Effects of Prescribed Fire in the Coastal Prairies of Texas

By James B. Grace, Larry K. Allain, Heather Q. Baldwin, Arlene G. Billock, William R. Eddleman, Aaron M. Given, Clint W. Jeske, and Rebecca Moss

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Executive Summary

Prescribed fire is widely applied for habitat management in coastal ecosystems. Fire management plans typically list a variety of objectives for prescribed burning, including succession management, promotion of native flora and fauna, providing habitat for species of importance, wildfire risk reduction (fuels management), as well as reduction and/or prevention of invasive species. In most cases, the information needed to determine the degree to which management objectives are met is not available. This study sought to provide an assessment of key objectives of fire management at the U.S. Fish and Wildlife Service (USFWS) Texas Mid-coast National Wildlife Refuge Complex. The main purpose of this work was to provide information and recommendations that will support Region 2 of the USFWS in the conduct of their fire and habitat management activities in the Western Gulf coast region.

There were four main components of this project: (1) a historical analysis of the role of fire in this ecosystem, (2) the development of standard methodology for assessing and monitoring fire effects in this system, (3) an evaluation of the effects of prescribed burning on the habitat being managed, and (4) an evaluation of the effects of burning on select fauna of special concern. A team of researchers, including some from the U.S. Geological Survey (USGS), Southeast Missouri State University, and Louisiana State University were involved in the various components of this project. Extensive support by USFWS personnel, both at the Texas Mid-coast National Wildlife Refuge Complex and in the Regional Office (Region 2, USFWS), was a key component in this work. Data from the three years of this study were combined with the results of previous USGS studies performed at the site to strengthen our conclusions.

Historical Analysis

An analysis of the history of the region indicates that human-caused fires were an integral part of the landscape prior to extensive European settlement in the region. It is likely that many of the habitat features of this region have been modified and maintained by Native American burning practices over hundreds, if not thousands of years. Early European explorers reported a landscape that appears to have been substantially different from the one encountered today. With few exceptions, writers referred to a landscape of vast prairies of luxuriant grass filled with flowers and abundant in wildlife. One of the primary components of the modern landscape, eastern baccharis (*Baccharis halimifolia* L.),was not mentioned in the records of early botanical explorations that we read, suggesting that its abundance in coastal prairie is of recent origin.

Records suggest that early European pioneers continued the Native American practice of regular burning coastal grasslands. Large-scale fires that burned for days across the landscape were commonly reported in the early 1800s. The introduction of herds of cattle (*Bos* spp.) in this period is widely noted, however, and it appears that the most dramatic changes to grassland habitat took place following 1836 when Texas became independent of Mexico. During the period from 1836 to 1860, the population of Texas increased from an estimated 33,000 to 600,000. Accompanying the increase in the human population was a dramatic increase in cattle. Writers who witnessed the changes that took place from the early 1800s through the mid 1800s noted the major changes to the natural landscape associated with grazing. The replacement of native prairie vegetation by shrubs and species of disturbed ground was found clearly recorded in the historical documents of the period. It was also noted that extensive grazing led to a great reduction in fire in the landscape as heavy growths of grass were replaced by sparse vegetation and invading shrubs. Thus, it would seem from these records that the most dramatic change to the fire regime of the coastal region during the 1800s was a reduction in the importance of fire associated with heavy grazing.

The historical records seem to support the current management practice of the USFWS to use frequent fires for the purpose of maintaining or recovering a grass-dominated ecosystem in areas that were formerly prairie and marsh. Further, it would seem that contemporary shrub populations in many areas are not representative of the historical prairie landscape and their reduction is justified.

Fire Monitoring Methodology

A protocol of monitoring habitat changes by using plot-based sampling appears to be suitable both for research purposes and important for routine monitoring. Protocols developed for intensive assessments are sufficiently flexible to permit adaptation for specific objectives. Of greatest importance in this study was the finding that an adequate method for measuring fire characteristics that are relevant to habitat management is needed. For this reason, we developed an inexpensive and easy to use electronic system for measuring fire temperatures that can fill this void. This system, referred to as the “Firelogger”, is capable of providing a continuous record of fire temperatures during burns and can be deployed and recovered with little effort. This system appears to be of substantial value for quantifying fire characteristics and units have now been distributed to the fire teams in Region 2 of the USFWS.

The Effects of Burning on Habitat Conditions at the Texas Mid-coast National Wildlife Refuge Complex

The elements of this investigation were to (1) develop a baseline vegetation database, (2) evaluate the effectiveness of burning on reducing densities of the shrub eastern baccharis, and (3) evaluate the potential for fire to be used in managing the invasive tree Chinese tallow (*Triadeca sebifera* (L.) Small). Over 200 species of flowering plants were encountered in our surveys of prairie and associated wetlands. A digital database of these species, including illustrations and life history information was developed. This database should provide useful information for further studies and assessments of the Texas Mid-coast National Wildlife Refuge Complex (TMC). This database is available from the USGS in compact disk form.

Controlling Baccharis with Fire

Results from vegetation assessments indicate that fire is an effective method for temporarily reducing baccharis growth. Data from 58 burns at the TMC in which baccharis was present were collected. These data provide for a thorough evaluation of short and long-term responses of baccharis to burning. Fire nearly always results in topkill for baccharis plants exposed to heating. However, conspicuous in these results is the finding that mortality rates are widely variable. For those plants that resprout, regrowth of shoots can be rapid. Thus, we found that in some cases a year following burning baccharis had recovered a great fraction of its preburn stature and original density. We also found that in other cases, mortality was very high and long-term reductions in baccharis were achieved by burning.

To provide a more complete picture of baccharis responses to burning, additional data were obtained from a previous study of fire effects at the Aransas NWR. When all data (from Aransas NWR and the Texas Mid-coast NWRs) were combined, 88 burns in which baccharis occurred could be included in our analyses. Exaamination of the frequency distribution of responses revealed that mortality following a fire tends to be either very high or very low, with intermediate levels of mortality being the least common outcome. The reasons for this variable outcome are not known and for the time being we must conclude that the response of baccharis to burning is probabilistic (i.e., a matter of chance instead of predictably deterministic).

Examination of a variety of factors revealed that the probability of an effective burn (defined as one in which mortality of baccharis was greater than 50%) is three times higher during growing season burns than in dormant season burns. Thus, while season of burn does not consistently predict baccharis mortality, it greatly improves the chances of a successful burn. A number of other factors were examined, including fuel load, fire severity, fuel moisture, soil moisture, and preburn baccharis height and density. Only soil moisture was found to influence the probability of a successful burn. Burns conducted when surface soil moistures were less than 40% had a probability of success of 90%, while burns when soils were wet had only a 10% probability of success. The available data upon which conclusions about soil moisture are based are somewhat limited, and this finding deserves further study to determine its general applicability.

Given the probabilistic nature of baccharis’ response to fire, the monitoring of baccharis densities (not heights) will be very important for an efficient fire program. It may be, for example, that frequent repeated burning will be needed to bring population levels under control. However, it is typically a single burn out of several that has the desired effect of reducing baccharis densities. Monitoring will permit management to apply the needed number of burns to achieve their goals without either over or underestimating the number and frequency of burns required.

Controlling Chinese Tallow Trees with Fire

Chinese tallow was also found to be impacted by burning, though complete mortality is largely restricted to very small plants and resprouting is to be expected. Top kill can be achieved in even the largest tallow trees if fuel is sufficient. However, the ability of tallow to suppress fuel beneath its canopy means that only isolated trees can be successfully managed using fire. In prairie areas where fire has not been applied frequently, increases in tallow can be dramatic and this makes it clear that frequent burning, again in combination with monitoring, will be needed to prevent major invasions of tallow. Once closed-canopy tallow stands have established, fire will be ineffective without the use of additional methods such as chemical or mechanical treatments.

Fire Effects on Select Fauna

Prairie Grassland Birds

Grassland birds are among the most imperiled group of birds in North America. An extensive survey of prairie grassland birds conducted at the TMC recorded several species of conservation concern, including Henslow's sparrow (*Ammodramus henslowii* Audubon 1829), LeConte's sparrow (*Ammodramus leconteii* Audubon, 1844), Lincoln's sparrow (*Melospiza lincolnii* Audubon, 1834), grasshopper sparrow (*Ammodramus savannarum* Gmelin), Sprague's pipit (*Anthus spragueii* Audubon, 1844), as well as several other species. Four of the species encountered were found in sufficient numbers to allow estimation of population densities and to permit us to examine their relationships to habitat conditions. These four most common species included LeConte's sparrows, savannah sparrows (*Passerculus sandwichensis* J. F. Gmelin, 1789), sedge wrens (*Cistothorus platensis* Latham, 1790), and swamp sparrows (*Melospiza georgiana* Latham, 1790). LeConte's sparrows and sedge wrens are of particular interest because they have been identified as high priority species in need of conservation attention by Partners in Flight, a public-private partnership dedicated to protecting birds not covered by other initiatives.

Surveys were conducted at 183 transect segments stratified within management units that had been burned within 1 year, within 2 years, or within 3 years. Five management units in each year-since-burn category were studied. An intensive analysis of habitat characteristics was conducted along with the bird survey to permit an evaluation of the habitat conditions under which species are most commonly found. Results indicated that LeConte's sparrows are most commonly associated with prairies burned within the past 2 years. It was further determined that they were less likely to be found in sites with heavy vegetation. Sedge wrens, in contrast, were uncommon in grasslands that were recently burned and were most likely to be found in the 3-year-since-burn prairies. Correspondingly, they were most often associated with high-density vegetation. Savannah sparrows were those that were most highly associated with 1-year-since-burn conditions and where vegetation was sparse. Finally, swamp sparrows were equally likely to be found at any of the locations sampled and appear to be generalists in this habitat.

Rails and Their Behavior

Over two winter seasons, 112 individual rails were captured and banded, including 86 yellow rails (*Coturnicops* Gray 1855), 10 black rails (*Coturnicops* Gray 1855), 9 sora rails (*Porzana carolina* Linnaeus, 1758), 6 Virginia rails (*Rallus limicola* Vieillot, 1819), and one clapper rail (*Rallus longirostris* Boddaert, 1783). Recaptures of yellow rails were sufficiently common within a year to indicate a high degree of winter site fidelity for this species.

Rails were also monitored by using radio telemetry to evaluate their behavioral responses. Data collected in this fashion were used to estimate home range sizes and to gain insights into their potential behavioral responses to fires. Previous reports have indicated that under some circumstances, rails are susceptible to being trapped during prescribed burn operations, resulting in their mortality. Thus, there is interest in understanding their behavioral repertoire in more detail.

Sixteen yellow rails were monitored for their movements by using radio telemetry. The average home range size estimated from a total of 270 observations was 1.16 hectare. Further, it was found that yellow rails were most commonly associated with areas dominated by saltgrass (*Distichlis spicata* (L.) Greene) and gulf cordgrass (*Spartina spartinae* (Trin.) Merr. ex A.S. Hitchc.). Also, 12 rails, including 7 yellow rails, two black rails, two Virginia rails, and one sora rail, were followed during two separate burn events.

Telemetry indicates that yellow rails were most often associated with dense, short vegetative cover. Shallow water conditions have been suggested to be important to habitat use by yellow rails. In this study, however, only 41% of yellow rail locations were flooded. Further, radio telemetry revealed that after an area dried out, yellow rails did not move to a new location, suggesting that other factors help regulate their habitat usage.

Because of logistical difficulties, limited data were obtained on the direct responses of rails to fire and, in particular, mortality from fire. No direct mortality of rails from fire was observed in this study. For the cases where birds were tracked for the longest period, their ability to survive fire was documented. Several yellow rails relocated to adjacent unburned habitat the day after they presumably encountered a burn, indicating survival of the fire. In addition, one sora rail was found alive under a clump of burned gulf cordgrass while one Virginia rail was observed coming out of the ashes following a burn.

Overall, we do not yet have sufficient information to draw broad conclusions about the direct mortality risk fire poses to rails. It is clear that they have the capability to escape in some cases and to survive in the face of fire in others. While direct mortality from fire was not observed, indirect mortality that was due to predation was noted. Raptors attracted to fires were observed pursuing fleeing birds and remains indicated that at least some rails were killed by predators in conjunction with burns.

Implications for Management

Historical records support the presumption that prairie grasslands in the region were characterized by luxuriant growths of grasses and a generally low density of shrubs. No records of eastern baccharis, the dominant shrub species in the Texas gulf coast, were made by early botanical explorers in this region. Based on this and other historical information, if the agency’s goals include managing for the purpose of preserving historic features of the natural landscape, efforts to reduce baccharis levels would support such a goal. While there is no fixed density of baccharis that can as yet be established as a set target, the goal of maintaining an open grassland with scattered shrubs seems appropriate.

Examination of changes in shrub densities over time in this study suggests that the burn program at the TMC is resulting in an overall reduction in woody cover for targeted areas. At the same time, it is clear that success is not uniform and that efforts are not always rewarded with positive results. A continuation of the recent focus on growing season burns for prairie habitat would seem advisable. At the same time, we expect that frequent, repeated applications of fire will be required for areas with high densities of shrubs if those densities are to be reduced substantially. Once densities are reduced to the point that prairies have a predominantly grassy character, less frequent burning should be sufficient. The use of routine monitoring for shrub densities may prove very helpful for the efficient use of fire to control habitat structure by allowing fire teams to target sites most in need of burning.

The continuous invasion of prairie habitat by Chinese tallow trees poses a severe problem for the management of the TMC. In the absence of burning, colonization and canopy development are rapid, suggesting that vigilance is required to avoid resorting to intensive chemical applications.

Prairie grassland birds vary in their association with prairies based on the number of years since they were burned. LeConte’s sparrows were found in this study to be less common in prairies burned more than two years previously. Other important species, such as sedge wrens were most common in prairies burned more than two years previously, while savannah sparrows were most closely associated with prairies burned within the past year. It would seem clear from these results that a mosaic of successional habitats in the landscape is required to maintain a diversity of grassland birds.

Overall, an average burn frequency of approximately every 3 years may be ideal for prairie habitat that is not badly overgrown with woody vegetation. Evidence suggests that an important part of the effect of burn frequency on habitat use is related to the density of herbaceous vegetation. Thus, variations in regrowth rates for vegetation may suggest either greater or lower burn frequencies for particular locations.

Despite the fact that direct mortality of rails during winter marsh burns was not observed in this study, it would seem that caution to avoid trapping birds during such burn operations is advised. Further work will be needed to determine with greater confidence whether certain types of firing procedures create a greater risk of mortality for these birds.

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Abstract

Prescribed burning is widely applied, though in many circumstances the full range of its ecological effects is undocumented. This study provides an assessment of some of the effects of fire management in coastal grasslands in Texas. These studies were conducted primarily at the U.S. Fish and Wildlife Service (USFWS) Texas Mid-coast National Wildlife Refuge Complex (the TMC), though additional data from other locations in the region are also presented. There were four main components of this project: (1) a historical analysis of the role of fire in this ecosystem, (2) the development of standard methodology for assessing and monitoring fire effects in this system, (3) an evaluation of the effects of prescribed burning on the habitat being managed, and (4) an evaluation of the effects of burning on select fauna of special concern. Historical records suggest that both Native Americans and early Europeans contributed to widespread burning in the region and that settlement and the introduction of large cattle herds have been associated with reduced fires and increased shrub dominance. Data from a large number of burns shows that the response of the shrub eastern baccharis to fire is highly variable, but burning during the growing season and under drought conditions improves the chances of controlling baccharis. Chinese tallow was also found to be sensitive to burning, though complete control is largely restricted to small or isolated plants. Surveys of grassland birds found that LeConte’s sparrows were most commonly associated with prairies burned within the past two years, that Sedge wrens were most likely to be found in the 3-year-since-burn prairies, Savannah sparrows were most highly associated with 1-year-since-burn conditions, and swamp sparrows were equally likely to be found at any of the locations sampled. Rails were also monitored by using radio telemetry to evaluate their behavioral responses. Data collected in this fashion were used to estimate home range sizes and to gain insights into their potential behavioral responses to fires. Collection of sufficient data to draw broad conclusions about the direct mortality risk that fire poses to rails was not possible. Still, it is clear that rails have the capability to escape in some cases and to survive in the face of fire in others. While direct mortality from fire was not observed, indirect mortality that was due to predation was noted. Raptors attracted to fires were observed pursuing fleeing birds, and remains indicated that at least some rails were killed by predators in conjunction with burns. Overall, an average burn frequency of approximately every 3 years may be ideal for prairie habitat that is not badly overgrown with woody vegetation. Evidence suggests that part of the effect of burn frequency on habitat use is related to the density of herbaceous vegetation. Thus, variations in regrowth rates for vegetation may suggest either greater or lower burn frequencies for particular locations.

Introduction

Prescribed fire is widely used as a method of habitat management in coastal grassland ecosystems (Wade and others, 2000). For many natural communities in North America, fire has been a major feature of the disturbance regime since before the beginning of the Holocene Epoch, which began some 10,000 years ago (Pielou, 1991). While fire frequency has been shown to vary with climatic shifts (Clark, 1990), it has been estimated that in recent times fire return intervals have ranged from between 1and 10 years in coastal areas to between 35 and 100 years in desert regions (Brown and Smith 2000). In part, because of

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the historical importance of fire and the fire-adapted nature of many native communities, prescribed burning is commonly used to mimic the effects of the natural fire regime on habitat conditions.

Fire is commonly used, along with other management practices, to achieve management goals such as habitat restoration, fostering native fauna and flora, and fuel/hazard reduction. The specific conservation goals of different U.S. Fish and Wildlife (USFWS) refuges typically vary, though the overall objective of maintaining or restoring ecological integrity applies to most situations. While fire most commonly acts to maintain native habitat structure as well as to promote the availability of food for fire-adapted members of the community (Smith, 2000), adverse effects such as wildlife mortality, the spread of invasive species, reduction of habitat suitability, and habitat degradation (e.g., through soil erosion), are known to occur in some circumstances. At present, our understanding of the impacts of prescribed fire activities on habitat and wildlife is, in most cases, inadequate to evaluate the question of whether burning practices are optimal for a particular set of habitat objectives. Within this context, the challenge for USFWS refuges is to use prescribed fire to promote their conservation objectives without inadvertently creating long-term, adverse effects. Since most refuges typically represent complex landscapes of habitat units, the effects of fire programs must be considered at the landscape level. The need for a landscape perspective is especially true where management programs seek to simultaneously achieve a variety of objectives.

