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FIRE IN THE SOUTHERN U.S.: ADMINISTRATIVE LAWS AND REGULATIONS IN THE SOUTHEAST AND WILDFIRE SIZE DISTRIBUTION IN MISSISSIPPI

By

Branden Tolver

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FIRE IN THE SOUTHERN U.S.: ADMINISTRATIVE LAWS AND REGULATIONS IN THE SOUTHEAST AND WILDFIRE SIZE DISTRIBUTION IN MISSISSIPPI

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Wildfires in the United States present a complexity of problems for private landowners and policy makers. This thesis takes a look at two key issues faced by private and government stakeholders; the first being a lack of knowledge regarding current prescribed fire laws and regulations. A legal review of administrative laws and regulations for prescribed burning in the Southeastern United States in the context of management-based regulation is used to address this issue. It was found that regulation for prescribed burning has shifted to a more management–based regime. The second is an empirical study of wildfire distribution in the state of Mississippi. Wildfires appear to fit a Pareto distribution throughout the state given a certain threshold. When analyzed in conjunction both studies could aid lawmakers in projecting the effects of a given policy change on actual wildfire occurrences and distribution.

Key words: wildfire, management-based regulation, Pareto distribution

DEDICATION

I dedicate this thesis to my parents, A.C. and Bertha Tolver and also my brothers, sisters and fiancé.

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TABLE OF CONTENTS

APPENDIX

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The Southeastern United States is abundant in natural resources. With over 200 million acres of forest land the region's natural resources provide a diverse array of economic benefits (Mississippi Forestry Association 2007). The timber sector for example is a billion dollar industry that drives local economies and provides tens of thousands of jobs throughout the Southern U.S. In addition hunting continues to be a popular activity that brings in revenue from both local and outside sources. Over the last half century Americans have also flocked towards recreational activities provided by forests, such as camping, bird watching, and hiking. As the needs of forests become more diversified so too does the need to understand the dynamics associated.

Over 70% of forestlands in the South are owned by non-industrial private forest (NIPF) landowners (Mutch 1994). These landowners have become increasingly concerned about the threat to their forest land as a result of things such as wildfires. According to the National Interagency Fire Center wildfires nationwide have destroyed over 40 million acres of land in the last decade alone. The threat posed by large wildfires has spurred change in both policy and research direction. Landowners are now looking to reduce the risk of wildfire and increase the productivity of land by prescribed burning. The problem arises when liability concerns outweigh the potential benefits thus creating an unfavorable burning environment.

This thesis will first outline current administrative laws and regulation for prescribed burning in the Southeastern U.S. and its evolution. A management-based approach, which is a new and innovative form of policy formulation, was used to study the evolution. Second, it will analyze the fire size distribution for wildfires in the state of Mississippi. Two separate studies were conducted with the first, chapter II, being a legal review and chapter III consisting of an empirical study. Each paper included its own introduction and conclusion sections. The second study included sections on methodology, and results. Chapter IV will conclude the thesis tying both studies together with future implications.

CHAPTER II

A MANAGEMENT-BASED REGULATION APPROACH TO PRESCRIBED FIRE: A REVIEW OF ADMINSTRATIVE LAW AND REGULATION IN THE SOUTHEASTERN UNITED STATES

Introduction

Prescribed burning has been widely acknowledged as a valuable land management tool. In the southeastern United States this recognized fact is even more prevalent due to the large proportion of privately owned forestlands. Benefits of prescribed burning range from habitat improvement, fuel reductions, forest pest management, to site preparation. In many areas prescribed burning is used to return habitats back to their original ecological stage which consisted of a periodic fire-maintained forest ecosystem. According to the National Interagency Fire Center each year between two and four million acres of forestlands are treated by prescribed burning in the Southeastern U.S. which is more than any other region of the country. These numbers however experienced declines in the mid to late 1990s due to fewer qualified and experienced prescribed burners (Haines and Cleaves 1999). In 2007 the southeastern states only accounted for 1.2 million of 3.1 million acres burned (National Fire Interagency Center 2007). The Prescribed burners are citing liability concerns, higher operating costs, and more efficient means of forest utilization practices as the key contributors to their reluctance to prescribe burn. In addition the past three decades have seen public concern over air quality and smoke related accidents increase considerably.

The environmental movement of the late sixties and seventies brought attention to the areas of habitat protection as well as air and water quality. Laws such as the Clean Air Act called for the protection and enhancement of air quality across the board. It also called for stronger regulation of activities that have adverse effects on air quality such as prescribed burning (Hauenstein and Siegel 1981). This concern has been the result of an increasing population throughout the South as well as a growing trend of individuals wishing to live in and around densely forested areas (Haines and Busby 2001). To combat the growing anxiety by both the public and private land managers prescribed burning has been increasingly regulated in attempts to reduce the liability on landowners and burners. New approaches in administrative law and regulation have evolved in the last two decades that have changed the legal environment of prescribed burning throughout the southeast. One of these regulatory approaches called management-based regulation (MBR) is relatively new and has become an important component of both regulatory and administrative law.

At present there is a need to review both the evolution and current administrative laws and regulations for private landowners in the southern United States to use prescribed fire. Many have been implemented with the sole purpose of reducing the liability threat posed to prescribed burners each time a burn is conducted. This paper will include case study examples from Florida and Mississippi in order to outline the evolution of administrative regulations in each state over the past 30 years. It will also include a 13 state comparison of current administrative laws and regulations for the southeastern U.S within the theoretical framework of MBR. The MBR approach has been proven effective in other environmental fields and is in the early stages of introduction in prescribed burning. In addition, the linkage between administrative and statutory laws will be discussed in hopes of better clarifying the origination of various components of each administrative law and regulation. Management-based regulation's origin, its processes, and examples will be used to help better understand the trend within prescribed burning. Providing a review of current regulations and administrative laws will greatly aide the general public, who are becoming more invested in the policy making process and its future implications. It will also benefit private land managers by providing a better understanding of current trends involving administrative law reform.

Management-Based Regulation

Typically environmental regulations have been crafted with an emphasis on the overall input or output stages of activities. Input stage regulations are generally referred to as technology-based because they focus on specific instruments or technologies to be used (Coglianese and Lazer 2003). For example, if an agency's goal is to reduce pollution emissions a technology-based regulation then will require that a specific machine or tool be used in order to achieve proposed reductions. Technology-based regulations have been fairly common in the areas of air pollution. An example would be in the reduction of carbon monoxide from vehicle exhaust systems. A technology-based regulation calls for a specific instrument such as a catalytic converter to be used in order to reduce the emissions made by a vehicle. In contrast, output stage regulations, or more commonly called performance-based regulations do not take into account the "how" of an objective but rather the overall accomplishment of that goal. A performance-based regulation for pollution control does not state what specific instruments to use to reduce pollution levels, however it specifies to an agency or firm that they reduce pollutions emissions by a certain amount over time (Bennear 2006).

MBR intervenes in neither the input nor the output stages of regulation. MBRs are employed during the planning stages of regulatory strategizing. It calls for individual agencies or firms to become more active in the formulation of their own regulations (Bennear 2006). In addition to a reduction of risk these strategies are formulated to comply with the firm's overall goal of efficiency. The discovery of risk location, mitigation, and information collection are vital components of management-based regulation. Location of risk during the planning stages of regulation allows for flexibility and effective internal decision making (Coglianese and Lazer 2003). The collection and sharing of information is important because it provides the public with information that allows them to feel more involved in the policy making process.

The advantages of MBR over technology and performance-based regulations are that it gives sole responsibility and decision-making authority to the agency or firm itself. By doing this agencies can create regulations that are both reasonable and compliance driven (Coglianese and Nash 2006). Examples where MBRs have proven beneficial include applications in the food industry, industrial safety, and toxic chemical use and release (Bennear 2006). The food safety industry in response to increasing concerns of microbial food contamination implemented in the mid 1990s the Hazards Analysis and Critical Control Points strategy (HACCP). This MBR requires firms to assess, observe, and manage any dangers that could arise during the processing of food (Coglianese and Lazer 2003). Management-based regulations on industrial safety include the

Occupational Safety and Health Administration's 1990 standards for process safety management (PSM) (Coglianese and Lazer 2003). Similar to the HACCP strategy this regulation requires manufacturers who handle hazardous waste to develop plans that both assess potential hazard zones as well as implement steps that will reduce the risk of an industrial accident. Another example of MBRs in the United States is found in the use and release of hazardous waste. These regulations state that plants must monitor their toxic chemicals throughout the production stages in order to identify alternative techniques that would serve to reduce the risk of a toxic spill and become more efficient economically (Bennear 2006).

Evolution of Administrative Regulations for Prescribed Fire in Florida

Each year between 1.5 and 2 million acres of forestland is prescribed burned in Florida (Haines and Busby 2001). It has become one of the most important and cost-effective tools used to manage Florida's forested lands for wildlife, fuels reduction, and forest health. The state is among the leaders in acreage burned per year along with Alabama. Florida has also been near the forefront of both statutory and administrative law reform in the South since the early 1970s. Four reasons can be attributed to this and they include (1) the substantial population boom that has occurred in Florida over the past thirty years. The population has grown from approximately 10 million people in 1980 to around 18 million as of 2008 (United States Census Bureau 2009). (2) Many of these immigrants arriving in Florida are retirees from northern states who have both the incentive and time to become actively involved in natural resource issues (Wade and Brenner 1995). (3) More people are wishing to live near and inside of densely forested areas. These areas, referred to as wildland-urban interface, are making the task of fire management progressively difficult. (4) There are the severe wildfire conditions created by years of fire exclusion policies partly created by these new arrivals protests of burning activities (Brenner and Wade 1992). Some see prescribed fire as an unnecessary nuisance that only serves the purpose of the agencies and not themselves.

The cumulative effect resulted in increased numbers of annual wildfires coincided with decreased amounts of prescribed burning throughout the state of Florida. The years of fire exclusion, the public's disapproval of burning, and the increasing number of people living within the wildland-urban interface created unfavorable conditions for which burn managers found it more difficult to burn. In order to reverse this unwanted trend lawmakers and administrators in Florida implemented substantial changes in administrative laws and regulations over the past three decades. In 1975 the Environmental Reorganization Act transferred the regulation of all open burning activities to the state's Department of Agriculture and Consumer Services, Division of Forestry (Department of Agriculture and Consumer Services 1975). With its new mandate the Division of Forestry would begin to craft what is considered to be the most extensive prescribed fire policy in the southern U.S. Under the 1975 Florida administrative code 5I-2.06 titled Agricultural and Silvicultural Fires the allowable hours of burning were to be between 9:00 a.m. and one hour before sunset. This timeframe was contingent upon proper notification being given to the Division of Forestry prior to burning. It also was flexible if assurances of good atmospheric and meteorological conditions existed. These, however, were only the requirements when burning in a non-rural area. Landowners who wished to burn in a rural setting were required to give special attention to occupied buildings and the burn was to be conducted under the supervision of the Department of Transportation (Department of Agriculture and Consumer Services 1975). If the rural setting was adjacent to a nearby forest or grassland the Division of Forestry was again the overseeing agency.

There were several amendments to the 5I-2 code with the first and perhaps the most important coming in 1990. Florida's passage of their Prescribed Burning Act would provide landowners with more incentive to control burn their land with a renewed confidence that their risk of liability would be reduced. The act incorporates the use of a "Certified Prescribed Burner" whom is defined to be "an individual who successfully completes the certification program of the Division of Forestry of the Department"(Department of Agriculture and Consumer Services Division of Forestry 1990). The Prescribed Burning Act also charged the Division of Forestry with the task of regulating the Certified Prescribed Burner certification and decertification processes as well the minimum requirements for the written prescription. According to Florida administrative code 5I-2.0061 in 1990 to become a Certified Burn Manager an individual must have successfully completed a burner course and have had direct experience in three prescribed burns prior to taking the course or he/she must have successfully completed an inter-agency basic prescribed fire course. In addition any certified individual could be decertified in accordance with Florida statutes (Department of Agriculture and Consumer Services Division of Forestry 1990). In terms of the written prescription, the 1990 amendments state the minimum requirements of the prescription to be:

1) Stand or Site Description
2) Map of the area to be burned
3) Personnel and equipment to be used on the burn

4) Desired weather factors, including but not limited to surface wind speed and direction, transport wind speed and direction, minimum mixing height, minimum relative humidity, maximum temperature, and fine fuel moisture
5) Fire behavior factors, such as type of burn technique, flame length, and rate of speed
6) The signature of the Certified Burn Manager

A later amendment in 1993 would serve to clarify any vague language originating from earlier definitions and statements. It also gives the Division of Forestry the authority to extinguish fires that are illegally set or set without following the proper channels. Other additions added in the amendment included the suspension of burning during periods of air stagnation and time frames in which to burn within areas designated as smoke sensitive by the Division of Forestry. Provisions for burning during night time authorizations stated that the fire could be set until midnight except for around smoke sensitive areas. Rural land open burning is also clarified stating a distance of 300 feet or more that a prescribed fire had to be away from any occupied building and 100 feet or more from any public highway (Department of Agriculture and Consumer Services Division of Forestry 1993).

