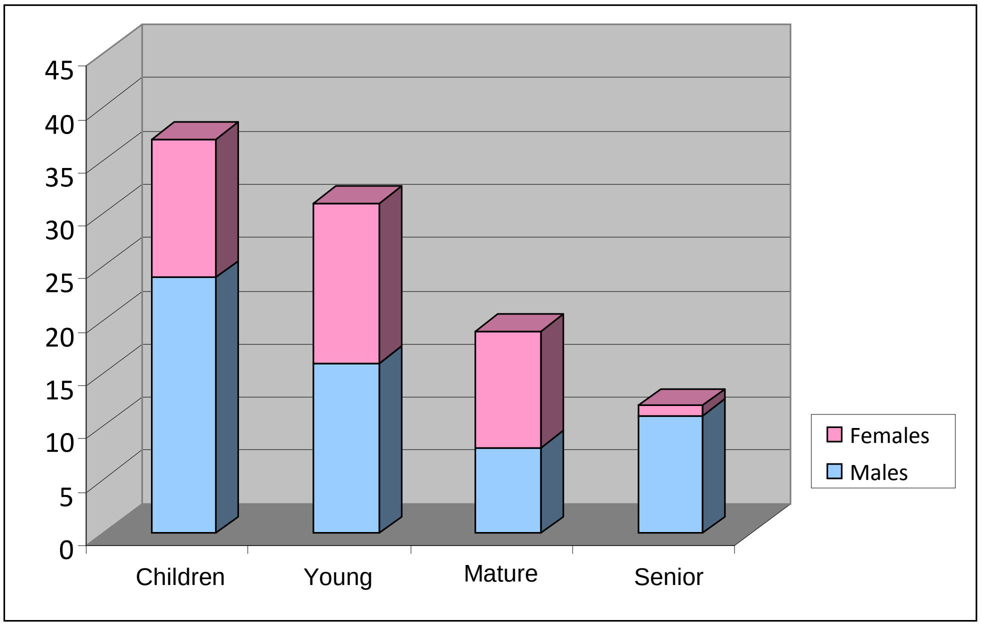


Figure 3.3b. Population of the ejido Valle de Corzo in each age group, by gender, as of January 2008. Age groups: Children = 0-14 years of age; Young = 15-29 years of age; Mature = 30-49 years of age; and Senior = 50+ years of age. (n=99.)

3.2.2. Ensuring Local Relevance: The Advisory Committee

To help ensure the local relevance and appropriateness of this study, three key informants and I initiated a local advisory group. The group consisted of a woman and a man from each of the two communities, plus one person who staffed a small non-governmental organization (NGO) that focused on natural resource conservation and community development in the area (Table 3.2). Initially, the NGO staff person was neither a resident of either study community nor a government employee; however, toward the end of the project he became a staff member of the reserve.

Table 3.2. Members of the local project advisory committee.

Name	Community or Organization
Sixto Esteban Pinacho Posada	Corazón del Valle
Joaquín Sánchez Rosales	Valle de Corzo
Zenaida Cruz Molina	Corazón del Valle
Inés Ramos	Valle de Corzo
José Domingo Cruz López	Conservación y Desarrollo, A.C. and later CONANP

3.2.3. Cultural Appropriateness of Research Methods

Matching research methods to the cultural environment enabled me to behave more appropriately as a guest in my research community and, I hope, to improve the accuracy of the information that I gleaned. I wanted to produce a reflection of relevant knowledge held by the local participants that was as accurate as possible, and truly useful to the participants. As a person who is from a different culture with modest ability to speak the local language, I sensed that using only Western methods of ecological research, such as experimentation toward findings based on strong inference theory (Magnusson and Mourão, 2004) would likely be permissible to my academic audience, it would likely generate incomplete insights and limit the utility of the project to local people. I also wanted to avoid any perceptions that might shrink my opportunities for further research in the community.

Each of the research methods I used involved the complexities, uncertainties and trade-offs that are common in interdisciplinary, participatory research (Bawa, 2006, Lele and Norgaard, 2005, Chambers, 1994b, Fernandez, 1986). Engaging local people in data collection meant that local people could converse with one another about what I was actually doing out there in the pine forests, and they enjoyed learning how to operate equipment such as video cameras, GPS units, dbh tapes and a laptop computer. The trade-offs that resulted included sacrificing a few data points and a handful of GPS locations for sample plots.

I tried to learn or develop techniques that were suitable to the ideal case in which producers, reserve managers and researchers would sit in the same room and evaluate findings together, on equal footing. When I was seeking permission from the two local communities to do my study, one of the stakeholders said often the government and the researchers would come in to do projects, but that the communities would rarely see the full report, or sometimes a watered down version of it. This phenomenon is apparently not unique to my study; Cabrera–Garcia and Frias (2004) noted the same thing in their study of bird conservation in rural Central Mexico.

3.2.4. Periods of Field Work

I conducted six periods of field work over three years (Table 3.3). Materials and equipment used are shown in Table 3.4. For field assistance and to help inform community members about the project, I trained 14 local people to work beside me in data collection, data entry, photography and other tasks (Appendix 3.B).

Table 3.3. Dates and activities for each field visit to the study site.

Dates	Activities
February 2006	Study site exploration; meet people in both ejidos and ask permission from the local people to conduct the study.
May 2006	Observe community-based fire planning workshop sponsored by The Nature Conservancy and CONANP; conduct group interviews; and observe and measure fire behavior on two prescribed burns associated with the workshop.
March 2007	Visit local pine forests, including sites of prescribed burns and wildfire site with two academic committee members, one from the Universidad Autónoma de Chapingo and one from Colorado State University
January 2008	Conduct individual interviews
March 2008	Measure pre-burn tree size classes, seedlings, fuels and canopy openness.
May-June 2008	Complete individual interviews. Observe and measure fire behavior on four prescribed burns; measure pre-burn trees size classes, seedlings, fuels, and canopy openness. Conduct fuel removal experiment on seedlings. Measure post-burn bark char, canopy scorch, seedlings, fuels and canopy openness.
November 2008	Present preliminary results to the general assembly of each ejido, and to agency managers, and gather feedback.

With the advisory committee's guidance, I used a combination of focus groups, semi-structured individual interviews and participant observation to investigate the research propositions.

Table 3.4. Equipment and materials used during the project.

Task	Field Equipment	Data Processing and Analysis
Semi-structured group and individual interviews	digital audio recorder, digital still camera, paper plates, 3x5 cards, pencils, kernels of corn, spiral notebook, clipboard, approved interview script	Laptop computer, NVivo 2.0 software
Fire behavior observation	Personal Protective Equipment (hardhat, Nomex clothing, leather gloves, leather boots, fire shelter, canteen); digital video cameras (2), digital still camera, steel conduit pipes (1.5 and 1.0 meter lengths), stopwatch, sling psychrometer, wind meter, data books, pencil, compass, GPS unit, clinometer, first-aid kit.	Laptop computer, Microsoft Excel, Microsoft Moviemaker software

3.2.5. Focus Groups and Semi-structured Individual Interviews

Methods for data collection and qualitative analysis of focus groups and interviews are those described in Bernard (2002) and Russell and Harshbarger (2003). Using locally available materials in the focus groups was inspired by the participatory methods of Chambers (1994a).

With the assistance of two advisory committee members who served as facilitators, I conducted two focus groups in May 2006. These groups concentrated on a free listing and ranking exercise focused on the question, "What factors influence the behavior of fire in the forest?" If needed, a second question for clarification was, "What things do you take into consideration when you are doing a prescribed burn?"

Participants for the focus groups volunteered from each community. One focus group included ten participants from Corazón del Valle. The second group had five participants from Valle de Corzo and one participant from Corazón del Valle. I suspect that the difference in group sizes relates to the distance and time it required for participants from Valle de Corzo to travel in order to participate. Participants from Valle de Corzo had to walk a few kilometers to the community building where the exercise took place; whereas participants from Corazón del Valle did not have to travel.

Before the exercise started, each participant received a small bag containing 100 kernels of local corn. The facilitator then asked participants to name factors about fire that came to mind. For each factor named, either the participant or the facilitator wrote a word or symbol for that factor on a 3x5 piece of paper. After the group named all of the factors that came to mind, the facilitator placed each paper on a paper plate visible to the group. After all the plates were ready, the facilitators asked participants to weight the variables by placing a portion of their 100 corn kernels in the plates to indicate the factors' relative importance: more kernels placed in a given plate would mean that the group saw this factor as more important. When the group finished putting all of its corn kernels on the plates, participants briefly discussed the visual results and made adjustments by re-distributing the corn as they saw fit. Finally the participants and I counted the total number of kernels assigned to each factor by each group.

Two members of the advisory group who had the ability to read reviewed the interview questions, which had been previously approved by the Institutional Review Board at Colorado State University. With introductions made by three community members, I conducted the individual interviews during 2008.

The sampling design for individual interviews included stratifying the sample population by community, gender and age group (Table 3.5). Two members of the local advisory committee helped us to identify three age groups that seemed to them pertinent to studying how local people use fire: young, mature and senior. These groups included the following ages: Young = 15-29 years, Mature = 30-49 years, and Senior = 50+ years. Our goal was to sample approximately 30 percent of the adult population of both communities, and to sample equal numbers of people from each community in each of the three age groups. Although men typically do the burning in both communities, I included some women in the sample population.

Table 3.5. Sampling scheme for semi-structured individual interviews. Age groups were defined by producers as being relevant to fire management: Young = 15-29 years old; Mature = 30-49 years old; Senior = 50+ years old. (n=36.)

Participants from Corazón del Valle	Participants from Valle de Corzo	Subtotal
Men Senior = 3 Mature = 5 Young = 4	Men Senior = 5 Mature = 4 Young = 4	n = 24
Women Senior = 2 Mature = 2 Young = 2	Women Senior = 1 Mature = 2 Young = 2	n = 12
n = 18	n = 18	Total Participants n = 36

I made two exceptions to the intended sample design. Because the community of Valle de Corzo has only one woman in the senior age group, I included an additional senior male in the sample population. During one interview, a participant from Corazón del Valle who was identified in the census as belonging to the Senior age group indicated that he was younger than 50 years old, so afterward I included him in the Mature age group.

In total, male participants from Corazón del Valle represented 47.1 percent of the men and 25.7 percent of the adult population of the community. Male participants from Valle de Corzo represented 51.4 percent of the men and 29.0 percent of the adult population of the community.

Together with local assistants, I selected participants using the local registries of each community, one community at a time. We wrote the name of each household on a small piece of paper and, by local custom, rolled each paper into a little ball and put it into a hat. We drew names of households from the hat. In the order of names drawn, we filled the gender and age slots of participants starting with the senior group, moving to the mature group and ending with the young age group. We drew household names without replacement, so as not to choose more than one person from each household.

From the names selected, I conducted 36 individual semi-structured interviews according to the script approved by the Institutional Review Board of Colorado State University, CONANP and the local advisory committee (Appendix 3.B.). With permission from each participant, I recorded interviews using a hand-held digital audio recorder and took notes on a laptop or on paper. I completed 30 interviews during January of 2008 and the remaining six interviews in May and June of 2008. To ensure confidentiality, I assigned an alpha-numerical code to each interview.

After downloading the digital interview files, native Spanish speakers and I transcribed each audio file into Spanish written text. I checked the content of each of the transcriptions against excerpts of the audio tapes for general accuracy. Then I coded and analyzed the text of each transcription using NVivo software, version 2.0.

I used an inductive approach to analyze the interviews. Based on the results of the focus groups, I expected to hear particular themes about fire; however, I allowed topics to emerge from the interview transcriptions anew, coding them one by one as they appeared (Miles and Huberman, 1984, Gibbs, 2002). I also noted when participants described connections among two or more factors that influence fire, for example, talking about the influence of fuels and wind together. I coded a total of 125 schemas relevant to the physical-ecological-social system of fire at La Sepultura (Appendix 3.C.).

In displaying these results, I classified the schema into thematic groups, which I called "factors of fire," e.g., days since rain. I tallied the number of respondents that mentioned each factor of fire, and displayed the results in five classes based on the percent of respondents who mentioned them. The classes follow natural breaks in the data, as follows: 1-10%, 11-25%, 26-50%, and 51-100%. The fifth class was for factors that were included in direct questions, biasing the number of people who mentioned them. Based upon participant responses, these factors still seemed to be real in the minds of the producers.

3.2.6. Literature Review of Traditional Fire Knowledge around the World

To accomplish Objective 2, I conducted a simple review of the literature on traditional burning practices recorded in 19 studies from Africa, Australia, the US and Canada, and elsewhere in Latin America. I considered each factor of fire as a kernel of traditional fire knowledge that can be compared across cultures and geographic boundaries. I tallied the fire factors detectable in the text of each study, starting with the list of fire factors that had emerged from the interviews at La Sepultura and then adding new factors as they appeared in the literature. When fire factors were described in slightly different terms among studies, I subjectively broadened the description of the factors to be slightly more inclusive.

3.2.7. Participant Observation of Controlled Burns and Fire Behavior

Participating in several controlled burns at the study site provided an opportunity to corroborate what producers said about their burning practices during the focus groups, interviews and in casual conversation, and to see their traditional knowledge in practice. Data collected on the weather during each burn and the flame characteristics generated as they conducted each burn provided insights into producers' ability to manipulate the fire factors they described in order to achieve their the goals they had described.

I participated in two prescribed burns during May of 2006 and four prescribed burns in May-June of 2008. Locations of each burn are shown in Figure 3.4. Among these, one controlled burn occurred at night. There was at least one other burn that occurred at night during the time I was in residence. I was not notified that this burn was happening, and so I was unable to participate in it. The two burns that took place in 2006 were associated with the community-based fire management workshops sponsored by The Nature Conservancy and CONANP. Those two fires included large crews made of both government employees and community members, which is not typical. These fires were started after sunrise and burned into midday which is also not typical.

I trained four local assistants to assist with videography of fire behavior using a handheld video camera (Appendix 2.A.) CONANP staff members and I took still pictures during the fires. With the help of Oscar Rodríguez of Pronatura-Sur and local assistants, we captured repeated measures of weather conditions, flame lengths and rates of spread during the fires. I used a combination of ocular estimates of live fire, video footage and still photography to record flame lengths, which I estimated to the nearest five centimeters.

I used both direct and indirect methods to measure fire rates of spread (Rothermel and Rinehart, 1983). The direct method is appropriate for low intensity fires in which an investigator can work safely in close proximity to the flames. When safety allowed, I placed pieces of steel tubing (conduit), some a meter long and others a meter and a half long, directly in the path of the fire, oriented perpendicular to the fire's spread direction. Then we used a stopwatch and videography to measure the time it took the fire to burn the length of the pipe (Figure 3.5). While the fire was burning near the pipe, I also estimated flame length, using the pipe as a reference.

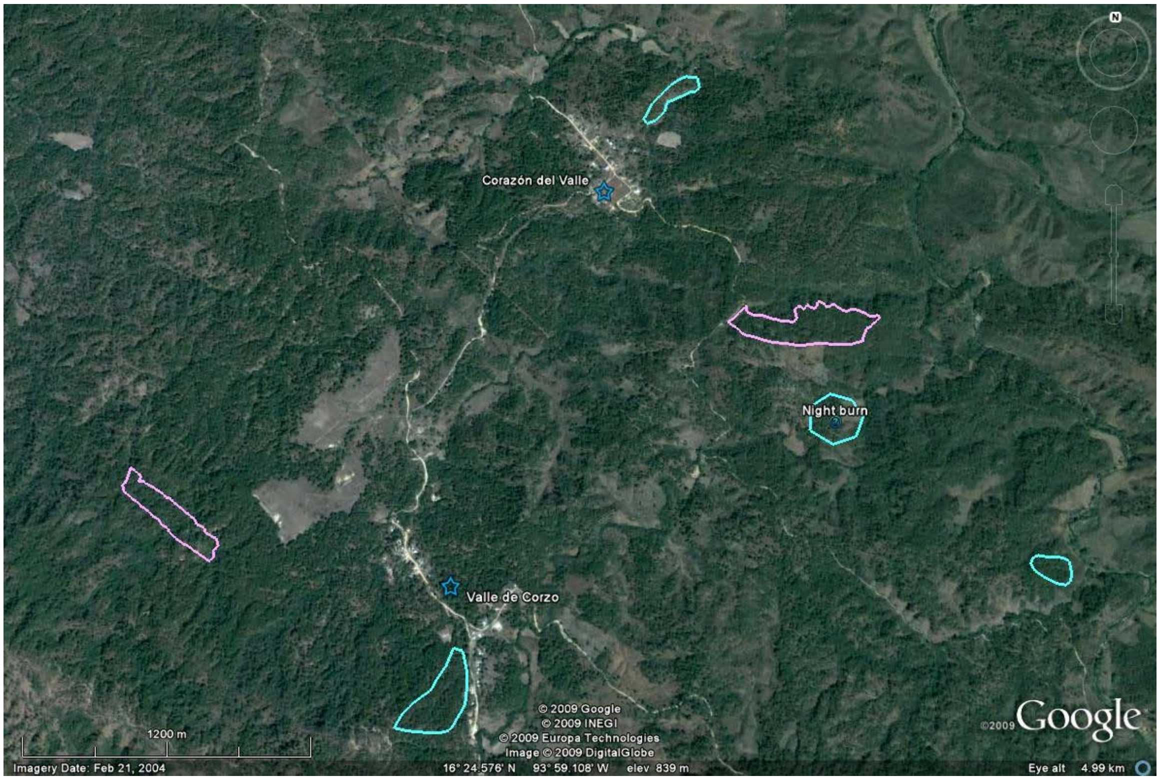


Figure 3.4. Locations of controlled burns that I observed within the two study communities. Burn parcels bounded in pink took place in 2006, and burns bounded in light blue took place in 2008 (Google, 2010).

I also utilized an indirect method for measuring the rate of spread, which can be used to safely study fires burning in inaccessible locations, those exhibiting high or variable intensity, or those that pose some other safety risk (Figure 3.6.) In this method, the photographer stays in one place, taking video footage of the fire from a secure location that has a good view of the flames. In the example shown in Figure 3.6, the photographer was located across a creek and in a firebreak on one side of a valley while the fire was burning down slope on the opposite side of the valley. From this vantage point, he took video footage of the fire burning on the opposite slope for an extended period of time. After the fire, I reviewed the videos for suitable landmarks, returned to the

Figure 3.5. A direct method of measuring the rate of spread and of estimating flame height, when it is possible to work safely next to the flames. In this example, we utilized a meter-long metal tube, visible in the photograph to the left of the blue line, plus an ordinary stop watch. An estimate of the average flame length in this photo would be 10 centimeters.

slope where the fire was burning and measured the distances between trees and other points visible in the video. With these distances, it is possible to review the video multiple times along with a timer, either the clock inside the camera or a stopwatch. Calculated as the distance the fire traveled per unit of time, we recorded rate of spread in units of meters per minute.

Figure 3.6. An indirect method for measuring the rate of spread, by analyzing video footage after the fire and measuring distances between trees or other points on the landscape. The location of the fire at two points in time, together with time passed, as indicated by either the timer inside the camera or a stopwatch, enable calculation of the fire's rate of spread.

3.3. Results

3.3.1. Respondent Characteristics

There were some detectable differences in years of age, years of fire experience and years of formal school education within the sample (n=36). The average age of all interview participants was 40.3 years, and the average age was similar in both communities. In the total sample, the average years of experience with fire was 13.4 years, including both men and women; and the average years of formal schooling was 4.6 years.

The difference in years of experience working with fire in the countryside (in milpas, potreros and forests as opposed to indoors) was pronounced between genders (Figure 3.7a). In the total sample, men averaged 17.5 years of self-reported experience, including all age groups, while women averaged 2.0 years of fire experience. At Corazón del Valle, men reported an average of 21.8 years of experience, while women reported zero years of experience. At Valle de Corzo, women reported a slightly higher number, 3.2 years of fire experience. I think this is due to women's experience assisting with suppression of the wildfire that burned near the houses in the ejido a few years ago. The men of Valle de Corzo self-reported an average of 13.1 years of fire experience.

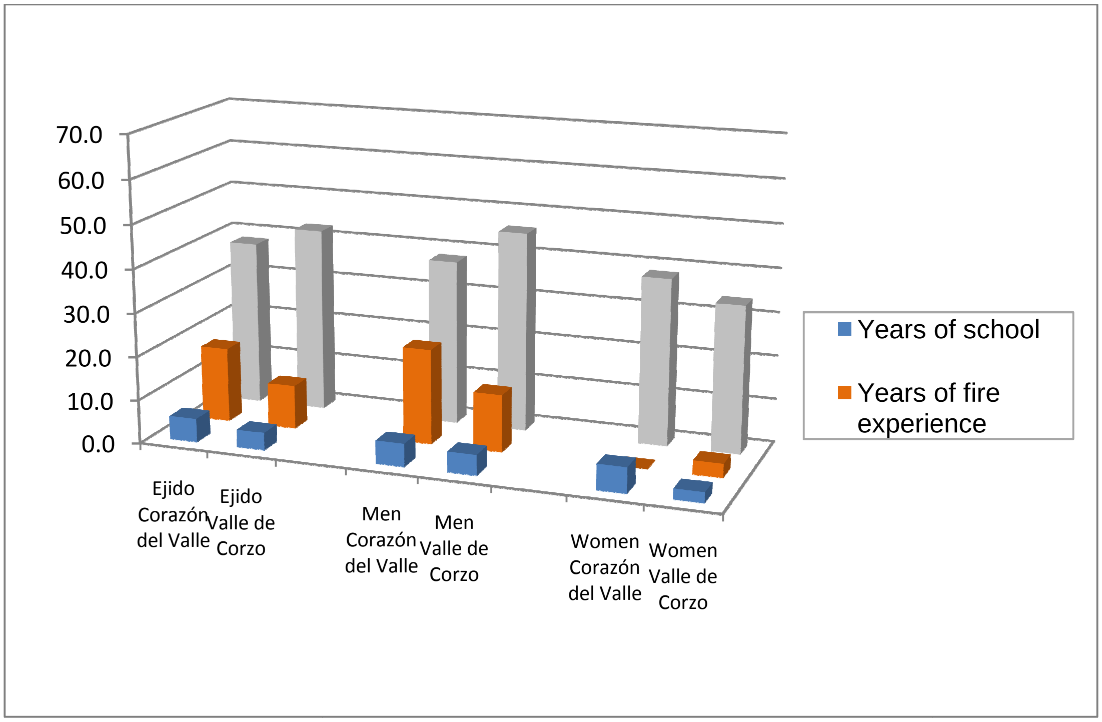


Figure 3.7a. Average years of age, years of fire experience and years of school among interview participants from Corazón del Valle and Valle de Corzo according to community and gender. (n=36). La Sepultura Biosphere Reserve, Chiapas, Mexico.

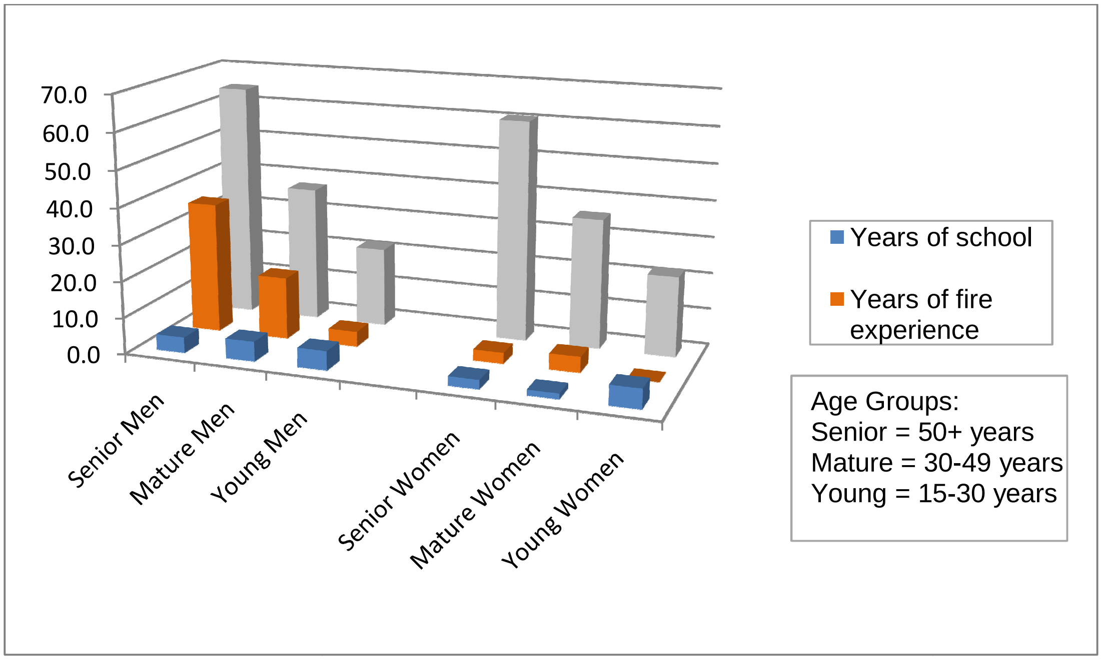


Figure 3.7b. Average years of age, years of fire experience and years of school among interview participants from Corazón del Valle and Valle de Corzo according to age groups and gender. Age groups: Young = 15-29 years, Mature = 30-49 years, Senior = 50+ years n=36. La Sepultura Biosphere Reserve, Chiapas, Mexico.

Examining differences in these same factors by age group and gender, we see that in general, women report less fire experience than men, and women of all age groups report similar average years of fire experience (0-4.3 years). Young men report a similar level of experience: 4.1 years. Men in the Senior age group report experience with fire for more than half the lengths of their lives (average 35.8 years of fire within the average age of 64.4 years) (Figure 3.7b). Men in the Mature group report an average of 17.1 years of fire experience.

3.3.2. The Initial List of Factors that Producers Consider when Thinking about Fire

Participants in the two focus groups provided the first list of the topics producers consider when they think about fire on the landscape (Table 3.6). The topics generated by free listing touch upon five of the six propositions within Objective 1, including purposefulness, fire control, weather, fire behavior, fire effects and field practices. The remaining proposition relates to relative quantities of fire variables, which this free listing exercise was not designed to address. The first focus group indentified eight fire-related factors; the second group identified twelve factors (Table 3.6). Among the total of 16 factors mentioned, five were discussed by both groups. These are wind direction, slope, season of burn, time of day and fire break (Table 3.6). I note that both groups had participated in the recent community-based fire planning workshops, and this could have influenced their responses.

I attempted to repeat the free-listing and ranking exercise from the focus groups in the individual group interviews, but the activity was generally unsuccessful. Most individuals found it problematic to rank the fire factors they identified in any perceived order of importance (e.g., slope more important than wind). Some participants paused at the request; others remarked that it was difficult to say one factor was more important than another. Some indicated that the factors work together or affect each other. Although I did not anticipate this result, the response suggests that some participants understood that fire-related factors interact with one another in various combinations.

One individual, a male from the mature age group, related to this exercise with considerable interest. He listed 19 factors, and in the process he arranged them in hierarchical order. No other participant responded to this exercise in a similar manner.

Table 3.6. Results of the two focus groups, one from each community, about the factors that influence fire behavior. Also included are the results of one interview in which a man in the Mature age group mentioned 19 factors. Shaded boxes indicate factors identified in both focus groups.

Factor	**Corazón del Valle**	**Valle de Corzo**	**Factors named by one Mature male**
Wind direction	X	X	X
Slope	X	X	X
Season of the year	X	X	X
Hour, schedule during the day	X	X	X
Fire break	X	X	X
Fire purpose or goal	X		X
Quantity, height of fuels		X	X
Wind speed		X	X
Rain		X	X
Organization of the group		X	X
Livestock	X		X
Month	X		X
Tools (hand tools)		X	
Sun's temperature		X	
Fuel type		X	

Factor	**Corazón del Valle**	**Valle de Corzo**	**Factors named by one Mature male**
Clouds			X
Group size sufficient to control the fire			X
Ignition pattern and survival of animals			X
Air temperature			X
Humidity of the air			X
Humidity of pine needles			X
Parcel shape and proximity			X
Number of factors listed	**8**	**12**	**19**

The semi-structured individual interviews revealed considerable depth of understanding and specificity as to how each of these factors, plus several additional factors, contribute to traditional burning practices. Table 3.7 provides a summary of the fire-related factors that producers mentioned in their interviews.

Excluding factors about which I asked direct questions, the most commonly mentioned factor that producers report as influencing fire behavior was the force or strength of the wind. This was mentioned by 86 percent of participants (n=31). The fire break was the second most commonly mentioned (n=26, 72%), followed by the hour (n=24, 67%), the month (n=22, 61%) and the quantity of fuels (n=21, 58%).

Table 3.7. Factors of fire: results of group and individual interviews with producers of Corazón del Valle and Valle de Corzo within La Sepultura Biosphere Reserve. Colors represent the frequency with which each factor was mentioned by participants. Colors of boxes represent the percent of participants who mentioned a given factor. The high percent of respondents in green boxes are the result of answers to direct interview questions.

Topography	Fuels	Weather	Operations	Other
Slope, contour (n=12, 33%)	Quantity (n=21, 58%)	Wind force, strength (n=31, 86%)	Tools (n=34, 94%)*	Management goal, purpose of burn (n=24, 67%)*
Steepness of slope (n=2, 6%)	Height (n=8, 22%)	Time of day (n=24, 67%)	Number of participants (n=28, 78%)*	Animals (n=8, 22%)
Position on slope (n=2, 6%)	Humidity of fuels (n=7, 19%)	Month (n=22, 61%)	Condition, type of fire break (n=26, 72%)	Parcel size (n=6, 17%)
Aspect (n=1, 3%)	Types of living plants and litter (n=6, 17%)	Humidity of the day (n=16, 44%)	Group organization (n=17, 47%)	Grazing schedule (n=3, 8%)
	Degree of consumption (n=2, 6%)	Temperature (n=16, 44%)	General assembly or government approval (n=15, 42%)	Life stage of plants, phenology (n=3, 8%)
	Rate of accumulation, canopy density (n=1, 3%)	Wind direction (n=14, 39%)	Design of ignition (n=13, 36%)	Soil humidity (n=2, 6%)

1-9%

10-24%

25-49%

50-100%

Not applicable: direct interview question

Topography	Fuels	Weather	Operations	Other
		Number of rains (N=14, 39%)	Cleaning (mop-up) after the burn (n=13, 36%)	Forage condition, height (n=2, 6%)
		Force, strength of the sun (n=13, 36%)	Years since fire (n=11, 31%)	Parcel shape and proximity (n=1, 3%)
		Quantity of rain (n=10, 28%)	Sparks, spot fires, rolling cones (n=7, 19%)	
		Days since rain (n=7, 19%)	Direction of spread (n=1, 3%)	
		Weather (frontal) direction, type (n=6, 17%)		
		Season of year (n=6, 17%)		

1-9%

10-24%

25-49%

50-100%

Not applicable: direct interview question

The following text is a composite of producers' knowledge gleaned from the semi-structured individual interviews, followed by findings based upon participant observation of controlled burning operations. They are organized by research proposition. Additional supporting evidence from the interviews is provided in Appendix 3.E.

3.3.3. Results for Proposition 1.a.: Producers do not burn mindlessly or indiscriminately; they purposely manipulate a variety of fire variables to accomplish specific goals.

Learning How to Conduct Controlled Burns

The first evidence that producers do not burn mindlessly or indiscriminately is that individuals must reach a certain age before they are encouraged to participate in controlled burning. After that they learn burning techniques from their fathers, grandfathers and elders in the community. A young man often attends his first fire when he is between the ages of 12 and 18. When they are learning, sons work with their fathers because the fathers are responsible for the son's actions. "Here's what happens: I have my 12-year old son and I already take him to do a burn with me." Investigator: "With you?" "Yes, with the fathers or also he goes with the group, because at the age of 12 they can understand this business about fire; and they aren't very little anymore" (M2-HMR29). Generally, a young man works with his father (n=16, 44%), who learned how to conduct controlled burns from his father. Grandfathers also help teach grandsons (n=6, 17%). Investigator: "When does a person learn to use fire?" Participant J2-LTE12: "I think it is when their fathers or their grandfathers teach them."

In cases where fathers and grandfathers are unavailable, or when others have experience to share, young men learn from their uncles or other community members, often elders (n=6, 17%). Investigator: "Who is your teacher when you learn how to do a burn?" "My father and the older men in the community. They taught us" (M2-LDR15).

One participant indicated, "Well, in my life (I learned) only from the community" (J4-LYR18). Most men said that their first fires occurred in milpas or tame pastures, "My father worked in that (burning), making the cornfield; and I learned everything about it there" (A4-LHR10). One woman in the young age group reported that she learned about fire in school at the agriculture preparatory school in Cintalapa. Only two interview participants had attended preparatory school (which follows secondary school). Her agriculture class had practiced making a firebreak.

In the case of Valle de Corzo, where some of the fathers grew up in the city and do not have local fire knowledge, two or three community members who do have fire knowledge and experience, including the most influential community leader, are looked upon as the teachers of fire (n=5, 14%). Some young men in Valle de Corzo experienced their first fire when a wildfire entered the community from adjacent land.

The Decision to Burn, Permits and Responsibility

A second line of evidence that producers do not burn mindlessly or indiscriminately is that each burn undergoes a prior planning and decision making process within the community. This includes what parcels in the ejido will be burned each year. There is also a sense of responsibility for the fire and its effects upon the land. Most participants indicated that "the owner of the parcel decides when to burn" (A4-LHR10), but there is also a role for the community. Some parcels belong to the community as a whole, and the resources of those parcels are to be used for the benefit of the community, for example, to support the local school. For these parcels, "The assembly decides it" (J3-LAR14). Some participants referred to the recently developed community fire management plan as a factor in the decision. Whether formal or informal, coordinating which parcel to burn, and when, is to use fire within the context of the other community activities. “The owner and everyone in the ejido (decides when to burn) so we can assist him" (M1-LUE1).

Respondents expressed various thoughts about whether or not permission to burn was necessary from outside the community. A few participants indicated that no permits are necessary for a controlled burn; others said that permission from the government at the level of the Municipality of Cintalapa is necessary. One participant indicated permission is needed during certain times of the year, but not at others.

Participants also shared their ideas about responsibility in case a controlled burn escapes. The majority of participants indicated that the owner of the parcel was responsible in the case of an escape. Some participants indicated that the group that worked on the fire shared the responsibility. One respondent said that it was necessary to tell the owner of the land onto which the fire escaped. Another participant said that if someone lit a fire independently, acting apart from the local system, and that fire escaped, he would be punished. I did not inquire as to what form of punishment this would be or how it would be imposed.

Fire Management in Milpas and Potreros (Tame Pastures)

Although this study focuses upon fire management in the tropical pine-oak forests at La Sepultura, the way that respondents talked about management in milpas or potreros provides more information about producers’ purposes in using fire. For example, milpas are burned to clean them before planting. "And before my father, the people worked in agriculture like now; and obviously they had to burn to get rid of all the trash (stubble) and to be able to plant” (A4-LHR10). J3-HGR33: “at times they burn their potreros for the pasture and when the rain greens up the grass; and in the cornfield because there shouldn’t be brush but (rather) pure soil.” In my observation, the cleaning is not just to remove plant remains from the prior year's crops, but it is to reduce the substantial brush (sometimes a meter tall) that has grown up in the parcel during the year:

Producers usually burn milpas earlier than the pine forest, often in March or April, so that they have time to plant the areas before the rains arrive. Fuels in the milpas are less continuous, less deep and less flammable than the pine fuels in the forest, so producers can burn milpas under the drier, windier conditions that are typical earlier in the year. Investigator: “Are there different months for burning different parts of the land? Is fire in the milpa during a different month than fire in the pine forest?" Participant M2-LDR15: "Yes, very different. To burn at the sowing time in the cornfield . . . when you are going to have to burn the corn stalks, you can burn the corn although the wind is strong and nothing (bad) will happen. You can't burn in the pines in this way because, yes, you can make a big wildfire in the forest." One respondent did cite burning milpas without adequate care as a cause of wildfires in the forests.

Producers also burn their potreros earlier than the pine forests. Because these areas are cleared, planted with specific grasses and managed for grazing livestock, the fuel loads are lower than in the forest. Producers burn them in April before the onset of the rain, and to improve the growth of new grass. Participant M4-LCR17 identified producing better quality forage as a purpose for burning, "To get rid of the weeds from the land and in the potreros so that the animals have good pasture grass to eat.”

Since livestock can keep the fuels down in the potreros, and in the forest to some extent, fuel reduction is not always the sole objective. Investigator: “So then, it is possible that the sheep or cows control the level of fuels, so is there another reason to use fire? (You mentioned that) with fire the land is cleaner?" Participant A3-LIR8: “Yes, indeed, yes. . . To clean against bad herbs, for example, thorns, and also to reduce the ticks a little, or it would be that when a lot of fuel (accumulates) it can produce bad snakes." While several respondents mentioned burning to control ticks as a general purpose of fire, two respondents explained that the fire does not kill all the ticks and that when gravid ticks fall off of the cattle they re-colonize the area rapidly.

Tolerance for Fire-induced Tree Mortality and Scorch

Figure 3.8. Two photographs of forests at La Sepultura used in individual interviews. The green forest on the left is a parcel located within Ejido Corazón del Valle. The scorched forest on the right, located outside of Valle de Corzo, was burned in a wildfire.

When I asked participants which of the two photographs in Figure 3.8, they preferred and why, participants offered more information and perspectives than in response to any other interview question. Their responses suggest further insight as to possible goals and things to avoid when burning. Producers do not like to see crown scorch after a controlled burn. Scorch is not only considered detrimental to tree growth (which has been documented for *Pinus palustris* (Haywood, 2004)), but it is viewed as a reflection of the producer’s skill in using fire to care for the forest.

With the exception of two participants, all of the respondents indicated that they preferred the photograph of the green forest. Several participants preferred the green photograph because to them there was more life, more homes for animals and more oxygen produced by this forest. Participants also clarified that although the forest in the green photograph may have been burned in the past, the scorched forest was the result of a fire that was out of control and without purpose.

Respondents indicated that the photo with the scorched trees was dry and that some of the trees would likely die. They indicated that the grasses would come back after the rains came, but that the scorched pine needles would fall off and it would take time for the new needles to emerge. One respondent explained that new pine needles grow each year in April just before the rains arrive. If these new needles are scorched in a fire after that, it will take another year to replace them.

Other participants explained that fires may kill pine trees by damaging their roots, especially if the organic matter around the base of the tree is burned. One Participant who is involved with selling pine seeds (cones) to the government nursery said he doesn't like the scorch because the heat burns off the flowers (reproductive structures) of the trees and they don't produce seed that year.

The two people who expressed no preference for one photo over the other were knowledgeable participants who had 15 and 35 years of fire experience respectively. They seemed to have a broader tolerance for the scorch. It was interesting though that one of the two looked at the two pictures for a long time and replied that the difference he saw between the two was a difference in slope. Later when I noticed how similar the two pictures look in black and white print, I wondered if that particular person might be color-blind. The other respondent seemed to have a higher tolerance for scorch and confidence that the vegetation would recover. Or, perhaps the person had a higher tolerance for differences in tree density.

Some participants recognized that fire can lower tree density. They indicated that fire kills the smaller pines (although some resprout). Some interviewees discussed the differences in species and growth of grasses in areas of more open canopies, as in the scorch photo, compared to areas with closed canopies. They expected ranchers who are more interested in growing grass for cattle than growing trees to burn more frequently and to be less concerned about scorch. One person to whom trees were more important than forage explained that he prefers a closed canopy, because it provides less opportunity for the winds to penetrate the forest and blow trees over. Windthrow is a common occurrence in these forests because the winds are very strong for several consecutive months of the year.

3.3.4. Results for Proposition 1.b. Producers do not see fire escapes as unexplainable but rather they have in mind a suite of contributing factors.

"Good" Fires and "Bad" Fires

Several participants indicated that there are “good” and “bad” fires. Not only did their responses show further evidence of purposefulness in burning, but they interpreted “bad fires” in terms of factors that contribute to fire escapes. “The good fire is the controlled fire and the bad is provoked (arson)” (M1-HCE21). Bad fires were those that escape beyond the firebreaks and/or scorch the tree canopies. “Yes, there are bad fires because bad fires you light the fire and it goes burning everything without control; and the good fire you work it and it is going to burn in a way that doesn’t burn the trees – that is what you can call a good fire and the bad is one that goes outside of the forest" (M2-LDR15).

“So the good are the ones that are done with a determined purpose so that you want it. If I want to make a fire to maintain my vegetation, not run the risk that it burns in a moment less suitable, it is better for me to do it with certain practices and wisdom and my forest doesn’t have to change. And the bad fire is when my forest is not burned and a fire arrives that is out of control, which would destroy my forest. It would lower the fuel; but it is another thing to reduce the fuel and not to run the risk of destroying my forest” (M3-LFR16)”

“So the biggest (fires) are where the fuels are more thick, that is to say, the dry leaves and (pine) needles. The good ones are where there are less dry leaves and needles, where it burns more slowly. Where there are more fuels the flames are taller” (A4-LHR10). In addition to high fuel loads, additional factors include burning from the bottom of the slope upward, burning without adequate fire breaks and burning with too few crew members. Participants usually talked about escaped fires in terms of fires that spread onto their land from areas outside of their ejido boundaries. Producers speak unfavorably about fires resulting from careless burning practices or those provoked by throwing cigarette butts. They indicated that they actively work to suppress these freely burning fires, which burn with higher intensity than they would use to meet management goals.

I did observe one small fire escape, which I would call a "spot fire," that occurred during one of the fire planning workshops. Immediately upon discovering the spot, the participants ran to the site and forcefully and efficiently extinguished the flames. The spot fire was put out before it moved off of ejido property; and it covered less than 500 square meters. In the workshop de-briefing that took place after the burn, local community members criticized CONANP for scheduling the burn during the middle of the day when escapes are more likely.

The Pine Forest without Fire

Most men whom I interviewed indicated that without fire in the forest for many years, fuels would build up and when a fire eventually came the flames would be more forceful, the fire would be difficult if not impossible for them to control and the forest would be more severely burned. When asked if there would be problems without fire for many years, M4-LCR17 replied, “Everything is fine only that the leaf litter is going to accumulate more and more and when a little bit of fire arrives it destroys everything.” Likewise, A4-LHR10 replied, “Yes because there are a lot of fuels, so then when the fire ignites, it burns too much and it dries the trees.” In this way, controlled burning is an important method for reducing fuels and caring for the forest. A few respondents, mostly women and young men with less fire experience, indicated that there would be no problems without fire if the forest did not burn for many years, suggesting that ecological fire knowledge is uneven in some cases.

3.3.5. Results for Proposition 1.c. Producers do not burn in any kind of weather, but rather they proactively burn on days that have specific weather that they consider conducive to traditional burning. They also choose specific seasons, times of day, and conditions related to moisture.

All together, producers named twelve weather-related factors that they incorporate into their burning practices (Table 3.7). More than half of the producers mentioned three factors: the strength or force of the wind, the time of day, and the month. Between 25-49 percent of the producers indicated that they also consider the humidity of the day, the temperature and the wind direction. In general, producers preferred to burn their parcels at the beginning of the rainy season, which typically arrives in May or early June. When enough rain has fallen that the vegetation and leaf litter has been moistened somewhat, the humidity is higher, and the evenings cool off with intermittent rain, then a few weeks of burning begins.

The description below illustrates the way producers balance the variables of weather, season and moisture to achieve their goals. What is also interesting in this interview is the respondent’s understanding of how nine different factors are involved and interact:

> *Investigator: "Ecologically, are mild fires the same as strong ones?"*
>
> *Participant M2-HMR29: "No, they are distinct, because the strong fire is one that starts in March or April, because that is when everything is dry and the fire burns very rapidly, until the land stays burning inside. And the good fire is one that doesn't mistreat the plants and it stays controlled. That is when it burns after it has rained a little in May or June. For example, today it rained heavily and we are waiting for it to dry. Tomorrow if it doesn't rain we can burn and nothing will light except the top (surface) of the fuels and the fire won't carry. It will burn over the top and if we excavate a little it is wet below and not much happens. It doesn't burn the trees, either big or little. And in March and April it burns everything that is there, because everything is dry. So that is our custom, to carry out the burns when it is moist . . ."*

The eight factors included in this explanation are, the month of burning, moisture, rate of spread, fire type (ground fire), fuels, fire's effect on the plants, fire control, quantity of rain, and days since rain.

Weather Conditions Observed During Controlled Burns

Table 3.8 shows the ranges of weather conditions I observed during five of the six controlled burns in which I participated. Local field assistants and I took weather observations opportunistically and sample sizes vary from n=1 to n=11 among burn parcels and weather parameters. My observations should be considered estimates; and ranges of conditions observed are probably more informative than any particular measure. I did not measure weather during the fire that occurred at night.

The ranges of conditions I observed are within, or more moderate than, the typical ranges for controlled burning more broadly in Southern Mexico (A. Nolasco, pers.com., 2009, Tuxtla Gutiérrez). Producers tended to burn with lower wind speeds and higher relative humidities than those reported by Nolasco (Table 3.9). Hudson and Salazar (1981) reported that in *P. oocarpa* savannas of Honduras, prescribed burns conducted with relative humidity below 40 percent would be difficult to control, and burns conducted with relative humidity above 70 percent would not generate enough heat to accomplish typical burn objectives. At La Sepultura, a single gust of wind measuring 21 km/hr was the highest wind observation. This gust lasted for a few seconds and it produced the most extreme fire behavior that I observed during the six burns (see fire behavior results below).

Relative humidity was higher than Nolasco's general ranges during four of the five burns. The highest relative humidity took place when a thunderstorm was arriving toward the end of one burn and the cloud cover was approximately 80%. The rain from the storm extinguished the fire.

Table 3.8. Weather observed during each of five controlled burns at La Sepultura between 2006-2008 (does not include the controlled burn that occurred at night). Sample sizes vary from n=1 to n=11, depending upon opportunity and safety.

Burn parcel code	Ejido	Date of burn	Average wind speed (km/hr)	Maximum wind speed (gusts)	Tempera-ture ℃	Relative humidity (%)
SP	Corazón del Valle	17 May 2006	2-10	9-16	17-28	36-72
VdC	Valle de Corzo	18 May 2006	1-8	6-14	20-28	39-72
MP	Corazón del Valle	25 May 2008	5-12	10-21	27-29	61-73
DJ	Valle de Corzo	15 June 2008	5	12	27	62
MB	Corazón del Valle	19 June 2008	3-7	4-12	25-28	62-91
Overall Range		17 May to19 June	1-12	6-21	17-29	36-91

Table 3.9. Comparison of weather conditions observed during controlled burns between 2006-2008 at La Sepultura, and conditions generally used for controlled burning in Southern Mexico. Conditions for the controlled burn that occurred at night are not included.

Parameter	Minimum to maximum conditions observed	Average of all observations	Conditions generally used in controlled burning in Southern Mexico*
Average wind speed (5 minute average) (km/hr)	1-12	6	5-15
Maximum wind speed (km/hr)	6-21	12	No data
Temperature (℃)	17-29	24	20-30
Relative humidity(%)	36-91	60	40-60
Slope (%)	4-72	29	No data
Wind direction (coming from)	N, NE, E, S, SW, W		No data
*Observations for Mexico provided by Alfredo Nolasco of CONAFOR (pers.com., 2009, Tuxtla Gutiérrez,)			

3.3.6. Results for Proposition 1.d. Producers do not desire just any kind of fire behavior, but rather they manipulate a suite of fire variables in order to produce specific fire characteristics.