As per the Federal Wildland Fire Management Policy Report (www.fs.fed.us/land/wdiap.htm), which applies to all Department of the Interior (DOI) as well as U.S. Department of Agriculture (USDA) wildland properties, Federal land managers are being asked to develop

- fire management plans for all areas subject to wildland fires,
- research programs that provide a sound scientific basis for the integration of wildland fire into land-use and resource management,
- collaborative fire research programs to improve the predictive understanding of wildland fire and its relationship to ecosystem dynamics, and to strengthen the technological capabilities and organizational framework necessary to sustain the role of fire in natural ecosystems, and
- an assessment process for determining the probability of success and/or failure associated with the use of prescribed fire and evaluating potential positive and negative consequences.

These requirements represent a substantial challenge for the management of USFWS refuges and suggest an important partnership role for the scientific capabilities of the U.S. Geological Survey (USGS) as well as other Federal and State agencies, universities, and nongovernment organizations.

The overall objective of this project was to conduct research and scientific assessments of the ecological effects of fire in order to support Region 2 of the USFWS in their prescribed burning program. Because the multitude of unanswered questions greatly exceeded available resources, this project focused on those issues most critical to current operations at select refuges. At the direction of the USFWS Region 2 Office, the fieldwork associated with this project was conducted at the Texas Midcoast National Wildlife Refuge Complex (hereafter referred to as the TMC). This refuge complex contains both a wide range of habitats, from wetlands to upland prairie, as well as a wide range of environmental conditions. A considerable amount of background information had already been gathered, as our research team had worked there for several years before this project.

The research conducted in this project focused on several major problems. Through consultation with USFWS personnel, we attempted to tackle some of the top concerns facing the land management staff. In assembling this report, we also have incorporated considerable information from our other related studies. By using a broad approach to the topic, therefore, we organized this report around four broad questions:

(1) *What is the history of fire in this landscape?* It is generally believed that Gulf Coastal Plain ecosystems, including those along the Texas coast, have been shaped by a history of frequent fire. Unlike many other areas of the country, a historical description of the occurrence of wildland fire in the Texas gulf coast region does not exist. As part of this study, a historical analysis was conducted to determine what is known about the role of fire in this area and human influences on the fire regime.

(2) *What standard methods should be used and/or developed to provide for assessment and monitoring of fire effects on habitat?* An immediate question that we faced had to do with the methods to be used for fire effects evaluation in this study. At the same time, a goal was to employ methods that could be applied by USFWS personnel in subsequent studies, both at this site and at others. The focus of the methodology work was on techniques for monitoring fuels, fire characteristics, and habitat responses. Additional work has related to innovative methods of data analysis that enhance our ability to extract meaningful interpretations from complex field data. The emphasis in this report will be on the first of these two methodological efforts.

(3) *What are the effects of prescribed burning on the habitat?* Central goals of the USFWS burn program include succession and habitat structure management, which involve creating targeted impacts on vegetation.

The broad objective of fire management is to simulate, to some degree, the natural disturbance regime (periodic wildfires). The purpose of doing so is to provide habitat for the native flora and fauna and to create a range of habitat structure in the landscape that promotes the diverse character of the coastal ecosystem. The TMC is distinctive in that it includes both extensive coastal marshes and a considerable amount of coastal tallgrass prairie. Reduction of woody plants is one key objective of the fire program at the TMC as it relates to both wetlands and uplands. While a number of woody species occur there, eastern baccharis (*Baccharis halimifolia* L.) is by far the most common woody species and is the primary target of much of the burning program as it relates to uplands (and to some degree for wetlands as well). A previous study has shown that burning has variable effects on eastern baccharis and that much could be done to improve the success of the burn program in managing this species. In addition to assessing the effectiveness of the burn program in meeting its desired goals, the role of fire in controlling or fostering select invasive plants was also considered.

(4) *What are the effects of prescribed burning on select avian taxa of concern?* Two major concerns about burning and avifauna were addressed in this study. The first has to do with grassland birds. Grassland birds are considered to be one of the most imperiled groups in North America. An obvious contributing factor to this trend is the loss of grassland habitat, which has, more than any other ecosystem type, been replaced by agriculture. Another contributing factor is reduced habitat value for the remaining habitat caused by a loss of its natural characteristics. Prescribed burning in coastal grasslands, especially in the coastal prairie community, is designed to create conditions favorable for grassland birds of special concern. In the Texas Midcoast region, of special interest is the LeConte's sparrow, which is globally rare but locally common in good habitat. To address the issue of how burning influences grassland birds, studies were conducted to look at their occurrences in areas with different burn histories and to evaluate their movement patterns.

The second part of the work concerns yellow rails. Rails are secretive and tend to hide instead of flush in the face of danger. It has been reported that rails have sometimes been known to die in burn operations because they were unable to escape from the fire. Little is known about either the occurrence of rail species at the TMC or their behavior. To address these issues, a study was conducted to learn more about their behavior and to determine their reactions to fire.

The Texas Mid-coast National Wildlife Refuge Complex

The TMC (fig. 1) is located in the western gulf coast region. The refuge complex consists of three refuges and is part of the National Wildlife Refuge System. At present, the TMC comprises Brazoria, San Bernard, and Big Boggy refuges. Together, these three refuges represent an important preserve for coastal wetlands and uplands in the Texas midcoast region. Over 300 bird species, as well as numerous other fauna, are protected in the TMC. Located at the end of the Central Flyway for waterfowl and along the flight corridor for migrating Neotropical songbirds, the TMC is a vital resource in the Nation's system for protecting wildlife. Habitat types that occur within the TMC include salt, brackish, and freshwater marshes, sloughs, ponds, coastal prairies, and bottomland.

The Brazoria NWR was established in 1966. In 1991, an additional 11,605 ha (28,655 acres), known as the Hoskins Mound Unit, was added, bringing the total to 16,546 ha (40,854 acres). Brazoria contains several thousand hectares of prairie that have never been plowed (though they have been subjected to intense grazing), as well as several thousand acres previously tilled, but now fallow and are recovering their flora and fauna. These holdings, along with smaller pieces of coastal prairie located at San Bernard and Big Boggy NWRs, make the TMC one of the most important locations for the preservation of the endangered coastal tallgrass prairie ecosystem. Less than 1% of this native ecosystem remains intact, and very little of what remains is under permanent management for preservation. The coastal tallgrass prairie can be thought of as comprising two types, upland (bluestem) prairie and salty prairie. Salty prairie is both more common and more resilient than upland prairie. The primary method of management for both prairie types is regular prescribed burning.

The San Bernard NWR was first established in 1968 and its more than 16,000 hectares (40,000 acres) are largely composed of coastal marsh habitat. While its management objectives are diverse, waterbirds are a primary concern. Wetland management, including the use of prescribed burning, is commonly practiced. Upland grassland and shrubland habitat are managed primarily by burning, while some other upland habitats at the refuge are being managed for forest recovery. This refuge is important to a wide variety of species, including grassland birds and Neotropical migrants.

The Big Boggy NWR is a more recent acquisition, and totals some 4,860 ha (12,000 acres) of coastal habitat. In addition to salt, brackish, and fresh marshes, Big Boggy NWR contains several hundred acres of coastal prairie and abandoned agricultural fields. It is of prime importance as a rookery and also a haven for colonies of shorebirds.

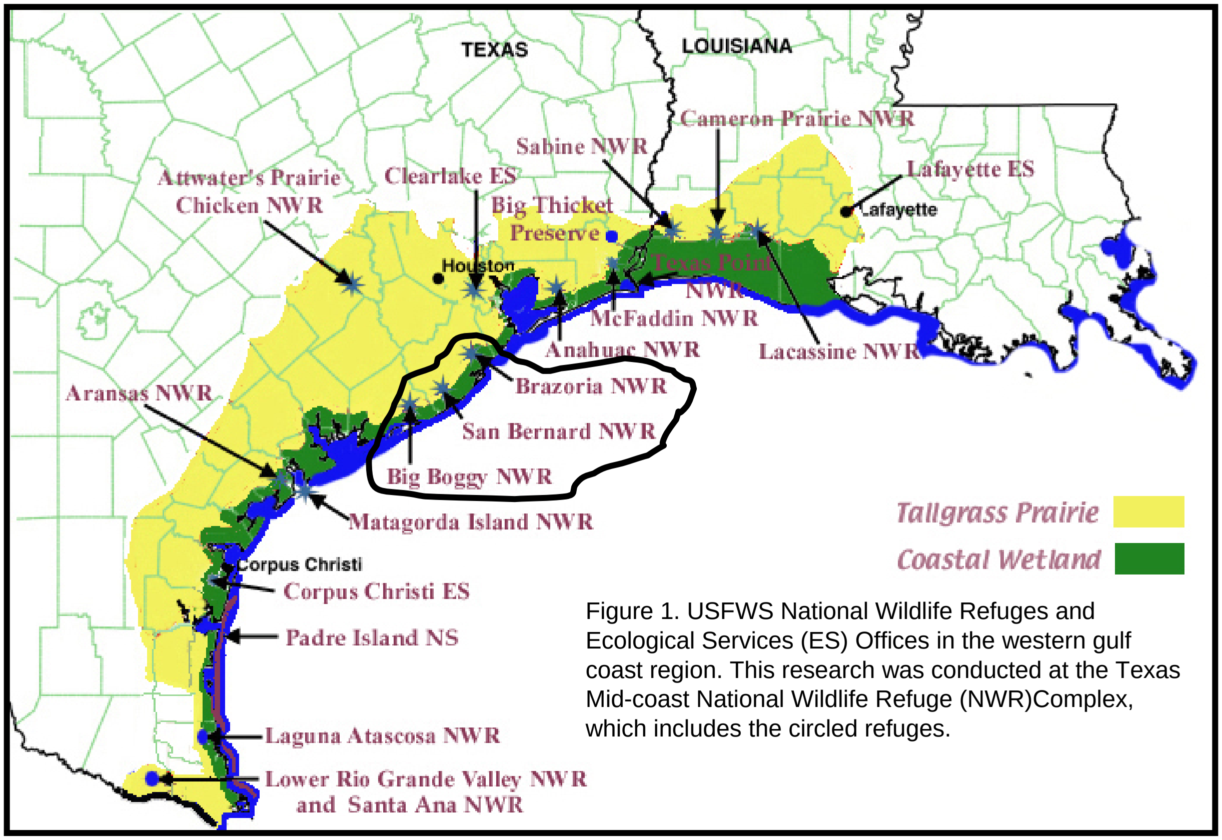

Figure 1. USFWS National Wildlife Refuges and Ecological Services (ES) Offices in the western gulf coast region. This research was conducted at the Texas Mid-coast National Wildlife Refuge (NWR)Complex, which includes the circled refuges.

Methods

Fire History of the Texas Coastal Prairies and Marshes

"The surveys and notes of the General Land Office (1796-1925) are generally considered to be the most reliable source of historic landscape data to use for reconstruction of pre-European landcover because of standardized data collection and systematic coverage" (Galatowitsch 1990). Unfortunately, there are no U.S. surveys of Texas because it was not a public land state when admitted to the union and Texas still retains control over its public lands (Johnson, 2002). For this reason, historical descriptions of the prairie and coastal prairie landscape are perhaps the most useful sources of information available. These accounts differ in form and content, but provide valuable comparative information for evaluating changes over time (Juras 1997). The writings of explorers, pioneers and early settlers offer descriptions and details about the Texas prairie that are currently unavailable from any modern source. These sources of information provide descriptions of both the flora and fauna as well as human settlement activities and land-use patterns. Many of these descriptions are somewhat limited in utility by their fragmentary nature and by the imprecision of the descriptions. The material is sometimes also limited by the incomplete knowledge of the writers as well (Johnston, 1963, Hadley and Sheridan, 1995). The most notable exceptions to this limitation are the plant collection notes and writings of the botanist/naturalists, especially Thomas Drummond and Ferdinand Lindheimer who were among the first to document the plants found on the coastal prairie.

Methods for Assessing Fire Characteristics and Fire Effects

Various methods have been used to characterize fire and its effects on habitat. While some aspects of fire-effects assessment are generally applicable to a broad range of conditions, others are specific to the circumstances. In this study, we were interested in developing the methods that were most suitable for evaluating fire effects in the coastal grassland habitat. Therefore, much of the forestry-based methodology that exists was not appropriate. At the same time, because our studies needed to be intensive in order to detect trends in a relatively short-term study (3 years in duration), many of the common rangeland methods were also not deemed to be adequate. A survey of the available methodology indicated that we needed to focus on two main questions relating to methodology: (1) What plot-based techniques should be used to assess the effects of fire on vegetation structure, particularly shrub and fuel responses? and (2) How can we measure the characteristics of a fire so as to best relate them to plant responses?

Box 1. Events involved in establishing and measuring fire plots.

A. Plot Establishment
B. Preburn Measurements
1. density and heights of woody plants
2. determination of dominant herbaceous plant species
3. identification of all plant species
4. estimation of percent cover of dominant vegetation, litter, and bare ground
5. estimation of fuel load
6. proportion of live fuel versus proportion of dead fuel

C. Day-of-burn Measurements
1. live fuel moisture for dominant herbaceous fuel
2. live fuel moisture for baccharis
3. surface soil moisture immediately prior to burn
4. weather conditions (relative humidity, temperature, wind speeds)
5. visual fire characteristics (flame lengths, rate of spread)
6. fire temperatures
7. postburn assessment of
    a) percent of plot burned
    b) percent of total fuel consumed
    c) minimum and maximum scorch height of baccharis
    d) percent of baccharis browned or burned
    e) percent of baccharis leaves consumed

D. Follow-up Measurements
1. number of woody plants top killed
2. number of woody plants resprouting
3. heights of resprouts
4. herbaceous regrowth

Plot-based Measurement Techniques

Measuring and monitoring fire effects on vegetation involves several steps and procedures. The steps followed in this study are outlined in Box 1. Methods for this study were developed following a thorough consideration of the guidance provided in the U.S. Fish and Wildlife Service Fuel and Fire

Effects Monitoring Guide prepared by Bill Leenhouts (http://fire.r9.fws.gov/ifcc/monitor/RefGuide/default.htm). The main components of plot-based assessments were (1) plot establishment, (2) preburn measurements, (3) day-of-burn measurements, and (4) follow-up measurements.

Plot Establishment

Based on previous experience and the desire to compare data from this study with prior work at Brazoria NWR, the basic sample plot design was chosen to be a 10 x 10 m square. This plot size and configuration have been found to be well suited to studying the combined dynamics of woody and herbaceous plants in response to habitat management. Various types of subplot sampling can be conducted within the whole plot to provide more detailed estimations of spatial variability. For the establishment of assessment plots (fig. 2), metal posts were placed on each corner and a fireproof numbered tag secured on one post. Plots were temporarily subdivided into four subplots A,B,C, and D to allow for more detailed information on within-plot heterogeneity when measurements were taken.

Figure 2. Fire assesment plot.

Preburn Measurements

At some time prior to burning, typically two weeks or less before a burn, a number of vegetation characteristics were measured or determined: (1) number and height of each woody plant, by species, in each quadrant, (2) percent aerial cover for three to five most abundant herbaceous species in each quadrant, (3) coverage of ground surface by plant litter in each quadrant, (4) list of all species in the plot, (5) estimate of fuel load for each quadrant, and (6) proportion of fuel that is live versus dead.

Fuel loads were estimated nondestructively by using a Decagon Ceptometer, which measures photosynthetic radiation (fig. 3). The basic method uses the ceptometer to measure light captured by the vegetation by taking readings above the herbaceous vegetation and then again at the ground surface. In order to calibrate the method, a light reading was also taken immediately outside the plot in conjunction with a plot that was clipped and processed for dry biomass. The simultaneous measurement of light penetration and biomass associated with the clip plot allowed for the calibration of the method. As shown in figure 4, the percent of full sun reaching the ground surface is proportional to the quantity of biomass measured by clip plots. The regression relationship was then used to convert light readings inside the plot to fuel load estimates. Further work has shown that this technique can be refined by shading the light wand with a portable diffuser to reduce the effects of sun angle on estimates.

Figure 3. Decagon Ceptometer for measuring light to estimate biomass.

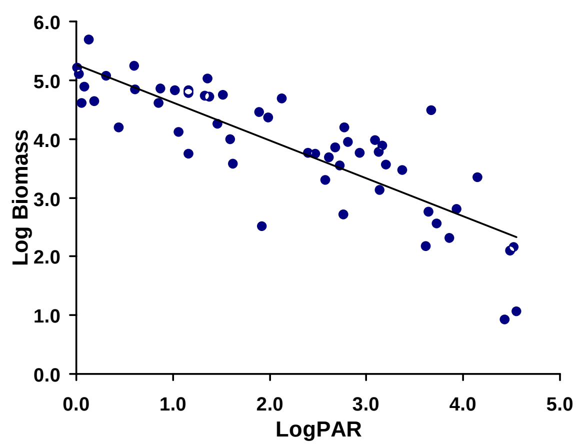

Figure 4. Calibration curve for estimating fuel load from light penetration measurements.

Day-of-burn Measurements

A number of types of measurements were made immediately before, during, and immediately after a burn. These measurements were intended to capture fuel, weather, and soil conditions that may be important determinants of fire effects. In addition, measurement of the first-order fire effects (described below) were taken as further measures of the characteristics of the burn.

Live fuel moisture is known to be an important determinant of fire behavior. In this study, it was measured by using representative tissues of shrubs and grasses, which were sealed in watertight containers, placed on ice, and returned to the lab. Live fuel moisture was routinely taken for *Baccharis halimifolia* and the major grass present in the plot, which was typically either *Spartina spartinae* (Trin.) Hitchc. (gulf cordgrass) in salty prairie or *Schizachyrium scoparium* (Michx.) Nash (little bluestem) in upland prairie. In the lab, total weight of container and sample was obtained prior to drying. Following drying, container weight and dried sample weights were obtained. Percent live fuel moisture was measured as the sample fresh mass/sample dry mass times 100, where fresh mass included the weight of any moisture released from the plant into the container during storage.

Surface soil moisture was measured immediately before burning by taking three, 5-cm-deep soil cores (2-cm in diameter) from inside the plot. Each core was subdivided into 1-cm sections vertically, and each section was placed in a metal airtight container for transport to the lab, where moisture content was determined by drying to a constant weight.

During the course of the fire, weather conditions were recorded by a member of the fire team using standard techniques. In addition, visual characteristics of fire behavior and smoke dispersion were noted.