In 1995 yet another amendment repealed several sections of the administrative code. Sections regarding the general information (5I-2.001), declaration and intent (5I-2.002), prescribed burning; burner certification (5I-2.0061), rural land clearing (5I-2.007), and penalties (5I-2.008) were all removed from the chapter. Also sections on definitions (5I-2.003), prohibitions (5I-2.004), and agricultural and silvicultural fires (5I-2.006) were consolidated and streamlined to remove duplication (Department of

Agriculture and Consumer Services Division of Forestry 1995). Under the 1999 amendment, sections 5I-2.003, 5I-2.004, and 5I-2.006 were again revised in order to simplify and clarify open burning rules and procedures. The revision included the re-certification process as well as requirements for both certified and non-certified burn managers (Department of Agriculture and Consumer Services Division of Forestry 1999). The revisal included the same rules for certification, decertification, etc.; however it includes new steps in order to renew your prescribed burn manager certification. Under section 5I-2.006 in order to receive a renewal of his/her certification an individual would have to have participated in a minimum of eight hours of training every five years related to prescribed fire or have participated in a prescribed fire council meeting. In addition he/she would have to have their prescribed burn certification number submitted at least two times within the same time period for a completed burn; participated in five burns that have been documented by a certified burn manager or simply have had retaken the prescribed fire correspondence course or inter-agency basic prescribed fire course (Department of Agriculture and Consumer Services Division of Forestry 1999). The amendment also adds several new requirements for the written prescription including an evaluation and approval of the anticipated impact of fire on smoke sensitive areas, the time and date the prescription was prepared, and the desired fire behavior factors such as flame length and rate of spread.

The final amendment to date occurred in 2005 with its intent again being to add relevant definitions and to remove those that were no longer necessary. For example the definition of “Air Pollution Episode” is added whereas the term “Land Clearing Debris” was removed from the rule. The addition of the word “controlled” in the definitions section also was incorporated with hopes that the general public would feel as if the fire was being "managed". The amendment also indicated that the burn was to proceed in accordance with the written prescription. There were instances in which certified burners contended that there was no such rule requiring strict compliance with the prescription (Department of Agriculture and Consumer Services Division of Forestry 2005). Also a more detailed description of the decertification process is explained stating that the process will be based on a certified burner violations-point assessment table (See Appendix).

Florida has experienced significant changes in prescribed burning law and regulation in the past 35 years. From the vague, limited technical jargon that was in place in the mid 70's to the more comprehensive, simpler to understand regulations of today, the rules and regulations reflect a more management-based means philosophy. At present the Florida Division of Forestry under the statutory authority of the Prescribed Burning Act still promulgates the rules associated with the requirements of the written prescription, open burning hours, permit measures, and also prescribed burner certification, de-certification, and re-certification procedures. Florida's Division of Forestry also continues to set requirements for those who do not seek the liability protection of the certified burner laws.

The response by Florida administrators to the increased public and political pressure has resulted in a prescribed fire program that has become the golden standard for all southern states. Many states have since followed Florida's statutory lead with their own versions of Prescribed Burning Acts and subsequent certified burner laws but none to the extent as Florida. The southern United States as a whole is experiencing increases in population, although not at the rate or numbers of Florida. They are also faced with the issue of urbanization and greater public interest which will undoubtedly create tension between the public and administrative agencies. With Florida's example these concerns can now be addressed with more efficiency and actual cases of success.

Evolution of Administrative Regulations for Prescribed Fire in Mississippi

The cases of both Florida and Mississippi represent the two extremes of prescribed fire administrative law and regulation in the Southeast. Florida's population, age demographic, and forest fuels situation created an environment that required radical regulatory change. On the other hand Mississippi with its lucrative forestry industry and reasonably low population left no real incentive for fire policy reform. Mississippi will need to further address fires issues as the population as well as air quality concerns continue to grow.

Mississippi when compared to Florida presents a completely different situation both demographically and politically. For example Florida's population is six times greater than that of Mississippi, which has around 2.9 million residents according to Census Bureau statistics. This created a more hospitable environment for prescribed burners throughout the state. Fewer people resulted in fewer instances of prescribed fires directly affecting communities and individuals. Also Mississippi is composed of 65% forestland with around 19.8 million acres compared to Florida's 16.2 million acres of forestland which accounts for about 47% of its land (Mississippi Forestry Association 2007). Forestry and related activities account for almost 18 billion dollars of Mississippi's economy and 8.5% of all jobs. These favorable conditions have lead to reluctance or delayed interest in policy reform of their prescribed fire program. The

Mississippi Forestry Commission has the duty of overseeing all fire related activities and has done so since its creation in 1926.

Before the enactment of Mississippi's Prescribed Burning Act in 1993 there were few if any administrative codes or regulations for prescribed burning. Most prescribed burning on privately owned lands from the early 1960s until the mid to late 1980s were conducted by the state's forestry commission. It was not until 1992 that the commission was given statutory authority to promulgate the requirements for such things as the permit and the written prescription. Prior to the enactment of the Prescribed Burning Act all open burning activities, including prescribed fire, were regulated by the Mississippi Department of Environmental Quality (MDEQ). In 1978 the MDEQ only required that "permission" be obtained from the Mississippi Forestry Commission in order to conduct a burn. It was not until later amendments to air emission regulations in 1991 that actual permits were to be obtained from the commission in conjunction with MDEQ. The MDEQ also required at the time that all fires were to occur between one hour after sunrise and one hour before sunset. Upon enactment of the Mississippi Prescribed Burning Act in 1993 the forestry commission was charged with stating the appropriate burning hours.

The acquisition of the burning permit is contingent upon favorable atmospheric conditions that consist of a mixing height of 500 meters (984 feet) and a transport speed of 3.5 meters per second (7.8 mph) (Sun and Londo 2008). The commission also has the responsibility of regulating the burn manager certification process. In order to become a certified burner within the state of Mississippi an individual must complete a prescribed burning short course that is sponsored by Mississippi State University. The course teaches potential prescribed burners the steps to preparing burn plans as well as proper burning techniques. Also the commission was and still is willing to accept certification from states that have similar certification processes. In recent years yet another approach to becoming certified within the state has been accepted. An agreement was made with the Mississippi Forestry Commission and Mississippi State University that allows students who are enrolled in the school's forest fire class to become certified upon completion of the course with a grade of 80 or better. The Mississippi Forestry Commission also sets the guidelines for the mandatory written prescription. The Forestry Commission requires that the burn plan must contain at least the following items: (1) legal description of property (2) name of owner (3) stand description (4) purpose of the burn (5) Pre-burn information such as maps, fire, lanes, smoke management etc. (6) range of desired weather conditions (7) summary of burn.

Made effective in 1996 MDEQ states that any burning for the purposes of agriculture waste removal must be done within a time period that will allow for adequate diffusion of smoke. MDEQ also regulates the ignition sources of prescribed fires and only allows "dried vegetation, petroleum derived fuels of the gasoline, kerosene, or light fuel oil types (diesel), or a combination thereof" to be used for starting a burn. Also under open burning regulations prescribed burns must be at least 500 feet away from an occupied dwelling and highway.

There have been very few amendments to burning laws and regulations in Mississippi since their enactments. Like many other states Mississippi has followed the path left by Florida which could explain the lack of amendments. Both the open burning regulations and the Forestry Commission administrative laws mirror those of Florida almost exactly. Perhaps the only areas in which the state has yet to completely adopt Florida laws involve re-certification and de-certification procedures for burn managers. At present once an individual becomes certified he/she is not required to take any other classes or show that he/she has been active in burning.

Management-Based Administrative Regulations for Prescribed Fire in the South

The southern United States accounts for about 90% of all prescribed burning activities nationwide (Haines and Cleaves 1999). Regulation of burning has varied from state to state due to factors such as population, public outcry, terrain, land usage, and forest fuels conditions. One similarity between all states is that their regulations, whether strenuous or not, has the characteristics of being management-based. This means that state legislators have given authority of regulating prescribed burning over to state and local agencies. In the case of most states nationwide the regulating of burning falls under the state's local forestry commission or department of forestry. These agencies then have the power to promulgate the rules for every aspect of prescribed fire. Under the management-based premise regulations are calling for more attention during the planning stages of a burn. This is evident by the fact that most states require authorization or a permit from their local forestry agency prior to burning. This authorization is usually given after the agency has determined whether or not weather conditions are conducive for a burn and will cause limited smoke intrusion problems. By committing more to the planning stages fire managers hope to locate potential problems areas before the burn takes place and take the appropriate measures to ensure that the potential risk is addressed. This risk location is yet another feature of MBR and is of the utmost concern to fire-managers and the general public.

The increasing risk of liability associated with an escaped fire or smoke-related accident over the past decade has lead to this increase in regulating pre-burn activities. States such as Alabama, Georgia, Florida, Louisiana, Mississippi, North Carolina, South Carolina, Texas, and Virginia have established certified prescribed burner laws that give the states overseeing forestry agency the authority of regulating the prescribed burn manager certification process. It also gives the agencies the power of stating the requirements of the written prescription which is required for a prescribed burn in the before mentioned states. For example in Alabama a certified prescribed burn manager is defined to be "an individual who successfully completes a certification program approved by the Alabama Forestry Commission" (Alabama Forestry Commission 2000). This requirement includes taking courses discussing the various aspects of prescribed burning such as fire behavior, smoke management, fire safety, planning, and burning methods. If an individual has received training that is equivalent to the course offered by the Alabama Forestry Commission then the commission has the authority to either accept or deny the equivalent training. The certification period usually lasts about five years after which the individual has to recertify themselves by either showing that they have been active in burning over the past five years or by re-taking the written exam.

Along with re-certification requirements there are also regulations that call for the revocation of prescribed burn manager certification. For instance Louisiana administrative code § 913 states that "In the event that any certified prescribed burn manager demonstrates that his practices and procedures during one or more of prescribed burns substantially deviates from accepted practices and procedures for prescribed burning in effect at the time of certification or at the time of the aforesaid prescribed burn or burns then, in that event, and upon such finding determined after an adjudicatory hearing conducted in accordance with the Administrative Procedure Act, the commissioner may suspend or revoke the certification of any such certified prescribed burn manager".

Revocation of certification is not permanent in states that have a de-certification process but it does make it more difficult to become re-certified in the future. These requirements are not universal across the entire southeast as some states lack the incentive to enact such laws and regulations. Some states such as Arkansas, Kentucky, Oklahoma, and Tennessee do not have a Certified Prescribed Burner law and thus no certification process is required of their fire managers. In fact the requirement of certified prescribed burn managers in most of the South are merely voluntary processes that serve the purpose of liability reduction. It does not hinder the ability of a landowner to burn their land.

Responsibilities of the Certified Prescribed Burn Manager

In the remaining southern states that require certified burners to conduct burning activities it is the CPBM's responsibility to among other things formulate the written prescription or burn plan and acquire the permit necessary to conduct the burn. The permit is either verbal or written with each state having separate requirements (Haines and Cleaves 1999). Depending on atmospheric conditions the request for a permit can either be accepted or denied. The overseeing forestry agency for each state regulates the overall responsibilities of the CPBM. The Louisiana Forestry Division states that a the certified burn manager must acknowledge that the ignition process has been accomplished, the fire is contained within the firelines, and the smoke appears to be acting in a manner consistent with reported atmospheric conditions in order for the burn to be declared safe and completed. In Texas and many other states who have certified prescribed burner laws it is the up to the CPBM to notify all appropriate agencies of the upcoming burns and adhere to any rules required by that subsequent agency. For example Texas administrative code § 226.3 recommends that the local sheriff's office be contacted as well as additional local fire departments. Georgia and Oklahoma's forestry commissions also require that the department of public safety and the general public be notified prior to the burn. In the case of Georgia that responsibility would fall to the CPBM. In Oklahoma the general burn manager or landowner would be charged with that duty.

Maybe the most important duty of the certified prescribed burn manager is the formulation of the written prescription. The purpose of the prescription is to provide a roadmap that leads to the successful application of a prescribed burn on a given tract of land. The prescription can range from very elaborate to the bare minimum depending on the burn manager and the state regulations. Alabama's minimum requirements for a prescribed burn include: (1) personal information such as name of landowner (2) stand description (3) Purpose of the burn (4) pre-burn information such as equipment to be used (5) desired weather conditions (6) starting and completion time of burn (7) sketch of area to be burned (8) signature of burn manager (9) burn permit number. As of now only six states; Alabama, Florida, Mississippi, Oklahoma, Texas, and Virginia have set minimum prescription requirements. Most states require the prescription to be in place before the burn starts and onsite throughout its duration. As stated earlier Florida administrative law not only requires that the prescription be onsite at all times but also that the procedures and duties outlined in the prescription be followed to the letter. No other southern state specifically states that the prescription be followed exactly as written but it is assumed given the potential of liability if an accident or escaped fire were to occur. Regulations and laws calling for written prescriptions represent the optimal use of management based regulations in prescribed fire. It allows for potential risks before, during, and after the burn to be located and handled appropriately. The risk of smoke intrusion is one of the most worrisome to fire managers as most accidents resulting from prescribed fires are due to smoke impeding the vision of drivers on nearby highways. These concerns are specifically stated in the written prescription and laws mandate that they be included in the plan in most southern states.

Smoke Management

The smoke management requirements in the written prescription are an essential component. Encouragement from Congress, who has maintained that air quality is not the responsibility of the federal government, has lead to state and local governments development of various administrative regulations. These regulations usually call for compliance with the state's smoke management guidelines that were in place prior to the prescription requirements. North Carolina's Division of Forest Resource's smoke management guidelines categorize each day based on the area's smoke dispersion index (Hauenstein and Siegel 1981). It ranges from allowing very limited burning to almost no burning hour restrictions. The specific category for a particular day outlines what the appropriate burning periods are.

- Category 1 --- VERY limited
- Category 2 --- Daytime burning only. Burning to start after inversion burnoff temperature is reached and will cease by sunset. Burning will cease 2 hours before sunset if nighttime dispersion is forecasted to be poor or very poor.
- Category 3 --- Daytime burning only. Burning to start after inversion burnoff temperature is reached and will cease by sunset. Burning will cease 2 hours before sunset if nighttime dispersion is forecasted to be poor or very poor.
- Category 4 --- Daytime burning and nighttime burning except during nighttime when poor or very poor smoke dispersion is forecasted.
- Category 5 --- Daytime burning and nighttime burning except during nighttime when poor to very poor smoke dispersion is forecasted.

Other smoke management guidelines such as those in Arkansas outline what constitutes smoke sensitive areas and the precautions to take in order to protect these areas. Each state's guidelines related to smoke all serve the purpose of improving air quality and reducing smoke related mishaps.