Producers also think about the factors and combinations of factors that affect fire behavior. A respondent in the young male group recognized the basic connection between fire behavior and wind: ". . . at times the wind gets strong and the fire follows according to the wind" (J1-LZR7). A man in the senior age group pointed to relationships among four factors: fuel height, flame height, heat output and the ability to control the fire. "It should be burned when it (the grass) is some 10 or 15 centimeters, because if it is very small, it won't burn." Investigator: "So, can you burn with taller fuels?" A1-LGR3: "Yes you can, but when the fuel measures, say, one or one and a half meters the fire is very tall, arriving at five or six meters . . . " Investigator: "Is it possible to control the flames when they are that tall?" A1-LGR3: "No, because the heat arrives at about 10 or 15 meters."

Fire Behavior Observed during Controlled Burns

Participant observation during six fires revealed that producers' current burning techniques produce very low-intensity fire behavior (Table 3.10). This includes short flame lengths that release relatively little heat (Byram, 1959), narrow strips of flames that cannot gain momentum, and burning with moisture conditions that result in few if any spot fires igniting outside of planned burn parcel boundaries. Producers indicate that they produce such fire behavior in order to "care for the forest," to keep the fire under control, and to avoid damage to pine trees. The low-intensity fire behavior makes it possible for participants to control the flames using locally available hand tools.

Together with local field assistants, I measured rates of fire spread (ROS) during five controlled burns; we did not attempt to measure ROS during the burn that occurred at night. Among 62 observations, the minimum rate of spread was 0.1 m/min and the maximum was 38 m/min (Figure 3.10). The median ROS was 0.6 m/min. While there was only a single observation of ROS ≥ 16 m/min (Figure 3.10), this observation served as a reminder that more rapid rates of spread can occur in this ecosystem under different operational or climatic conditions.

Samples of ROS were not gathered at random. Safe access to and escape from live fire dictated when and where ROS observations were made. While ease of access and retreat could lead to sampling bias toward observations of slower rates of spread, it is also true that faster moving fires tend to capture the observers' attention; and crew excitement over unusual fire behavior notified the researcher of the opportunity to observe the faster moving flames along with slower moving flames. Slow rates of spread were indeed the most common during the controlled burn operations I observed. Faster rates of spread typically occurred during brief wind gusts or when the fire was burning upslope for a short time in patches of contrary topography, such as up the side of a small valley in the interior of the burn parcel.

Table 3.10. Fire behavior observed during six controlled burns observed between 2006-2008, including one burn that occurred at night time. Flame lengths were estimated to the nearest five cm.

Parameter	Minimum-maximum observed	Mean	Median
Fire type	Surface fire	na	na
Flame length (cm)	5-150 cm	31.1	30.0 cm
Rate of spread (m/min)	0.1-38.3 m/min	3.4	0.6 m/min

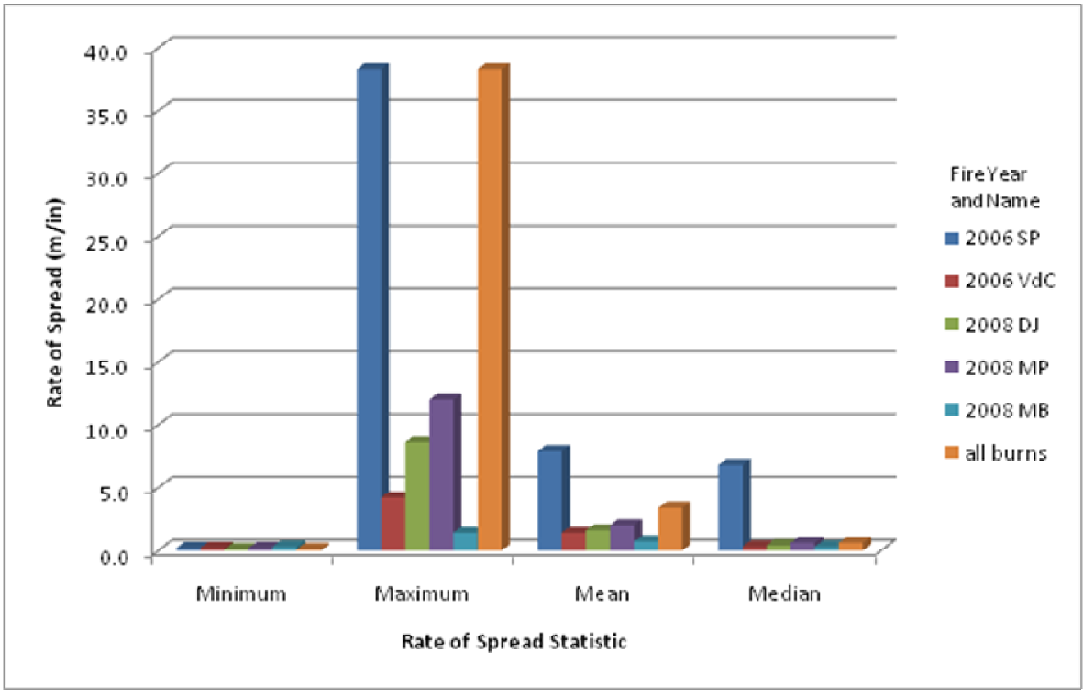


Figure 3.9. Rates of fire spread observed during five controlled burns (n=62).

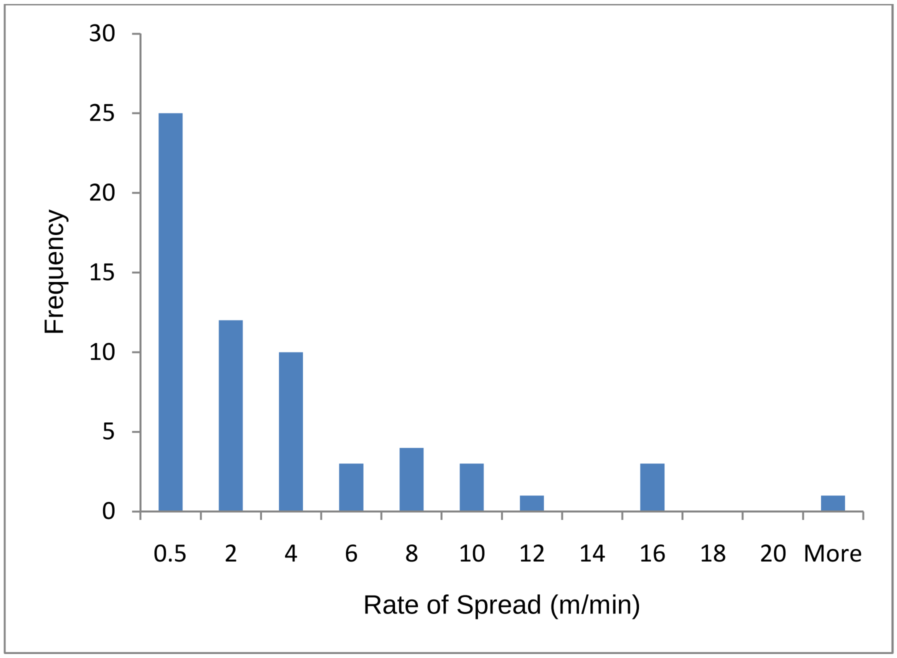


Figure 3.10. Frequency distribution of rate of spread observations during five controlled burns (n=62).

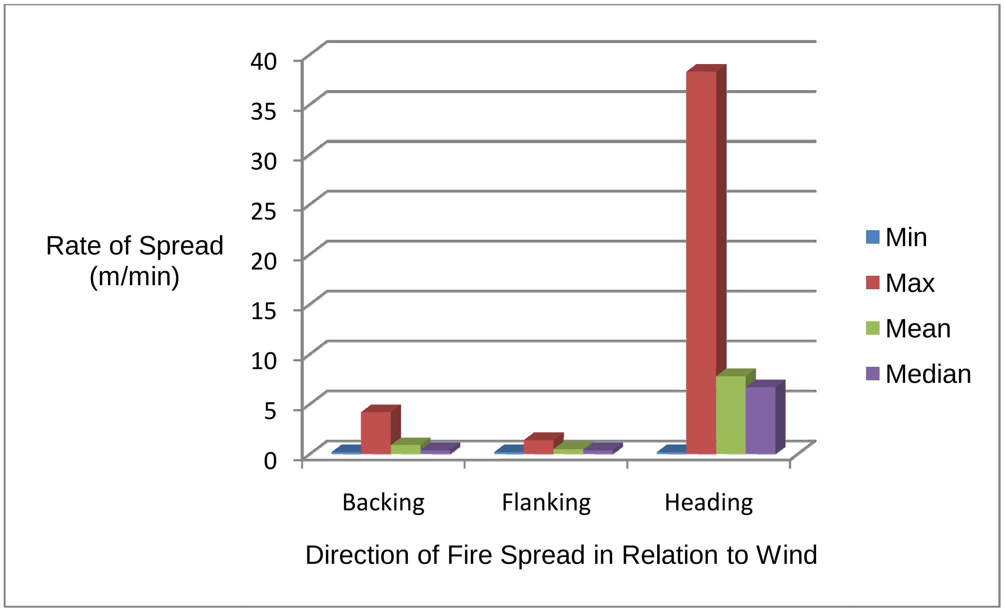


Figure 3.11. Rate of spread in relation to wind direction on five controlled burns (n=50).

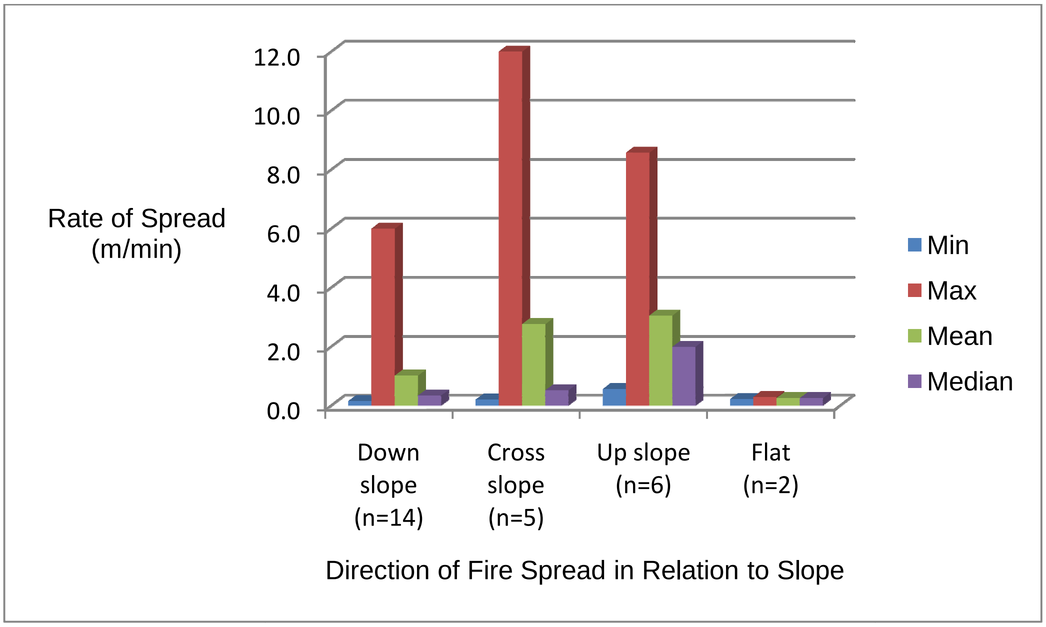


Figure 3.12. Rate of spread in relation to slope on five controlled burns (n=27).

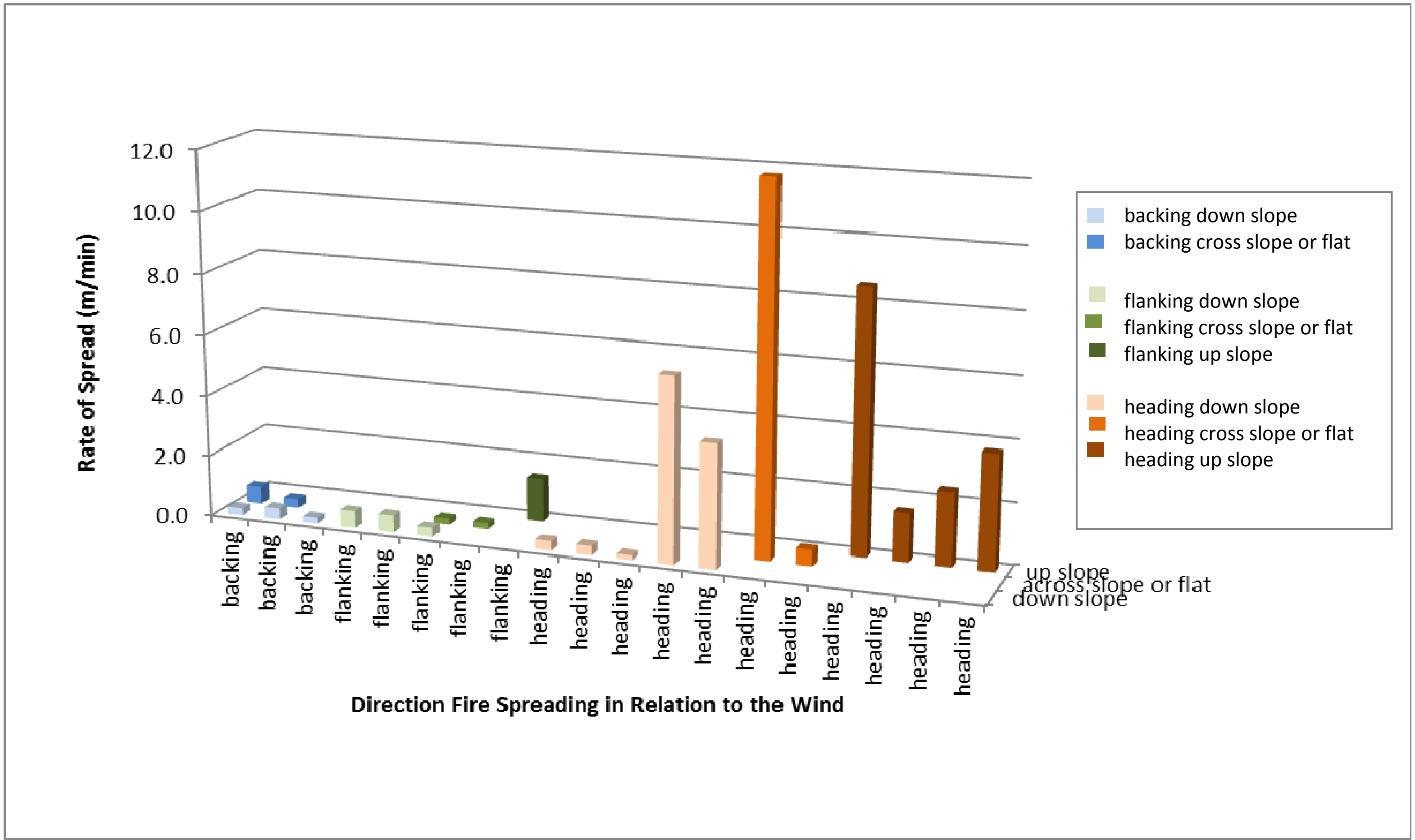


Figure 3.13. Rate of spread in relation to combinations of wind and slope on five controlled burns (n=22).

During the six controlled burns, I made 163 observations of flame lengths. Because flame lengths can be estimated from a distance during live fires, and from still photographs after the fire, it is easier to make observations than it is for rate of spread. The range of flame lengths observed was 5-150 centimeters (cm). The mean flame length was 31.1 cm and the median was 30.0 cm. The frequency distribution of the flame lengths was skewed toward the shorter flames; flame lengths were ≥ 100 cm only four times (Figure 3.14). The tallest flame length occurred during a gust of wind when the fire was burning across a slope in grass fuels; and it lasted for only a few seconds.

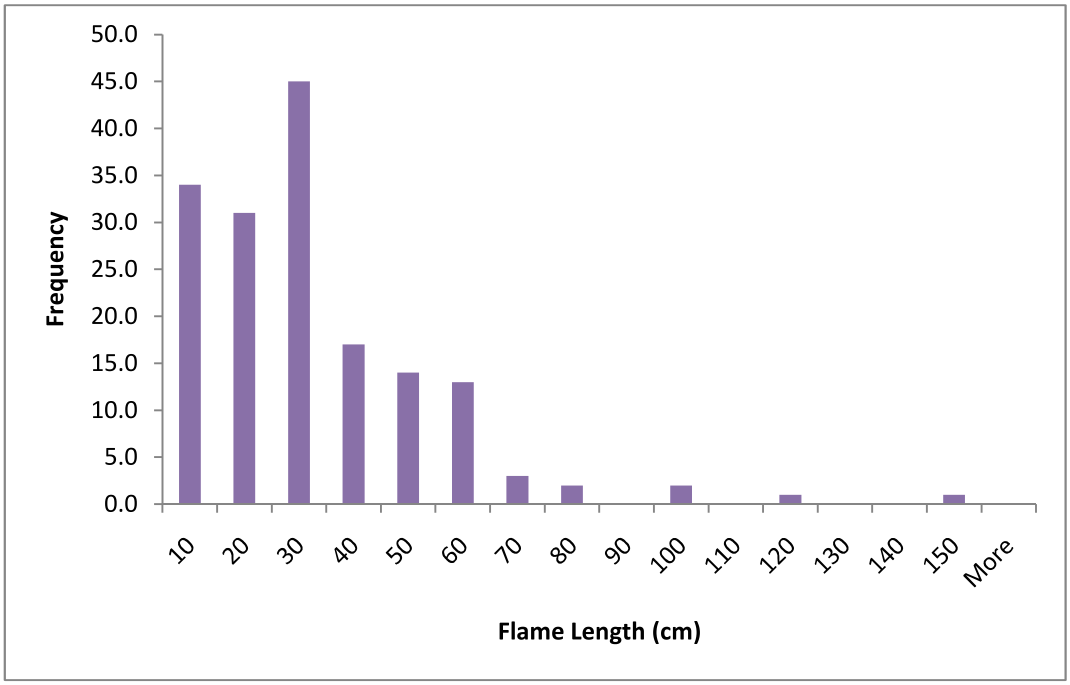


Figure 3.14. Frequency distribution of flame lengths observed on six controlled burns using ocular estimates of live fire, video footage and still photography (n= 163). Flame lengths were estimated to the nearest five cm.

I was able to estimate flame lengths and record the direction the fire was spreading in relation to slope for 154 observations (Figure 3.15). As expected, the shortest flame lengths occurred when the fires were burning down hill or on flat terrain.

The longest flame lengths occurred when fires were burning either across (flanking) the slope or up hill (Figure 3.15).

Figure 3.15. Flame lengths in relation to slope on six controlled burns using ocular estimates of live fire, video footage and still photography (n= 154). Flame lengths were estimated to the nearest five cm.

I estimated flame lengths and the direction the fire was spreading in relation to the wind for 159 observations (Figure 3.16). On average, as expected, the shortest flame lengths occurred when the fire was backing into (burning against) the wind or flanking the wind; the tallest average flame lenghts occurred when when the fire was heading into (burning with) the wind.

When I observed fire behavior in relation to both wind and slope, the tallest flame lengths occurred, as expected, when fires were burning either across slope or up slope together with either no wind or heading into the wind (Figure 3.17). Although the total number of observations was 153, sample sizes for each combination were unequal, ranging from n=1 for fire burning with no wind and across slope to n=36 for fire burning against the wind and down slope. The latter does reflect the most common direction of fire spread. Both flame lengths and rates of spread for fires burning downhill and against the wind represent the fire behavior that producers intend to create with their current burning practices

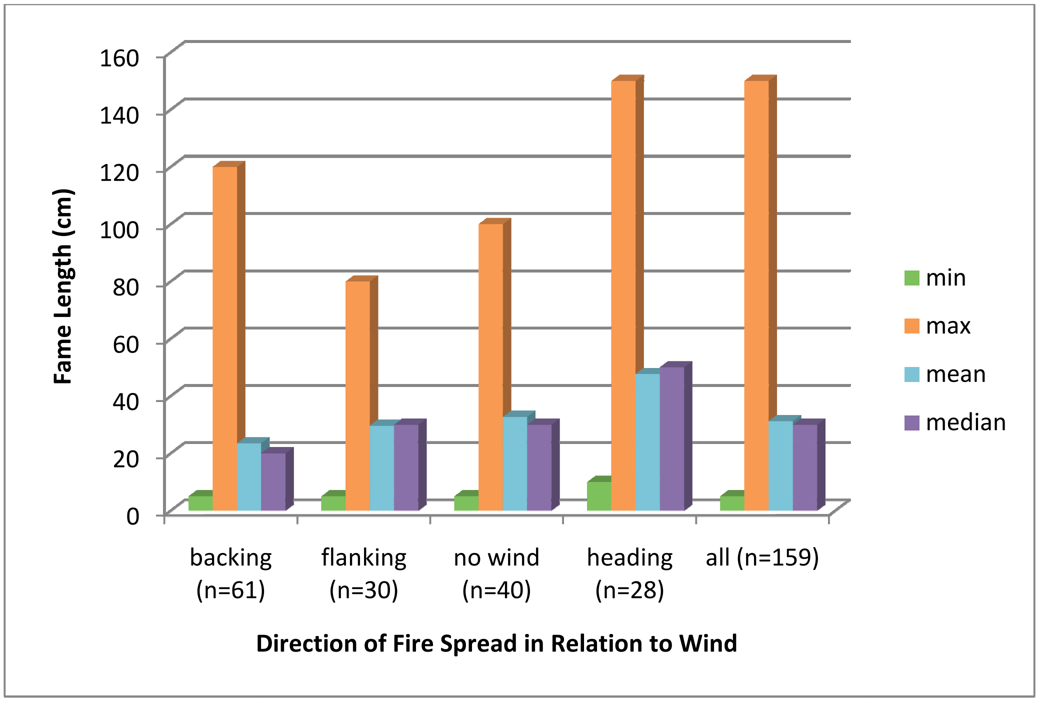


Figure 3.16. Flame lengths in relation to wind on six controlled burns using ocular estimates of live fire, video footage and still photography (n= 154). Flame lengths were estimated to the nearest five cm.

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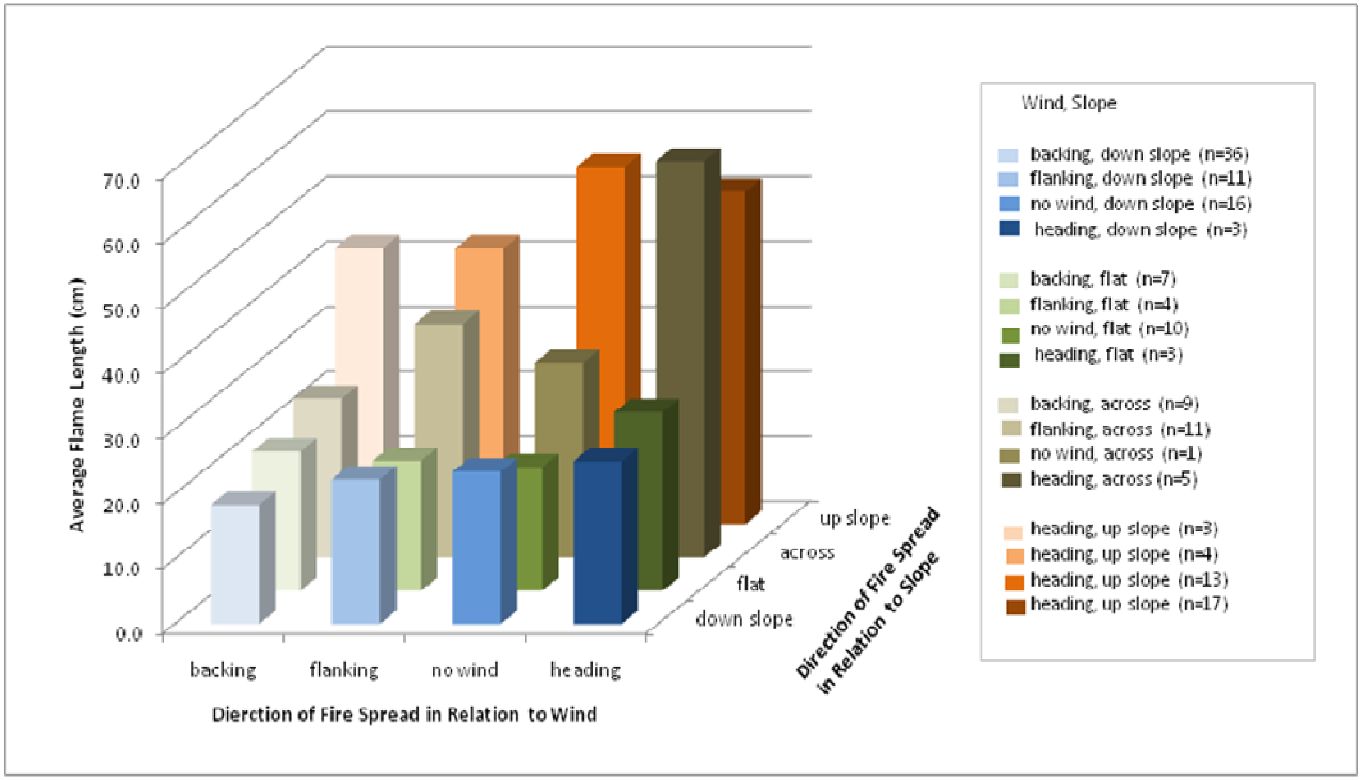


Figure 3.17. Flame lengths observed on six controlled burns in relation to combinations of wind and slope (n= 153).

3.3.7. Results for Proposition 1.e. Producers not only know what factors they want to select for burning, but they also know in relative terms what quantities of each of these factors they want to use.

Participants readily listed the relative quantities of factors that would produce “good” and “bad” fires. Participants are not only aware of these factors, but they also purposely select the conditions under which they burn to take advantage of conditions to produce a "good" fire and to avoid a "bad" fire (Table 3.10).

Table 3.10. Levels of fire variables that producers in the two study communities, Corazón del Valle and Valle de Corzo, associate with "good" and "bad" fires in tropical pine-oak forests.

Fire factor	**Level of that factor for a "good fire"**	**Level of that factor for a "bad fire"**
Wind	Silent	With the wind
Fuels	Shorter than 10 cm	Taller than 10 cm
Direction from which the weather comes	From the South	From the North
Season, month	May-June	March-April
Hour	5:00 PM or early in the morning before dawn	Mid-day
Number of rains	After 1-3 rains	Before the rains arrive
Fire break	3 meters wide	Narrow or not clean
Ignition pattern	From the top of the hill downward, using strips if necessary	From the bottom of the hill upward.
Humidity of the air	Moderate	Dry
Humidity of the soil	Humid	Dry
Flame height	Less than 1 meter	More than 1.5 meters
Fire rate of spread	Slow	Fast
Sparks	Do not start new fires	Start new fires, outside of the fire break
Control	Controlled	Not controlled
Care	Cares for the forest	Burns/dries the forest

3.3.8. Results for Proposition 1.f. Producers have particular field practices they use to accomplish traditional burning.

The Firebreak

Before each burn, the parcel owner prepares, or hires someone to prepare, a clean firebreak around the parcel. The breaks that I observed were one or two meters wide. The man that I observed preparing a firebreak was using a “coa,” a small shovel with a long wooden handle and a flattened, sharpened blade. He used the coa to remove dry pine needles and to scrape away any flammable material (such as vegetation or organic soil) from the break.

Clean firebreaks are considered a primary mechanism for controlling a fire (n=26, 72%): "Our custom is to use a fire break, depending on how the terrain is. If we are going to burn the whole area, we make it around the whole area" (M4-LCR17). Drawing a diagram of a burn parcel in the dirt, one respondent indicated, "We put the fire break here. When the fire advances up to the break it stops. This is the way be burn here" (A4-HOR23).

In addition to the firebreaks that individual parcel owners make prior to their burns, the ejido is also surrounded by a wide break. In reply to my question "Do you have enough fire breaks?" a respondent indicated, "Yes, we do have, three meters wide around our border" (A4-HOR23). The ejido firebreaks serve to prevent wildfires coming from the outside land ownerships from entering each community.

Size of the Group Participating in the Burn

The size of the group that conducts a controlled burn can vary from a few individuals to the entire community. Group size is sometimes adjusted to correspond with the size of the parcel to be burned: "If it's a big area, there are a lot of people that help; and if it is a little parcel, a few people come" (A1-LXE4). Investigator: “For example, for 10 hectares, how many men help?" A1-LXE4: "Some 20 or 15 who want to go, because it is voluntary that the people help their companions." Investigator: “But 20 is a lot of men." A1-LXE4: “Yes, there are many, but here we never burn that many hectares. Here we burn in (smaller) pieces." Investigator: “And for three hectares, how many men help?" A1-LXE4: “Some 10 men.”

Among the six fires that I observed, the two that appeared most typical (not influenced as much by the recent fire workshops or this study) utilized six and nine people respectively.

Three other burns that I observed utilized all or the majority of the men in the community. Two of these were associated with the workshops for developing community-based fire plans. The burns were conducted together with personnel from CONANP. The third was a controlled burn at Valle de Corzo, the community that is learning and working to re-introduce controlled burns in their pine forests.

I observed one controlled burn conducted by two people who had extensive fire experience. The burn parcel was small and the two men did the burn late in the season (in June) when the relative humidity was high and on a day when they expected rain later the same day. The parcel owner conducted the burn as a favor, specifically for the purposes of this study. The fire was well in control and there were no injuries during the burn. It rained as expected.

Ignition: Design and Methods of Ignition, Roles of Men and Women.

Controlled burns are typically lit initially with a match, and then the fire is spread using dry pine needles or a stick of dry ocote pine that contains a lot of resin. Using pine needles, the fire is spread either by dragging handfuls of burning needles along by hand, or by dragging them using a rake or horqueta (forked stick). During the two "workshop" fires, producers experimented with using drip-torches, tools provided by workshop organizers from The Nature Conservancy.

The design of ignition, the pattern in which the fire is spread, depends upon the terrain and fuels. Groups usually use two igniters, who coordinate their progress and communicate by shouting or whistling to one another. At Corazón del Valle, the igniters are often the same two men, who are older and who have a lot of fire experience. However, I did observe two burns in which the owner and his son were the igniters and neither of the two usual igniters was present.

Where the land is flat, ignition can proceed along the inside edges of the firebreak, starting on the downwind side of the parcel. The two igniters then work in opposite directions along the firebreak, spreading ignition along each side and finally meeting on the upwind side. Where the land is steep, the fire is started according to the topography and less so by the wind direction. Igniters start at the top of the hill and bring the fire down the sides of the hill and then meet at the bottom after almost the entire parcel has burned in low intensity fire.

As the fire proceeds, other workers sometimes light small areas inside of the parcel to help complete the burn. They use either red needles or pieces of ocote and they typically ignite points or small strips of fire. I observed one group member using his machete to lift the pine needles up and then put the burning ocote under the lifted needles until they caught fire. Point after point, he created a grid of spot fires one to two meters apart in a shaded area near a dry creek bed that might otherwise not have burned in a timely fashion.

Participants also ignite a steep hillside in strips ranging from three to five meters wide for the steepest slopes. Igniters light one strip and let the fuels burn away, then progress downhill for successive strips. In this way, only one strip of fuels burns at a time, preventing the fire from gaining momentum. Igniters also adjust the width of the strips according to the fuels and slopes, sometimes widening the strips beyond the five meters. Some participants indicated that they learned this technique from the fire planning workshops facilitated by the staff person from the local NGO.

The following dialogue gives an idea of an ignition plan involving strips, giving attention to keeping the flames small and moving slowly. Investigator: “Here is a parcel (sketching a rectangular area in the dirt).” A3-HPR27: “Uh-huh, a parcel, so then we are going to see where the air is from, similar to what it is now. We are going to start a strip of fire here. Here is the edge (drawing), we are going to start the fire like this." Investigator: “Ah, little by little.” A3-HPR27: “Yes, little by little, the fire (strips) are close together. Now here is the fireman with the backpack pump. So then the path is already lit here, now the other little strip goes here, considering the flames are going to be 40-50 centimeters high. Okay, here I already finished the strip and here goes the other strip, and when I finish this strip I light another strip. Investigator: "The slope of the land is important?” A4-HOR23: “Yes, we can't set fire from below because the flames are taller. The fire should be set from the top so the fire will come slowly. After the fire has advanced about four to five meters already we can extinguish it." Investigator: “If there is a parcel on a slope, how do the men start the fire?" A4-HOR23: “If the fire starts on the slope like here, they should start the fire here (at the top) because when they have started it here (at the bottom), the fire gains force and fans to there. And if it begins here (at the top), the fire goes little by little."

Controlling the Fire: Holding, Hand Tools, Sparks and Cleaning (Mop-up).

While the igniters are working, other group members make sure that the fire burns only the intended area. Again, firebreaks are important. Investigator: “How do they control the fire after it is started?" A2-LWE9: “With backpack pumps, fire breaks. They make fire breaks on the land so the fire doesn't cross it." The men watch for sparks that may land outside of the firebreak and immediately extinguish any small fires that start from embers. They use backpack water pumps, green leafy branches, rakes, coas and machetes to extinguish the new points of fire, by smothering the fire or by pulling the burning material back across the firebreak into the parcel. Burning in high humidity lessens the chance that sparks will start new fires. Burning at night aids the group's observation of sparks. A common phenomenon on hilly parcels is for pine cones on the ground to ignite and roll downhill, igniting areas within the parcel farther downslope. Crew members make sure that no burning cones start fires outside of the firebreak. Investigator: “I am thinking that perhaps the fire crosses the fire break." M3-HKR30: “If the wind is blowing very hard, it could be. Or in the hills, sometimes (it does) because of the fruit of the ocote.” Investigator: “The cones?” M3-HKR30: “Yes the cones. They just roll down the hills. That’s another risk. And just cleaning (mop-up). If we see something like a cone, just clean and make sure the fire won’t continue.”

As the fire nears completion, group members check around the parcel to make sure the fire will not escape when they leave the area. I watched one participant sit by a large, meter and a half tall stump that was burning after the main fire, which at some point was likely to fall into the firebreak and send sparks outside of the unit. Waiting with a machete, he intended to wait for the stump to burn away or fall, for the humidity to rise, or a combination of the three, until he could chop away burning parts of the stump, move anything that fell near the firebreak, or otherwise be sure that the stump would no longer cause a problem.

Participants indicated that the owner of the parcel usually returns to the parcel the next day to make sure that there are no problems with the burned area. If the owner sees a problem, he gathers helpers to return to the area to extinguish anything that is a problem. Community members help one another with burning; and reciprocity among family members and friends within the community appears to be common. If necessary to combat a wildfire, members of nearby ranches and communities also come to help.

The burn parcels that I observed ranged in size from three to seven hectares. The total duration of each fire was approximately one to three hours, excluding time to prepare the firebreak in advance of the burn and excluding time to return to the parcel afterwards.

Several participants referred to the new fire brigades. The communities organized these community-based fire brigades as an outcome of the community-based fire planning process sponsored by CONANP and The Nature Conservancy. Members of the brigades voluntarily take on responsibilities for fighting wildfires in their respective communities. It appeared that the concept of the brigade was more highly valued in the community of Valle de Corzo, likely influenced by the demography of the community, the fuel loads and the experience of the wildfire there.

Interview participants indicated that men usually do the burning. Men conducted all of the controlled burns that I observed and women were not involved. On ranches where there are fewer people available, sometimes the women help. Several participants from Valle de Corzo recalled the role of women in combating a wildfire that burned into the community a few years ago, for example, “The women help to pass water (in pails) when the fire is near the houses” (J4-HFR34).

Field Practices Observed during Controlled Burning

The four burns that I observed in 2008 took place from May 16 through June 19 (Table 3.11). They were not associated with any workshops and, as such, they are probably a better reflection of customary practices. Three of those burns were located in Corazón del Valle and one was located in Valle de Corzo. Each burn was started after 1200 (noon); the one night burn started at 2100 (9:00 PM). The duration of the burns ranged from two hours and fifteen minutes to three hours. The number of participants in each burn at Corazón del Valle ranged from two to nine men, all of which were inhabitants of the community. The burn at Valle de Corzo included 13 men, all from that community.

Table 3.11. Fire operations during controlled burns observed at La Sepultura during 2008: time of ignition, duration, numbers of participants, tools used.

Burn parcel code	CC	MP	DJ	MB
Ejido	Corazón del Valle	Corazón del Valle	Valle de Corzo	Corazón del Valle
Date of burn	16-May-08	25-May-08	15-Jun-08	19-Jun-08
Ignition time	2100	1322	1230	1415
Duration of burn	3:00	2:23	3:15	2:15
Number of participants	9	6	13	2

Unlike agency led burns in the United States, in which fire managers conduct extensive briefings with their crews both before and after each burn, producers do not conduct briefings at the fire site. As soon as the owner and the assistant community members arrive at the burn parcel, a match is struck and the burn gets underway. Parcel owners and helpers leave the site at various times without a meeting afterward. The arrival and departure of the participants seems informal, and timed to individual schedules. It appears that all of the participants know what will happen and everyone seems comfortable with the operation. The owner and helpers return to check on the site as needed after the main fire is accomplished.

Tools Observed in Use during Controlled Burning

The tools used during the burns associated with the workshops in 2006 included a mix of the tools that producers indicated they normally use and additional equipment given to each ejido to help supply the new community fire brigades. The additional equipment included hardhats, leather gloves, yellow cotton work shirts, collapsible backpack pumps ("bladder bags"), McLeods and drip torches. During one of the burns associated with the workshop, I asked one of the elders how he liked using the drip torch. He said that he liked it because it didn’t burn his hands (in comparison to using traditional tools).

Two years after the workshops, some of the equipment was still in use on controlled burns. Some participants in Valle de Corzo wore the yellow shirts and hardhats. Participants from both communities used the collapsible backpack pumps. Producers appear to value the backpack pumps for the enhanced ability it provides in controlling the fire. They also used the backpack pumps to extinguish the burning bark of ocote pine trees.

Ocote pine trees commonly have fire scars that are susceptible to burning embers; and the bark can be dripping with flammable resin. In Corazón del Valle, older trees in some areas have scars related to turpentine collection, which was practiced by the previous landowner until the ejido was established (A. Posada, pers. com., July 18, 2008, Corazón del Valle). (As of the early 1990s, *P. oocarpa* was the primary source of pine resin in Mexico, as well as in Guatemala and Honduras (Perry, 1991). Turpentine scars at the bases of the trees are susceptible to catching fire from embers or passing flames. The backpack pumps are a welcome addition to the producers' tools available for using fire to "care for the forest."

During the more typical burns of 2008, the three tools most commonly used were matches (used only for the initial ignition), pine needles and machetes. These three tools were used on all four of the 2008 burns (Table 3.12). Backpack pumps and rakes were used in three of the four burns. Although several interviewees indicated that hoes were used on controlled burns, I did not observe this. Interviewees from Valle de Corzo also indicated that if needed, the women would carry buckets of water to assist, especially if the fire escapes. For preparing firebreaks, producers also use a pickaxe.

Table 3.12. Tools used in each controlled burn observed in 2008.

Burn parcel code	CC	MP	DJ	MB
Ejido	Corazón del Valle	Corazón del Valle	Valle de Corzo	Corazón del Valle
Date of burn	16-May-08	25-May-08	15-Jun-08	19-Jun-08
Matches	x	x	x	x
Machete	x	x	x	x
Pine needles	x	x	x	x
Rake	x	x	x	
Backpack pump	x	x	x	
Horqueta			x	x
Green leafy branches			x	x
Coa		x (to prepare firebreak)	x	
Wood of ocote pine			x	
Branches with red pine needles				x
Hoe				

Traditional Burning is Considered Mundane

During the interviews, I asked the question, "Do you have a favorite story about a particular fire that you would like to share?" Among 36 interview participants only two shared a story about a particular fire, and both of these examples were stories of combating wildfires that came from outside of the ejido boundaries. All other respondents gave simple negative answers, akin to, "No, not really." Although I am not sure why controlled burns did not evoke interesting stories, I infer from participants' answers and their body language that conducting burns is a normal, unremarkable activity. In her study of Aboriginal burning in northern Australia, Strang (1997, p 94) found that local indigenous people viewed burning “as mere housekeeping.” Otterstrom’s study of local fire management in a dry tropical forest of Nicaragua (2004) and Lewis and Ferguson’s study of indigenous fire management in Alberta (1988) also corroborate this finding. However, my observation should still be checked by local participants.

3.3.10. Results for Proposition 2.a: Traditional fire knowledge used by producers shares factors in common with traditional fire knowledge documented from around the world.

Tables 3.13 and 3.14 summarize the factors of fire recorded in the literature about indigenous and local cultures from four regions of the globe: Africa, Australia, the US & Canada and Latin America. A variety of ecosystems were represented in these studies, including forests, savannas, shrublands and grasslands, which occurred at a variety of elevation and moisture gradients (e.g., riparian zones to ridge tops). Among the findings of 20 authors, indigenous and local people have recognized a total of 65 factors related to fire management.

Within this total list of fire factors, 91 percent were mentioned by multiple authors. More than half of the factors (51 percent) were recorded in all four geographic regions;

68 percent were recorded in at least three geographic regions (Table 3.13). Only six factors were unique to a single study. Tallies of the components of TFK reported from each study in each region are provided in Appendix 3.G. (Tables 3.G.1.-3.G.4.).

As represented by the factors of fire, the body of TFK used by producers at La Sepultura is similar to what has been reported from these four regions of the globe. None of the factors of fire in use at La Sepultura are unique to the global TFK literature; everything I discerned about the fire knowledge of producers has been recorded in other studies. Eighteen factors were documented in every region and in at least half of the studies (Table 3.14). Producers at La Sepultura mentioned all but two of these factors. Six factors were documented in every region and in at least 70 percent of the studies. They are: season, fire effects on vegetation, fire effects on animals, moisture of live or dead fuels, fire control and the consequences of not burning (Table 3.14). TFK at La Sepultura incorporates 44 of the 65 factors recorded worldwide (68 percent). Among the 33 factors that are common to all four regions, producers in the two study communities mentioned all but three: fire effects upon soil, danger and landscape pattern (Table 3.13).

Although not necessarily new knowledge to the people who actually do traditional burning, the present study does add new information to the body of knowledge recorded in the literature for the Western Hemisphere. Among 45 factors of fire recorded at La Sepultura, 24 factors had not been previously recorded in Mexico (Table 3.15). Six factors had not previously been reported from Latin America and six had not been reported from North America. Two factors are new to the literature for the Western Hemisphere: concern about scorch (scorch height) and internal regulation of fire by the local community (Table 3.15).

Table 3.13. Factors of fire observed at La Sepultura compared with those recorded in the literature from four regions of the globe: Africa, Australia, the USA and Canada, and Latin America.

Factor of Fire	Observed at La Sepultura	Africa	Australia	US & Canada	Latin America	Global literature composite	Factors reported in all four regions
Geology/Topography							
Geologic substrate/landform			X	X		X	
Elevation			X	X		X	
Soil type, moisture	X	X	X	X	X	X	X
Soil temperature		X				X	
Water level			X	X		X	
Slope	X	X	X	X		X	
Aspect	X	X		X		X	
Vegetation/Fuels							
Consumption: degree/speed/patchiness	X	X	X	X	X	X	X
Moisture of live or dead fuels	X	X	X	X	X	X	X
Fuel load	X	X	X	X	X	X	X
Plant phenology	X	X	X	X	X	X	X
Fuel composition/ species	X	X	X	X	X	X	X
Fuel/vegetation structure, arrangement, continuity, height	X	X	X	X	X	X	X
Fuel diameter or size (logs vs. grass)	X	X		X	X	X	
Vegetation type		X	X	X		X	
Weather							
Humidity of air/ day	X	X	X		X	X	
Onset/end of rainy season, timing of rain	X	X	X	X	X	X	X
Season	X	X	X	X	X	X	X
Wind speed/force	X	X	X	X	X	X	X
Water level			X	X		X	
Quantity of rain	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X
Wind direction/ source	X	X	X	X	X	X	X
Lightning			X	X		X	
Phase of moon					X	X	

Factor of Fire	Observed at La Sepultura	Africa	Australia	US & Canada	Latin America	Global literature composite	Factors reported in all four regions
Sun's force and position in sky	X		X		X	X	
Snow location/ snow melt				X		X	
Fire Behavior							
Backing/heading fire	X	X	X	X	X	X	X
Fire size/area/aerial extent	X	X	X	X	X	X	X
Flame height	X		X		X	X	
Rate of spread	X	X	X	X		X	
Fire type (surface, ground, canopy)	X	X	X	X		X	
Fire intensity (hot or cool fire)	X	X	X	X	X	X	X
Frequency/ return interval	X	X	X	X	X	X	X
Residence time				X		X	
Direction of fire spread	X	X	X	X	X	X	X
Natural extinguishment			X	X		X	
Scorch height	X		X			X	
Evenness, smoothness					X	X	
Operations							
Time of day	X	X	X	X	X	X	X
Firebreaks	X	X	X	X	X	X	X
Control	X	X	X	X	X	X	X
Spatio-temporal sequence of fires, incl. for prevention		X	X		X	X	
Authority/decision to burn	X	X	X		X	X	
Age of participants	X		X	X	X	X	
Gender	X	X	X	X	X	X	X
Crew size	X	X	X	X	X	X	X
Planning	X		X		X	X	
Tools for prep/ignition/control	X	X	X	X	X	X	X
Ignition pattern	X	X	X	X	X	X	X
Knowledge transmission	X	X	X	X	X	X	X
Danger/ risk		X	X	X	X	X	
Fire placement		X	X	X		X	
Other							
Fire effects on animals	X	X	X	X	X	X	X

Factor of Fire	Observed at La Sepultura	Africa	Australia	US & Canada	Latin America	Global literature composite	Factors reported in all four regions
Fire effects on vegetation	X	X	X	X	X	X	X
Fire effects on soil	🟥	X	X	X	X	X	X
Fire effects on watershed/water delivery		X				X	
Effects of smoke (desirable)				X	X	X	
Consequences of not burning	X	X	X	X	X	X	X
Landscape pattern / Patch size	🟥	X	X	X	X	X	X
Caring for the land, clean up country, controlling our space	X	🟫	X	X		X	
Areas prohibited from burning (custom, sacred, other)			X			X	
Regulatory							
Burning illegal by government		X		X		X	
Burning regulated by government	X	X	X	X	X	X	X
Burning regulated by community	X		X			X	
Total number of fire factors reported	**44**	**46**	**55**	**52**	**44**	**65**	**32**

Legend:

◼ = factor documented in the literature for all four regions of the globe

🟥 = factor not observed at La Sepultura, but documented in all regions

🟫 =factor documented in all regions except Africa

🟨 =factor documented in all regions except Australia

🟩 =factor documented in all regions except the USA or Canada

🟪 =factor documented in all regions except Latin America

Table 3.14. The most commonly reported factors of fire in 20 published studies of traditional fire knowledge from four regions of the world, sorted by the percent of authors recording each factor.