Postburn Assessments

Immediately following a burn (sometimes slightly later when necessary), an assessment was made in order to characterize the initial (first order) effects of the fire. These measurements were made inside the permanent plots in so that we could relate initial fire effects to subsequent vegetation changes. A number of measurements were made in order to characterize how complete the fire was and the magnitude of combustion of vegetation. To accomplish this assessment, in each plot we estimated (1) percent of plot that burned, (2) percent of preexisting herbaceous fuel that was consumed (and, therefore, how much fuel was not consumed), (3) minimum and maximum scorch height of baccharis, (4) percent of baccharis leaves browned or burned, and (5) percent of baccharis leaves consumed by the fire. Collectively, these data were used to create an estimate of *fire severity* using the formula

$$(P + F + S + B + C) / 5$$

where P = percent plot burned, F = percent fuel consumed, S = average scorch height relative to the maximum observed across plots, B = percent baccharis browned or burned, and C = percent baccharis leaves consumed.

Follow-up Measurements

At various times following a burn, an assessment was made of the impact of that burn on preexisting woody plants, as well as regrowth of herbaceous vegetation. Measurements of woody plants (separated by species) included estimates of the number of woody plants that were top killed, the number of woody plants that resprouted, and the heights of resprouts.

The Firelogger: A Methodology for Measuring Fire Temperature Dynamics

Background

A major conclusion from this study is that one factor currently limiting our ability to assess fire effects is the lack of a suitable method for measuring ecologically relevant fire characteristics. The typically measured parameters, flame length and rate of spread, are aimed at providing information that is useful for fire fighter safety and control/suppression efforts, not for relating to ecological effects. Routine methods for estimating fire temperatures, for example using temperature-sensitive tablets and paints, give crude and highly variable results.

Researchers have long used electronic data loggers and thermocouples to characterize temperature dynamics during fires (e.g., Stinson and Wright, 1969; Wright, 1970). Knowledge of the temperatures during a fire, either at ground level, critical soil depths, or at various heights above the ground, has been shown to be helpful in quantifying fire characteristics and understanding ecological fire effects (Wells and others, 1979; Whelan, 1995; Molina and Llinares, 2001). Up to the present, measurement of fire temperatures under field conditions has been somewhat limited by the expense, size, and complexity of available measurement instruments (e.g., Bradstock and others, 1992; Jacoby and others, 1992; Sackett and Haase, 1992). Because of this situation, a substantial fraction of the ecological studies of fire have either not measured fire temperatures at all or have relied on less comprehensive approaches such as the use of temperature-sensitive paints or tablets (Drewa and others, 2002). With this in mind, we developed an inexpensive, miniature datalogger-thermocouple system designed for routine measurement of fire temperatures in prescribed or wildfire situations.

The data logger-thermocouple systems described here (hereafter, Fireloggers) are based around recently developed miniature data loggers that are comparatively inexpensive relative to previously used equipment. Because of their small size and affordability, we believe such miniature data loggers will prove to be suitable for routine use in measuring fire temperatures. Already we have provided Fireloggers to a variety of individuals, including USFWS Region 2 fire personnel, as well as several research scientists. We further believe that routine measurement of fire temperatures will significantly advance our ability to relate wildland fire effects to fire and fuel characteristics.

Structure and Operation of Fireloggers

Additional details concerning the structure and operation of Fireloggers can be found in the Firelogger User's Manual (Version I, March 2004 USGS Technical Report). Here we provide an abbreviated description. The data loggers used in constructing Fireloggers are HOBO thermocouple loggers (Onset Computer Corporation, Bourne, Massachusetts). Three types of loggers are currently available from the Onset Corporation, types K, J, and T. Type K loggers can be used up to temperatures of 1250° C, type J loggers can be used up to temperatures of 750 C, and type T loggers can be used up to 180° C. Resolution of loggers depends on both type and the software-selectable scale of measurement. For example, type K loggers have two channels for external measurement, one with a range of 0° C to 500° C and a resolution of 1-2° C and a second with a range of 0° C to 1250° C with a resolution of 5-10° C. Loggers provide internal cold-junction temperature compensation in the range of 0° C to 50° C with a resolution of 0.4° C. Internal temperatures can be logged if desired. HOBO data loggers measure 48 x 68 x 19 mm, and are currently priced under US$100. Loggers are programmable and can store a maximum of 32,530 readings. At a logging interval of one reading per second, recording can take place up to 9 hours. Memory modes available include automatic shutdown when memory is full and wrap-around (continuous) recording.

The thermocouples used in Fireloggers are 20-gauge, solid conductor thermocouple wires insulated with braided Nextel® ceramic fibers enclosed within an overbraid of high-temperature, high nickel content alloy Inconel 600® (Omega Corporation, Stamford, Connecticut, USA). These thermocouples can withstand temperatures up to 1090° C for brief periods. The thermocouple junction where temperatures are sensed is at the terminal 4.5 mm of the wire. K-type thermocouples are capable of obtaining accurate readings up to 1372° C while J-type thermocouples can read up to 1200° C. Thermocouples must be fitted with microconnectors for interfacing with HOBO data loggers (available from the Onset Computer Corporation).

Data loggers can be deployed in several ways. The basic Firelogger is composed of a single HOBO logger sealed within a hard plastic shell, equipped with a thermocouple and a minijack coupler (fig. 5). The logger is enclosed inside a PVC housing and equipped with waterproof seals. The basic Firelogger is designed to be buried in the ground during use. The internal temperature recording capability of the HOBO loggers permits the user to determine the temperatures to which the loggers are exposed, if overheating is a concern in situations where prolonged heating of the soil may cause deep penetration of high temperatures.

Figure 5. Firelogger s howing HOBO datalogger, white plastic case, and thermocouple wire

A variety of alternative methods can be used to deploy data logger-thermocouple systems when it is desirable to make several readings from a single location. Systems containing sets of four and six loggers each can be constructed by securing several HOBO loggers within watertight plastic cases (e.g., Pelican brand, CPD Industries, Chino, California, USA). Such cases can be buried to protect them from fire damage. Deployment of data loggers in fire proof boxes without burial has been successful, as well, though the capability of loggers for internal temperature compensation is only valid if the loggers remain under 50° C.

Interface with the HOBO loggers (e.g., depoyment and readout) can be obtained either with a laptop computer or by using a hand held (palm) computer. Interface cables and data management software are available from the Onset Corporation. Hand held computers are often most convenient for launching the logging process as well as for downloading data. Available software permits a variety of data analyses, including graphical display of time-temperature relations.

Measurement Of Fire Characteristics

To evaluate the utility of Fireloggers under field conditions, we have deployed units in a variety of horizontal and vertical arrays. Vertical arrays have included both measurements at various soil depths as well as at different heights above ground. In our typical application horizontal arrays are used to measure fire temperature dynamics at or near the ground surface. Commonly, four to six loggers are deployed so as to measure fire temperatures over time at various locations in a plot. Thermocouples are usually placed at ground surface in our studies because the ecological effects of most interest (top-killing shrubs, damage to grasses and forbs, effects on seeds near the soil surface) can be related most simply to temperatures (and, thus, heating) at the ground surface. Measurements at various depths below the ground surface are also used in some of our more detailed studies.

Calculations

A variety of measures of fire characteristics can be obtained from data logger-thermocouple systems (e.g., Pyne and others, 1996; Morgan, 1999; Molina and Llinares, 2001). In our studies we usually calculate (1) peak temperature, defined as the maximum value logged, (2) duration of heating, defined as the time over which temperatures exceed some predetermined baseline value (e.g., 60° C), (3) total heating, defined as the sum of temperature values above baseline during a fire, measured in degree-minutes (see Molina and Llinares, 2001 for conversion to net radiant heat), and (4) rate of spread, defined by the time lapse between peak temperatures at thermocouple junctions at known distances apart (measured in meters per second). These parameters can then be related to both fuel and weather as well as to ecological responses.

Applications

During the course of this project we have continuously refined the Firelogger design and application approaches. Fire temperature records have been obtained under a wide variety of circumstances. Sufficient data were not collected from fires at the TMC, however, to permit us to associate fire temperatures to the other results of this study. For this reason, examples of fire temperature dynamics collected with Fireloggers will not be presented in this report.

Effects of Prescribed Burning on Habitat Conditions

Several questions relating to fire effects on habitat conditions were addressed in this study. For convenience, we have organized the studies around five main subheadings (1) vegetative community characterization, (2) fuel and fire characteristics, (3) responses of eastern baccharis (*Baccharis halimifolia*), and (4) responses of the Chinese tallow tree (*Triadeca sebifera*).

The Vegetative Community

In conjunction with this study, it was necessary to characterize the native and nonnative flora of the habitats studied. This characterization relied on (1) plot data and other inventories, (2) previous studies we have conducted at the TMC, and (3) species lists compiled by the USFWS and others. This work has focused on the upland coastal prairie, salty and mixed prairie communities, and wetland communities associated with our studies. In these habitat types, we encountered and identified or confirmed approximately 700 species of flowering plants. A digital plant list, including photographs for most species, along with basic botanical information, has been compiled (Allain, L. and Billock, A. 2004. Texas Midcoast NWR Complex Plant List. USGS Digital Report). A copy of this digital plant list is available from the USGS.

Prairie gentian (*Eustoma exaltatum* (L) salisb. ex G.Dom from Brazoria NWR (photo by L. Allain, USGS).

Fuel Conditions and Fire Characteristics

In conjunction with this study, we were able to collect measurements on fuel conditions and fire characteristics for prescribed burns conducted during the course of this study. The protocol for our studies is summarized in Box 1 (p. 5). Using this protocol, we were able to collect information on (1) herbaceous fuels and their dynamics over time, (2) information on fuel species, (3) information on fuel moisture, (4) soil moisture (as a measure of conditions at time of the fire), (5) fire weather, (6) fuel consumption, and (7) fire severity. Details relating to these methods were presented above under Plot-Based Measurement Techniques.

Because of logistical limitations, we were not able to collect a complete set of measurements of fire characteristics for all of the plots included in this study. The majority of the above seven parameters were measured on select fires only. For plots where these additional parameters were measured, detailed comparisons between fuel/fire characteristics and fire effects were possible.

Responses of Eastern Baccharis to Fire

Previous studies conducted at the TMC on the responses of eastern baccharis to fire (Allain and Grace, 2001) have shown that results are widely variable. It is clear, both from quantitative results and qualitative observations that burning is often unsuccessful at reducing the abundance of baccharis for very long. This finding is problematic for managers because one of the objectives of the fire program at the TMC is to reduce baccharis levels (densities and heights) to those characteristic of the native community. While specific values have not been determined, it is clear from considering the native (pre-European settlement) conditions of the coastal prairie, that it was not widely reported to be a baccharis woodland. However, at present, many areas at the TMC support extensive and heavy growths of this shrub.

Eastern Baccharis

Several woody species occur in coastal grasslands subject to fire management at the TMC. Of these, the most common is *Baccharis halimifolia* L. (we will refer to it simply as baccharis here). Baccharis is a native, dioecious, perennial shrub that grows to 4 m tall, often forming dense colonies. It occurs along both the Atlantic and Gulf of Mexico coasts of North America from Massachusetts to Texas and into Mexico. It is most common on the southeastern Coastal Plain, extending as far inland as Arkansas and the central Piedmont Plateau (Duncan and others, 1957; Duncan and Duncan, 1988; Patton and Judd, 1988; Krischik and Denno, 1990a; b). It occurs in a wide variety of habitats, including prairie, old fields, marshes, and woodlands (Penfound and Hathaway, 1938; Oosting, 1954). Site affinities indicate that baccharis typically grows in moist soils with a high organic content (Egler, 1952; Duncan and Duncan, 1987; Barbour and Billings, 1988).

Baccharis is a successional species that rapidly invades disturbed grasslands and it appears to have become more common over its historical range in response to human influences (Penfound and others, 1938; Allen, 1950; Scifres and others, 1983). It has been introduced into Australia and the Mediterranean region of Europe, where it is a major pasture pest (Haseler, 1969; Westman and others 1975), and as of 1973, baccharis was reported to have colonized 81,720 ha in east and southeast Texas (unpubl. records, USDA Soil Conservation Service, Tempel, TX). It invades coastal prairie in Louisiana and Texas where it has been shown to reduce herbaceous diversity (Harcombe 1989). While it can be controlled with herbicides and mowing, these practices are expensive and can have unwanted consequences on the plant and animal communities. Mimicking the role of the natural fire regime, prescribed fire is often used to control baccharis in coastal prairie. However, observations on its susceptibility to fire vary (Leenhouts and Baker 1982, Grelen 1975, 1983, Miller and Miller 1999). When burned (or clipped), baccharis resprouts readily (DeLoach and others 1986, authors, pers. obs.). However, there is little published research on the effectiveness of prescribed fire in reducing the abundance of this species.

Sampling

In this study, our objective for studying baccharis was to characterize its response to fire, both immediately and for a period after being burned. It was not deemed feasible to establish and maintain unburned control plots at each site because of the logistics that would be involved. First, the sites are spread across a largely roadless landscape and many are only accessible by marsh buggy, making the maintenance of fire breaks by mowing and fire retardant foam (as in King and Grace, 2000) difficult. Second, maintenance of fire breaks in this system typically involves repeated disking of the soil, which we considered to be an unacceptable level of impact on what is one of the most extensive remnants of virgin coastal prairie remaining. Rather, plots were established in a number of management units that were not burned and these plots provide a basis of comparison for those that were burned. Thus, our approach was to monitor the dynamics and recovery of baccharis before and after burning by using a repeated-measures philosophy. It is recognized that this approach is somewhat limited for extrapolating results to other situations, but we feel that it is adequate for documenting the effects of the fires conducted in this study.

The establishment of plots was designed to capture some representation of the effects of burning at the TMC. Our sampling objectives were (1) to resample all our preexisting plots to provide a linkage to longer-term response estimates and (2) to establish plots in every unit to be burned at the TMC during the course of this study. Typically only a single plot could be located in each burn unit (with a few exceptions aimed at comparing plot responses within a unit). Thus, the emphasis was on studying burn-to-burn variability in responses. At the TMC, a total of 68 plots was monitored during the period of 2001 through early 2004. Data were collected from a total of 58 individual burns in which baccharis occurred.

This database of information was supplemented with additional data obtained from the Aransas NWR (also in coastal Texas) on the responses of Eastern baccharis to burning. At Aransas, ten plots were monitored for a period of ten years (1991 through 2000). Based on monitoring events, these records were used to estimate baccharis changes in conjunction with 29 burns (some of these "burns" actually included two to three fires at different times). Together, the data from TMC and Aransas are from a total of 87 burn events.

Responses of Chinese Tallow to Fire

The greatest threat to the TMC from an exotic species would seem to be from the Chinese tallow tree. Tallow (as we shall refer to it here) has a number of characteristics that make it particularly troublesome (Grace 1998). First, this species invades rapidly with a high success rate for colonization. It produces plentiful large seeds that are able to germinate and produce successful seedlings under a wide range of soil and moisture conditions (Barrilleaux and Grace 2000). Tallow is one of the most rapidly growing woody species in the world and has been bred as a crop species in China for 14 centuries. Widely planted throughout the southern coastal region, tallow has produced an ample seed supply in the environment, which can be dispersed by both birds and water. Second, once it successfully invades, it can develop into a dominant population in five to seven years. Tallow has been found to virtually eliminate the native plant community in coastal prairies and marshes (forests as well), leading to a complete life form change for the ecosystem. A third major problem with tallow for coastal systems is that it is a fire suppressor. Once it achieves any degree of canopy closure, it greatly reduces fuel species from beneath its boughs and becomes immune to burning. Its ability to resprout from damage, caused by fire or other sources, is tremendous, making it especially difficult to control.

Previous studies (Grace and others, 2001) have found that small tallow trees can be killed by fire if fuel is sufficient. Further, even large trees can be topkilled in hot fires, providing a means of control as long as fuel is not suppressed due to high stand density. From the perspective of fire management of the TMC, as well as similar habitats, the question about tallow is whether prescribed burning can prevent it from successfully invading and replacing the native species. To address this question, we have also examined the responses of tallow to burning. Data have been taken from previously established experimental plots at the TMC where season of burn was examined as well as from new plots established during this study. Repeated censusing of trees has allowed us to estimate the (1) probability of mortality, (2) frequency of topkill, (3) relationship of preburn tree size to burn response, and (4) relationship of burn response to other conditions.

Effects of Prescribed Burning on Select Avifauna

Two subcomponents of this overall research project dealt with the relationships between avifauna and fire. One study sought to examine the relationships of grassland birds to burn history and habitat structure. The TMC and especially its upland grassland habitat is considered to be of potentially great importance for grassland birds of concern. Grassland birds are considered to be one of the most imperiled groups in North America. One primary motivation for the burn program is to support populations of grassland birds. A second study sought to examine a second group of primary concern - rails. Several species of rails are known to occur at TMC, though little quantitative study of their abundance or use of the habitat is available. A study of the mortality and movements of yellow rails (*Coturnicops* Gray 1855) was conducted to determine their susceptibility to direct impact from prescribed burning.

Effects of Fire on Site Fidelity and Species Abundance of Wintering Grassland Birds

Surveys and Vegetation Measurements

Surveys of grassland birds were conducted from January 6 through March 10 of 2003 to determine avian community composition, population densities, and habitat relations. The primary focus of this part of the study was to compare bird abundances between sites that were within 1 year since being burned, 2 years since being burned, and 3 years since being burned. Five replicate management units were selected for sampling within each of the three burn history types. Thus, the study included 15 habitat management units. Within each unit, four 300-m-long transects were randomly located using ArcView GIS software. Each 300-m-long transect was divided into three 100-m-long segments for sampling of birds and habitat characteristics.

Bird surveys were conducted using a recently developed method specifically designed for wintering grassland birds in conjunction with Project Prairie Birds (Shackelford and others, 2001). According to this method, birds were flushed and recorded by three observers working in tandem. This approach was chosen because grassland birds are secretive and do not call in winter. Transects were oriented NE to SW to facilitate visual observation. For the team of three people, one walked between the two who disturbed vegetation with 3-m-long poles. All birds observed to flush were identified to species and recorded, along with an estimate of the distance from the transect centerline where each bird was flushed.