State Differences

No two states have the exact same smoke management laws and regulations, in fact major differences exist in certain state's regulation of burning activities. As stated earlier most southern states took their cue from Florida's example but not all. States such as Arkansas, Kentucky, Tennessee, and Oklahoma do not have regulations for burn manager certification. Oklahoma only requires that a prescribed burn be conducted by a "fire manager with previous experience". Laws regulating the prescription requirements also differ between states. Eight of the 13 southern states do not have minimum prescription requirements and Arkansas administrative laws don't require a written prescription but rather suggests that one is prepared. Other states either don't have set regulations on prescription requirements or they are willing to provide assistance with the formulation of the prescription or plan. While Florida's regulations call for strict open burning hours only 6 other southern states: Arkansas, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, and Texas have followed with similar administrative laws. In Alabama the permit is good from whenever it is issued until midnight. After midnight the Alabama Forestry Commission must again be contacted and new permit must be requested. Even with state differences future trends point to more MBRs and laws. With the exception of Kentucky most states in the central and eastern part of the southeast have similar administrative laws for prescribed burning while states West of the Mississippi such as Oklahoma and Arkansas have been slower in revamping their regulations. These regional differences in prescribed fire regulation and law could be attributed to several factors both simple and complex in nature. Perhaps the enactment of these laws would cause the overall price of prescribed burning to increase at levels higher than present rates. Or maybe the benefit to cost ratio of implementing new regulations and laws does not warrant further investigation. No matter the differences Florida's example has spread throughout the region and will continue to be the base at which states compare their regulations.

Origination of Laws and Regulations

Most prescribed burning regulations and laws stem from older federal laws and state statutes and are used to further elaborate on subjects that are either not fully understood by Congress and state legislators or are too time consuming to undertake. The 1970 Clean Air Act for example provides the legal framework for state control of air pollution stemming from prescribed burning activities (Hauenstein and Siegel 1981). It authorized state and local authorities to begin to formulate their own plans to improve and protect air quality. These plans include EPA approved air quality procedures that are included in sections on open burning. Open burning regulations set time of day restrictions on burning in southern states and sets standards for particulate matter release (Hauenstein and Siegel 1981). Along with the states open burning regulations are the smoke management guidelines within the written prescription. These regulations also originate from the Clean Air Act of 1970 and also include restrictions on ignition sources. All 13 southern states regulate the use of accelerates and prohibit the use of materials that will create an inordinate amount of smoke such as rubber tires, asphalt material, and certain types of chemicals to start a prescribed fire.

Along with federal laws such as the Clean Air Act there are state statutes that have spurred the creation of administrative law and regulation. For example under the statutory authority of Mississippi’s Prescribed Burning Act the Mississippi Forestry commission promulgates the process for acquiring a burn permit and the Certified Prescribed Burn Manager laws task the same agency with stating the certification process. The same is true for the southern states that have CPBM laws in place. Authority is handed down from state legislators and the subsequent statutory laws that are passed.

Regulations whose origins are traced back to the administrative agencies themselves are scarce but one case of such fact can be found in Texas. The Texas Forest Service requires that proof of burners insurance be presented before authorization to burn is given. This regulation was adopted in September of 2001 and is the only such regulation of its kind among the states of the southern U.S. No other southern state regulates the requirement of insurance before a burn or for that matter having insurance in general.

Discussion

Applying MBR to new areas has been the direct result of its successes in other realms of environmental policy such as food safety. The momentum behind incorporating MBR into prescribed fire can be explained by the inherent danger of the activity as well as its “one strike and out nature”. Once a fire results in undesirable smoke or escapes the boundary the damage that ensues cannot be easily reversed and can lead to financial repercussions. In prescribed burning, there has also been a shift from strict liability to more negligence laws which creates incentives to provide the public with assurances that every measure is being taken to reduce the risk of an accident. MBR’s interjection into the planning stages of an activity proves beneficial to burn managers because it establishes that due care has been taken beforehand. The benefits of MBR and the nature of pre-planning that exists in prescribed burning have resulted in widespread adoption of MBR in the Southeast. Although MBR is being used heavily in the region some states are more comprehensive in their regulations and laws than others.

Management-based regulation has become a new and innovative approach to handling environmental issues. Florida was the first among southern states to regulate the written prescription as well as the creation of a burner certification to reduce the risk of liability. It still is considered the most elaborate administrative law on prescribed burning in the South today. Whether intentional or not its roots are derived or at least resemble that of being management-based. The threat of liability continues to be the most important factor for landowners and burn managers. Most of the southern states have followed Florida and have created laws that will give burners more incentive to burn without the cloud of liability looming over their heads. MBR has been proven to be effective in the areas of food and industrial safety as well as in the area of chemical waste disposal. The management-based approach to prescribed burning law and regulation has yet to be proven effective. There have been few court cases in which the regulations have been questioned or a landowner's compliance with the laws has been challenged. Nevertheless the implementation of MBR looks to be a continuing trend with more and more states enacting similar laws and regulations. Discussions continue concerning additional regulations and the effect they would have on the amount and cost of prescribed burning in the South.

One example of possible amendments to state administrative law would be the earlier mentioned insurance requirement. Only Texas has such an administrative law but talks continue among southern states regarding whether or not regulating the insurance aspect of prescribed burning is a viable option. A requirement of insurance could result in a reduction in an already decreasing amount of qualified prescribed burners in the South. The appropriate insurance coverage is also being discussed. At present Texas requires one million dollars in coverage but some contest that this number is not appropriate and in fact more coverage consisting of several million dollars of coverage will be needed to cover potential lawsuits. Prescribed burn managers across the South are concerned and point to the already high cost of insurance premiums for burners and complain that more regulation could lead to many privately owned forestry firms to go out of business. There have been no studies evaluating the impact of 2001 enactment calling for insurance coverage in Texas.

The time frame in which a burn is started and completed could also lead to more regulation change in the coming years. Florida requires that all daytime burns should be completed one hour before sunset however they do issue nighttime burning authorizations given the appropriate atmospheric conditions. Other states in the South have similar laws but could altering the time period in a manner that calls for all flames to extinguished several hours before sunset prove beneficial to both landowners and the general public. Most highway accidents involving smoke from burning occurs either in the late evening or early morning hours (Brenner and Wade 2003). Imposing such a restriction or something similar could reduce the number of highway accidents substantially by better guaranteeing that the smoke will not mix with evening and morning fog to create low visibility issues. Potential objectors to this idea could protest that such a regulation would put undue pressures on prescribed burners to complete the burn and that a shorter time frame would not be plausible. A more constricted daytime burn limit could, like the insurance proposal, result in fewer acres being burned as larger tracts of land would most likely have to broken into smaller parcels in order to abide by the law.

Yet another possible addition to present administrative law could involve the certified prescribed burn manager certification requirements. Each state with administrative laws concerning the certification process has in place a five year certification period with the exception of Mississippi who does not have a re-certification process. In that time period each state requires that either the CPBM participate in agency approved training courses and/or show proof of participation in a prescribed burn within the five year time frame. What would be the effect of shortening the certification period? Would that ensure that the CPBMs are more active in burning activities and thus more experienced or would it yet again lead to more reluctance from the burning community? These proposals as well as many other ideas either have been or will be the subject of discussion for new regulations for prescribed burners.

As state populations in the South continue to increase so too will the need to re-examine present administrative laws and regulations. Pre-planning has always been the key to a successful burn and will continue to over the years with the present MBR approach. The self regulating of burning activities by each state's forestry agency has proven to be a successful approach this environmental issue. Time will most likely be the ultimate judge in determining its true effectiveness in reducing risk of accidents and air quality degradation. Until then the key requirements of MBR which are: individual regulation by firms and agencies, planning that includes location of risk, risk mitigation, and recommendations for improved efficiency will continue to be driving force behind burning regulations in the South.

CHAPTER III.

FIRE DISTRIBUTION ANALYSIS: STATISTICAL ASSESSMENT OF FIRES IN MISSISSIPPI

Introduction

Each year large, relatively infrequent wildfires wreak havoc on the economy causing hundreds of millions of dollars worth of damage. According to the U.S. Forest Service fire suppression costs have exceeded $1billion dollars each of the last ten years. In many cases these costs have exceeded the congressional funds appropriated for suppressing them (Holmes et al. 2008). Wildfires also have significant impacts on both the climate and ecosystem (Schmoldt et al. 1999). Wildfires such as those experienced in California in the past few years kill endangered and vulnerable species, destroy wildlife habitat, and emit tons of climate warming carbon particles. Human structures have increasingly come under attack as more homes are built in or around forested areas. These areas referred to as the wildland urban interface put homes and lives at risk of being drastically affected by a large wildfire.

These catastrophic fires are in part the result of years of fire suppression policies that sought to eliminate the threat of wildfires. Policies such as the Forest Service's "10 am" rule called for all wildfires to be extinguished before 10:00 a.m. of the following morning. The policy, although done with good intentions, as well as many other fire policies had the effect of creating fuel heavy forests primed for large wildfires (Moritz et al. 2005). As the attitudes toward the role of fire in the ecosystem changed so too did the policy and management techniques. Fire is now widely accepted as a beneficial component of overall forest health.

Historically, large wildfires have been discarded from analysis which has created a bias towards small fires despite the fact that large fires cause the majority of damage. Large fires, even those with low probability, should be taken seriously. Recently, the understanding of wildfires and their related fire regimes have begun to garner the appropriate attention. A key component of the analysis of wildfires is the distribution of wildfire or fire size distribution (FSD) (Schoenberg et al. 2003). The damage inflicted by different fire sizes varies greatly over space and time. The expression "one percent of fires cause 99 percent of the damage" is popular among fire managers and personnel (Strauss et al. 1989).

The aim of this study is to analyze the FSD for the state of Mississippi with a focus on size distribution over time and by specific fire cause. Historically the state has not been prone to wildfires of disastrous proportions as those experienced by other regions of the United States, but vital information could be gleaned from a study of size distribution in the state. Understanding FSD can provide great benefits to forest planning and management. The scheduling of forest harvest schedules can be derived from FSD studies as schedules coincide with the suspected return level of a large fire. Predictions of FSD are also an important input for fuel management and fire suppression objectives (Cui and Perera 2008). Accurately predicting FSD gives managers an idea of what the suppression costs of a particular fire size would be based on similar fires.

Literature Review

FSD is the distribution probability that quantifies the relationship between fire size and its corresponding number occurrences or occurrences in a forest landscape during a certain time period (Cui and Perera 2008). It is a vital indicator of forest fire regimes. FSD studies are ever more important now as wildfire events nationwide have raised awareness and concern. For example the state of Florida in the summer of 1998 experienced one its worst fire seasons in half a century. Over 200,000 hectares burned costing the state $600 million in economic losses (Holmes et al. 2004). The rapid population growth in once rural areas and alteration of forest ecosystems called for a more thorough examination of all wildfire regime aspects. FSD studies can be broad in terms of objectives, the data sources, distribution, and methodologies.

Objectives vary as some studies evaluated wildfire regimes in human-dominated landscape while others used FSD of mostly unpopulated and isolated areas (Holmes et al. 2004; Li et al. 1999). There have been studies focusing on the analysis of temporal variations in FDS as well as factors influenced by FDS such as suppression efforts (Schoenberg et al. 2003; Song et al. 2001; Song et al. 2006). The statistics behind FSD can be troublesome as fire records are often skewed towards larger fires leaving out many small events or vice versa. Studies such as Alvarodo et. al (1998) sought to give a better description of the statistics involved. In terms of data collection the more popular method is to collect fire data from historical records (Strauss et al. 1989). In instances where historical records are not available a variety of simulation models are employed to estimate FSDs (Reed and McKelvey 2002).

FSD is referred to in a number of different terms or concepts (Cui and Perera 2008). FSD is referred to as: wildfire size distribution (Li et al. 1999; Schoenberg et al. 2003; Ward et al. 2001), fire size frequency distribution (Holmes et al. 2004), number-size distribution of forest fire areas (Burroughs and Tebbens 2001), probability distribution that describes fire-size population (Alavarado et al. 1998; Moritz 1997), and frequency area or distribution of fire size (Rideout and Omi 1990). No matter what term is used they all involve the analysis of the distribution of a particular fire size.

Several probability distributions have been applied to analyze wildfire sizes over various landscapes, the most prominent of which being the power law family. These include Pareto, exponential, log, and log-normal distributions. There are also truncated versions of each (Cui and Perera 2008). The probability distribution function of power law distribution is:

$$\boldsymbol{P(X = A) \sim A^{-b}} \tag{3-1}$$

Where $P(X = A)$ is the probability distribution function, *X* is a random variable *A* is a given fire size, and b is the constant (slope) (Strauss et al. 1989). The slope value b is the most important parameter of the power law distribution of fire sizes. When *b*<1, large fires account for more of the total area burned than small fires; when *b*>1, small fires account for more total area burned than large fires; and when *b*=1, all fires contribute equally to the total area burned. According to Cui and Perera (2008) it was Malamud et. al(1998) who were the first to provide empirical evidence that forest fires followed power law distribution. The authors determined that from as far north as Alaska to the western United States and even Australia followed a power law distribution with slopes ranging from 1.31 to 1.49 indicating that small fires contributed heavily to the area burned.

Empirical fire size data has also been fitted using Pareto distribution (Cumming 2001; Robertson 1972). The cumulative distribution function of a Pareto distribution *P(X >A)* can be expressed as:

$$\boldsymbol{P}(\boldsymbol{X} > A) \sim \boldsymbol{A}^{-\boldsymbol{k}} \tag{3-2}$$

Where *P(X >A)* is the probability distribution function, *X* is a random variable, *A* is the given fire size, and constant *k* is the Pareto distribution shape parameter (Cui and Perera 2008). These distributions and others such as negative exponential are basically the same family distributions with differences in mathematical expressions. For example the power law distribution explains how many fires equal a certain size *A*. The Pareto distribution on the other hand explains how many fires have a size that is greater than *A*.

