HISPID COTTON RAT (SIGMODON HISPIDUS) POPULATION AND BEHAVIORAL RESPONSES TO PRESCRIBED FIRE IN MAITIME GRASSLANDS

by

JOSEPH E. COLBERT III

(Under the Direction of KIMBERLY M. ANDREWS)

ABSTRACT

Maritime grasslands are a rare and declining habitat that has received little study, and to date, how prescribed fire impacts the wildlife community is unknown. Following a prescribed burn, I monitored cotton rats (*Sigmodon hispidus*) bi-monthly over the course of a year using game cameras, and during the summer and winter using live trapping. During summer, biomass did not differ, but in the winter biomass was reduced in burned plots. Camera visitation trends reflected live trapping population estimates, and camera cohort detection ratios were comparable to detection probabilities. According to cameras, survival was comparable between treatments. These results indicate that populations in burn plots were not different in the winter, but may have experienced reduced biomass likely due to sub-lethal behavioral effects resulting from the loss of ground cover following the prescribed burn. Cameras were an effective tool, capable of collecting more data efficiently compared to live trapping.

INDEX WORDS: Cotton rat, *Sigmodon hispidus*, small mammal, camera study, prescribed fire, maritime grasslands, gulf hairawn muhly, *Muhlenbergia sericea*, survival, population, activity, predation risk, temporal dynamics, beach dunes, barrier island

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DEDICATION

To the *Homo sapiens*: May we resort to and believe in academic-based research to make the best decisions rather than being motivated by the almighty dollar bill. Also, may we use our short merry lives to do something meaningful and be protective of our future generations who are to inherit our Mother Earth.

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From my field site, Little Saint Simons Island (LSSI), I can’t thank the members of the ecological management team enough for providing me the many resources necessary to achieve such a demanding study. Scott Coleman taught me great deal over the course of our study, and was a tremendous help with plant identification, and Lauren Gingerella was always there for my

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INTRODUCTION

Maritime Grasslands

Maritime grasslands are found in four states along the Atlantic coast, North Carolina, South Carolina, Georgia, and Florida. Maritime grasslands are a coastal habitat type, typically found on barrier islands within <1m above sea level. They are an early successional habitat type found in secondary and tertiary dunes with high and low ridges. Maritime grasslands go by many designations: maritime wet grasslands, muhly meadows, muhly prairies, and Southern Atlantic interdunal swales (Porter 1967, Barret et al 1986, www.natureserve.org accessed 2016). These grasslands are classified by a dominance of gulf hairawn muhly (*Muhlenbergia sericea*, formerly known as *Muhlenbergia capillaris var. filipes)*, other graminoids and shrubs, and a small amount of emergent trees. Maritime grasslands are maintained through periodic flooding events from heavy rains where the water table is close to the surface, saltwater spray or spillover, and fires.

Because of their endemic nature along the coast, reduction in range, and sensitivity to threats, maritime grasslands are a G2 globally imperiled community (www.natureserve.org accessed 2016). As a result, maritime grasslands should be prioritized for maintenance, enhancement, and restoration where they still exist. Maritime grasslands are threatened by several anthropogenic activities. Development and private ownership have led to destruction and degradation of natural maritime grassland habitats. In addition to development, the coast is popular for a number of human activities ranging from tourism to agriculture, which increases fragmentation, reduces biodiversity, and places an immeasurable amount of pressure on endemics especially with human population increases (Lithgow et al. 2013). Invasive species have also placed a burden on coastal barrier island dune habitats and can facilitate the removal of natives through displacement and competition (e.g. Oldfield and Evans 2016).

Maritime grasslands are a highly dynamic wetland habitat type. Beyond direct removal and altering disturbance regimes, altered hydrology has also diminished abundance of these habitats. Further withdrawing water from the water table for residential use on a small scale can prevent seasonal flooding (Noss 2013). These grasslands are also among the first habitats to establish in succession as dunes grow from accretion. As islands accrete when sediment is deposited, maritime grasslands are the next habitat in succession to take over tertiary dunes following salt tolerant communities in the primary and secondary dunes (see also Thompson and Thomas 2013). On a large scale, altered hydrology in the form of dams and dredging has prevented the flow of sediments downstream and resulted in less accretion and more erosion along the coast, which reduces the range and span of maritime grasslands. Finally, if climate change is unabated, sea level rise could overwhelm these habitats and transition them into marsh, eliminating them altogether.

Muhly grass, the dominant vegetation found in maritime grasslands, carries cultural significance to Gullah and Geechee peoples of the southeast Atlantic coast as muhly grass, or "sweet grass" is one of the main items necessary to construct handmade baskets that have cultural connections to African slave communities that were established in the southeast (Hart et al. 2004). In recent decades, these communities have brought attention to the reduction of muhly, limited access due to private ownership, and the fact that now they are required to purchase the grass, which results in price increases on their homemade baskets. The Gullah claim to be able to distinguish between cultivated varieties and wild-grown muhly which is preferred for basket making due to its quality, which lends concern for mixing wild genotypes with cultivars (Grabbatin 2012). With the reduction of muhly comes the loss of cultural practice and supplemental income for the Gullah and Geechee peoples.

Fire has been used to reduce fuel loads in maritime grasslands. Interviewed Gullah and Geechee peoples have revealed that the use of fire in these habitats and Florida Panther National Wildlife Refuge (Barret 1986, Main and Barry 2002, Slocum et al. 2003). Of interest, they recommend burning no less than every three years as fires after one year hardly ignited, and fires after two years carried poorly and burned patchily. It took two years for living biomass to reach preburn levels and three years for dead above-ground fuels to reach equilibrium. Fuel carrying capacity was not strongly affected by soil depth, but did increase significantly in patches found in low points that had long hydroperiods. They suggest that long hydroperiods likely allow for blue-green algae growth, increasing soil nitrogen, therefore increasing above-ground biomass. It is also suggested that muhly flowers poorly with clipping, winter season burns, and with no burn at all, but flowered the best with early growing season fires. While vegetation response to prescribed fire in maritime grasslands are described, no study to date describes wildlife response.

Hispid Cotton Rat Natural History

Hispid cotton rats (*Sigmodon hispidus*; hereafter, cotton rat) are generalist herbivores that show some vegetation preferences for monocots, but they generally eat available vegetation (Fleherty and Olsen 1969) and have also been documented eating small vertebrates such as insects and crabs (Whitaker and Hamilton 1997). Weights and size vary with locality of populations and season, but average weight of adults are between 49-143 grams. However, weights exceeding 200 grams have been reported during warm weather and when food resources are plentiful (Meyer and Meyer 1944, Goertz 1965a). In Kansas, cotton rat densities were related to the amount of vegetation clipped as a result of herbivory, as cotton rats forage at the base of vegetation resulting in leftover clippings. Individuals may clip up to 1.3 kilograms per month during autumn peaks (Petryszyn and Fleherty 1972). The impacts of primary production removal in the form of cotton rat clippings is a subject of little study. Future research could provide some interesting insight on the microhabitat implications of grass litter, the significance to vegetation in terms of growth stimulation, and any additional ecological services that clipped vegetation provides such as nesting material for cotton rats or even birds.

Nests for cotton rats exhibit some importance. Only one study examined cotton rat nest significance in terms of differences in populations and environmental conditions and found that nests were constructed to meet the needs of the cotton rats based on their environment and location (Shrump 1978). Importantly, nests served as a mechanism to survive winters in Florida and Kansas, so it is assumed that fat alone is not enough for this species to survive cold conditions even in the most temperate areas. Something that is unclear, are the consequences disturbance such as fire or flood may have on nest construction.

Cotton rats are associated with old-field grassland habitats (www.natureserve.org accessed 2016). Numerous studies refer to cover density of grassland vegetation as an important factor of their survival due to reduction of predation risk (Schnell et al. 1968, Cameron et al. 2009), which can be extremely pronounced following controlled burns which reduces cover density completely and decreases cotton rat abundances significantly (Layne 1974, Kirchner et al. 2011, Connor et al. 2011, and Morris et al. 2012). Some small mammal species have been shown to benefit greatly from prescribed fire (see Masters et al. 1998), but cotton rat response to prescribed fire involves an immediate, yet temporary population decline, mostly as a result of predation followed by a small amount of emigration (Connor et al. 2011, and Morris et al. 2012). Using radio-telemetry to follow a cohort before and following a burn, Morris (2011) found that most individuals died from predation, due to the loss of vegetation cover and increased exposure to avian predators. As vegetation recovered so did cotton rat populations.

Even without disturbances, cotton rats typically demonstrate seasonal population fluctuations that peak in autumn and are subject to inter-annual variation (Odum 1955, Goertz 1965a, Mabry et al. 2003, Brady and Slade 2004, Cameron et al. 2009). In addition to population fluctuations, the hispid cotton rat is the sole member of its genus to expand to temperate regions found in the United States, and as a result can experience local population extinctions and reduced fitness on the periphery of their range where colder winters occur (Clark et al. 2003, Bergstrom and Rose 2004, Green and Rose 2009, Reed and Slade 2010, Wright et al. 2010).

Densities of cotton rats have typically been reported in “minimum known alive per unit area” (see methods of Krebs 1966). In oldfield prairie habitat, populations trapped in a 2.25 ha grid ranged from 20 in winter and up to 200 during autumn peaks in productive years over the course of a 20-year study (Brady and Slade 2004). In similar habitat, reported densities in an Oklahoma population ranged from 1.2-112.5 per ha depending on season and year (Clark et al. 2003). In another Oklahoma population, plots that were supplementally fed had densities upwards of a 100 per ha, while in control plots, densities maxed out at 39.5 per ha (Doonan and Slade 1995), stressing the importance of food resources in regulating density. Doonan and Slade (1995) noticed that cotton rats that had increased food resources through supplemental feeding had higher recruitment (individuals >60g), but increased recruitment failed to reduce winter mortality or increase the amount of large adults. This indicates that food is a limiting resource but increasing it does not improve cotton rat ability to survive in cold winters. This study also noted that supplemental feeding did not increase densities of large adults, and that large adult densities may be governed by some degree of social territoriality (see Cameron 1995). No studies reporting densities used spatially explicit population models. Without knowing how much space individuals in a population use, density estimates are generally inflated (see Krebs et al. 2011). Additionally, supplemental feeding has been known to increase densities (Doonan and Slade 1995), but it is not known whether long-term monthly trapping can positively augment populations with an easy meal and refuge from predation, which could also lead to inflated density estimates.

One population in a coastal environment has been studied. In the Texas Gulf region, a coastal prairie population of cotton rats was compared to a cordgrass community (Cameron et al. 2009). Results indicated that high marsh cordgrass (*Spartina spp.*) had higher densities at 12-20 per ha compared to 0.5-3.0 per ha in coastal prairie grassland habitat. This study stressed the importance of both communities as the individuals found in cordgrass were suggested to be transients that visited from other habitats and individuals found in the coastal prairies were residents which indicates that cotton rats may have restrictions on habitats that meet all of their needs versus ones that provide some degree of forage.

Reproduction of cotton rats varies across their range, and depends largely on environmental conditions and densities present at the time of reproduction (Doonan and Slade 1995, Bergstrom and Rose 2004, Reed and Slade 2008 and 2010, Wright et al. 2010). Cotton rats have a gestation period of 27 days, producing average litters of 5-7 (range 1-15), and it takes 2-3 months to reach sexual maturity (www.natureserve.org accessed 2016). It has been suggested that cotton rats can reproduce year-round under the right conditions (Goertz 1965b). On the northern periphery of their range, in Nebraska, cotton rats have been observed pregnant from

April to October, and females were non-reproductive from November to January (Wright et al. 2010). In a comparison between a Virginia and Georgia population, it was discovered that the proportion of reproductive adults was higher in Georgia but pregnant females were larger and had larger litter sizes in Virginia (Bergstrom and Rose 2004). The Georgia population exhibited at least a small amount of reproductive activity year-round when Virginia populations were reproductively inactive. The authors credit reduced average litter sizes to reabsorption of fetuses during pregnancy in the cooler months. Cotton rats are known to have a higher portion of pregnant females when densities are highest, but fecundity and recruitment are negatively affected by high densities (Reed and Slade 2008).