Vegetation measurements were recorded after birds were surveyed for each transect. Measurements included species community type (based on cover estimates) and several measures of herbaceous vegetation density. Measures of vegetation density included average maximum height and visual obstruction (using the Robel method, Robel and others, 1970), total contacts with a randomly placed measurement pole in vertical strata, and maximum height of vegetation. Density of woody vegetation for the area sampled was also estimated, along with shrub and tree heights. A point-centered quarter method (Cottam and others, 1953) was used for woody plant sampling. From a random point within each 100-m segment, a random distance and direction were selected. These starting points were used to estimate densities and average maximum heights for each species present.

LeConte's sparrow (photo by Keith Ramos)

Site Fidelity and Home Range of LeConte's Sparrows

A species of special concern at TMC is the LeConte's sparrow (*Ammodramus leconteii* Audubon, 1844). LeConte's sparrows are believed to commonly winter in fire-managed habitat and are potentially sensitive to burn frequency and habitat structure. In addition, they are globally uncommon, though locally abundant at the TMC, which makes this location of particular importance for their preservation. LeConte's sparrows are short-distance migrants that breed in tallgrass prairies in the northern United States and southern Canada and that winter in the southern United States (Robinson, 1990; Hubbard, 1978; McNair and Post, 1993; Peterson, 1980; 1990). LeConte's are believed to be primarily granivorous, though known to eat arthropods as well. LeConte's sparrows are poorly studied, primarily due to their secretive habits. Little is known about their site fidelity and, therefore, the degree to which they rely on specific habitat locations.

During the winters of 2001-2002 and 2002-2003, home range and site fidelity of LeConte's sparrows, were examined. This work was conducted at the Brazoria NWR, primarily in upland prairie habitat. Capture-recapture techniques, in combination with banding, were used to determine site fidelity, both within-season and across years, for LeConte's sparrows. For banding, in each of the 15 burn units studied (five each from 1, 2, and 3 years since burning) a one-net lane was randomly placed in each burn unit. Each net lane was 100 m in length and 1 m wide. Vegetation was cleared to the ground at the base of the net to allow nets to be easily lowered to ground surface so as to maximize the capture rate. Monthly banding efforts were organized and carried out in December, January, and February. Each effort consisted of more than 10 people.

For radio telemetry work, LeConte's sparrows were captured in 10 management units that had been burned within the previous 2 years at the Brazoria National Wildlife Refuge, Texas, during January and February 2003. Sparrows were captured using portable nets and a small group of volunteers to drive them into the nets. Each sparrow was fitted with 0.48 g radio transmitters (Holohil Systems, Ltd. Model LB-2; 10-day battery life) attached using a leg harness. Birds were located daily using telemetry equipment, global positioning system (GPS) unit, and compass.

Estimates of avian abundance of the four most common species were corrected for detectibility factors using the software program "DISTANCE" (Buckland and others 1993, 2001). Prior to DISTANCE correction methods, raw data were examined using frequency distribution plots for each species group. We found that each species had a different detectability curve in high and low vegetation densities.

After splitting data according to individual species observation ranges, density estimation curves were produced and examined. Upon examination we selected a model based upon best visual fit and low AIC value. Models were selected from those assuming Half normal, Uniform and Hazard-rate functions. We wanted to keep the models simple, so the use of series expansions were avoided because they seemed to "overfit" the data. Using the detectability curve for each category and perpendicular distance for each observation a value or abundance was calculated.

The Effects of Prescribed Fire on the Mortality and Movements of Wintering Yellow Rails

The yellow rail is a poorly studied species of wetland bird that requires specialized breeding and wintering habitats maintained by fire. Some detailed studies have been conducted on the ecology and distribution of breeding yellow rails (Stalheim, 1974; Stenzel, 1982; Gibbs and others, 1991; Robert and Laporte, 1997; Popper and Stern, 2000; Robert and others, 2000), but only one study has ever been done on yellow rails during winter (Mizell, 1998). Bookhout (1995) found a lack of research on yellow rail life history and ecological characteristics on wintering areas and suggested that a research priority be placed on obtaining such information necessary for effective management. In this study, we addressed the effects of prescribed fire on yellow rail habitat.

Loss of wetlands because of human activity (dredging, filling, channelization, and draining) is a major factor affecting rallid populations (Eddleman and others 1988). In the United States, the yellow rail is listed as a "Migratory Non-game Bird of Special Management Concern" (USFWS 1995) and is considered a "Species of Special Concern" or "Vulnerable" in most states and in Canada where it breeds. Population size and trends are unknown because of its secretive nature and the difficulty in observing it. As a consequence, yellow rail numbers may be higher than current estimates.

Photo of yellow rail

Yellow rails migrate to wintering grounds along the Gulf of Mexico Coast in late fall. In wintering areas, they prefer drier portions of gulf cordgrass (*Spartina spartinae*) and marshhay cordgrass (*S. patens*) marshes (Bookhout, 1995). Prescribed fire is used to manage these habitats in the coastal region of Texas for waterfowl, particularly snow geese (*Chen caerulescens*). Although the effects of prescribed fire on vegetation and seasonal abundance of avian species is well documented in these habitats (Van't Hul and others, 1997), immediate impacts on bird behavior and mortality are poorly understood. Because of water depth preferences, there may be a potential conflict between habitat requirements of wintering yellow rails and the management goals of other species (Eddleman and others, 1988).

While the immediate effects of prescribed fire on wildlife are not well known, few studies have evaluated mortality and movements of a variety of wildlife relative to prescribed fire. Fischer and others (1997) and Seaman and Krementz (2000) found no evidence of mortality of sage grouse (*Centrocercus urophasianus*) and Bachman's sparrows (*Aimophila aestivalis*) as a result of prescribed fire. There was no difference in daily movements of sage grouse in burned areas (Fischer and others, 1997), but Bachman's sparrows had longer daily movements in burned stands than in unburned stands (Seaman and Krementz 2000).

Nothing is known about the behavior of yellow rails during prescribed fire, but some preliminary evidence suggests that fire can cause mortality of some wintering rallids (W.R. Eddleman, oral pers. comm. 2004). By studying the effects of prescribed fire on the mortality and movements of yellow rails, we hope to determine whether better design of prescribed burns is needed to minimize direct mortality of rails. Based on this overall goal, the specific objectives of this study were to determine (1) the movements and home range of yellow rails before and after prescribed burns, (2) wintering site fidelity of yellow rails, (3) microhabitat use and preference by yellow rails in winter, and (4) direct mortality of yellow rails and other marsh birds as a result of prescribed burns.

Study Locations

Fieldwork was conducted at the TMC, specifically at the Brazoria and San Bernard National Wildlife Refuges. The project was limited to coastal prairie and high salt marsh habitat types that were typically burned during the winter. Dominant plant species of the study area typically included grasses such as gulf cordgrass and marshhay cordgrass in drier portions, and saltgrass (*Distichlis spicata*) in the wetter depressions (Tiner 1993). Intermixed among the grasses were fleshyleafed, woody plants such as saltwort (*Batis maritima*) and annual glasswort (*Salicornia bigelovii*). At the uppermost edges of the high salt marsh, eastern baccharis was dominant.

Radio Telemetry

Yellow rails were captured from January to May in 2003 and 2004 in areas designated for winter prescribed burns. Capturing was delayed until January to allow birds to complete migration and establish site fidelity before being disturbed. Areas with high densities of yellow rails were assessed by participating in the Freeport (at Brazoria) and San Bernard Christmas Bird Counts in mid-December 2002. A marsh buggy was used in these counts to access rail habitat and to flush individuals.

Yellow rails were captured at night by pulling weighted drag-lines through marsh habitat (Mizell 1998). Drag-lines were constructed using a 15-m rope with 8 plastic milk jugs attached to the line by wire. About 50 marbles were added to each milk jug, giving the line enough weight to drag through the vegetation but allowing it to be light enough to permit the line to be pulled. Beginning 30 minutes after sunset, a group of volunteers pulled these lines through the marsh to flush yellow rails. One volunteer was needed to pull each end of the rope, while others walked behind and flanked the sides of the rope carrying dip-nets and shining flashlights to spot a flushing yellow rail. When an individual was flushed, a high-intensity, hand-held spotlight was used to locate where the bird landed. The birds had a tendency to flush farther when being chased in flight, so we did not pursue the bird until it had landed. After the individual had landed, volunteers rushed to the site of landing and put a net over the bird, or high-intensity spotlights were used to freeze the bird, which allowed volunteers to pick it up. With a net over the bird, volunteers reached under the net and got the bird in hand.

Once captured, a USGS aluminum band was placed around the tarsus of each yellow rail and morphological measurements were taken. Body weight (g) was measured using a hand-held Pesola metric scale. Wing chord measurements, culmen, tarsus, and tail length were taken using an Avinet wing rule. Age and sex is unknown in winter, but wing photos of the coverts and the P9 feather of some yellow rails were taken. Age may be able to be determined in some birds by looking at the wing photos and determining if molt limits exist (P. Pyle, oral per. comm. through C. Brower 2004).

A 1.6 g transmitter (Advanced Telemetry Systems, Isanti, Minnesota) was attached to individuals that weighed $\geq$ 45 g. Transmitters never exceeded 3% of an individual's body weight. Two types of transmitter attachment were used: glue-on and harness. The glue-on technique consisted of cutting a small patch of feathers on the interscapular region between the wings, exposing the skin and feather remnants. The transmitter was then attached directly to the back of yellow rail with cyanoacrylate glue (Duro® Quick Gel®) (Johnson and others, 1991; Robert and Laporte, 1999). The transmitter was placed to one side of the backbone, increasing adhesive surface area between the skin and the transmitter, and held in place for 2 min. This process required one person holding the bird, while the other cut the feathers and applied the transmitter. Any surrounding feathers that adhered to the transmitter were removed. The harness technique used a modified Rappole and Tipton (1991) synsacrum attachment designed for soras (Haramis and Kearns 2000).

Each transmitter was equipped with attachment tubes made of heat shrink tubing; one tube was epoxied horizontally across the front of the transmitter and the second across the rear of the transmitter. Light elastic thread was wrapped around the abdomen, cross-threaded through the front tubes of the transmitter and knotted. Then the remaining two ends of ligature were wrapped around both legs and cross-threaded through the rear tubes and double knotted, and glued. A drop of glue was placed at the tip of the antenna to prevent interference from contact with brackish water. Handling time was less than 15 min for most individuals. Individuals were released in the area of capture and monitored for approximately 5 min to make sure the transmitter did not interfere with normal movements. The glue-on technique was unsuccessful in adhering to individuals for more than a few days. Transmitters attached using the harness technique were more successful and remained on the birds for up to 4 weeks until they were recaptured and removed.

Wintering Site Fidelity and Home Range

During the winter of 2004, increased banding efforts were made in areas where Yellow Rails were banded the previous years. Recaptured birds were classified according to a system by Robert and Laporte (1999) as “repeats” (same site, same year), “returns” (same site, different year), “displacements” (same year, different sites), or “recoveries” (different site, different year).

Movements of radio-tagged yellow rails were monitored before, during, and after a prescribed burn. After a 24-hour adjustment period, individuals were located using a receiver (Advanced Telemetry Systems, Inc. Isanti, Minnesota, model R4000) and a hand-held 3-element Yagi antenna. Individuals were located using the homing method (White and Garrott, 1990; Mech, 1983), which often allowed location of an individual within 1 m. Tracking periods were conducted during 1 of 3 diurnal time periods of greatest yellow rail activity (Bookhout and Stenzel, 1987); morning (0600 – 1000 hours), midday (1001 - 1400 hours), and afternoon (1401 - 1800 hours). Geographical location of fixes were taken with a Magellan (San Dimas, California), model GPS 320, geographical positioning system unit.

All telemetry information was recorded and saved as UTM coordinates and analyzed with THE HOME RANGER version 1.5 radio-tracking program (Ursus Software, Revelstoke, British Columbia, Canada). THE

HOME RANGER calculates 95% fixed kernel estimates of home range sizes of wintering yellow rails.

Microhabitat Use and Preference

Once a location was determined, a 0.5 x 0.5 m vegetation-sampling plot was established in the immediate vicinity. Habitat characteristics sampled within the quadrat included plant-species height and cover, percent coverage of total vegetation, percent coverage of dead vegetation, depth of dead vegetation (cm), and depth of standing water (cm). The tallest individual of each plant species was measured to calculate species height. Percent cover was assessed using cover classes. Cover classes were assigned a value of 1 to 7, with 1 = 0-1%, 2 = 1-5%, 3 = 5- 10%, 4 = 10-25%, 5 = 25-50%, 6 = 50-75%, 7 = 75 –100%.

In addition, 0.25-m^2 vegetation-sampling plots were used throughout the study site to compare yellow rail microhabitat use with availability. In the 2002-03 season, sampling plots were created by generating random pairs of UTM coordinates using ArcView software. An analysis of variance (ANOVA) was used to determine how many random plots would be needed. The random sampling plots were measured until the variance began to level off. In the 2003-04 season, each yellow rail location was used as the plot center and 4 habitat samples were taken in 4 compass directions 50 m from the plot center.

Direct Mortality by Prescribed Fire

Yellow rails fitted with radio transmitters were monitored during prescribed burns and located the next day. Area burned, firing technique, rate of spread, and flame length were recorded, and an assessment of fire intensity and coverage was determined.

Results and Discussion

Fire History of the Texas Coastal Prairies and Marshes

Thomas Drummond, an English botanist, collected 700 plant species and 180 birds in the vicinity of Galveston Island during 1833-34 (Winkler, 1915). In 1836, Ferdinand Lindheimer, a German immigrant, began collecting from the coastal prairie and later throughout Texas. His collection eventually included more than 1,400 species, including several hundred new species, and was published as *Plantae Lindheimerianae* (Fasicles I – V). Fascicle I (plants no. 1-214) was collected in 1843 around Galveston Island, Houston, and the Brazos River. Fascicle II (plants no. 215-318) was collected in 1844 between the Brazos River near San Felipe and the Colorado River in the neighborhood of Cat Spring, then towards the Colorado and along its bottomlands (Blankinship, 1907; Englemann and Gray, 1845).

It is apparent from early pioneer accounts that the coastal landscape they encountered was very different from what remains today. With few exceptions, writers spoke about the beauty of the coastal prairie and the bountiful game. They described a landscape with vast prairies of thick luxuriant grass filled with flowers and great canebrakes along river bottoms (“Old Caney”, the “Brazos bottom”, “Caney Creek”, “Caney Creek bottom timbers”) and ponds.

The giant cane described by early travelers through the bottomlands of the coastal prairie, is *Arundinaria gigantea*. It is reported to have grown to a height of 10 m and created nearly impenetrable “brakes” along the Brazos, Colorado, and Trinity Rivers (Corner, 1897; Vines, 1986). According to Jordan (1973), Caney Creek was the name given to the area “between the lower Brazos and Colorado rivers in Matagorda and Wharton counties. This brake began about twelve miles from the gulf coast and reached some seventy-five miles upstream.” In 1821, Stephen Austin (1904) described the bottom area around the Trinity River as follows: “there is a large smooth Prairie on each side, covered with the highest and thickest growth of grass I ever saw – the grass is coarse and very much resembles sugar cane . . . “.

Another striking difference between the early accounts of the area and the conditions today is the lack of references to *Baccharis halimifolia*. The only shrub or small tree that we found to be mentioned by name is mesquite (*Prosopis pubescens)*. The historical accounts do name many of the large trees that grew along waterways or on the edge of the prairie: pecan, ash, cedar and the post, overcup, red, water and black-jack oaks (Wood 1901, Austin, 1904).

Readers of these accounts and descriptions of Coastal Prairie should recognize that the landscape they described was not pristine, unaltered by humans but rather a landscape changed over time (perhaps millennia) by Native Americans (Baisan and Swetnam, 1997). M. K. Anderson wrote, “Perhaps it is more reasonable and accurate to view Indian interventions in North American landscapes as part of a continuum or spectrum that would encompass a full range of human modifications from a very little or no Native American influence (true wilderness) to fully human-created (anthropogenic) ecosystems” (Stewart, 2002). Pyne (1982) states, “Except for the High Plains, where the short grass expanses were more or less determined by climate, nearly all these grasslands were created by man, the product of deliberate, routine firing [by Native Americans].”

Fire on the Texas Coastal Prairie

It has been suggested that perhaps the greatest influence of the Spanish in their first 200 years in North America was the introduction of diseases that depleted the Native American population, thereby altering land-use and fire frequencies (Grahame and Sisk, 2002). Disease was a factor in some areas such as the Colorado plateau, following a major smallpox outbreak among the Pueblo tribes in the 1780s (Morris, 2002). There was a reported smallpox outbreak in Texas in 1706, but nothing was found to suggest that the regular burning of the coastal prairie was interrupted. The historical accounts from the 1700s and 1800s describe many encounters with the native population and their frequent use of fire continuing into the middle of the 19th century. Explorers and early settlers of the Texas coastal prairie wrote about the native population using fire to reduce insect, snake, and rodent populations; to drive game, to improve pasture, to flush out enemies, and to improve visibility. Fires also resulted from campfires left unattended. (Mitchell, 1974; Pyne, 1982; Parker, 1990; Joutel, 1998; Williams, 2003) According to Higgins (1984), “There are no records of fire suppression by Native Americans except to save occupied camp sites”.

The early pioneers continued the Native American practice of regularly setting prairie fires. Stephen Austin in 1829, ordered his surveyor to “fire the prairie at different places as you go along” (Jordan, 1973); Amos Parker wrote in 1834, “the prairies are all burnt over twice a year - in mid-summer, and about the first of winter” (Jordan, 1973). The practice was apparently so common that a settler wrote to Austin in 1824 requesting a law “to prevent persons from setting the praria (sic) on fire near the Settlements” (Jordan, 1973). Fire was also used to clear the canebrakes. The cane was considered a “certain indication of the best soil, and it could be cleared by the simple expedient of setting a fire." (Lewis, 1899; Jordan, 1973) No reference to the Native Americans using fire to clear or burn the canebrakes was found.

Not only were fires numerous in the 19th century but they also frequently occurred on a huge scale, burning for days (Mitchell, 1974). “(F)or days afterwards we could trace by the smoke on the horizon” (Parker, 1990); “[fire] had burned over the whole surface of the country. In places no grass was to be found for a distance of 20 to 30 miles” (McClintock, 1931); “The country, the entire two leagues . . . was not in its full beauty as the Indians had recently set fire to it . . .” (Joutel, 1998); “ . . . one of our people set the grass on fire which spread in a short time, so we could see the exposed country for a great distance.” (Joutel, 1998).