Literature on FSDs has become diverse and fluid in all aspects of exploration. Study area extents and observation periods could be contributing factors to the variability as well as other innate reasons (Cui and Perera 2008). Spatially, FSDs may vary due to differences in regional geo-climate that influence the broader fire regime (Malamud et al. 2005). On smaller spatial scales FSDs may vary by location as incidence and fire size changes over small landscape changes. Temporally, FSDs can change within a short time period. Cramer (1959) found that the number of fires increased at an average rate of 37 fires per year over a period of 14 years in the north-western United States, while the fire size decreased continuously over the same period, thus changing the FSD. For observation periods longer than two decades, there have been more reports of changes in FSD (Song et al. 2001; Ward et al. 2001). One exception to the evidence on temporal variability in FSD is Malamud et al. (2005), who reported a constant FSD for the continental United States over a 30-year period from 1970 to 2000.

Environmental factors play a crucial role in fires occurrence and behavior (Cramer 1959; Malamud et al. 2005). Li et. al(1999) examined size distribution under natural conditions, meaning there were no instances of drought or over saturation from rain. They found that fire frequency and its size distribution are correlated with each other under ideal environmental situations. Moritz (1997) on the other hand compared weather conditions and fire occurrence and found that the number of fires is positively correlated with the number of rainless days. Perhaps the most agreed upon aspect in all literature is that local weather determines fire behavior and burn time, and therefore final fire size. It is also accepted that climate influences FSD (Reed and McKelvey 2002). Climate regulates short-term weather patterns and the length of the fire season, which directly affect FSD in the short term (Cui and Perera 2008).Temporal changes in climate can have an impact on long-term trends of FSD by changing the fire cycle (Bridge 2005). Human influences can affect FSD at equal or higher levels than climatic or environmental factors. Land cover modification can change fuel availability thus making flammability more or less of an issue. For example the construction of roads fragments land thus altering the size of a given fire (Cardille et al. 2001). The harvesting of forests also creates temporary gaps that affect fuel availability. When these forest gaps are not regenerated the affect on FSD becomes permanent (Cramer 1959). Fire management practices such as prescribed fire have been implemented to alleviate the threat of large fire events. As the available flammable material's composition and configuration changes so does the distribution of subsequent fires (Cramer 1959). Fire suppression is a direct factor affecting FSD. Cummings (2001) concluded that suppression during the early stages of a fire reduces the number and frequency of large fires in several regions. This fact has been argued by researchers whom feel that intense fire suppression actually increases occurrences of larger fires due to fuel build-up. In addition fire suppression is also believed to increase the frequency of small fires as well (Malamud et al. 1998).

Study Area

The study area consisted of the entire state of Mississippi which is approximately 49,907 square miles broken into 82 counties. Sixty-five percent of the state's land is in forests, which equates to 19.8 million acres. Timber is one of the state's most valuable crops. Forest composition is made up of 46 percent hardwood, 39 percent pine and 15 percent mixed oak and pine species (Mississippi Forestry Association 2007). Loblolly pine (*Pinus taeda*) and shortleaf pine (*Pinus enchinata*) are the most dominant of the softwood group accounting for 84 percent softwood species. The red and white oaks make up the 50 percent of all hardwood species in the state. Forestry is a vital component of the economy of Mississippi. Most counties depend on the production of timber as primary driver of its economy. It accounts for 8 percent of all jobs and creates over 4 billion dollars in wages (Mississippi Forestry Commission 2008).

There are at least ten physiographic regions in Mississippi (Stewart 2003). The coastal zone located along the Gulf Coast of Mississippi includes Hancock, Harrison, and Jackson counties. It is low in elevation and contains barrier islands, coastal lagoons, marshes, and swampy lowlands. Land cover includes pines as well as oak-gum-cypress communities. The Jackson Prairie region is a narrow strip of low, broad hills consisting of Yazoo clay. At present much of the region is dedicated to pine plantation and row crop agriculture. The Loess Hills and Delta regions are the fertile grounds adjacent the Mississippi river. The area is almost exclusively used for agriculture today with some areas being reverted back to forestland. Other regions include the Pine Belt, South and North Central Hills, the Black Prairie and the Tombigbee Hills (Stewart 2003).

The state's climate ranges from a maritime, warm-temperate climate along the Gulf Coast to more continental temperate in the north. From south to north weather factors create substantial variability due to (1) cessation of the passage of cold fronts along the coast than further inland, (2) more frequent afternoon thunderstorms during the summer months along the coast than in the north, (3) more frequent lightning in the south than in the north, and (4) higher rainfall amounts during the summer months. This variation creates drought conditions in southern Mississippi from early summer to late fall. Northern Mississippi rarely experiences drought due to the continuance of cold fronts passing through the area. This weather gradient manifests itself in south-north vegetation that ranges from the pine forests and savannas along the coast to deciduous hardwood and mixed hardwood-pine forests in the north. Fuel flammability is greatest in the southern portion of the state. Seasonal attributes include short mild winters with an average of 52 degrees Fahrenheit and long humid summers where temperatures easily can reach into the upper 90s and 100s. On average 86 centimeters (34 inches) of rain falls upon the state each year. During brief periods of drought the forests can become susceptible to wildfires ranging from minor to catastrophic.

The history of Mississippi forests is that of lush old growth forests with little to no undergrowth. Early settlers documented being able to navigate the area with relative ease due to fires set by both lightning and Native Americans (Fickle 2001). These fires, which were often minor in comparison to today's fire events, created a park like environment with grassy understories. An interruption in natural wildfire cycles created a compacted forest understory of mixed-hardwood species that are primed for extreme fire events. According to the National Interagency Fire Center there were 2300 wildfires in the state in 2009 which accounted for more than 31,000 acres of forest destroyed. The majority of these fires occurred between the months of March and September which is indicative of the historical records of Mississippi. The actual number of fires per year has decreased significantly over the past 40 years. Figure 3.1 outlines this steady decline as the number of fires dropped from around 10,000 fires per year in 1967 to around 4000 per year in 2004.

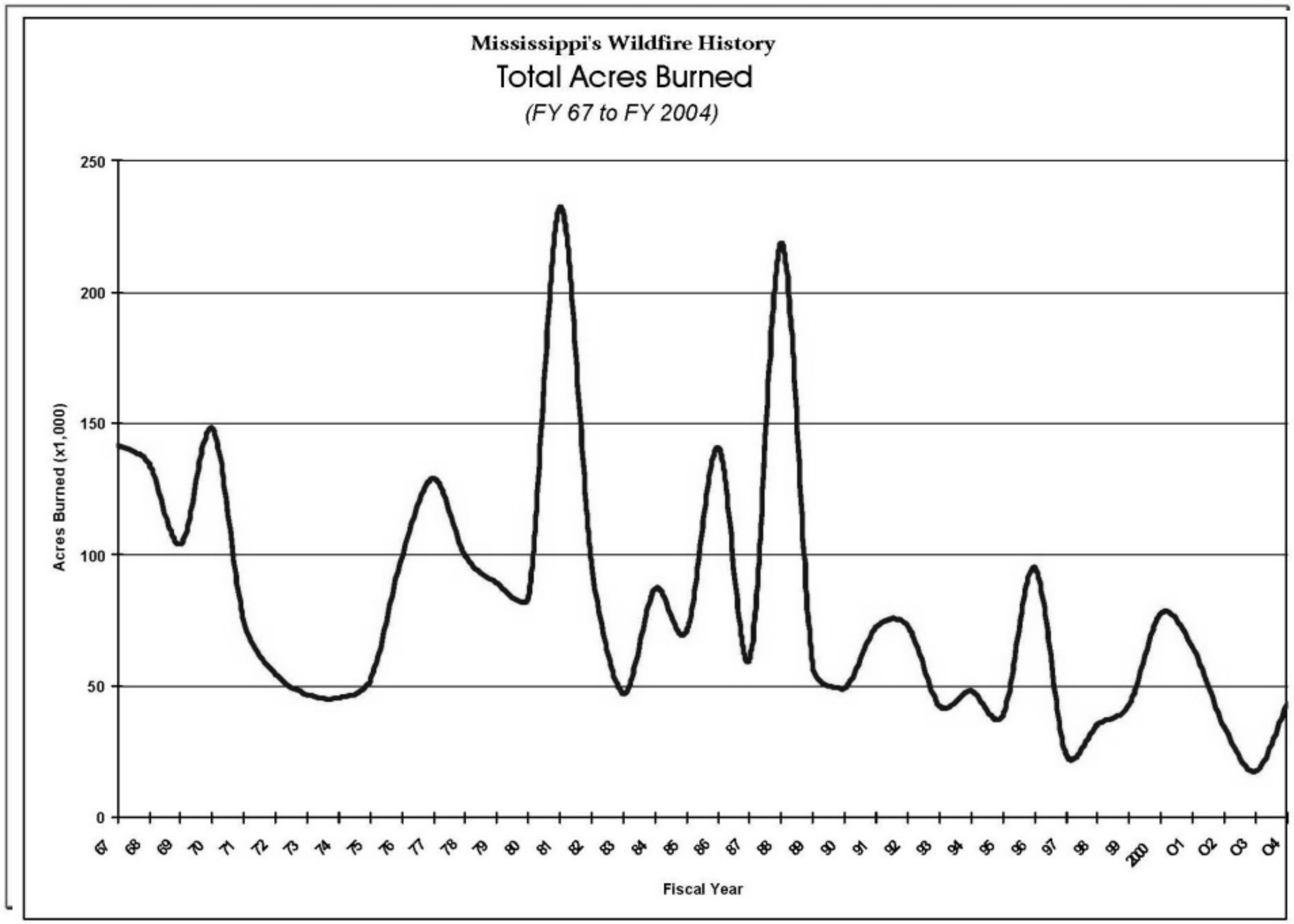

Figure 3.2 Number of acres burned per year between 1967 and 2004 (Courtesy: Mississippi Forestry Commission)

There has also been a decline in total acres burned during this same period of time (Figure 3.2). These wildfire trends are in accordance with nationwide trends where drops in both the number of fires and acreage burned have been documented.

Data and Methods

A detailed database of wildfire history was provided by the Mississippi Forestry Commission (MFC). The MFC kept records on wildfires dating back to early sixties. These records were later converted into a digital format making statistical analysis readily accessible. For this study records used were from July of 1990 until June of 2008 and were only of fires responded to by the MFC. Fires on National Forests are usually under the jurisdiction of the U.S. Forest Service and thus not sufficiently documented in the dataset. In instances in which the MFC assisted the U.S. Forest Service on National Forest land fire sizes were recorded. The database included: the location, time, date, response crew, acreage burned, injuries, fire cause, fire class, time in which fire was extinguished, etc.

Importing and Configuring Dataset

The dataset was imported for analysis using the statistical language R which is a language and environment for statistical computing and graphics. It provides a wide variety of graphical techniques and is highly extensible. The data were then examined for incomplete data entries which would inhibit the analysis or create inaccurate results. In addition all zero entry fire acres were also removed for similar reasons. Upon inspection of the data and appropriate modifications the total database consisted of 69,980 individual wildfires from 1990-2008. In order to evaluate FSD by year separate subsets were created and sorted for each year. Similar techniques were employed for wildfire ignition sources or causes.

A power law family model was used to examine the distributions of wildfire size in Mississippi over the given time span and variables. The most commonly used of these being the Pareto model (Coles 2001).

$$F(x) = 1 - \left(\frac{a}{x}\right)^{\beta}, a \leq x < \infty \qquad (3\text{-}3)$$

The parameter β in the Pareto model is the slope of the decrease in the survivor function 1-*F(x)*. The lower truncation point a, sometimes called the completeness threshold represents the lower limit on the sensitivity of the records. Its popularity is due to the inherent nature of wildfire data to have large tails. The Pareto model takes into account the absence of small wildfires in record keeping. Another power law model known as the truncated Pareto is also a well known method of determining wildfire distribution.

$$F_{trunc}(x) = F(x)/F(\gamma), a \leq x < \gamma \qquad (3\text{-}4)$$

Where γ is the hard upper threshold observed in a fire size dataset. It was formulated due to observations that the upper tail of wildfire distribution decayed to zero more rapidly than the Pareto model indicates (Coles 2001). Due to the completeness of the dataset which include both large and small wildfire records a generalized form of the Pareto distribution model, taking into account a scale parameter, was determined to be the appropriate for use with the dataset. The generalized Pareto model use excesses over a given threshold and assumes that the excesses will have a corresponding distribution over the entirety of the dataset. The distribution function would then be:

$$F(x) = 1 - \left(1 + \frac{\xi x}{\sigma}\right)^{-1/\xi} \qquad (3\text{-}5)$$

Where x represents the number of threshold excesses, ξ is the shape parameter, and σ is the scale parameter.

Threshold Determination

Generalized Pareto models are more efficient when using multiple observations per period but the most difficult aspect is the selection of a threshold (Holmes et al. 2008a). Several thresholds were calculated by plotting the sample mean excess function against the threshold value. Where the excess function becomes linear gives the appropriate value. Upon calculations of proper thresholds the parameters of the Generalized Pareto distribution were calculated by the method of maximum likelihood. The parameters of interest include the scale and shape parameters (σ,ξ) as well as their respective standard errors. The larger the scale the more dispersion there is in the distribution of wildfires (Holmes et. al 2008). Pareto distributions are obtained when the shape parameter is greater than zero. It affects the shape of the distribution overall.
For ξ≠0 the likelihood function is

$$L(\xi,\sigma) = \prod_{i=1}^{m} \frac{1}{\sigma} \left[1 + \xi \frac{x_i - u}{\sigma}\right]^{-(1+\frac{1}{\xi})} \quad (3\text{-}6)$$

and the log-likelihood is

$$lnL(\xi,\sigma) = -mln\sigma - \left(1 + \frac{1}{\xi}\right) \sum_{i=1}^{m} \ln[1 + \xi/\sigma(x_i \text{ -u})] \quad (3\text{-}7)$$

Where m is the number of observations, x_i is the size in acres of fires $i,$ and u is the threshold fire size in acres. Another method of determining appropriate thresholds will be by analyzing the mean residual life plot.

$$\left\{\left(u, \frac{1}{n_u} \sum_{i=1}^{n_u} (x(i) - u)\right) : u < x_{max}\right\} \quad (3\text{-}8)$$

Where $x_1, \ldots, x(n_u)$ consist of n_u observations that exceed u, and x_{max} is the largest of the X_i. Above a threshold u_0 at which the generalized Pareto distribution provides a valid approximation to the excess distribution, the mean residual life plot should be approximately linear in u (Coles 2001). Using the same techniques, several threshold values were determined and tested for each year and fire cause.