Legend: 1-9 % 10-24 % 25-49 % 50-100 %

	Africa	Australia	US & Canada	Latin America	Global	
	Number of authors reporting (among 6)	Number of authors reporting (among 5)	Number of authors reporting (among 4)	Number of authors reporting (among 5)	Percent of authors reporting (among 20)	Observed at La Sepultura
Season	6	5	4	5	100	X
Fire effects on animals	5	5	4	4	90	X
Fire effects on vegetation	5	5	4	4	90	X
Moisture of live or dead fuels	5	4	4	3	80	X
Control	4	5	1	4	70	X
Consequences of not burning	4	4	2	4	70	X
Fire intensity (hot or cool fire)	5	4	1	3	65	X
Firebreaks	3	4	2	4	65	X
Plant phenology	4	4	3	1	60	X
Onset/end of rainy season, timing of rain	1	3	3	4	55	X
Frequency/ return interval	2	2	3	4	55	X
Landscape pattern / Patch size	3	5	1	2	55	
Fuel load	2	4	3	1	50	X
Fuel composition/ species	1	4	4	1	50	X
Wind speed/force	3	3	1	3	50	X
Time of day	2	3	1	4	50	X
Tools for prep/ignition/control	1	3	3	3	50	X
Fire effects on soil	2	1	2	5	50	
Soil type, moisture	2	2	3	2	45	X

	Africa	Australia	US & Canada	Latin America	Global	
	Number of authors reporting (among 6)	Number of authors reporting (among 5)	Number of authors reporting (among 4)	Number of authors reporting (among 5)	Percent of authors reporting (among 20)	Observed at La Sepultura
Gender	1	3	2	3	45	X
Ignition pattern	1	3	2	3	45	X
Fuel/vegetation structure, arrangement, continuity, height	1	2	4	1	40	X
Backing/heading fire	2	2	1	3	40	X
Fire size/area/aerial extent	1	4	1	2	40	X
Crew size	2	2	2	2	40	X
Consumption: degree/speed/patchiness	1	2	1	3	35	X
Wind direction/ source	1	2	2	2	35	X
Humidity of air/ day	2	2		3	35	X
Fire type (surface, ground, canopy)	1	4	2		35	X
Temperature	2	2	1	1	30	X
Knowledge transmission	1	2	2	1	30	X
Burning regulated by government	2	1	1	2	30	X
Geologic substrate/landform		3	3		30	
Quantity of rain	1	2	1	1	25	X
Danger/ risk	1	2	1	1	25	
Authority/decision to burn	2	2		1	25	X
Flame height		3		2	25	X
Burning illegal by government	3		2		25	
Direction of fire spread	1	1	1	1	20	X
Slope	1	1	2		20	X
Rate of spread	1	2	1		20	X
Spatio-temporal sequence of fires, incl. for prevention	1	2		1	20	
Elevation		2	2		20	

	Africa	Australia	US & Canada	Latin America	Global	
	Number of authors reporting (among 6)	Number of authors reporting (among 5)	Number of authors reporting (among 4)	Number of authors reporting (among 5)	Percent of authors reporting (among 20)	Observed at La Sepultura
Snow location/ snow melt			4		20	
Vegetation type	1	1	1		15	
Age of participants		1	1	1	15	X
Fire placement	1	1	1		15	
Water level		1	2		15	
Fuel diameter or size (logs vs. grass)	1		2		15	X
Water level		2	1		15	
Natural extinguishment		1	2		15	
Planning		2		1	15	X
Phase of moon				3	15	
Aspect	1		1		10	X
Lightning		1	1		10	
Sun's force and position in sky		1		1	10	X
Effects of smoke (desirable), smoke color			1	1	10	
Caring for the land, clean up country, controlling our space		1	1		10	X
Burning regulated by community		2			10	X
Soil temperature	1				5	
Residence time			1		5	
Scorch height		1			5	X
Evenness, smoothness				1	5	
Fire effects on watershed/water delivery	1				5	
Areas prohibited from burning (custom, sacred, other)		1			5	

Table 3.15. Factors of fire documented at La Sepultura that are new to the body of published literature on traditional fire knowledge in Mexico, North America, Latin America or the Western Hemisphere.

	Factors new to the literature for Mexico	Factors new to the literature for Latin America	Factors new to the literature for North America	Factors new to the literature for the Western Hemisphere
Geology/Topography				
Slope	X	X		
Aspect	X	X		
Vegetation/Fuels				
Moisture of live or dead fuels	X			
Fuel load	X			
Plant phenology	X			
Fuel composition/ species	X			
Fuel diameter or size (logs vs. grass)	X	X		
Weather				
Quantity of rain	X			
Temperature	X			
Sun's force and position in sky	X		X	
Fire Behavior				
Backing/heading fire	X			
Fire size/area/aerial extent	X			
Flame height	X		X	
Rate of spread	X			
Fire type (surface, ground, canopy)	X			
Fire intensity (hot or cool fire)	X			
Scorch height	X	X	X	X
Operations				
Authority/decision to burn	X		X	
Age of participants	X			
Crew size	X			
Planning	X		X	
Knowledge transmission	X			
Other				
Caring for the land, clean up country, controlling our space	X	X		
Regulatory				
Burning regulated by community	X	X	X	X
Number of fire factors reported	**24**	**6**	**6**	**2**

3.4. Discussion

The evidence in support of each of the propositions related to traditional fire management at La Sepultura is strong. Producers in the two study communities burn for specific purposes, using techniques passed down from generation to generation. They are aware of 44 factors relative to local fire management, which they consider in deciding when, where and how to burn individual small parcels. These components of TFK address specifics of the fire environment (Countryman, 1966), planning and regulation of burning, controlled burning operations and fire effects. Not only are producers aware of these factors, but they are also aware of a variety of interactions among them, such as the interactions among season, local weather, fuels, and ignition patterns. They are well aware of the effects of different kinds of fire behavior upon plants and animals, such as upon pine cone production, pine seedling mortality and pest control.

In their burning practices, producers demonstrate further depth of knowledge by utilizing relative quantities of each variable that will keep their fires moving slowly downhill, with short flame lengths that generate minimal heat. They know that this fire behavior will enable them to achieve their goals of fuel reduction and forest maintenance. Their burning techniques also allow producers to control their fires with community labor and locally available hand tools, which would become inadequate if fuels were allowed to accumulate.

The community decision-making process about what will be burned each year is a fundamental piece of evidence that burning in the study communities is not thoughtless or random. In addition, in the ejido setting, every small parcel is spoken for and utilized according to the determination of each ejidatario (parcel “owner”). Fire escapes from one family's parcel of land onto another could interrupt a neighbor's plans for farming crops or livestock that year, and an escaped wildfire that resulted in substantial pine mortality could be disastrous for the family's future wood supply. Reinforced by the local disdain for even light canopy scorch, there is little evidence to suggest that producers burn indiscriminately at the study site.

The several methods that producers use to minimize fire escapes reinforce the notion that they understand factors that lead to escapes and that they actively work to prevent them. Examples of these practices include:

- Maintaining clean fire breaks around each community and around each burn parcel;
- Burning the pine forest every three to six years;
- Keeping aware of fuel accumulation and take action to reduce fuels through grazing and burning;
- Burn using the methods articulated for "good fires" (Table 3.7).
- Keeping the entire community involved in fire management including mature and elder members of the community who have deep fire knowledge and the young men who will likely conduct the burning in the future.

The only spotover (small escape) that I observed took place on a workshop-related burn organized by the government at mid-day, a time when producers normally avoid burning. Participants on that workshop fire quickly extinguished the spot.

Producers' burning practices also demonstrate their awareness of changes in burning conditions that occur during the transition between the dry and rainy seasons. As the weather changes from fronts arriving primarily from the north to weather bringing moist air from the south over the Pacific Ocean, both ecological and physical conditions improve for accomplishing fire control and agricultural objectives. During this weather transition, rains are sporadic and relatively light, allowing fuels to moisten. This improves the ease of fire control, but does not prevent burning compared to a few weeks later when the heavy daily rains arrive each day and soak all burnable material. In addition, producers are able to burn off dead fuels right at the time that green-up of grasses and forbs is occurring. This removes unwanted fuels and improves foraging opportunities for livestock. In milpas and potreros, where burning takes place slightly earlier, burn timing enables producers to plant before the rains arrive and to rid pastures of unwanted thorns and shrubs before new forage growth begins in earnest.

The timing of burning at this seasonal transition is also relevant to the phenology of ocote pines. While some interview participants indicated that pine trees drop their needles little by little throughout the year, others indicated that the trees drop most of their needles in March or April at the end of the dry season. These respondents indicated that the trees flush a new set of needles at the beginning of the rainy season. If it is true that the trees drop the bulk of their needles at the end of the dry season, then burning would be advantageous during the transition. Producers could use fire to consume the fuel load created by the prior year's needle drop. Any needles that are still on the trees and that get scorched during a burn could be replaced in the flush of new needles just arriving.

In contrast, the Tropical pine-oak ecosystem would have a tendency to burn with varying intensity if fire were not managed in this way by local people. If people were not involved except for sources of ignition (e.g., cigarette butts), then chance ignitions would be more likely to spread into larger fires in the dry season when temperatures are hot, fuels are dry and fuel accumulation is ample. Because the topography is highly dissected into multiple hills and valleys, creating landscape patches of a few hectares, a fire would burn with high rates of spread (quickly) and with high intensity (tall flames) when it traveled upslope and with the wind. When the fire reached the tops of slopes and began backing down slope, it would have lower rates of spread and shorter flame lengths. Portions of the wildfire burning at different angles to the wind and slope, and navigating through different fuel patches, would produce a variety of fire behaviors, including variable flame lengths, rates of spread and residence times. Because fire behavior is related to fire severity (Regelbrugge and Smith, 1994, Graham et al., 2004), this ecosystem would have a mixed severity fire regime (Taylor and Skinner, 1998, Fulé et al., 2003) instead of the current low severity fire regime. Such a scenario would have forest patches that burned aggressively and with high severity (e.g., burning uphill and with the wind); patches that burned lightly and with low severity (e.g., downhill and against the wind); and a variety of intermediate patches juxtaposed with one another and interspersed across the landscape (Fulé et al., 2003).

Producers' finesse in utilizing this large combination of environmental and organizational factors (Table 3.7) to consistently produce low intensity fire behavior is remarkable. It is extremely unlikely that the specific combination of factors that producers employ at La Sepultura occurs by chance. Producers are using many of the techniques documented in Western science to reduce fire intensity; however, local knowledge passed from generation to generation is the primary source of their knowledge.

As it has been historically, the complex fire system (Figure 1.2d.) at La Sepultura is currently anthropogenically driven. Although the producers I interviewed indicated that lightning did occur, and although I observed two trees that had been struck by lightning, producers insisted repeatedly that lightning did not start fires in the area because lightning was always accompanied by sufficient rain. This suggests that local communities, and those people who start fires through neglect or arson, control the ignition process and thus the pattern of burning (fire regime) in the landscape over time. Their choices have a powerful influence upon when, where and how vegetation burns, and therefore upon the ecological character of the tropical pine-oak ecosystem within the reserve.

The depth of TFK in the study communities at La Sepultura is impressive, but it is not unique. There does appear to be a body of knowledge that is common to traditional fire users around the world (Pyne, pers. com., 2009, Fort Collins). Although this study falls short of identifying a set of universal fire factors that are characteristic of TFK, it is interesting that producers at La Sepultura employ comparable numbers and kinds of variables utilized by other traditional fire cultures. For example, producers at Corazón del Valle and Valle de Corzo identified 44 factors of fire, while the highest number of factors recorded in any other study was 46 (Garde et al., 2009).

Whether or not factors of fire gleaned from observation and the literature is a true reflection of the depth of TFK in any given place may depend upon the style of inquiry and the building blocks of research available to the investigator. For example, the work by Garde et al.(2009) is especially rich for several reasons. First, it is focused on Aboriginal burning in Australia, where “more is known about Aboriginal fire usage compared with any other group of hunter-gatherer people on Earth” (Bowman et al., 2004, p 208). Fire has been used for landscape management by Aboriginal people in Australia far longer than in any other region (Haynes, 1991, Jones, 1969, Strang, 1997), and its use has continued in some form to this day where it can be directly observed and explained as living knowledge. In Garde et al., “these studies are the voices of the Aboriginal people themselves” (Garde et al., 2009, p 85), the people who are doing the burning. The Australia research situation contrasts with other studies, in North America for example, where indigenous cultures have been largely exterminated, most traditional knowledge has been lost and historical accounts are the primary sources of information.

Despite the richness of TFK among producers and the practices they employ to prevent fires from getting out of control, there is still an unexplained contradiction between this and the high percentage of wildfires documented from agricultural burning. If producers are so knowledgeable and so careful, then how could roughly 60 percent of the fires at La Sepultura and 45 percent of the wildfires nationwide be caused by escaped agricultural fires?

One explanation may be that what has been noted in some areas of Mexico, that producers allow fires to escape on purpose in order to clear land or to achieve other goals (Rodríguez-Trejo, pers. com., November 9, 2009, Fort Collins.), could be happening at the reserve. In other areas, changes in local demographics and loss of TFK have resulted in fire escapes due to lack of skill or insufficient numbers of people to control the burn (E. Jardel-Peláez, pers. com., October 24, 2008, Morelia). Given the disincentives for people living in agricultural ejidos to allow fires to escape onto their neighbors' parcels, the opinion of one local producer may explain part of the story. He indicated that wildfires are more likely to come from burns conducted by ranchers who have fewer individuals available to control their fires, and from lands with absentee landowners who burn infrequently, allowing their fuels to accumulate (Anonymous, May 2008).

Inherent in any calculation of either controlled fires or wildfires in Mexico is incomplete accounting. If on average 45 percent of the wildfires in Mexico are attributed to agricultural fire escapes (SEMARNAT, 2010), that percent is based on the number of wildfires documented, not on the number of controlled burns that take place. The following example using readily available numbers will serve as an example of how different the perception of producers' carefulness with fire could be. In 2007, the state of Chiapas had 500,701 people living in ejidos, 480,815 of whom were engaged in agriculture (INEGI, 2007). If each agricultural household did some controlled burning, and each had seven family members (more than the typical household I observed at La Sepultura), then the number of families using fire for agriculture in Chiapas would be 68,688. If only half of those families performed a single controlled burn in any given year, this would generate 34,344 controlled burns annually. Now then, for the twelve year time period including 1996-2007, CONAFOR documented an average of 352 wildfires in Chiapas (CONAFOR, 2010). Accepting that the national definition of fires from agriculture includes fires from, lightning, trains, electric lines, illicit crops and trash burning, we still multiply the national average for the percent of wildfires caused by agriculture annually during the same time period (46 percent) by the 352 documented wildfires. This equals 162 wildfires caused by agriculture in Chiapas annually during that time. If we then divide the 162 wildfires by the estimated 34,344 controlled burns generated by producers, we estimate an escape percentage of 0.0047, or roughly one half of one percent. If we use the percent of fires attributed to agricultural burning within La Sepultura between 1997-2005, which is roughly 60 percent (Cruz-López, 2006), the escape percentage would be 0.006. Both estimates are certainly inaccurate, but they do suggest that a more complete accounting of controlled fires and escaped fires would reflect more favorably upon the application of fire by producers at La Sepultura, and perhaps throughout Chiapas and the nation of Mexico.

3.5. Conclusion

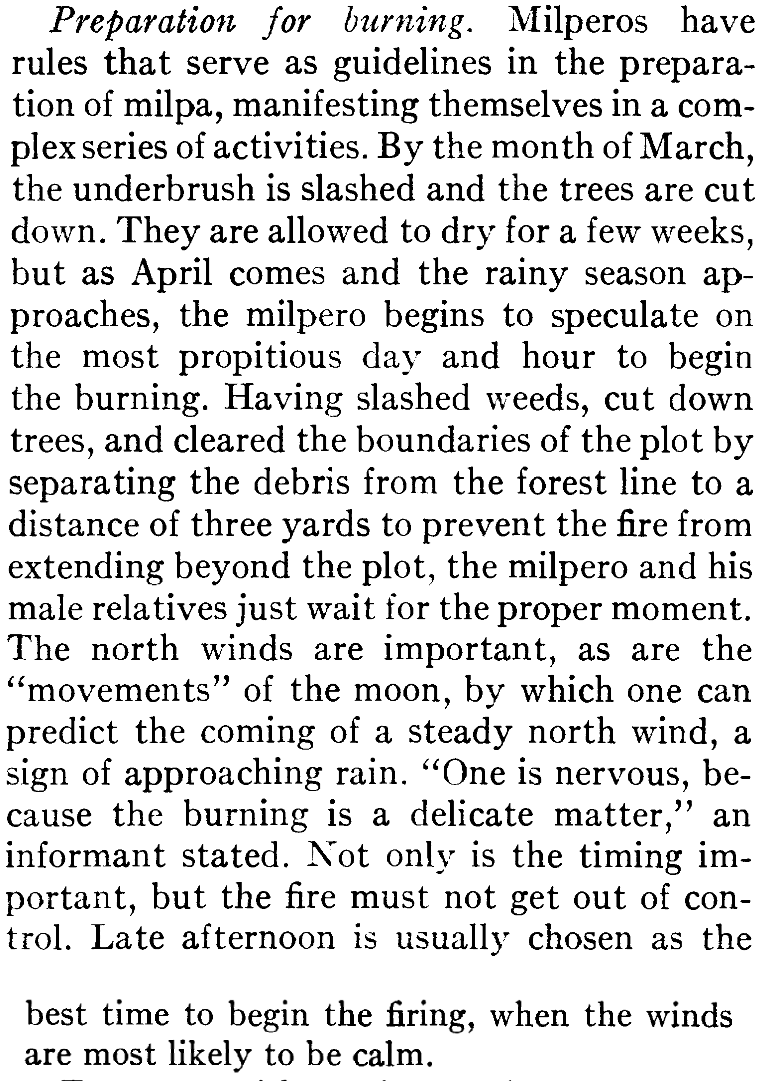
In this chapter, I have proposed that producers in the two study communities possess and apply a depth of traditional fire knowledge in their fire management practices. These fire managers are both purposeful and careful in their burning practices, which maintain a high frequency, low intensity fire regime. This allows producers to achieve their management goals while controlling the fires with locally available labor and equipment.

The effort to capture the variety of components that constitute TFK at La Sepultura, and to compare the richness of TFK there to TFK reported in the literature, resulted in identifying and tallying factors of fire management. While these factors are not universal, the method did provide a sense that traditional fire cultures around the word share overlapping, though not identical, sets of fire knowledge. The numbers and kinds of fire factors considered by producers at La Sepultura is comparable to those identified by other fire cultures such as by Aboriginal peoples in Australia, whose knowledge is very rich.

What remains to be clarified is why fires started for agricultural purposes at La Sepultura constitute more than half of the wildfires documented in the area. Simple calculations based on census records and wildfire occurrence suggest that a more complete accounting would reflect more favorably upon the use of fire by producers in the region and throughout Mexico.

Appendix 3.A. Excerpts from Reina (1967) detailing traditional fire management among Maya descendants in Guatemala.

p.4



Preparation for burning. Milperos have rules that serve as guidelines in the preparation of milpa, manifesting themselves in a complex series of activities. By the month of March, the underbrush is slashed and the trees are cut down. They are allowed to dry for a few weeks, but as April comes and the rainy season approaches, the milpero begins to speculate on the most propitious day and hour to begin the burning. Having slashed weeds, cut down trees, and cleared the boundaries of the plot by separating the debris from the forest line to a distance of three yards to prevent the fire from extending beyond the plot, the milpero and his male relatives just wait for the proper moment. The north winds are important, as are the "movements" of the moon, by which one can predict the coming of a steady north wind, a sign of approaching rain. "One is nervous, because the burning is a delicate matter," an informant stated. Not only is the timing important, but the fire must not get out of control. Late afternoon is usually chosen as the best time to begin the firing, when the winds are most likely to be calm.

Two men with torches of dry weeds and palms move to carefully selected areas of the field, over which felled branches and debris are evenly spread. The owner of the milpa directs each man to a corner of the field. The fire is started at one of the corners and is allowed to spread toward the center, directed by the wind. The helpers walk ahead of the fire and continue to ignite the dry debris with their torches. Soon the smoke rises and the entire area becomes hot and smoky.

When the fields are burning, one can easily tell by the color of the smoke whether the milpa is first year (*milpa de monte*) or second year (*milpa de cañada*). Smoke from the former is very black, while smoke from the latter is lighter in color. Since "the yield of second-year milpa is expected to be higher than that of first-year crops," the milpero knows, when he sees many of the fields burning with the lighter colored smoke, that if all other factors are favorable, there will be abundant maize that year.

While the fire continues to burn, the green leaves explode, and each of the persons present takes pleasure in the thought that snakes are being caught in the fire. It is pleasant to know that insect and animal pests as well as weeds are being destroyed, though it is known that ants and other animals with underground dwellings manage to survive. A successful burning operation brings release and joy to the men. Optimism is high among them, and they transmit this sentiment to their wives and children. Wives never join in the burning of the milpa but anxiously await the return of the party to learn how it all turned out.

The field is now ready for immediate seeding, though it is not a clean field. Partially burned branches and trunks of trees remain, and it is in the midst of this charred debris that the planting will be done. Stones are removed, however, and piles of them accumulate over the years in unused areas of the fields.

> When one burns the fields, the heat brings out a juice ["sweat"] from the soil; and this is excellent for the seed. It helps in the germination process. Therefore, one seeds the milpa while it has "hot" soil.

Seeding "hot" soil does not mean planting maize immediately after the burning process has been completed, but the next day. The milpero wants to take advantage of three elements simultaneously: the rain, the "sweat" of the soil, and the ashes produced by the burning. However, he is also interested in this "hot" property of the soil just in case his timing of the coming of the rains is not exact. Seeding *can* take place as long as eight days after the burning because the "sweat" is supposedly effective for that period of time. If, for any reason, the milpero cannot complete his seeding within this eight-day period, he prefers to wait for the first rainfall, which is a different type of moisture but also effective. All types of soil "sweat" during the burning process; the milpero refers to this process as *tik'imu'*. However, the rain must come soon to moisten the soil and "take substance" from the ashes into the soil for the benefit of the seeds.

Appendix 3.B. Local Research Assistants

	Year	Assistant number	Assistant's name	Community	Task/Measurement
Vegetation and fire ecology:	2006,2008	1	Jorge Pinacho Posada	Corazón del Valle	Fuels, trees, seedlings, terrain, canopy photos, data entry
	2006,2008	2	Sixto Esteban Pinacho Posada	Corazón del Valle	Pre-burn seedlings, terrain
	2006	3	Jacobo Hernández Hernández	Corazón del Valle	Post-burn seedlings
	2008	4	Andrés Hernández Benítez	Valle de Corzo	Fuels, trees, pre-burn seedlings
	2008	5	Joaquín Sánchez Rosales	Valle de Corzo	Fuels, trees, pre-burn seedlings
	2008	6	Miguel Ramos Calymayor	Valle de Corzo	Fuels, trees, pre-burn seedlings
	2008	7	Familia de Pacífico Pérez Hernández	Corazón del Valle	Equipment preparation: pin flags with numbered tags
	2008	8	Genaro Pérez Hernández	Valle de Corzo	Seedling treatments
	2008		José Domingo Cruz López	CONANP	Post-burn scorch and char
Fire behavior observation:	2006		Miguel Ramos Calymayor	Valle de Corzo	Videography ofburning techniques and fire behavior
	2006		Oscar Rodríguez	Pronatura-Sur	Weather, fire behavior, terrain
	2006	9	Andrea Pérez Ramos	Valle de Corzo	Distances between video landmarks
	2006	10	Urías Hernández Esquipulas	Valle de Corzo	Distances between video landmarks

	Year	Assistant number	Assistant's name	Community	Task/Measurement
	2006	11	Saqueo Hernández Hernández	Corazón del Valle	Videography of controlled burns
	2008	12	Osmar Nanjera Arellano	Valle de Corzo	Videography of controlled burns
	2008	13	José Hernández Hernández	Corazón del Valle	Videography of controlled burns
	2008		Jorge Pinacho Posada	Corazón del Valle	Videography of controlled burns
	2008		Sixto Esteban Pinacho Posada	Corazón del Valle	Videography of controlled burns
Assistance with interviews:	2008	14	Virginia Cruz Ocaña	Corazón del Valle	Introductions and translation assistance
	2008		Sixto Esteban Pinacho Posada	Corazón del Valle	Introductions and translation assistance
Owners of burn parcels (not all were burned)	2006		Sixto Esteban Pinacho Posada	Corazón del Valle	Permission to study his parcel
	2006		Anonymous	Valle de Corzo	Permission to study his parcel
	2008		Eustaqueo “Cacho” Cruz Posada	Corazón del Valle	Permission to study his parcel
	2008		Carlos Cruz Posada	Corazón del Valle	Permission to study his parcel
	2008		Miguel Pinacho Ramos	Corazón del Valle	Permission to study two parcels
	2008		Joaquín Sánchez Rosales	Valle de Corzo	Permission to study his parcel

Appendix 3.C. Semi-Structured Individual Interview Questions

(Translated from the Field Version in Spanish)

Name of participant: _______________ Date: _____________

Participant code: _________________________

Audio file: _________________

PART A. Introduction checklist

_____ I am a student, from Colorado, USA, studying for degree
_____ My interest - natural resources, fire, pine forest
_____ Participants selected at random, 18 from Corazón del Valle, 18 from Valle de Corzo
_____ Responses are confidential, assign number to your name
_____ No good or bad answers
_____ May I use audio recorder?
_____ Voluntary participation

PART B. Demographics

Name of Ejido:
☐ Corazón del Valle (CdV)
☐ Valle de Corzo (VdC)
☐ Other _________________________

Gender ☐ male ☐ female

How old are you? _______ Age group: _____________

How many years of school do you have? ___________

How many years have you lived in this community? ___________

How many years have your ancestors lived in this area? ________

Do you have cattle or livestock? _______ How many? ________

How many years of experience do you have with fire in the countryside? __________

Normally, how many days per month do you work in the field?

____

Do you work outside of the community? ☐ no ☐ yes

____

PART C. Questions about fire

How many years do you think people have been using fire in this area?

____

In the pine forest? ______________________

Photographs. "During my previous visits, I took these pictures of the pine forest." Which photo do you prefer? Why?

The density of pines is different in the two photos. Which density is better? Why?

Are there good fires and bad fires?

What would happen in the pine forest if there were not any fires for many years?

What are a producer's motives or purposes for starting a fire in the forest?

How many people participate in each prescribed burn?

How does a person learn to use fire? Who is his/her teacher?

Who decides when and where there will be a burn in the pine forest?

What tools do the participants use?

Typically, how are the fires lighted/started?

What controls the fire after it is started?

Who is responsible for the fire after it is started?

PART D. Components of Fire (exercise with corn kernels)

What things influence the behavior of fire in the forest?

Among these factors, which are the most important or influential?

(Participants put a portion of their 100 corn kernels in each paper plate, according to the importance of each factor)

Relative quantities: For the factors in the paper plates, what relative quantity of each factor makes a *good* fire in the pine forest?
(Possible scales)

Scale for factor 1: None Low Medium High

Scale for factor 2: Few Medium Many

Scale for factor 3: Short Medium Tall

Scale for factor 4:

Relative quantities: For the factors in the paper plates, what relative quantity of each factor makes a *bad* fire in the pine forest?

(Possible scales)

Scale for factor 1: None Low Medium High

Scale for factor 2: Few Medium Many

Scale for factor 3: Short Medium Tall

What else should I know about fire in your area?

Do you have a favorite story about a particular fire that you would like to share?

a. Is this a common thing?

I have been asking you a lot of questions. Do you have any questions for me?

Appendix 3.D. Topics of Interview Analysis: Nodes Used in Coding Interviews with NVivo 2.0.

(Interviews were transcribed and coded in Spanish. This list of nodes is translated from the Spanish list, which was alphabetized.)

Total number of nodes: 129

1 (3) /Animals
2 (3 1) /Animals/good animals[1,1]
3 (3 2) Animals/bad animals[2,1]
4 (5) /Learning fire
5 (5 1) / Learning fire /Learning from elders
6 (5 5) / Learning fire /Knowledge
7 (5 7) / Learning fire /Age at first fire
8 (5 10) / Learning fire /Experience
9 (5 15) / Learning fire /Jose Domingo
10 (5 20) / Learning fire /Teachers of fire
11 (10) /Kitchen, fire in the kitchen
12 (15) /Fire behavior
13 (15 10) / Fire behavior /Flame height
14 (15 15) / Fire behavior /Heat
15 (15 16) / Fire behavior /Sparks
16 (15 18) / Fire behavior /Direction of spread
17 (15 20) / Fire behavior /Force of the flames ~intensity~
18 (15 25) / Fire behavior /Speed of flames
19 (20) /Community, colony
20 (25) /Connections, complex ideas
21 (25 1) / Connections, complex ideas /2 factors
22 (25 2) / Connections, complex ideas /3 factors
23 (25 3) / Connections, complex ideas /more than 3 factors
24 (25 4) / Connections, complex ideas /4-5 factors
25 (25 6) / Connections, complex ideas /more than 5 factors
26 (27) /Care for the forest
27 (30) /Tree density
28 (33) /Fire ecology
29 (35) /Escapes
30 (39) /Factors of fire
31 (39 5) / Factors of fire /Weather - direction of weather
32 (39 10) /Factors of fire/Weather - in total, in general
33 (39 15) /Factors of fire/Fuels
34 (39 15 1) /Factors of fire/Combustibles/Fuels - humidity of
35 (39 15 2) /Factors of fire/Fuels/Fuels - height
36 (39 15 9) /Factors of fire/Fuels/Fuels - quantity
37 (39 15 10) /Factors of fire/Fuels/Fuels - type
38 (39 20) /Factors of fire/Season

39 (39 22) /Factors of fire/Schedule of grazing, planting
40 (39 25) /Factors of fire/Factors are equal in importance
41 (39 30) /Factors of fire/Phenology, stage of grass
42 (39 35) /Factors of fire/Hour, time of day
43 (39 40) /Factors of fire/Humidity
44 (39 45) /Factors of fire/Smoke
45 (39 65) /Factors of fire/Interval between fires
46 (39 70) /Factors of fire/Rain
47 (39 70 1) /Factors of fire/Rain/Days since
48 (39 70 2) /Factors of fire/Rain/Number of rains
49 (39 70 3) /Factors of fire/Rain/Quantity of rain
50 (39 75) /Factors of fire/Month
51 (39 80) /Factors of fire/Wet, dry
52 (39 85) /Factors of fire/Clouds, fog
53 (39 90) /Factors of fire/Slope
54 (39 95) /Factors of fire/Whirlwind, fire whirl
55 (39 100) /Factors of fire/Sun
56 (39 105) /Factors of fire/Soil
57 (39 107) /Factors of fire/Parcel size
58 (39 110) /Factors of fire/Temperature
59 (39 120) /Factors of fire/Wind
60 (39 120 1) /Factors of fire/Wind/Wind direction
61 (39 120 3) /Factors of fire/Wind/Wind quantity, force
62 (39 120 8) /Factors of fire/Wind/Wind - speed
63 (40) /Two photos: green and scorched
64 (40 1) /Two photos: green and scorched/Urias and both photos
65 (40 10) /Two photos: green and scorched/Green forest
66 (40 11) /Two photos: green and scorched/Scorched forest
67 (40 11 1) /Two photos: green and scorched/Scorched forest/Canopy
68 (40 11 2) /Two photos: green and scorched/Scorched forest/Roots
69 (40 11 31) /Two photos: green and scorched/Scorched forest/Crown fire
70 (41) /Fire good or bad
71 (41 1) /Fire good or bad/Good fire
72 (41 2) /Fire good or bad/Bad fire
73 (41 3) /Fire good or bad/ The two photos
74 (42) /Controlled fire
75 (49) /Livestock
76 (52) /Government
77 (55) /Wildfires
78 (55 1) /Wildfires/Lightning
79 (55 2) /Wildfires/Cigars, cigarettes
80 (55 3) /Wildfires/Wildfire behavior
81 (55 32) /Wildfires/Wildfire operations
82 (60) /Milpa, tame pasture
83 (65) /Motives, goals, purposes
84 (66) /Don't know
85 (67) /Operations during a burn
86 (67 10) /Operations during a burn/New fire brigades
87 (67 12) /Operations during a burn/Calendar, schedule of community
88 (67 15) /Operations during a burn/Duration of the burn
89 (67 20) /Operations during a burn/Tools
90 (67 25) /Operations during a burn/Ignition
91 (67 25 1) /Operations during a burn/Ignition/ignition pattern
92 (67 25 2) /Operations during a burn/Ignition/pine cones
93 (67 30) /Operations during a burn/mop-up
94 (67 32) /Operations during a burn/Number of participants

95 (67 35) /Operations during a burn/Organization of participants
96 (67 40) /Operations during a burn/Roles of men and women
97 (67 45) /Operations during a burn/Responsibility
98 (68) /Contrary answers
99 (68 1) /Contrary answers/there are no fire factors
100 (68 2) /Contrary answers/without fire - no problem
101 (68 3) /Contrary answers/fire bad for forest
102 (68 4) /Contrary answers/put out every fire
103 (68 6) /Contrary answers/North wind for burning
104 (69) /Mary's favorite quotes
105 (70) /Oxygen, air
106 (73) /Grass
107 (80) /Ocote pine
108 (80 7) /Ocote pine/big trees
109 (80 10) /Ocote pine/little trees, seedlings
110 (80 12) /Ocote pine/bark
111 (80 15) /Ocote pine/needles
112 (80 20) /Ocote pine/wood
113 (80 20 1) /Ocote pine/wood/red, heartwood
114 (80 20 2) /Ocote pine/wood/white, sapwood
115 (80 22) /Ocote pine/resin
116 (80 25) /Ocote pine/sprouts
117 (80 27) /Ocote pine/seeds, cones
118 (80 30) /Ocote pine/shade
119 (85) /Preparations for burning
120 (85 2) /Preparations for burning/Decision to burn
121 (85 3) /Preparations for burning/Permission, permits
122 (90) /Prevention, suppression
123 (100) /Burn with care
124 (150) /Reciprocity
125 (153) /Risks, dangers
126 (155) /Fire break
127 (160) /Without fire
128 (180) /An interesting fire story
129 (190) /Pretty view

Appendix 3.E. Representative Participant Responses to Topics in the Semi-structured Individual Interviews

3.E.1. Proposition 1.a. Producers do not burn mindlessly or indiscriminately; they purposely manipulate a variety of fire variables to accomplish specific goals.

Learning How to Conduct Controlled Burns

Investigator: "Who is your teacher when you learn how to do a burn?”
Participant A1-HEE25: "The fathers and those in the group of partners who have genuine experience.”

Investigator: "Who is your teacher in burning?”
Participant M4-LCR17: "My father, my grandfather.”

Participant A4-LHR10: "My father worked in that (burning), making the cornfield; and I learned everything about it there.”

Participant J4-LYR18: "Well, in my life only from the community.”

Participant M2-LDR15: "My father and the older men in the community. They taught us.”

Investigator: "When does a person learn to use fire?”
Participant J2-LTE12: "I think it is when their fathers or their grandfathers teach them.”

Investigator: "In the traditional system, how old is a young man before his first burn?”
Participant M2-HMR29: "Here’s what happens: I have my 12-year old son and I already take him to do a burn with me.”
Investigator: *"With you?"*
Participant M2-HMR29: "Yes, with the fathers or also he goes with the group, because at the age of 12 they can understand this business about fire; and they aren’t very little anymore.”

The Decision to Burn, Permits and Responsibility

Investigator: “Who decides when to burn the pine forest?”
Participant A4-LHR10: “The owner of the parcel decides when to burn.”

Investigator: “For a parcel, who makes the decision when there will be a burn?"
Participant J3-LAR14: “The owner of the parcel.”

Investigator: “There are parcels owned by the community in general, right? In this case, who decides?"
Participant J3-LAR14: “The assembly decides it.”

Investigator: “In the ejido there are family parcels and ejido parcels. For a family parcel, who decides when there will be a burn?"
Participant M1-LUE1: “The owner and everyone in the ejido so we can assist him."

Fire Management in Milpas and Potreros (Tame Pastures)

Investigator: “And before your father?”
Participant A4-LHR10: "And before my father, the people worked in agriculture like now; and obviously they had to burn to get rid of all the trash (stubble) and to be able to plant.”

Investigator: "What is the purpose of starting a fire? One is to control the fuels . . .”
Participant M4-LCR17: "To get rid of the weeds from the land and in the potreros so that the animals have good pasture grass to eat.”

Investigator: “When the producers use fire, what is their motive?”
Participant J3-HGR33: “Because at times they burn their potreros for the pasture and when the rain greens up the grass; and in the cornfield because there shouldn’t be brush but (rather) pure soil.”

Investigator: “So then it is possible that the sheep or cows control the level of fuels, so is there another reason to use fire? (You mentioned) with fire the land is more clean?"
Participant A3-LIR8: “Yes, indeed, yes."
Investigator: “To clean against . . .”
Participant A3-LIR8: "To clean against bad herbs, for example, thorns, and also to reduce the ticks a little, or it would be that when a lot of fuel (accumulates) it can produce bad snakes."

Investigator: “Are there different months for burning different parts of the land? Is fire in the milpa during a different month than fire in the pine forest?"
Participant M2-LDR15: "Yes, very different. To burn at the sowing time in the cornfield . . . when you are going to have to burn the corn stalks, you can burn the corn although the wind is strong* and nothing (bad) will happen. You can't burn in the pines in this way because, yes, you can make a big wildfire in the forest."

*Author's note: Underlying the remarks of Participant M2-LDR15, above, is that the weather is generally windy at corn sowing time, in March or April. Typically the producers wait until May or June to burn the pine forest when, among other things, there is less wind.

3.E.2. Proposition 1.b. Producers do not see fire escapes as unexplainable but rather they have in mind a suite of contributing factors.

"Good" Fires and "Bad" Fires

Investigator: “Are there good fires and bad fires?”
Participant M1-HCE21: “Yes, because the good fire is the controlled fire and the bad is provoked (arson).”

Investigator: “Are there good fires and others bad?”
Participant M2-LDR15: “Yes, there are bad fires because bad fires you light the fire and it goes burning everything without control; and the good fire you work it and it is going to burn in a way that doesn’t burn the trees – that is what you can call a good fire and the bad is one that goes outside of the forest."

Investigator: “Are there good fires and bad fires?”
Participant A4-LHR10: “Clearly so, the biggest are where the fuels are more thick; that is to say the dry leaves and (pine) needles. The good ones are where there are less dry leaves and needles, where it burns more slowly; and where there are more fuels the flames are taller.”

Investigator: “Are there good fires and others bad?”
Participant M3-LFR16: “Yes, there would have to be, so the good are the ones that are done with a determined purpose so that you want it. If I want to make a fire to maintain my vegetation, not run the risk that it burns me in a moment less suitable, it is better for me to do it with certain practices and wisdom and my forest doesn’t have to change. And the bad fire is when my forest is not burned and a fire arrives that is out of control, which would destroy my forest. It would lower the fuel; but it is another thing to reduce the fuel and not to run the risk of destroying my forest.”

The Pine Forest without Fire

Investigator: “If there are no fires in the forests for many years, are there problems?”
Participant A4-LHR10: “Yes because there are a lot of fuels, so then when the fire ignites, it burns too much and it dries the trees.”
Investigator: “So then it (to burn) is a technique to control the level of the fuels?”
Participant A4-LHR10: “Exactly.”

Investigator: “¿What happens in the pine forest if it goes without fire for many years?”
Participant M4-LCR17: “Everything is fine only that the leaf litter is going to accumulate more and more and when a little bit of fire arrives it destroys everything.”

Investigator: “What would happen in the forest if there wasn’t any fire?”
Participant J1-LZR7: “It would be green, well taken care of, if no fire entered the forest.”
Investigator: “¿The forest would be good for 20 years?”
Participant J1-LZR7: *“I think so.”*

3.E.3. Proposition 1.c. Producers do not urn in any kind of weather, but rather they proactively burn on days that have specific weather that they consider conducive to traditional burning. They also choose specific seasons, times of day, and conditions related to moisture.

Investigator: "Ecologically, are mild fires the same as strong ones?"
Participant M2-HMR29: "No, they are distinct, because the strong fire is one that starts in March or April, because that is when everything is dry and the fire burns very rapidly, until the land stays burning inside. And the good fire is one that doesn't mistreat the plants and it stays controlled. That is when it burns after it has rained a little in May or June. For example, today it rained heavily and we are waiting for it to dry. Tomorrow if it doesn't rain we can burn and nothing will light except the top (surface) of the fuels and the fire won't carry. It will burn over the top and if we excavate a little it is wet below and not much happens. It doesn't burn the trees, either big or little. And in March and April it burns everything that is there, because everything is dry. So that is our custom, to carry out the burns when it is moist . . ."

3.E.4. Proposition 1.d. Producers do not desire just any kind of fire behavior, but rather they manipulate a suite of fire variables in order to produce specific fire characteristics.

Factors that Influence Fire Behavior

Investigator: “Does the wind have some affect on the fire?"
Participant J1-LZR7: "Yes because at times the wind gets strong and the fire follows according to the wind."

Investigator: "About how tall should the grass be for a burn, or doesn't the height matter?"
Participant A1-LGR3: “It should be burned when it (the grass) is some 10 or 15 centimeters, because if it is very small, it won't burn."

Investigator: “So, can you burn with taller fuels?"
Participant A1-LGR3: “Yes you can, but when the fuel measures, say, one or one and a half meters the fire is very tall, arriving at five or six meters . . ."

Investigator: “Is it possible to control the flames when they are that tall?"
Participant A1-LGR3: “No, because the heat arrives at about 10 or 15 meters."

3.E.6. Proposition 1.f. Producers have particular field practices they use to accomplish traditional burning.

The Firebreak

Investigator: "How do you control the fire?”
Participant M4-LCR17: "Our custom is to use a fire break, depending on how the terrain is. If we are going to burn the whole area, we make it around the whole area."

Investigator: "How do they control the fire once it is lit?"
Participant: A2-LWE9: "With pumps, fire breaks. They make fire breaks on the land so nothing happens."

Investigator: "How do you control the fire so it doesn't burn the pines?"
Participant J3-HGR33: "They make fire breaks and in this way the fire doesn't leave."

Participant A4-HOR23: (drawing a diagram of a parcel in the dirt)"We put the fire break here. When the fire advances up to the break it stops here. This is the way be burn here."
Investigator: "Do you have enough fire breaks?"
Participant A4-HOR23: "Yes, we have, three meters wide around our (ejido) border."

Size of the Group Participating in the Burn

Investigator: "How many people participate in a burn?
Participant A4-LHR10: “Depending on how many people can help, we will have 15 or 16 people together. At times we will have 25 ejidatarios (registered owners of the ejido) and everyone goes, some pobladores (settlers, non owners in the community) also accompany us."

Investigator: “How many men help with a burning a parcel?"
Participant A1-LXE4: "If it's a big area, there are a lot of people that help; and if it is a little parcel, a few people come."
Investigator: “For example, for 10 hectares, how many men help?"
Participant A1-LXE4: "Some 20 or 15 who want to go, because it is voluntary that the people help their companions."
Investigator: “But 20 is a lot of men."
Participant A1-LXE4: “Yes, there are many, but here we never burn that many hectares. Here we burn in (smaller) pieces."
Investigator: “And for three hectares, how many men help?"
Participant A1-LXE4: *“Some 10 men.”*

Investigator: “How many men participate in a burn?"
Participant A5-HQR28: "Here we see like, living in the community, like thirty, twenty-five, more or less."

Ignition: Design and Methods of Ignition, Roles of Men and Women.

Investigator: “Here is a parcel.” (Making a sketch in the dirt.)
Participant A3-HPR27: “Uh-huh, a parcel, so then we are going to see where the air is from, similar to as it is now, we are going to start a strip of fire here. Here is the edge (drawing), we are going to start the fire here."

Investigator: “Ah, little by little.”
Participant A3-HPR27: “Yes, little by little, the fire (strips) are close together. Now here is the fireman with the backpack pump. So then the path is already lit here, now the other little strip goes here, considering the flames are going to be 40-50 centimeters

high. Okay, here I already finished the strip and here goes the other strip here, and when I finish this strip I light another strip.

Investigator: "The slope of the land is important?"
Participant: A4-HOR23: "Yes, we can't set fire from below because the flames are taller. The fire should begin to be set from the top so the fire will come slowly. After the fire has advanced about four to five meters already we can extinguish it."

Investigator: "So the fire starts at the top of the hill?"
Participant A4-HOR23: "Yes, so that the fire comes to the bottom."
Investigator: "If there is a parcel on a slope, how do the men start the fire?"
Participant A4-HOR23: "If the fire starts on the slope like here, they should start the fire here because when they have started it here (at the bottom), the fire gains force and fans to there. And if it begins here (at the top), the fire goes little by little."
Investigator: "When the fire is secure, is it possible to spread the fire this way (uphill), or no?"

Participant M3-LFR16: "We almost always make the fire like this when the land is more even, but if it has a peak, like this, we couldn't start it in this way. We would have to bring it down until here so we don't take the risk with the slope."
Investigator: "What if there would be parts in the middle that aren't completely flat and steeper parts?"
Participant M3-LFR16: (with hand motions, describing the fire moving up and downslope) "Or if it is like that, then we do this. Or even if we include this peak here, we have ravines. A ravine here and the border here, then what we would cause is the fire to hit all of this and descend calmly there and this here."
Investigator: "And where are the igniters (people who are lighting the fire)?"
Participant M3-LFR16: "One lighter burning low all of the border and then the other lighter comes here and says to the first to help him while this is low here."

Controlling the Fire: Fire Breaks, Hand Tools, Sparks and Cleaning (Mop-up).

Investigator: "How do they control the fire after it is started?"
Participant A2-LWE9: "With backpack pumps, fire breaks. They make fire breaks on the land so the fire doesn't cross it."

Investigator: "¿Do you have experience with fire?"
Participant J4-HFR34: "Yes, because I was in the workshop and the volunteer fire brigade when they gave me a uniform. I have about for years (of experience) since I have been here.

Investigator: "I am thinking that perhaps the fire crosses the fire break."
Participant M3-HKR30: "If the wind is blowing very hard, it could be. Or in the hills, sometimes because of the fruit of the ocote."
Investigator: "The cones."
Participant M3-HKR30: "Yes the cones. They just roll down the hills. That's another risk. And just cleaning (mop-up). If we see something like a cone, just clean and make sure the fire won't continue."

Investigator: "Here in the community the men do the burning?"

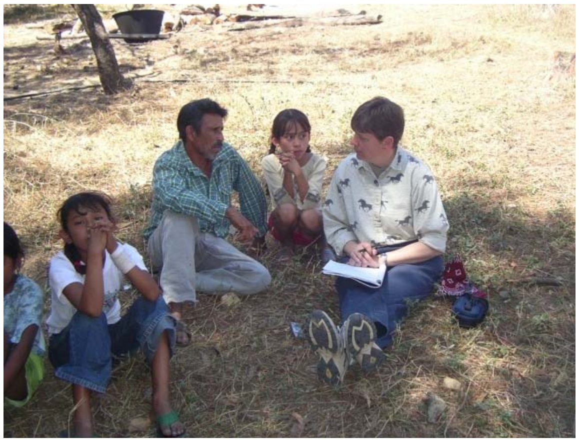
Participant from Corazón del Valle: *“Yes, the men.”*
Investigator: “And the women?”
Participant from Corazón del Valle: *“No, the women, no.”*

Investigator: “In the process of burning the forest, is it only the men, or do the women participate?"
Participant from Valle de Corzo: “Sometimes when the parcel is nearby the women carry water and the men carry the backpack pumps." (the women carry water in pails to refill the backpack pumps.)