Cotton rats are known to be active at all times of day, and are thought to be crepuscular (Hall et al. 1981, Whitaker and Hamilton 1997). Laboratory experiments have led to mixed conclusions on cotton rat activity (Calhoun 1945, Kilduff and Dube 1979, Johnson and Zucker 1983), and studies of different populations have produced reports of different activity patterns that may reflect ecological conditions unique to each study site (see Calhoun 1945, Goertz 1964). Temperature and extreme weather, such as snow and precipitation, has been shown to reduce cotton rat activity, particularly in winter (Stokes et al. 2001). Numerous studies note that populations decline in the winter (Odum 1955, Goertz 1965a, Clark et al. 2003, Mabry et al. 2003, Brady and Slade 2004, Cameron et al. 2009), but these studies only attribute declines in survival to cold weather without discussing how behavioral responses to cold weather result in reduced survival.

Small Mammal Temporal Dynamics

Evolutionarily, mammals began as nocturnal organisms, then diurnal activity evolved independently as a result of numerous non-photo stimuli (Kronfeld-Shor and Dayan 2008). Currently, many small mammal species exhibit a variety of behavioral adaptations and activity patterns in a broad spectrum of habitats ranging from diurnal in desert to nocturnal in wetlands (see Ilan and Yom-tov 1990, Blanchong and Shmale 2000, Skibla et al. 2007, Meek et al. 2012, Shebler et al. 2014). Small mammal behavior generally is associated with light, but social behavior, temperature, and predation can alter activity patterns (Barun et al. 2011, Montessero 2013, Skibla et al. 2014). Reasons for temporal shifts are difficult to detect in nature, likely due to the complication and influence of multiple factors (e.g. Kronfeld-Schor and Dayan 2003). While laboratory experiments with rodents have shown individual variation in activity distributions (see Kilduff and Dube 1979, Johnson and Zucker 1983), populations of small mammals in the wild have spatially and temporally distinct patterns (Abu Baker 2014). The most influential factors affecting temporal patterns likely vary among species.

Methods to detect temporal shifts include intensive live trapping, live trapping combined with timers, giving up densities, light loggers, PIT tag scanners, radio-telemetry, and recently, cameras. PIT tag scanners have been used to measure amount activity in rodents related to fluctuations in temperature and lunar light (Rehmeier et al. 2006, and Scheibler et al. 2014). Radio-telemetry and light loggers have also been used to determine that the importance of the role of even small temperature shifts for fossorial small mammals (Skibla et al. 2007, Williams et al. 2014). Using cameras to detect shifts of activity is a relatively new application and has proven effective in relating temperature to temporal shifts in activity (Montessero et al. 2013, Cid et al. 2015). In the past, labor intensive live trapping has been used to identify activity patterns, but this method loses precision by separating activity into broad time windows. More recently, live traps have been combined with timing sensors that record time of capture providing precision in time of capture (see Ferriera and Vieira 2016), but results in the removal of an individual that may have continued activity that goes undetected while it remains in a trap.

Predation risk can modify small mammal time of activity. For example, risk of predation from diurnal mongooses (*Herpestes javanicus*), on the Adriatic Islands in Croatia, has resulted in shifting a diurnal population of ship rats (*Rattus rattus*) into nocturnal activity based on species found on predator free islands and islands with predators (Barun et al. 2011). Even a nocturnal population of Norway rats (*Rattus norvegicus*) has transitioned into diurnal activity to avoid fox predation based on the use of predator-free enclosures in Britain (Fenn and MacDonald 1995). In South Carolina, using food placed in open and dense shrubby habitats, giving up densities were measured, and in open areas where the risk of predation was higher, cotton rats gave up more food than ones fed where dense microhabitat surrounded them, ultimately sacrificing food for safety (Hinkleman et al. 2012). Additionally, in Texas, cotton rats have also been shown to respond to warning calls by non-predatory birds, resulting in reduced foraging to seek safety (Felts and Schmidt 2010), demonstrating their propensity to respond to predation risks.

Temperature changes can also result in reduced activity or temporal activity shifts, that limit small mammal activity to preferred temperature ranges. This relationship was demonstrated with several small mammal species from high altitudes in the Andes placed in temperatures of lower altitudes resulting in significantly reduced activity windows and temporal distribution shifts (Sassi et al. 2015). Small mammals also may avoid high temperatures by dividing activity in bimodal peaks. Individuals degus (*Octogon degus*) that were supplementally fed in shade foraged more efficiently and unimodally versus bimodally in sunny areas (Barigalupe 2003). The authors did not address whether shade played a role in reducing predation risk. Lunar light can result in reduced or increased activity depending on the species and what kind of predatory pressures they face (see Upham and Hammer 2013, Scheibler et al. 2014).

The Use of Game Cameras to Monitor Small Mammals

The use of game cameras in small mammal research is still a relatively new application. Game camera technology has rapidly improved enough in reliability and affordability to employ in field research studies with small mammals. Increasingly, camera affordability has approached a price comparable to live traps, with even greater efficiency for certain research objectives, particularly in regards to personnel costs (De Bondi 2010). Thus far, many small mammal studies using cameras have sought to provide new methodologies (see De Bondi et al. 2010, Alistair et al. 2013, and McCleery et al. 2014). Cameras have proven to be particularly useful in studying small mammal species richness and occupancy (Castleberry et al. 2014), especially where some species are difficult to trap (De Bondi 2010. Cameras have demonstrated great value in small mammal research for behavioral studies, and while lacking so far, have shown potential for use in population studies.

Using cameras to study small mammal behavior has gained recognition and surpassed many of the capabilities of live trapping in the past few years. Previously, the vast majority of behavioral studies with small mammals occurred in laboratory settings. In the field, some small mammal behavioral research has taken place by assessing giving up densities, using PIT tag sensors, or through labor intensive trapping efforts that require checking traps multiple times of day and night. Information from camera monitoring has been used readily with little effort to report small mammal behaviors with greater reliability than most other techniques available. For small mammal studies, cameras have a superior ability to determine activity times, shifts, peaks, and distributions (Meek et al. 2012, Montessero et al. 2013, Sunyer et al 2013, Cid et al. 2015), in addition to time partitioning between species or groups, giving up densities along with time spent foraging, and specific activities such as contribution to pollination (see Zoeller et al. 2016). Cameras outperform using timers on traps (see methods of Ferrierra and Viera 2016) to determine activity times because they do not result in the removal of an individual that may remain active, or observe additional peaks of later activity prior to release. Cameras also could save money on studies that have high costs associated with PIT tag scanner studies of rodents that enter and exit burrows (see methods of Rehmeier et al. 2006). Alternatively, cameras focused on bait stations or burrows could be paired with PIT tag scanners for demographic data associated with behavior. Cameras can be deployed for extended periods of time with little effort compared to live traps.

Cameras can be used to monitor populations, but there are some significant limitations. To date cameras have not been used to acquire recaptures of tagged small mammals on camera. With recent advancements cameras are capable of recording images of small mammals with ear tags. However, cameras have not yet advanced enough to read small mammal tag identification numbers, but tags can be treated as a batch mark to follow cohorts. Depending on objectives the strategy of monitoring cohorts can be suitable, but acquiring individual demographic information is the biggest limitation for the use of cameras to study small mammals. Without individual identification, spatial information cannot be acquired and estimating densities cannot be achieved. It is also important to note that monitoring cohorts still requires live trapping, meaning that cameras do not replace live traps when employing this strategy. Although cameras can significantly reduce the amount of live trapping necessary, using both can increase costs.

Literature related to small mammal populations using cameras is scarce. One study reported detection probabilities using occupancy models (Castleberry et al. 2014), and in another small mammal densities were correlated to camera hit windows, or the length of time images were grouped together (Villette et al. 2016). Each study used data acquired from previous trapping as an index of camera value, which in many cases may be necessary for any study wishing to validate the use of cameras as an alternative to traps. All separate populations may exhibit differences only detected if that population has been trapped and some demographic information has been recorded or require some trapping to confirm camera viability as a methodology. Results generated from other small mammal studies should never be universally applied across all populations. Hence, using cameras in population studies will likely reduce the need for other methods, but is unlikely to replace them completely.

Using multiple techniques can avoid some of the methodological biases involved with using one technique alone. For certain management objectives, visitation rates alone may be suitable, but in population studies, cameras are better regarded as a complementary tool alongside trapping, to mark a cohort, to gain spatial information, and validate camera utility. Using live trapping combined with cameras, can minimize the intensive amount of effort required for long-term trapping studies. Trapping a large spatial area requires multiple sessions at different locations at different times. As a result, studies typically trap a single area intensively to make inferences about broader scale populations, or trap several areas sequentially, which can be complicated by stochastic elements that increase uncontrolled variability (e.g. precipitation, temperature). Cameras can be used to sample a broad spatial range and maintain temporal uniformity when monitoring small mammal populations with minimal manpower to deploy them and retrieval can be done by a single individual over the course of a day rather than a strict time window in the morning. Data that are collected with temporal uniformity will at least exhibit the same conditions and reflect those elements all together.

Field Site: Little Saint Simons Island

Little Saint Simons Island (LSSI) is a barrier island located in coastal Glynn County, Georgia, USA. Approximately 4,450 ha in size, with approximately 1,215 ha of upland habitats, the island was formed during the current Holocene epoch, less than 5,000 years ago. Its geographic location at the mouth of the Altamaha River has resulted in consistent accretion since its formation. Past farming practices that promoted erosion along the Altamaha River accelerated erosion along the river and in turn accelerated the accretion rate on LSSI (Alexander 2013).

LSSI is one of the more unique and relatively natural barrier islands on the coast of Georgia and is one of the most significant natural areas remaining on the southeastern Coastal Plain of the United States. The island has not experienced the extent of farming, timber harvesting, or development that most others have, and has recently been placed in conservation easement in perpetuity. Currently, LSSI is managed by an ecological team that is supported by an eco-tourism operation with a 32 guest capacity, which minimizes human impacts. Approximately, four hectares of land support staff and guests while the rest of the island remains untouched and is only accessed by naturalists who take guests on tours through a network of primitive roads and firebreaks.

LSSI has the most expanse maritime grasslands on the Georgia coast, and the LSSI ecological management team is concerned with enhancing and maintaining the habitat on LSSI. The large amount of maritime grassland found on LSSI allows for experimental research. Data gathered through research conducted on LSSI aids in developing further management guidelines and practices on the island and in the region. One of LSSI's ecological management goals is to serve as a model for the best practices of conservation management and restoration.

LSSI is known to harbor high densities of small mammals and eastern diamondback rattlesnakes (*Crotalus adamanteus*; hereafter, EDB), which is likely credited to the existence of the expanse high quality maritime grasslands found on LSSI. EDBs have been considered for federal protection due to range-wide habitat loss and persecution (Atkins Geise et al. 2011). EDBs are a dietary small mammal specialist unlike other generalist predators, including other snake species, predatory birds, raccoons, and coyotes, that inhabit maritime grasslands on LSSI. Therefore, LSSI is protective of EDBs and any consequences to their prey base are important to understand from a management perspective. LSSI places priority on a hands-off approach and seeks to minimize interference and handling of wildlife as much as possible, so I approached this study as an opportunity to monitor small mammal abundance and behavior in response to prescribed fire at a reference site. I explored the use of game cameras in conjunction with live trapping to reduce handling or disturbing species as much as possible. Here, I report the impacts of prescribed fire to cotton rats, a significant prey base for predators found in maritime grasslands.

Study Objectives

In coastal Georgia, maritime grasslands, given enough time, can transition through succession into successional dune shrub-land dominated by shrubs such as wax myrtle (*Morella cerifera*). In this study, prescribed fire was used as a management tool to prevent common shrubs from taking over a rare habitat that is not traditionally burned. While several studies describe maritime grassland response to fire, the benefits and effects of fire to wildlife remains unclear.