Several questions were addressed by estimating the FSD in the state of Mississippi. The first being whether or not wildfire size is stable over time. To do this the distribution was determined by year from 1990-2008. The second question involved evaluating the ignition source of the wildfires in the data set. There were ten sources documented and whether or not the distribution changes given a change in wildfire ignition source was determined. The final question of whether or not the top one percent of fires causes 99 percent of damage was examined and calculated.

Results

Descriptive Analysis

Table 3.1 Analysis of fire frequency, area, and average size by year from 1990-2008

Year	Freq	Area	Average
1990	3,888	38,656	9.94
1991	4,738	55,970	11.81
1992	4,298	55,938	13.01
1993	3,872	49,270	12.72
1994	3,255	47,683	14.65
1995	4,824	64,181	13.3
1996	4,739	93,381	19.7
1997	2,650	28,810	10.87
1998	3,292	37,777	11.48
1999	5,185	58,939	11.37
2000	6,609	89,294	13.51
2001	2,315	26,868	11.61
2002	2,320	32,016	13.8
2003	1,847	22,593	12.23
2004	2,728	40,575	14.87
2005	3,367	45,567	13.53
2006	5,338	122,590	22.97
2007	3,099	52,332	16.89
2008	1,616	24,737	15.31

The dataset included 69,980 individually recorded wildfires which burned nearly 1 million acres. From 1990 until 2008 the average fire size per year gradually increased from ten acres in 1990 to around 15 acres in 2008 (Table 3.1). The average fire size for the entire time span was 14.1 acres. The number of actual fires however decreased during the same period. In 1990 there were around 4000 recorded fires while in the years 2007 and 2008 the number of recorded fires fell below 3000. The total area burned per year fluctuated greatly over the past two decades with the highest year occurring in 2006 where over 122,000 acres were burned (Figure 3.3). The year 2006 was also the most active in terms of most recorded fire events (over 5000) and largest average fire size (22 acres/fire). The largest single wildfire event occurred in 1996 where 5208 acres of forest was burned in central Mississippi (Attala County).

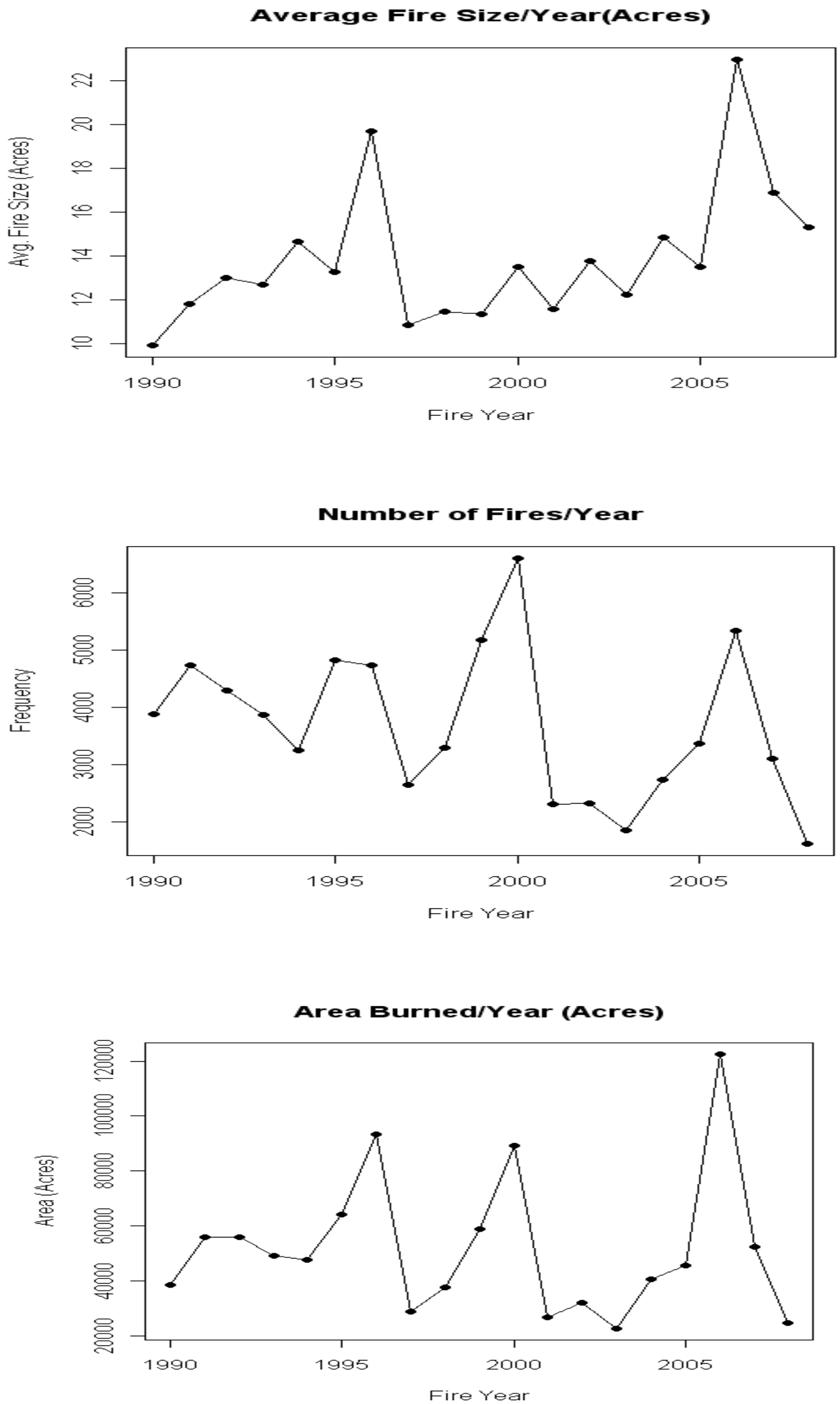

Figure 3.1 Graphs showing (top) The average fire size per year (middle) Number of fires per year and (bottom) Area burned per year from 1990-2008

Fire Causes

Of the ten wildfire ignition causes documented by the MFC use of incendiary devices was determined the most frequent ignition source causing over 38,000 wildfires (Table 3.2). Incendiary devices are items used for the purpose of starting fires. In this instance they have been defined as arson or the intentional setting of a fire for malicious reasons. Lighting only attributed to 439 wildfires over the past two decades while the burning of debris by individuals caused wildfires on 23,000 separate occasions. Accidental ignitions by children were negligible accounting for the second lowest in terms of area burned and third lowest in average fire size. Re-ignition of previously extinguished fires burned 28,208 acres and were on average significantly larger fires than those of any other fire cause.

Distribution

It was found that the old adage that one percent of all fires caused 99 percent of the total acreage burned did not hold true for wildfires in Mississippi. Of the 987,177 acres burned from 1990-2008 the upper one percent was responsible for 21.33 % of the total acreage burned (Table 3.3). That equates to 700 wildfires and over 210,000 acres. The Upper ten percent of all fires accounted for 58.82% of the total acreage burned with nearly 7000 total wildfires. Fires that were 150 acres or larger burned 20.75% of the total acreage burned with a mean fire size of 310 acres.

Table 3.2 Breakdown of wildfire causes, their frequency, area, and average acreage per fire from 1990-2008

Cause	Frequency	Area	Average
(1) Lightning	439	4877	11.11
(2) Campfires	113	865	7.65
(3) Smoking	1235	15172	12.29
(4) Debris burning	23204	257297	11.09
(5) Incendiary	38655	628169	16.25
(6) Equipment use	1145	10723	9.37
(7) Railroads	339	4349	12.83
(8) Children	423	3918	9.26
(9) Miscellaneous	3136	33599	10.71
(10) Re-ignition	1291	28208	21.85

Table 3.3 Distribution of fires by various fire classes, acreage burned, mean, and percentage of total area burned from 1990-2008

Fire Class	Num.	Min. Size	Max Size	acreage	**%**	Mean	**St. Error**
All fires	69980	1	5208	987177	**100**	14.11	**54.29**
Upper 1%	700	140	5208	210567	**21.33**	300.81	**424.2**
Upper 10%	6998	33	5208	580625	**58.82**	82.97	**154.07**
At least 50 acres	4274	50	5208	472512	**47.86**	110.55	**192.1**
At least 100 acres	1237	100	5208	270836	**27.44**	218.95	**332.53**
At least 150 acres	660	150	5208	204862	**20.75**	310.4	**435.04**
At least 200 acres	364	200	5208	156297	**15.83**	429.39	**558.35**
At least 250 acres	225	250	5208	126702	**12.83**	563.12	**676.78**
At least 300 acres	175	300	5208	113475	**11.49**	648.43	**746.09**
At least 500 acres	62	500	5208	71841	**7.28**	1158.73	**1082.53**
At least 1000 acres	21	1000	5208	45181	**4.58**	2151.48	**1407.57**
At least 2000 acres	7	3000	5208	27891	**2.83**	3984.43	**748.29**

Larger fires such as in the Midwest or Western United States can easily reach 100,000 acres or higher. Wildfire events in Mississippi on the other hand occur on a much smaller scale where a large fire event is considered to be a few hundred acres. There were only 4274 wildfires over 50 acres over the past two decades 175 wildfires over 300 acres and only 7 fires of at least 2000 acres.

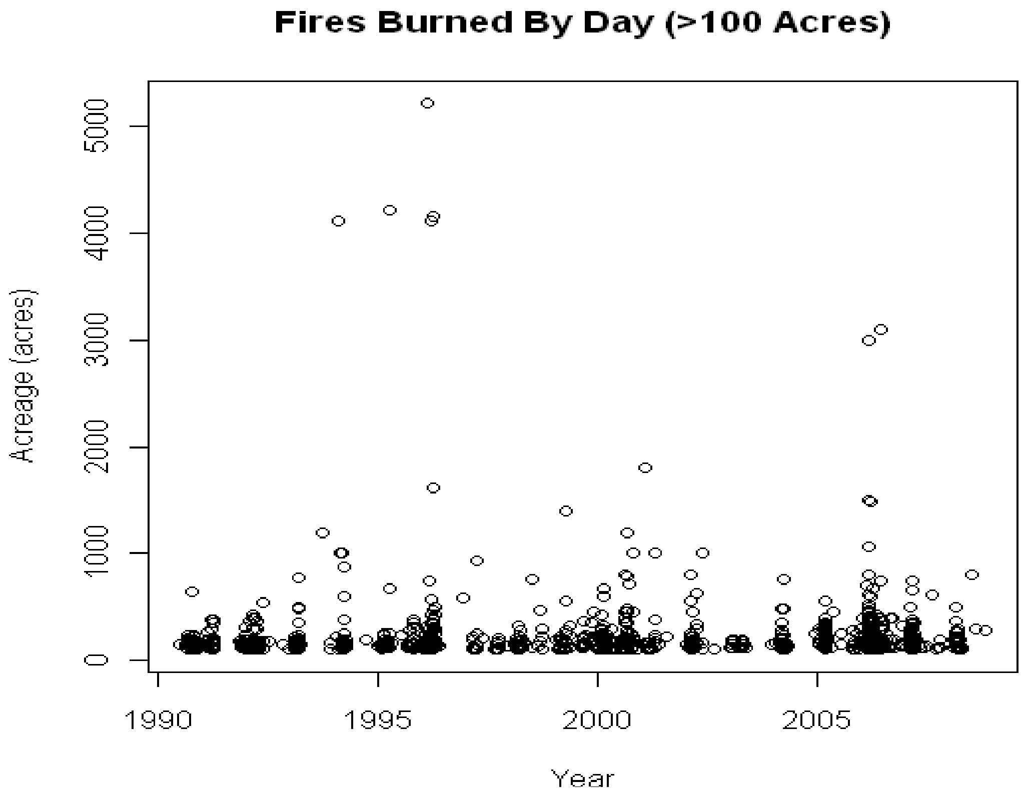

Figure 3.2 Fire observations greater than 100 acres in size from 1990-2008

Threshold

As mentioned earlier the main challenge when using Pareto models is the selection of a threshold (Holmes et al. 2008a). For the entire dataset it was determined that the most suitable threshold was 100 acres. There were only 1036 fires larger than one hundred acres which amounts to 1.4 percent of all fires in the sample. The mean residual life plot also supported a threshold of 100 acres (Figure 3.6). From that as well as results generated by plotting different thresholds by shape and scale parameters (Figure 3.5) the chosen threshold was deemed appropriate. When analyzing the FSD of wildfires caused by debris burning it was determined that an appropriate threshold would also be 100 acres. A threshold of 250 acres was calculated for fires caused by incendiary devices. The higher threshold can be attributed to the fact that these were arson fires that were located in areas that were not readily accessible or in remote areas which allowed for larger fires to form.