Appendix 3.F. Photographic Record of the Project

All photographs were taken by Mary Huffman unless otherwise noted.

Part A. Sequence of trips to the study site for data collection.



February 2006: Permission from the local communities to conduct the study. Photo: José Domingo Cruz-López

May 2006: Focus groups. Photo: Jorge Carlos Pinacho-Posada

May 2006: Participant observation of prescribed burns associated with a government and NGO sponsored workshop.

March 2007: Academic committee members Monique Rocca and Dante Arturo Rodríguez-Trejo discuss fire ecology of *Pinus oocarpa* at the study site.

January 2008: Individual interviews. Photo: José Domingo Cruz-López

March 2008: Pre-burn measures of ocote pine (*Pinus oocarpa).*

May-June 2008: Pre-burn fuel removal from around ocote pine seedlings.

May-June 2008: Pre-burn measures of fuels.

May-June 2008: Measures of fire behavior. The blue line is parallel to a black metal tube on the left, which is one meter long.

May-June 2008: Hemispherical photos to measure canopy openness.

May-Jun 2008: Post-burn measures of canopy scorch and bark char on ocote pine.

November 2008: Presentation of preliminary results to the two communities and to agency stakeholders. Photo: José Domingo Cruz- López

Part B. Focus groups and individual interviews

Focus group about factors involved in local burning practices. Photo: Jorge Carlos Pinacho Posada

Focus group participants rank the importance of each factor they consider in local burning practices. Photo: Jorge Carlos Pinacho Posada

Examination of local community censuses in preparation for individual interviews.

Selection of participants for individual interviews.

Individual interview with community elder regarding factors that influence fire behavior.

Individual interviews included participants from three age groups defined by the local advisory committee: senior, mature and young.

Participant from the young age group.

Interview with participant from the senior age group.

Investigator and participant from the mature age group. Photo: José Domingo Cruz-López

Removing pine needles and debris from a fire break using a "coa."

Comisariado (elected local leader) of one community participating in an interview.

Starting a prescribed burn at the top of the burn parcel. Photo: Víctor Negrete-Paz

Part C. Local Practices and Tools for Controlled Burning.

A prepared fire break about two meters wide.

Igniting a strip across the hill where the slope is steep. Photo: Víctor Negrete-Paz

A traditional ignition tool: a dry piece of resinous ocote pine.

A community elder experimenting with a modern drip torch. Photo: Víctor Negrete-Paz

Traditional tools: a wooden rake made of a forked branch ("horqueta") and a machete.

Extinguishing the flaming bark of an ocote pine using a backpack pump. Photo: Víctor Negrete-Paz

Igniting a strip using a hand-held bunch of pine needles.

Using a backpack pump to extinguish flaming bark high on an ocote pine. Photo: Víctor Negrete-Paz

Part D. Fire Behavior

Blacksmith cutting meter-long pipes for measuring fire rate of spread.

Assistant from Pronatura-Sur and the investigator preparing to take measurements of weather and fire behavior. Photo: Víctor Negrete-Paz

Local assistants taking video footage of fire behavior during a controlled burn.

Measures of three basic factors of fire behavior: fire type, flame length and rate of spread.


Typical low intensity fire behavior resulting from burning down slope and against the wind.


Frequently, the cones of ocote pine ignite and roll downslope, starting new fires below the main line of fire.


Burning at night helps to keep fire intensity low and it permits the local crew to see sparks in order to avoid fire escapes.


Differences in fire behavior according to topography. The shorter flames are burning downward into a small draw, whereas the flames near the blue arrow are burning up the side of the draw.


Crew member patrolling the fire break with a backpack pump during a night burn.

Appendix 3.G. Factors of Fire Reported in Other Studies of Traditional Fire Knowledge from Four Regions of the Globe.

Table 3.I.1. Factors of fire used by indigenous and local people reported in studies of traditional fire knowledge (TFK) in Africa.

	GEOGRAPHIC REGION: AFRICA							
Study author and date	Hough (1993)	Eriksen (2007)	Laris (2002)	Mbow et al.(2000)	Butz (2009)	Kull (2002)	Africa composite	Percent of authors reporting each factor
Country/Area	West Africa	Zambia	Mali	Senegal	Tanzania	Madagascar		
Ecosystems represented	Savanna and woodland	Savanna	Savanna and woodland		Savanna			
Geology/Topography								
Geologic substrate/landform								
Elevation								
Soil type, moisture			X	X			X	33
Soil temperature						X	X	17
Water level								
Slope						X	X	17
Aspect						X	X	17
Vegetation/Fuels								
Consumption: degree/speed/patchiness						X	X	17
Moisture of live or dead fuels		X	X	X	X	X	X	83
Fuel load		X			X		X	33

	GEOGRAPHIC REGION: AFRICA							
Study author and date	Hough (1993)	Eriksen (2007)	Laris (2002)	Mbow et al.(2000)	Butz (2009)	Kull (2002)	Africa composite	Percent of authors reporting each factor
Plant phenology			X	X	X	X	X	67
Fuel composition/ species					X		X	17
Fuel/vegetation structure, arrangement, continuity, height				X			X	17
Fuel diameter or size (logs vs. grass)						X	X	17
Vegetation type				X			X	17
Weather								
Humidity of air/ day					X	X	X	33
Onset/end of rainy season, timing of rain						X	X	17
Season	X	X	X	X	X	X	X	100
Wind speed/force		X			X	X	X	50
Water level								
Quantity of rain					X		X	17
Temperature					X	X	X	33
Wind direction/ source						X	X	17
Lightning								
Phase of moon								
Sun's force and position in sky								
Snow location/ snow melt								
Fire Behavior								
Backing/heading fire		X				X	X	33
Fire size/area/aerial extent					X		X	17
Flame height								
Rate of spread						X	X	17
Fire type (surface, ground, canopy)						X	X	17
Fire intensity (hot or cool fire)	X	X		X	X	X	X	83
Frequency/ return interval					X	X	X	33
Residence time								
Direction of fire spread						X	X	17
Natural extinguishment								

	GEOGRAPHIC REGION: AFRICA							
Study author and date	Hough (1993)	Eriksen (2007)	Laris (2002)	Mbow et al.(2000)	Butz (2009)	Kull (2002)	Africa composite	Percent of authors reporting each factor
Scorch height								
Evenness, smoothness								
Operations								
Time of day					X	X	X	33
Firebreaks		X			X	X	X	50
Control		X		X	X	X	X	67
Spatio-temporal sequence of fires, incl. for prevention						X	X	17
Authority/decision to burn		X			X		X	33
Age of participants								
Gender						X	X	17
Crew size					X	X	X	33
Planning								
Tools for prep/ignition/control						X	X	17
Ignition pattern						X	X	17
Knowledge transmission						X	X	17
Danger/ risk				X			X	17
Fire placement				X			X	17
Other								
Fire effects on animals	X	X		X	X	X	X	83
Fire effects on vegetation	X	X	X	X		X	X	83
Fire effects on soil		X				X	X	33
Fire effects on watershed/water delivery						X	X	17
Effects of smoke (desirable)								
Consequences of not burning			X	X	X	X	X	67
Landscape pattern / Patch size			X		X	X	X	50
Caring for the land, clean up country, controlling our space								
Areas prohibited from burning (custom, sacred, other)								

	GEOGRAPHIC REGION: AFRICA							
Study author and date	Hough (1993)	Eriksen (2007)	Laris (2002)	Mbow et al.(2000)	Butz (2009)	Kull (2002)	Africa composite	Percent of authors reporting each factor
Regulatory								
Burning illegal by government			X		X	X	X	50
Burning regulated by government				X		X	X	33
Burning regulated by community								
Number of fire factors reported	**4**	**12**	**8**	**14**	**21**	**36**	**46**	

Table 3.I.2. Factors of fire used by indigenous and local people reported in studies of traditional fire knowledge (TFK) in Australia.

	GEOGRAPHIC REGION: AUSTRALIA						
Study author and date	Haynes (1985)	Hill et al. (1999)	Garde et al.(2009)	Russell-Smith et al.(1997)	Yibaruk et al. (2001)	Australia composite	Percent of authors reporting each factor
Country	Australia	Australia	Australia	Australia	Australia		
Ecosystems represented	Floodplain, woodland, open forest and closed forest	Seaside, moist forest, open forest	Various	Various	Various		
Geology/Topography							
Geologic substrate/landform		X	X	X		X	60
Elevation			X		X	X	40
Soil type, moisture			X	X		X	40
Soil temperature							0
Water level			X			X	20
Slope			X			X	20
Aspect							
Vegetation/Fuels							
Consumption: degree/speed/patchiness	X		X			X	40
Moisture of live or dead fuels		X	X	X	X	X	80
Fuel load		X	X	X	X	X	80
Plant phenology	X		X	X	X	X	80
Fuel composition/ species	X	X	X	X		X	80
Fuel/vegetation structure, arrangement, continuity, height		X	X			X	40
Fuel diameter or size (logs vs. grass)							
Vegetation type	X					X	20
Weather							
Humidity of air/ day			X	X		X	40

	GEOGRAPHIC REGION: AUSTRALIA						
Study author and date	Haynes (1985)	Hill et al. (1999)	Garde et al.(2009)	Russell-Smith et al.(1997)	Yibaruk et al. (2001)	Australia composite	Percent of authors reporting each factor
Onset/end of rainy season, timing of rain	X		X		X	X	60
Season	X	X	X	X	X	X	100
Wind speed/force		X	X	X		X	60
Water level			X	X		X	40
Quantity of rain			X	X		X	40
Temperature			X	X		X	40
Wind direction/ source			X	X		X	40
Lightning				X		X	20
Phase of moon							
Sun's force and position in sky			X			X	20
Snow location/ snow melt							
Fire Behavior							
Backing/heading fire			X	X		X	40
Fire size/area/aerial extent	X	X	X		X	X	80
Flame height	X		X	X		X	60
Rate of spread			X	X		X	40
Fire type (surface, ground, canopy)	X	X	X	X		X	80
Fire intensity (hot or cool fire)	X	X	X		X	X	80
Frequency/ return interval	X		X			X	40
Residence time							
Direction of fire spread			X			X	20
Natural extinguishment	X					X	20
Scorch height	X					X	20
Evenness, smoothness							
Operations							
Time of day	X		X	X		X	60
Firebreaks	X	X	X	X		X	80
Control	X	X	X	X	X	X	100
Spatio-temporal sequence of fires, incl. for prevention	X		X			X	40

	GEOGRAPHIC REGION: AUSTRALIA						
Study author and date	Haynes (1985)	Hill et al. (1999)	Garde et al.(2009)	Russell-Smith et al.(1997)	Yibaruk et al. (2001)	Australia composite	Percent of authors reporting each factor
Authority/decision to burn	X	X				X	40
Age of participants		X				X	20
Gender		X	X	X		X	60
Crew size		X	X			X	40
Planning			X		X	X	40
Tools for prep/ignition/control	X	X	X			X	60
Ignition pattern	X	X	X			X	60
Knowledge transmission		X	X			X	40
Danger/ risk		X	X			X	40
Fire placement	X					X	20
Other							
Fire effects on animals	X	X	X	X	X	X	100
Fire effects on vegetation	X	X	X	X	X	X	100
Fire effects on soil			X			X	20
Fire effects on watershed/water delivery							
Effects of smoke (desirable)							
Consequences of not burning		X	X	X	X	X	80
Landscape pattern / Patch size	X	X	X	X	X	X	100
Caring for the land, clean up country, controlling our space	X					X	20
Areas prohibited from burning (custom, sacred, other)	X					X	20
Regulatory							
Burning illegal by government							
Burning regulated by government		X				X	20
Burning regulated by community		X	X			X	40
Number of fire factors reported	**26**	**26**	**45**	**26**	**14**	**55**	

Table 3.I.3. Factors of fire used by indigenous and local people reported in studies of traditional fire knowledge (TFK) in the United States and Canada.

	GEOGRAPHIC REGION: US AND CANADA					
Study author and date	Lake (2007)	Stewart et al. (2002)	Lewis and Ferguson (1988)	Anderson (2005)	US & Canada composite	Percent of authors reporting each factor
Country	USA	USA	Canada	USA		
Ecosystems represented	Riparian areas	Various	Boreal forest	Grassland, shrubland, forest		
Geology/Topography						
Geologic substrate/landform	X	X	X		X	75
Elevation	X			X	X	50
Soil type, moisture	X	X	X		X	75
Soil temperature						
Water level	X		X		X	50
Slope	X			X	X	50
Aspect	X				X	25
Vegetation/Fuels						
Consumption: degree/speed/patchiness	X				X	25
Moisture of live or dead fuels	X	X	X	X	X	100
Fuel load	X		X	X	X	75
Plant phenology	X	X		X	X	75
Fuel composition/ species	X	X	X	X	X	100
Fuel/vegetation structure, arrangement, continuity, height	X	X	X	X	X	100
Fuel diameter or size (logs vs. grass)	X		X		X	50
Vegetation type	X				X	25
Weather						
Humidity of air/ day						
Onset/end of rainy season, timing of rain	X	X		X	X	75

	GEOGRAPHIC REGION: US AND CANADA					
Study author and date	Lake (2007)	Stewart et al. (2002)	Lewis and Ferguson (1988)	Anderson (2005)	US & Canada composite	Percent of authors reporting each factor
Season	X	X	X	X	X	100
Wind speed/force				X	X	25
Water level			X		X	25
Quantity of rain	X				X	25
Temperature	X				X	25
Wind direction/ source	X			X	X	50
Lightning	X				X	25
Phase of moon						
Sun's force and position in sky						
Snow location/ snow melt	X	X	X	X	X	100
Fire Behavior						
Backing/heading fire				X	X	25
Fire size/area/aerial extent	X				X	25
Flame height						
Rate of spread			X		X	25
Fire type (surface, ground, canopy)	X			X	X	50
Fire intensity (hot or cool fire)	X				X	25
Frequency/ return interval	X	X		X	X	75
Residence time			X		X	25
Direction of fire spread		X			X	25
Natural extinguishment	X	X			X	50
Scorch height						
Evenness, smoothness						
Operations						
Time of day	X				X	25
Firebreaks	X			X	X	50
Control				X	X	25
Spatio-temporal sequence of fires, incl. for prevention						
Authority/decision to burn						

	GEOGRAPHIC REGION: US AND CANADA					
Study author and date	Lake (2007)	Stewart et al. (2002)	Lewis and Ferguson (1988)	Anderson (2005)	US & Canada composite	Percent of authors reporting each factor
Age of participants			X		X	25
Gender	X			X	X	50
Crew size		X		X	X	50
Planning						
Tools for prep/ignition/control	X	X		X	X	75
Ignition pattern		X		X	X	50
Knowledge transmission	X			X	X	50
Danger/ risk			X		X	25
Fire placement	X				X	25
Other						
Fire effects on animals	X	X	X	X	X	100
Fire effects on vegetation	X	X	X	X	X	100
Fire effects on soil	X			X	X	50
Fire effects on watershed/water delivery						
Effects of smoke (desirable)	X				X	25
Consequences of not burning	X			X	X	50
Landscape pattern / Patch size			X		X	25
Caring for the land, clean up country, controlling our space	X				X	25
Areas prohibited from burning (custom, sacred, other)						
Regulatory						
Burning illegal by government	X		X		X	50
Burning regulated by government	X				X	25
Burning regulated by community						
Number of fire factors reported	**40**	**17**	**19**	**26**	**52**	

Table 3.I.4. Factors of fire used by indigenous and local people reported in studies of traditional fire knowledge (TFK) in Latin America.

	GEOGRAPHIC REGION: LATIN AMERICA						
Study author and date	Otterstrom 2004	McDaniel et al. 2005	Mistry et al. 2005	Reina 1967	Cabrera-Garcia and Frias 2004	Latin America composite	Percent of authors reporting each factor
Country	Nicaragua	Bolivia	Brazil	Guatemala	Mexico		
Ecosystems represented	Dry tropical forest	Savanna	Cerrado savanna	Milpas	Grassland		
Geology/Topography							
Geologic substrate/landform							
Elevation							
Soil type, moisture		X		X		X	40
Soil temperature							
Water level							
Slope							
Aspect							
Vegetation/Fuels							
Consumption: degree/speed/patchiness	X	X	X			X	60
Moisture of live or dead fuels	X	X	X			X	60
Fuel load	X					X	20
Plant phenology			X			X	20
Fuel composition/ species		X				X	20
Fuel/vegetation structure, arrangement, continuity, height				X		X	20
Fuel diameter or size (logs vs. grass)							
Vegetation type							
Weather							

	GEOGRAPHIC REGION: LATIN AMERICA						
Study author and date	Otterstrom 2004	McDaniel et al. 2005	Mistry et al. 2005	Reina 1967	Cabrera-Garcia and Frias 2004	Latin America composite	Percent of authors reporting each factor
Humidity of air/ day	X	X			X	X	60
Onset/end of rainy season, timing of rain	X	X		X	X	X	80
Season	X	X	X	X	X	X	100
Wind speed/force	X		X		X	X	60
Water level							
Quantity of rain	X					X	20
Temperature	X					X	20
Wind direction/ source	X			X		X	40
Lightning							
Phase of moon	X		X	X		X	60
Sun's force and position in sky	X					X	20
Snow location/ snow melt							
Fire Behavior							
Backing/heading fire	X	X	X			X	60
Fire size/area/aerial extent	X	X				X	40
Flame height	X	X				X	40
Rate of spread							
Fire type (surface, ground, canopy)							
Fire intensity (hot or cool fire)	X	X	X			X	60
Frequency/ return interval	X	X	X		X	X	80
Residence time							
Direction of fire spread				X		X	20
Natural extinguishment							
Scorch height							
Evenness, smoothness					X	X	20
Operations							
Time of day	X	X	X	X		X	80
Firebreaks	X	X	X	X		X	80

	GEOGRAPHIC REGION: LATIN AMERICA						
Study author and date	Otterstrom 2004	McDaniel et al. 2005	Mistry et al. 2005	Reina 1967	Cabrera-Garcia and Frias 2004	Latin America composite	Percent of authors reporting each factor
Control	X	X	X	X		X	80
Spatio-temporal sequence of fires, incl. for prevention					X	X	20
Authority/decision to burn			X			X	20
Age of participants	X					X	20
Gender	X		X	X		X	60
Crew size	X		X			X	40
Planning	X					X	20
Tools for prep/ignition/control	X		X	X		X	60
Ignition pattern	X		X	X		X	60
Knowledge transmission			X			X	20
Danger/ risk	X					X	20
Fire placement							
Other							
Fire effects on animals	X	X	X	X		X	80
Fire effects on vegetation	X	X	X		X	X	80
Fire effects on soil	X	X	X	X	X	X	100
Fire effects on watershed/water delivery							
Effects of smoke (desirable), smoke color				X		X	20
Consequences of not burning	X	X	X		X	X	80
Landscape pattern / Patch size			X		X	X	40
Caring for the land, clean up country, controlling our space							
Areas prohibited from burning (custom, sacred, other)							
Regulatory							
Burning illegal by government							

	GEOGRAPHIC REGION: LATIN AMERICA						
Study author and date	Otterstrom 2004	McDaniel et al. 2005	Mistry et al. 2005	Reina 1967	Cabrera-Garcia and Frias 2004	Latin America composite	Percent of authors reporting each factor
Burning regulated by government			X		X	X	40
Burning regulated by community							
Number of fire factors reported	**31**	**19**	**24**	**16**	**12**	**43**	**43**

Appendix 3.H. Qualitative Project Evaluation

I reviewed the project and solicited feedback from stakeholders in five ways:

- presentations of preliminary results
- meeting with the advisory committee
- written feedback from CONANP and a key informant
- written and verbal interaction with the academic committee
- self-reflection and evaluation

In November of 2008 I made four presentations using PowerPoint software to solicit local feedback about our preliminary results. First I gave separate presentations to the general assemblies of both ejidos (including members of the advisory committee). A few government representatives from CONANP and the State of Chiapas attended these presentations on site at the ejidos.

After the two local presentations, I presented a similar program at CONANP's offices in the city of Tuxtla Gutiérrez. There the audience included personnel from CONANP and their invited guests from the following government agencies and NGOs: Comisión Nacional Forestal (CONAFOR), Comisión Forestal Sostenible del Estado de Chiapas (COFOSECH), Universidad Autónoma de Chiapas (UNACH), The Nature Conservancy (TNC), Pronatura-Sur, and the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP).

After the CONANP presentation, I traveled to San Cristóbal de las Casas to present results and to obtain feedback from the staff of the NGO Pronatura-Sur, A.C. I made a final presentation in Mexico City for representatives of the Fondo Mexicano para la Conservación de la Naturaleza (FMCN).

At each location our presentation of preliminary results was appreciated; and I received valuable advice. Community members from Valle de Corzo suggested adding two factors that influence local fire behavior: sparks and the density of the forest canopy. One suggestion from a Pronatura-Sur staff member was to clarify the difference between knowledge and beliefs, and the ways that each controls local fire practices. Another Pronatura-Sur staff member cautioned that the photographs of the two forests, one green and one scorched (Figure 6), may have elicited biased responses according to what participants thought the researcher wanted to hear. A representative from INIFAP wanted to see the statistical analysis of interview results. A representative from The Nature Conservancy offered to provide more information about the ranges of weather conditions that producers commonly use for controlled burning in the region.

I held one last meeting of the advisory committee to solicit feedback regarding the project and to ask for suggestions as to how to best share project results with members of the community. The committee indicated that the project was worthwhile, and that the project results were useful. We discussed a plan for sharing results with community members who cannot read.

I also asked two key informants to provide written feedback according to a set of written questions. Their responses, as well as the evaluation of the field researcher, are provided below, and translated from Spanish.

1. Was the level of participation of stakeholders sufficient?

Key Informant A: "My personal opinion is that the participation of the producers was sufficient and concrete. I have observed that they are happy with the results that have been obtained."

Key Informant B: "Yes it was sufficient, since they knew the details of the project since the beginning, as was the case for CONAFOR, COFOSECH, Municipality of Cintalapa, CONANP, PRONATURA and the landowners of members of Corazón del Valle y Valle de Corzo."

2. Were the methods of investigation appropriate and useful?

Key Informant A: "I think that the methodology that you applied in this investigation was appropriate since it was also assimilated by the producers, who supported and responded to them in the investigation. It is a shame that they themselves have not involved more producers in this process of investigation."

Key Informant B: "I consider them useful and appropriate, since they also permitted the ejido members to know the objectives and hypothesis of the project."

3. Did the project apply well to the fire situation at the reserve?

Key Informant A: "With the preliminary results that you presented, we observe that there is a lot of important information that is very useful for us at the Reserve, and that all of this is documented through this process of investigation."

Key Informant B: "Totally, since the results are and will be applicable to the theme of the fire in the Reserve, which is the principal risk factor to the forests and jungles, moreover being one of the main elements chiefly used by the rural producers of the reserve."

4. What were the strengths and weaknesses of the project?

Key Informant A: “The strengths of the project would be the ability of the communities to take advantage of the programmed activities, and the accompaniment of CONANP and the reserve staff at certain times. My personal opinion is that one of the weaknesses in the execution of the project was the small participation of the producers, the short schedule for development of the activities and the constant accompaniment of the personnel of the Reserve. "

Key Informant B: "The strengths were that there wasn't any information on the theme; it was a new project in the zone, both in the municipality (county) and in the State of Chiapas. Moreover, it had the endorsement of The Nature Conservancy and the associates of CONANP and PRONATURA. The weaknesses were because of the language; perhaps a translator was required to facilitate the work of the student and that the producers to know more."

5. What advice or suggestions do you have about the project?

Key Informant A: "A suggestion: Organize teams of work to induce the producers to greater participation and to involve them in more project work. Devise prescribed burn plans for each burn that producers carried out and cover the corresponding legal part (NOM 015 SEMARNAT/SAGARPA 1997)." Authors' note: I view prescribed burn planning and permitting as the purview of the landowners, not the researcher.

Key Informant B: "Present the results as soon as they are concluded. To me, the project seemed excellent because it allowed us to systematize information from the producers about the theme of fire management from the local perspective."

My individual opinion as the field investigator is that the support of the local communities, the reserve staff and the local NGO was crucial to conducting the project. The project methods worked well, especially the combination of group and individual interviews. With a foreign researcher, the multiple time periods of field work were important to gaining the trust of the local participants. Living in the community in the home of a well-respected family during the field visits also helped.

In the case of a foreign speaker with limited Spanish, it might be worth considering spending fewer but longer periods of time at the study site. This would improve the researcher's language skills and reduce travel expenses. However, I am not sure that this would be convenient for the schedules of the local communities or the family that generously provided me room, board and daily guidance.

Using a combination of focus groups and individual interviews seemed effective. The role of the 14 field assistants was very important in sharing the research questions and the methods of the study throughout both communities. Most of the field assistants were young people who had time to help. I agree with the opinion of one of the key informants that, although their time is more occupied, involving the older producers more in daily project activities would be useful.

I am grateful for the guidance of the advisory committee for shaping the participatory methods that I used in this study. I am pleased with the effectiveness of the combination of preliminary focus groups followed by individual interviews. Filming fire behavior was straight-forward for participants, including those who had never operated a video camera. Selecting participants that have experience with fire and who thus know how to stay safe while working around fire is important.

I also believe that the multiple periods of time that I spent in both communities is an important component of the success of these methods. Finally, the participation of the 14 helpers in fire-related field work strengthened the communities’ involvement and understanding of the study.

Appendix 3.I. Recommendations for Fire Training in Mexico's Protected Natural Areas.

3.H.1. Introduction to Training Approach

The funding partner FMCN invited me to include making fire training recommendations for PNAs throughout Mexico a part of this study (J. Frausto, pers.com., January 23, 2009, Mexico City). Accordingly, I designed the following training program that revolves around producers, their fire knowledge and their current style of learning about fire, which is different from the course work approach usually designed for natural resources managers.

Based upon my analysis of the fire system at the study site, it appears that, aside from climate, producers are controlling four primary processes that relate to fire management. These are fuel accumulation, fire ignition, fire spread and fire extinguishment (Figure 3.F.1.). Producers and government employees are involved at every level of the national program I envisioned. It emphasizes a mentoring approach to training that is led by community elders.

A fire training program that could work well in Mexico's wide variety of Protected Natural Areas (PNAs) should come from careful answers to the following ten questions:

1. What is the mission of the managing agency, in this case CONANP, and the specific purpose of each PNA in reaching CONANP's mission?
2. How does fire fit into the agency's mission in each PNA?
3. Are the ecosystems of the PNA fire-dependent, fire-influenced, fire-sensitive or fire independent (Myers, 2006)?
4. Do the ecosystems currently need more, less or different kinds of fire?
5. Who or what controls the fuel accumulation process?

6. Who or what controls the ignition process?
7. Who or what controls the fire spread process?
8. Who or what controls the extinguishment process?
9. Where do the knowledge and resources lie to alter these four processes?
10. What changes will the future probably bring to these processes?

For purposes of illustration, I will assume that in each ecosystem there are government representatives, researchers and local residents that can provide suitable answers to questions one through four. I will focus my recommendations on how to use questions five through ten as a new method to analyze fire problems and pinpoint fire training needs at the site level (Figure 3.15 repeated below). At first this process will seem laborious, but if used diligently, it will ensure that training is properly targeted for maximum effectiveness. I will use the pine-oak forests at La Sepultura Reserve as my example, since that is ecosystem and the PNA I know best.

5. Who or what controls the fuel accumulation process? Answer: The tropical climate, ranchers and ejidatarios (producers).

At La Sepultura Biosphere Reserve, fuels naturally accumulate quickly as a result of the tropical climate, including generous amounts of rainfall in the wet season. The fuel bed in the pine-oak forests is dominated by grasses and needle drop from ocote pines *(Pinus oocarpa)*.

Ocote pines produce new needles annually and shed the previous year's growth in the spring before the arrival of the rainy season. Pine stand density and age control the volume and distribution of needles that grow and fall each year. Once fallen, needles remain on the ground for several years (perhaps 4-6) years, decaying slowly. Frequent controlled burning, every 3-6 years, is a dominant method of reducing pine needle accumulation. Where landowners neglect burning or grazing, fuels accumulate to depths of 30 centimeters or more.

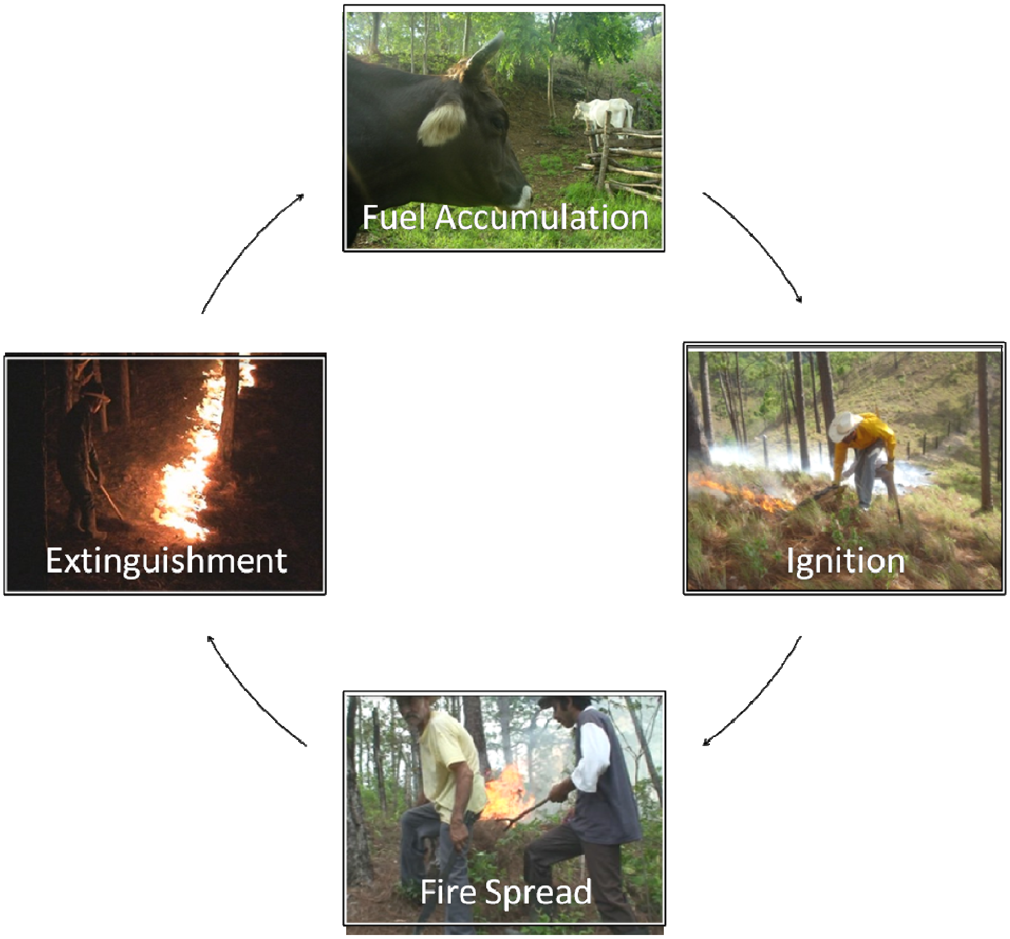


Figure 3.H.1. Four processes that producers manipulate at La Sepultura Biosphere Reserve that influence the fire regime.

Grass fuels accumulate rapidly each year during the wet season. On most properties, grass fuels are reduced by periodic grazing. The amount and timing of grazing (the grazing regime) is determined by each landowner, parcel by parcel. In the two ejidos that I studied, forest parcels are small, usually less than 10 ha in size. As such, the accumulation of grass fuels in these ejidos is a patchwork of higher and lower fuels, according to the livestock management program in each of the parcels. In this way, the accumulation of grass fuels is variable, whereas the accumulation of pine needles is steadier.

In summary, rapid growth of pine needles and grasses, plus producers, control the fuel accumulation process in the pine forests at La Sepultura.

6. Who or what controls the ignition process? Answer: Spring dry season, producers.

Nearly all fires at La Sepultura are human-caused. Although lightning does occur, it rarely ignites fires because it is usually accompanied by plenty of rain. Both arson and agricultural activities are sources of fires. Arson fires result from illicit activities such as illegal hunting or marijuana growing, and from land disputes. Carelessly tossed cigarette butts or other accidental ignitions also occur.

Burning for legitimate agricultural purposes is widespread from the month of March through the onset of the rainy season in May or early June. Milpas and potreros are burned earlier (March and April), while pine forests are burned after the arrival of the first few rains. Producers who depend upon fire for successful crops and timber management generally frown upon arson fires.

According to the 2007 agricultural census, there are more than 500,000 Mexican citizens involved in agriculture in the State of Chiapas (INEGI 2007). If ten percent of these citizens use fire in any given year, this would equal 50,000 ignitions.

7. Who or what controls the fire spread process? Answer: Annual dry season weather, drought, topography, natural and manmade fire breaks, ignition pattern.

As a matter of physics, regardless of ignition source, fires spread through fuels when the conditions are favorable for combustion. At La Sepultura, fires are most prone to spread during the height of the dry season in March and April when temperatures are high, fuel moisture is low and winds are gusty. For controlled burns, producers typically wait until the maritime weather pattern starts bringing in weather from over the Pacific ocean. Winds are less gusty, relative humidity is higher and rain is more common in this pattern. As witnessed in 1998, drought driven by El Niño and La Niña can be a major contributor to fire spread.

The variable topography and steep slopes of the pine forests also control fire spread. When uncontrolled fires burn, they spread with greater speed and intensity upslope, then burn with moderation going downslope. Moist gallery forests along streambeds tend to discourage fire spread and serve as natural fire breaks. In years with normal moisture conditions, humid vegetation and leaf litter in high elevation cloud forests also deter fire spread.

When controlled burning is planned, producers install fire breaks employ ignition tactics to limit fire spread. Ejidatarios also sometimes install a larger firebreak around the borders of their ejido to limit fires from traveling either into or out of the ejido. Parcels are typically ignited at the tops of hills and burn downward, sometimes with the aid of burning in narrow strips across slopes. Pine cones on the ground sometimes ignite and roll downhill, starting spot fires in advance of the intended line of ignition. Producers also intentionally light spot fires inside of a burn parcel to speed the fire's spread into the interior of the area while limiting fire intensity.

8. Who or what controls the extinguishment process? Answer: Rain, producers, government agencies.

Given the naturally favorable conditions for burning the pine-oak forests, including continuous flammable fuels, high temperatures, slope and wind, extinguishing fires at La Sepultura occurs mainly from rain in some months or from human efforts. Although fires are less likely to burn in the rainy season, I did participate in one controlled burn in June in which rain arrived in the late afternoon and extinguished the fire. Otherwise, human efforts, either by the landowners and their neighbors or by firefighting personnel from government agencies control the extinguishment process. When controlled fires go as planned, they are extinguished as normal part of the burning process. Fuel breaks such as manmade fire breaks or changes in vegetation assist by limiting fire spread as discussed in Question 7 above.

9. Where do the knowledge and resources lie to alter these four processes? Answer: Producers and government agencies.

Mexico's state and federal fire control agencies have professional expertise in fire prevention and control. They also have access to key technologies such as remote sensing, aviation, trucks, water tankers, pumps and personal protective equipment. However, the number of employees available on a daily basis in the vicinity of the reserve is few compared to members of the agricultural community.

Producers who often have been using fire in the pine forest since early adulthood are a locus of knowledge about fire, particularly about controlled burning. As the people who have the most influence upon fuel accumulation, fire ignition and fire spread, it makes sense to focus fire training for protected areas on this audience. Further, as people with extensive fire knowledge, it makes sense to consult producers how training should be designed and conducted. Certainly they should be involved as instructors and mentors.

10. What changes will the future probably bring to these processes? Answer: global warming and population migration.

Global warming and the movement of young people from the country into the city are two trends that will affect fire management in the future. We should design fire training programs so that future fire makers can adapt to these changes as they occur.

Global warming is projected to bring more frequent and more severe periods of El Niño driven drought throughout Mesoamerica (Magrin et al., 2007). This portends more fire ignitions, greater fire spread and greater difficulty with extinguishment. Agricultural areas including pine forests that are typically burned under control may experience more fire escapes. While producers may wish to wait through a drought for more favorable burning conditions to arise, reducing accumulating fuels and the need to prepare milpas for planting may necessitate burning even when escapes are more likely.

There are also concerns about erosion of local fire knowledge as children from agricultural areas pursue advanced education and leave the countryside to work in the cities. In the current knowledge system, sons learn controlled burning techniques from their fathers, who learned from their fathers, by working in the countryside together over extended periods of time. When children spend more years in formal schooling, sometimes traveling long distances away from home, they have less time to spend in the field learning fire management techniques. When sons move to the cities, a break in the chain of knowledge and practiced takes place.

3.H.2. Fire Training Assumptions

Based on answers to the background questions above, I make the following assumptions with regard to fire training in PNAs:

1. Except for weather, producers currently control the primary processes of fire in Mexico and will continue to do so in the foreseeable future.
2. Producers are accustomed to learning about fire in the field, little by little, through working with a mentor (father or grandfather) or other elders from the community whom they trust.
3. Protected Natural Areas (PNAs) are relatively recent in Mexico's history; and the people living in PNAs are adjusting to the involvement of government-mandated biodiversity conservation in their farming systems.
4. We should continue the current burning approach, which is designed to accomplish fire management cheaply and sustainably. Current practices rely on hand made firebreaks and careful selection of burning conditions. These tools are accompanied by low cost, low impact, readily available hand tools (e.g., matches, machetes, rakes).
5. Site-specific knowledge of the land and weather is required.
6. It takes years of practice for anyone to learn consistently successful controlled burning.

3.H.3. Organization of the Fire Training Program

Because producers control most aspects of the fire regime, and because PNAs involve cooperation between producers and government land managers, I recommend a fire training program that would be based in the agricultural populations and led by a combination of producers and government land managers. Because producers are currently learning through mentoring by their fathers, grandfathers or other fire practitioners in their communities, the program is based upon a mentoring approach.

At the national level, the training program should have an advisory team made of producers, natural areas professionals and government fire managers. Members of the advisory team should be selected for their talents in both fire and cooperation. The team should include both men and women who can, together, inform the training process from various perspectives including fire control, biodiversity conservation, agriculture, rural family life and societal trends.

While the national advisory team would set general direction and identify commonalities in the training process, each PNA should have its own site-based training program. Each PNA would have its own steering committee, similarly constituted of a combination of fire-seasoned producers and government natural resources managers. This advisory team would review the Questions 1-10 above and decide which things are most important for students in the PNA to learn. Students in the individual PNA training programs would be primarily residents from within the PNA, plus a few students from the appropriate government agencies. A cadre of teachers and mentors would be identified by the PNA advisory team and oriented to the program.

Just as government employees are paid their usual wages for conducting training, local producers who serve as instructors and mentors should be paid, also. A key aim of the mentoring approach is to make available the depth of knowledge that producers have in their minds, which is almost never written, recorded or explained in presentations. Community elders can be excellent candidates for teachers out in the field, because they may have as much as 40 or 50 years of local fire experience and they may have time to participate if they are no longer farming or ranching fulltime.

Training sessions would be based upon a field approach rather than a classroom approach, so that participants can learn outdoors on the land while walking, looking and touching, as is their custom. Each participant would have a mentor, either a family or community member with expertise in fire, or someone who is a mentor from the PNA training program. Because young people's time is valuable in farming, they would earn rewards of some kind deemed as appropriate by the families.

Over time, as field sessions were underway and local advisory teams and mentors gained experience developing each PNA training program, learning networks should be set up that would enable members to communicate with one another. Learning experiences, local knowledge, training techniques and ideas for improvement could be shared. Information exchange in these networks should not be tied to the telephone, computer or long distance travel, at least in this generation when much of the fire knowledge is held by people who do not read or have ready access to electronic communications. DVDs with photographs and narration that are formatted for home DVD players can serve as an effective communications medium.

Figure 3.H.1. shows an organizational chart for the proposed training organization. Of primary importance is involving producers at every level of the organization from the national level through the local level at each PNA. Travel expenses and compensation for producers' time invested in program development and mentoring should be included in the program budget.

3.H.4. Components of the Training Curriculum

The training curriculum would include certain basic components, but the exact contents of each site-level training session would vary. I have divided suggested training topics into six mentoring stages: walking in the woods together, observing controlled burns together, planning controlled burns, executing controlled burns, evaluating controlled burns, and walking in the woods to discuss the future of fire (Table 3.H.).

Each mentoring stage is then divided into four mentoring themes (Table B). For each mentoring theme, I have listed a series of training topics, along with simple questions that students and mentors could ask one another to draw out important information related to each subject (Table B). Answers to each question would vary by site and by mentor, but similar concepts would be addressed. The number of sessions required in each mentoring stage and curriculum theme could vary by PNA.

As an example, in the walking in the woods phase, mentors and students would simply walk together to various sites. Students would ask questions such as those posed in Table B; and mentors would share stories and information using examples from places the group visits along the walk. Other resource people could join in the walk or meet the group in the field at certain points in the lesson.

Certainly this style of learning is driven by the curiosity of the students and the ability of the mentor to share experiences and insights effectively. If desired, mentors could use portable digital audio recorders to help secure the availability of their knowledge for future generations.

Table 3.H.1. Mentoring stages and themes for each stage of the proposed fire training program.

Mentoring Stage	Mentoring Theme
1. Walking in the woods	A. Fire values, effects, goals
	B. Fire behavior
	C. Fire planning and operations
	D. Fire evaluation
2. Observing controlled burns	A. Fire values, effects, goals
	B. Fire behavior
	C. Fire planning and operations
	D. Fire evaluation
3. Planning a controlled burn	A. Fire values, effects, goals
	B. Fire behavior
	C. Fire planning and operations
	D. Fire evaluation
4. Executing a controlled burn	A. Fire values, effects, goals
	B. Fire behavior
	C. Fire planning and operations
	D. Fire evaluation
5. Evaluating controlled burns	A. Fire values, effects, goals
	B. Fire behavior
	C. Fire planning and operations
	D. Fire evaluation
6. Walking in the woods to discuss the future of fire.	A. Fire values, effects, goals
	B. Fire behavior
	C. Fire planning and operations
	D. Fire evaluation

Table 3.H.2. Sample questions to go with each mentoring theme and topic in the mentoring stages of the Protected Natural Areas fire training program.

Mentoring Theme	**Mentoring Topics**	**Sample questions to discuss for each topic**
A. Fire values, goals, effects	Fire values, perceptions	What do people around here think about fire?
	Fire effects	What does fire do to the land, plants and animals here?
	Fire values combined with effects	Is fire good, bad or both in this PNA?
	Fire goals	Why do people use?
	Fire decisions: rights, privileges and responsibilities	Who has the right to use fire? How are decisions made about what and when to burn?
B. Fire behavior: how fire works locally	Local weather	How does the weather affect fire around here?
	Local terrain	How does the form of the land affect fire here?
	Local fuels	What carries the fire?
	Local wind	What happens when the wind blows?
	Fire seasons	When do fires usually take place?
	Fire behavior	What are the flames like (height, velocity, heat)?
C. Fire planning and operations: how to plan and conduct a controlled burn	Pre-burn preparation	How do you prepare for a controlled burn?
	Burning operations	Who does what during a controlled burn? Who does what during a wildfire?
	Tools	What tools do you use and how do you maintain them?
	Safety	How do you keep from hurting yourself or anyone else?
	Communications	How does everybody know what is going on during the fire?
	Smoke	Is smoke important in this PNA? Where does the smoke go?
	Mop-up	How do you make sure the fire is out?
D. Evaluation: how to evaluate a controlled burn	Burn evaluation	How can you tell if it was a good fire or a bad fire?
	Safety	Did anyone get hurt or was anyone's property damaged?
	Signals from plants, animals, soil	What do the plants, animals and soil tell you about the fire?
	What to look for later	What should we look for later, maybe next month or next year?
	The next fire	When should we plan on burning this area again?

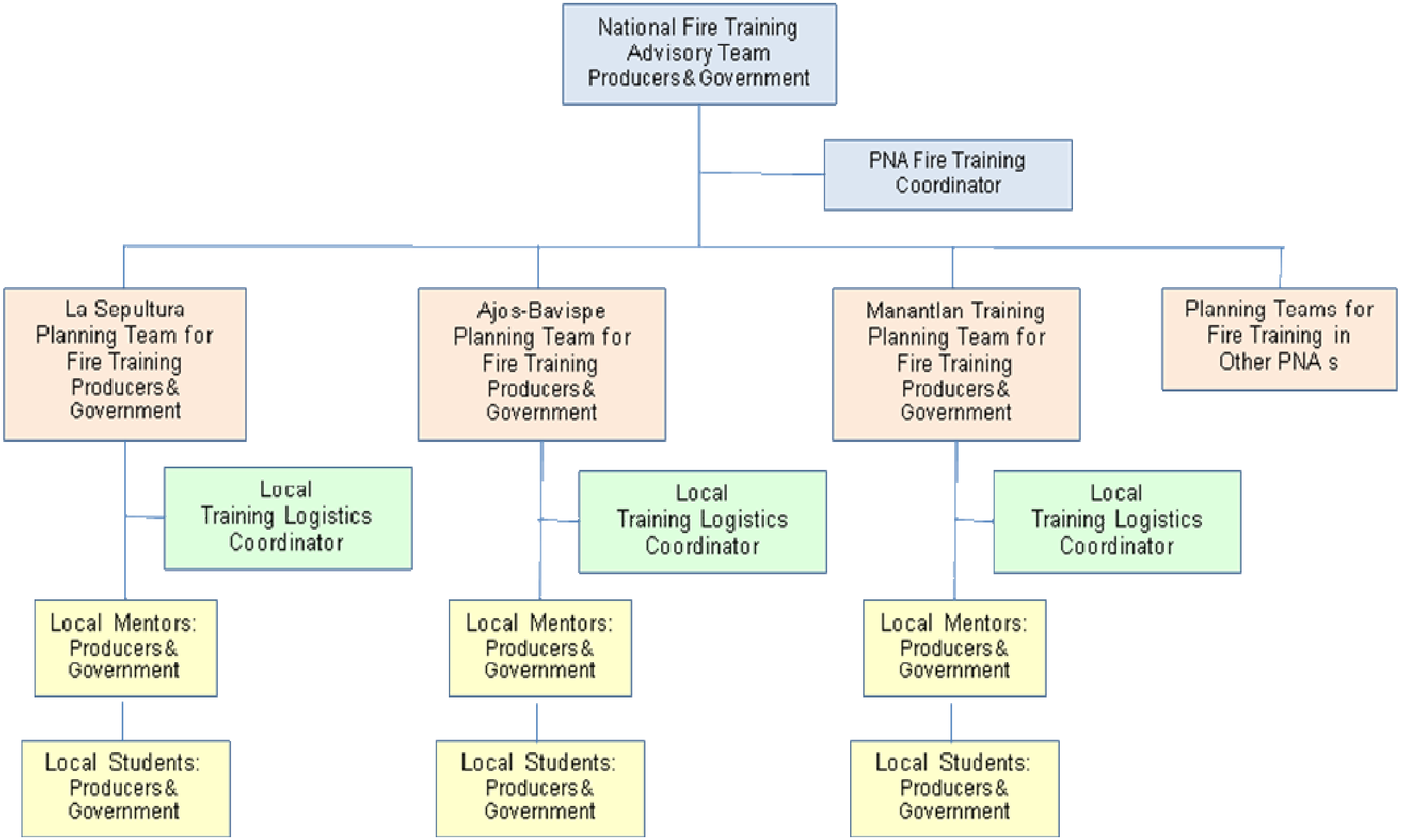


Figure 3.H.2. Organizational chart of proposed fire training program for Protected Natural Areas in Mexico. Specific PNAs are named only as examples. Of primary importance is including producers at every level of the organization.