Cattle Grazing

The introduction of cattle and horses by the Spanish did have dramatic and long-term effects on the coastal prairie. By the early 1800s large herds of cattle and horses roamed freely and grazed not only the prairie but also the canebrakes. Wealthy planters of the Austin colony as well as settlers in the Atascosita district of southeast Texas are reported to have grazed large cattle herds on the coastal prairie as part of a combination of plantation farming and livestock ranching (Jordan, 1973). Stephen Austin noted that there was an “abundance” of mustang and “plenty” of wild cattle in the Brazos Bottom in 1821 (Austin 1904). The numbers were large enough that herding and selling of wild stock became an important source of income to settlers in the 1820s. Austin noted that some of the mustangs he saw would sell from $100-$200 in Louisiana (Austin 1904). In 1846, herds of 5,000-7,000 mustangs were reported to be roaming loose on the prairie (McClintock 1931).

After Texas won its independence from Mexico in 1836 there was a rapid influx of American and European immigrants. The population surged from an estimated 33,000 in 1836 to 600,000 by 1860 (Coulson and Joyce, 2003). Settlers began managing the land for cattle and eventually, fencing it for more intensive grazing (Stewart, 2002). By 1854, W. B. Parker reported that there were one to two million head of cattle in Texas and they increased by 25% annually (Parker, 1990). One source of this rapidly increasing cattle population may have been the wild herds south of the Rio Grande. An American soldier in Mexico in 1847 wrote, “Countless herds of wild cattle once roamed over these extensive plains . . . They [Texans] have stocked their country with them from the Trinity to the Nueces, few are now met with south of the [Nueces]” (McClintock, 1931). The long-term impact on the canebrakes from intensive grazing and farming was due in large part to its irregular flowering habits. *Arundinaria* is reported to be very slow to recover from damage and can require several generations to return after being killed off (Hughes, 1951). On the prairie, the grazing pattern of cattle greatly reduced the fine fuel load, thereby making it increasingly difficult for a fire (set by lightning or humans) to sustain itself. Thus, even though settlers continued the practice of firing the prairie, it became increasingly more difficult to burn, making large-scale fires no longer possible. We believe that it was this dramatic population increase, combined with the intensive livestock grazing, that most likely changed the fire regime of the coastal prairie in the second half of the 19th century.

By the mid-1800’s, the effects of cattle grazing were already apparent to some who had seen the prairie and canebrakes in a more “pristine” state. An early settler commented about the change wrought on the landscape by the increasing number of cattle (Kuykendall, 1903):

> In 1821, and for several years afterwards, wild oats and wild rye grew in great luxuriance in the bottoms of the Brazos and Colorado. These fine grasses have long since disappeared. In many localities in the same bottoms where dense and extensive cane brakes formerly existed, scarcely a cane can now be found. Many of the prairies on which, of old, the grass waved in rank luxuriance, have been grazed and trodden by stock until weeds and bushes are fast usurping their surface. Formerly the annual burning of the grass prevented the spread of forest vegetation in the prairies.

The changes to coastal prairie in the second half of the 19th century may not have been apparent to most of the inhabitants. In 1908, O. F. Cook of the Department of Agriculture believed grazing had strongly altered the landscape in south Texas: "The change has come so gradually that even those who have the most intimate acquaintance with the facts have not appreciated their significance" (Stewart, 2002). Early settlers and ranchers on the coastal prairie continued the Native American practice of "firing the prairie" but as herds increased and grazing intensified throughout the 19th century, the landscape began to change. As grazing pressures increased, the grasses were no longer able to accumulate sufficient biomass to carry a fire or burn with sufficient intensity to destroy invading woody plants. The shade from the woody plants further reduced the grass making attempts to burn less and less effective; this process occurred throughout Texas and the southwestern United States. Several quotations reinforce the image of dramatic change:

> . . . before the prairies in south Texas were grazed by cattle, the luxuriant grass accumulated for several years before conditions were favorable for the spread of fire. Fires were especially destructive to trees and shrubs and favored the rise of grass to dominance. Settlers in southern Texas practiced burning grasslands every year, partly for protection, partly to give access of cattle to the fresh growth of grass. Burning kept the woody vegetation in check, though in areas where grass was thin *Juniperus* and *Prosopis* seedlings were not destroyed. They soon began to shade the ground, killing the grasses and giving protection from fire. With more intensive grazing, the quantity of grass decreased so that fires were fewer and less severe. Hence, oak-mesquite communities became well established over the area. (Axelrod, 1985).
>
> A sharp decline in fire frequency after about 1880 was observed in virtually all southwestern fire history studies and the fire frequency decline coincided with the beginning of intensive livestock grazing (especially by sheep) in each study area and preceded organized fire suppression by 1 - 3 decades. (Touchan and others, 1995).
>
> Land use patterns of the late 19th century had significant impacts on fire occurrence and vegetation changes in the southwestern United States. Prior to widespread grazing, desert grasslands were more robust, while pine and oak communities were more open. Grazing activities also fragmented the landscape, and in some areas caused arroyo cutting, erosion, and selection for unpalatable and fire-intolerant species, further exacerbating vegetation changes. Grazing-induced changes in vegetation also lead to the elimination of widespread fires in both the grassland and pine/oak communities. (Nunez and others 2003).

Historical Fire Regime

The historical fire regime classification system developed by Schmidt and others includes five regimes defined by fire frequency and severity "to reflect typical fire frequencies and effects that evolved in the absence of fire suppression." (Schmidt and others, 2002). The coastal prairie is placed in class II: 0-35 yr frequency, stand replacement severity. This classification is in agreement with Frost, who in his representation of Presettlement Fire Frequency Regions of the United States, places coastal prairie in a 1 – 3 year frequency regime because of its "almost annual fires over a large part of the landscape" (Frost, 1998). Among the data layers developed by Schmidt and others are the current cover types, historical natural fire regimes and fire regime current condition classes. This last layer depicts the three condition classes that describe the "degree of departure from historical fire regimes possibly resulting in alteration of key ecosystem components" (Schmidt and others 2002). The Texas coastal prairie contains areas under all three classes.

Illustration of high intensity fire in prairie with high density of baccharis (photo by A. Billock).

Within the historical fire regime, is it possible to separate the natural and anthropogenic sources of fire? Neither lightning nor the number of lightning strikes in an area are necessarily a predictor of ignition. Rorig and Ferguson (2002) found that high instability and high dewpoint depression corresponded more closely to lightning-caused fire than lightning strike densities (Schmidt and others, 2002). Also, strikes must be “dry” to provide the spark required. “The West has dry lightning and that is why, with or without people, . . . (it) will burn” (Pyne, 2001) but the eastern and coastal states, with the exception of Florida, have wet lightning accompanied by dousing rains (Pyne, 2001). Based upon the literature, lightning was not a major ignition source on the Coastal Prairie with the exception, perhaps, of drought years. No mention was found in any historical journals of coastal prairie fires ignited by lightning or to it as a possible source. We do not take this to mean lack of mention to mean that lightning was not an important ignition source. In fact, lightning is known to commonly cause wildfires today. Nonetheless, its absence in the historic literature is noteworthy.

Summary

Evidence indicates that lightning fires must have been important historically, as they are today. However, historical documents clearly indicate the importance of anthropogenic fires in shaping coastal ecosystems. Frost (1998) provided the following view, which we find to sum up the information we found quite well:

> . . . to manage for pre-European frequency, which was a combination of Native Americans and lightning. . . I suggest that we accept presettlement vegetation as the model for management of lands with natural vegetation since it had been around for some 6,000 years, in substantially stable composition, despite oscillations in rainfall and local effects related to movement of Native American settlements. If we do so, then it makes sense to include effects of Native Americans in the model, since they had the entire 10,000 years of the Holocene using fire to shape the vegetation we inherited (Pyne, 1982). In some areas such as the prairie region, it is impossible to separate lightning and anthropogenic effects, since Native American immigration and use of fire actually preceded development of the holocene grasslands (Bragg, 1995).

Effects of Prescribed Burning on Habitat Conditions

Appendix 1 summarizes the plots that were burned at the TMC during the study. Several plots were burned more than once over the course of 2001-2003. Forty-six of 66 plots established during this study were burned while the remaining 20 were not burned during the time period in which monitoring took place. The study sites that were burned were located at all three refuges, with the greatest number at Brazoria NWR (32), second at San Bernard NWR (12), and fewest at Big Boggy NWR (2).

Not all parameters measured were able to be collected for every plot and every burn. Assessments of plant responses were collected for all plots whose data are included in this report. However, we were not able to obtain fire and fuel characteristics for all burns. Therefore, analyses of different parameters were based on various sample sizes, depending on the availability of data for individual measurements.

Illustration of low intensity fire in prairie with high density of baccharis (*Baccharis halimifolia*) (photo by A. Billock).

Burn Conditions and Fire Behavior

A wide range of fire behavior was recorded during the study. We observed substantial variation in fuel loads, fuel types, weather conditions, and as a result, fire severities. The wide range of conditions and fire behaviors provided an excellent opportunity to evaluate a variety of preselected hypotheses about the importance of factors affecting baccharis resprouting (discussed further below).

Fuel loads measured ranged up to 22 tons/acre, with the median load at 12 tons/acre (fig. 6). In general, fuel loads were quite high relative to many if not most grasslands in the world, which frequently lie in the range of 4 to 8 tons per acre. Live fuel moisture values were also found to fall outside the norm. The values found during this study were most commonly in the range of 170 to 200 (fig. 6). In other areas of North America, it is generally considered that values in excess of 130 represent live fuels that are too “green” (i.e., contain excess moisture content) to sustain fire. Coastal prairie vegetation clearly deviates from that rule of thumb. *Spartina spartinae*, in particular, is highly flammable even at its greenest, most likely because of volatile oils that are observed to contribute to its flammability. Finally, baccharis live fuel moisture ranged widely within the range of 190 to 280. In general, baccharis did not carry the fires appreciably, though it was often consumed in the fire.

Ecological effects of fire strongly relate to impacts of heating on the basal parts of plants, including belowground structures. Soil moisture may serve as an index of both water status of plants as well as serving as an important component of soil properties that might affect the transfer of heat down the soil profile. For this reason, samples of soil surface moisture were collected immediately prior to burns. Moisture values were typically less than 30%, though they ranged up to 70% (fig. 6). As shown below, soil moisture varied with season and related to some fire response parameters.

Sites that were burned varied substantially in the heights and densities of baccharis (fig. 6). More successionally mature sites tended to be targeted for burning, which probably explains why the most common size class of baccharis was 180 cm tall. In a few cases, however, sites with relatively small plants were included in burns. Stem densities per plot (100 m^2) also varied widely, though most were in the range of 30 to 60 plants per plot.

As shown in figure 7, burns tended to be quite complete, with most approaching 100% of plot surface. Likewise, burns tended to consume most of the herbaceous fuel. Average scorch heights were most commonly in the range of 137 cm, though the maximum and minimum scorch heights did vary widely depending on apparent fire intensity. Of all the parameters relating to burn characteristics, percent of woody plant leaves consumed in the fire varied the most widely (fig. 7). This parameter appeared to be the most sensitive indicator of fire severity, since cool fires consumed few of the leaves of baccharis while very intense fires consumed nearly all the leaves. The index of fire severity, which included all the other parameters shown in figure 7, varied in the range of 60% to 96%.

Baccharis Dynamics and Mortality

Repeated measurements of baccharis densities over time provided a characterization of dynamics. Comparisons of densities immediately before and shortly after fire also permitted estimates of fire-induced mortality. When substantial time elapsed following a fire before stem densities could be assessed, no attempt was made to interpret stem changes simply as mortality because there was a potential for additional recruitment of new individuals. Figure 8 provides an illustration of baccharis dynamics in a long-term plot in response to fire. Such timecourse records were used in this study to estimate mortality, recruitment (based on changes over time not associated with fires), and height growth. It was often possible to obtain multiple estimates from a single plot using different portions of the time records.

Baccharis was observed to be top killed when exposed to fire in nearly all cases. Thus, it is very vulnerable to fire damage. However, resprouting from the plant base is common. Figure 9 (upper panel) provides a summary of the observed responses from the 58 burns that have been observed at the TMC. These data include measurements taken prior to this study (1997–1998 period; Allain and Grace 2001) as well as those taken during the 2001–2003 time period. What is striking about the mortality response of baccharis to fire is the extreme variability. Typically we would expect the frequency distribution of mortality responses to follow a normal distribution. However, it is clear that mortality is generally a binary response to burning, with most burns having either a strong effect on mortality or little if any effect. More specifically, the most common response to burning was near 100% mortality (22 of 58 cases). In 18 of the remaining 36 cases, mortality was less than 40%.

An effort was made to compare these results to those recorded at the Aransas NWR during the period of 1990 to 2000 (fig. 9 middle panel). These data represent 29 observation intervals involving 10 plots burned repeatedly over the 10-year period. It is interesting to note that the frequency distribution of responses is similar in character to those obtained from the TMC. When the two datasets are taken together (fig. 9 lower panel), they provide what we believe to be the most extensive database of burn responses of Eastern baccharis yet obtained, with a total of 87 burn observations. It is quite unambiguous that mortality responses to individual burns approximate a binomial outcome, though not strictly so. Most commonly, burns produce high mortality rates. However, the second most likely response is very little mortality. The arithmetic mean response (56%) is among the least common responses observed. We conclude from this pattern that mortality responses of baccharis to fire are probabilistic and do not represent an underlying average response, but instead, an underlying probability of experiencing either a high or low degree of mortality.

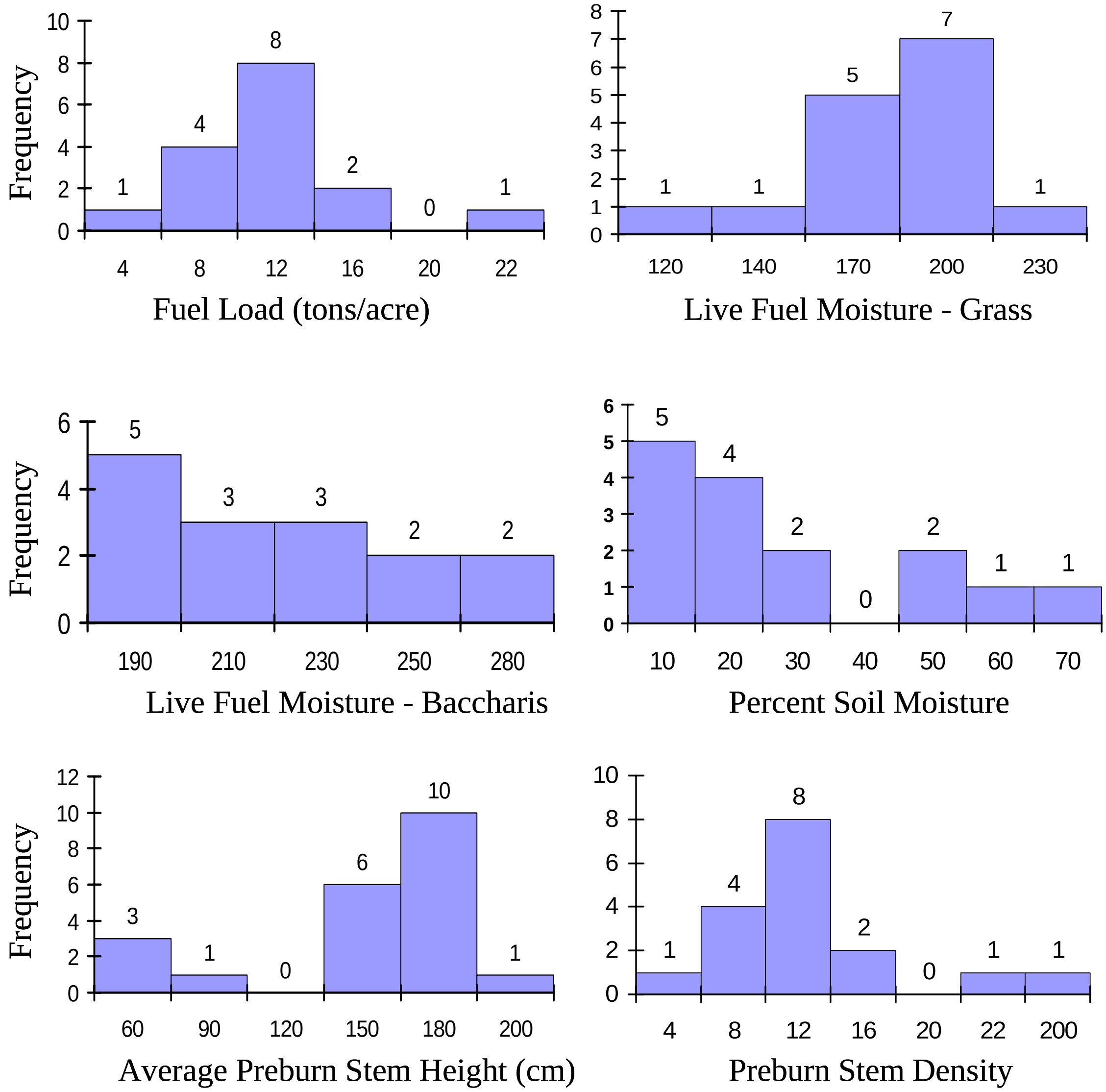

Figure 6. Illustration of preburn characteristics.