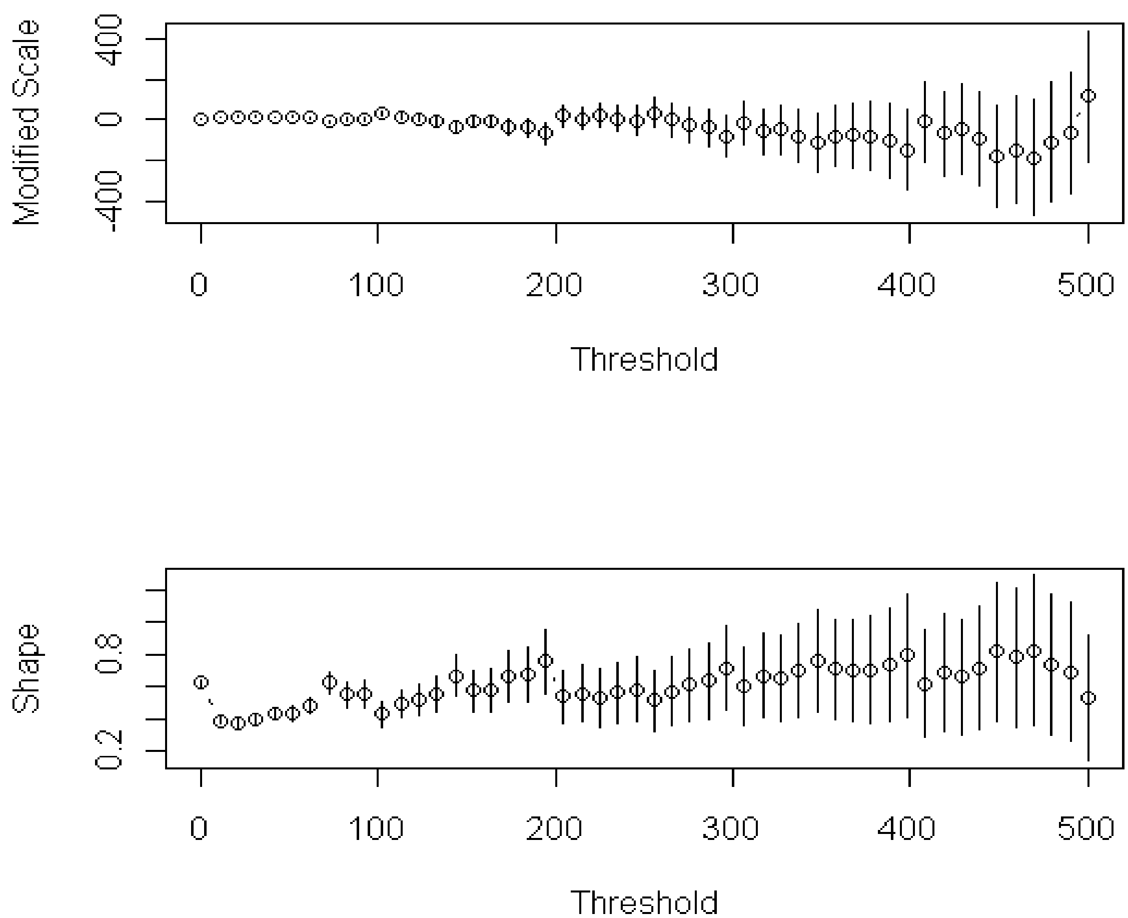

Figure 3.3 Graph of scale and shape estimates at a given threshold from 1990-2008.

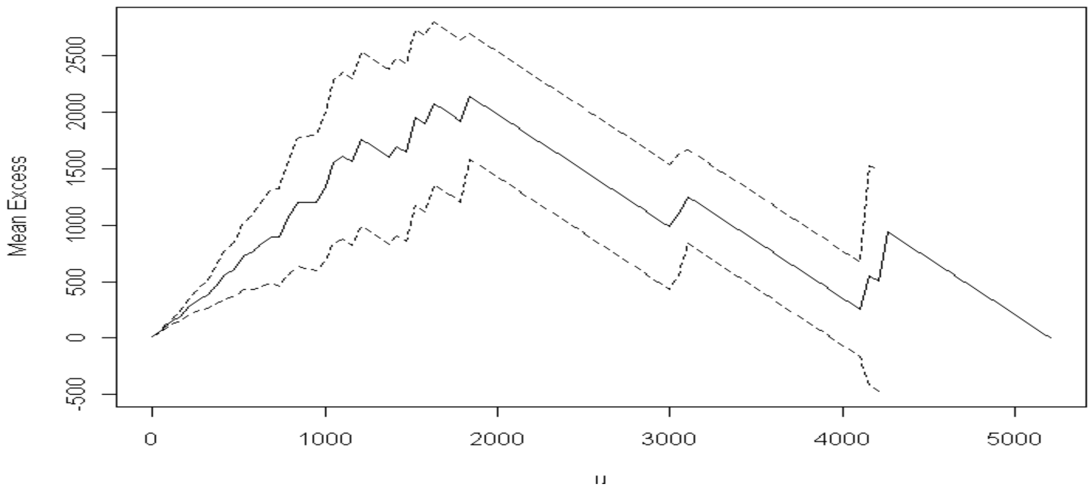

Figure 3.4 Mean residual plot with confidence intervals for wildfire data from 1990-2008

Pareto Model

Wildfires in Mississippi were determined to exhibit a Pareto distribution with a threshold of 100 acres. The probability plot, which is the difference between observed and predicted responses as well as the quantile plot in (Figure 3.6) are sufficiently close to linearity thus they lend support to the fitted model. The return level plot in (Figure 3.7) also indicates a good fit for the data. The maximum likelihood estimate for the scale and shape parameters (σ, ξ) were 77.8 and 0.409 respectively. The maximum log-likelihood was -5971.03. When studied against different fire causes it was determined that the wildfire data remained consistent with a Pareto distribution. Scale and shape parameters were 261.6 and 0.75 for fires caused by debris burning and 78.6 and 0.29 for those created by incendiary devices. The analysis of time trend indicated little to no change in distribution over time the span of data recorded.

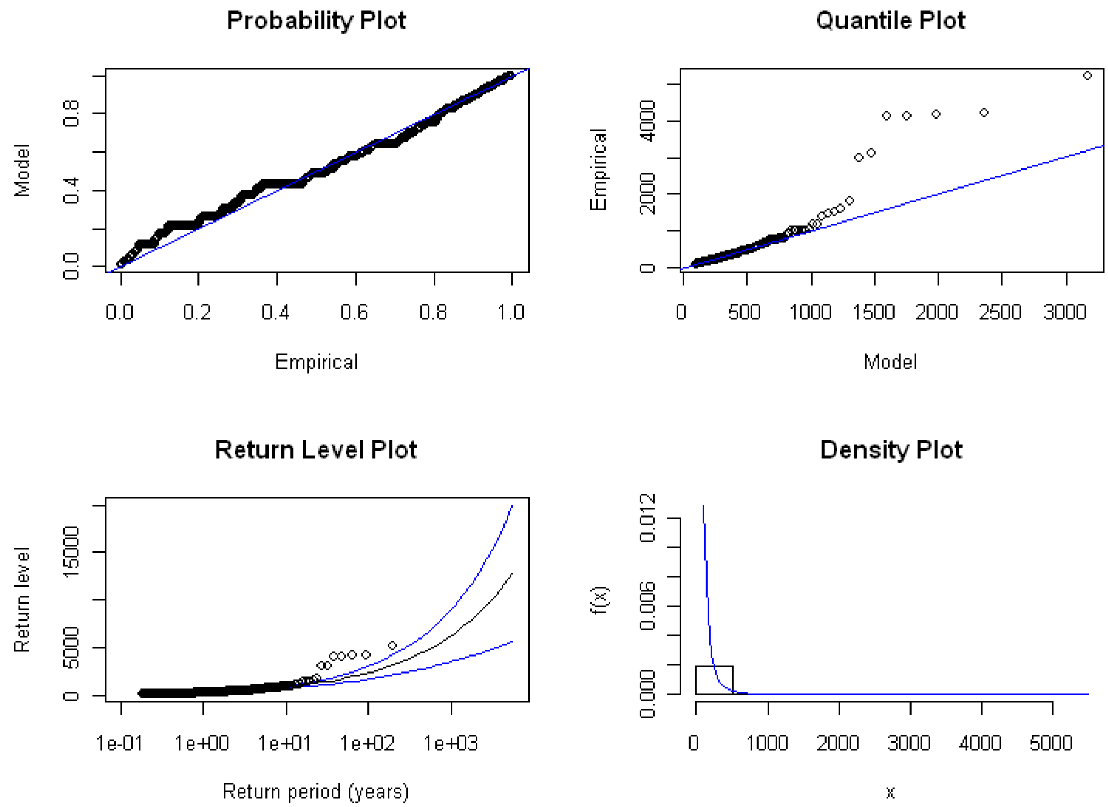

Figure 3.5 Diagnostic plots for threshold excess model fitted to wildfire data from 1990-2008 (threshold 100 acres)

Conclusions

It was concluded that wildfires in Mississippi do exhibit a generalized Pareto distribution as a whole, over time, and by various fire causes. More than half of the acreage burned was attributed to the upper ten percent of fires with few instances of wildfires over 1000 acres. There were significant differences between fire causes with incendiary and debris burning being among the leaders in wildfire causes. When compared with other regions of the United States Mississippi's wildfire characteristics may appear insignificant but with $4 billion of the state's economy being in forestry and related industries the need for FSD analysis is an all important one. Along with the implementation of harvest scheduling and cost analysis the understanding of FSD could aide private landowners with the financial analysis of their forest investments. Risk assessments taking into account the size distribution could help landowners decide whether or not to engage in an investment opportunity.

Limitations in Knowledge

This study involved the analysis of records of past forest fire records. Empirical observations can often contain insufficient data that can affect the reliability of FSD. For example a common error occurs when small fires are properly recorded or unrecorded altogether. The dataset rounded each wildfire to the nearest whole number while having well over 1,000 zero acreage records. The deletion of these records is accounted in the Pareto model however when using other models this can become problematic. The actual sizing of wildfires also creates difficulties for researchers. Identification of fire perimeters can result in different boundaries for historical fires. Some researchers use data extracted from the mapping of historical fire aerial photos while others use satellite imagery or field investigations. For this study the MFC determined fire size by mapping the area upon extinguishment by GPS. This provides a more accurate uniform measurement with little to no bias. Finally the return levels were not discussed in this study but subsequent research could use the scale, shape, and standard errors to calculate when a fire equal to a certain size is likely to occur.

Future Research

Mississippi has nine distinct physiographic regions in which FSD could focus. Studies would suggest that the distribution would change given a spatial change from region to region. For example is the distribution of wildfires in the Loess Hills region different from that of the Coastal Plains. The dataset includes latitude and longitude coordinates which would make that aspect of research applicable. Global climate change has been a hot button issue recently as scientists predict that average global temperatures will spike thus changing weather patterns worldwide. Understanding how FSD patterns change given weather and climate changes could provide critical incite for policy makers going forward. Fire suppression efforts have intensified over the decades as the fire intensity of large wildfires has increased. There is a need to evaluate the effects of direct fire suppression and indirect fire management through fuel modifications on FSDs (Cui 2008). Prescribed burning has become a vital tool in wildfire management. Future research is needed to better understand prescribed burnings influence on FSD.

CHAPTER IV

CONCLUSIONS

In Chapter II management based regulations presence in prescribed burning was assessed and found to have great influence on laws and regulations implemented since the early 1990s. Florida's innovative approach to prescribed fire policy led to a regional adoption of items such as Prescribed Burning Acts, CPBM laws, and minimum prescription requirements. While reduction of landowner liability and wildfire reduction were the principle drivers of the policy shift there are other repercussions that have yet to be analyzed fully.

Management based regulation holds great promise for landowners and prescribed burners moving forward. Time will answer the question of whether or not the changes will increase the frequency of prescribed burning. Also the validity of this new policy approach against potential lawsuits as mentioned in Chapter II has not been thoroughly tested. Whether or not the regulations are robust enough to withstand the scrutiny of a courtroom will determine management based regulation's future in other realms of agriculture and natural resources. With the implementation of more management-based regulations in prescribed fire the question of its effectiveness will give rise to new study directions. For example how do these regulation changes affect the number of prescribed burns in a particular state or region? Results garnered from such a study could then be used to analyze the effect of regulation and law change on wildfires and their distributions.

In Chapter III wildfires in Mississippi were determined to fit a Pareto distribution with a majority of the acreage burned being attributed to the largest ten percent of all fires. The average size of wildfires from has grown while acreage burned and total fires have decreased. The sample used in the Chapter III was for the years of 1990 through 2008. During this same period of time prescribed fire policy began to shift in the Southeast to more of a management based approach. In Mississippi the introduction of minimum prescription requirements, CPBM requirements and responsibilities and other regulations were implemented in the early to mid 1990s. Future research topics investigating the connection between policy changes, prescribed burning frequency, and wildfire frequency and distribution could present a bounty of new revelations going forward.

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APPENDIX A

SUMMARY OF CURRENT ADMINSTRATIVE LAWS AND REGULATIONS FOR EACH STATE IN THE SOUTHERN U.S.