Chapter Four: Growth Habits and Stand Characteristics of *Pinus oocarpa*

A parcel owner and his nephew walk through a *Pinus oocarpa* stand at the study site, looking for seedlings.

This chapter addresses the first hypothesis of the fourth research objective:

Objective 4. To elucidate the ecological mechanisms that affect the survival of pine seedlings as a result of traditional fire behavior.

Hypothesis 4.a. The pine forest stands have a variety of size classes, with small size classes well represented.

The purpose of this objective was to provide a basic understanding of the demographics of each stand, in order to inform the pre-burn context of each controlled burn as well as to aid my interpretation of the post-burn results.

4.1. Introduction

Local producers and protected area managers at La Sepultura share a concern that in the tropical pine-oak ecosystem, reproduction of the dominant tree species, *Pinus oocarpa*, is low due in part to the traditional land management regime of frequent, low-intensity burning. While resprouting appears to be a viable means of genetic reproduction, local producers prefer trees grown from seed, which they feel grow into stronger, straighter trees (S. Pinacho, pers.com., May 24, 2006, Corazón del Valle). The shared concern about pine reproduction coupled with this local preference for seed-grown trees inspired the following research into stand characteristics of the tropical pine-oak ecosystem within the two study communities at La Sepultura.

The tropical pine-oak ecosystem of the reserve appears as savannas, open woodlands and forests (collectively "forests") dominated by *Pinus oocarpa.* Called "ocote pine" by the local people (Figure 4.1a. and 4.1b.), *P. oocarpa's* geographic range extends from the northwestern Mexico to western Nicaragua, occurring in a variety of environmental conditions throughout Mesoamerica (Perry, 1991).

P. oocarpa is the most common pine in Mexico and Central America (Moura et al., 1998)., and in Mexico the species occurs in three varieties: *P. oocarpa* Schiede ex Schlechtendal, *P. oocarpa* var. *ochoterenae* (or *P. tecunumannii* Eguiluz et Perry) and *P. oocarpa* var. *Trifoliata*.(Myers and Rodríguez-Trejo, 2009). I do not know which of these varieties occurs at La Sepultura.

Especially in the southern part of its natural range, *P. oocarpa* forests experience frequent surface fires (Perry, 1991). Descriptions of Honduran forests in the mid-1950s provide a glimpse into the extent of these fires in the dry season.

Vogel (1954) reports:

> *Honduras seems less attractive in May when it is dry and dark from the smoke originating from the forest fires, which burn dozens of thousands of hectares, than it seems September when the grass and little green trees give it a beautiful aspect.* (Translation mine, p.88.)
>
> *During the half of the year, from January to June, the pine forests of Honduras have suffered intense fires annually, which have burned without control almost the entire area of the Central Region. The smoke fills the air to such degree in April and May that transportation by air is very risky over almost all of the Republic.* (Translation mine, p.90-91.)

Tropical pine-oak forests are fire-dependent, meaning that without fire, they undergo fundamental changes in composition and structure (Myers, 2006, Rodríguez-Trejo, 2008). Several authors indicate that without fire, tropical pine-oak forests are overtaken by broadleaf vegetation (Vogel, 1954, Myers and Rodríguez-Trejo, 2009, O'Brien et al., 2008, Allen, 1955).

P. oocarpa has several characteristics of fire adapted pines, including thick bark, self-pruning branches and the habit of regenerating well in a seedbed prepared by fire (Rodríguez-Trejo and Fulé, 2003, Perry, 1991). Ocote pine cones are generally considered serotinous (Hudson and Salazar, 1981, Rodríguez-Trejo and Fulé, 2003, Perry, 1991). Perry (1991) indicated that the high temperatures of the dry season play a role in opening ocote pine cones. At the study site, a community elder indicated that the warmth of the sun opens the cones (M. Pinacho, pers. com., July 15, 2008, Corazón del Valle). Fire is considered important to enable ocote pines to outcompete broadleaf vegetation in this ecosystem (Perry, 1991, Hudson and Salazar, 1981, Danida Forest

Seed Centre and FAO, 2001, O'Brien et al., 2009). Needle drop and other plant tissues rich in flammable compounds increase the likelihood of recurrent fires (Mutch, 1970).

Unlike other fire adapted pines that have a fire-tolerant seedling strategy to protect young regeneration (O'Brien et al., 2009) (such as the grass stage of longleaf pine (*Pinus palustris*), *P. oocarpa* seedlings are sensitive to fire and are readily destroyed by surface fires in both natural and *ex situ* stands (Perry, 1991, Danida Forest Seed Centre and FAO, 2001). Heavy grass cover is also a deterrent to seedling establishment and survival, and it contributes to the fire hazard particularly in the dry season (Danida Forest Seed Centre and FAO, 2001, Hudson and Salazar, 1981, Vogel, 1954). Young trees have the ability to resprout, which is considered an important adaptation considering seedling vulnerability to fire (Perry, 1991, Hudson and Salazar, 1981). Fire occurring at too high a frequency is considered a threat to remaining natural stands (Danida Forest Seed Centre and FAO, 2001). Hudson and Salazar (1981) report that a fire return interval of thee to six years is sufficient to support *P. oocarpa* forest regeneration, and Vogel (1954) recommended an average of five years.

In Honduras, prescribed burning was introduced to *P. oocarpa* forests to reduce fuel loads in 1979 (Hudson et al., 1983b). Although sediment loss did increase on controlled burn plots compared to controls, burning to reduce fuels was considered preferable over allowing fuels to accumulate, thereby increasing the already high risk of wildfires, which can be of high intensity (Hudson et al., 1983a, Hudson and Salazar, 1981).

As it is in other parts of Mesoamerica, ocote pine is an important forest species to local farmers (producers) who conduct subsistence agriculture within the reserve. In the two communities (ejidos) that I studied, local people use wood from the ocote pine for home construction and fuel. While oak is the preferred wood for cooking, ocote pine is used as kindling. The pine-oak forests are grazed by cattle and to a lesser extent by sheep, horses and burros. The forests provide home sites and a variety of non-timber forest products, including wildlife habitat, herbs for cooking and local medicine, and fresh air. Local producers in the study sites often express their love of the fresh air of the pine forests and their sense of responsibility for taking care of this landscape.

Reserve regulations at La Sepultura allow cutting only dead trees and do not allow commercial sale of timber or timber products from the reserve. Soon after a tree dies, local inhabitants cut it down and use the wood for home construction and fence posts (Figure 4.1c.). Producers also collect pine cones to sell to Mexico's national forestry commission, La Comisión Nacional Forestal (CONAFOR), which uses the seed to grow forest nursery stock (Figure 4.1d.).

The appearance of ocote pine at the study site is often knotted, crooked and dripping in resin, sometimes with multiple trunks (Figure 4.1e.). On ridge tops, the tree can be short in stature with a wide, flat crown (Figure 4.1f.). Some trees had resin exuding from pitch tubes, likely evidence of insect attack or disease. Tall, straight trees are less common and these are preferred by local producers. Most of the producers with whom I spoke believe that trees that grow from seedlings become the straighter and stronger trees, while trees that grow from sprouts produce twisted wood or weaker trunks. One community elder indicated that high winds influence how straight the trees can grow. Indeed, the study site experiences high winds during the months of November through February, during which time pine trees fall and tree limbs break off. He felt that with proper trimming to advantage a dominant stem, a sprouting stem could turn into a suitable timber tree (M. Pinacho, pers.com., May 19, 2008, Corazón del Valle) (Figure 4.1g.).

Ocote pine wood is highly resinous and the heartwood is dense (Vogel, 1954) (Figure 4.1h). In the community of Corazón del Valle, resin was harvested for turpentine when the property was owned by a single individual, prior to the establishment of the ejido approximately 40 years ago (A. Posada, pers.com., July 18, 2008, Corazón del Valle). I found evidence of past turpentine collection on both the MP site and the INC-FGT site in Corazón del Valle. Evidence took the form of old v-shaped scars on tree "cat-faces" (Weaver, 1943, p 7), v-shaped metal blades still in the tree trunks, and nails positioned to hang resin collection cups (Figures 4.1h. and 4.1i.).

Figure 4.1a. *P. oocarpa* stand structure seen from a distance at La Sepultura Biosphere Reserve.

Figure 4.1b. Typical appearance of timber in local pine forests.

Figure 4.1c. Local people use *P. oocarpa* to meet domestic needs, such as for fence posts. This tree was killed in the wildfire on the INC-FGT site.

Figure 4.1d. A local elder indicated that the warmth of the sun can open *P. oocarpa* cones. These fresh cones were lying open on the forest floor, before a controlled burn.

Figure 4.1e. Approximately ten percent of ocote pine trees had double, or rarely triple, trunks.

Figure 4.1f. *P. oocarpa* tree growing on a ridge-top, short in stature with a broad, flat crown.

Figure 4.1g. Parcel owner trimming a young pine to improve its growth form.

Figure 4.1h. Multiple fire scars and dense, resinous wood are visible in this log, which was cut from the tree in Figure 3.1c., above.

Figure 4.1i. *P. oocarpa* with “cat-face” made from collecting turpentine. Note v-shaped cut at the yellow arrow.

Figure 4.1j. Evidence of past turpentine collection, including the metal blade and a nail for holding a resin cup.

4.1.1. What Producers Say about Ocote Pines

The central concern in this study is pine regeneration under current fire management practices. Throughout my study, I asked local producers to teach me what they knew about the forest and about *P. oocarpa*. In addition to questions about seedlings, I asked a lot of questions about resprouts, since the species appears to resprout readily after fire. From an ecological perspective, and not a timber production perspective, it would seem that even if seedling survival was low, resprouting could provide ample regeneration.

Producers had a variety of opinions about why certain trees develop their particular growth forms. Below is a paraphrased summary of the observations and opinions of five contributors. Some opinions are contrary to one another, and I include them all as a representation of the collective knowledge of the local producers.

Ocote Pine Trees and Trunks

- When dead needles accumulate in the crook of a double trunk tree, a fire can move from the understory into the crook of the tree, starting it on fire and injuring it. The tree will produce resin in response to the injury. In the next burn, the resin will catch fire and increase the size of the injury.
- When two resprouts grow into two adjoining tree trunks, the double tree can split and one part fall to the ground (I did observe a large tree that had split with this result).
- When a stem sprouts from the main tree trunk and grows into a tree, it is vulnerable to the wind because it is not directly connected to the taproot.
- If a small tree dies and leaves part of its trunk sticking upward like a stake that could injure a cow, a producer might cut the stake and live with the sprouts. (I saw several examples of this along cattle trails).
- Some producers routinely cut competing plants from their forests with a machete.
- A tree that grows out of the side of a steep slope can produce a j-shaped trunk.
- A double trunked tree can grow from a single seed.

Pine cones and seeds

- Pine cones open with the heat of the sun.
- Pine cones open in a fire, but fire can kill the seeds.

- Seeds normally fall during the winter.
- Pine trees produce seeds every year, but some seed years are better than others.
- Seeds germinate on freshly burned ground.
- Squirrels eat seeds.
- Hot fires kill the pine “flowers” and then the trees don’t produce as much seed that year.

Seedlings

- Seedlings grow better out in the open.
- Seedlings grow better in the shade.
- Once a seedling grows to a height of between 1.5 to two meters, it will survive a controlled burn.

Resprouts

- Resprouts are not useful; they make twisted wood.
- Resprouts make crooked trunks.
- Among resprouts, one stem can become dominant and grow into a tree.
- Producers can cut away competing stems, choosing one stem to become dominant, but this practice is not ubiquitous because producers do not get paid to grow trees.

- Resprouts work as well as trees from seed. It is the young trees growing “in search of” light that makes the tree trunks uneven.
- If a seedling and a resprouts were to grow at the same time after a fire, the resprout would grow taller faster because of its existing root system.
- A resprout can grow up between two larger twin tree trunks.
- Resprouts can grow at the base of a living tree. (I observed this.)

Pine needles

- Pine needles fall at the end of the dry season.
- Pine needles fall little by little all year long.
- Pine needles fall little by little all year, with most falling in April and May before the onset of the wet season, when the tree grows new needles.

Cattle

- Producers graze the forests for forage and to reduce the fuels.
- Cattle do not eat red pine needles.
- Cattle do not eat resprouts.
- Cattle do not purposely eat seedlings. They may eat a seedling if it is growing in a bunch of grass that the animal bites off.

4.2. Methods

In order to explore these forest dynamics, and to test Hypothesis 4.a., I sampled a suite of ocote pine characteristics in two controlled burn parcels. Both controlled burn parcels had been managed for at least a decade with low intensity fire (S. Pinacho, pers. com., May 2006, Corazón del Valle, J. Sánchez, pers. com., May 2008, Valle de Corzo). Both parcels were grazed for a portion of the year in most years. I observed the owner of one parcel cutting shrubs, side branches and sprouts from small pine trees with a machete as he walked through his parcel (Figure 4.1g.), and it is likely that other producers do the same.

I collected data in 37 plots located randomly in the two controlled burn parcels (DJ and MP). Data on the location, elevation, aspect and slope of each circular plot are provided in Appendix 4.A. Using data from these circular plots, I characterized the stand size class distributions, seedling and resprout densities, canopy openness (1- canopy cover), and char and scorch. I later added six circular plots in each of two wildfire sites (for more detail, see Section 4.2.1). All together, the scope of the data collection effort included measuring 2468 genetic individuals (genets) and 6323 stems (many genets had multiple trunks or resprouts) (Table 4.1. and Appendix 4.B.).

Figure 4.2. Locations of circular plots within the DJ controlled burn parcel and three subjectively located plots to the West in an adjacent patch that was severely burned in a wildfire (INC-DJ). The date of the background imagery is prior to the occurrence of the wildfire (Google, 2009).

Table 4.1. General scope of the data collection effort to explore stand characteristics. DJ, MP, and FGT are abbreviations for individual parcels. INC denotes wildfire sites.

Site	Sample size (n=number of circular plots)	Area sampled (ha)	Number of genets counted	Number of stems measured
DJ	27	0.58	641	1626
MP	10	0.21	265	570
Subtotal controlled burn sites	37	0.79	906	2196
INC-FGT	6	0.13	160	218
INC-DJ	6	0.13	1402	4127
Subtotal wildfire sites	12	0.26	1562	4127
All sites	49	1.05	2468	6323

4.2.1. Methods for Sampling Circular Plots

Field assistant Carolyn Craig lays out a circular plot, 10 m in radius.

In each controlled burn parcel, I placed circular sample plots in transects, which I strung from baselines co-located with firebreaks around the edges of each parcel. Starting from a randomly generated number of paces, I placed transects at 30 meter intervals, running perpendicular to the baseline toward the interior of each parcel. I placed the centers of circular sample plots at 30 meter intervals along each transect, allowing for a 10 meter buffer zone inside of the firebreak that bordered each parcel. For ease of local understanding and repeatability, circular plots were 10 meters in radius, or 214 square meters (m^2) in area. In a few cases where the circular plot naturally fell in a steep gully with atypical vegetation, I advanced the location of that plot forward a few meters until I passed the gully and then resumed plot placement at 30 meter intervals. Because the DJ parcel was larger, it accommodated more plots; the DJ parcel had 27 plots while the smaller MP parcel had 10 plots.

Within each circular plot, I measured diameter at breast height (dbh) of each tree that was greater than two meters in height. If trees had multiple trunks, I noted that and measured the dbh of both trunks. In tallies of individual pines, I counted each trunk as a "tree" but the cluster of trunks as a genet. For trees shorter than two meters, I measured height to the tip of the apical bud. This height is relevant because local producers and members of the local advisory committee indicated that after an ocote pine tree grows to a height of between one and a half and two meters tall, it typically survives a controlled burn. Shorter pine trees, they said, are typically top-killed. I also recorded tree species, although I rarely encountered other taxa, and those were of only three other species: *Byrsonimia crassifolia*, which the producers call, “Nanchi,” and two species of oak, most likely *Quercus squineri* and *Quercus rugosa*, which producers call “encino” and “roble” respectively.

For genets shorter than two meters I measured height to the top of the apical bud. If the genet had multiple stems sprouting from its base, I counted the number of stems and recorded the height of the tallest stem, assuming that the tallest stem would most likely become the dominant stem, and that it would be the most likely stem to survive a fire. If the tallest stem was leaning and not perfectly vertical, as most of the sprouted stems were, I measured the height to which its apical bud was naturally reposed above the ground, again because this measure seemed most relevant to bud and stem damage from an approaching fire. In other words, the cambium, needles and bud of a stem leaning almost parallel to the ground would likely receive more fire-related damage than a stem of equal length standing vertical.

For data collection and tallying purposes, and based solely on visual observation, I distinguished the following morphological forms of ocote pine: genet, tree, sprouting stem, multiple trunk genet, seedling, "callo," and "resprout.” I defined these as follows:

Genet: a single genetic individual.

Tree: any pine stem taller than two meters.

Multiple trunk genet: a genet having multiple trunks (usually two or three) that are ≥ two meters in height. Each cluster of trunks apparently arising from the same root stock was tallied as a single genet. Each trunk was also tallied as a tree, according to the definition above. A genet having one or more tall trunks plus one or more sprouting stems was still tallied as a multiple trunk tree.

Seedling: a genet shorter than two meters that had a single, original stem and no sprouting stems. A short genet with a single stem that appeared to have sprouted after the death of the original stem was not counted as a seedling.

Callo: the root collar of a genet. These sometimes grew to 10 or more cm in diameter, apparently after successive top-kill of the above ground stems.

Resprout: a genet less than two meters tall with one or more sprouting stems arising from the root collar in addition to the original stem, whether the original stem was living or dead.

At the center of each plot, I also recorded Geographic Positioning System (GPS) coordinates, slope, elevation, aspect and canopy openness (Appendix 4.A.).

4.2.2. Methods for Purposive Sampling of High Severity Patches in Wildfire Sites.

Toward the end of my study, I noticed a severely burned patch of forest located adjacent to the DJ controlled burn parcel, just beyond the Valle de Corzo ejido boundary (Figure 4.2). The occurrence of high severity patches within a fire site, either wildfire or controlled burn is a subject of cultural interest as well as ecological interest. Producers do not like to see crown scorch after a controlled burn. Scorch is not only considered detrimental to tree growth (which has been documented for *Pinus palustris* (Haywood, 2004)), but it is viewed as a reflection of the producer's skill in using fire to care for the forest.

Consequently, when I observed the high tree mortality and the high numbers of seedlings in the wildfire area, I wondered if I had come across a finding that would be contrary to local attitudes about fire and forest management, but which could have significant management implications. According to a key informant, the patch had burned in a wildfire within the past two years. Curious about the high tree mortality and the apparent abundance of pine seedlings that I observed, I subjectively located six circular plots in the site where the fire severity appeared the highest. I judged this by visually observing the first order effects of bark char and crown scorch (Reinhardt et al., 1997), plus the second order effect of tree mortality or top-kill (Figure 4.3).

A few days later, I was granted permission to visit a second wildfire site (INC-FGT), which was located within the ejido boundary of Corazón del Valle. Judging by bark char, crown scorch and tree mortality or top-kill, the site appeared to have burned more moderately overall. Again I purposively located six plots in the most severely burned patches within the wildfire area. Whereas the first wildfire site (INC-DJ) did not appear to have been recently managed, the second wildfire site (INC-FGT) had been managed on a continuing basis by the son of the parcel owner, both before and after the wildfire.

Within each wildfire sample plot, I measured the size class distribution of pines after wildfires using the same methods as described for controlled burn plots. I also noted whether each tree was top-killed or dead ("dead") or not top-killed ("alive"). When genets had multiple trunks each greater than two meters tall, I recorded the results for each trunk individually. In a few cases, I found dead trees whose appearance indicated that they had likely died before the fire occurred (e.g., the bark had fallen off before the wildfire, and as a consequence, the wildfire charred the sapwood), and I noted this during data collection.

Because I had only enough time to collect data from a few sample plots in the wildfire sites, and because I located my sites subjectively, my sampling method provided data that can only serve as a description of seedling densities and fire effects associated with ocote pine in limited circumstances.

Figure 4.3. A subjectively located wildfire sample plot in an area where fire severity appeared the highest.

4.2.3. Methods for Estimating Canopy Openness

For canopy openness, I took a hemispherical photograph using a Nikon D-70 camera body fitted with a Sigma 8mm fisheye lens that had a 180° field of view (Figure 4.4a.). I mounted the camera on a tripod, aimed it skyward, leveled it with a fisheye level, and set the height so that the surface of the lens was one meter above the ground. I oriented the camera position with a compass so that the top of each photograph would represent a northward view (Weiss et al., 1991). Local field assistants helped me with this process (Figure 4.4b.) For a list of local assistants, see Chapter 2, Appendix 2.A). As suggested by Weiss et al.(1991), I took photographs at times near sunrise and sunset to minimize the sun's glare in the photographs (Figures 4.4c and 4.4d). I used the automatic setting on the camera, which allowed the camera to select the focus, shutter speed and f-stop settings. I recorded the circular plot number, photograph frame number and time of day for each photograph.

To estimate canopy openness from the digital images, I used a free software package, called Gap Light Analysis Version 2.0, which I downloaded from the internet (Frazer et al., 1999). I used the standard setting for the “circular mask” provided in the software to block out the black corners of the processed images (Figures 4.4e and 4.4f.). The canopy openness was then calculated using the software, based on the remaining circular view in each image.

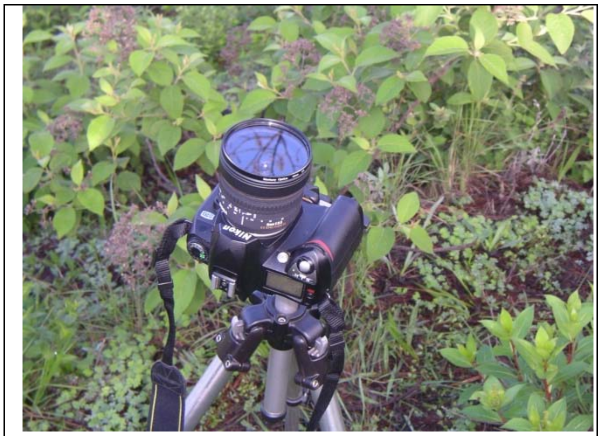


Figure 4.4a. Camera and fisheye lens used for hemispherical photography of the forest canopy.

Figure 4.4b. Local assistant leveling camera for hemispherical photography of the forest canopy.

Figure 4.4c. Unprocessed hemispherical photograph of controlled burn sample plot MP T02 R01.

Figure 4.4d. Unprocessed hemispherical photograph of wildfire sample plot INC-DJ T03 R03.

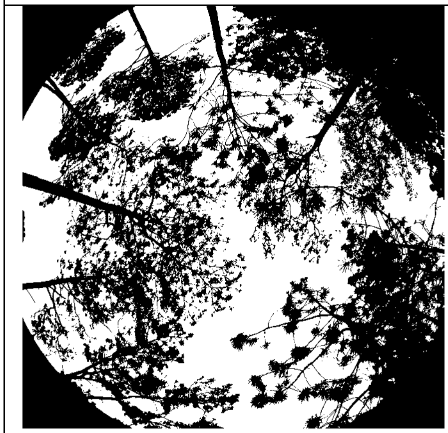


Figure 4.4e. Processed hemispherical photograph of controlled burn sample plot MP T02 R01.

Figure 4.4f. Processed hemispherical photograph of wildfire sample plot INC-DJ T03 R03.

4.2.4. Methods for Estimating Bark Char and Canopy Scorch

After each controlled burn, I visually estimated two first order fire effects in each circular plot: bark char (“char”) and crown scorch (“scorch”). (Reinhardt et al., 1997). I estimated the char height to the nearest 0.5 meter, and scorch height to the nearest meter. I estimated the crown fraction scorched to the nearest ten percent.

I did not estimate crown scorch in the wildfire plots. Both wildfires had occurred more than one growing (wet) season before my field work, so the primary evidence of scorch, discolored needles, had already fallen off of the trees. I did estimate scorch height, using the height of small burned twigs remaining in the lower canopy of the trees. This likely underestimated the true scorch height; however, the majority of the trees in the wildfire sites were scorched in their entirety and top-killed which made estimating more straightforward. This likely lessened the impact of this bias.

4.2.5. Methods for Analyzing Size Class Distributions

For each of the sample plots in the four sites, I separated the pine genet data into seedlings, resprouts and trees according to the definitions above. I separated tree diameters into five-centimeter size classes and graphed the size class distribution using Microsoft Windows Excel 2003 software. I produced an average size class distribution for each site by averaging the numbers of individuals in each of the size classes from that site, including the seedling and resprout classes.

For the wildfire sites, I graphed both the size class distribution of living genets after the wildfire, and the size class distribution of what I inferred were living trees before the wildfire. Many trees were top-killed in the wildfire but had living resprouts. These individuals were included in the resprout class in the post-wildfire size class distribution. I did not attempt to estimate the numbers of seedlings or resprouts that existed prior to the wildfire because too much of the evidence would have been destroyed by the fires. A few trees had broken boles, which appeared either to have been snapped off by high winds (in which case the tops were lying on the ground), or cut and removed for domestic purposes within the reserve.

In addition to making qualitative interpretations of the resulting distributions, I specifically evaluated Hypothesis 4.a, whether or not the forest stands had “small size classes well represented,” by comparing the averaged size class distributions to a negative exponential model. This model, also called a reverse-J curve, is typical for many forest types (Gilliam and Platt, 1999, Pulido et al., 2001, Stephens and Gill, 2005, Meyer, 1952). The formula for this distribution is provided by Davis et al. (1987):

$$Y = a\, e^{-bX}$$

where:

Y is the dependent variable (expected number of trees in the diameter size class);

a is a constant;

e is the base of the natural logarithms (=2.7182);

b is another constant; and

x is the tree diameter size class.

Using the graphing and data analysis functions in Microsoft Windows Excel 2003, I fit the size class distribution curves to a standard negative exponential model. Because some size classes had zero individuals, I added a value of one to the data for each size class on each site.

4.3. Results

4.3.1. Results for Controlled Burn Sites

To get a first impression of the data, I tallied the number of genets in seedling, resprout and tree classes. Represented in Figure 4.5 as percentages for each site, the general result was that seedlings were poorly represented in the two controlled burn sites: 11 percent of all genets tallied in the DJ site, and less than one percent of the genets tallied in the MP site. Seedlings were better represented in both wildfire sites: 65 percent of genets in the INC-DJ site and 35 percent of genets in the INC-FGT site. The relative abundance of resprouts appeared to be the most similar morphological form of ocote pine among the different sites, ranging from ten and 34 percent.

In 33 of the 37 plots sampled in the controlled burn parcels, the density of seedlings was very low, ranging from zero to three per plot. Twenty-five of the plots (69 percent) contained no seedlings at all. In four plots in the DJ site, however, I counted 11, 15, 17 and 29 seedlings. Geographically, these plots were at least partially located on small, conical knobs, each roughly 500 m^2 in size and rising above the rest of the parcel in elevation (Figure 4.6). I will return to my observations of these knobs in the discussion section of this chapter. Among the 33 plots that had low seedling counts, the mean density of seedlings, using a 95 percent confidence interval, was 0.4 $\underline{+}$ 0.2 per plot, or

14.2 ± 10.2 seedlings/ha. Including all plots in controlled burn sites, the mean density of seedlings was 103.6 ± 90.8 seedlings/ha. In contrast, the seedling density in the two wildfire plots was significantly higher ($p < 0.0001$), with a mean density 3423 ± 2163 seedlings/ha, using an alpha level of 0.05 and a 95 percent confidence interval.

Controlled Burn Sites	Wildfire Sites

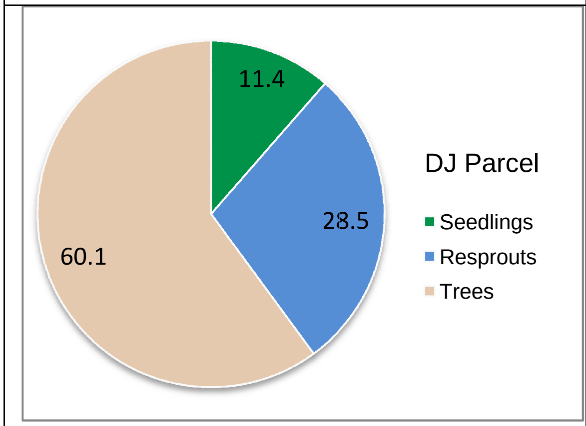


Figure 4.5a. The number of plots= 27 and the total number of genets= 641

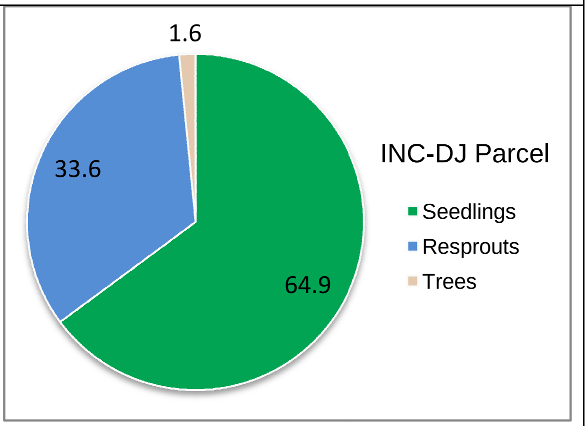


Figure 4.5b. The number of plots= 6 and the total number of genets=1402.

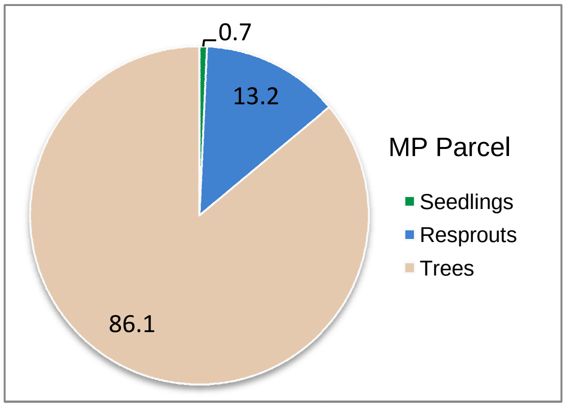


Figure 4.5c. The number of plots= 10 and the total number of genets= 265.

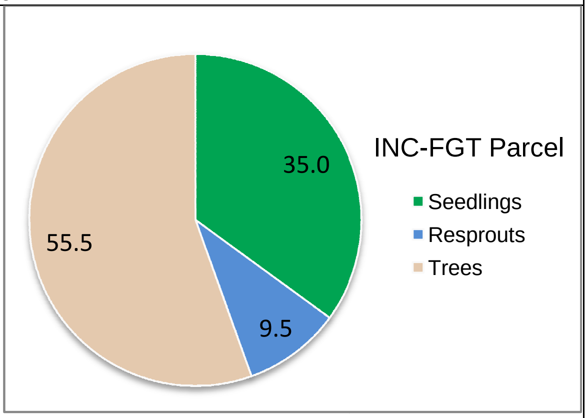


Figure 4.5d. The number of plots= 6 and the total number of genets=160.

Figure 4.5. Percent of *Pinus oocarpa* seedlings, resprouts and trees tallied in each of the study sites at La Sepultura Biosphere Reserve.

Figure 4.6. A conical knob in the DJ Parcel that had a higher than average density of seedlings before the controlled burn. After the burn the knob appeared heavily grazed and trampled. The size of a person is visible in the photograph, circled in blue.

While seedlings were relatively rare in the controlled burn sites, genets that had sprouted new stems (resprouts) were common. Using a 95 percent confidence interval, on average 24 ± 6 percent of the genets in controlled burn plots had at least one sprouting stem. Among a total of 251 resprouting genets growing in the 37 controlled burn plots, the number of sprouting stems originating from a single individual ranged from one to 38, with an average of 6 ± 1 sprouting stems (95 percent confidence interval) .

The variety of forms of sprouting that I observed during the study attests to *P. oocarpa's* morphological flexibility (Figure 4.7). Some large trees had one or more small sprouting stems at their bases, while other individuals appeared as only a cluster of sprouts with no obvious dominant stem. Some sprouts were long and stringy, growing beneath pine needle litter for lengths up to 180 cm, with only a few needles around the apical bud appearing above the litter. Some sprouting stems were simple stems, while others had secondary stems. I observed epicormic branching on a few trees; and one tree had sprouted a whorl of many stems about a meter and a half above ground. Field assistants Jorge Carlos Pinacho Posada and Chano Hernandez Benitez discovered a sprouting stem growing underneath pine litter that had grown a normal sized pine cone (Figure 4.7.f).

Figure 4.7a. Multiple resprouting stems arising from a small genet with a top-killed stem

Figure 4.7b. Multiple resprouting stems arising from a larger root stock.

Figure 4.7c. A single resprouting stem growing from a small top-killed genet, seven months after a controlled burn.

Figure 4.7d. A single resprouting stem growing from a top-killed genet that was about 20 cm long and had root collar of about one cm in diameter.

Figure 4.7e. Some resprouts were long and stringy, growing underneath pine needle litter (litter removed for this photograph).

Figure 4.7f. Normal pine cone produced on a long, stringy resprout in the DJ site.

Figure 4.7g. Resprouts emerging from the base of a small top-killed tree.

Figure 4.7h. Epicormic branching starting in the notch of a small damaged tree.

Figure 4.7i. Epicormic branches growing about 1.5 m above ground, below the dead portion of a smal tree.

Figure 4.7j. A double trunk tree, which could have grown from a single resprouting individual or from two seedlings.

Figure 4.7. Growth forms of various resprouts.

A few sprouting genets had developed root collars larger in size than the largest diameter sprouting stem. When root collars become hard, woody knots with evidence of repeated sprouting they are called “callos” (Figure 4.8). These presumably represent genets that are not young, but rather those that have survived repeated fires (Rodríguez-Trejo, pers. com., March 30, 2007, Corazón del Valle).

Figure 4.8. A woody root collar, called a “callo.”

My field assistants and I measured the diameters of root collars for 210 pine genets that occurred in sample plots of the controlled burn areas. Root collars ranged in diameter from one to 38 cm. Using a 95% confidence interval, the mean diameter of root collars in the sample was 9 ± 1 cm. The median was 8 cm. Very few of these root collars had the knotty, multi-stem appearance of actual callos. Most were simpler root collars representing the general diameter of the genets from which the sprouting stem arose. Due in part to the extensive tree mortality and down wood in the wildfire sites, I did not measure root collar widths in these sites.

The focus of this chapter is on post-fire seedling survival and pine reproduction (both seedlings and resprouts). However, because little is published about natural stands of *P. oocarpa* in southern Mexico, compared to *ex situ* stands and natural stands in Honduras (Danida Forest Seed Centre and FAO, 2001, Hudson and Salazar, 1981), I have included descriptive statistics in the Appendices for 12 additional forest measurements. Tree-related observations include mean diameter, density, basal area, percent single trunk trees, and canopy openness (Appendix 4.C). Additional observations of seedling and resprouts include seedling density, seedling height, percent of genets having at least one resprouting stem, number of stems per resprouting genet, resprout density, height of tallest resprouting stem, and resprout root collar width (Appendix 4.D).

4.3.2. Results for Canopy Openness

Results for canopy openness in each sample plot are detailed in Appendix 4.C. Mean canopy openness on controlled burn sites was 50 ± 3 percent (95 percent confidence interval). Mean canopy openness was similar for the INC-FGT wildfire site (47 ± 4 percent), but higher for the INC-DJ site (77 ± 8 percent).

4.3.3. Results for Bark Char and Crown Scorch

On controlled burn sites, measured to the nearest half meter, char height ranged from zero to one meter in height (Figure 4.9.). Only one controlled burn plot had char one meter tall, while five plots registered no char and 13 plots had char < 0.5 m. Scorch height on controlled burn sites ranged from zero to eight meters high, with a mean of 3 ± 1 m. Percent crown scorch on controlled burn sites ranged from zero to 55 percent, with a mean of 12 ± 7 percent (95 percent confidence interval).

Estimates were considerably higher on wildfire sites, which were selected specifically for their high char and scorch. Char height ranged from one to 15 meters, with a mean of 7 ± 3 m. The INC-DJ site had the highest char, with a mean of 10 ± 4 m. Scorch height on wildfire sites ranged from 8 to 25 m, with a mean of 16 ± 3 m. Additional details of char and canopy scorch for each sample plot in each site are given in (Appendix 4.E.). No genets of tree size (>2m tall) appeared to have been top-killed in either prescribed burn site.

Figure 4.9a. Partial fuel consumption visible in the DJ plot a few days after the controlled burn.

Figure 4.9b. Minimal post-burn char in the DJ site a few days after the controlled burn.

Figure 4.9c. Minimal char and scorch in the MP site a few days after the controlled burn. Note the stump still smoldering in the background (circled).

Figure 4.9d. Minimal char and scorch in the MP site a few weeks after the burn. The pink ribbon marks the average char height. Note the burro grazing on new green grass (circled).

Figure 4.9e. In contrast, scorch and char can be quite high in wildfire sites. This site was ranched and not a study site.

Figure 4.9f. Committee members and a key informant examine seeds from a singed pine cone from the same wildfire site.

Figure 4.9. Post-burn char and scorch from controlled burns and a wildfire.

4.3.4. Results for Size Class Distributions

The general appearance of the averaged size class distributions for each site did not appear to form a reverse-J curve. Generalized size class distributions for each site are shown in Figure 4.10. Distributions for individual sample plots from each site are provided in Appendix 4.F.

Qualitatively, there were relatively few small trees in the seedling and sapling (two to five cm) size classes in controlled burn sites (MP and DJ), while resprouts were common in both sites. Wildfire sites had significantly higher densities of seedlings (p-value <0.0001), with a very high density (>6000/ha) in the INC-DJ wildfire site.

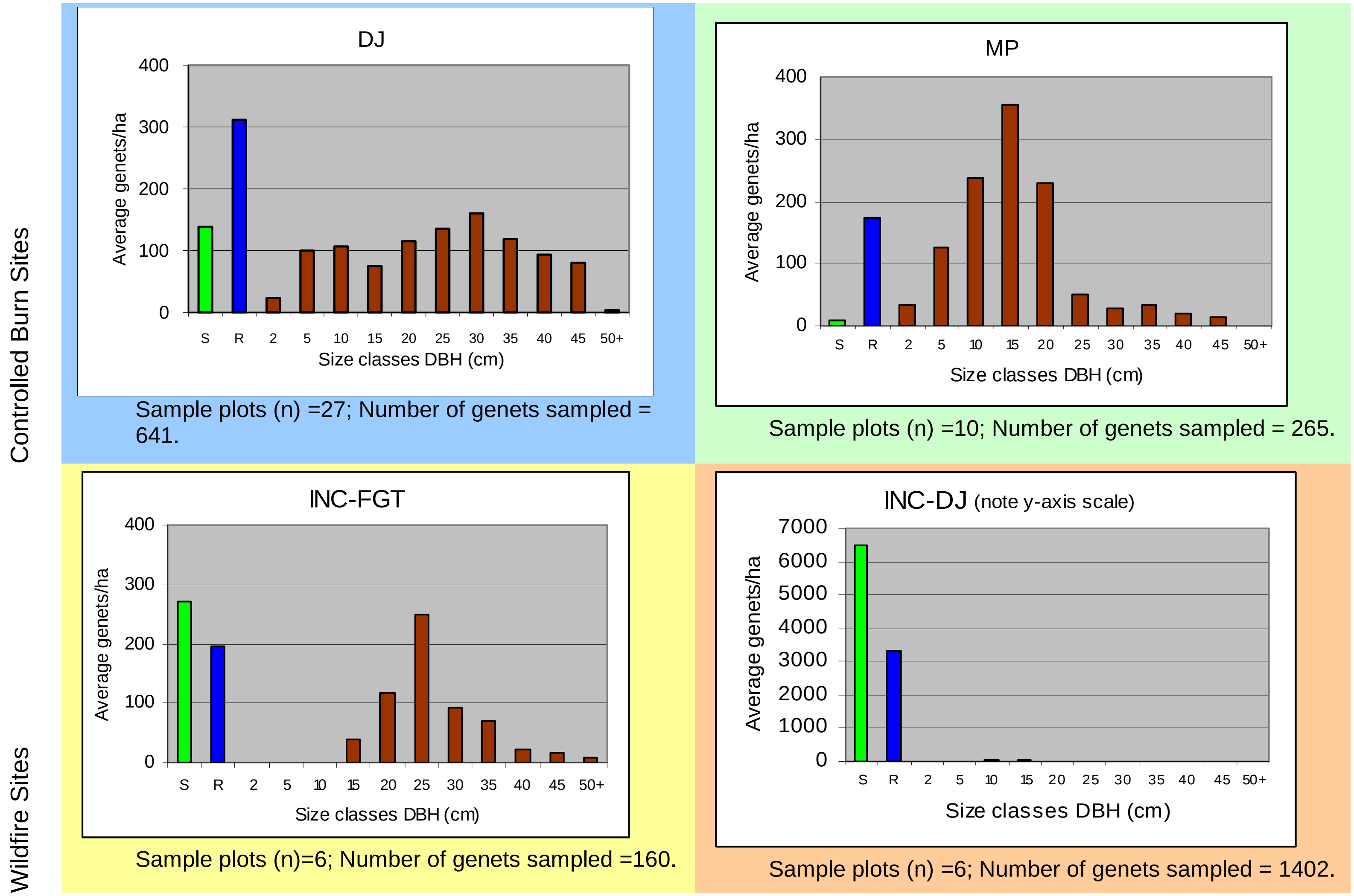
In the two controlled burn sites, the most common size classes of pine trees were in the 10, 15 and 20 cm diameter classes. Together, these three classes accounted for approximately 35 percent of the mean number of genets per plot. Seedlings accounted for only eight percent of the mean number of genets per plot in controlled burn sites. Resprouts, on the other hand, constituted the largest single size class, accounting for about 24 percent of the mean number of genets per plot. This was double the frequency of any other single size class.

In the wildfire sites, the most common size classes of pine trees were different at each site, both before and after the wildfires (Figure 4.11.). Before the wildfire in the INC-FGT site, the 20, 25 and 30 cm size classes accounted for nearly half (47 percent) of the tree-sized genets. (I did not attempt to estimate the number of seedlings and resprouts before the wildfires.) Adding the 15 and 35 cm classes, these five size classes constituted 63 percent of the genets.

The general appearance of the size class distribution in the INC-FGT site remained similar before and after the wildfire, with a slight shift of the curve to the right, toward the larger class sizes, indicating some top-kill in the smaller class sizes (Figure 4.11). Trees in the 10 cm and 15 cm size classes experienced the greatest top-kill; and one large tree in the 65 cm size class also was top-killed.

In the INC-DJ site, changes in the relative frequency of size classes before and after the wildfire were much more dramatic. Before the wildfire, small diameter trees (class sizes 2, 5 and 10 cm) constituted 80 percent of the trees in the sample plots. After the wildfire, more than 99 percent of these trees were top-killed.

Seedlings and resprouts dominated the sample plots after the wildfire in the INC-DJ site. Seedlings constituted the largest size class, accounting for 65 percent of the living genets. Resprouts constituted the second largest class, accounting for 33 percent of the living genets. Together, seedlings and resprouts represented 98 percent of the live genets in the sample plots. The dominance of seedlings and resprouts plus the nearly total conversion of live trees to top-killed trees attest to the severity of this wildfire in the selected sample area.



Sample plots (n) =27; Number of genets sampled = 641.

Sample plots (n) =10; Number of genets sampled = 265.

Sample plots (n)=6; Number of genets sampled =160.

Sample plots (n) =6; Number of genets sampled = 1402.

Figure 4.10. Averaged size class distributions for all four sites: two controlled burn sites (DJ and MP) and two wildfire sites (INC-DJ and INC-FGT). S = seedling size class and R = resprout size class. Note the different scale on the y-axis for the DJ parcel.

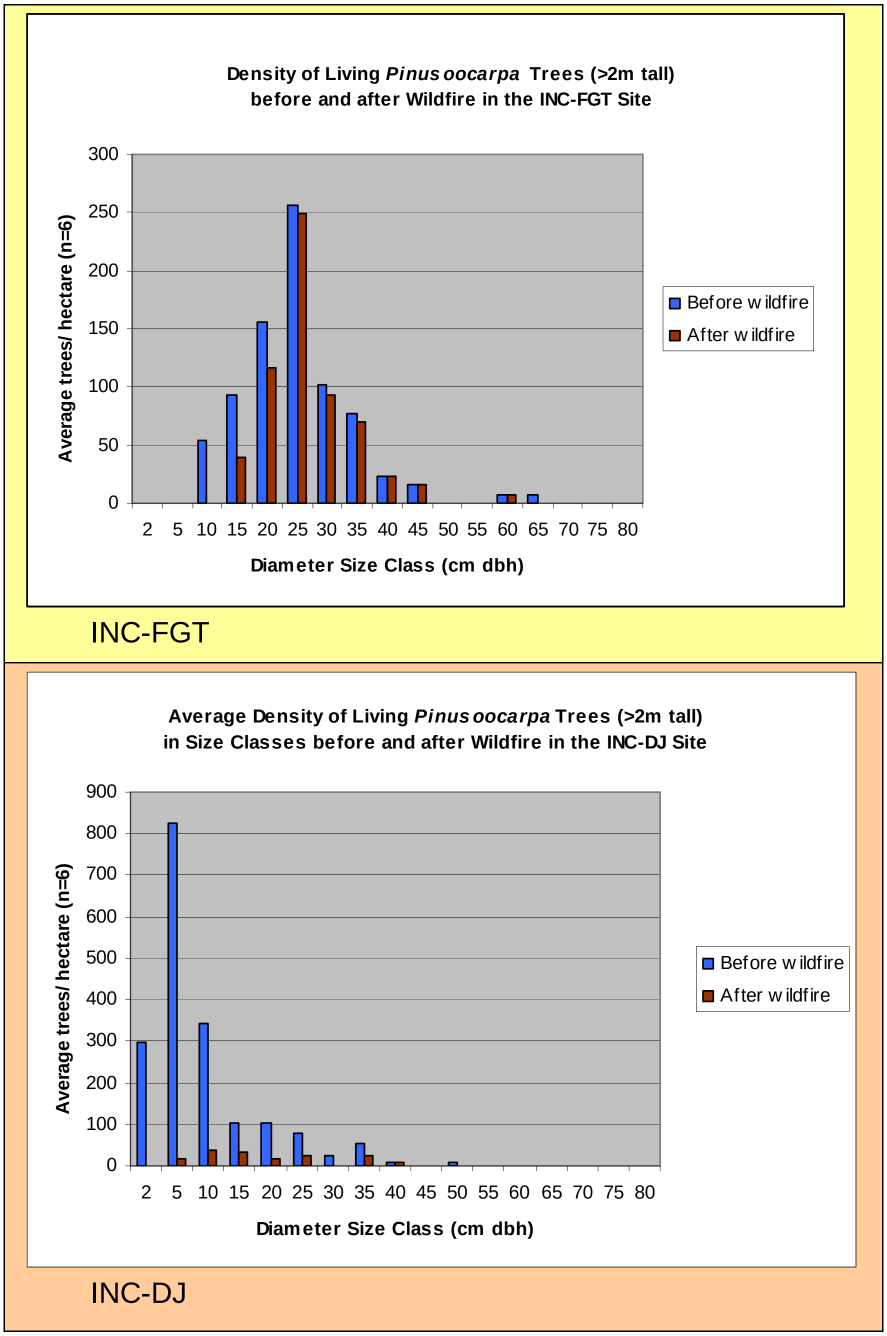


Figure 4.11. Size class distributions of each of the wildfire sites, before and after the wildfires. Note the difference in the scale of the y-axis for each graph. The distribution of trees living before the wildfires was inferred from the post-fire appearance of trees, and included those that were top-killed (both those that resprouted and those that did not), and trees that were not top-killed. Seedlings and resprouts were not included.