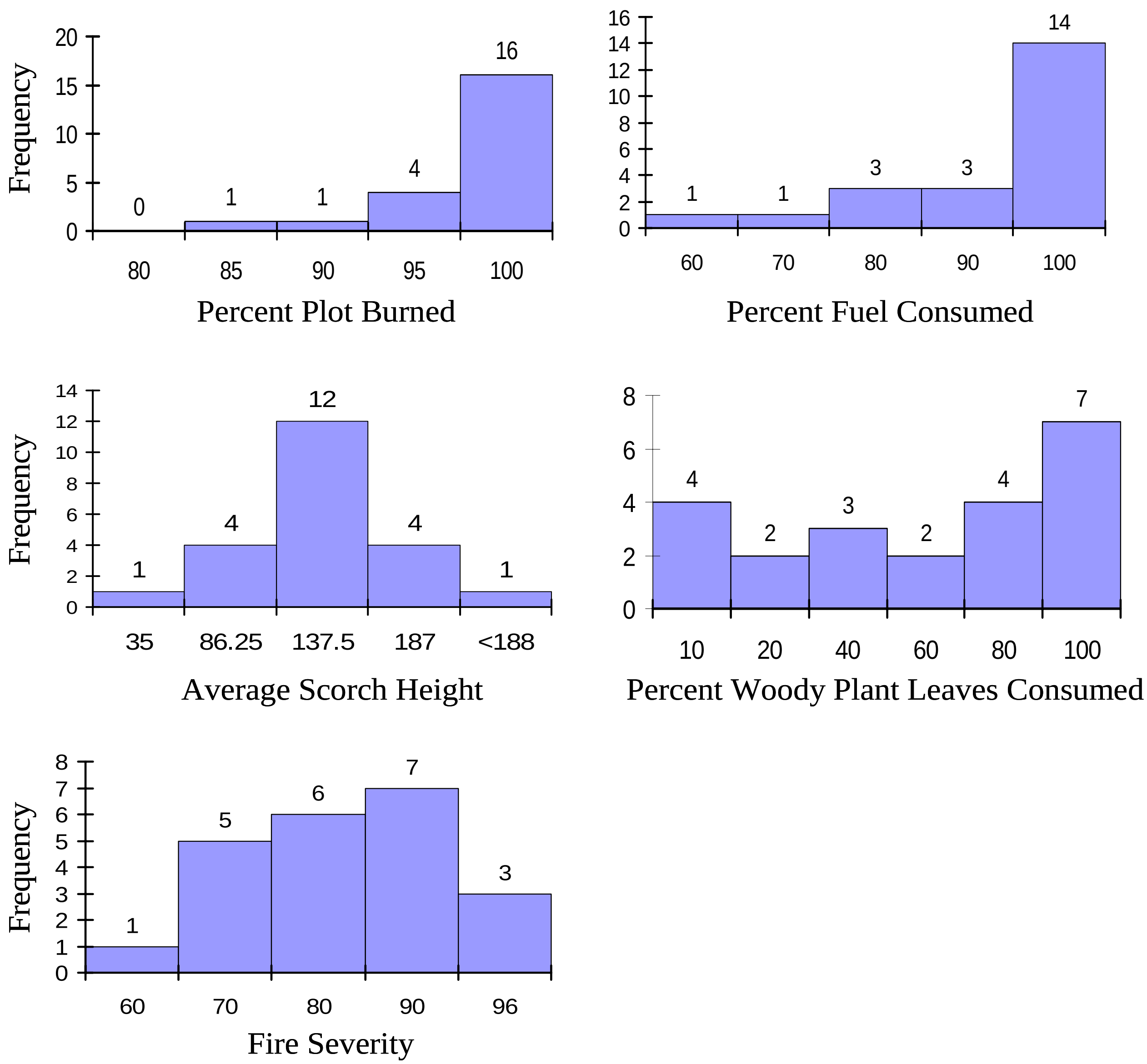

Figure 7. Illustration of burn characteristics.

Factors Contributing to the Variation in Baccharis Responses

Because the mortality response of baccharis to fire is basically binomial (fig. 9), attempts to understand how various factors affect mortality does not lend itself to regression analysis. Instead, categorical analyses were performed to determine if high, medium, or low mortality rates were associated with various factors. Using the data from the TMC, mortality was evaluated relative to a variety of parameters. Results were evaluated using chi-square tests. Where cell observations were low, Fisher's exact test was used. Parameters examined included fire

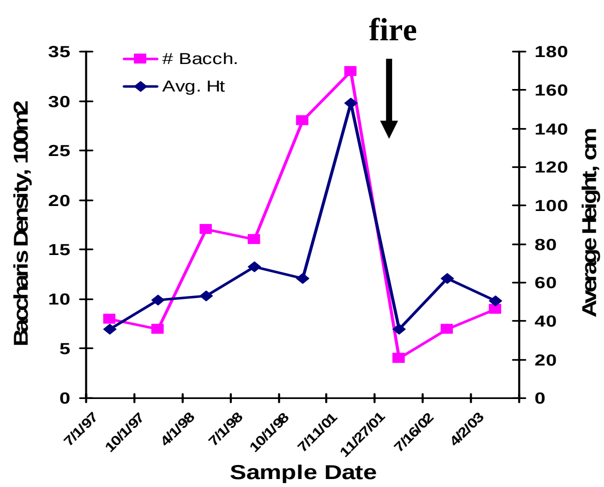

Figure 8. Illustration of baccharis dynamics in a long-term plot in respone to fire.

severity, preburn baccharis density, mean preburn baccharis height, fuel loads, grass live fuel moisture, baccharis live fuel moisture, season of burn, and soil moisture.

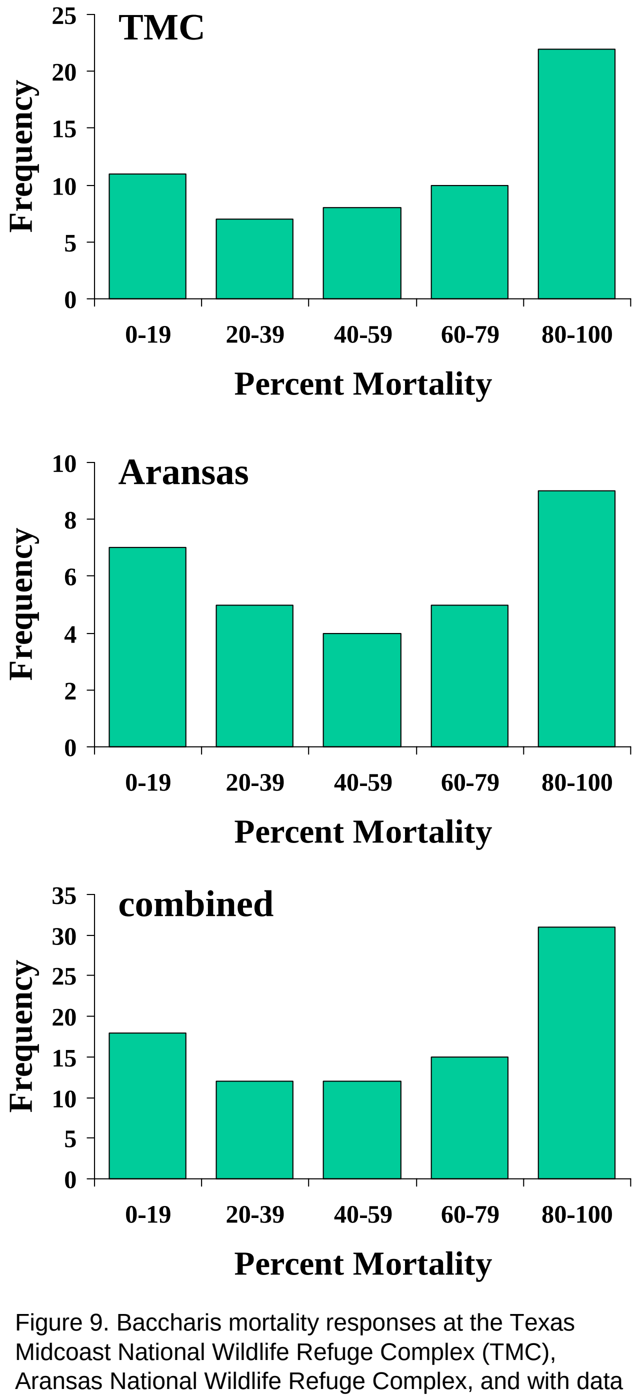

Figure 9. Baccharis mortality responses at the Texas Midcoast National Wildlife Refuge Complex (TMC), Aransas National Wildlife Refuge Complex, and with data from both sites combined.

Despite the high degree of variability in baccharis responses, the probability of high mortality was found to be strongly related to the season of burn. Figure 10 illustrates the magnitude of difference in the probability of observing a mortality greater than 50% as a function of the season of burn. For this analysis, growing season burns were classified as those occurring from May through October. Based on the observation that only 5 of 24 burns resulted in greater than 50% mortality in dormant season burns, the probability of a so-called effective burn was estimated to be 21% for this season. Likewise, the observed 49 of 64 growing season burns that produced effective burns results in an estimated probability of 76%.

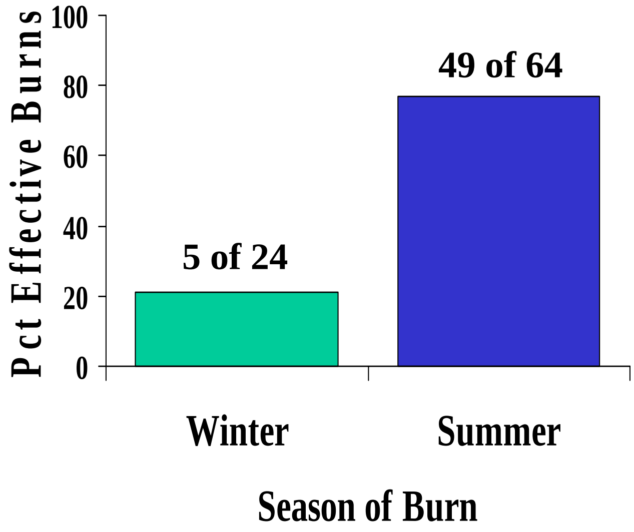

Figure 10. Frequencies of effective reductions of baccharis (mortality > 50%) during winter versus summer burns. Numbers above bars represent the number of effective burns out of the total conducted during that season.

A number of things differ between the growing and dormant seasons that could contribute to differences in the probability of mortality. There was no evidence that the characteristics of the fire (percent of plot burned, fire severity) differed between dormant and growing season burns. Similarly, there was no evidence that season of burn was confounded with fuel conditions in a way that might obscure contributing factors.

The one environmental factor that was found to relate to mortality was soil moisture. While there were several examples where mortality was high under conditions of high soil moisture, overall, mortality was more likely to be high when soil moisture was low. Out of a total of 19 cases where soil moisture data were available, the probability of an effective burn was 90% when soil moisture was below 40% and only 9% when greater than 40%. The majority of the soil moisture data was from growing season burns. Thus, soil moisture differences do not appear to be a major cause for growing season effects, though they could act in concert.

Overall Effectiveness of Burning for Reducing Baccharis

All plots studied at the TMC were resampled during April 2003 in order to assess the changes in number of woody plants and their heights. Results for average changes in numbers of woody plants are given in figure 11. For all three refuges, changes from 2001 to 2002 reflected reductions in the number of Baccharis resulting from burning (as well as some reductions that were probably the result of baccharis beetles). However, from 2002 to 2003, all refuges saw increases in the number of plants, being least conspicuous at Brazoria and most dramatic at Big Boggy. Some of the increase in plant number from 2002 to 2003 appears to have resulted from recruitment of new plants from seed, which in some cases was very significant. As indicated above, behind these average numbers there was a substantial amount of variation in responses.

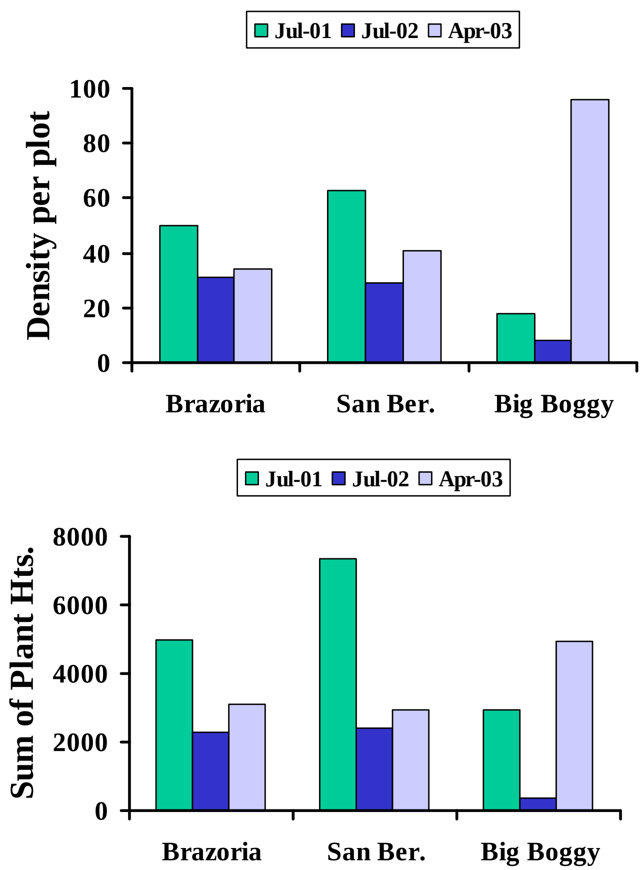

Figure 11. Changes in baccharis density and the sum of plant heights in 100 m^2 plots at Brazoria, San Bernard, and Big Boggy National Wildlife Refuges.

Changes in total plant length (which serves as an index of total abundance) are also shown in figure 11. Again, we can see that there was a reduction in plant abundance from 2001 to 2002 overall. Also, a rebound in plant abundance was observed in 2003, being roughly equivalent in magnitude at Brazoria and San Bernard, but very substantial at Big Boggy. Taken together, these data indicate that prescribed burning is having an effect on reducing both density and total abundance of baccharis. However, the need for sustained vigilance is also evident in these results.

Examination of the effects of repeated burning is clearly evident at Aransas NWR, where a sustained annual-biannual burning program resulted in a great reduction over a 10-year period (Aransas NWR, unpublished data). There is some indication that this principle applies at the TMC as well. Figure 12 illustrates the changes that took place at one of the study sites over a nearly 7-year period. This location, known as the "Bermuda Triangle Unit", was burned three times during that period. All burns were conducted during the growing season. Observed short-term mortality rates were 27%, 92%, and 50% for the three burns. Cumulatively, the number of baccharis were reduced from 44 per 100-m^2 plot to only 2 per plot, an overall reduction of 95%. Most of the reduction in numbers was associated with a single burn, the second one. However, all three burns contributed to reducing the regrowth and recruitment of new individuals, which was observed in other locations where only a single burn took place.

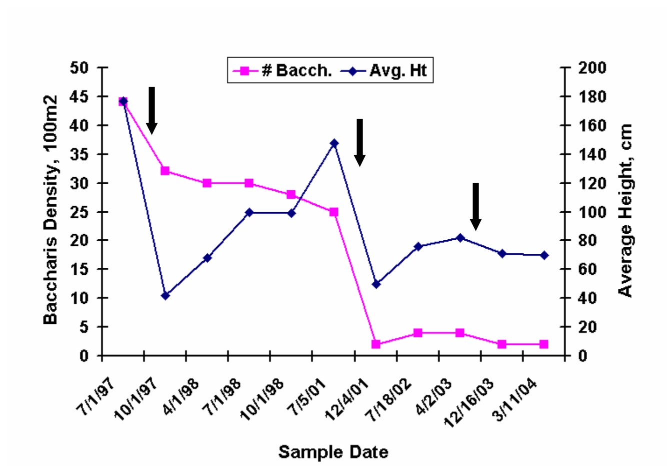

Figure 12. Changes in baccharis under repeated burning. Arrows indicate burn events.

Responses of Chinese Tallow to Fire

Evidence suggests that smaller tallow trees are vulnerable to fire (fig. 13). In this study, the smallest size class of plants (seedlings less than 10 cm tall) were all killed when burned. Mortality is greatly reduced for larger trees, however. Death rates in our extensive study dropped from 40% for 0.1-1 m tall trees to virtually zero for large trees (greater than 3 m tall). However, it was found that even the tallest trees can be topkilled or heavily damaged by burning when there is sufficient fuel, though the probability declines with increasing tree size.

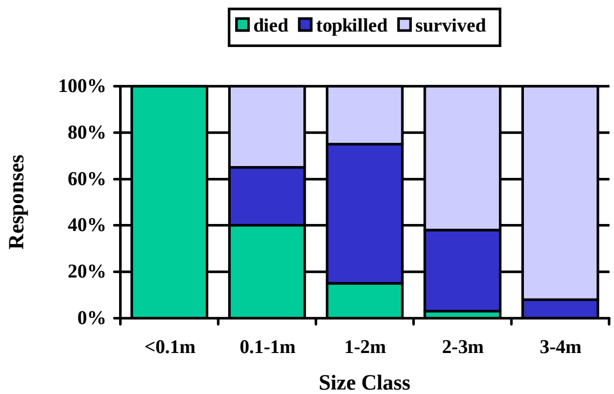

Figure 13. Responses of Chinese tallow trees to fire as a function of tree size.

An assessment of the accuracy of prediction of individual tree fate based on preburn size (fig. 14) revealed considerable variation. Subsequent analyses showed that several factors contribute to the scatter. The most important influencing factors are (1) fuels, (2) fire intensity, and (3) season of burn. Further, these factors interact in a complex way to influence the fate of trees.

While figure 14 reflects some of the complexities of the interaction between tallow and fire, there are two main take home lessons. First, when fuels around trees are abundant and fires are hot, substantial damage can be done to tallow trees by prescribed burning. When trees possess a closed canopy, either due to high densities or because individuals are large, fuels are suppressed and fire is ineffective. Second, dormant season burning can subject trees to just as much damage as growing season burns. However, tallow tree responses to burning are influenced by season. Trees burned during the growing season show weaker recovery from fire damage and greater long-term impacts.

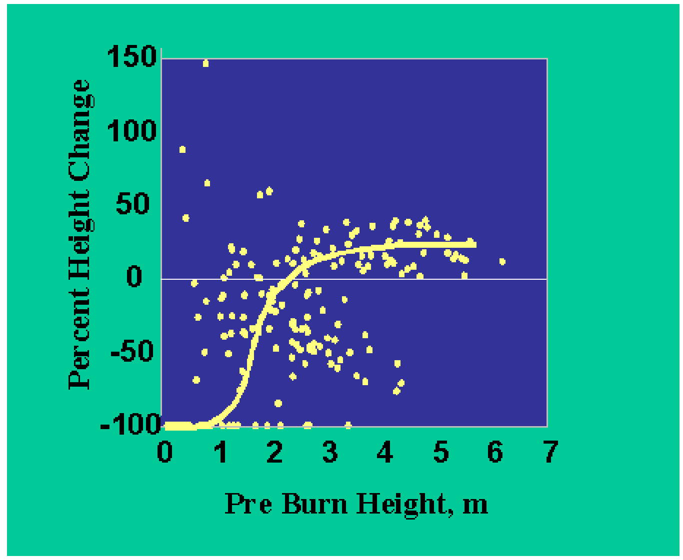

Figure 14. Net changes in Chinese tallow tree heights 2 years after they had been burned. Points below the zero change line represent trees that were smaller than before the fire. Points above the zero change line were taller than before burning.