Because maritime grasslands as a vegetation community are resilient to fire, my goal was to determine the effects of fire to inhabitants of the habitat. Specifically, my goal was to monitor cotton rats for a year following a controlled burn and to examine the benefits of maritime grasslands to cotton rats in both burned and unburned plots. Specific objectives are as follows:

1. Population and Biomass (Chapter 2)
    a. To estimate cotton rat population sizes, average biomass, and total biomass in maritime grasslands;
    b. To assess how prescribed fire and season impact cotton rat populations and biomass estimates.
2. Cameras (Chapter 3)
    a. To compare the ability of wildlife cameras to detect small mammals to traditional live trapping and to use these two techniques to complement each other;
    b. To use cameras to monitor visitation and proportion of juveniles of cotton rats in each treatment group over the course of a year;
    c. To use cameras to get recaptures of tagged small mammals, and to assess survival of cotton rats in each treatment group over time.
3. Behavior (Chapter 4)
    a. To determine daily and monthly activity patterns, and if burning impacts activity;
    b. To examine activity frequencies from an annual perspective and compare treatment groups to expected behavioral distributions;
    c. To determine how monthly activity distributions of activity time are affected by burning.

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CHAPTER 2

THE IMPLICATIONS OF PRESCRIBED FIRE FOR COTTON RAT POPULATIONS AND BIOMASS IN MARITIME GRASSLANDS

Materials and Methods

Prescribed Burns

Prescribed burns took place in four plots between 11-13 Feb 2015. Burning took place at the beginning of the growing season to avoid having a prolonged barren landscape and while it was still cold enough for reptiles to remain underground in order to avoid any unwanted casualties of ectotherms including priority species such as eastern diamondback rattlesnakes (*Crotalus adamanteus*), eastern kingsnakes (*Lampropeltis getula*), and island glass lizards (*Ophisaurus compressus*). The goal was to reduce pockets of trees and shrubs to provide more space for maritime grassland habitat. The firing technique employed involved a methodical interior grid ignition ahead of established trees, so that fire could gain intensity as it approached trees such as wax myrtles (*Morella cerifera*).

Plots were divided into control and burned sections as equally as possible as paired treatments, given the terrain and configuration of the landscape of the maritime grassland habitat (see Fig 2.1. Due to dune geography, plots were long linear fields that could generally be described as rectangular. Each plot was selected based on similarity in vegetation composition, proximity to each other, and uniform direction of the fields (north to south). Plots were separated by mowed fire breaks that cross the short width of the fields from east to west. Sizes of treatment plots ranged from 2-5 ha. The width of the plots ranged from ~70-120 m, and length ranged from ~225-500 m (see Fig 2.1 for specific spatial sizes, lengths, and widths).

Live Trapping

Summer trapping for small mammals was conducted from 14 May-26 June 2015, and winter trapping took place from 5 Jan-23 Feb 2016. Each treatment plot received approximately 20 traps per ha, placed in two transects which followed the entire long length of the plots. Transects were placed equidistant with respects to the plot boundaries and adjacent transects (Fig 2.2). I used transects to maximize sampling extent across plots and to increase my ability to capture movement of individuals through plots (see Pearson and Ruggiero 2003). Small Sherman Live Traps® (7.62x8.89x22.86 cm) were spaced equidistant from each other (generally 10 m apart), with half of the traps placed in either transect. Traps were baited in the evening with sunflower seeds soaked in vanilla, and checked in the morning just after sunrise, and completed by 1000 hours to prevent mortalities from heat stress. In winter, traps additionally received polyfil as insulation when temperatures routinely fell below 10°C. Trapping was conducted for each treatment plot twice, for a total of sixteen occasions, eight in the summer and eight in the winter. Each occasion consisted of three consecutive nights. Each season, summer and winter, consisted of twenty-four trapping nights each.

Captured mammals were weighed using a digital scale (OXO) by weighing the mammal in the trap and subtracting the weight of the trap after the mammal was removed for handling. Each cotton rat was given an Inconel National Band and Tag Kentucky® small ear tag (style 1005-1) on the left ear if captured in a burned plot and right ear if captured in a control plot to detect any exchange between treatments. Any exchange between plots was excluded from analyses as a recapture due to violation of general assumptions with closed capture sessions related to no emigration or immigration. Such instances took place rarely along treatment borders (<20 m). On two occasions, an individual was detected from another plot, 0.5 and 1 km linear distance.

Population Estimates and Statistical Analyses

Capture histories for each individual were constructed and summed for analyses (see methods of White 2008, and Cooch and White 2016). Burned plots and control plots were treated as a single population for estimates, using Program MARK. Closed capture estimates using Huggins P and C with equal capture probabilities were used to make estimates of $\hat{N}$ and 95% confidence intervals for each treatment group during summer and winter trap sessions. $\hat{N}$ and 95% confidence intervals were multiplied by mean biomass of all individuals captured in a treatment during a season, to determine mean, lower, and upper limits of biomass measurements in each treatment and during each season trapped. Paired t-tests (α=0.10) were used to determine differences in estimated population sizes and biomass among treatments and seasons using SPSS version 23 software.

Results

Cotton rats were captured in all plots and each treatment during trap sessions. In summer, a total of 177 and 195 individuals was captured and tagged in control and burned plots, respectively, and in winter a total of 108 and 104 individuals was captured and tagged in control and burn plots, respectively. Population estimates for each treatment and season were as follows: summer burn $\hat{N}$=277.29 (SE=17.83), summer control $\hat{N}$=250.72 (SE=16.79), winter burn

$\hat{N}$=201.10 (SE=28.53), and winter control $\hat{N}$=194.96 (SE=24.86) (Table 2.1). When comparing population estimates no significant differences were detected between treatment groups (P=0.355), but significant differences were detected between seasons (P=0.098).

Mean biomass for season and treatment were 108.04g for summer burn, 108.48g for summer control, 124.69g for winter control, and 104.68g for winter burn (Table 2.1). Biomass means were not significantly different between seasons (P=0.586) or treatments (P=0.324) (Table 2.1). When population estimates were related to mean weights, estimated biomass was 27,197.02g for summer control, 29,959.58g for summer burn, 24,307.74g for winter control, and 21,052.30g for winter burn. When comparing estimated biomass for treatment and season that they came from, there was no significant difference between treatment (P=0.963) or season (P=0.110).

Discussion

Initially, I predicted that cotton rat populations in the burned plots would be lower than in control plots. It has been observed that cotton rats suffer declines following prescribed fire (Layne 1974, Connor et al. 2011, Kirchner et al. 2011, and Morris et al. 2012), but in this study these populations were able to recover and exceed populations in control plots in three months, indicating that these declines were temporary. Approximately one year after the burn population estimates were comparable for burn and control plots. Generally, cotton rats experience significant declines in the winter, substantially reducing populations (Clark et al. 2003, Mabry et al. 2003, Brady and Slade 2004, Wright et al. 2010). I captured cotton rats in every plot throughout January and February, and while I did detect significant differences between summer and winter, they were not as extensive as the typical declines the species exhibits in the winter months in the aforementioned studies. The Georgia coast does not exhibit the severe cold weather conditions that other studied populations experience, which likely contributed to their ability to survive the winter. I also observed pregnant and reproductive females in January, and had several females give birth in live traps beginning in early February, confirming year-round reproduction observed in mild conditions elsewhere (Bergstrom and Rose 2004).

Mean biomass for both groups was nearly identical in summer. This finding shows that populations were resilient to prescribed burning and did not appear to experience biomass reductions. However, mean biomass was significantly different between seasons, particularly in winter in burn plots. Mean biomass in burned plots between summer and winter experienced a modest decrease in average of ~4g, compared to individuals in control plots that increased an average of ~16g. The ~20g difference in average biomass could imply consequences to fitness, but reasons why biomass of these populations were reduced in the winter can only be explained through thorough intensive monitoring beyond the abilities of periodic live trapping.

In control plots there was a total of 14.33ha, and 14.38ha in burned plots (see Fig 2.1). I did not use a spatially explicit model to make estimates, but if I assumed this model represented the entire plots, summer densities would be 19.28 per ha in burn plots and 17.49 per ha in control plots, and winter densities would be 13.98 per ha in burn plots and 13.61 per ha in control plots. Compared to other studies, densities using minimum known alive estimates in cordgrass (*Spartina* spp.) had densities ranging from 12-20 per ha compared to 0.5-3.0 per ha in coastal prairies, with higher densities in the fall and lower densities in the winter (Cameron et al. 2009). In Oklahoma, minimum known alive densities ranged from 0.06-112.5 per ha with the highest densities in the fall and the lowest densities in late winter (Clark et al. 2003). Clark et al. (2003) also noted from December to January a decline from 58.6-1.2 per ha, and for the year that followed densities never exceeded 3 per ha. In this study I did not observe the significant declines that have been observed in northern populations. Temperate climate in southern coastal habitat likely offers cotton rats the ability to retain more stable persistent populations. The results of this study are most congruent with Texas Gulf coastal populations found in marsh cordgrass communities, but coastal prairie habitats found in the same location were not as productive as maritime grasslands found on LSSI, although these habitats are more similar in vegetation content (Cameron et al. 2009). Only long-term research can tell for certain if inter-annual fluctuations vary widely on the southern coast, but with smaller declines in the winter, it is likely that there is more population consistency between years, and inland populations are not a reliable source of comparison for coastal cotton rat populations. Finally, while it is possible the population I sampled covered the plots in their entirety, it is most likely that the areas I sampled were smaller than the entire plot, meaning that population and biomass densities are higher than what is reported above.

I also related population estimates to mean biomass to estimate total biomass available in the population. If I extrapolate this to the cumulative size of burned and control plots, there would be approximately 1.9kg and 2.1kg of biomass per ha in summer control and burn plots, respectively, and approximately 1.7kg and 1.5kg per ha in winter control and burn plots, respectively. With densities that harbor an average biomass of 1.5-2.1kg per ha, cotton rats are a significant resource to predators year-round, and they are likely the most important and available prey resource in maritime grassland coastal dune habitats.

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Table 2.1. Summary of *Sigmodon hispidus* population estimates for each treatment and season based on Program MARK models, and how population estimates related to biomass in LSSI maritime grasslands. N is the number of individuals weighed for average biomass. Estimated total biomass is the average weight multiplied by population estimates. Summer trapping took place 14 May-26 June 2015, and winter trapping took place from 5 Jan-23 Feb 2016.