Based upon visual inspection of residuals and comparison of R^2 values, the negative exponential curve explains from 45 to 86 percent of the variability in the data for controlled burn plots, and from five to 63 percent of the variability in the data for wildfire plots (Figure 4.12a.). The steep decline between the frequencies of seedling and resprout classes, and the frequency of the two and five cm diameter size classes suggests that small genets are experiencing some difficulty growing into tree class sizes.

Since producers expressed their preference for pines produced from seed, it is useful to view the results from this perspective. Using this socially-driven definition of useful pine reproduction, Figure 4.12b excludes resprouts from the analysis. Using this approach, the negative exponential curve fits the data somewhat less well, explaining 38 to 80 percent of the variability in data for controlled burn plots and three to 64 percent of the variability in the data for wildfire plots. Returning to Figure 4.10, visually excluding the resprout size class shows the gap between seedlings and tree size classes. It appears that pine reproduction that produces trees that local producers prefer is even more limited.

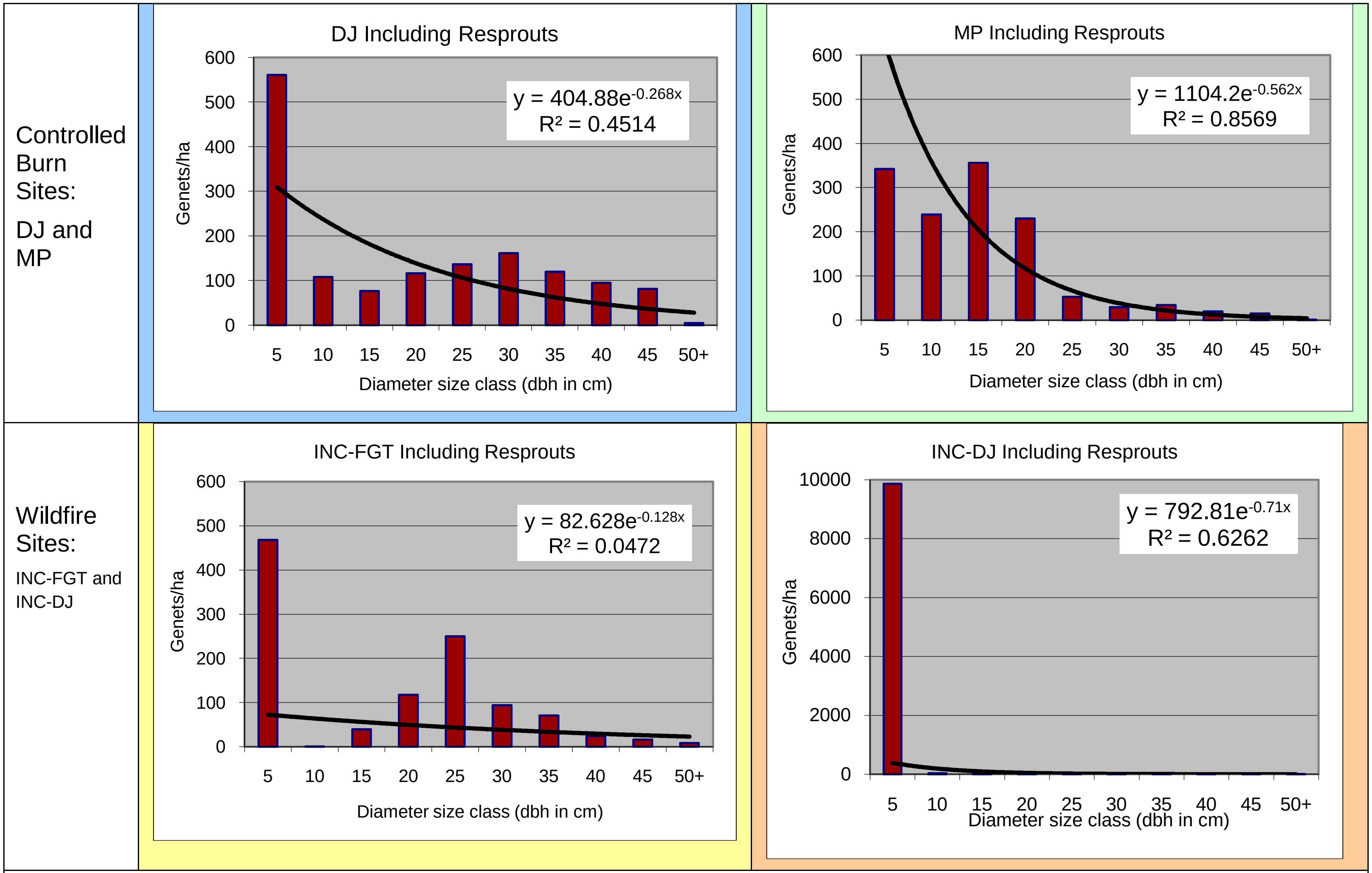


Figure 4.12a. Comparison of negative exponential models fitted to the averaged size class distributions of the two controlled burn sites and the two wildfire sites, *including* both seedlings and resprouts in the 0-5 cm size class. This series of graphs is designed to show stand dynamics from the ecological perspective (compare with Figure 4.12b below).

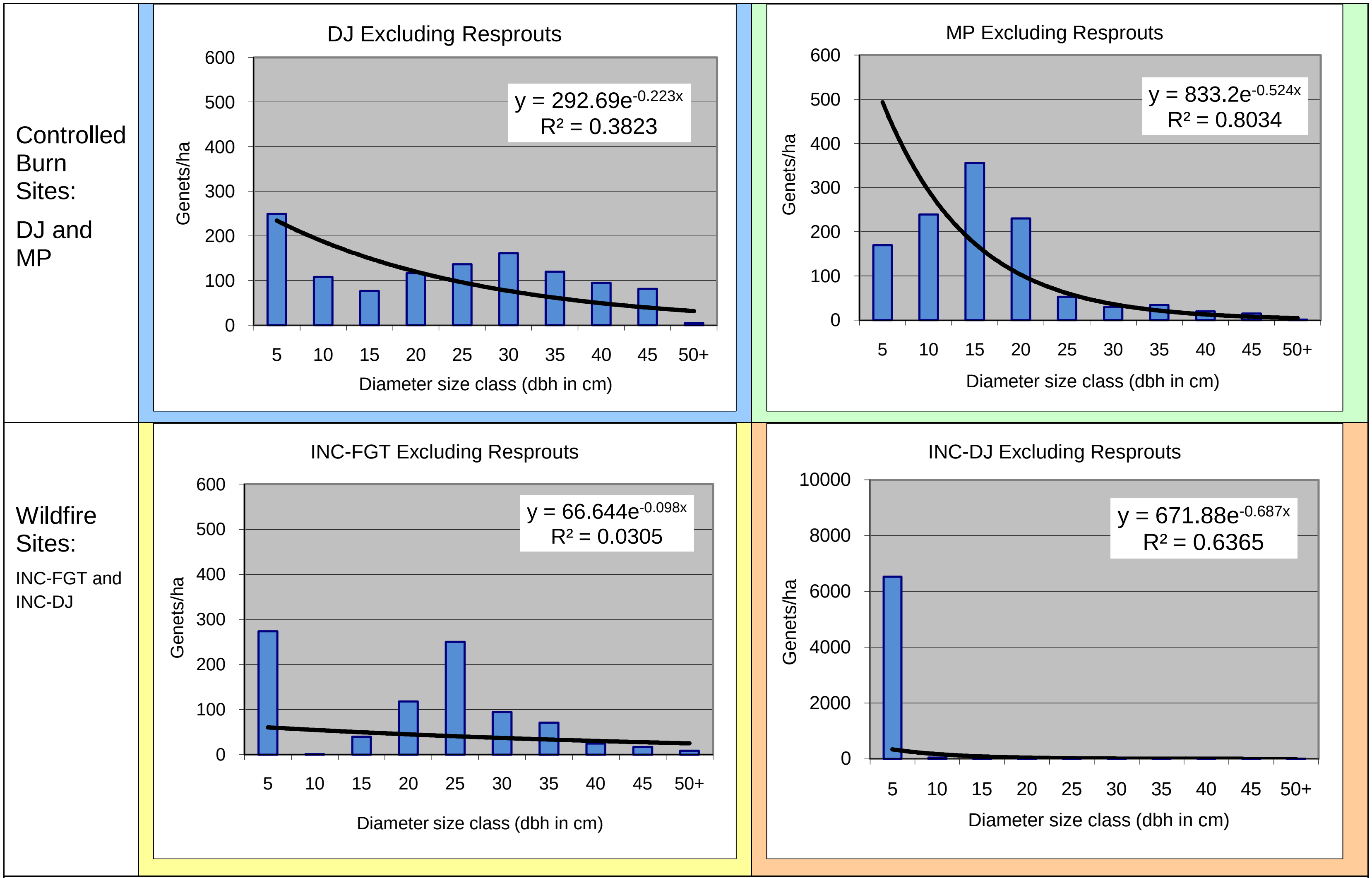


Figure 4.12b. Comparison of negative exponential models fitted to the averaged size class distributions of the two controlled burn sites and the two wildfire sites, *excluding* resprouts from the 0-5 cm size class. This set of graphs is designed to show the size class distribution of useful trees from the producers' perspective.

Table 4.2. R-square values for negative exponential curves fit to the averaged size class distributions of each site. The center column includes resprouts in the analysis and the right column excludes resprouts.

Site	Negative Exponential (Reverse-J) Curves including resprouts	Negative Exponential (Reverse-J) Curves excluding resprouts
DJ	$R^2 = 0.4514$	$R^2 = 0.3823$
MP	$R^2 = 0.8569$	$R^2 = 0.8034$
INC-FGT	$R^2 = 0.0472$	$R^2 = 0.0305$
INC-DJ	$R^2 = 0.6262$	$R^2 = 0.6365$

4.4. Discussion

The published literature on the range of seedling densities observed for *P. oocarpa* and other pine species growing in various conditions gives some indication of whether or not the densities I observed are be within a reasonable range (Table 4.3). In a study conducted on the ochoterenae variety of *P. oocarpa* in the adjacent state of Oaxaca, Juárez-Martínez and Rodríguez-Trejo (2003) reported seedling densities ranging from 10 to nearly 40,000/ha occurring two to four years after fire. This range encompasses the densities I observed in my unknown variety of *P. oocarpa,* although my observations were more recent post-fire. In comparison to other pine species, the highest density I observed, 12,506 in the INC-DJ site, is within upper extremes of pine seedling density observed for *P. ponderosa* by Battaglia et al. (2009). Similar to my sample plots, in which I encountered several plots that had zero seedlings and the next lowest density of 47 seedlings/ha, Gilliam and Platt (1999, p 15) described regeneration of *P. palustris* in their study sites as “minimal” when several sample plots had no seedlings and other plots had between 50-70 seedings/ha.

Table 4.3. Published seedling densities of *P. oocarpa* and other pine species growing in various forest conditions.

Species of tree	Range of seedling density (mean seedlings/ha ± standard error)	Reference
Pinus oocarpa	9-6,456	Observed at La Sepultura
Pinus oocarpa var. *ochoterenae*	10-39,850 (two-four years post-fire)	Juárez-Martínez and Rodríguez-Trejo (2003)
P. caribaea	Approximately 3400	O'Brien et al. (2008)
P. jeffreyi	101 (14)	Stephens and Gill (2005)
P. palustris	50-70 to approx. 4000	Gilliam and Platt (1999)
P. ponderosa	174 (132) – 40,935 (9948)	Battaglia et al. (2009)
Mixed conifer including *P. lambertiana (11%)* *P. ponderosa (14%)* *Abies concolor (23%)* *Calocedrus decurrens (22%)* *Psuedotsuga menziezii* (18%) Mixed hardwood (12%)	Fire suppressed environment, all tree species combined: 470 (105) – 579 (108)	Collins et al. (2007)

Using an ecologically based definition of small class sizes, which would include both seedlings and resprouts, the data *do not* support rejecting Hypothesis 4.a. that "The pine forest stands have a variety of size classes, with small size classes well represented." Together, seedlings and resprouts represent, on average, nearly a third (32 percent) of the mean number of genets sampled per plot in parcels managed with controlled burning. Local producers, however, prefer trees grown from seedlings over those that have grown from resprouts.

In this interdisciplinary study, it is appropriate to include local producers' social values in the analysis of forest size class distribution. Seen through producers' eyes, resprouts are unimportant or detract from a desirable size class distribution. If, according to this socially relevant view, I include only seedlings in the definition of small class sizes, then the evidence suggests that small class sizes are not well represented. Seedlings constitute less than one tenth (eight percent) of the mean number of genets sampled per plot in parcels managed with controlled burning.

The producers' concern for the survival of seedlings under the current fire regime is well founded. The absence of trees in the two to five centimeter diameter classes in most sample plots is conspicuous. Genets most often appear as resprouts, and then as trees in size classes above five centimeters in diameter. I speculate that this is due to the current fire regime under which seedlings or sprouting stems are top-killed by even low-intensity burning, and they do not have time to grow to a fire-safe height or bark thickness before the next fire (Battaglia et al., 2009, Ryan and Reinhardt, 1988).

The form of the size class distributions suggests that, at the study site, *P. oocarpa* reproduces in cohorts, with multiple cohorts sometimes apparent in a single stand. Smith et al. (1997, p 24) describe stands with this kind of size class distribution as "irregular uneven-aged" stands. A simple conversation with a local elder supports this conclusion. Along the road to one of my study sites, I observed a hillside with an obvious collection of different cohorts (Figure 4.13a.). Seeing the ample pine reproduction in this area, I brought one of the community elders to see it and offer his interpretation. When he arrived at the spot he said, "Oh, that's easy, there was a wildfire here seven years ago." He further explained that this particular parcel, which I call "the school site," was managed by the community as a whole for the benefit of the school. As such, the site was not fenced or grazed. Accumulation of herbaceous fuels on this site would therefore be accelerated compared to sites that are routinely grazed, and an easy toss of a match from the roadside could ignite unplanned fires.

The primary question for discussion, then, is "Why is *P. oocarpa* reproduction from seed high in some places and non-existent in others?" The literature points to several possible factors.

Juárez-Martínez and Rodríguez-Trejo (2003) documented that *P. oocarpa* var. *ochoterenae* in the adjacent State of Oaxaca had higher seedling densities in burned plots compared to unburned plots, and more seedlings after high intensity fire. In addition, they found that this variety of ocote pine generated a pulse of seedling production two years after fire.

For decades, authors have recognized the ecological importance of canopy gaps (Vogel, 1954, O'Brien et al., 2008, Myers and Rodríguez-Trejo, 2009), which have a variety of primary and secondary effects on the microsites they create (Zhu et al., 2003). For the purposes of this study, I use Myers' (2000a) definition of forest gaps, which is adapted from Brokaw (1982): a hole through all levels of the canopy reaching to within one meter of the forest floor. Forest gaps allow more light to reach the forest floor, which can be an advantage for seedling growth (Hudson and Salazar, 1981, Battaglia et al., 2003, Bolibok and Andrzeczyk, 2008, Zhu et al., 2003).

Gaps created by fires consume fuels and create a seedbed suitable for germination of *P. oocarpa* seedlings (Perry, 1991, Rodríguez-Trejo and Fulé, 2003). Where the canopy is opened for several years by the death or heavy pruning of overstory trees, fuel accumulation is reduced, thereby lessening the likelihood of successive fires during the critical fire-free years until fire-sensitive seedlings can reach a safe height (Hudson and Salazar, 1981, O'Brien et al., 2009). Where high winds topple some trees, wind created gaps also provide opportunities for regeneration (Gilliam et al., 2006), although for fire-sensitive seedlings, wind thrown trees increase fuels until after the first few fires, and then provide a reduced fuel environment (O'Brien et al., 2009, Myers and Rodríguez-Trejo, 2009).

Water availability can also be affected by forest gaps, in some cases making water more available and sometimes less. If gaps are large and seedlings are exposed to sunlight throughout the day, they may have less available water, whereas the reduced root competition from grown trees may make water more available particularly in the top layers of soil where seedlings have their roots (Zhu et al., 2003). Gap size and spatial distribution are also important in the regeneration process, influencing several microsite variables (Myers and Rodríguez-Trejo, 2009, O'Brien et al., 2009, Stephens et al., 2009).

The knobs that had higher than average seedling densities in the DJ controlled burn site are interesting microsites. Their slope is greater, but the elevation is only slightly higher. When I returned briefly to the site seven months after the burn, I noticed that one of the knobs was heavily trampled and nearly denuded of understory vegetation, apparently due to grazing. The rest of the burn unit appeared to be moderately grazed.

It would be interesting to ask the land owner if cattle tend to linger on these knobs to take advantage of the cool, moist ocean breezes that sometimes pass through the site, or for any other reason. I experienced several days in which a cool mist cascaded down to the site from the ridge above. If cattle spend more time on these microsites, trampling them and grazing them, then more bare soil would be available and the unpalatable pine seedlings might gain a competitive advantage of over grazed herbaceous cover.

Also, when I observed this parcel being burned, the participants lit the knobs from the bottom and allowed the fire to burn to the tops, generating higher intensity. With sufficient intensity, more trees could be killed and the canopy could become more open than the surrounding area. If so, this would result in less tree competition, expose the soil to the heavy rains causing erosion, and exposed more bare soil. It is interesting to compare the conditions of these knobs to the INC-DJ wildfire site that had extraordinary pine reproduction. The INC-DJ site was steep, experienced a lot of erosion (Figure 4.13d), had a lot of bare ground, and had very little fuel accumulation.

A pulse of reproduction did seem to occur after wildfire events at La Sepultura, for example at the INC-DJ site and the school site described above. This could occur as a result of a combination of the factors described above, and others that I have not considered.

Figure 4.13a. Three pine cohorts visible at the school site, burned in a wildfire seven years prior to this photograph.

Figure 4.13b. Pockets of successful pine reproduction were present in some locations.

Figure 4.13c. Vigorous growth of resprouts in the INC-DJ wildfire site. Note the open canopy created by extensive tree mortality on the site.

Figure 4.13d. A seedling at the INC-DJ site in which soil particles have collected after a rainstorm, attesting to the high rate of erosion on the site.

Figure 4.13e. A cool mist covers a sample plot on the INC-DJ wildfire site. Seedlings are marked with white pin flags.

Figure 4.13f. A knob in the DJ site showing more bare ground than the surrounding flat areas.

Figure 4.13g. Robust seedling typical of the INC-DJ wildfire site.

Figure 4.13h. Seedling supporting fewer needles, typical of the DJ controlled burn site.

Figure 4.13. Examples of areas with robust pine seedling reproduction.

Based upon the high numbers of resprouts and the paucity of seedlings in controlled burn sites, it is reasonable to infer that resprouting serves as an important mechanism for individual survival in the current forest management situation. A tree's ability to re-sprout after being tip-killed would improve its resilience to disturbances such as wind damage, disease or fire.

With recurring sprouting and conversion of seedlings into a sprouting form, the proportion of resprouts in a forest parcel would increase over time. When a cohort of seedlings is top-killed and then resprouts, it contributes a cohort of resprouts to the population. If resprouting genets are added to the population with each controlled burn or other disturbance, then successive conversion of seedlings to resprouts will occur.

Demographically, we could say that under the current fire regime seedlings are a temporary stage in the lives of *P. oocarpa* genets. More often than not, seedlings move into the resprout stage as they age. Demonstrated by the presence of root collars of varying sizes, including some callos, resprouts can continue to age through multiple fires or disturbances. The population of resprouts, then, includes genets of various ages. It is reasonable to infer that this is the dynamic that results in the dominance of resprouts in the sample population at La Sepultura.

Two forest engineers from the NGO Pronatura-Sur said that was a common field observation is that forest gaps aid reproduction of several pine species in Chiapas, including *P. oocarpa*. In fact, the engineers were preparing to propose a forest management program for the reserve that involved mechanically creating gaps. While the sampling in this study is insufficient to draw definitive conclusions, I offer the following informal observations for producers and agency managers to consider.

The current fire regime is designed to care for the forest through the application of low intensity fire on a frequent fire return interval. Careful preparation of fire breaks, selection of the most moderate conditions for burning, specific ignition patterns and large crew sizes characterize this fire regime. Most of the area of each burn parcel burns in backing and flanking fires. Using only hand tools, producers can accomplish their goals of minimizing pine scorch and pine mortality, reducing the accumulation of fuel, avoiding fire escapes, improving forage and diminishing shrubs in this highly flammable environment. This is an impressive accomplishment that would be difficult for people with less expertise to achieve.

However, the survival of pine seedlings does not appear to be enhanced by this regime. Low mortality of the larger pines results in more closed canopies and shadier conditions which may be unsuitable to rapid seedling growth. Denser canopies translate to more pine needles, which fall and create more fuels. A continuous bed of pine needles lessens the chance that a pine seed will fall on bare ground, which if similar to other pine species, it requires for germination.

Producers indicate that small pines taller than a meter and a half can usually survive the customary low-intensity fires. They say that a seedling can reach this height in about three years. Smaller pine seedlings appear sensitive to the heat of even the lowest fires; they either die or resprout to survive. However, once a seedling becomes a re-sprout, it no longer meets the producers' preference for pine reproduction.

How can a producer who is already using a highly refined suite of techniques to create the lowest possible fire intensity reduce the heat of a fire enough for the pine seedlings to survive without resprouting? I propose that seedling survival may improve with more open canopies and less fuel accumulation. If these conditions do not occur under the current fire regime, I propose that the producers and other stakeholders explore how they can be created. For purposes of discussion, I describe the basics of two experiments below.

One experiment would be to make arrangements for a burn parcel in which the fire could be controlled around the edges but be allowed to burn with greater force in the interior (where there is little chance of escape), purposely killing some overstory trees. The resulting patch of pine mortality would create a canopy gap, reduce the needle drop within the patch, and allow the pine seedlings to germinate on bare soil. The results of this more forceful, gap-producing fire could then be compared to areas where the customary fires did not produce gaps. Conducting this experiment would require a location where a large enough burn parcel could be designed, perhaps through a combination of smaller parcels, and it would require local acceptance of some fire-related pine mortality. People involved in the experiment would need to decide in advance whether any dead trees killed in the fire would be left standing afterwards or be cut for local use. Leaving the trees standing at least until after the pine seeds drop would be important to the experimental design.

A second experiment, one that would probably be more pleasing to the producers, would be to mechanically create gaps by cutting small patches of timber (for example, three to five mature trees), and then by clearing the understory either with controlled burning or raking so that bare soil is exposed. Participants could then compare the establishment of pine seedlings in artificial gaps to otherwise similar areas where no gaps were created.

A separate series of future research questions of importance to local producers relates to whether or not, and under what circumstances, a resprout could become a useful tree.

- Left alone, how frequently do resprouts develop a dominant stem that becomes a useful tree? Under what conditions can this take place?
- What strengths and weaknesses do trees that develop from resprouts have compared to trees that develop directly from seedlings?
- How many years and how many successive disturbances can resprouts survive?
- Could a modified fire regime support the development of useful trees from resprouts?

Each of these questions presents an opportunity for future research. If producers wish to continue the current management regime, then studying the longer term demographics of resprouts could be important. An alternative is for producers to experiment further with what I learned from the experiment involving simple fuel removal, which is described in the next chapter.

Appendix 4.A. Sample Plot Locations, Elevations, Aspects and Slopes

Sample Plot	Site	Latitude	Longitude	Elevation (msl)	Aspect (deg)	Slope (deg)
DJ RD T01 R01	DJ	N 16º 23.977	W 093º 59.359	876	64	9
DJ RD T02 R01	DJ	N 16º 23.964	W 093º 59.357	880	71	10
DJ RD T03 R01	DJ	N 16º 23.946	W 093º 59.360	880	124	9
DJ RD T02 R02	DJ	N 16º 23.944	W 093º 59.345	869	134	17
DJ RD T05 R01	DJ	N 16º 23.917	W 093º 59.375	887	102	21
DJ RD T08 R01	DJ	N 16º 23.	W 093º 59.	.	.	.
DJ RD T09 R01	DJ	N 16º 23.	W 093º 59.	.	.	.
DJ BR T11 R01	DJ	N 16º 23.927	W 093º 59.350	900	299	25
DJ BR T09 R01	DJ	N 16º 23.894	W 093º 59.345	886	360	17
DJ BR T07 R01	DJ	N 16º 23.865	W 093º 59.357	881	296	10
DJ BR T07 R02	DJ	N 16º 23.871	W 093º 59.365	893	304	18
DJ BR T07 R03	DJ	N 16º 23.888	W 093º 59.382	878	300	16
DJ BR T06 R01	DJ	N 16º 23.851	W 093º 59.374	887	333	12

Sample Plot	Site	Latitude	Longitude	Elevation (msl)	Aspect (deg)	Slope (deg)
DJ BR T06 R02	DJ	N 16º 23.862	W 093º 59.384	887	259	22
DJ BR T03 R01	DJ	N 16º 23.836	W 093º 59.451	897	2	11
DJ BR T02 R01	DJ	N 16º 23.833	W 093º 59.466	896	54	7
DJ BR T05 R01	DJ	N 16º 23.843	W 093º 59.393	885	360	21
DJ BR T05 R02	DJ	N 16º 23.850	W 093º 59.397	886	71	19
DJ BR T04 R01	DJ	N 16º 23.841	W 093º 59.426	894	8	18
DJ BR T04 R02	DJ	N 16º 23.852	W 093º 59.437	894	17	15
DJ RD T04 R01	DJ	N 16º 23.932	W 093º 59.368	881	120	13
DJ RD T06 R01	DJ	N 16º 23.899	W 093º 59.383	898	108	17
DJ RD T07 R01	DJ	N 16º 23.	W 093º 59.	.	.	.
DJ RD T07 R02	DJ	N 16º 23.	W 093º 59.	.	.	.
DJ RD T10 R01	DJ	N 16º 23.	W 093º 59.	.	.	.
DJ BR T10 R01	DJ	N 16º 23.909	W 093º 59.338	882	309	7
DJ BR T08 R01	DJ	N 16º 23.888	W 093º 59.343	899	294	19
DJ mean values				887	181	15

Sample Plot	Site	Latitude	Longitude	Elevation (msl)	Aspect (deg)	Slope (deg)
Standard deviation				8.4	127.7	5.2
Confidence interval (95%)				3.5	53.4	2.2
MP T01 R01	MP	N 16º 25.308	W 093º 58.911	799	315	20
MP T01 R02	MP	N 16º 25.315	W 093º 58.897	788	77	10
MP T01 R03	MP	N 16º 25.323	W 093º 58.884	787	52	25
MP T02 R01	MP	N 16º 25.293	W 093º 58.919	806	132	26
MP T02 R02	MP	N 16º 25.300	W 093º 58.906	788	120	22
MP T02 R03	MP	N 16º 25.304	W 093º 58.887	789	108	12
MP T04 R01	MP	N 16º 25.263	W 093º 58.944	804	144	22
MP T05 R01	MP	N 16º 25.248	W 093º 58.954	798	30	26
MP T05 R02	MP	N 16º 25.259	W 093º 58.938	785	75	28
MP T06 R01	MP	N 16º 25.237	W 093º 58.964	798	132	13
MP mean values				794	118	20
Standard deviation				7.7	78.6	6.5
Confidence interval (95%)				4.7	48.7	4.0

Sample Plot	Site	Latitude	Longitude	Elevation (msl)	Aspect (deg)	Slope (deg)
INC-FGT T01 R02	INC-FGT	N 16º 25.569	W 093º 59.480	804	45	22
INC-FGT R02	INC-FGT	N 16º 25.549	W 093º 59.592	796	136	18
INC-FGT R03	INC-FGT	N 16º 25.458	W 093º 59.603	807	123	9
INC-FGT R04	INC-FGT	N 16º 25.467	W 093º 59.598	810	360	12
INC-FGT R05	INC-FGT	N 16º 25.402	W 093º 59.639	804	85	12
INC-FGT R06	INC-FGT	N 16º 25.308	W 093º 59.728	825	80	15
INC-FGT mean values				807	138	14
Standard deviation				9.7	113.4	4.7
Confidence interval (95%)				7.8	90.8	3.8
INC-DJ T01 R01	INC-DJ	N 16º 23.852	W 093º 59.514	896	268	32
INC-DJ T02 R01	INC-DJ	N 16º 23.849	W 093º 59.523	887	10	32
INC-DJ T02 R02	INC-DJ	N 16º 23.840	W 093º 59.507	909	1	35
INC-DJ T03 R01	INC-DJ	N 16º 23.780	W 093º 59.536	923	186	26
INC-DJ T03 R02	INC-DJ	N 16º 23.775	W 093º 59.590	936	180	32
INC-DJ T03 R03	INC-DJ	N 16º 23.784	W 093º 59.597	928	218	32

Sample Plot	Site	Latitude	Longitude	Elevation (msl)	Aspect (deg)	Slope (deg)
INC-DJ mean values				913	143	31
Standard deviation				19.2	111.6	2.9
Confidence interval (95%)				15.3	89.3	2.4

Appendix 4.B. Circular Plot Sampling: Genets Counted and Stems Counted in Each Sample Plot.

Sample Plot	Genets Counted	Stems Counted
DJ RD T01 R01	6	10
DJ RD T02 R01	18	73
DJ RD T03 R01	7	8
DJ RD T02 R02	17	39
DJ RD T05 R01	32	116
DJ RD T08 R01	18	19
DJ RD T09 R01	7	11
DJ BR T11 R01	22	35
DJ BR T09 R01	14	41
DJ BR T07 R01	14	39
DJ BR T07 R02	9	32
DJ BR T07 R03	36	51
DJ BR T06 R01	31	79
DJ BR T06 R02	27	160
DJ BR T03 R01	21	112
DJ BR T02 R01	11	16
DJ BR T05 R01	33	74
DJ BR T05 R02	16	25
DJ BR T04 R01	68	142
DJ BR T04 R02	47	66
DJ RD T04 R01	12	12

Sample Plot	Genets Counted	Stems Counted
DJ RD T06 R01	14	14
DJ RD T07 R01	18	18
DJ RD T07 R02	26	107
DJ RD T10 R01	22	60
DJ BR T10 R01	13	15
DJ BR T08 R01	82	252
DJ subtotal	641	1626
MP T01 R01	8	13
MP T01 R02	10	26
MP T01 R03	22	23
MP T02 R01	23	45
MP T02 R02	11	63
MP T02 R03	20	80
MP T04 R01	60	68
MP T05 R01	43	138
MP T05 R02	38	50
MP T06 R01	30	64
MP subtotal	265	570
Controlled burn subtotal	906	2196
INC-FGT T01 R02	25	57
INC-FGT R02	40	58
INC-FGT R03	34	35
INC-FGT R04	20	21
INC-FGT R05	17	23
INC-FGT R06	24	24

Sample Plot	Genets Counted	Stems Counted
INC-FGT subtotal	160	218
INC-DJ T01 R01	169	767
INC-DJ T02 R01	348	618
INC-DJ T02 R02	347	1149
INC-DJ T03 R01	244	602
INC-DJ T03 R02	194	603
INC-DJ T03 R03	100	170
INC-DJ subtotal	1402	3909
Wildfire subtotal	1562	4127
Total for all sites	2468	6323

Appendix 4.C. Characteristics of Pine Trees (*Pinus oocarpa*) and Canopy Openness at Each Site

Sample Plot	**# Pine genets in plot**	**Mean tree diameter (cm dbh)**	**Tree basal area (m^2/ha)**	**Tree density (trunks/ha)**	**Among trunks, % single trunk trees**	**Canopy Openness (%)**
DJ RD T01 R01	280.4	26.2	1.8	280.4	83.3	46.91
DJ RD T02 R01	841.1	21.9	4.1	560.7	66.7	68.95
DJ RD T03 R01	327.1	26.8	2.3	373.8	75.0	39.26
DJ RD T02 R02	794.4	24.0	1.9	373.8	100.0	49.39
DJ RD T05 R01	1495.3	16.5	1.6	514.0	100.0	44.91
DJ RD T08 R01	841.1	23.8	4.0	794.4	94.1	65.14
DJ RD T09 R01	327.1	24.3	1.6	280.4	83.3	50.36
DJ BR T11 R01	1028.0	17.1	2.6	700.9	100.0	29.27
DJ BR T09 R01	654.2	24.5	3.4	560.7	75.0	58.72
DJ BR T07 R01	654.2	18.8	1.6	467.3	100.0	54.39
DJ BR T07 R02	420.6	17.3	1.0	280.4	83.3	48.12
DJ BR T07 R03	1682.2	6.3	0.8	1635.5	100.0	49.46
DJ BR T06 R01	1448.6	21.6	3.4	794.4	100.0	54.44
DJ BR T06 R02	1261.7	17.2	2.4	560.7	100.0	43.57
DJ BR T03 R01	981.3	17.1	1.5	560.7	83.3	42.14
DJ BR T02 R01	514.0	21.0	2.4	420.6	100.0	40.06
DJ BR T05 R01	1542.1	20.4	2.4	700.9	100.0	40.72
DJ BR T05 R02	747.7	24.2	2.3	420.6	100.0	50.57
DJ BR T04 R01	3177.6	13.4	2.4	1215.0	92.3	45.54
DJ BR T04 R02	2196.3	11.9	2.7	1401.9	100.0	47.84
DJ RD T04 R01	560.7	26.4	3.2	560.7	100.0	42.79

DJ RD T06 R01	654.2	24.6	3.4	654.2	73.3	40.64
DJ RD T07 R01	887.9	22.0	3.1	700.9	100.0	40.94
DJ RD T07 R02	1215.0	17.4	1.9	654.2	100.0	56.3
DJ RD T10 R01	1028.0	23.2	4.8	887.9	89.5	65.18
DJ BR T10 R01	607.5	20.5	2.7	700.9	73.3	47.46
DJ BR T08 R01	3831.8	13.4	2.0	981.3	90.5	33.62
DJ mean values	1111.1	20.1	2.5	668.1	91.2	48.0
Standard deviation	833.2	5.0	1.0	329.6	10.9	9.3
Confidence interval (95%)	314.3	1.9	0.4	124.3	4.1	3.5
MP T01 R01	373.8	28	1.9	280.4	100.0	75.49
MP T01 R02	467.3	25	2.7	467.3	80.0	.
MP T01 R03	1028.0	17	2.9	1074.8	91.3	65.56
MP T02 R01	1074.8	13	2.0	1215.0	61.5	54.98
MP T02 R02	514.0	39	1.7	140.2	100.0	66.31
MP T02 R03	934.6	15	1.3	700.9	58.3	.
MP T04 R01	2803.7	10	3.4	3130.8	77.6	38.95
MP T05 R01	2009.3	12	2.2	1495.3	80.6	59.77
MP T05 R02	1775.7	13	2.7	1635.5	85.7	56.39
MP T06 R01	1401.9	13	1.9	1308.4	78.6	53.81
MP mean values	1238.318	18.4	2.3	1144.9	81.4	58.9
Standard deviation	773.9	9.2	0.6	866.5	14.0	10.8
Confidence interval (95%)	479.7	5.7	0.4	537.0	8.7	6.7
Means for controlled burns	1145.5	19.6	2.4	796.9	88.6	50.5
Standard deviation	809.0	6.3	0.9	558.8	12.4	10.6
Confidence interval (95%)	260.7	2.0	0.3	180.1	4.0	3.4
INC-FGT T01 R02	1074.8	34.2	2.7	280.4	100.0	49.76
INC-FGT R02	1542.1	23.1	2.7	560.7	100.0	47.48
INC-FGT R03	1261.7	24.3	4.2	841.1	94.4	47.66

INC-FGT R04	934.6	21.6	2.6	654.2	92.9	42.43
INC-FGT R05	607.5	26.6	1.9	327.1	100.0	55.14
INC-FGT R06	934.6	24.4	5.0	934.6	100.0	41.29
INC-FGT mean values	1059.2	25.7	3.2	599.7	97.9	47.3
Standard deviation	319.2	4.5	1.2	265.0	3.3	5.1
Confidence interval (95%)	255.4	3.6	0.9	212.1	2.7	4.0
INC-DJ T01 R01	5560.7	22.5	1.0	140.2	100.0	71.48
INC-DJ T02 R01	14906.5	19.1	1.1	327.1	100.0	60.91
INC-DJ T02 R02	12243.0	2.0	0.0	0.0	NA	78.19
INC-DJ T03 R01	10093.5	11.8	0.8	467.3	100.0	80.64
INC-DJ T03 R02	8925.2	18.2	0.0	0.0	NA	81.58
INC-DJ T03 R03	4158.9	0.0	0.0	0.0	NA	89.19
INC-DJ mean values	9314.6	12.3	0.5	155.8	100.0	77.0
Standard deviation	4031.8	9.4	0.5	199.7	0.0	9.7
Confidence interval (95%)	3226.0	7.5	0.4	159.8	NA	7.8
Means for wildfire sites	5186.9	19.0	1.8	377.7	98.6	62.1
Standard deviation	5101.2	9.9	1.6	322.2	2.8	17.2
Confidence interval (95%)	2886.2	5.6	0.9	182.3	1.6	9.7
Mean for all sites combined	2135.2	19.5	2.3	694.3	90.5	53.5
Standard deviation	3088.3	7.2	1.1	539.6	11.9	13.4
Confidence interval (95%)	864.7	2.0	0.3	151.1	3.3	3.8

Appendix 4.D. Mean characteristics of pine seedlings and resprouts (*Pinus oocarpa*) in each sample plot at each site.

Sample Plot	**Seedling density (seedlings/ha)**	**Mean seedling height (cm)**	**Resprout density (resprouts/ha)**	**Mean height of tallest resprouting stem (cm)**	**Genets w/ at least one resprouting stem (%)**	**Mean # resprouting stems per sprouting genet**	**Mean root collar width (some callos) (cm)**
DJ RD T01 R01	0.0	NA	46.7	38.0	16.7	4.0	NA
DJ RD T02 R01	0.0	NA	373.8	39.1	44.4	7.6	12.1
DJ RD T03 R01	0.0	NA	0.0	NA	0.0	NA	NA
DJ RD T02 R02	46.7	7.0	373.8	30.9	47.1	1.1	3.2
DJ RD T05 R01	46.7	23.0	373.8	46.5	25.0	13.0	7.2
DJ RD T08 R01	46.7	37.0	46.7	NA	5.6	1.0	NA
DJ RD T09 R01	0.0	NA	93.5	13.0	28.6	2.5	2.0
DJ BR T11 R01	140.2	15.7	140.2	85.0	13.6	5.7	7.3
DJ BR T09 R01	0.0	NA	186.9	22.0	28.6	7.3	4.0
DJ BR T07 R01	0.0	NA	186.9	39.0	28.6	7.3	9.0
DJ BR T07 R02	0.0	NA	186.9	26.8	44.4	6.5	8.0
DJ BR T07 R03	0.0	NA	93.5	30.0	5.6	8.5	10.0
DJ BR T06 R01	794.4	22.3	420.6	34.9	29.0	5.0	8.8
DJ BR T06 R02	46.7	7.0	654.2	62.8	51.9	10.5	8.5
DJ BR T03 R01	0.0	NA	514.0	56.8	52.4	9.1	8.3
DJ BR T02 R01	46.7	20.0	46.7	52.7	9.1	6.0	8.3
DJ BR T05 R01	0.0	NA	841.1	37.6	54.5	3.3	6.3
DJ BR T05 R02	0.0	NA	327.1	38.0	43.8	2.3	6.8
DJ BR T04 R01	700.9	39.9	1308.4	32.5	41.2	3.6	8.4
DJ BR T04 R02	514.0	126.2	280.4	38.1	12.8	4.2	9.4

Sample Plot	Seedling density (seedlings/ha)	Mean seedling height (cm)	Resprout density (resprouts/ha)	Mean height of tallest resprouting stem (cm)	Genets w/ at least one resprouting stem (%)	Mean # resprouting stems per sprouting genet	Mean root collar width (some callos) (cm)
DJ RD T04 R01	0.0	NA	0.0	NA	0.0	NA	NA
DJ RD T06 R01	0.0	NA	0.0	NA	0.0	NA	NA
DJ RD T07 R01	0.0	NA	0.0	NA	0.0	NA	NA
DJ RD T07 R02	0.0	NA	514.0	28	42.3	8.4	9.7
DJ RD T10 R01	0.0	NA	186.9	52.2	18.2	10.3	7.0
DJ BR T10 R01	0.0	NA	0.0	NA	0.0	NA	NA
DJ BR T08 R01	1355.1	24	1588.8	32.6	41.5	4.3	6.4
DJ mean values	138.5	32.2		39.8	25.4	6.0	7.5
Standard deviation	324.4	34.7		15.6	19.0	3.2	2.4
Confidence interval (95%)	122.4	13.1		5.9	7.2	1.2	0.9
MP T01 R01	0.0	NA	93.5	107.0	25.0	3.5	11.5
MP T01 R02	0.0	NA	46.7	39.0	10.0	16.0	NA
MP T01 R03	0.0	NA	0.0	NA	0.0	NA	NA
MP T02 R01	0.0	NA	93.5	37.0	8.7	5.5	10.4
MP T02 R02	46.7	120	327.1	88.7	63.6	8.4	9.3
MP T02 R03	0.0	NA	327.1	83.3	35.0	7.0	12.2
MP T04 R01	0.0	NA	46.7	12.0	1.7	0.0	NA
MP T05 R01	46.7	27	747.7	57.8	37.2	6.6	11.4
MP T05 R02	0.0	NA	280.4	15.8	15.8	2.5	10.0
MP T06 R01	0.0	NA	233.6	64.6	16.7	6.8	19.0
MP mean values	9.3	73.5	219.6	56.1	21.4	6.3	12.0
Standard deviation	19.7	65.8	222.5	33.0	19.5	4.5	3.3
Confidence interval (95%)	12.2	40.8	137.9	20.4	12.1	2.8	2.0
INC-FGT T01 R02	467.3	15.4	373.8	36.0	34.8	4.9	.
INC-FGT R02	887.9	15.9	186.9	35.0	12.1	3.3	.
INC-FGT R03	327.1	18.3	0.0	NA	0.0	NA	.
INC-FGT R04	233.6	16.0	0.0	NA	0.0	NA	.

Sample Plot	Seedling density (seedlings/ha)	Mean seedling height (cm)	Resprout density (resprouts/ha)	Mean height of tallest resprouting stem (cm)	Genets w/ at least one resprouting stem (%)	Mean # resprouting stems per sprouting genet	Mean root collar width (some callos) (cm)
INC-FGT R05	0.0	16.0	46.7	36.0	7.7	7.0	.
INC-FGT R06	420.6	NA	0.0	NA	0.0	NA	.
INC-FGT mean values	389.4	16.3	101.2	35.7	9.1	5.0	no data
Standard deviation	295.0	1.2	151.9	0.6	13.6	1.9	no data
Confidence interval (95%)	236.1	0.9	121.5	0.5	10.8	1.5	no data
INC-DJ T01 R01	3644.9	15.8	1775.7	66.7	31.9	8.5	.
INC-DJ T02 R01	12056.1	14.6	2570.1	43.8	17.2	4.5	.
INC-DJ T02 R02	7663.6	16.2	4299.1	46.1	35.1	5.8	.
INC-DJ T03 R01	6308.4	12.5	3504.7	25.0	34.7	5.4	.
INC-DJ T03 R02	5467.3	14.1	3177.6	24.3	35.6	6.6	.
INC-DJ T03 R03	3598.1	77.0	560.7	12.0	13.5	12.0	.
INC-DJ mean values	6456.4	25.0	2648.0	36.3	28.0	7.1	no data
Standard deviation	3158.7	25.5	1331.5	19.7	10.0	2.7	no data
Confidence interval (95%)	2527.5	20.4	1065.4	15.7	8.0	2.2	no data
Mean for all sites	916.5	30.5	560.7	42.7	22.9	6.1	
Standard deviation	2342.7	32.6	951.9	21.6	18.1	3.3	
Confidence interval (95%)	656.0	9.1	266.5	6.0	5.1	0.9	

Appendix 4.E. Descriptive statistics for characteristics of tree-size *Pinus oocarpa* at the study site: genet density, tree density, diameter, basal area, percent single trunk trees, and canopy openness.