Administrative Regulations and rules	AL	AR	FL	GA	KY	LA	MS	NC	OK	SC	TN	TX	VA
Authorization prior to burn	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Restrictions nighttime burning	No	N/A	Yes	Yes	Yes	Yes	Yes	No	No	No	No	Yes	N/A
Proof of insurance given prior to burn	No	No	No	No	No	No	No	No	No	No	No	Yes	No
certification process available	Yes	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes	No	Yes	Yes
de-certification process available	Yes	No	Yes	N/A	No	Yes	No	Yes	No	N/A	No	Yes	Yes
re-certification process	Yes	No	Yes	N/A	No	Yes	No	Yes	No	N/A	No	Yes	Yes
Separate requirements for non-CPBM	No	N/A	Yes	Yes[1]	N/A	N/A	Yes	N/A[#]	N/A	Yes	N/A	Yes	Yes
Prescription Required	Yes	No[3]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Minimum requirements	Yes	No	Yes	No	No	No	Yes	N/A[#]	Yes	No	No	Yes	Yes
Smoke Management Guidelines in burn plan	Yes	Yes[3]	Yes	Yes	Yes	Yes	Yes	N/A[#]	Yes	Yes	Yes	Yes	Yes
Prescription on site at all times	N/A	N/A	Yes	N/A	N/A	No	No	N/A[#]	N/A	Yes	Yes	N/A	Yes[#]
Acceptable atmospheric conditions stated	Yes	Yes	N/A	Yes	Yes	No	Yes	Yes	N/A	Yes	Yes[4]	Yes	N/A
Set open burning hours	No	Yes	Yes	Yes	Yes	Yes	Yes[2]	Yes*	No	Yes	No	Yes	N/A

APPENDIX B

TABLE OUTLINING EVOLUTION OF PRESCRIBED FIRE REGULATION IN FLORIDA

Year	Item	Description	Source of Law
1975	5I-2.06	Open burning is allowed between the hours of 9:00 AM and one hour before sunset	Chapter 75-22, Laws of Florida/ Clean Air Act
1991	5I-2.006	Additions includes: (1)Division of Forestry can suspend any prescribed burn after reasonable notice (2) Fires must be attended at all times	Florida Statute 590.026 (4)
	5I-2.0061	Requirements for a written prescription and certified prescribed burn manager certification and decertification	Florida Statute 90.026 (4)
1993	5I-2.006	Additions include: (1) nighttime authorizations to burn until midnight (2) list of prohibited starter fuels (3) distance restrictions from occupied buildings (4) authorization to burn must be received from the Florida Division of Forestry	Florida Statute 570.07 (23) (28), 590.026 (4)
1995	5I-2.006	Additions include: (1) permit must be obtained prior to igniting the burn or after 4:00 PM of the previous evening (2) appropriate atmospheric conditions must exist for permit to be issued (3) the person requesting the permit must identify the certified burn manager by submitting the certification number (4) more details on the burn manager certification and re-certification requirements	Florida Statute 570.07 (23) (28), 590.026 (4)
1999	5I-2.006	Changes include: (1) the burning hours of 9:00 AM until one hour before sunset apply only to non-certified burn managers (2) certified burn managers may burn from 9:00 AM until one hour after sunset	Florida Statute 570.07 (23) (28), 590.026 (4)
2005	5I-2006	Additions include: (1) clarification of burn hours based on the multiple time zones of Florida (2) prescription must be completed prior to the burn taking place	Florida Statute 570.07 (23) (28), 590.026 (4)

APPENDIX C

CURRENT REGULATIONS IN FLORIDA

Administrative Rules for Prescribed Burning in Florida

Permit

Written Prescription (FAC 5I-2.006)

Prescription. A prescription for the burn must be completed prior to any ignition and it must be on site and available for inspection by a Department representative. The prescription will contain, as a minimum, the following:

1) Stand or Site Description

2) Map of the area to be burned

3) Number of personnel and equipment types to be used on the prescribed burn

4) Desired weather factors, including but not limited to surface wind speed and direction, transport wind speed and direction, minimum mixing height, minimum relative humidity, maximum temperature, and the minimum fine fuel moisture;

5) Desired fire behavior factors, such as type of burn technique, flame length, and rate of spread;

6) The time and date the prescription was prepared;

7) The authorization date and the time period of the authorization;

8) An evaluation and approval of the anticipated impact of the proposed burn on related smoke sensitive areas;

9) The signature and number of the Certified Prescribed Burn Manager.

Open Burning Hours

1) Daytime CPBM Authorizations will be issued for the burning to be conducted from 8:00 a.m. CT or 9:00 a.m. ET and the fire must discontinue spreading one hour after sunset.

2) Nighttime CPBM Authorizations will be issued with a Dispersion Index of 6 or above for the burning to be conducted between one hour before sunset and 8:00 a.m. CT or 9:00 a.m. ET the following day. Ignition of these fires is authorized up to midnight: however the fire can continue to spread until 8:00 a.m. CT or 9:00 a.m. ET the following day. If additional time is required a new authorization (daytime) must be obtained from the Division. The Division will issue authorizations at other times, in designated areas, when the Division has determined that atmospheric conditions in the vicinity of the burn will allow good

dispersement of emissions, and the resulting smoke from the burn will not adversely impact smoke sensitive areas, e.g., highways, hospitals and airports.

Burn Manager Certification Process. Certification to become a Certified Prescribed Burn Manager is accomplished by:

1) Satisfactory completion of the Division of Forestry's Prescribed Fire Correspondence Course and direct experience in three prescribed burns prior to taking the course; or

2) Satisfactory completion of the Division of Forestry's Prescribed Fire Classroom version of the Correspondence Course and a minimum of managing three prescribed burns prior to taking the course; or

3) Satisfactory completion of the Florida Inter-Agency Basic Prescribed Fire Course and direct experience in three prescribed burns following successful completion of the classroom training. The burns conducted during the training do not count as part of this three burn requirement.

4) Applicants must submit a completed prescription for a proposed certifying burn to their local Florida Division of Forestry office prior to the burn for review and approval, and have the burn described in that prescription reviewed by the Division of Forestry during the burn operation. The local Division of Forestry District Manager (or their designee) will recommend DOF Prescribed Burn Manager certification upon satisfactory completion of both the prescription and required number of burns.

5) In order to continue to hold the Division of Forestry Prescribed Burn Manager Certification the burner must comply with paragraph 5I-2.006(2)(d), F.A.C., or Division Certification will terminate five years from the date of issue.

Certification Renewal Certified Prescribed Burn Manager must satisfy the following requirements in order to retain certification.

1) Participation in a minimum of eight hours of Division of Forestry approved training every five years relating to the subject of prescribed fire, or participation in a Division of Forestry recognized Fire Council Meeting; and

2) The Certified Prescribed Burn Manager has submitted their certification number for two completed prescribed burns in the preceding five (5) years; or

3) Participation in five (5) burns and have this documented and verified in writing to the Forest Protection Bureau's Prescribed Fire Manager of the Division of Forestry by a current Certified Prescribed Burn Manager; or Page 2 5I-2.006, F.A.C.

4) Retaking either the Prescribed Fire Correspondence Course or the Inter-Agency Basic Prescribed Fire Course.

_Decertification.

A Certified Prescribed Burn Manager's certification shall be revoked if the Burn Manager's

1) Actions constitute violations of Florida law and agency rules which equal or exceed 15 points within any two year period using the Certified Prescribed Burn Manager Violations - Point Assessment Table (Find Table in Appendix A). A decertified Burn Manager must complete the Burn Manager Certification process outlined in paragraph 5I-2.006(2)(c), F.A.C., in order to be recertified.

Documentation requirements for Certified Prescribed Burn Managers

If you have used your Certified Prescribed Burn Manager number twice in the last five years there is no documentation that needs to be sent in. The Division of Forestry can check your authorization history. If you have burned five times under another Certified Prescribed Burn Manager the information we will need is the following:

1) Your Certified Prescribed Burn Manager number

2) The number of the Certified Prescribed Burn Manager you worked under.

3) The dates of the burns you worked on verified by the Certified Prescribed Burn Manager listed in number 2.

4) Training documentation: Provide a copy of any certificates to your local Division of Forestry office and ask them to forward your information to the Forest Protection Bureau, Prescribed Fire Manager.

Open Burning Non-Certified Broadcast Burners

1) All burning conducted under this section is related to broadcast burning of acreage not conducted as a certified prescribed burn. Authorizations for this type of burning are issued on the day of the burn or after 4:00 p.m. of the previous day.

2) Daytime Non-Certified Authorizations will be issued for the burning to be conducted from 8:00 a.m. (CT) or

3) 9:00 a.m. (ET) and the fire must discontinue spreading one hour before sunset.

4) Nighttime Non-Certified Broadcast Authorizations will be issued with a Dispersion Index of 8 or above for the burning to be conducted between one hour

before sunset and 8:00 a.m. (CT) or 9:00 a.m. (ET) the following morning. Ignition of these fires is authorized up to midnight CT or ET, specific to the time zone where the fire is located; however the fire can continue to spread until 8:00 a.m. (CT) or 9:00 a.m. (ET) the following day. If additional time is required, a new daytime authorization must be obtained from the Division.

APPENDIX D

R CODE FOR CHAPTER III

Study: Fire Size Distribution
Created: August 11, 2009
Modified: Jan 24, 2010

```
###########################################################################
           ##### R Program Table of Contents
###########################################################################

# Step 1   Import Data and Transformation
#   1.1    Import Data
#   1.2    Delete Records with Incomplete Data
#   1.3    Create Final Dataset

# Step 2   Descriptive Analysis
#   2.1    Summary for Acreage by Year
#   2.2    Determine Fire Causes
#   2.3    Summary by Cause
#   2.4    Summary by Percentage

# Step 3   Generalized Pareto Distribution by Year
#   3.1    Create Time Trend Variable
#   3.2    Estimate GPD for All Years

# Step 4   Generalized Pareto Distribution by Fire Cause
#   4.1    GPD for Cause (Debris Burning)
#   4.2    GPD for Cause (Incendiary Device)

# Step 5   Export Results


library(RODBC); library(ggplot2); library(ismev)



###########################################################################
## Step 1 Import Data and Transformation
###########################################################################
```

 # 1.1 Import data

```
getwd(); setwd("C:/Directory")

# fire  <-
        odbcConnectExcel2007('Fires.raw.data.1991to2008.xls
        x')
# sheet <- sqlTables(fire)
```

```
# str(sheet)
# (name <- sheet$TABLE_NAME)
# varnam <- sqlFetch(fire, "VarName"); str(varnam);
         head(varnam)
# data91 <- sqlFetch(fire, "data91");  str(data91);
         head(data91)
# data04 <- sqlFetch(fire, "data04");  str(data04);
         head(data04)
# odbcClose(fire)
# save(varnam, data91, data04, file="firedata.Rdata")

load("firedata.Rdata"); ls()
head(varnam); data91[1:5, 1:4]; data04[1:5, 1:4]

data <- rbind(data91, data04); tail(data)
dim(data91); dim(data04); dim(data)
colnames(data) <- tolower(names(data))
names(data)
```

 # 1.2. Delete records with incomplete information

```
raw <- data[, c("fir_det_dt", "fireyear", "firemonth",
         "fireday", "class", "totacres",
    "cause")]
dim(raw); head(raw)

n.acre <- as.data.frame(with(raw, table(totacres,
         useNA="ifany")))
dim(n.acre); head(n.acre); tail(n.acre); sum(n.acre[,2])

n.clas <- as.data.frame(with(raw, table(class,
         useNA="ifany")))
dim(n.clas); n.clas; sum(n.clas[,2])

n.caus <- as.data.frame(with(raw, table(cause,
         useNA="ifany")))
dim(n.caus); n.caus; sum(n.caus[,2])

na.detd <- subset(raw, is.na(fir_det_dt)); dim(na.detd);
         na.detd # 37 obs
na.year <- subset(raw, is.na(fireyear));   dim(na.year);
         na.year # 0
na.mont <- subset(raw, is.na(firemonth));  dim(na.mont);
         na.mont # 0
na.dayy <- subset(raw, is.na(fireday));    dim(na.dayy);
         na.dayy # 0
```

```
na.acre <- subset(raw, is.na(totacres));   dim(na.acre);
         na.acre # 38
na.clas <- subset(raw, is.na(class));      dim(na.clas);
         na.clas # 0
na.caus <- subset(raw, is.na(cause));      dim(na.caus);
         na.caus # 38

small <- subset(raw, totacres>0 & cause>0); dim(small);
         head(small); tail(small)
na.det <- subset(small, is.na(fir_det_dt)); dim(na.det);
         na.det # 0 obs

# This block shows that "fire_det_dt" has the same info as
         fireyear / month / day.

small$yy <-
         as.numeric(format(small$fir_det_dt,format="%Y"))
small$mm <-
         as.numeric(format(small$fir_det_dt,format="%m"))
small$dd <-
         as.numeric(format(small$fir_det_dt,format="%d"))
small$pp <- small$fireyear + small$firemonth +
         small$fireday - small$yy - small$mm - small$dd
head(small)
sum(small$pp)
```

 # 1.3 Final dataset for analysis

```
sma <- small[,c(1:4, 6, 7)]
colnames(sma) <- c("date", "year", "month", "day", "area",
         "cause")
final  <- sma[order(sma$date),]
head(final); tail(final)
dim(final)
sum(as.numeric(complete.cases(final)))


###########################################################
```
Step 2 Descriptive statistics
```
###########################################################
```

 # 2.1 Summary for acreage by year

```
cf <- as.data.frame(with(final, table(year,
         useNA="ifany")))
```

```
ca <- aggregate(final$area, by=list(year=final$year),
         FUN="sum")
sum.yy <- merge(cf,ca, by="year")
colnames(sum.yy) <- c("year", "freq", "area")
sum.yy$average <- with(sum.yy, round(area/freq, 2))
sum.yy$year <- 1989+as.numeric(sum.yy$year)
sum.yy; sum(sum.yy$area)

plot(sum.yy$year, sum.yy$average, main= "Average Fire
         Size/Year(Acres)",
xlab="Fire Year", ylab="Avg. Fire Size (Acres)", type="o",
         pch=19)

plot(sum.yy$year, sum.yy$freq, main= "Number of
         Fires/Year", xlab="Fire Year"
, ylab= "Frequency", type="o", pch=19)

plot(sum.yy$year, sum.yy$area, main= "Area Burned/Year
         (Acres)", xlab="Fire Year"
, ylab= "Area (Acres)", type="o", pch=19)


win.graph(width=5.1,height=2.5,pointsize=9)
fig1 <- ggplot(sum.yy, aes(x=year) ) +
    geom_line(aes(y=freq)) + labs(x="Date", y="Number of
         Fires per Year")+ (main= "Fire Frequency Per Year")
fig1

win.graph(width=5.1,height=2.5,pointsize=9)
fig2 <- ggplot(sum.yy, aes(x=year) ) +
    geom_line(aes(y=area)) + labs(x="Date", y="Total Areas
         Burnt per Year (Acres)")
fig2

win.graph(width=5.1,height=2.5,pointsize=9)
fig3 <- ggplot(sum.yy, aes(x=year) ) +
    geom_line(aes(y=average)) + labs(x="Date", y="Average
         Areas Burnt per Year (Acres)")
fig3
```