Season & Treatment	**N**	**Average Biomass (g)**	**Total Recorded Biomass (g)**	**N̂**	**95-lower**	**95-upper**	**Estimated Total Biomass (g)**	**Estimated Lower (g)**	**Estimated Upper (g)**
Summer - Control	181	108.04	19556	277.29	249.07	320.22	29959.58	26910.57	34597.91
Summer - Burn	185	108.48	20068	250.72	224.44	291.55	27197.02	24346.28	31626.08
Winter - Burn	105	104.69	10992	201.1	159.24	274.68	21052.3	16670.15	28755.07
Winter - Control	119	124.68	14837	194.96	158.21	258.61	24307.74	19725.73	32243.67

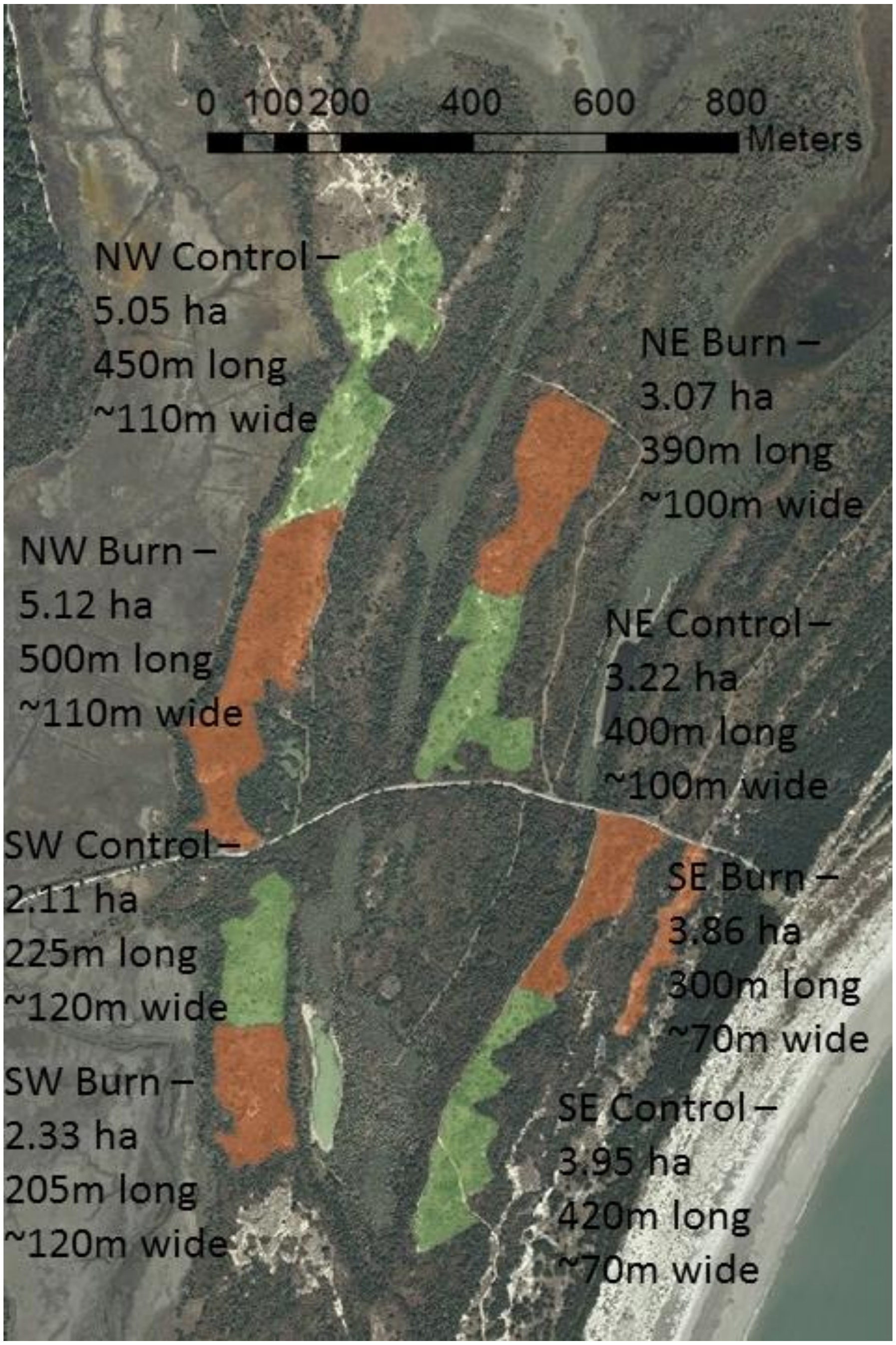

Figure 2.1. Imagery of each of the four plots that were divided in control (green) and burn (red) units. Controlled burns took place between 11-13 Feb 2015.

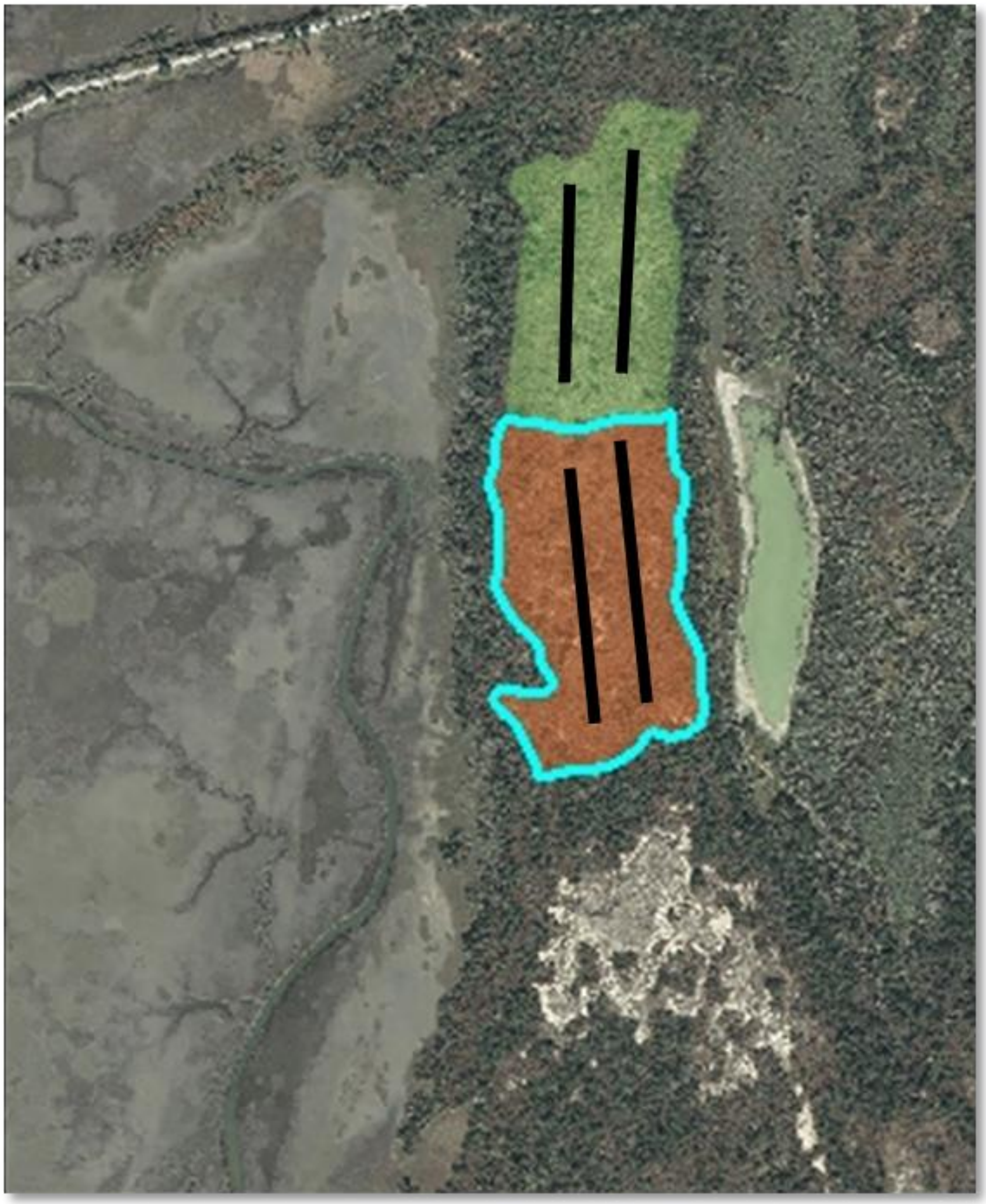

Figure 2.2. Example of transect arrangement. Transects are equidistant from edge to transect and transect to transect. This plot width is ~120 m, meaning there is ~40 m of space between plot edges and transects, and ~40 m of space between transects. This trapping configuration was repeated across all four plots.

CHAPTER 3

SUPPLEMENTING LIVE TRAPPING WITH GAME CAMERAS TO MONITOR SIGMODON HISPIDUS POPULATIONS

Materials and Methods

Camera Surveys

Cameras were used in conjunction with live trapping to conduct a methodological investigation into the efficacy of using the two techniques independently and as complements to monitor the effects of prescribed fire on small mammal populations. Camera traps were deployed to capture images of small mammals located within each treatment plot immediately following controlled burns. Bushnell Nature View HD Max Model 119440 cameras were used with 600mm close focus lenses, capable of capturing images by sensing movement and heat. All parameter settings were standardized across cameras after a pilot season in early 2015 on Little Saint Simons Island to determine the most effective settings (see Table 3.1 for parameter settings for the cameras). Additionally, because the IR flash was too bright at night time, producing white out images, yellow electric tape was placed over the IR flash, reducing the brightness enough to capture clear images at night.

Cameras were placed on a pod constructed from a 355.6mm piece of 50.8x101.6mm wood with two one inch holes drilled on each side. A 19.05mm diameter PVC pipe, at a length of 914.4mm were placed firmly in the holes (Figure 3.1). This was designed to face the cameras straight down to maximize image quality, standardize the distance from where images were captured, and to gain an even profile of the small mammals that visited the camera trap. Pods were placed 254mm in the ground allowing 58.8mm of space between the camera and the ground.

Bait stations were constructed from the leftover PVC pipe. Four-inch (101.6mm) pieces of PVC were capped, then holes were drilled on one side to allow the aroma of bait to spread around the area. Having standard-sized bait stations also provided a reference scale in images. Bait consisted of peanut butter wrapped in wax paper and soaked in vanilla that could be easily removed and replaced by removing one of the caps. The PVC bait stations were attached to a piece of curved rebar staked into the ground with a combination of zip ties and string so that rodents could not carry the bait outside of the camera's view.

Cameras were placed in a location within plots at a point randomly assigned using ArcGIS 10.x software (ESRI, Redlands, CA). Points were established no closer than 10 m to the treatment plot boundary. Given that transects were equidistant from edge to transect and adjacent transects (see methods of Chapter 2 and Figure 2.2), and that the longest width of a plot was 120 m (see Figure 2.1), the longest linear distance between a transect and camera location was 30 m, which is well within cotton rat home range and spatial movement estimates (Guy et al. 1979, Slade and Swihart 1983, Cameron 1995, Bowne et al. 1999, Barrett and Dreelin 2001, Diffendorfer and Slade 2002, Mabry and Barrett 2002, Morris et al. 2011). When random points landed in a dense cluster of trees, camera locations were shifted up to a maximum of five meters. When generating points, a minimum distance of 1/10 the long linear length of the entire plot from north to south, including both treatments, was used as a reference distance to more evenly and broadly separate randomly generated points (see Fig 2.3: NW=95m, SW=43m, NE=79m, SE=72m). Vegetation was prepared at camera locations by clipping or matting down any grasses that may trigger excessive false positive images from wind.

Over the course of a year, cameras were deployed on 26 survey occasions using 16 cameras each, for a total 400 survey locations. Each month, two surveys were conducted for three to four days. Two months, in which only one survey was conducted, were exceptions. Surveys began at the time of camera deployment, and ended when a camera was retrieved, or at 17:00 on the fourth day in the event a camera was not retrieved by then. If a camera survey did not immediately follow a trap session, two cameras were placed in the plot most recently trapped in order assess initial camera cohort detection ratio (CDR).

CDR is defined as the total number of known marked individuals that are detected from a cohort that was marked during a closed sampling period, divided by the total number of known marked and known unmarked individuals recorded during a camera survey. Initial CDRs collected, immediately following live trapping, were compared to detection probabilities from Program MARK as an index of success. I made the general assumption that cameras were capable of detecting marked individuals, those that were detected during live trapping, and unmarked individuals, that population estimates accounted for with detection probabilities, equally during the three-day camera survey that followed live trapping. If this general assumption is met, then CDR and detection probability should be comparable. An immediate camera survey following live trapping served two purposes; 1) to validate the methodological credibility of using CDR by comparing it to detection probabilities estimated from the three day closed live trapping period, and 2) to establish our initial CDR in order to follow cohort survival in the following camera surveys. CDR is expected to decline thereafter for each subsequent survey, as survival for members of the cohort is expected to decline over time, and unmarked individuals are expected to increase as new individuals enter the population over time. CDR can then be used as a measure of the decline in survival from one survey period to the next.

Data Syntheses and Statistical Analyses

Images were sorted following survey periods to isolate positive wildlife images and to remove false positives of vegetation and shadows. All images of cotton rats were assessed to determine if an individual remained in a series of images for consecutive frames, to prevent counting an individual more than once per image series. A minimum of five minutes was required to pass before an image was included in analysis following an observation of a small mammal that exited the screen. I assumed that any individual that entered the frame within five minutes was the same individual re-entering the frame. Exceptions were made when multiple individuals entered the frame at the same time, or when there was an obvious size disparity.