In order to get a partial view of the rates at which tallow invades prairie, aerial photographs were examined for two locations, an abandoned agricultural field and a prairie site that was not burned extensively during the 1990s. Comparing delineated, ground-truthed photos from 1991, 1995, and 1999, we were able to estimate the coverage of tallow trees and how it changed over that time period for those two areas. For the abandoned field, coverage by tallow increased from less than 1% following abandonment in 1990 to over 30% in 1999 (fig. 15). For the prairie site, invasion was slower, beginning with less than 1% in 1991 and increasing to 12% in 1999. It is not known how representative these rates are for areas not subjected to burning. Nevertheless, these observed rates of invasion and canopy development are remarkable, we believe, and suggest the need for vigilance in keeping tallow from getting out of control before treatments are applied.

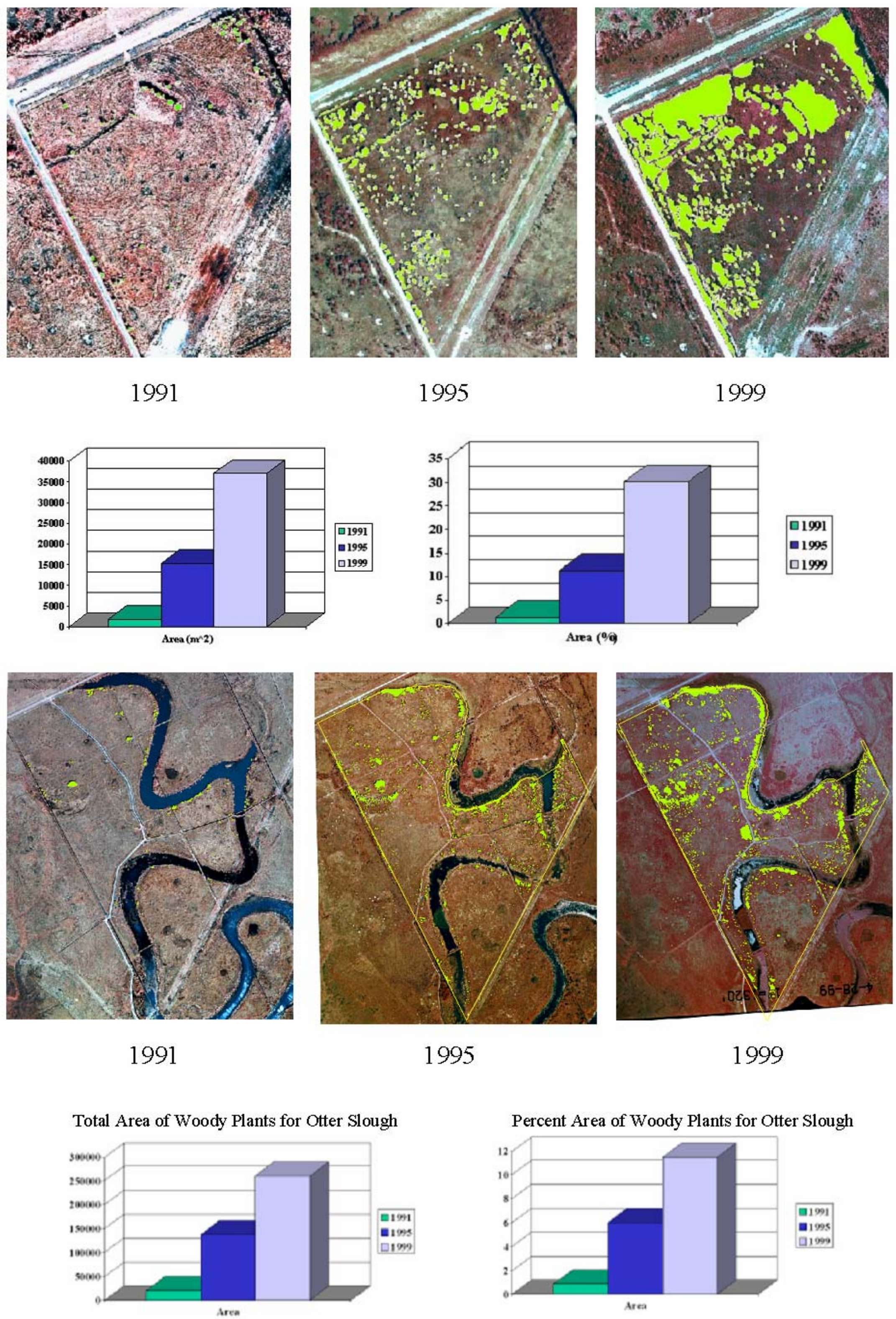

Figure 15. Invasion of Chinese tallow into unburned sites from 1991-1999. Upper figures are from the Pipeline site at Brazoria NWR. The lower figures are from Otter Slough at Brazoria NWR. Green on photos represents tallow coverage.

Overall, fire is likely to be an effective treatment for preventing taken over by tallow whenever fuel conditions are good and tree invasions have not proceeded very far. In cases where trees are large, fuels are sparse, or conditions are otherwise not favorable for burning, methods other than fire will need to be employed.

Effects of Prescribed Burning on Select Avifauna

Wintering Prairie Grassland Birds

Species-Habitat Relations

Because habitat conditions vary substantially at the level of the 100-m length of transect, this is the scale at which relationships to environment were examined. In this study there were a total of 183 100-m transect lengths sampled. For the four most common species, LeConte's sparrows were recorded at 33 transects, savannah sparrows were recorded at 29, sedge wrens were found at 39, and swamp sparrows were found at 30. The relationships between the occurrence of birds and burn history were examined using categorical analysis procedures. Specifically, chi-square tests were performed individually for each of the four most common species in order to determine whether they were more likely to be found at any one type of grassland than another.

Results for each of the four most common species are summarized in figure 16A. Shown in this graph are the estimated probabilities of finding birds for each of the three habitat types (year since burn). For example, for LeConte's sparrows, there was found to be a 17% chance of finding birds at sites burned 1 year previously, while there was a 27% chance of finding them in fields burned 2 years previously. Chi-square tests found that for LeConte's sparrows, savannah sparrows, and sedge wrens, there were significant differences among habitats in occurrences. For swamp sparrows, the differences observed could not be distinguished from a chance occurrence. Based on these results, we conclude that LeConte's sparrows were more likely to be found in 2-year-since-burn (YSB) prairies than 3 YSB prairies. Savannah sparrows were almost exclusively associated with 1 YSB sites. Sedge wrens, in contrast, were least likely to be found in 1 YSB prairies, while swamp sparrows were equally likely to be found in any field. Taken together, these results suggest that each species differs from the other in its habitat associations.

The relationships of birds to vegetation were also examined, in part to better understand the observed relationships to year since burn (fig. 16B). Vegetation abundance was estimated using the total number of contacts with a randomly placed pole. Again, three of the four species showed significant differences in their likelihood of being found in vegetation of different densities. LeConte's sparrows were most likely to be encountered in fields with intermediate amounts of vegetation, while savannah sparrows were much more common in areas with sparse vegetation. Sedge wrens were most common where the vegetation was densest, while swamp sparrows did not show a clear affinity for any vegetation category.

Site Fidelity and Movements of LeConte's Sparrows

Within-season site fidelity of wintering grassland sparrows was examined through intense banding efforts. A total of 218 birds were banded. A sufficient sample size was obtained for only two species, LeConte's sparrows and swamp sparrows. On each of the 15 burn units surveyed, a 1-ha plot was netted once each month (Dec.–Feb.). Within-season site fidelity was estimated using mark-recapture techniques and the closed population model (White and others, 1982) in program MARK (White and Burnham, 1999; 2002). Preliminary results indicated that recapture rates for banded birds were very low. Normally this would indicate population densities were high. However, netting efforts revealed that banded birds avoid recapture, therefore, adjustments for this behavioral response will be required. Final analysis of these data are continuing and results are pending.

Movement patterns of radio-tagged birds were analyzed with the Animal Tracking Extension in ArcView GIS (Krementz and Thatcher unpub. data, 2001). Bird movement patterns indicated that LeConte's sparrows generally remain in a small area throughout the season (see figs. 17 and 18 for illustrations of a bird's recorded movements).

Recommendations

The findings in this study are consistent with other literature that suggests that a mosaic of conditions is required to maintain a variety of grassland bird species in the landscape. Savannah sparrows are strongly associated with 1 YSB conditions and sparse vegetation. Neglect of the burn program or adverse burn conditions could easily lead to an absence of these conditions in the landscape. Year-to-year variations in the ability to accomplish burn objectives are very great and it is not unprecedented for little burning to take place for 2 years in a row at the TMC. LeConte's sparrows, since they depend on conditions burned within either 1 or 2 years, are also highly dependent on frequent burning in this landscape. On the other side of the issue, species such as the sedge wren, for example, seem to rely on habitat that has not been recently burned. Taken all together, these results would suggest that a 3-year burn rotation, with a mosaic maintained in the landscape would be optimal.

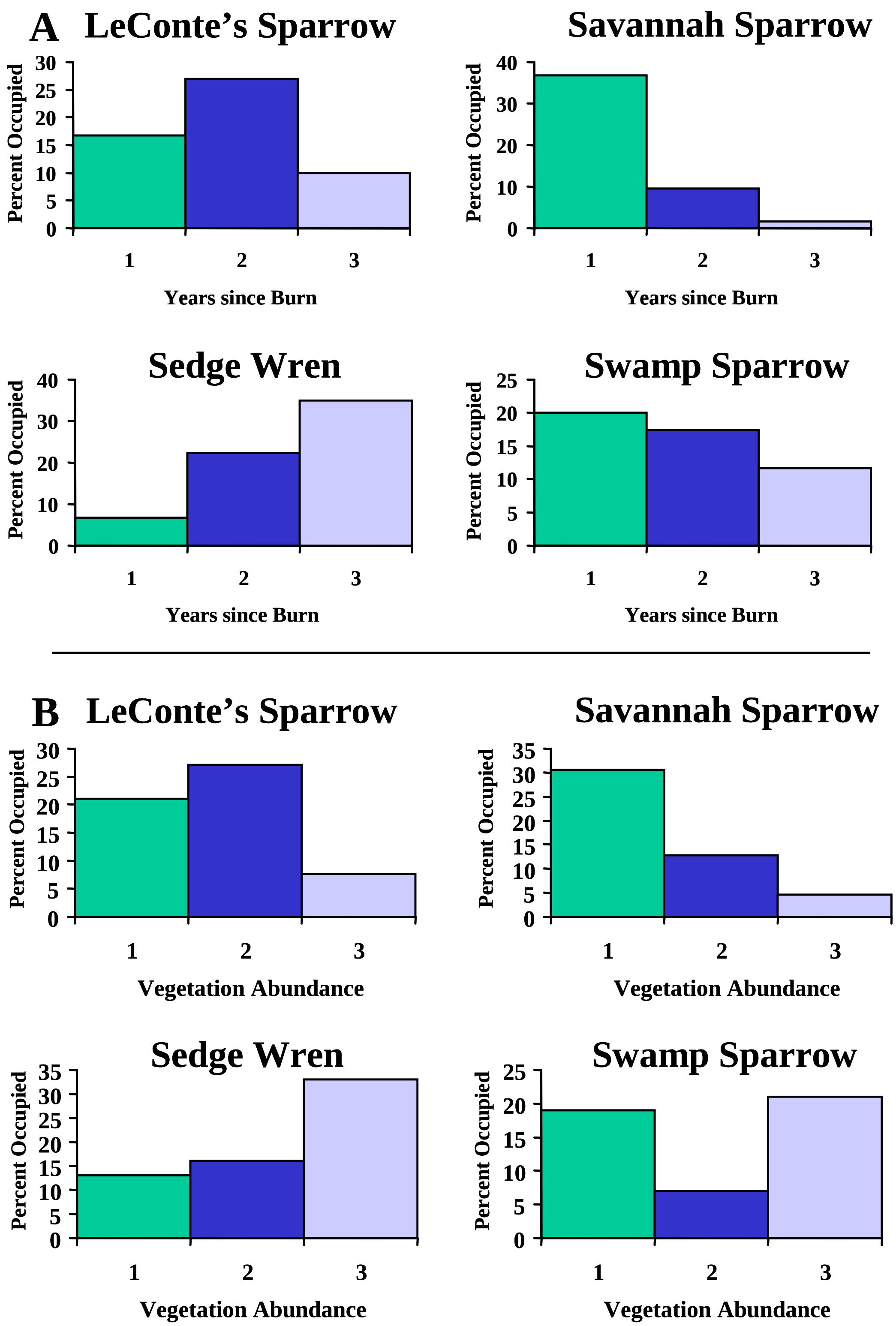

Figure 16. Frequency of occurrences of birds under different conditions. Each bar represents the percent of sites with the specified condition (years since burn or vegetation abundance) that were observed to be occupied by a species of bird.

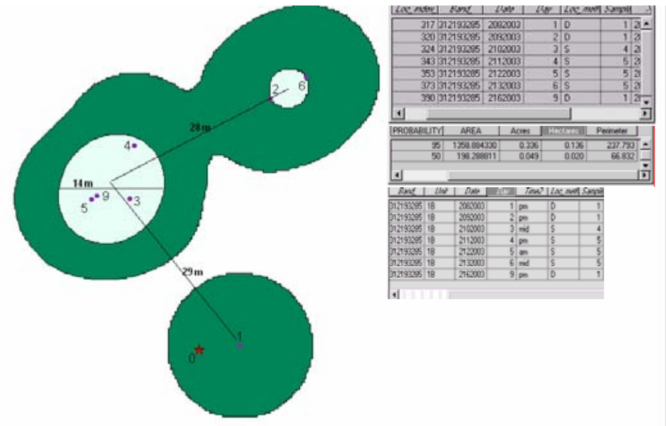

Figure 17. Representation of movements of individual LeConte's sparrow tracked using a radio transmitter.

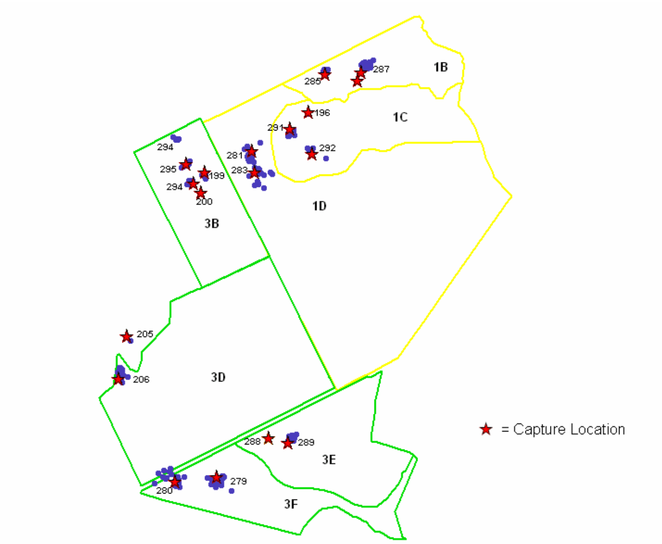

Figure 18. Representation of movements of various LeConte's sparrows tracked using a radio transmitter. Red stars represent capture locations while blue dots represent subsequent locations. Outlines represent different management units.

Yellow Rails

Rail Morphology

Morphological characteristic data were collected on rallids wintering at the Texas Mid-Coast NWR Complex (TMC) during the winters of 2002-03 and 2003-04. Body weight, wing cord, culmen, tarsus, and tail lengths were measured on 5 species of rails that included yellow rail (n = 86), black rail (n = 10), sora (n = 9), Virginia rail (n = 6), and clapper rail (n = 1) (table 1). An increased banding effort resulted in a significant increase in the number of rails processed from 35 in 2002-03 to 77 in 2003-04.

Differences in some morphological traits were discovered between yellow rails at TMC and those reported by Bookhout (1995). The average weight reported by Bookhout was greater than at BNWRC. A majority of yellow rails reported by Bookhout (1995) were males, which could explain the difference between average weights because Bookhout (1995) reported that males are generally 12% heavier than females. Sex is indistinguishable on wintering ground because of similarities in plumage, but a few yellow rails were sexed at the end of April by the presence of a cloacal protuberance (CP) on the females. A CP was not present on any other birds earlier in the winter.

Wintering Site Fidelity

Banding efforts so far have revealed that some rails have wintering site fidelity (table 2). Four yellow rails were banded and recaptured within the same year and same site. In addition, a Virginia rail was recaptured the following year at the same site, calidating that site fidelity does occur in that species.

Preliminary results from band recoveries show that yellow rails exhibit wintering site fidelity within the same year. A more intensive banding program is needed to determine if site fidelity exists between years. Banding will continue during the winter of 2004-05 in an effort to fill this information void.

Yellow Rail Home Range

The average home range and number of locations of 16 individuals was determined to be 1.16 ha and 16.9 respectively in 2002-03 and 2003-04 (table 3). Home range overlap and longest distance moved in successive days have not yet been analyzed and are not included in this report.

Average home range size of yellow rails (ξ = 1.16 ha) was less than reported by Mizell (1998) (ξ = 1.70 ha). This difference is probably a result of different home range analysis programs, radio-telemetry errors, and habitat differences. In addition, yellow rails are reported to be gregarious on breeding (Terril, 1943; Bart and others, 1984) and wintering grounds (Mizell, 1998). Evidence from trapping and radio telemetry at TMC supported this behavior because concentrations of yellow rails were found during trapping sessions. Whether yellow rails are sociable in winter or whether these concentrations are a function of habitat is still debatable and further research is required. Unlike other species of rails, yellow rails are silent during winter and their habitat is very dense, so we hypothesize that the latter is probably the case.

Yellow Rail Habitat

Habitat characteristics were measured at 269 independent locations taken on 16 yellow rails during

2002-03 (n = 141) and 2003-04 (n = 129). Analysis of plant species occurring in yellow rail habitat revealed that the species with the highest frequency (table 4) was saltgrass in both years. gulf cordgrass had the highest cover class rating (table 5) and leafy three-square (*Schoenoplectus robustus*) was the tallest plant species (table 6) in both years. Differences were found in total-plant cover, total-plant height, dead-plant depth, dead-plant cover, and water depth (table 7) between study years. In general, vegetation was more robust in 2003-04, and all measurements were larger in the second year.

Yellow rails appeared to be associated with a wide range of habitat characteristics in winter. Based on radio-telemetry data, dense vegetative cover associated with relatively low plant height was the most constant factor encountered at all yellow rail locations. Other factors, such as water depth and food availability may be supporting factors in yellow rail habitat association.