<table>
<tr><td colspan="7">Parameter: Genet density (genets/ha)</td></tr>
<tr><th>Site</th><th>Data range</th><th>Mean</th><th>Median</th><th>Mode</th><th>Standard deviation</th><th>Confidence interval (95%)</th></tr>
<tr><td>DJ</td><td>280-3832</td><td>1111</td><td>841</td><td>654</td><td>833</td><td>± 330</td></tr>
<tr><td>MP</td><td>373-2804</td><td>1238</td><td>1051</td><td>NA</td><td>774</td><td>± 554</td></tr>
<tr><td>INC-FGT</td><td>607-1542</td><td>1059</td><td>1005</td><td>935</td><td>319</td><td>± 335</td></tr>
<tr><td>INC-DJ</td><td>4159-14907</td><td>9315</td><td>9509</td><td>NA</td><td>4032</td><td>± 4231</td></tr>
<tr><td colspan="7">Parameter: Tree density (trunks/ha)</td></tr>
<tr><td>DJ</td><td>280-1636</td><td>668</td><td>561</td><td>561</td><td>330</td><td>± 130</td></tr>
<tr><td>MP</td><td>140-3131</td><td>1145</td><td>1145</td><td>NA</td><td>866</td><td>± 620</td></tr>
<tr><td>INC-FGT</td><td>280-935</td><td>600</td><td>607</td><td>NA</td><td>265</td><td>± 278</td></tr>
<tr><td>INC-DJ</td><td>0-467</td><td>156</td><td>70</td><td>0</td><td>200</td><td>± 210</td></tr>
<tr><td colspan="7">Parameter: Tree Diameter (dbh in cm)</td></tr>
<tr><td>DJ</td><td>6-27</td><td>20</td><td>21</td><td>NA</td><td>5.0</td><td>± 2.0</td></tr>
<tr><td>MP</td><td>10-29</td><td>18</td><td>14</td><td>NA</td><td>9.2</td><td>± 6.6</td></tr>
<tr><td>INC-FGT</td><td>22-34</td><td>26</td><td>24</td><td>NA</td><td>4.5</td><td>± 4.7</td></tr>
<tr><td>INC-DJ</td><td>0-22.5</td><td>12</td><td>15</td><td>NA</td><td>9.4</td><td>± 9.9</td></tr>
<tr><td colspan="7">Parameter: Basal Area (m^2/ha)</td></tr>
<tr><td>DJ</td><td>0.8-4.8</td><td>2.5</td><td>2.4</td><td>NA</td><td>1.0</td><td>± 0.4</td></tr>
<tr><td>MP</td><td>1.3-3.4</td><td>2.3</td><td>2.1</td><td>NA</td><td>0.6</td><td>± 0.4</td></tr>
<tr><td>INC-FGT</td><td>1.9-5.0</td><td>3.2</td><td>2.7</td><td>NA</td><td>1.2</td><td>± 1.2</td></tr>
<tr><td>INC-DJ</td><td>0.0-1.1</td><td>0.5</td><td>0.4</td><td>0.0</td><td>0.5</td><td>± 0.6</td></tr>
<tr><td colspan="7">Parameter: Percent single trunk trees</td></tr>
<tr><td>DJ</td><td>67-100</td><td>91</td><td>100</td><td>100</td><td>11</td><td>± 4</td></tr>
<tr><td>MP</td><td>58-100</td><td>81</td><td>80</td><td>100</td><td>14</td><td>± 10</td></tr>
<tr><td>INC-FGT</td><td>93-100</td><td>98</td><td>100</td><td>100</td><td>3</td><td>± 3</td></tr>
<tr><td>INC-DJ</td><td>100-100</td><td>100</td><td>100</td><td>100</td><td>0</td><td>± 0</td></tr>
<tr><td colspan="7">Parameter: Canopy openness (%)</td></tr>
<tr><td>DJ</td><td>29-69</td><td>48</td><td>47</td><td>NA</td><td>9</td><td>± 4</td></tr>
<tr><td>MP</td><td>39-75</td><td>59</td><td>58</td><td>NA</td><td>11</td><td>± 9</td></tr>
<tr><td>INC-FGT</td><td>41-55</td><td>47</td><td>48</td><td>NA</td><td>5</td><td>± 5</td></tr>
<tr><td>INC-DJ</td><td>61-89</td><td>77</td><td>79</td><td>NA</td><td>10</td><td>± 10</td></tr>
</table>

Appendix 4.F. Descriptive statistics for seedling and resprout characteristics of *Pinus oocarpa* at the study site.

Parameter: Seedling density (seedlings/ha)						
Site	**Data range**	**Mean**	**Median**	**Mode**	**Standard deviation**	**Confidence interval (95%)**
DJ	0-1355	138	0	0	324	± 128
MP	0-47	9	0	0	20	± 14
INC-FGT	0-888	389	374	NA	295	± 310
INC-DJ	3598-12,056	6456	5888	NA	3159	± 3315
Parameter: Seedling height (cm)						
DJ	7-126	32	23	7	35	± 25
MP*	27-120	73.5	73.5	NA	no data	no data
INC-FGT	15-18	16	16	16	1	± 1
INC-DJ	13-77	25	15	NA	25	± 27
* The MP site included only two observations, thus standard deviation and confidence interval are not calculated.						
Parameter: Percent of genets having at least one resprouting stem						
DJ	0-54	25	29	0	19	± 8
MP	0-66	21	16	NA	20	± 14
INC-FGT	0-35	9	4	0	14	± 14
INC-DJ	13-36	28	33	NA	10	± 10
Parameter: Number of stems per resprouting genet						
DJ	1-13	6	6	7	3	± 1
MP	0-16	6	7	NA	5	± 3
INC-FGT	3-7	5	5	NA	2	± 5
INC-DJ	5-12	7	6	NA	3	± 3
Parameter: Resprout density (resprouts/ha)						
DJ	0-1589	325	187	0	393	± 155
MP	0-748	220	164	93	223	± 159
INC-FGT	0-374	101	23	0	152	± 159
INC-DJ	561-4299	2648	2874	NA	1331	± 1397
Parameter: Height of tallest resprouting stem per genet (cm)						
DJ	13-85	40	38	38	16	± 7
MP	12-107	56	58	NA	33	± 25
INC-FGT	35-36	36	36	36	1	± 1
INC-DJ	12-66	36	34	NA	20	± 21
Parameter: Resprout root collar width (cm)						
DJ	2-12	8	8	8	2	± 1
MP	9-19	12	11	NA	3	± 3
INC-FGT	no data	no data	no data	no data	no data	no data
INC-DJ	no data	no data	no data	no data	no data	no data

Appendix 4.G. Post-burn char and scorch of *Pinus oocarpa* in each sample plot at each site.

Sample Plot	Fire source: C=controlled burn W=wildfire	Plot char height (m)	Plot scorch height (m)	Plot percent scorch
DJ RD T01 R01	C	<0.5	4	5
DJ RD T02 R01	C	<0.5	3	2
DJ RD T03 R01	C	<0.5	0	0
DJ RD T02 R02	C	0	0	0
DJ RD T05 R01	C	<0.5	2.5	15
DJ RD T08 R01	C	0	0	0
DJ RD T09 R01	C	.	.	.
DJ BR T11 R01	C	.	.	.
DJ BR T09 R01	C	.	.	.
DJ BR T07 R01	C	<0.5	0	0
DJ BR T07 R02	C	<0.5	2	2
DJ BR T07 R03	C	<0.5	3	20
DJ BR T06 R01	C	0	2	1
DJ BR T06 R02	C	0.5	2.5	5
DJ BR T03 R01	C	<0.5	1.5	5
DJ BR T02 R01	C	<0.5	0	0
DJ BR T05 R01	C	<0.5	1	1
DJ BR T05 R02	C	<0.5	1.5	2
DJ BR T04 R01	C	0.5	5	40
DJ BR T04 R02	C	0.5	3	10
DJ RD T04 R01	C	.	1.5	0
DJ RD T06 R01	C	0.5	4	40
DJ RD T07 R01	C	.	.	.
DJ RD T07 R02	C	.	.	.
DJ RD T10 R01	C	0.5	0	0
DJ BR T10 R01	C	.	.	.
DJ BR T08 R01	C	0	0	0
DJ mean values		0.3	1.7	7.0
Standard deviation		0.2	1.6	12.2
Confidence interval (95%)		0.1	0.7	5.3
MP T01 R01	C	<0.5	4	0
MP T01 R02	C	.	.	.
MP T01 R03	C	1	6	10
MP T02 R01	C	0.5	3	1
MP T02 R02	C	<0.5	3	1
MP T02 R03	C	0.5	6	55
MP T04 R01	C	.	.	.
MP T05 R01	C	0.5	7	30

Sample Plot	Fire source: C=controlled burn W=wildfire	Plot char height (m)	Plot scorch height (m)	Plot percent scorch
MP T05 R02	C	0.5	8	45
MP T06 R01	C	0.5	6	50
MP mean values		0.5	5.4	24.0
Standard deviation		0.2	1.8	23.7
Confidence interval (95%)		0.2	1.3	16.4
Controlled burn means		0.3	2.7	11.7
Standard deviation		0.2	2.3	17.5
Confidence interval (95%)		0.1	0.9	6.5
INC-FGT T01 R02	W	7	15	NA
INC-FGT R02	W	5	13	NA
INC-FGT R03	W	3	17	NA
INC-FGT R04	W	3	13	NA
INC-FGT R05	W	4	15	NA
INC-FGT R06	W	1	12	NA
INC-FGT mean values		3.8	14.2	NA
Standard deviation		2.0	1.8	NA
Confidence interval (95%)		1.6	1.5	NA
INC-DJ T01 R01	W	8	8	NA
INC-DJ T02 R01	W	7	13	NA
INC-DJ T02 R02	W	12	23	NA
INC-DJ T03 R01	W	4	12	NA
INC-DJ T03 R02	W	14	25	NA
INC-DJ T03 R03	W	15	20	NA
INC-DJ mean values		10.0	16.8	NA
Standard deviation		4.3	6.8	NA
Confidence interval (95%)		3.5	5.4	NA
Wildfire means		6.9	15.5	NA
Standard deviation		4.6	4.9	NA
Confidence interval (95%)		2.6	2.8	NA
All plot means		2.3	6.5	
Standard deviation		3.9	6.7	
Confidence interval (95%)		1.2	2.1	

*I estimated char height to the nearest 0.5 meter. When the char height was <0.5 meter, I calculated the standard deviation and confidence interval by substituting a value of 0.25 for the char height.

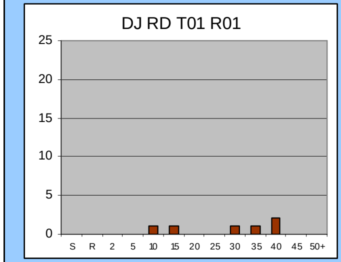
**It was not possible to estimate percent scorch in wildfire plots, because scorched needles had fallen off between the time when the wildfires occurred and the time of field sampling.

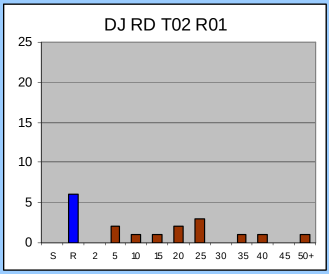
Appendix 4.H. Descriptive statistics for bark char and canopy scorch of *Pinus oocarpa*.

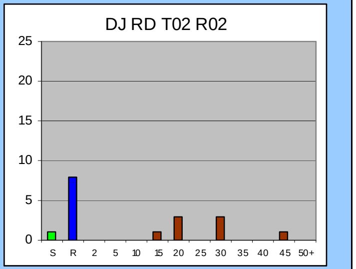
<table>
<tr><td colspan="7">Parameter: Post-burn char height (m)</td></tr>
<tr><td>Site</td><td>Data range</td><td>Mean</td><td>Median</td><td>Mode</td><td>Standard deviation</td><td>Confidence interval (95%)</td></tr>
<tr><td>DJ</td><td>0-0.5</td><td><0.5</td><td><0.5</td><td><0.5</td><td><0.5</td><td>± 0.1</td></tr>
<tr><td>MP</td><td>0.25-1</td><td>0.5</td><td>0.5</td><td>0.5</td><td>0.2</td><td>± 0.2</td></tr>
<tr><td>INC-FGT</td><td>1-7</td><td>3.8</td><td>3.5</td><td>3</td><td>2.0</td><td>± 2.1</td></tr>
<tr><td>INC-DJ</td><td>4-15</td><td>10</td><td>10</td><td>NA</td><td>4.3</td><td>± 4.6</td></tr>
<tr><td colspan="7">Parameter: Scorch height (m)</td></tr>
<tr><td>Site</td><td>Data range</td><td>Mean</td><td>Median</td><td>Mode</td><td>Standard deviation</td><td>Confidence interval (95%)</td></tr>
<tr><td>DJ</td><td>0-5</td><td>1.7</td><td>1.5</td><td>0</td><td>1.6</td><td>± 0.7</td></tr>
<tr><td>MP</td><td>3-8</td><td>5.4</td><td>6</td><td>6</td><td>1.8</td><td>± 1.5</td></tr>
<tr><td>INC-FGT</td><td>12-17</td><td>14.2</td><td>14</td><td>15</td><td>1.8</td><td>± 1.9</td></tr>
<tr><td>INC-DJ</td><td>8-25</td><td>16.8</td><td>16.5</td><td>NA</td><td>6.8</td><td>± 7.1</td></tr>
<tr><td colspan="7">Parameter: Percent of canopy scorched (%)</td></tr>
<tr><td>Site</td><td>Data range</td><td>Mean</td><td>Median</td><td>Mode</td><td>Standard deviation</td><td>Confidence interval (95%)</td></tr>
<tr><td>DJ</td><td>0-40</td><td>7</td><td>2</td><td>0</td><td>12.2</td><td>± 5.5</td></tr>
<tr><td>MP</td><td>0-55</td><td>24</td><td>20</td><td>1</td><td>23.7</td><td>± 19.8</td></tr>
<tr><td>INC-FGT</td><td>no data</td><td>no data</td><td>no data</td><td>no data</td><td>no data</td><td>no data</td></tr>
<tr><td>INC-DJ</td><td>no data</td><td>no data</td><td>no data</td><td>no data</td><td>no data</td><td>no data</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

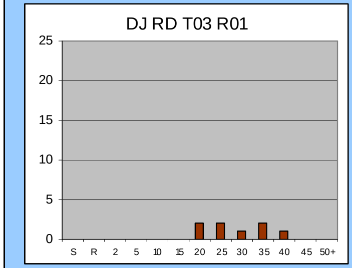
Appendix 4.I. Size class distributions of *Pinus oocarpa* in each sample plot

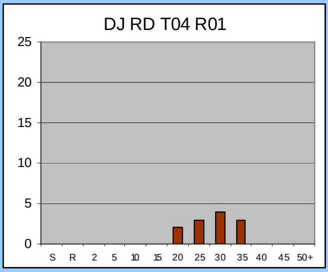
DJ Controlled Burn Site
n=27
Y-axis Scale = 0-25

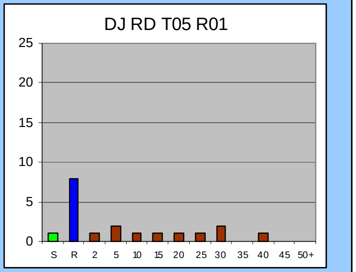


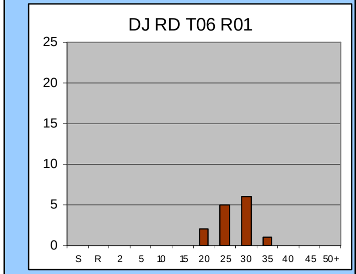


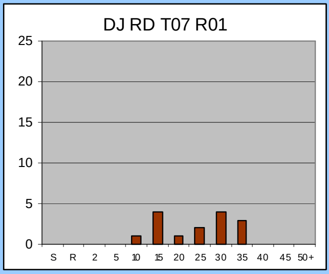


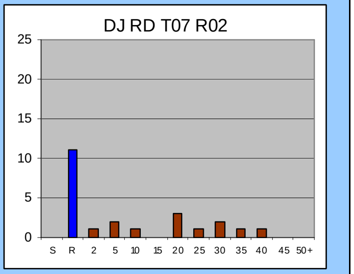


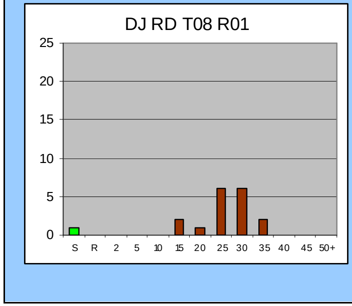


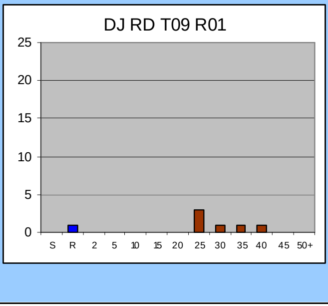


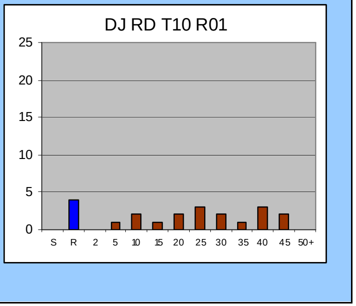




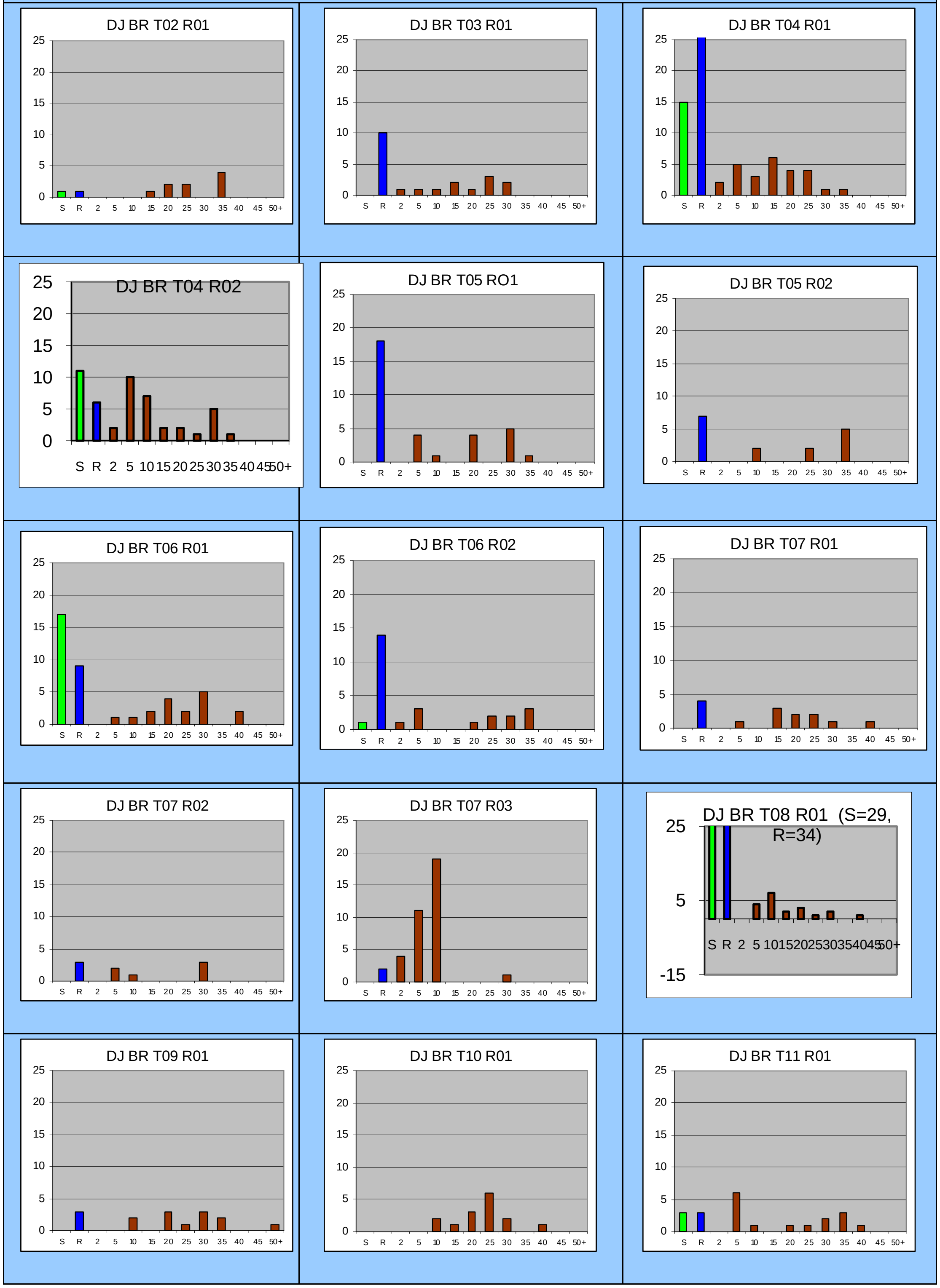




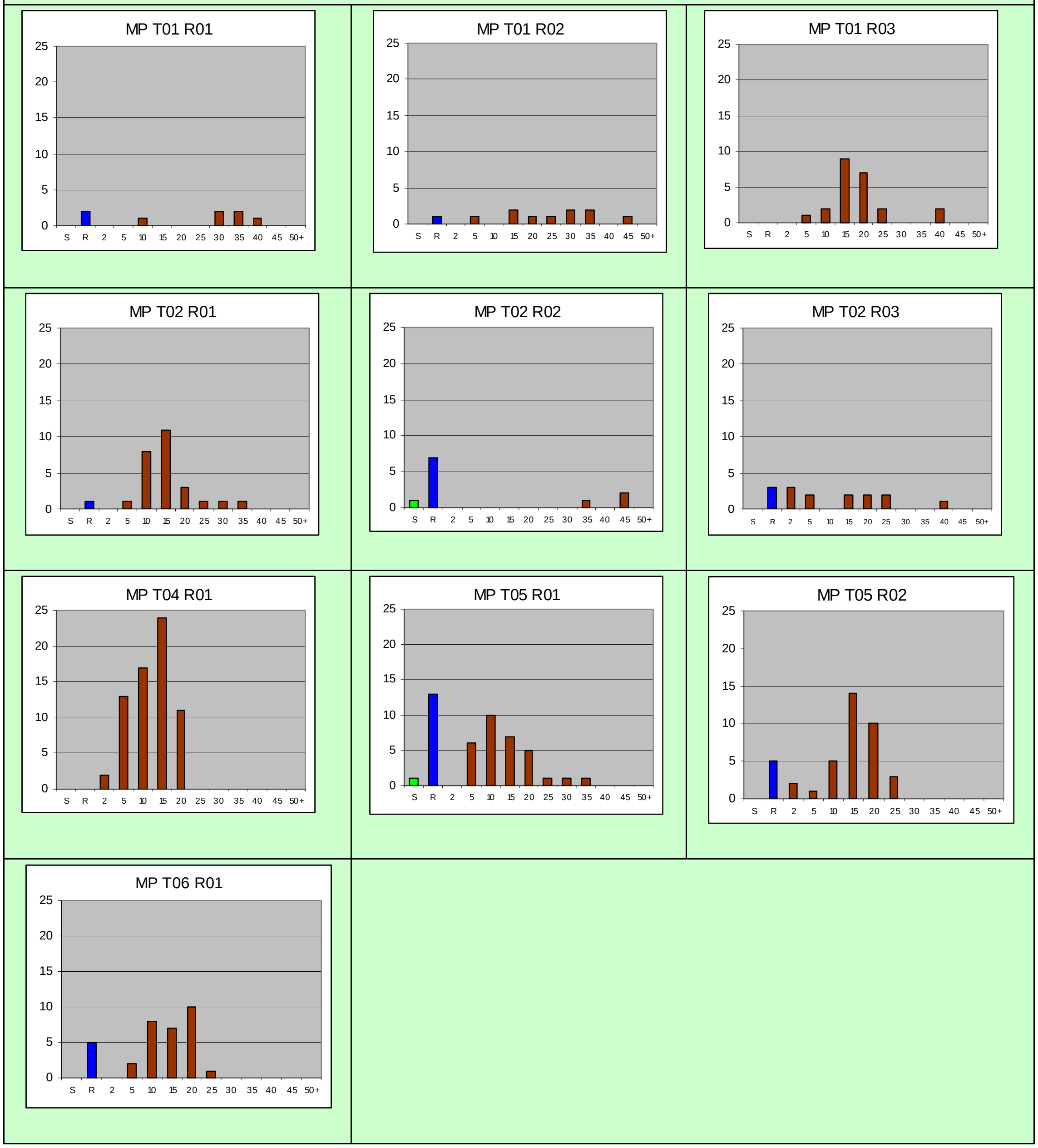




DJ Controlled Burn Site
n=27
Y-axis Scale = 0-25



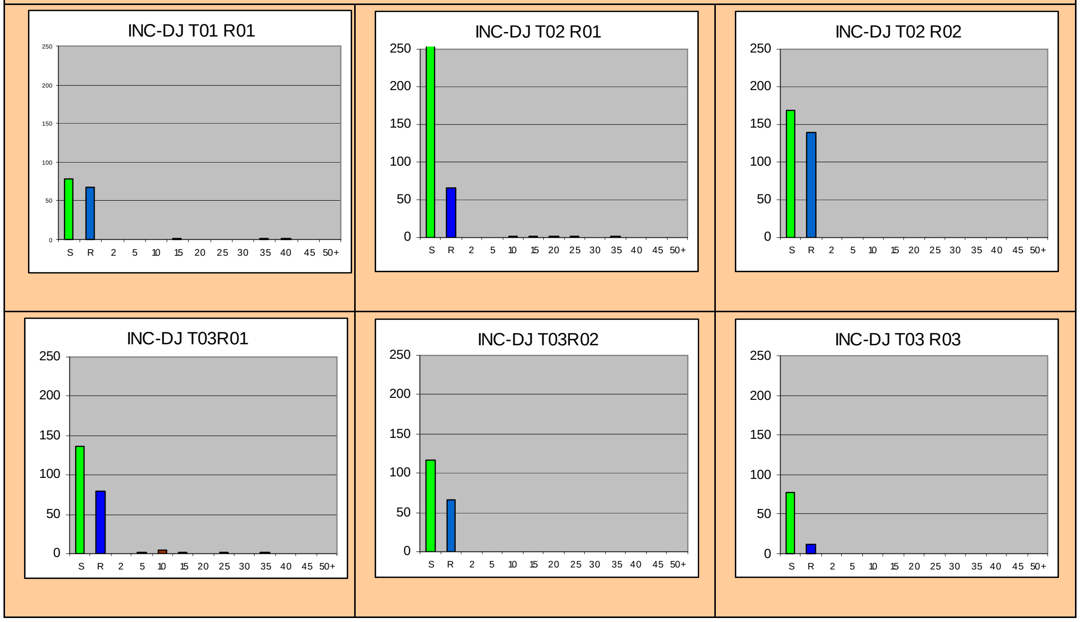
MP Controlled Burn Site
n=10
Y-axis Scale = 0-25



INC-DJ Wildfire Site

n=6

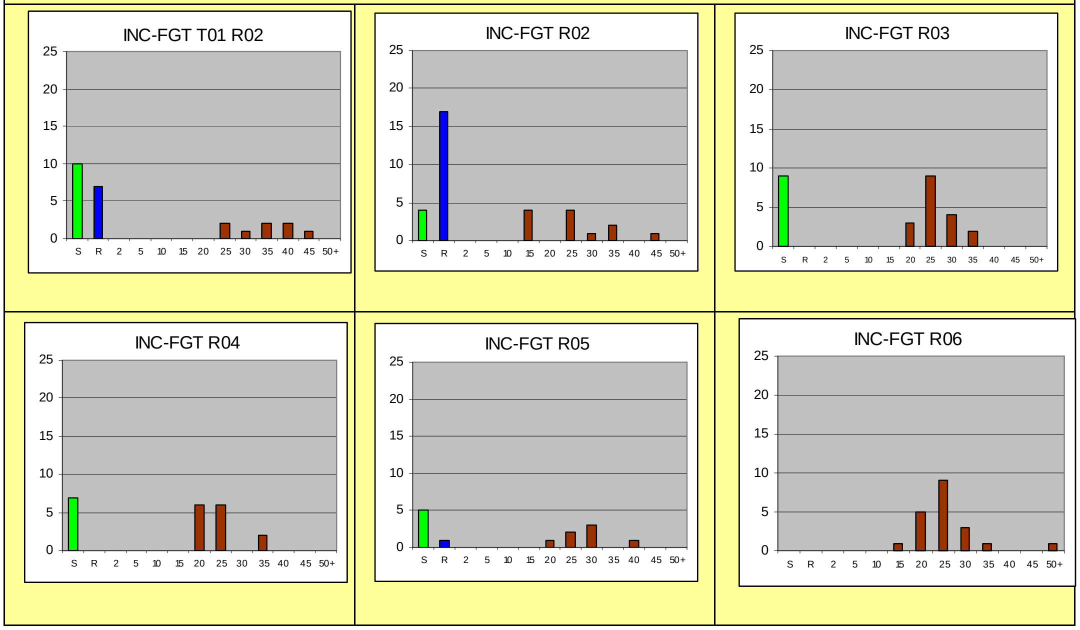
Y-axis Scale = 0-250



INC-FGT Wildfire Site

n=6

Y-axis Scale = 0-25



Chapter Five: Fuels and Pine Seedling Survival

Field assistant measures the depth of fuels and the GPS location of a pine seedling before a controlled burn.

This chapter addresses the following research objectives and hypotheses:

Objective 4. To elucidate the ecological mechanisms that affect the survival of pine seedlings as a result of traditional fire behavior.

Hypothesis 4.b. Traditional fire behavior results in significant top-kill of pine seedlings.

Hypothesis 4.c. Greater terminal bud height, low depth and cover of pine needle fuels, low proportion of needles to grasses in the fuel bed, and low slope will contribute in varying importance to small pine survival.

Objective 5. To test the effect of simple fuels treatments on pine seedling survival.

> Hypothesis 5.a. Simple fuel treatments to remove available fuels from around pine seedlings can reduce their top-kill.

5.1. Introduction

Studies of *Pinus oocarpa* in various locations indicate that seedlings of the species are fire-sensitive. Vogel (1954) emphasized that repeated wildfires were the biggest deterrent to *P. oocarpa* reproduction when he explored the forests of Honduras in 1953. In the early 1980s, Hudson and Salazar reviewed prescribed burning in Honduran pinelands and reported that young *P. oocarpa* trees can resprout, and that if the main stem of a seedling dies from fire, it also can resprout (Hudson and Salazar, 1981). Perry (1991) reported that *P. oocarpa* is exposed to frequent surface fires throughout most of its southern range (including Chiapas), and that young reproduction is often decimated.

Hudson and Salazar (1981) offered a variety of observations related to fire and *P. oocarpa* reproduction in Honduras:

- The timing of prescribed burning in forest management of *P. oocarpa* stands is important to seedling survival, because while burning prior to seed fall improves seedling establishment, burning afterward discourages seedling development.

- Seed fall occurs primarily in the dry season, from March through May, although some seeds also fall during the brief dry period (the canícula), which occurs in July or August in the middle of the wet season.

- Natural regeneration of *P. oocarpa* rarely occurs with any density in areas where the canopy is nearly closed.

- If a fire occurs in the dry season, the grasses do not grow substantially before the onset of the rainy season, and the pine seeds that fall suffer high mortality due to predation by birds and rodents.

- Fire behavior resulting from burning ocote pine litter has slow rates of spread and short flames (therefore, low fire intensity (Byram, 1959)) (Hudson and Salazar, 1981).

In the early stages of my fieldwork (May 2006), I wanted to explore what the producers said, that once *P. oocarpa* seedlings reach 1.5 to 2 meters tall, they usually survived a controlled burn, whereas shorter seedlings usually did not. At this early stage of my project, I was also working to build trust and credibility among the local communities in which I hoped to work. I wanted to explore the question of pine seedling survival using some technique that was quick, easy to conduct in the field and easy to understand within communities that were not accustomed to quantitative research. A key informant, and the owner of a parcel to be burned, indicated that a producer might be willing to spend a half-day taking simple measurements in a forest parcel. Accordingly, I crafted and conducted a simple analysis before and after the controlled burn (detailed in Section 5.2).

Much later, after observing traditional burning practices at the study site and the fire behavior generated by those practices, I realized that producers are already burning in a way that produces minimal fire behavior (Chapter Three). Reducing the intensity of controlled fires by changing fire operations or the burn prescription (e.g., ignition pattern or weather conditions), was not a likely solution to the problem of post-fire pine seedling survival. If producers were already keeping the temperature of the fires very low, limiting the time to which seedlings were exposed to lethal temperatures (60℃ according to Byram (2006)), then they were already doing as much with burning techniques as practically possible.

After puzzling over this, I reasoned that if it were not practical to appreciably alter the fire behavior then perhaps the solution would be to alter the fuel matrix itself. The basic fire intensity equation articulated by Byram (1959) indicates that reducing the weight of available fuel will reduce fireline intensity (heat output per unit time over a foot of fire front). I decided to test three simple fuels treatments, keeping in mind that producers have limited time and equipment for such an activity.

5.2. Methods

For the three experiments described in this chapter, I used the same definitions of ocote pine morphology for small pines as in the previous chapter:

- Seedling: a genet shorter than two meters that had a single, original stem and no sprouting stems.
- Resprout: a genet less than two meters tall with one or more sprouting stems arising from the root collar in addition to the original stem.

As before, I measured terminal bud height as the vertical height of the terminal bud above ground. If the seedling was leaning, I measured the height from the ground to the bud and not the length of the leaning stem.

5.2.1. Methods for Seedling Mortality Observation in 2006

Field data were collected using only a meter tape, meter stick, plastic flagging tape, notebook and pencil. Given the steep terrain, I first checked my 10 meter pacing for uphill, downhill and level ground. Starting from a random number of paces from the top corner of the parcel to be burned (named the SP site), a local assistant and I located 13 transects approximately 25 meters apart along the firebreak running along the top ridge of the parcel. Then we paced uphill or downhill along each transect, stopping every 25 meters to measure the distance to the nearest three pine seedlings from that sample point. We also measured height of the apical bud above the ground surface. Leaning seedlings were measured vertically from the ground to the apical bud. We measured heights and distances for nearest seedlings in 100 sample points. We conducted this procedure both before the controlled burn and afterward.

I selected the distances between transects and between sample points based upon my crude estimate of distances between seedlings that I saw, and upon the number of transects needed to sample 100 points in the small burn parcel. The distances I chose worked well for the pre-burn measures, but after the burn seedlings were more difficult to find and thus were farther from each sample point. This resulted in double sampling eight seedlings, counting once from one sample point and once from a neighboring point. In data analysis, I did not double count these eight seedlings in calculating the average seedling height, but I did use the two distances to the same seedling, since the distances were different, and since it was true that the nearest seedling was farther away in the post-burn setting.

Initial data analysis was simply to create scatter plots of the mean distance and mean seedling height for each set of three seedlings at each sample point, for both pre-burn and post-burn data (Figures 5.1 and 5.2). This provided a visual impression of both the height of the seedlings that survived the controlled burn and some indication of the density of surviving seedlings (shorter distances imply greater density). Then I calculated mean distances and heights for seedlings before and after the controlled burn and used a T-test to compare those means.

5.2.2. Methods for Simple Fuels Treatments

The three fuels treatments that I planned to test were 1) raking fuels away from within a circle around the seedling that was approximately one meter in radius. 2) spraying the seedling with water from a backpack sprayer prior to the arrival of the flames and 3) spraying the seedling with water and a surfactant (ordinary dish soap) from a backpack sprayer prior to the arrival of the flames.

Using equal numbers of colored marbles, drawn with replacement from a bowl, local assistants and I randomly assigned each of three treatments and a control to a series of pin flags (Figure 5.1a). Pin flags were of four colors representing the three treatments and a control. Assistants attached a numbered steel tag to each flag so that the assigned treatment and the individual seedling could be identified both before and after a controlled burn. (Figure 5.1b.).

To orient members of both communities and to ensure the safety of any livestock that might encounter a pin flag, I showed the colored flags with the numbered tags attached and explained the associated treatments to the owners of each parcel in which I had permission to conduct the experiment. I also explained the experiment to members of the project steering committee and to the general assembly of one community (Figure 5.1c.). Parcel owners assured me that either livestock would not be in the parcel before the burn, or that if livestock were present, the pin flags, flagging tape, and treatments would not cause any injury to their livestock

Local field assistants and I located every seedling we could find in six parcels within the two communities (Figure 5.1d.). We placed each pin flag at a distance of 0.25 m uphill from each seedling to minimize any heat impacts of the hot wire or burning plastic to seedlings as the flames passed. We also marked trees near the seedlings with simple flagging tape to enable us to locate seedlings rapidly during and after the fires.

Figure 5.1.a. Local assistants help select seedling treatments randomly with colored marbles.

Figure 5.1b. Local assistants attach numbered tags to colored pin flags according to the assigned treatments.

Figure 5.1c. Investigator explains the fuels treatments to producers at a community meeting at Valle de Corzo.

Figure 5.1d. Recording location, elevation and slope for each seedling.

Figure 5.1. Working with local community members to prepare and explain the fuel treatment experiment.

Each parcel was slated to be burned in the following days or weeks. We collected pre-treatment data and raked pine needles away from the seedlings in the fuel removal test group. My intent was to prepare as many seedlings as possible in various parcels to maximize the chance of gathering useful data in the event that a given parcel was burned.

In general, seedlings were so sparse that we marked every seedling we found. In the few locations in the DJ parcel where seedlings appeared to be unusually common, I omitted flagging some seedlings and moved on, in order to improve the spatial coverage of marked seedlings throughout the parcel. All together we flagged and collected pre-burn data on 200 seedlings (Table 5.1).

Table 5.1. Numbers of seedlings prepared and measured in each parcel slated to be burned.

Parcel	Control	Fuel Removal	Water	Water + Soap	Subtotals
MP	2	2	2	5	11
PS	5	3	5	4	17
AB	4	3	1	1	9
CC	14	10	10	7	41
DJ	25	21	19	23	88
SX	9	11	10	4	34
Subtotals	59	50	47	44	200

Pre-burn data collected for each seedling included GPS location, elevation, slope, terminal bud height, canopy base height, fuel characteristics and the intended treatment. Post-burn measures included the actual treatment received, percent scorch, scorch height, percent char, char height, bud appearance (green, brown or black) and characteristics of the remaining fuels.

To statistically compare the results among treatments and controls for the categorical data of post-burn pine seedling survival, I conducted a Chi-square analysis. The final sample sizes of seedlings in each of the test categories was not the same as was planned (See Results).

I also had the opportunity to visit three of the burn parcels a few weeks to a few months following the controlled burns. I visited the MP and the AB sites 19-33 days after the burn. I visited the MP and DJ sites eight months after the burn, in the dry season, in February of the following calendar year. For the few seedlings that I could relocate during these later visits, I recorded whether or not the seedling appeared to be living and whether or not it had resprouted. I also recorded the height of the seedling or the tallest resprouting stem. If I came across a new seedling that had germinated after the fire, I measured its height. I offer the results of these few, casual observations in Appendix 4.A., as feedback to my research assumptions and to guide suggestions for future research.

5.2.3. Methods for Fuel Characteristics and Post-fire Pine Seedling Survival

In addition to examining which simple fuels treatments affected pine seedling survival, I studied the potential relationship of 20 pre-burn and post-burn variables to seedling survival (Table 5.2.). I selected these variables based upon similar research conducted on a temperate Mexican pine species, *Pinus hartwegii*, by Vera-Vilchis and Rodríguez-Trejo (2007). Their research included both low and high intensity fires.

Cover classes of fuels included separate measures for bare ground, grasses, needles, woody material and other (usually leafy herbs). I defined a seedling's "canopy" as the group of needles growing at the top of its stem. I measured the depth and cover of fuels in 0.5 meter diameter circular plots, centered on each seedling. Fuels data included separate measures for pine needles, grasses, other vegetation, wood and bare ground.

For depth, I averaged four samples taken to the nearest centimeter in each plot, one sample from each quadrant of the plot where possible. To estimate cover, I used Daubenmire cover classes (Daubenmire, 1959), omitting the 95-100 percent cover class (Table 5.3). I used the 0-5 percent cover class because I wanted to record trace occurrences of woody debris that might affect fire behavior by increasing heat output and residence time, thereby influencing the fire's effect on a seedling. I did not use the

Table 5.2. Pre-burn and post-burn parameters sampled and tested for their possible relationship to pine seedling survival.

Site variables	**Pre-burn variables**	**Post-burn variables**
site	terminal bud height	percent scorch
elevation	canopy base height	percent char
slope	grass volume	grass consumption
	needle volume	green grass remaining
	cover of dead and down wood	blackened grass remaining
	cover of bare ground	needle consumption
	ratio of needles to grass	blackened needles remaining
		brown needles remaining
		dead and down wood
		bare ground

95-100 percent cover class typical of a Daubenmire classification. Having observed fuels and fire behavior, and the sensitivity of pine seedlings to the controlled burn conducted in 2006, I reasoned that, by the time a fire burned through a plot having 75-95 percent cover of any of the fuel types, an additional five percent cover (the 95-100 percent cover class) would not significantly affect the fire behavior or consequent fire severity.

Table 5.3. Cover classes used for characterizing each type of fuel surrounding seedlings in 0.5 meter diameter circular plots and the midpoint of each cover class used in data analysis.

Cover Class	Percent Cover	Midpoint percent used in calculation
1	0-5	2.5
2	5-25	15.0
3	25-50	37.5
4	50-75	62.5
5	75-100	87.5

Post burn measures included the actual treatment the seedling experienced (e.g., areas around some seedlings did not burn), stem char height, percent stem char, scorch height, percent of canopy scorched, apical bud appearance, depth of fuels remaining and cover classes of fuels remaining. The post-burn fuel measurements were taken in the same way as the pre-burn measures. Understanding that seedlings are small and their canopies sometimes contain only a few needles, I estimated canopy scorch in five broad consumption classes (Table 5.4). All pin flags and other flagging tape was removed immediately after the post-burn measures so that I could be sure that no harm would come to any livestock returned to the burned areas to graze.

Table 5.4. Scorch classes used as a measure of fire severity on pine seedlings.

Scorch Class	Definition
0	Not scorched
1	1-50% scorch
2	51-100% scorch
3	< 50% needles consumed
4	> 50% needles consumed
5	Stem consumed (totally gone)

With assistance from the Statistical Laboratory at Colorado State University, I developed a logistical model to test the relative importance of these 20 factors in pine seedling survival. Whereas I originally intended to include the factor, “resprouts with callos,” I did not locate enough true callos to include it in the analysis. Because both prescribed burns were low in intensity, I also dropped this factor from consideration.

I utilized two statistical software packages to examine the potential significance of these 20 variables to post-burn pine seedling survival: SAS version 9.2 and JMP version 7. For both analyses, the dependent variable was whether or not the terminal bud of a seedling appeared to be alive (green) or dead (brown or black) within a week after the fire.

I used the Partition procedure in JMP for exploratory data analysis, which identified the variables of slope, terminal bud height, canopy base height, and the ratio of pre-burn needles to grasses as the variables that best explain the seedling survival results.

After JMP identified these variables as ones that were suitable for inclusion in a statistical model, I examined these variables further. First I used the univariate procedure in SAS to examine normality and variability of the data for these four variables. Three of the variables, terminal bud height, canopy base height, and the ratio of pre-burn needles to grasses, were right skewed, so those data were transformed using a $\log_{10}$ scale.

Then I performed T-tests to compare means of various characteristics for seedlings that appeared alive (had a green apical bud) within a week after controlled burning with those that appeared dead within a week after controlled burning (had a brown or black apical bud).

The sample size for the first stage of data analysis (JMP) was 91 seedlings. For the T-tests performed in SAS, the sample size was 62 seedlings, which excluded seedlings that had received the fuel removal treatment prior to the burn. I had no pre-burn fuels data for the seedlings that were measured ad-hoc on the MY site, so they were not included. I was unsuccessful locating a few of the marked seedlings after the fire.

Finally, I used logistic regression in SAS to develop a model to predict the probability of seedling survival using the four variables. I ran both forward selection and backward elimination procedures in SAS. I then used results from this procedure to calculate the log odds ratio. Using the four variables to be tested for possible inclusion in the model, the formulas used for logistic regression and the log odds ratio are given below (Ott and Longnecker, 2001).

The logistic regression model is

$$p = \frac{e^{\beta o + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4}}{1 + e^{\beta o + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4}}$$

where:

p = the probability of occurrence of the binomial variable “seedling alive”

e = 2.71828 (the natural log = ln = $\log_e$)

βo = the intercept to the y-axis

$X1$ = slope

$X2$ = transformed (log10) terminal bud height

$X3$ = transformed (log10) canopy base height

X4 = transformed (log 10) ration of pre-burn needles to grasses

$\beta 1$ = the constant associated with the $X1$ variable

$\beta 2$ = the constant associated with the $X2$ variable

$\beta 3$ = the constant associated with the $X3$ variable, and

$\beta 4$ = the constant associated with the $X4$ variable.

The formula for the associated log odds ratio is:

$$\ln (p/1-p)) = \beta o + \beta 1X1 + \beta 2X2 + \beta 3X3 + \beta 4X4.$$

5.3. Results

5.3.1. Results for Seedling Mortality Observation

The general visual impression from the scatter plot (Figure 5.2.) was that the shorter, presumably younger seedlings that were present and closer together before the burn were “replaced” by taller, presumably older individuals spaced farther apart. Quantitatively, both the mean distance to the nearest seedling and the height of the nearest seedling differed at the SP site before and after the controlled burn (Figures 5.2 and 5.3). Using a 95% confidence interval, the mean distance to the nearest live seedling prior to the burn was 4.8 ± 0.6 meters, while the mean distance after the burn was 11.9 ± 0.7 m (p-value = 0.06229). The mean height of live seedlings before the burn was 0.42 ± 0.06 m, and after the burn it was 1.19 ± 0.06 m (p-value = 0.00701). In my sample, no seedling shorter than 0.50 m survived the controlled burn. While the results of this simple analysis do not contradict the local knowledge that once a seedling reaches 1.5 to 2 meters tall it is likely to survive a burn, they do provide a new lower height limit (a half meter), below which seedlings at the study site will not survive traditional controlled burning without being top-killed.

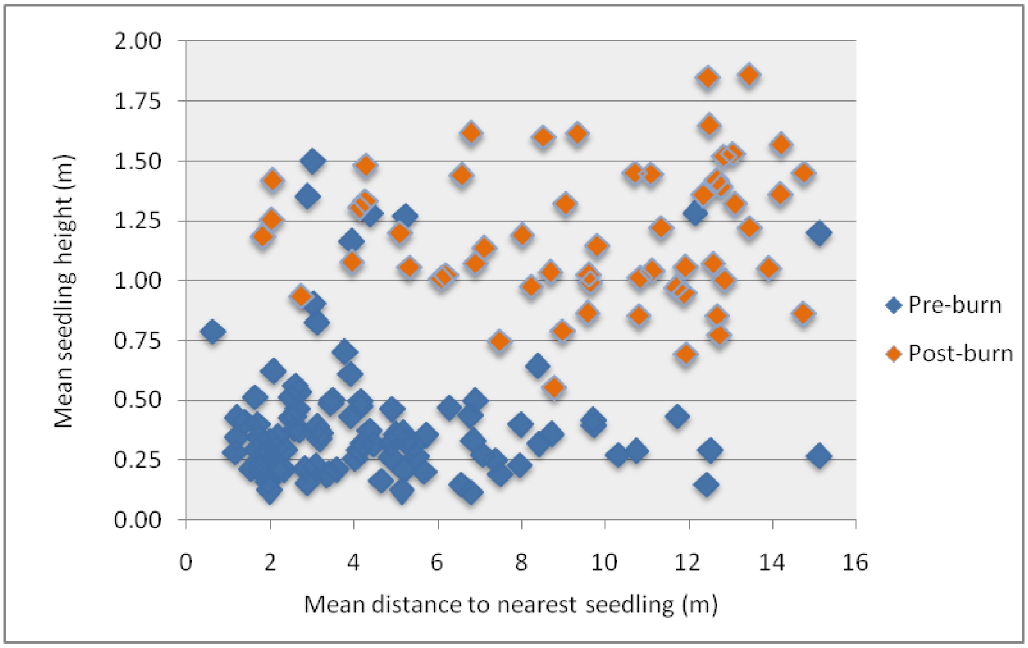


Figure 5.2. Scatter plot showing comparing the mean distance and mean heights of pine seedlings before and after controlled burn in the SP site in 2006.