A record of each visitation included time, date, and temperature. For an individual that remained in a series of photos for several minutes, the initial time of encounter was recorded as time of activity. Additionally, age class (adult or juvenile) and whether an individual was marked (see Chapter 2 for methods) was recorded. Juveniles were small individuals, ~75mm or less, with thin tails, and slender bodies estimated to be less than 40g (see Figure 3.2 for examples). PVC bait stations in images were used as a frame of reference to estimate sizes of individuals that were determined to be juveniles. Marked status was recorded only if both ears were observed (see Figures 3.3 and 3.4 for examples). When both ears were not observed, an individual was recorded as unknown. Several reasons for this included blurry image resulting from movement or occasional very humid foggy conditions, partial body shots, and the inability to observe both ears (Figure 3.5). Survey hours were recorded per camera and combined for each treatment group, which allowed me to quantify average visits per camera-day per treatment. Total counts were pooled by survey period and treatment.

Visitation rates, proportion of visitation per camera day in each treatment group, accounted for cameras that failed occasionally, and temporal variation in survey hours from deployment and retrieval of cameras. A camera day was 24 hours; a survey began upon camera deployment and ended upon retrieval or 17:00 on the fourth survey day. Only observations within that time window were used for analyses. Individual survival was quantified for the summer cohort involved in the closed sampling period by calculating the CDR of marked individuals divided by total observations for each survey period. Individuals recorded as unknown were not included in CDRs. Survival was assessed using the CDR for each treatment plot on each survey occasion starting from the time a plot was initially camera trapped following live trapping as day zero (t=0), and subsequently from days since trapping for each occasion thereafter, up to a maximum of 255 days (t=255). Proportion of juveniles was assessed by dividing total estimate of juveniles by total number of cotton rat observations. Initial camera CDRs were used to compare to Program MARK detection probabilities (see Chapter 2 for population estimates and total captures) as an index of success in detection following live trapping. For detection probabilities ($m^{(t+1)}$, the total number of observed individuals), was divided by $\hat{N}$, the estimated population, to determine the probability of detecting an individual during a trap session.

Statistical Analyses

All statistical analyses were conducted using SPSS version 23 software except for survival which was quantified using Microsoft Office 2013. A Kolmogorov-Smirnov (K-S) test for normality revealed that CDRs, visitation rates, total counts, and proportion of juveniles were non-parametric. Initial CDR and detection probabilities were compared using an independent samples t-test (α=0.05). A Wilcoxon singed ranks test was used to compare visitation rates, total counts, and proportion of juveniles between treatments. Survival was assessed using a general linear regression model fit to camera CDRs of marked individuals over time since initial mark. The X-intercept was set at the initial CDR that was calculated immediately following trapping, as this ratio was expected to be at its highest following trapping, and expected to decline thereafter. The slope of the linear regression was reported as daily decline in survival.

Results

Summary of Camera Data

On nine occasions cameras failed or were not switched all the way on. A total of 636.66 and 636.43 survey days were logged in control plots and burned plots respectively. Mean survey time for both burned and control was 3.06 days for each. A total of 1,694 individual *S. hispidus* were recorded according to the criteria and used for analyses. Of that total, 1,385 were recorded following summer trapping, 791 in control plots and 594 in burned plots. Of the 1,385 that were recorded following trapping, 136 and 102 from control and burned plots, respectively, were recorded as unknown due to movement or foggy conditions, comprising a total of 17% from both treatments. Therefore, 83% of images from each treatment were useable for survival analysis.

Population Dynamics

My ability to detect marked individuals was consistent with detection probabilities determined from live trapping, as there were no significant differences between detection probabilities calculated by Program MARK and CDRs recorded by wildlife cameras (P=0.302). Detection probabilities predicted by Program MARK from live trapping, although not significantly different, were consistently higher than CDRs according to cameras in each season and treatment (Figure 3.6).

The proportion of juveniles detected in each control (N=91) and burned plots (N=65) per month were not significantly different (P=0.301). Both treatments followed a similar stochastic pattern except for the burned group immediately reached a peak in March 2015 following the burn in February and the control plot had a peak in late November not seen in the burned plot (Figure 3.7).

The total number of visitations was 962 cotton rats in control plots and 732 in burned plots. Total visitations per period (P=0.017) and visitation rates (0.016) were both significantly different, although visitation stayed relatively consistent and reached peaks in late spring and mid-winter in both treatments (Figures 3.8 and 3.9).

Daily survival of the marked summer cohort declined at a rate of 0.48% (N=37), 0.26% (N=35), 0.13% (N=50), and 0.32% (N=55) per day in the four control plots (total N=177), and 0.18% (N=62), 0.36% (N=60), 0.32% (N=44), and 0.23% (N=29) per day in the four burned plots (total N=195) (Figure 3.10). Average 30 day decline in cohort survival was 9% in control plots and 8% in burn plots.

Discussion

Camera CDRs were consistently lower but statistically comparable to live trap detection probabilities (Fig 3.6). An explanation for consistently lower CDRs, is the possibility that population estimates made by Program MARK underestimated population sizes, resulting in overestimated detection probabilities. Alternatively, I deployed cameras randomly within the assigned plots and I did not use a spatially explicit population model to make population estimates, so the area I sampled with traps may be smaller than the size of the designated plots, leading to population estimates of an unknown area smaller than the plots. Regardless, these data were not significantly different, which validated our use of cameras to monitor summer live trap cohorts.

Visitation rates exhibited stochasticity throughout the year that largely followed a similar pattern in each treatment group (Fig 3.9). Immediately following the burn, visitations in burn plots for the first month nearly reached zero when the control plots saw at least one visit per camera day. This finding was supported in a radio-telemetry study by Conner et al. (2011) where cotton rats experienced high mortalities associated with increased avian predation due to reduced ground cover that increases predation risks. Following this decline from March to May 2015, there was a sharp increase in visitation. Conner et al. (2011) also noted that cotton rat declines were temporary and recovered quickly, providing predators with a short-term benefit at no long-term cost to the cotton rat populations. I saw populations recover and exceed that of the control plots by May, which was confirmed by trapping (see Chapter 2). Visitation remained relatively stable and comparable in both treatments until late November 2015, when burn treatment visitation declined to nearly zero and control treatment visitation exceeded two visits per camera day.

Several studies note the importance of dense ground cover to protect cotton rats from predation (Schnell et al. 1968, Layne 1974, Cameron et al. 2009, Connor et al. 2011, Kirchner et al. 2011, Morris et al. 2011), but there is little focus on how ground cover may protect rodents from reduced temperatures during the winter, although most studied populations experience significant declines when it becomes cold (Odum 1955, Goertz 1965a, Clark et al. 2003, Mabry et al. 2003, Bergstrom and Rose 2004, Brady and Slade 2004, Cameron et al. 2009, Green and Rose 2009, Reed and Slade 2010, Wright et al. 2010). Fat alone is not enough for cotton rats to survive winter, therefore nests are important (Shrump et al. 1978). Following the prescribed fire, several nests were noticed in the remnants of muhly (*Muhlenbergia sericia*) clumps. With reduced ground cover from the recent burn and less above ground vegetation biomass, it is possible that nests were difficult to construct sufficiently, resulting in individuals found in winter burn plots burning more fat to maintain body heat in the winter (see Chapter 2). Another possibility is that the risk of predation following trapping in June was greater in burned areas with reduced cover, exposing cotton rats to more predators, resulting in behavioral decisions that led to decreased foraging activity and therefore decreased biomass.

Proportion of juveniles did not exhibit significant differences between treatments, and experienced the biggest peaks in spring and fall. Following the prescribed fire, there was a large immediate spike of juveniles found in the burn plots. It has been shown that high adult densities can restrict recruitment (Reed and Slade 2008). Given that predation, followed by emigration, is known to result in cotton rat decline following burns (Conner et al. 2011), it is likely that juveniles were taking advantage of reduced densities in burn plots left vacant by mortality and emigration. It is difficult to say if juveniles were birthed into control plots, and immigrated into burn plots from safer habitat left behind in controls, or if reduced densities in burn plots allowed for increased reproduction by survivors. Likely a combination of both took place. Burn plots showed decreased visitation rates for the first month, indicating densities were reduced. While high densities negatively impact recruitment, they do not reduce pregnancies (Reed and Slade 2008), and a disturbance, such as prescribed fire in this study, that reduced densities may have led to increased proportions of juveniles from pregnant females. In support of this, there was evidence of winter pregnancies in the following January and births in February when live trapping took place (see Chapter 2).

With the daily rates of decline that I recorded for each cohort, monthly (30 day) survival averaged approximately 91% in control and 92% in burned plots. Visitation in burn plots was less overall, although the summer cohort in both treatment groups exhibited comparable survival rates. Throughout the year, densities may have changed while survival for certain demographics remains constant (see also Reed and Slade 2008), or predation risks may have reduced visitation in burned plots (Conner et al. 2011). Predation may disproportionately affect younger, naïve individuals, while older experienced adults remain vigilant from predation.

I observed the last recapture on camera, following initial mark, at day 241 for the control plots and day 199 in burned plots. In control plots during winter trapping I recaptured three individuals originally marked in the summer, 237-253 days since first capture. In burned plots, three individuals originally marked in the summer were recaptured in winter, living from 242-249 days. Most cotton rat mortality occurs from predation (Schnell 1968, Conner et al. 2011), which is also most likely the main cause of survival decline in this study. My results showed higher than expected survival compared to other studies reporting monthly survival (Green and Rose 2009, Conner et al. 2011). These survival results reflect the accuracy of cameras, and the value of maritime grassland habitat to cotton rats.

Camera Utility and Benefits

Using cameras for population studies has gained little attention since cameras have been introduced as a tool for small mammal studies, mostly based on the criticisms of cameras compared to live traps (see Table 3.2). Live traps are able to obtain data related to individual demographics such as gender, weight, length, and health parameters. Importantly, live trapping provides the ability to conduct mark-recapture using unique marking, such as ear tags and can often be used to gain some spatial information, allowing for more accurate population estimates. To date, cameras have been used with many other species to identify individuals in a population that are marked or uniquely identifiable by a pattern, and spatial information can be acquired when individuals are photographed on several cameras in an area (e.g. Carbone et al. 2001). However, game cameras are not capable of individual identification with small mammals yet, and getting recaptures of marked small mammals in photos and video has not yet taken place to the best of my knowledge. With the recent advancements of game cameras, such as close focus lenses and increased photo quality and improvements in affordability, using game cameras to monitor cohorts of marked small mammals has recently become an option and was used as a method in this study. Rather than trapping monthly to assess the significance of prescribed fire to cotton rats in maritime grasslands, two closed trapping sessions were employed in the summer and winter following the burn and I was able to openly monitor cotton rats bimonthly with cameras. Once images of recaptures were confirmed successful, using cameras minimized small mammal handling and provided significant insight into small mammal populations in terms of cohort survival rates, visitation rates, proportion of juveniles, and behavioral differences among treatment groups and seasons.

I detected no significant differences in detection probabilities calculated by Program MARK and CDRs recorded by game cameras. This finding validated the use of cameras to assess survival. In this study, I followed two cohorts marked in separate ears found in burned and control plots. This strategy could be applied easily to studies comparing males and females, or juveniles to adults, or similar-looking species could be marked in separate ears to reduce misidentification. When employing cameras alongside traps, a closed population can be marked in one ear as a cohort, and periodic open sampling can still be used to mark individuals in the other ear. During the trapping time frame, visitation rates accurately reflected the population estimates (see Chapter 2), in that I saw increased visitation in burned plots when population estimates were higher and I saw relatively equal visitation in the winter when estimates were nearly equal.

Cameras offer numerous benefits depending on ultimate research objectives, and have been demonstrated as a useful tool in studying small mammal populations (see Table 3.2 for list of camera benefits compared to live trapping). I was able to observe 2,252 small mammals with no mortalities, in comparison to live traps that resulted in seven small mammal mortalities out of 938 captures. To follow a cohort, I needed to live trap at least one time, but cameras saved us the need to trap every plot monthly with the broad spatial scale they covered. They also recorded data with temporal uniformity at the spatial scale necessary for the research objectives of this study. I possessed enough traps to sample one of eight plots one at a time, so trapping monthly would have taken the entire month every month of the study in order to entirely cover the broad spatial scale essential for my study objectives. Even with the necessary amount of traps required to cover all plots with temporal uniformity, more personnel would have been required to check all them in a timely fashion, and cameras offered an efficient alternative.