Mizell (1998) reported that yellow rails were associated with a narrow range of standing water depth, which was the most important determinant of their habitat. However, standing water was only found in 41% of the locations where they were found. Radio-telemetry data revealed that after an area dried, yellow rails did not move to a new location. Therefore, we hypothesize that other factors, including food availability, may be more important than standing water depth in describing yellow rail habitat. Yellow rails consume a wide variety of food items (Robert and Laport, 1997) and, thus, may have the ability to change diet when water dries.

Vegetative habitat characteristics associated with yellowrRail use were consistent between years. Saltgrass was the most frequently encountered species. Gulf cordgrass provided the most cover, while leafy three-square was the tallest. Additionally, in 2003-04, jointgrass was heavily used by yellow rails.

Direct Mortality by Prescribed Fire

There was no direct mortality on rails observed during prescribed burns. Radio transmitters were glued to the backs of 5 rails (3 yellow rails, 1 Virginia rail, and 1 sora) and tracked before and after a prescribed burn at Brazoria NWR on February 17, 2004. One yellow rail was not found the day after the burn and was assumed to have left the area. Another yellow rail was found alive the next day in unburned fringe habitat, but the signal was lost on the 2nd day. The third yellow rail was tracked for 4 days after the burn until the transmitter fell off. The Virginia rail was tracked for 3 days after the burn until its transmitter fell off. Finally, the sora was tracked for 4 days after the burn until the signal was lost. The sora was located in the middle of the burned area the day after the fire under a clump of burned gulf cordgrass.

Seven rails (4 yellow rails, 2 black rails, 1 sora) were radio tagged and tracked after a prescribed burn at San Bernard NWR on March 6, 2004. All but one of the transmitters fell off the birds during or shortly after the burn and were recovered the next day. The sora for which the transmitter did not fall off was tracked for 6 days after the burn until its transmitter fell off.

Transmitter attachment problems prevented rail mortality data from being obtained during prescribed burns. The transmitters were glued to the backs of rails a few days before a prescribed burn. Many transmitters fell off of the rails sometime during or immediately following the fire. There was no evidence of mortality (feathers, carcass, hard body parts) near the areas of the fallen transmitters, so it was assumed that the rails were still alive when the transmitters fell off. Additionally, most of the fallen transmitters were found in burned habitat. Two speculations are offered as to why the transmitters did not stay attached to the birds: (1) the transmitters became snagged on vegetation as the rails were fleeing from the fire or (2) the heat of the fire broke the bond of the glue. Therefore, we recommend using a harness attachment for radio transmitters in future studies with rails and prescribed fire.

Evidence of rail survival during prescribed burns was documented by radio-telemetry data. One sora was found alive under a clump of burned gulf cordgrass, and several yellow rails were relocated in nearby unburned habitat the day after the prescribed burn. These rails abandoned the area between 1 and 4 days later, apparently because of unsuitable habitat conditions. A Virginia rail was observed popping out of the ashes by one of the crew members just after the fire moved over the area. The rail was captured, inspected, and released with no apparent injuries.

We believe that the rails that are unable to escape the fire managed to survive by burying themselves underneath dead, damp vegetation beneath clumps of cordgrass. The presence of standing water could aid in the survival of rails during prescribed burns. Managers conducting winter prescribed burns in rail habitat should burn early in the winter when water is still present. Waiting until late winter when the growing season has already started and after the water has dried up, could result in higher rail mortality.

Although no direct mortality from prescribed fire was discovered with rails, evidence of indirect mortality from predation was found. Prescribed fire temporarily reduces cover and exposes rails to increased predation. Raptors were attracted to the fires and were observed pursuing prey fleeing from the fire. Fresh remains of a yellow rail and a Virginia rail were found on the levee adjacent to the burn. Many species of rails were observed using the tall strips of unburned vegetation along the ditch between the levee and the burn. We suspect that these areas are vital to the short-term survival of rails because they provide cover from predators and refuge from fire.

Table 1. Morphological measurements of rail species on the Texas Mid-coast National Wildlife Refuge Complex during the winters of 2002-03 and 2003-04. YEAR = yellow rail; BLRA = black rail; VIRA = Virginia rail; and CLRA = clapper rain. ξ = mean; SD= standard deviation.

Morphological measurements	YERA (n = 86) ξ ± SD	BLRA (n = 10) ξ ± SD	SORA (n = 9) ξ ± SD	VIRA (n = 6) ξ ± SD	CLRA (n = 1)
Body weight (g)	50.7 ± 7.6	37.4 ± 4.8	74.8 ± 17.7	77.8 ± 15.5	295
Wing cord (mm)	84.4 ± 3.7	75.4 ± 2.1	103.2 ± 2.9	99.8 ± 4.3	159
Culmen (mm)	12.9 ± 1.0	13.7 ± 1.5	19.1 ± 1.1	35.7 ± 2.6	61
Tarsus (mm)	24.1 ± 1.6	23.6 ± 1.5	32.4 ± 2.7	33.2 ± 2.6	53
Tail (mm)	33.2 ± 2.5	34.8 ± 1.9	48.1 ± 2.3	41.3 ± 4.8	68

Table 2. Wintering site fidelity of rails on Texas Mid-coast National Wildlife Refuge Complex during the winters of 2002-03 and 2003-04 using a system of classification by Robert and LaPorte (1999), where "repeats" = same site, same year; "returns" = same site, different year; "displacements" = same year, different site; and "recoveries" = different year, different site. YEAR = yellow rails; VIRA = Virginia rail.

Species	Banding date	Recapture date	Classification system
YERA	01/25/03	02/12/03	Repeat
YERA	01/25/03	04/05/03	Repeat
YERA	02/12/03	03/34/03	Repeat
YERA	03/22/04	04/14/04	Repeat
VIRA	01/28/03	2/15/04	Return

Table 3. Results of yellow rail (YERA) radio telemetry locations at the Texas Mid-coast National Wildlife Refuge Complex and analysis of home ranges (mean = 1.16 ha) during the winters of 2002-03 and 2003-04.

YERA ID no.	Transmitter frequency	No. of locations	Home range in ha
SL3	166.094	8	0.99
SL4	166.343	22	0.77
SL6	166.177	23	1.29
SL7	166.740	19	1.11
SL8	166.169	19	0.07
SL9	166.329	19	0.97
SL10	166.281	7	0.66
SL12	166.593	16	0.91
SL13	166.714	8	0.87
SL21	166.714	7	0.96
CR22	166.653	16	0.50
CR25	166.614	18	2.21
CR26	166.740	18	0.88
HR23	166.631	22	3.86
HR27	166.302	24	1.07
MP24	166.454	24	1.47

Table 4. Plant-species relative frequency (*rf*) and frequency (*f*) for yellow rail habitat association at the Texas Mid-coast NWR Complex during the winters of 2002-03 (n = 141) and 2003-04 (n = 128), where *rf* = [(frequency value for a species)/(total frequency values for all species)] X 100 and *f* = (number of plots species occur)/ *n*(total number of plots sampled).

Plant species	2002-03 frequencies		2003-04 frequencies	
	rf	*f*	*rf*	*f*
Saltgrass	30.5	74.5	28.4	58.6
Gulf cordgrass	28.2	68.8	21.6	44.5
Annual glasswort	28.2	68.8	0.05	0.1
Saltwort	28.2	68.8	0.4	0.8
Marshhay cordgrass	7.2	17.7	19.3	39.8
Sea ox-eye daisy	2.3	5.7	0.4	0.8
Leafy three-square	0.6	1.4	2.7	5.5
Smooth cordgrass	0.1	0.7	0.0	0.0
Jointgrass	0.0	0.0	17.1	35.2
Olney three-square	0.0	0.0	9.8	20.3
Unknown	0.0	0.0	0.4	0.8

Cordgrass (ξ = 5.5 ± 1.8; ξ = 6.7 ± 1.1) had the highest cover class rating (table 5) and leafy three-square (ξ = 95.8 ± 4.9; ξ = 113.9 ± 28.0) was the tallest plant species (table 6) in both years. Differences were found in total-plant cover, total-plant height, dead-plant depth, dead-plant cover, and water depth (table 7) between study years. All habitat characteristics were greater in 2003-04 than in 2002-03.

Table 5. Plant species cover class and standard deviation (SD) associated with yellow rails at the Texas Mid-coast NWR Complex during the winters of 2002-03 and 2003-04, where 1 = 0–1%, 2 = 1–5%, 3 = 5–10%, 4 = 10–25%, 5 = 25–50%, 6 = 50-75%, 7 = 75-100% represent each cover class.

Plant species	Year			
	2002-03		2003-04	
	ξ	SD	ξ	SD
Saltgrass	3.4	2.2	5.6	1.6
Gulf cordgrass	5.5	1.8	6.7	1.1
Annual glasswort	2.9	1.8	4.0	0.0
Saltwort	1.8	1.2	2.8	1.1
Marshhay cordgrass	3.7	2.4	6.1	1.3
Sea ox-eye daisy	3.1	2.2	6.0	0.0
Leafy three-square	3.5	0.7	2.7	2.2
Smooth cordgrass	4.0	0.0	0.0	0.0
Jointgrass	0.0	0.0	6.4	1.0
Olney three-square	0.0	0.0	3.8	1.8
Unknown	0.0	0.0	2.0	0.0

Table 6. Plant species height and standard deviation (SD) associated with yellow rails at the Texas Mid-coast National Wildlife Refuge Complex during the winters of 2002-03 (n = 432) and 2003-04 (n = 275).

Plant species	Year			
	2002-03		2003-04	
	ξ	SD	ξ	SD
Saltgrass	45.6	10.2	57.5	8.7
Gulf cordgrass	56.7	10.4	68.7	12.0
Annual glasswort	39.7	7.8	49.5	9.0
Saltwort	35.4	10.0	43.2	7.8
Marshhay cordgrass	59.5	13.6	81.6	12.3
Sea ox-eye daisy	54.1	16.4	64.5	0.0
Leafy three-square	95.8	4.9	113.9	28.0
Smooth cordgrass	88.1	0.0	0.0	0.0
Jointgrass	0.0	0.0	47.7	6.9
Olney three-square	0.0	0.0	96.5	19
Unknown	0.0	0.0	34.0	0.0

Table 7. Average habitat characteristics associated with 269 yellow rail radio-telemetry locations at the Texas Mid-coast NWR Complex during the winters of 2002-03 (n = 141) and 2003-04 (n = 128). Cover classes are represented by the following values; 1 = 0–1%, 2 = 1–5%, 3 = 5–10%, 4 = 10–25%, 5 = 25–50%, 6 = 50-75%, 7 = 75-100%.

Habitat characteristics	Year			
	2002-03		2003-04	
	ξ	SD	ξ	SD
Total plant cover (cover class)	6.7	0.9	7	0
Total plant height (cm)	45.8	13.7	66.8	20.7
Dead plant depth (cm)	1.0	1.3	1.5	2.1
Dead plant cover (cover class)	3.9	2.9	5.8	1.7
Water depth (cm)	1.0	1.4	1.7	3.1

Conclusions

Our historical analysis supports the often-made presumption that the coastal prairie was characterized by luxuriant stands of grasses. No records of eastern baccharis, the dominant shrub species along the Gulf of Mexico coast, were reported by early botanical explorers in this region. Based on this, we conclude that if the goal is to manage so as to preserve historic features of the natural landscape, efforts to reduce baccharis levels are justified. While there is no fixed density of baccharis that can as yet be established as a set target, the goal of maintaining an open grassland with scattered shrubs seems appropriate based on what is known at present.

The results of this study indicate the need for two emphases in order to reduce baccharis densities (1) repeated growing-season burns and (2) annual monitoring of baccharis densities. It is clear that the burn program at the TMC has caused an overall reduction in woody cover for targeted areas. At the same time, it is also clear that success is not consistent and that efforts are not always rewarded with positive results. A continuation of the recent focus on growing season burns for prairie habitat would seem advisable given their greater probability for success. However, repeated applications of fire may be required for areas with high densities of shrubs if those densities are to be reduced substantially. Given the probablistic nature of fire responses, it is the occassional fire that has a substantial impact on baccharis densities; therefore, it is highly recommended that regular monitoring of baccharis densities be used to determine when further burning is needed and when density reductions have been achieved. Once densities are reduced to the point that prairies have a predominantly grassy character, less frequent burning should be sufficient and winter burns may be more appropriate.

The continuous invasion of prairie habitat by Chinese tallow trees poses a severe problem for the management of the TMC. In the absence of burning, colonization and canopy development are rapid, suggesting that vigilance is required to avoid resorting to intensive chemical applications. Again, we would recommend monitoring as a means of assessing whether burning is keeping Chinese tallow in check or whether it is continuing to expand.

It was our finding that prairie grassland birds varied in their preference for areas based on the number of years since they were burned. LeConte's sparrows were found to be less common in prairies burned more than two years previously and appeared to prefer sites burned within the last two years. Other important species, such as sedge wrens were most common in prairies burned more than 2 years previously, while savannah sparrows were most closely associated with prairies burned within the past year. We conclude from these results that a mosaic of successional habitats is needed to maintain a diversity of grassland birds in this habitat. We also note, however, that the effects of burning on bird preferences can be explained by associated vegetation conditions. Thus, variations in regrowth rates for vegetation should be taken into account when setting either greater or lower burn frequencies for particular locations.

Despite the fact that we did not observe direct mortality of rails during burns in this study, we recommend caution be taken to avoid trapping birds during such burn operations. There is particular concern about ignition methods that do not provide birds with escape routes, such as ring fires.

Acknowledgments

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Appendix 1. List of study sites at the Texas Mid-coast National Wildlife Refuge Complex. WBB = wood plant leaves browned or blackened; WC = woody plant leaves consumed; FC = fuel consumed; ScHt = scorch height.

Site	Unit	Date Burned	Date Assessed	Date Measured	Percent Burned	Percent WBB	Percent WC	Percent FC	ScHt min	ScHt max	Burn Index
3	Alligator	7/12/2001	7/17/01	11/27/01	100	100	100	100	90	116	100
4	Alligator	7/12/2001	7/17/01	11/27/01	100	100	20	99	9	162	80
6	Alligator	7/12/2001	7/17/01	11/27/01	100	100	99	100	105	205	100
7	Blue Stem Central	6/12/2003	4/02/03	03/11/04	na	na	na	na	na	na	na
8	Blue Stem East	2/18/2003	2/18/03	04/02/03	100	100	99	95	50.5	50.5	98
14	Chocolate	8/3/2002	1/27/03	04/01/03	100	100	100	100	35	169	100
15	Chocolate	8/3/2002	1/27/03	04/01/03	100	100	100	100	35	169	100
16	Wharton East	8/3/2002	8/08/02	04/01/03	100	100	100	100	85	162	100
17	Wharton East	8/3/2002	8/23/01	04/01/03	100	100	100	100	85	162	100
18	Wharton East	8/3/2002	8/23/01	04/01/03	na	na	na	na	na	na	na
20	Triangle WB#1	12/3/2002	7/10/01	04/01/03	na	na	na	na	na	na	na
25	Rice East	8/4/2001	8/21/01	12/04/01	100	100	67	99	40	200	92
26	Bermuda Triangle	7/10/2001	7/12/01	12/04/01	97	100	75	95	50	180	92
27	Wharton West	8/3/2002	8/21/01	04/01/03	na	na	na	na	na	na	na
29	Bluestem	7/6/2001	7/09/01	12/06/01	100	99	na	65	0	70	66
30	Bluestem	7/6/2001	7/09/01	12/06/01	95	100	na	98	50	170	73
32	Big Slough North	7/19/2001	8/02/01	12/04/01	99	100	50	90	60	246	85
34	Olney North	3/27/2002	7/04/01	04/21/02	99	99	95	99	70	164	98
35	Olney South	3/27/2002	7/04/01	04/21/02	100	100	99	100	183	183	100
36	Cedar Lake	7/17/2001	7/18/01	12/05/01	95	99	10	75	25	150	70
37	Cedar Lake	7/17/2001	7/18/01	12/05/01	97	100	50	75	33	223	80
38	Long Pond	7/11/2001	7/16/01	11/26/01	100	100	90	100	80	170	98
39	Show Pasture	9/25/2001	7/09/01	12/04/01	95	100	5	90	94	276	72
40	Show Pasture	9/25/2001	7/09/01	12/04/01	85	90	25	85	49	190	71
43	Fire Hall	2/14/2002	7/11/01	04/21/02	35	20	10	35	0	100	25
44	Below Rail Pond	7/18/2001	7/19/01	12/05/01	100	100	99	100	148	229	100
45	Below Rail Pond	7/18/2001	7/19/01	12/05/01	92	100	75	97	15	163	91
46	Otter Slough West	9/27/2001	7/16/01	11/26/01	100	100	100	98	0	165	99
47	Long Pond	7/11/2001	7/16/01	11/26/01	100	99	98	100	225	255	99
48	Long Pond	7/11/2001	7/16/01	11/26/01	100	100	20	100	30	200	80
49	Otter Slough East	9/27/2001	7/19/01	04/04/03	na	na	na	na	na	na	na
50	Show Pasture Test	8/3/2001	8/21/01	12/05/01	90	98	10	80	30	130	69
51	Otter Slough	9/27/2001	9/27/01	11/26/01	99	100	95	98	70	200	98
52	Cockleburr Slough	9/26/2001	10/10/01	12/05/01	99	100	65	99	85	185	91
53	2004 Otter Slough	2/4/2002	2/25/02	04/21/02	100	100	99	100	130	190	100
56	Bull Pasture	4/20/2002	1/09/02	07/17/02	95	80	55	95	0	167	81
57	Teal Pond	3/27/2002	1/09/02	04/21/02	100	100	75	100	15	143	93
59	River Bend	2/27/2002	1/29/02	04/20/02	100	100	98	100	10	110	99
60	Fire Hall	2/14/2002	4/21/02	07/15/02	100	100	100	95	120	170	99
61	Austin South	6/21/2003	4/04/03	03/11/04	na	na	na	na	na	na	na
62	Wolfweed	8/3/2002	7/17/02	04/17/03	na	na	na	na	na	na	na
63	Blue Stem East	1/21/2003	1/28/03	04/02/03	100	100	75	85	0	141	90
64	Wharton	8/3/2002	1/27/03	04/01/03	100	100	100	100	85	162	100
66	McNeil	12/3/2002	12/09/02	06/09/03	na	na	na	na	na	na	na
67	Canvasback 1	6/3/2003	6/09/03	03/11/04	na	na	na	na	na	na	na
68	Canvasback 2	6/3/2003	6/09/03	03/11/04	na	na	na	na	na	na	na