 # 2.2 Determine fire causes

```
d.cau <- subset(raw, fir_det_dt >= as.POSIXlt("2007-07-01")
         & fir_det_dt <= as.POSIXlt("2008-06-30") )
dim(d.cau);head(d.cau); tail(d.cau)
```

```
(sum08.1 <- as.data.frame(with(d.cau, table(cause,
         useNA="ifany"))))
(sum08.2 <- aggregate(d.cau$totacres,
         by=list(cause=d.cau$cause), FUN="sum") )
sum08 <- merge(sum08.1, sum08.2, by="cause")
colnames(sum08) <- c("cause", "freq", "area")
(sum08 <- sum08[order(sum08$cause),])

code <- c("Unknown        -  0",
          "Lightning      -  1",
          "Campfires      -  2",
          "Smoking        -  3",
          "Debris burning -  4",
          "Incendiary     -  5",
          "Equipment use  -  6",
          "Railroads      -  7",
          "Children       -  8",
          "Miscellaneous  -  9",
          "Re-ignition    - 10")
sum08$name <- code
sum08 <- sum08[,c("name", "cause", "freq", "area")]
(sum08 <- sum08[order(sum08$area),])
sum(sum08[,3])
```

#2.3. Summary by cause

```
hf <- as.data.frame(with(final, table(cause,
         useNA="ifany")))
ha <- aggregate(final$area, by=list(cause=final$cause),
         FUN="sum")
sum.ss <- merge(hf,ha, by="cause")
colnames(sum.ss) <- c("cause", "freq", "area")
sum.ss$average <- with(sum.ss, round(area/freq, 2)); sum.ss
sum.ss <- sum.ss[order(sum.ss$cause),]
sum.ss$name <- code[-1]
sum(sum.ss[,2])
sum.ss
```

 # 2.4. Summary by percentage

```
sum.per <- data.frame(
           fire.num     = dim(final)[1],
           min.size     = min(final$area),
           max.size     = max(final$area),
           acreage      = sum(final$area),
```

```
          acreage.pert =
        round(sum(final$area)/sum(final$area)*100,2),
          mean          = round(mean(final$area),2),
          st.error      = round(sd(final$area),2))

cut <- c(50, 100, 150, 200, 250, 300, 500, 1000, 2000)
for (i in 1:(2+length(cut)) ) {
    per <- final[order(final$area, decreasing=T), ]
    if (i==1) {
       nn <- ceiling(0.01*dim(per))[1]
       pp <- per[1:nn,]
    }
    if (i==2) {
       nn <- ceiling(0.10*dim(per))[1]
       pp <- per[1:nn,]
    }
    if (i>2) { pp <- subset(final, final$area>=cut[i-2]) }

    sum.per[i+1,] <- c(dim(pp)[1], min(pp$area),
         max(pp$area), sum(pp$area),
        round(sum(pp$area)/sum(final$area)*100, 2),
         round(mean(pp$area),2), round(sd(pp$area),2))
}
fire.class <- c("All fires", "Upper 1%", "Upper 10%",
    "At least 50 acres", "At least 100 acres", "At least
         150 acres",
    "At least 200 acres", "At least 250 acres", "At least
         300 acres",
    "At least 500 acres", "At least 1000 acres", "At least
         2000 acres")
sum.per <- data.frame(fire.class=fire.class, sum.per)
sum.per

############################################################
## Step 3    F i t    G e n e r a l i z e d    P a r e t o
         by year
############################################################
```

 # 3.1 Create time trend variable

```
final <- final[order(final$date),]
dim(final); head(final); tail(final)

date  <- seq(from=as.Date("1990-07-01"), to=as.Date("2008-
         11-11"), by="days")
year  <- as.numeric(format(date,format="%Y"))
```

```
month <- as.numeric(format(date,format="%m"))
day   <- as.numeric(format(date,format="%d"))
trend <- data.frame(date, year, month, day)
trend$time.day <- as.numeric(row.names(trend))
dim(trend); head(trend); tail(trend)

new <- merge(final, trend, by=c("year", "month", "day"))
new <- new[order(new$date.x),]
new[2479:3000,]; tail(new)

new$time.year <- 0
for (i in 1990:2008) {
    new$time.year <- ifelse(new$year==i, i-1989,
         new$time.year)
}
head(new); tail(new)

dim(final); dim(trend); dim(new)

win.graph(width=5.1,height=3.5,pointsize=9)
plot(area~date.x, data=new, xlab="date", ylab="acreage
         (acres)", main="Acres Burned By Day")

win.graph(width=5.1,height=3.5,pointsize=9)
tt <- subset(new, new$area>100)
plot(area~date.x, data=tt, xlab="date", ylab="acreage
         (acres)", main="Fires Burned By Day (>100 Acres)")
```

 # 3.2 Estitmate GPD for all years

```
# create variables to use: acreage, time trend by day or
         year

xa <- new$area; head(xa); NROW(xa)
tb <- as.matrix(new$time.day);  head(tb); tail(tb); dim(tb)
tc <- as.matrix(new$time.year); head(tc); tail(tc); dim(tc)

length(xa[xa>50])     # 3633
length(xa[xa>100])    # 1036
length(xa[xa>200])    # 305
length(xa[xa>300])    # 154
length(xa[xa>400])    # 87
length(xa[xa>500])    # 55
length(xa[xa>1000])   # 18
```

```
length(xa[xa>1500])  # 10
length(xa[xa>2000])  # 7

# compare and determine threshould to be th=100

gpd.fitrange(xa, umin=1, umax=500, nint=50, show=T)
mrl.plot(xa)

source("gpd.fitrange.m.r"); gpd.fitrange.m
ed <- gpd.fitrange.m(data=xa, umin=1, umax=500, nint=50,
         show=F)
ed$est

source("gpd.trend.r"); gpd.trend
ub <- gpd.trend(xdat=xa, ydat=tb, umin=10, umax=1000,
         nint=40, show=F); ub$log; ub$est
uc <- gpd.trend(xdat=xa, ydat=tc, umin=10, umax=1000,
         nint=40, show=F); uc$log; uc$est

# estimate GPD

th <- 100
xa2 <- subset(xa, xa > th); NROW(xa2); head(xa2);
         mean(xa2);
plot(xa2, xlab= "Number of Fire", ylab= "Acreage",
         main="Fires > 100 Acres")

ra <- gpd.fit(xa, threshold=th)                   #
         stationary
win.graph(width=8,height=6); gpd.diag(ra)
#gpd.prof(ra, m=2000, xlow=10, xup=2000)

rb <- gpd.fit(xa, threshold=th, ydat=tb, sigl=1)  #
         nonstationary with time trend in day
win.graph(width=8,height=6); gpd.diag(rb)

rc <- gpd.fit(xa, threshold=th, ydat=tc, sigl=1)  #
         nonstationary with time trend in year

win.graph(width=6,height=5); gpd.diag(rc)

lla <- -1*as.numeric(ra$nllh)
llb <- -1*as.numeric(rb$nllh)
llc <- -1*as.numeric(rc$nllh)
dif.b <- 2*(llb-lla)
dif.c <- 2*(llc-lla)
```

```
lla; llb; llc; dif.b; dif.c

# format output

out.ra <- data.frame(model="stationary", ra$threshold,
         ra$nexc, ra$rate, lla, test=0, ra$mle, ra$se )
out.rb <- data.frame(model="trend day",  rb$threshold,
         rb$nexc, rb$rate, llb, test=dif.b, rb$mle, rb$se )
out.rc <- data.frame(model="trend year", rc$threshold,
         rc$nexc, rc$rate, llc, test=dif.c, rc$mle, rc$se )
colnames(out.ra) <- colnames(out.rb) <- colnames(out.rc) <-
         c("model","threshold",
    "num.exceed","rate.exceed","loglikehood","Ratio test",
         "estimate","s.e.")

(out.year <- rbind(out.ra, out.rb, out.rc))



############################################################
         ##################################
## Step 4    F i t    G e n e r a l i z e d    P a r e t o
         by fire cause
############################################################
         ##################################

# 4.1 GPD for cause = 4

# Create dataset

input<- 4
da <- subset(new, cause==input); dim(da); head(da)
xa <- da$area; head(xa); NROW(xa)
tb <- as.matrix(da$time.day);  head(tb); tail(tb); dim(tb)
tc <- as.matrix(da$time.year); head(tc); tail(tc); dim(tc)


# compare and determine threshould to be th=250

gpd.fitrange(xa, umin=1, umax=500, nint=50, show=T)
mrl.plot(xa)

ed <- gpd.fitrange.m(data=xa, umin=1, umax=500, nint=50,
         show=F)
ed$est
```

```
ub <- gpd.trend(xdat=xa, ydat=tb, umin=10, umax=1000,
         nint=40, show=F); ub$log; ub$est
uc <- gpd.trend(xdat=xa, ydat=tc, umin=10, umax=1000,
         nint=40, show=F); uc$log; uc$est

# estimate GPD

th <- 250
xa2 <- subset(xa, xa > th); NROW(xa2); head(xa2);
         mean(xa2);
plot(xa2, main=c("Acreage >", th) )

ra <- gpd.fit(xa, threshold=th)                    #
         stationary
win.graph(width=8,height=6); gpd.diag(ra)
#gpd.prof(ra, m=2000, xlow=10, xup=2000)

rb <- gpd.fit(xa, threshold=th, ydat=tb, sigl=1)  #
         nonstationary with time trend in day
win.graph(width=8,height=6); gpd.diag(rb)

rc <- gpd.fit(xa, threshold=th, ydat=tc, sigl=1)  #
         nonstationary with time trend in year
win.graph(width=8,height=6); gpd.diag(rc)

lla <- -1*as.numeric(ra$nllh)
llb <- -1*as.numeric(rb$nllh)
llc <- -1*as.numeric(rc$nllh)
dif.b <- 2*(llb-lla)
dif.c <- 2*(llc-lla)
lla; llb; llc; dif.b; dif.c

# format output

out.ra <- data.frame(model="stationary", ra$threshold,
         ra$nexc, ra$rate, lla, test=0, ra$mle, ra$se )
out.rb <- data.frame(model="trend day",  rb$threshold,
         rb$nexc, rb$rate, llb, test=dif.b, rb$mle, rb$se )
out.rc <- data.frame(model="trend year", rc$threshold,
         rc$nexc, rc$rate, llc, test=dif.c, rc$mle, rc$se )
colnames(out.ra) <- colnames(out.rb) <- colnames(out.rc) <-
         c("model","threshold",
    "num.exceed","rate.exceed","loglikehood","Ratio test",
         "estimate","s.e.")

(out.year.4 <- rbind(out.ra, out.rb, out.rc))
```

```
# 4.2 GPD for cause = 5
         ====================================================
         ======

# Create dataset

input<- 5
da <- subset(new, cause==input); dim(da); head(da)
xa <- da$area; head(xa); NROW(xa)
tb <- as.matrix(da$time.day);  head(tb); tail(tb); dim(tb)
tc <- as.matrix(da$time.year); head(tc); tail(tc); dim(tc)

# compare and determine threshould to be th=100

gpd.fitrange(xa, umin=1, umax=500, nint=50, show=T)
mrl.plot(xa)

ed <- gpd.fitrange.m(data=xa, umin=1, umax=500, nint=50,
         show=F)
ed$est

ub <- gpd.trend(xdat=xa, ydat=tb, umin=10, umax=1000,
         nint=40, show=F); ub$log; ub$est
uc <- gpd.trend(xdat=xa, ydat=tc, umin=10, umax=1000,
         nint=40, show=F); uc$log; uc$est

# estimate GPD

th <- 100
xa2 <- subset(xa, xa > th); NROW(xa2); head(xa2);
         mean(xa2);
plot(xa2, main=c("Acreage >", th) )

ra <- gpd.fit(xa, threshold=th)                   #
         stationary
win.graph(width=8,height=6); gpd.diag(ra)
#gpd.prof(ra, m=2000, xlow=10, xup=2000)

rb <- gpd.fit(xa, threshold=th, ydat=tb, sigl=1)  #
         nonstationary with time trend in day
win.graph(width=8,height=6); gpd.diag(rb)

rc <- gpd.fit(xa, threshold=th, ydat=tc, sigl=1)  #
         nonstationary with time trend in year
```

```
win.graph(width=8,height=6); gpd.diag(rc)

lla <- -1*as.numeric(ra$nllh)
llb <- -1*as.numeric(rb$nllh)
llc <- -1*as.numeric(rc$nllh)
dif.b <- 2*(llb-lla)
dif.c <- 2*(llc-lla)
lla; llb; llc; dif.b; dif.c

# format output

out.ra <- data.frame(model="stationary", ra$threshold,
         ra$nexc, ra$rate, lla, test=0, ra$mle, ra$se )
out.rb <- data.frame(model="trend day",  rb$threshold,
         rb$nexc, rb$rate, llb, test=dif.b, rb$mle, rb$se )
out.rc <- data.frame(model="trend year", rc$threshold,
         rc$nexc, rc$rate, llc, test=dif.c, rc$mle, rc$se )
colnames(out.ra) <- colnames(out.rb) <- colnames(out.rc) <-
         c("model","threshold",
    "num.exceed","rate.exceed","loglikehood","Ratio test",
         "estimate","s.e.")

(out.year.5 <- rbind(out.ra, out.rb, out.rc))
```