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Table 3.1. Shows game camera parameters, what they were set to, and a brief explanation of each selection.

Parameter	**Setting**	**Explanation**
Mode	Camera only	Video required too much memory
Image Size	8m pixel	Highest photo quality was best for viewing ear tags
Image Format	Full Screen	Easier to view entire small mammal
Capture Number	Two images	Often one image was blurry, a second was usually more clear
LED Control	Low	The lowest setting, and tape over LED lens prevented white-out photos at night
Interval	15 seconds	Prevented too many photos and allowed us to see relatively how long a mammal stayed and when they left
Sensor Level	Normal	Low setting missed some activity, high and auto produced excessive photos from shade and vegetation movement
NV Shutter	High	Produced clearest night photos

Table 3.2. Summarizes the pros and cons of cameras compared to live traps when collecting data in the field. Studies that provide examples or identify these benefits are listed in the fourth column.

	Camera	Live Trap	References
Affordability	This study used a high quality camera purchased for $183 each. Price range depending on brand and performance is $50-$650.	Prices range from $15-$38 each, and averages ~$25 each. For this study, the price of one camera amounted to seven traps.	see De Bondi 2010 for personnel costs
Spatial Coverage	Cameras can be deployed over large spatial areas and require little to no maintenance. Cameras can be deployed and recovered by a single person, and recovery is not time sensitive or dangerous to small mammals.	Traps must be concentrated in an area small enough to mark and release small mammals before they become mortalities. Live traps require high maintenance and increased personnel to cover large spatial scales. Increased personnel result in increased costs.	De Bondi et al. 2010, This study
Sample Area and Temporal Uniformity	Can record in many locations simultaneously.	Generally trapping involves either one location, or trapping multiple locations sequentially, which results in temporal variation, or using a small area to make broad inferences. Trapping is limited by the amount of traps an individual can check in a brief time window.	De Bondi et al. 2010, This study
Efficiency (Failure rate)	Success will likely vary depending on the focal species, as some move more frequently and produce poor images and others may be difficult to distinguish between each other depending on the species present at a field site, the quality of the camera used.	Knowing when a trap failed to deploy, or if it deployed prematurely is difficult to quantify. It likely depends on species, and their propensity to eat standing on the track plate, or to investigate the trap by climbing on it, and subsequently setting it off.	Alistair 2013, Meek et al. 2013, This study
Small Mammal Impacts	Do not result in any incidental mortality form heat, cold, or stress and do not remove small mammals from activity throughout a trap night.	Can result in mortality from heat, cold, stress, and remove small mammals from activity until released.	De Bondi et al. 2010, This study
Identification	Proper identification could be difficult at field site with species that look similar. Additionally, some photos with movement or taken in foggy weather may not be identifiable.	Proper identification is guaranteed.	Meek et al. 2013, This study
Demography	By ear tagging two groups in separate ears, some demography information can be recovered.	All individual demographic information is available.	This study
Species Richness and Species Inventory	Cameras have demonstrated value in detecting more species than traps where species are trap shy.	Trapping can be used to detect species richness, but may detect more species that are trap happy, and miss some that are trap shy.	De Bondi 2010
Occupancy	Cameras are very efficient and cost effective when presence absence is the research objective.	Traps can gather presence absence data, but require much more work and personnel than cameras.	De Bondi 2010, Castleberry et al. 2014
Marking	Traps are required to mark individuals. To date no method exists to uniquely identify individuals captured on camera.	Trapping allows researchers to mark small mammals with unique identification tags.	This study

Recapture	Cameras can record recaptures, but unique identification is not yet possible. Marked individuals can be treated as a cohort, and using separate ears can be used identify groups (i.e. male vs female, juvenile vs adult, closed vs open populations).	Can get recaptures and provides ability to identify individuals. Detailed demographic information can be recorded and used to make accurate population estimates. Additionally, some spatial information can be gained from unique recaptures.	This study
Survival	Can be assessed for cohorts.	Can be assessed for individuals.	This study
Visitation and Trap Rates per Unit Effort	Visitation rates per unit of time can be gathered with ease, and is one of the best alternatives to density estimates gathered by live traps and could be used as a hands-off alternative index of abundance.	Visitation does not apply, but trap rates per unit of time such as captures per trap night can be reported. Relatively easy measures of density such as "minimum known alive" can be quantified.	Alistair et al. 2013, This study
Densities	Hit window has been used to assess densities.	Can be determined using numerous methodologies. The most accurate density models are spatially explicit.	Vilette et al. 2016
Behavioral Information	Can be used to collect a wide scope of behavioral activities with ease and accuracy. Daily and seasonal activity distributions can be assessed in multiple treatments, amount of time spent foraging can be observed, time partitioning between species can be assessed, and specific activities such as pollination can be observed in the field.	Can be used to collect some information on activity times. Generally, traps are checked in time windows throughout a day or night, or equipped with timing devices. The big criticism is that the trap removes an individual from continued activity that goes undetected until it is released.	Meek et al. 2012, Cid et al. 2015, Zoeller et al. 2015, This study

Figure 3.1. Camera pod set-up facing downward towards bait station in maritime grassland.

Figure 3.2. Examples of juveniles estimated to be less than 40g.

Figure 3.3. Examples of daytime recaptures.

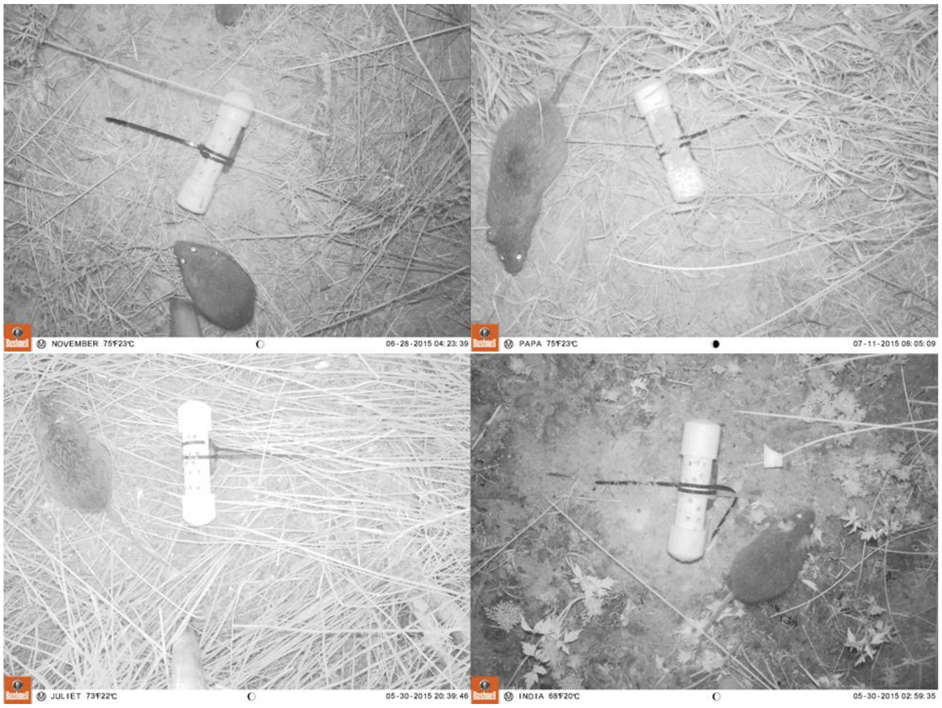

Figure 3.4. Examples of nighttime recaptures.

Figure 3.5. Examples of individuals identified as cotton rats that were unknown whether to be marked or not.

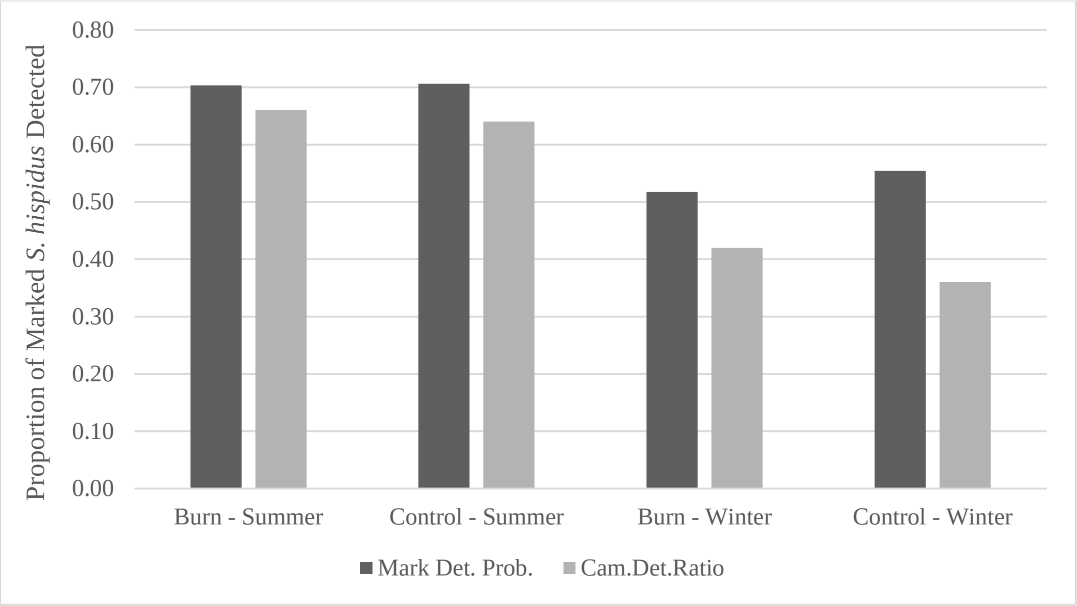

Figure 3.6. Detection probabilities from Program MARK compared to initial camera CDRs, immediately following live trapping were not significantly different (P=0.312).

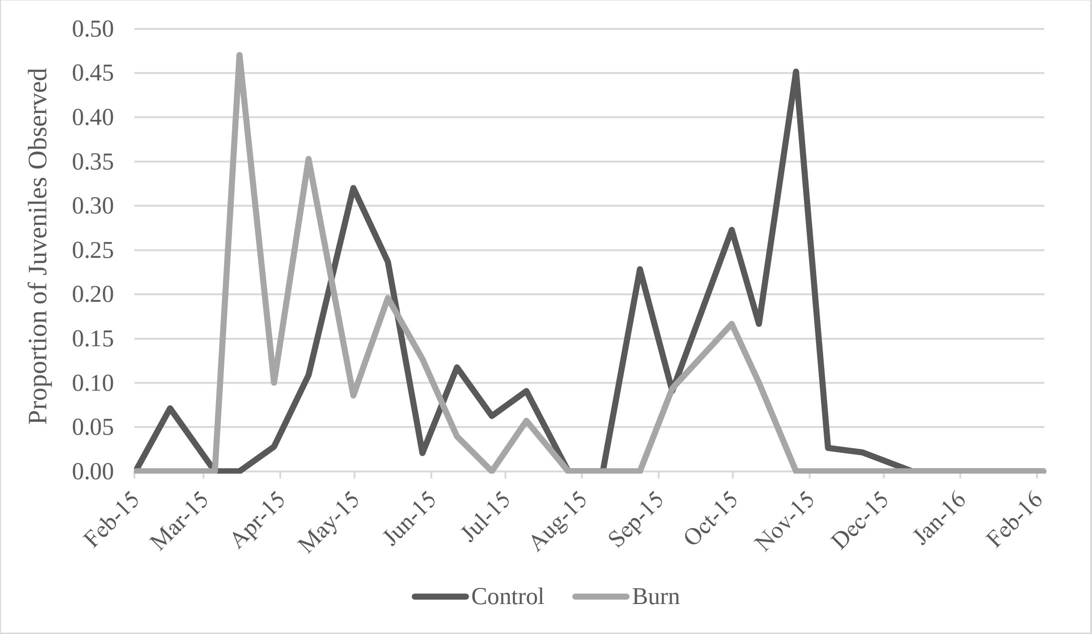

Figure 3.7. Proportion of juveniles (N=156) observed by cameras from February 2015-2016 (P=0.301).