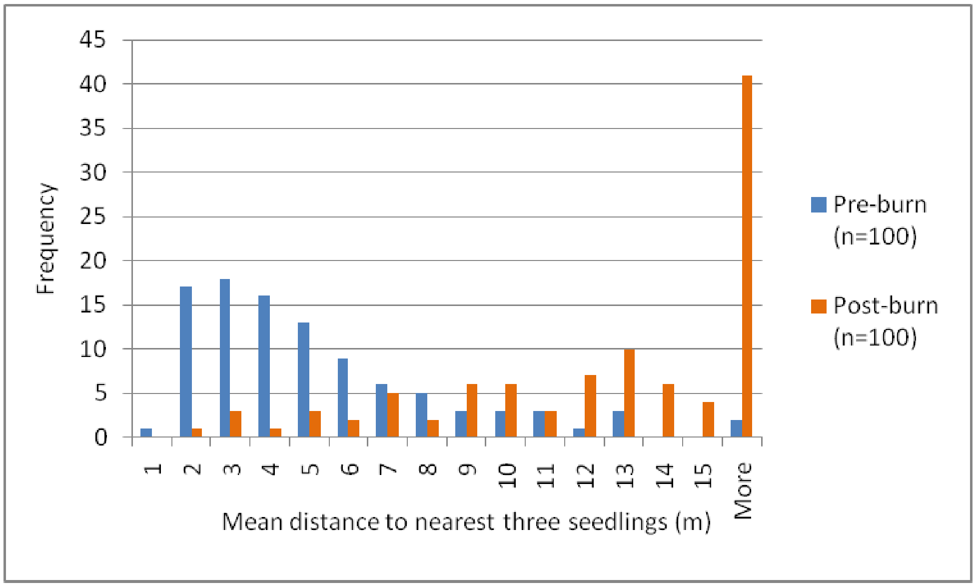


Figure 5.3. Distribution of the mean distance from sample points to the nearest three pine seedlings before and after the controlled burn in the SP site.

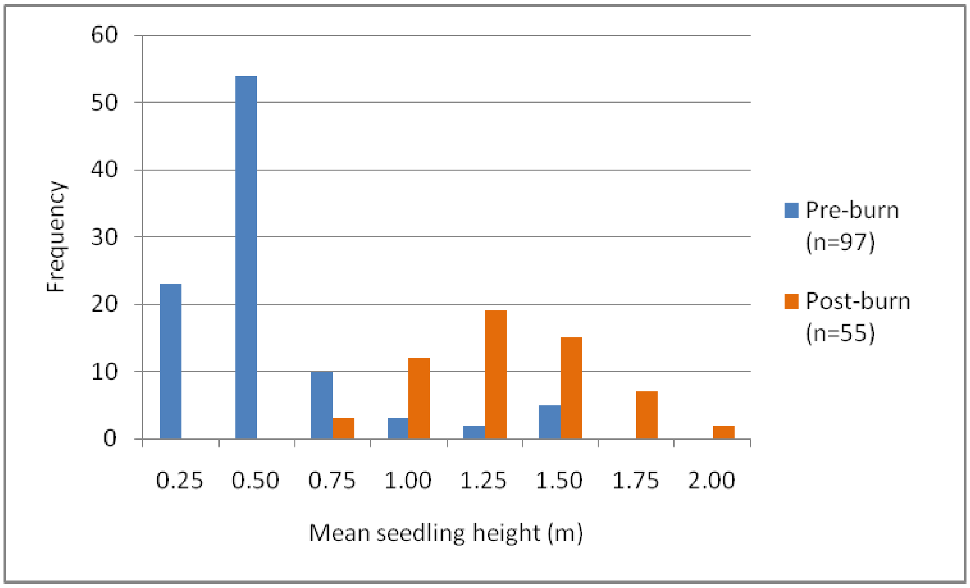


Figure 5.4. Distribution of mean seedling height for the three seedlings nearest to sample points before and after the controlled burn in the SP site.

5.3.2. Results for Fuel Characteristics and Pine Seedling Survival

Among the 91 seedlings used in the Partition procedure, 73 percent was killed in the fire and 27 percent survived. The first split made by the Partition procedure in JMP was based on the ratio of the pre-burn volume of needles to grass in the fuel bed. If the ratio was $\geq$ 1.25 (more needles than grasses), then 95 percent of the seedlings died in the fire. If the ratio was < 1.25, then 56 percent died and 44 percent survived. This split was statistically significant at the alpha = 0.05 level, with a p-value of 0.0439.

Further partitioning resulted in different second order splits for the two groups of seedlings: those with ratios of pre-burn volume of needles to grasses $\geq$ to 1.25 and those with ratios < 1.25. If the ratio of needles to grasses was $\geq$ 1.25, then slope was the next most influential factor. In this group, all seedlings located on slopes $\geq$ 12 degrees were killed in the fire. Twenty-two percent of the seedlings located on slopes of < 12 degrees survived. This split based upon slope had a p-value of 0.1031.

For seedlings with a fuel bed ratio of needles to grasses < 1.25, canopy base height was the next most influential factor (p-value = 0.1097). In this group, seedlings whose canopy base height was $\geq$ 29 cm had an 80 percent chance of survival, whereas seedlings whose canopy base height was < 29 cm had a 34 percent chance.

Next, using these variables of terminal bud height, ratio of pre-burn needles to grass, canopy base height and slope to build a multiple regression model in SAS, the only variable that met the 0.05 significance level for inclusion in the model was terminal bud height (p-value = 0.0068) (Table 5.5).

Table 5.5. Chi-square test results for four variables related to pine seedling survival. These variables were selected first by data partitioning and then evaluated using logistic regression.

Variable	Pr > Chi-square statistic
Terminal bud height	0.0068
Ratio of pre-burn needles to grass	0.2438
Canopy base height	0.4203
Slope	0.4761

Using the correlation procedure in SAS, I checked these four variables for correlation. Not surprisingly, terminal bud height and canopy base height were positively correlated, with a Pearson correlation coefficient of 0.94705 and a p-value < 0.0001. The other variables were not significantly correlated.

Among the 62 seedlings used in the T-tests, 82 percent appeared dead within a week after the fire and 18 percent appeared alive. The mean terminal bud height for the seedlings appearing alive was 0.57 ± 0.35 m, while the mean terminal bud height for seedlings appearing dead was 0.19 ± 0.03 m (95% confidence interval). Means and confidence intervals for the other three variables, slope, canopy base height and ration of pre-burn needles to grass, are provided in Table 5.4. Using an alpha level of 0.05, three of the four variables were significantly different for seedlings that appeared live after the fire compared to seedlings that appeared dead. These were terminal bud height ($p < 0.0008$), canopy base height ($p<0.0074$) and ratio of pre-burn needles to grass ($p<0.0411$) (Table 5.6).

Running both forward selection and backward elimination procedures in SAS generated the same model, which had only one significant factor: terminal bud height. Using this one factor, the logistic regression equation for estimating the probability of a seedling surviving was (Ott and Longnecker, 2001):

$$p = \frac{e^{\beta o + \beta 1 X1}}{1 + e^{\beta o + \beta 1 X1}}$$

where:

p = the probability of occurrence of the binomial variable “seedling alive”

e = 2.71828 (the natural log = ln = $\log_e$)

βo = the intercept to the y-axis = -6.7181

$\beta 1$ = the constant associated with the $X1$ variable = 3.8122

$X1$ = transformed (log10) terminal bud height

Table 5.6. Characteristics of seedlings that appeared alive (had a green apical bud) within a week after controlled burning with those that appeared dead (had a brown or black apical bud). (n=62).

	Seedlings appearing alive			Seedlings appearing dead			T-test
Factor	Sample size	Mean	Standard error	Sample size	Mean	Standard error	P-value
Slope (degrees)	11	14.5 ± 4.2	2.1378	51	15.9 ± 1.7	0.8733	0.4996
Terminal bud height (m)	11	0.57 ± 0.35	1.3614	51	0.19 ± 0.03	1.0859	0.0008
Canopy base height (m)	11	0.31 ± 0.12	1.2981	51	0.15 ± 0.03	1.1087	0.0074
Ratio of pre-burn volume of needles to grass (cm^3)	10	0.73 ± 0.50	1.6118	49	9.6 ± 13.3	1.2865	0.0411

Substituting model results into the equation, we find that the estimate of p, the probability that a seedling will survive a controlled burn, is:

$$\frac{2.71828^{(-6.7181 + (3.8122 \text{ x log10 terminal bud height}))}}{1 + 2.71828^{(-6.7181 + (3.8122 \text{ x log10 terminal bud height}))}}$$

For example, the probability that a seedling with a 60 cm terminal bud height will survive a controlled burn is 52 percent, as calculated below. The graphic representation of this model is provided in Figure 5.5.

$$p = \frac{2.71828^{(-6.7181 + (3.8122 \text{ x log10 } (60)))}}{1 + 2.71828^{(-6.7181 + (3.8122 \text{ x log10 } (60)))}}$$

$$= \frac{2.71828^{(-6.7181 + (3.8122 \text{ x } 1.778151))}}{1 + 2.71828^{(-6.7181 + (3.8122 \text{ x } 1.778151))}}$$

$$= \frac{2.71828^{(0.060568)}}{1 + 2.71828^{(0.060568)}}$$

$$= \frac{1.06244}{1 + 1.06244}$$

$$= 0.52$$

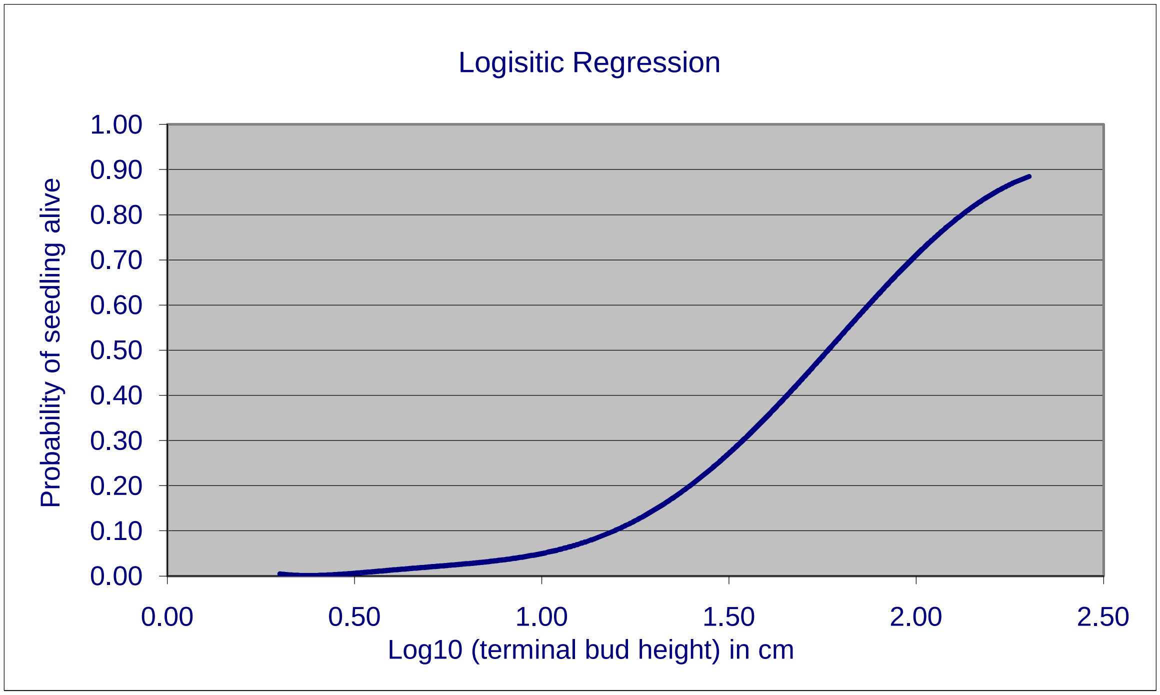


Figure 5.5. Graphic representation of the logistic regression model for the probability that a seedling will appear alive (have a green bud) after controlled burning.

The formula for the associated log odds ratio is:

$$\ln (p/(1-p)) = \beta o + \beta 1X1.$$

For example, if a practitioner wants the odds of a seedling surviving to be three to one (equivalent to 75 percent survival), the estimated terminal bud heights would need to be 112 cm, as calculated below.

$$\ln (0.75/(1- 0.75)) = -6.7181 + 3.8122 (X1)$$

$$\ln (3) = -6.7181 + 3.8122 (X1)$$

$$1.098612 = -6.7181 + 3.8122 (X1)$$

$$7.1816712 = 3.8122 (X1)$$

$2.050447 = (X1) = \log 10$ terminal bud height

$10^{2.050447}$ = terminal bud height

112 cm = terminal bud height.

5.3.3. Results for Simple Fuels Treatments

Only two of the six parcels where I had flagged and measured seedlings were burned in such a way that the simple fuels treatments I had designed could be tested. One parcel (the AB parcel) was burned without my knowledge and three other parcels were not burned because the value of the forage became too great as the season progressed. During the two burns in which I participated, the crew and I discovered that both the water and the water + soap treatments were impractical. Producers who had access to the limited number of backpack pumps preferred to use them to extinguish the burning bark of large trees rather than to treat seedlings. In the end, I was able to measure enough seedlings to compare results only for the pre-burn fuels removal treatment and the controls. Because most seedlings that were originally slated for water or water + soap did not actually receive their treatments, these effectively became controls (Table 5.7).

Toward the end of the second to last burn, which was in the DJ parcel, a community elder demonstrated another treatment. This was to clear away the fuels from around the seedling with a machete and then to carefully fold over the seedling and cover it with a pile of freshly cut green leaves. Both seedlings that he treated this way survived the burn with zero percent char and zero percent scorch.

In a late attempt to further examine the effect of this treatment, I treated seven seedlings and two resprouts in a similar way, ad-hoc during a final burn in a new parcel, which I was invited to observe on short notice. Using a few resprouts as surrogates for seedlings was a last ditch effort, assuming that bark char and terminal bud damage would be similar for seedlings and resprouts. Using only machetes, a field assistant and I cleared vegetation from around each individual and covered it with a pile of freshly cut leafy green vegetation. For resprouts serving as seedling surrogates, we cut away all but a single stem from the plant. I had very little time to find seedlings prior to the burn, and I had only time to flag them and to prepare the one treatment of clearing fuels and covering seedlings with leafy green vegetation. I did not have time to measure any of the seedlings or fuels prior to the burn. After the burn I was able to locate additional seedlings and resprouts that had not been treated to measure and use as *de facto* controls.

Despite the difficulties in preparation, eight of the nine individuals that I treated survived the burn with less than ten percent scorch. All had green apical buds after the fire, and none had any stem char. Upon closer inspection, the genet that incurred 30 percent scorch had been only partially covered with green leafy vegetation prior to the burn, leaving some needle tissue exposed to the fire.

The appearance of various seedlings after the burn is shown in Figure 5.6. Despite low-intensity fires and partial fuel consumption, seedlings most often sustained damage to their bark, needles and buds (Figure 5.6a.). Some seedlings had most of their needles scorched but had a green bud remaining (Figure 5.6b.); others had their needles consumed but a green bud remaining (Figure 5.6c.). Some seedlings were almost totally consumed, but I found the blackened terminal bud near the pin flag (Figure 5.6d.).

Table 5.7. Actual treatments of seedlings in parcels that were burned. Three of the parcels with pre-burn data were not burned (SX, CC and PS). One additional parcel was burned on short notice (MY) and I treated seedlings as I located them minutes before and even during the burn. The only treatment in the MY parcel was removing fuel and covering seedlings with green leaves, plus controls observed after the burn.

Site name	Control	Fuel removal	Water	Water + Soap	Leafy cover and fuel removal	Subtotal
MP	1	2	4	3	0	10
AB	10	0	0	0	0	10
DJ	52	27	2	0	2	83
MY	9	0	0	0	9	18
Subtotals	72	29	6	3	11	121

Figure 5.6a. Typical appearance of fuels and seedlings after controlled burning.

Figure 5.6b. Young seedling with nearly complete scorch but a green bud post burn.

Figure 5.6c. Older seedling with needles consumed leaving only fascicles and a bud protected by bud scales.

Figure 5.6d. Charred remnant of small seedling.

Figure 5.6e. Young seedling that survived in the fuels removal treatment .

Figure 5.6f. Older seedling that did not survive in the fuels removal treatment.

Figure 5.6g. Ad-hoc treatment of clearing fuels from around a seedling and covering it with fresh green leaves. Photograph is after the fire.

Figure 5.6h. Appearance of small seedling after the covering of green leaves is removed.

Figure 5.6. Post-fire appearance of various seedlings in the fuel treatment study.

Table 5.8. shows the counts and percents of seedling survival in each treatment and the control. The poorest survival result was for the control, with 82 percent of the seedlings appearing dead after the controlled burn. Removing fuel only resulted in survival of slightly less than half of the seedlings (48 percent).

Using an alpha level of 0.05, the survival of seedlings was significantly higher in the fuels treatment than in the control (p-value = 0.0019). Because the seedlings treated in the fuel removal + green leafy cover were not selected randomly as part of the general sampling scheme, I cannot statistically compare the results of this treatment with the others. It is interesting to note, however, that 100 percent of these seedlings survived.

Table 5.8. Post-fire seedling appearance for two fuel removal treatments and a control (n = 112).

Seedling count **Percent within rows** **Percent within columns**	**Fuel removal only**	**Fuel removal plus cover of green leaves**	**Control**	**Subtotal**
Bud alive	**14** **37** **48**	**11** **29** **100**	**13** **34** **18**	**38** **100**
Bud dead	**15** **20** **52**	**0** **0** **0**	**59** **80** **82**	**74** **100**
Total	**29** **100**	**11** **100**	**72** **100**	**112**

Figure 5.7 shows the levels of scorch and char exhibited by seedlings receiving different fuels treatments. On average, seedlings in the control group experienced 96 ± 4 percent needle scorch and 59 ± 7 percent bark (stem) char (95 percent confidence intervals). The percent scorch dropped to 76 ± 16 percent in the fuel removal treatment, and char dropped to 1 ± 2 percent. In the *ad hoc* fuel removal + green leaf cover treatment, the average percent char was zero and scorch declined to 4 ± 6 percent.

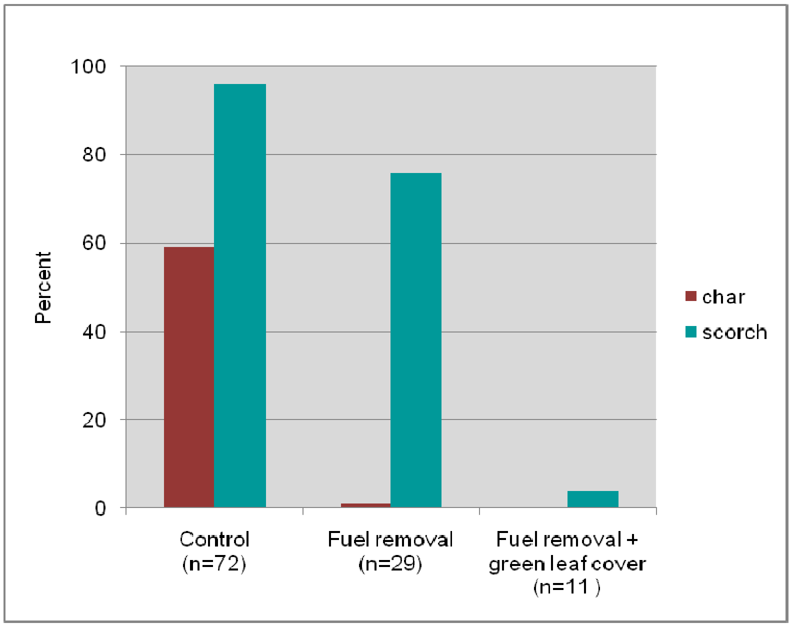


Figure 5.7. Mean percent char and scorch for seedlings treated with two simple fuel treatments (fuel removal only and fuel removal + green leaf cover), compared to seedlings in the control group.

5.3.4. Ancillary Observations of *P. oocarpa* Seedlings One Day after Controlled Burning, and again 19-33 Days after Controlled Burning.

During the course of the study, I revisited two of the controlled burn sites within 19-33 days post-fire. I located a few of the seedlings that I had measured one day post-fire and I noticed changes from my initial post-burn assessment of seedling condition (Figure 5.8). First, some of the apical buds that appeared green one day after the fire had since turned brown or black. Had I waited longer after the burn to assess it effects, I would have labeled these seedlings as dead. Second, several of the seedlings had resprouted.

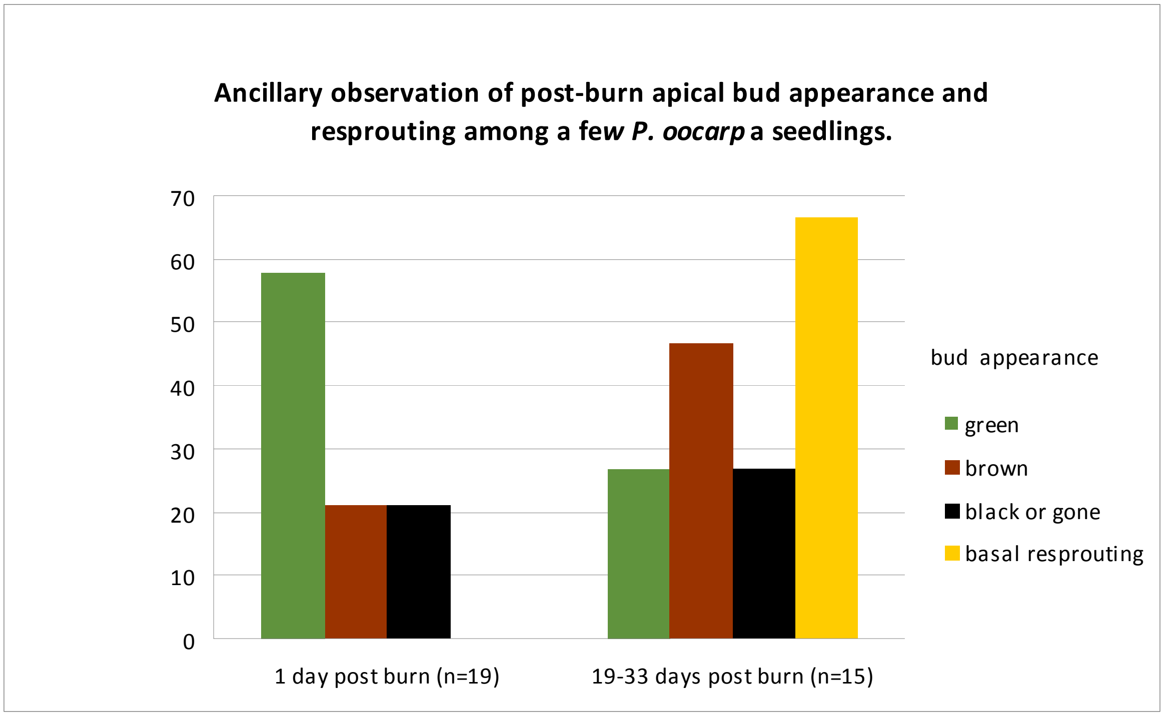


Figure 5.8. Comparison of apical bud appearance and resprouting of a few seedlings, one day post-burn (n=19) and 19-33 days post-burn (n=15). The y-axis represents the percent of genets measured on each date.

5.3.5. Ancillary Observations of *P. oocarpa* Seedlings and Resprouts Seven to Eight Months after Controlled Burning.

In January of 2009, seven to eight months after the controlled burns, I had a half-day to revisit the MP site and the DJ site. I had removed all flagging and tags from each site. Still, I was able to relocate 40 seedlings that I had studied in May-June of 2008, thirty in the DJ site and ten in the MP site. Thirty-seven of these had appeared dead (terminal bud brown or black) during my original post-burn assessment, which took place within a week of the controlled burns.

I was able to locate these genets because they had resprouted, making them visible. They had an average of 3.8 resprouting stems per plant. While the average height of the original seedlings was 23.5 ± 3.7 cm, the average height of the tallest resprouting stem arising from the same plants was 17.2 ± 3.0 cm (95 percent confidence interval) (Figure 5.9a). Resprouting individuals recovered from 10 to 363 percent of their pre-burn height, with an average of 87 percent (Figure 5.9b.). In eight cases, the height of the tallest resprouting stem exceeded the height of the original seedling. Root collar widths for these resprouting genets were not large; they ranged from 0.4 to 5 cm, with an average of 1.6 ± 0.4 cm (95 percent confidence) (Figure 5.10c). While I do not know the ages of these genets, it was apparent that a pine seedling less than 10 cm tall with a root collar of less than a centimeter wide had the capability to resprout.

For comparison, I also located 39 new seedlings in the two sites, which had germinated after the controlled burns. I was interested to see how tall the new seedlings had grown in comparison to the resprouting genets. The mean height for new seedlings was 10.2 ± 1.1 cm (95 percent confidence).

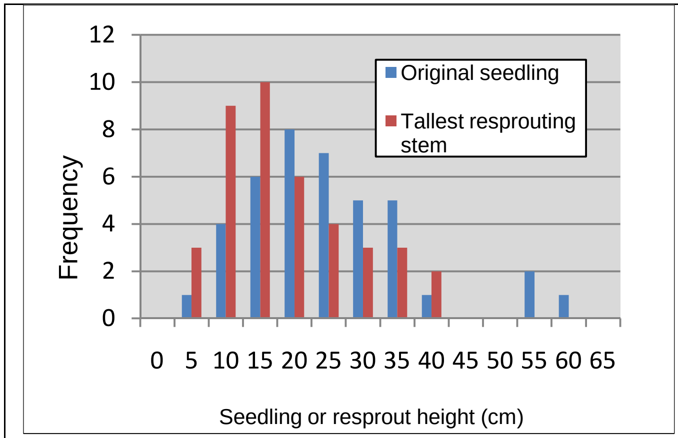


Figure 5.9a. Comparison of heights of the original seedlings and the tallest resprouting stem of the same plant within eight months of controlled burning.

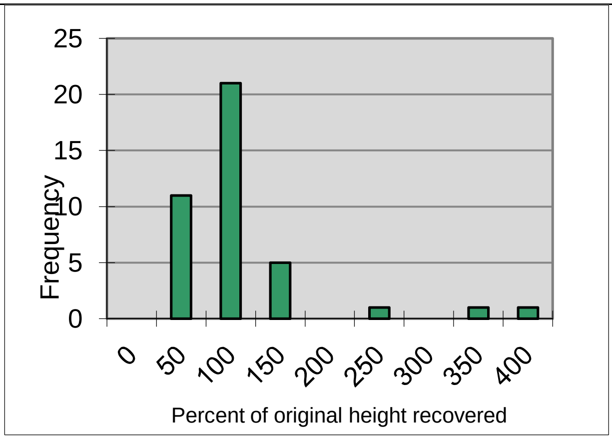


Figure 5.9b. Height recovery of seedlings that were burned in May-June of 2008 and re-measured as resprouting individuals in January 2009.

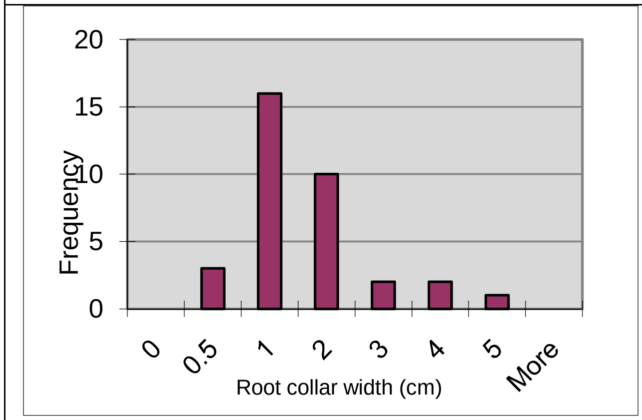


Figure 5.9c. Mean root collar width of genets that resprouted after the controlled burn.

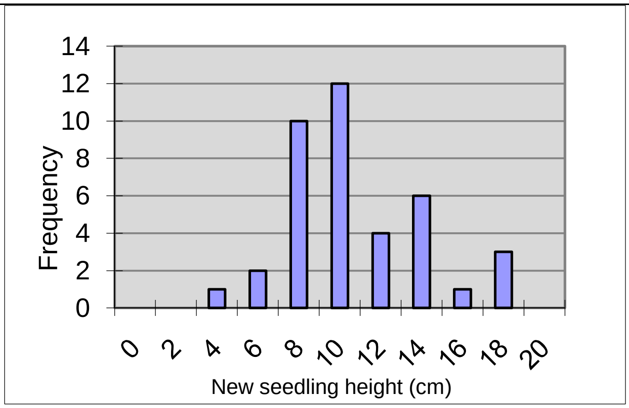


Figure 5.9d. Distribution of heights of new seedlings that germinated after the controlled burn.

Figure 5.9. Ancillary observations of heights and root collar widths in seedlings and resprouts after controlled burning.

5.4. Discussion

As in other places in Mesoamerica, ocote pine seedlings are susceptible to even low intensity fire (Vogel, 1954, O'Brien et al., 2008). The physiological nuances of fire-sensitivity in this pine species are not well known, but studies of seedling mortality are available for other pine species.

If the specifics of seedling mortality were important to know, I would recommend further study of the heat output from typical fuels found around seedlings at the study site, particularly *P. oocarpa* needles, in different seasons and under different moisture conditions. I would utilize one of the different methods (thermocouples, temperature sensitive paints, infrared photography) to detect the temperature profile experienced by the seedlings and the surface soil with the passage of flaming fronts of different intensities. I would also compare residence times of flames affecting pine seedlings when fires are burning uphill versus downhill to see how long the seedling tissue is being subjected to lethal temperatures.

However, in this case where generating practical results is a priority, I would focus more on what else producers can do to enhance post-fire seedling survival. Finding in this study that terminal bud height is an important factor in seedling survival, I would test what bud height is critical to ensuring seedling survival, so that producers could casually look at the seedlings in their parcels to help decide whether or not it was time to burn (for a more detailed study in ponderosa pine, see Battaglia et al., 2009). The current suggestion by reserve staff is to allow three years after a fire, without either grazing or burning, for seedlings to get established, but this idea has not been adopted by the producers (J. Cruz-López, pers. com., June 2008, Corazón del Valle).

While sampling design and sample sizes were inadequate to provide statistical evidence, the only method I observed that appeared to be consistently able to protect seedlings from fire damage was removing the fuels and covering the seedlings with a protective layer of leafy green vegetation. Because this method is quick, easy and inexpensive, it may be practical for producers to use if they continue to worry about pine seedling survival. I heartily recommend that someone, perhaps the producers themselves, conduct a follow-up experiment to test this method more fully.

Chapter Six: Conclusion

6.1. Evaluation of the Conceptual Model

In conclusion, the fire system model that I produced was very useful for exploring and describing the essential realities of the community-based fire management system of the ejidos Corazón del Valle and Valle de Corzo within La Sepultura Biosphere Reserve. Key findings from this application include that producers have extensive traditional fire knowledge, that local people control the fire regime and the fuel loads of the tropical pine-oak forests, and that their burning practices result in low intensity fire behavior that, under normal circumstances, allows fire to be controlled using only local expertise, labor and common hand tools.

Using this system model also helped me to realize that the fire regime local people have developed over time, frequent low-intensity burning early in the rainy season (accompanied by moderate grazing), serves to maintain the tree density, size class structure and predominance of reproduction via vegetative resprouting that characterize their forests today.

When asked by one of the funding partners to make recommendations for training fire practitioners in PNAs in Mexico, the model provided me a unique perspective. Understanding that the fire regime was controlled by local producers who learned traditional practices from their elders outdoors, I designed a training program that used mentoring by elders in the outdoors as the primary learning approach (Appendix 3.F).

Finally, the model enabled me to tease out possible management alternatives that could increase the survival of pine seedlings. These included fuel removal around pine seedlings, selective tree removal, or using fires of varying intensity to create canopy openings. Each of these treatments would, of course, need to be agreed upon by producers and reserve managers.

6.2. Realizations about the Loss of Traditional Fire Knowledge and the Value of Traditional Burning

Ancillary to the research objectives, I also used the model to guide my thinking about fire management at the regional, national and global scales. I subjectively evaluated the common perception that a majority of campesino fires escape, and that they escape due to ignorance or carelessness. I realized that, to the extent that the local fire practices I observed are repeated throughout the region, local producers in Mexico are providing a nationwide service of fuels management that is absent in the United States. To maintain this cost-effective service, retaining and sharing traditional fire knowledge throughout the country as demographics change could be important. Loss of traditional fire knowledge among traditional groups in Latin America is not without precedent. Mistry et al. (2005) describes the complaints of Krahô elders regarding burning the cerrado of Brazil. As the younger generations are eager to be in contact with and learn from contemporary Brazilians, they adopt the message that fire is bad for the environment. As a result, “youngsters are gradually losing their traditional knowledge, including that pertaining to fire management.” (Mistry et al., 2005, p 379).

6.3. Traditional Fire Management and Vulnerability to Climate Change

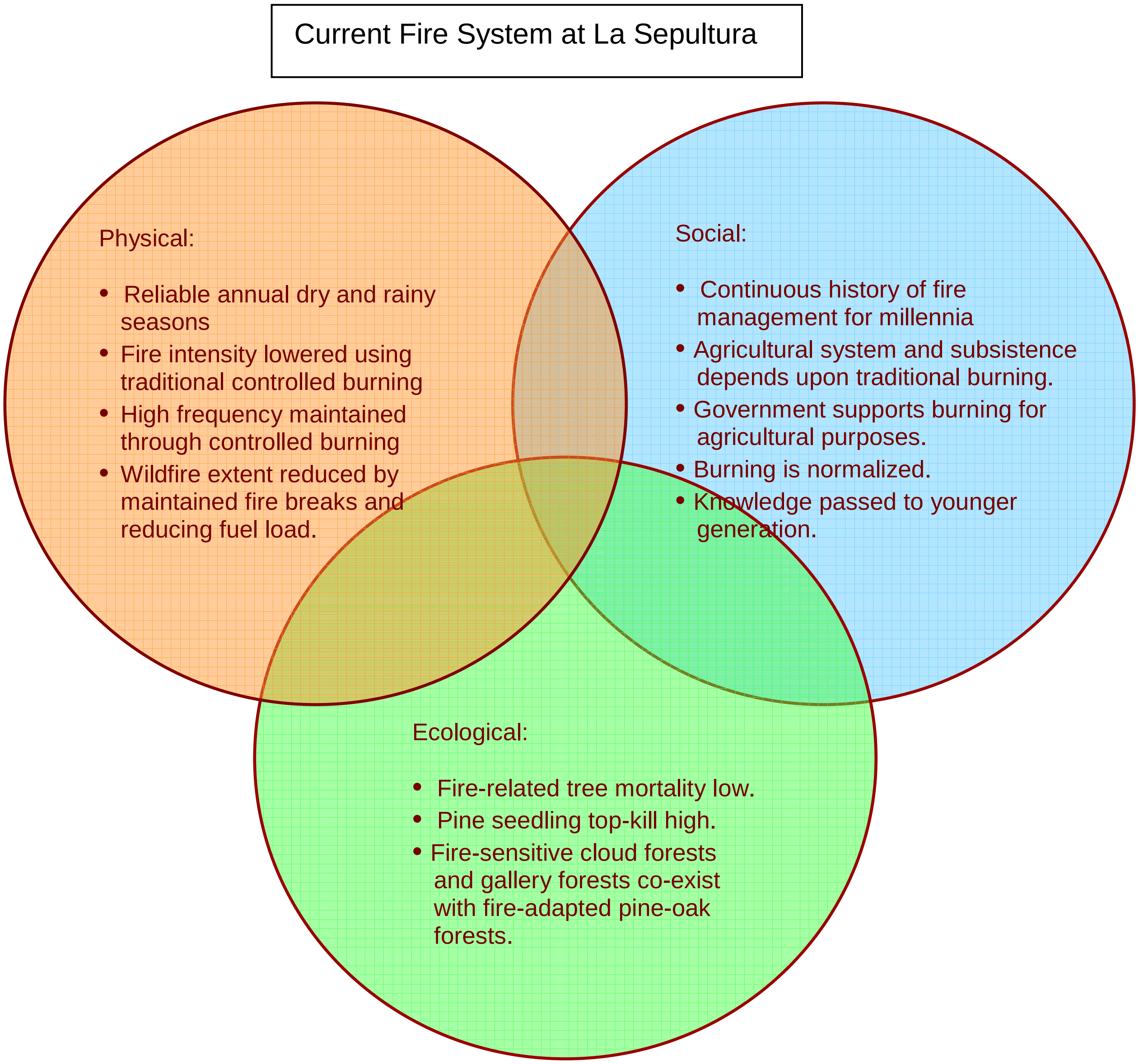
Finally, working closely with local people and observing traditional fire management in action enabled me to realize how the current agricultural system, which is dependent upon using fire, is vulnerable to changes in fire behavior that will likely occur under the influence of climate change.

The scope and impacts of altering fire regimes in the tropical forest systems of Latin America and the Caribbean is summarized concisely by Cochrane and UNEP (2002). Through their study of Amazonian forests, Cochrane et al. (1999) were the first to detail the potential for large-scale ecological and social changes wrought by fire in the tropics, emphasizing the positive feedback loops that make once-burned, closed-canopy tropical forests more prone to second and successive fires. At the micro scale, Laurance (2003) provided graphic insight into the biological breakdown that can occur for many species, both plant and animal, when even the smallest flames burn in fire-sensitive tropical forests. Negative ecological and social impacts of fire upon the high biodiversity cloud forests at the tops of local watersheds and the gallery forests that run along low elevation streams are a concern at La Sepultura.

The Intergovernmental Panel on Climate Change predicts that global warming will bring more, and more pronounced episodes of El Niño to the region (Magrin et al., 2007). Following seven years of drought, the El Niño episode of 1997-1998 provided a glimpse of the predicted future: severe drought and record wildfires throughout the nation, caused by anthropogenic ignition. In Central America, 2.5 million ha of broadleaf tropical forests burned. In Mexico, 14,445 fires burned nearly 850,000 ha of forested land (Cedeño, 2001). Eighty-six percent of Mexico’s fires were attributed to specific human causes (Rodríguez-Trejo and Pyne, 1999). Of the area burned, forty-seven percent, roughly 390,000 ha, was attributable to fires started for agro-pastoral land use. In Chiapas, 405 fires burned 113,500 ha (Cedeño, 2001). This represents approximately two and a half times more fires and eleven times more surface area than the average amounts recorded for Chiapas in the other nine years of that decade (Cedeño, 2001). In a state where a substantial portion of the landscape is used for subsistence agriculture that relies on fire, a whopping ninety percent of the wildfires in Chiapas were human caused (Cedeño, 2001).

Given the projection for more episodes of this kind, Figures 6.1 and 6.2 use the conceptual model to explore the differences in the current fire system and a potential future fire system that collaborators will want to work to avoid. In this way, the model can be used at different stages of analysis of a single fire system, and can be used to guide reflection on the past, present and future fire systems at a given site.

In Figure 6.1, I describe the fire system as presented throughout this study. Producers are providing an important service moderating the fuel load and maintaining a high frequency, low intensity fire regime. Fire is a normal part of rural society, having been passed down for generations.



Current Fire System at La Sepultura

Physical:

- Reliable annual dry and rainy seasons
- Fire intensity lowered using traditional controlled burning
- High frequency maintained through controlled burning
- Wildfire extent reduced by maintained fire breaks and reducing fuel load.

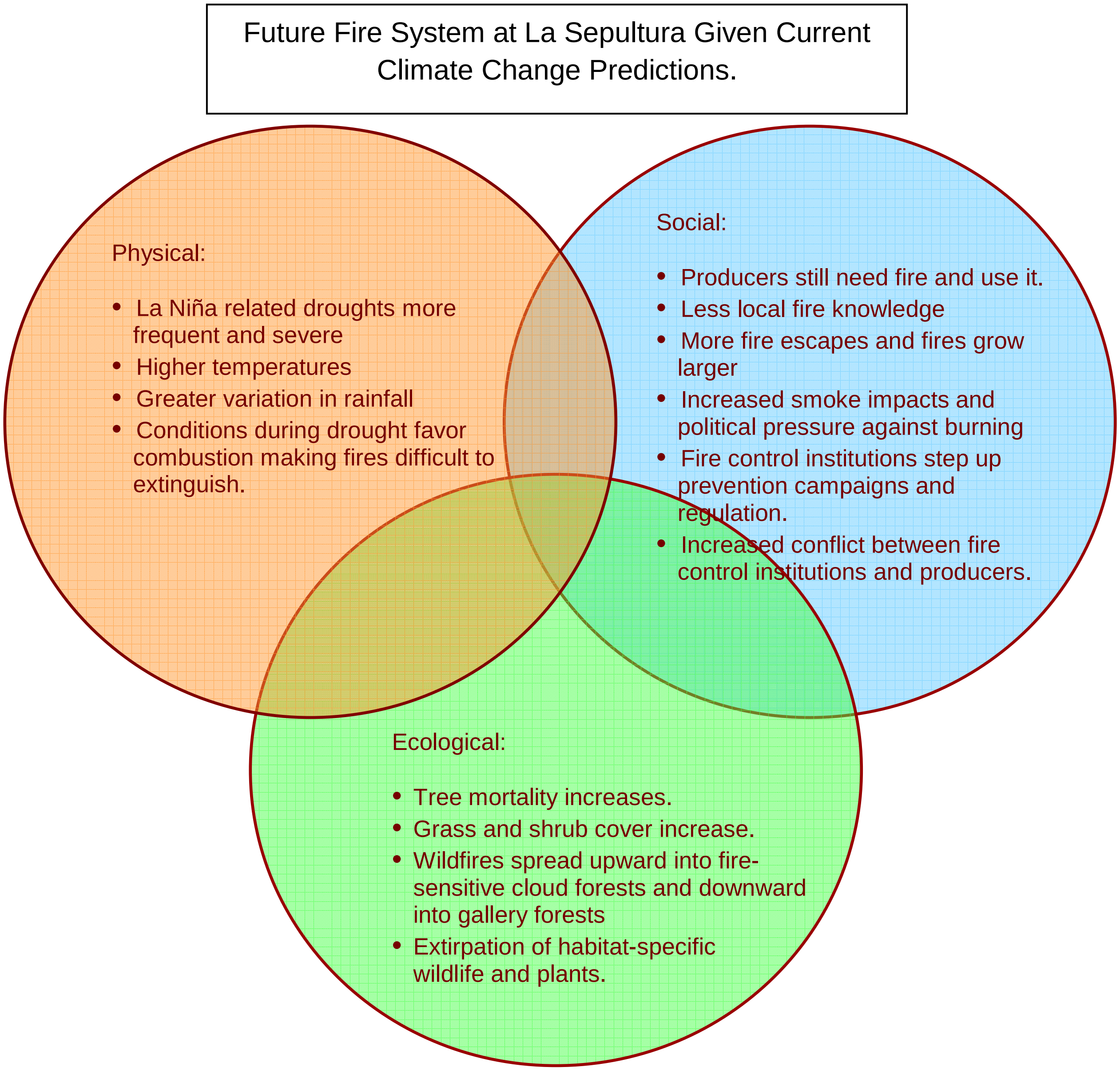
Social:

- Continuous history of fire management for millennia
- Agricultural system and subsistence depends upon traditional burning.
- Government supports burning for agricultural purposes.
- Burning is normalized.
- Knowledge passed to younger generation.

Ecological:

- Fire-related tree mortality low.
- Pine seedling top-kill high.
- Fire-sensitive cloud forests and gallery forests co-exist with fire-adapted pine-oak forests.

Figure 6.1. Conceptual model of the current fire system at La Sepultura.



Future Fire System at La Sepultura Given Current Climate Change Predictions.

Physical:

- La Niña related droughts more frequent and severe
- Higher temperatures
- Greater variation in rainfall
- Conditions during drought favor combustion making fires difficult to extinguish.

Social:

- Producers still need fire and use it.
- Less local fire knowledge
- More fire escapes and fires grow larger
- Increased smoke impacts and political pressure against burning
- Fire control institutions step up prevention campaigns and regulation.
- Increased conflict between fire control institutions and producers.

Ecological:

- Tree mortality increases.
- Grass and shrub cover increase.
- Wildfires spread upward into fire-sensitive cloud forests and downward into gallery forests
- Extirpation of habitat-specific wildlife and plants.

Figure 6.2. Conceptual model of the future fire system at La Sepultura given climate change predictions of more frequent and severe El Niño events.

In Figure 6.2, the complex fire system reflects the predicted scenario in which dry and wet seasons will become less reliable with droughts becoming more frequent. Producers will still need fire for subsistence crops and will continue to light fires using traditional practices and whatever traditional knowledge that they have retained. Fires that are normally manageable will resist control, and fires that escape beyond local firebreaks will grow large as they did in 1998. Fire sensitive ecosystems that occur at elevations above and below the tropical pine-oak forest (cloud forests and gallery forests which are normally too moist to burn) will carry fire, which will result in biodiversity loss. Smoke impacts would be severe, the public would suffer serious health consequences and understandably there would be calls for stopping burning and stepping up fire prevention campaigns. Fire control agencies and producers may clash over indigenous and agricultural rights to use fire. If producers reduce fire frequency, fuels would accumulate and exacerbate the problem rather than improve it.

While this scenario is certainly an unpleasant one, governments and local people will need to work together, diligently and proactively in collaboration to avoid it. However, in most Mesoamerican countries today, government responses to fires in tropical pine-oak ecosystems are prevention and suppression. Community-based programs focused on fire prevention are being piloted throughout tropical regions of the globe, including in Mexico (Moore et al., 2002, CONAFOR, 2009, FAO and Asia, 2003, McDaniel et al., 2005), but there are very few programs that integrate ecologically-based prescribed burning and wildfire management designed to maintain fire-dependent ecosystems and to protect adjacent fire-sensitive ecosystems of biodiversity value.

The specificity of the producer's fire management practices at La Sepultura and their dependence upon the unfailing onset of the rainy season causes me concern about their vulnerability to global climate change. Producers are currently using a combination of techniques to produce very low intensity, slow moving fires in an ecosystem that is capable of producing much higher intensity, rapidly spreading fires. In my interviews, producers talked about and demonstrated with their hands and arm waving their observations of such fire behavior during local wildfires. If weather conditions change as predicted so that there are more, and more pronounced, El Niño episodes, I predict that the current fire system at La Sepultura and elsewhere in southern Mexico will be strained. Producers currently have the ability to achieve their goals of agricultural production and fire control using nothing but locally available expertise, labor and hand tools. This system has been sustainable for millennia; and in Chiapas alone, at least the agricultural population of 500,000 people depends upon fire for survival.

In the Third Assessment Report of the Intergovernmental Panel on Climate Change, McCarthy et al. (2001) write, "The ability of human systems to adapt to and cope with climate change depends on such factors as wealth, technology, education, information, skills, infrastructure, access to resources, and management capabilities." (McCarthy et al., 2001, p 8). The two communities that I studied are rural in character. I argue throughout this paper that community members possess profound knowledge, effective informal education and exquisite management capabilities. However, local producers do not have wealth, technology, ready access to information generated outside of the community, infrastructure, or deep access to outside resources. It is possible that their physical location within La Sepultura Biosphere Reserve and their productive association with the reserve staff will provide access resources in times of weather related crises. Conversely, CONANP's cooperative working relationship with producers at La Sepultura can provide the agency access to the knowledge and ingenuity of producers that the agency will need to reach its mission of preserving biodiversity in this time of change.

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