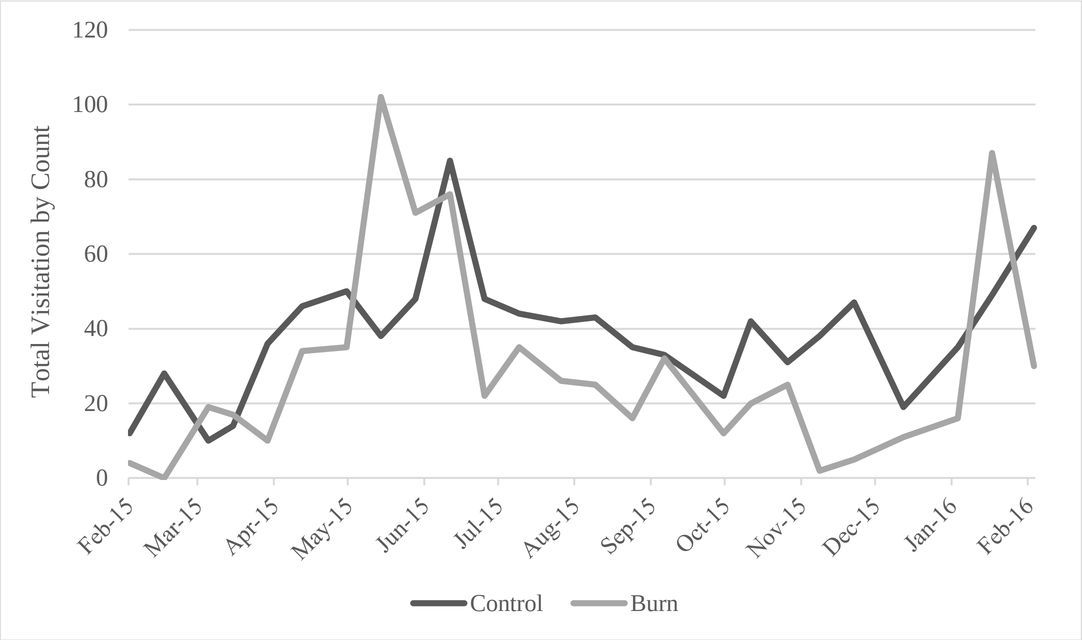

Figure 3.8. Total cotton rat visitation (N=1694) by count per survey period. P=0.017.

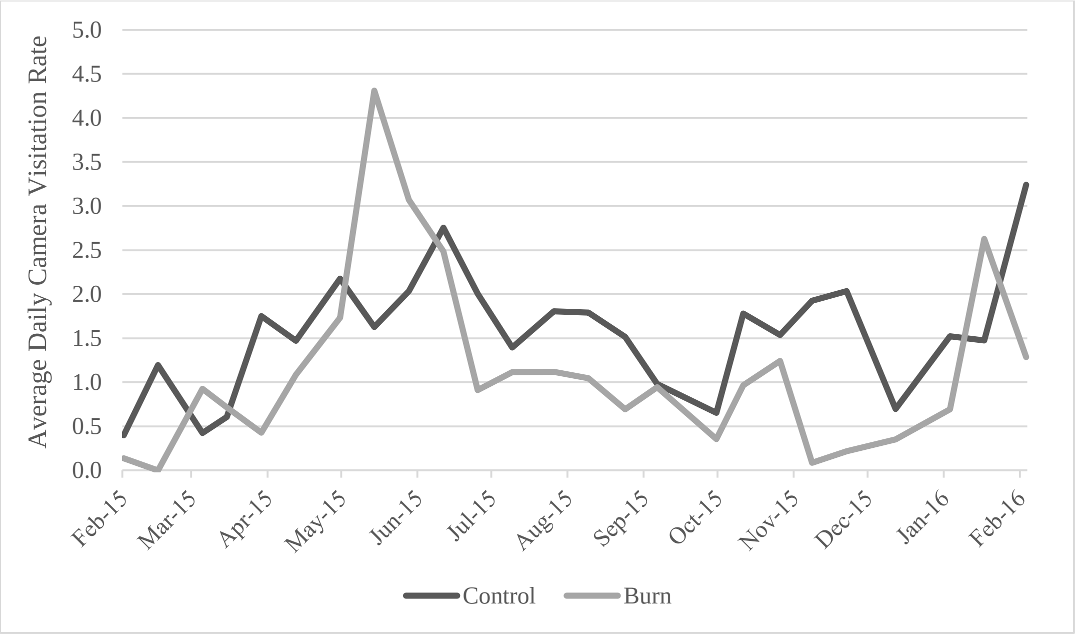

Figure 3.9. Average visitation rates (N=1694) per camera day for each survey period (P=0.016). A total of 636.66 and 636.43 camera days were logged in control and burn plots respectively.

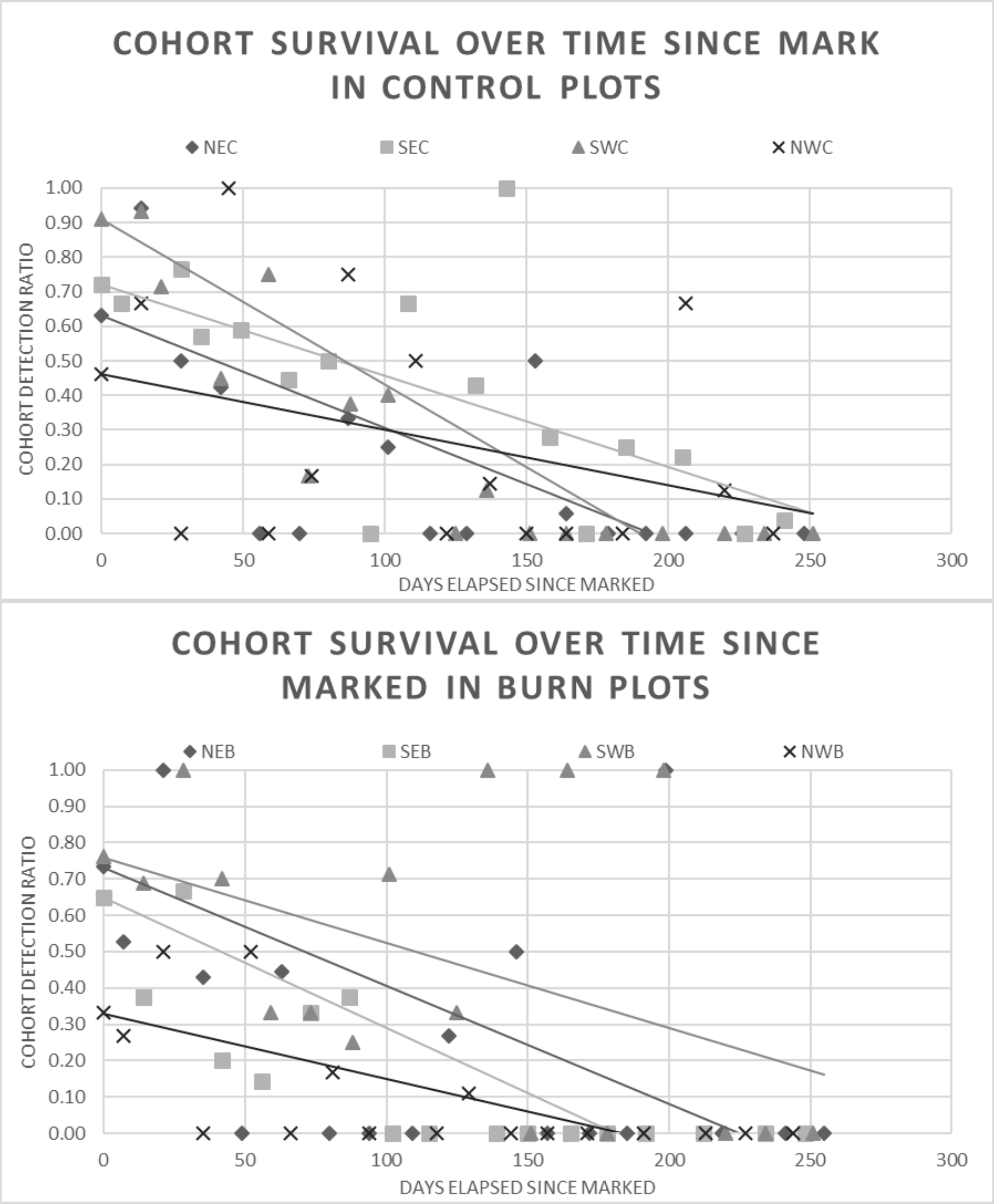

Figure 3.10. Survival for summer cohort over time since initial mark for each plot in each treatment group. The X-axis represents days since original mark, and the Y-axis represents proportion of individuals detected during a survey occasion following original mark. The X-intercept was set to the original CDR following trapping, and the slope of each line represents the average decline of survival in that particular plot. Daily survival declined at an average rate of 0.30% in control plots (range=0.13%-0.48%). Daily survival declined at an average rate of 0.27% in burned plots (range=0.18%-0.36%).

CHAPTER 4

AN EVALUATION OF SIGMODON HISPIDUS SEASONAL BEHAVIOR AND ACTIVITY PATTERNS USING GAME CAMERAS

Materials and Methods

Cameras surveys (see Chapter 3 for methods) were also used to detect behavioral differences of cotton rats (*Sigmodon hispidus*) that may have resulted due to habitat changes resulting from prescribed fire. Time and date were recorded for each observation of cotton rats during each 3-4 day survey period. Sunrise and sunset data were downloaded from Quick Phase Pro V.4.0.22 software.

Data Syntheses

Frequency tables were created using 2013 Microsoft Excel to calculate small mammal activity times by separating data in to one-hour categorical windows. Positive numbers were used to represent daytime hours and negative numbers were used to represent nighttime hours. Hence, the absolute value of each cotton rat activity time was subtracted from that day's temporally closest sunset or sunrise in order to determine the temporal distance an activity was from day or night. This assignment or grouping was of particular importance to assess crepuscular activity and trends of activity pulses.

Crepuscular activity was regarded as activity that took place two hours before and after sunrise or sunset. Nocturnal activity was regarded as that which took place between the hours of sunset and sunrise, including crepuscular activity that fell between sunset and sunrise. Every image that belonged to a defined activity category, crepuscular and nocturnal, was divided by the total number of images collected for a survey, for each survey period over the course of a year. Additionally, each month, an activity distribution was constructed using the approximate number of hours during the night and day that month and standardizing time zero to represent sunrise/sunset. All activity that took place during the two surveys each month was summed into a single 24-hour day. The sum of activity that took place each hour was divided by total activity in order to look at the proportion of activity within the 24-hour day.

Statistical Analyses

I compared nocturnal activity for each month for each treatment to determine what time of day cotton rats are most active. Burned plots experienced less visitation in terms of counts and frequency (see Chapter 3). To control for differences in population sizes between treatments, I looked at nocturnal activity in terms of its proportion to total monthly activity for each treatment group. To compare proportions, I performed an angular transformation and compared monthly nocturnal activity over the course of a year using an ANCOVA with month as the covariate and treatment as the fixed variable using SPSS version 23 software.

For crepuscular data activity times, proportions were used for analyses rather than counts to reduce biases due to disproportionate sample sizes from burned or control plots. For analyses of annual data regarding activity times, an angular transformation was performed on proportions and a chi-square test was used to detect differences between treatments. Treatments were individually compared to a proportionally even distribution of random frequencies throughout a day, and a proportionally even distribution of expected nocturnal frequencies throughout a night. Additionally, treatments were compared to an expected crepuscular frequency with the majority of activity (86%) concentrated within two hours of sunrise and sunset with the rest of the activity evenly spread throughout a day. All comparisons were conducted with a chi-square test with Microsoft Office 2013.

Activity distributions over a 24-hour period per month were compared, using the Durbin-Watson test for autocorrelation. This regression test was chosen because these circular data were meaningfully ordered by hour of the day, and I was interested in how similar treatment groups were each month following prescribed burning.

Results

Annual crepuscular activity accounted for 61% of total activity in both burned and unburned plots (Figure 4.1). There were no significant differences between annual activity distributions for burned and unburned plots ($P=0.977$). When annual cotton rat activity distributions were compared to a crepuscular activity distribution, control ($P=0.079$) and burn ($P=0.136$) indicated no significant differences. When annual activity distributions were compared to random distributions and nocturnal distributions, both burned and unburned plots indicated significant differences ($P<0.0001$).

When comparing monthly nocturnal activity between treatment groups ($P=0.171$) there were no significant differences (Figure 4.2). A trend that stood out is that cotton rats in both plots were predominately nocturnal from October to April, switching to predominately diurnal activity from May to September.

Monthly distributions demonstrated consistent bimodal peaks, usually around crepuscular time windows (Figure 4.3). Cotton rats exhibited activity at all times of day throughout the year. Cotton rats were least active at midday and largely avoided activity during daylight hours during the coldest months. According to the Durbin-Watson tests, seven of the months fell between 1.5 and 2.5 indicating strong similarities. March was 1.237, June was 1.050, October was 2.613, November was 1.493, and February was 1.177.

Discussion

Based on laboratory studies (Calhoun 1945, Johnson and Zucker 1983) and intensive live trapping (Eifler and Slade 1998) cotton rats can be active most times of day, but are typically active at crepuscular times. Using cameras, had precise around the clock coverage to determine activity times and did not remove individuals from continued activity. I typically observed crepuscular bimodal peaks, two hours before and after sunset, 61% of the time cumulatively, but cotton rats were still active nearly all times of day throughout the year. Calhoun (1945) suggests activity outside of crepuscular peaks may take place at higher densities where subordinates are avoiding social competition at peak times. It is possible that larger adults accounted for activity at crepuscular peaks, whereas smaller individuals may have been active during the remaining hours outside of peak adult activity. Cotton rats avoided activity around midday, but in the winter they largely avoided any daytime activity (see Fig 4.2 and 4.3).

I also observed temporal activity shifts in regards to photoperiod in which cotton rats were most active nocturnally in winter and diurnally in summer. Predominant nocturnal winter activity was an unexpected result, as it is energetically costly, especially for a species that is known to experience reduction and even local extinctions in the coldest climates found in its range (Odum 1955, Goertz 1965a, Clark et al. 2003, Mabry et al. 2003, Bergstrom and Rose 2004, Green and Rose 2009, Reed and Slade 2010, Wright et al. 2010).

Identifying mechanisms driving activity patterns and temporal shifts is difficult, but evidence and theory provided in the literature can be used to make inferences about these drivers. The circadian thermoenergetics (CTE) hypothesis predicts that nocturnal animals that are challenged by cold and hunger become diurnal to reduce energy expenditures associated with heat loss to reduce daily energy expenditures (Hut et al. 2012, Van der Vinne et al. 2015), which is in line with what Prochaska and Slade (1981) observed through intensive live trapping of cotton rats in Kansas, but the opposite of what I observed in this study. Staying warm in a nest at night allows individuals to conserve energy and forage at reduced rates during the day (Van Der Vinne et al. 2015). If this pattern holds true, deviations from this pattern would most likely depend on predation risks and potential foraging opportunities. Theoretically, by avoiding unwanted temperatures and being active at times that are less preferred may result in increased predation risk, increased energy expenditures, and reduced foraging. Conversely, shifting or avoiding activity to reduce predation risks can increase energy expenditures by exposing small mammals to unwanted temperatures and increased hunger. In accordance with the CTH, I propose that cotton rat activity shifts outside of what would be energetically most efficient were likely a result of seasonal predation pressures.

During warmer months, cotton rats in LSSI maritime grasslands are exposed to high densities of eastern diamondback rattlesnakes (EDB), which have adapted superior nocturnal ambush abilities using heat pits, in addition to several other snake species found in maritime grasslands. Snake presence may have driven diurnal cotton rat activity during the warmer months when EDBs are above ground. The transition between predominately nocturnal to diurnal activity coincides with snake emergence from hibernation in the spring, and the beginning of their foraging season (Fig 4.2; March, April, and May). Conversely, cotton rats in this population may be naturally diurnal, which is in accordance with the CTE. It is possible that increased risk from avian predators found in maritime grasslands that are active during the day may become the most prominent predation risk to cotton rats, influencing a shift from diurnal into an energetically costly nocturnal activity pattern. (Fig 4.2; October- March).

In addition to temporal activity shifts, individuals found in burn plots during the coldest winter months (see Fig 4.3; December, January, and February) were more active throughout the night, whereas individuals in control plots were active almost exclusively during crepuscular peaks prior to sunrise and after sunset. A couple of reasons may explain this phenomenon. One proposed reason is that individuals in the control plots were able to maintain body heat more efficiently with higher vegetation densities and better quality nests and therefore expended less energy, whereas individuals in burn plots needed to remain more active to forage throughout the night to maintain body heat to survive, and consequently burned through fat stores (see Chapter 2 for average biomass differences). Although predation risks likely drove nocturnal activity, the principles of the CTE explain minimal activity for individuals found in control plots for this scenario.

A second proposed reason is that individuals found in burn plots were of a lower age and weight class as a result of reduced activity and slower maturation. In burn plots with reduced ground cover that provides safety from predators, the predation risk cotton rats experience in the months leading up to winter following the prescribed fire can result in reduced activity and slower growth (Lima and Dill 1989). As a result, they would have had less fat required to survive with minimal activity; therefore, they exhibited more activity at night to maintain heat, where individuals in control plots were comprised of larger adults with higher fat content that provided them the ability to reduce activity to minimum necessary to survive. In winter in Kansas, Eifler and Slade (1998) documented increased daytime activity from individuals in lower weight classes than larger adults that exhibited bimodal peaks. They proposed that younger individuals likely do not have enough fat stores to reduce activity compared to larger adults. This concept is applicable in the context of this study, but in contrast we observed individuals in burn plots with lower average biomass maintain activity throughout the night, instead of the day, which is energetically costlier for fat stores as it is colder at night than day.

Cotton rats are known to store fat for winter and experience significant fat loss until spring (Fleherty et al. 1973), which may allow for reduced activity during the colder months (Eifler and Slade 1998), and may be necessary when food resources become scarce. It has been suggested that cotton rats may reduce activity to the minimum required to survive in extreme cold temperatures and under the risk of predation (Doonan and Slade 1995, Eifler and Slade 1998, Morris et al. 2012). Reducing activity can benefit a species by reducing loss of heat in cold temperatures or reducing predation risks, but reduced activity results in less time foraging and lower food intake, therefore reduced fat stores. Implementing strategies to preserve heat when temperatures are cold (scenario 1), and storing fat before winter (scenario two) are important and can potentially improve survival and fitness during the winter, especially where vegetation densities are reduced.

During winter, cotton rat populations were nearly equal in size. Therefore, the cause of decreased activity in burn plots was likely a result of sub-lethal behavioral effects during or leading up to the winter. These effects reduced biomass, which may imply reduced fitness, and modified behavior nearly a year after the burn, and long after populations recovered following the burn (Lima and Dill 1989). Observing reduced biomass in winter demonstrates the long-term seasonal consequences of management beyond observed population recovery, highlighting the importance of long-term monitoring.

Research into the trade-off of activity shifts for small mammals has received little attention to date. Time and distribution of activity in rodents is governed by a natural physiological circadian rhythm that can be influenced by ecological factors such as predation, temperature, and social behavior (Kronfeld-Schor and Dayan 2008, Montessero et al. 2013). Consequences of cotton rats making major temporal shifts, such as increased predation risk, could also result in sub-lethal behavioral effects to accommodate trade-offs, such as reduction of activity (i.e. Conner et al. 2011, Morris et al. 2011, Hinkleman et al. 2012). In this study, cotton rats in both treatments were active nocturnally during the winter, but in burn plots cotton rats were more active throughout the night than individuals in control plots during the winter. Temporal shifts occur to accommodate hunger, energy loss, and to reduce predation risk, meaning that there is a perceived benefit that improves survival over remaining in a natural physiological circadian rhythm, but the consequence is likely a trade-off that could possibly result in reduced fitness. The reduction of ground cover in burn plots had an impact on cotton rat behavior leading up to or during winter leading them to make decisions that reduced their mean biomass compared to control populations. Trade-offs for cotton rats found in burn plots resulted in reduced Biomass during the winter, and could have consequences on survival and reproduction. More research is required to determine whether temperature, predation risk, or another mechanism was responsible for the observed temporal shift in both plots, and reduced biomass in burned plots.

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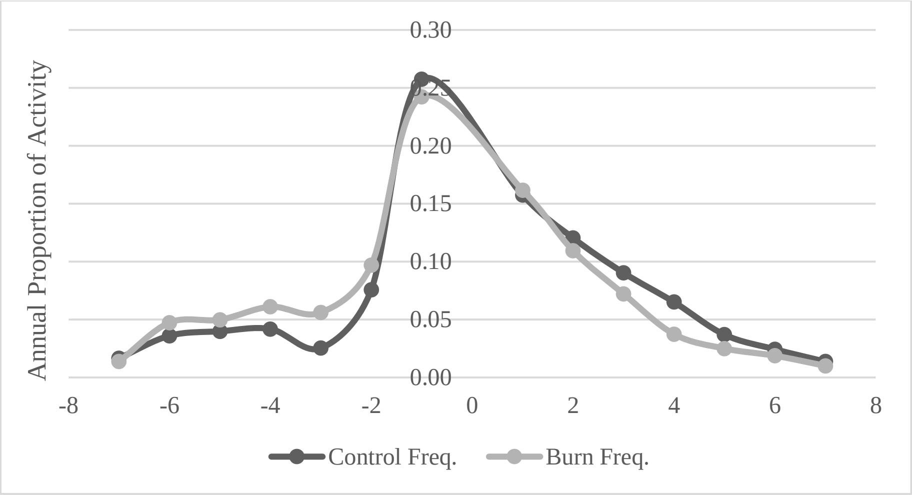


Figure 4.1. Cumulative proportion of annual activity. The amount of hours from sunset to sunrise (darkness) are lumped together and represented by negative numbers. The amount of hours between sunrise and sunset (daylight) are lumped together and represented by positive numbers (P=0.977). Crepuscular activity, that which takes place two hours before or after sunset and sunrise, accounts for 61% of cotton rat activity annually.

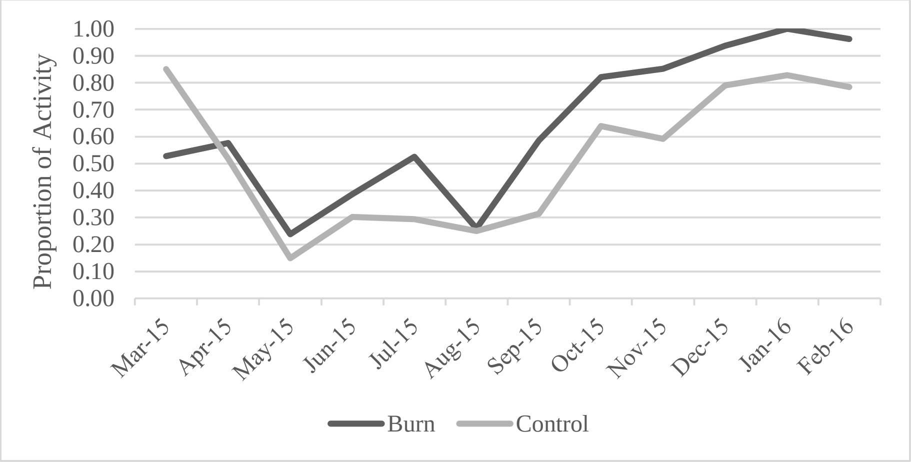
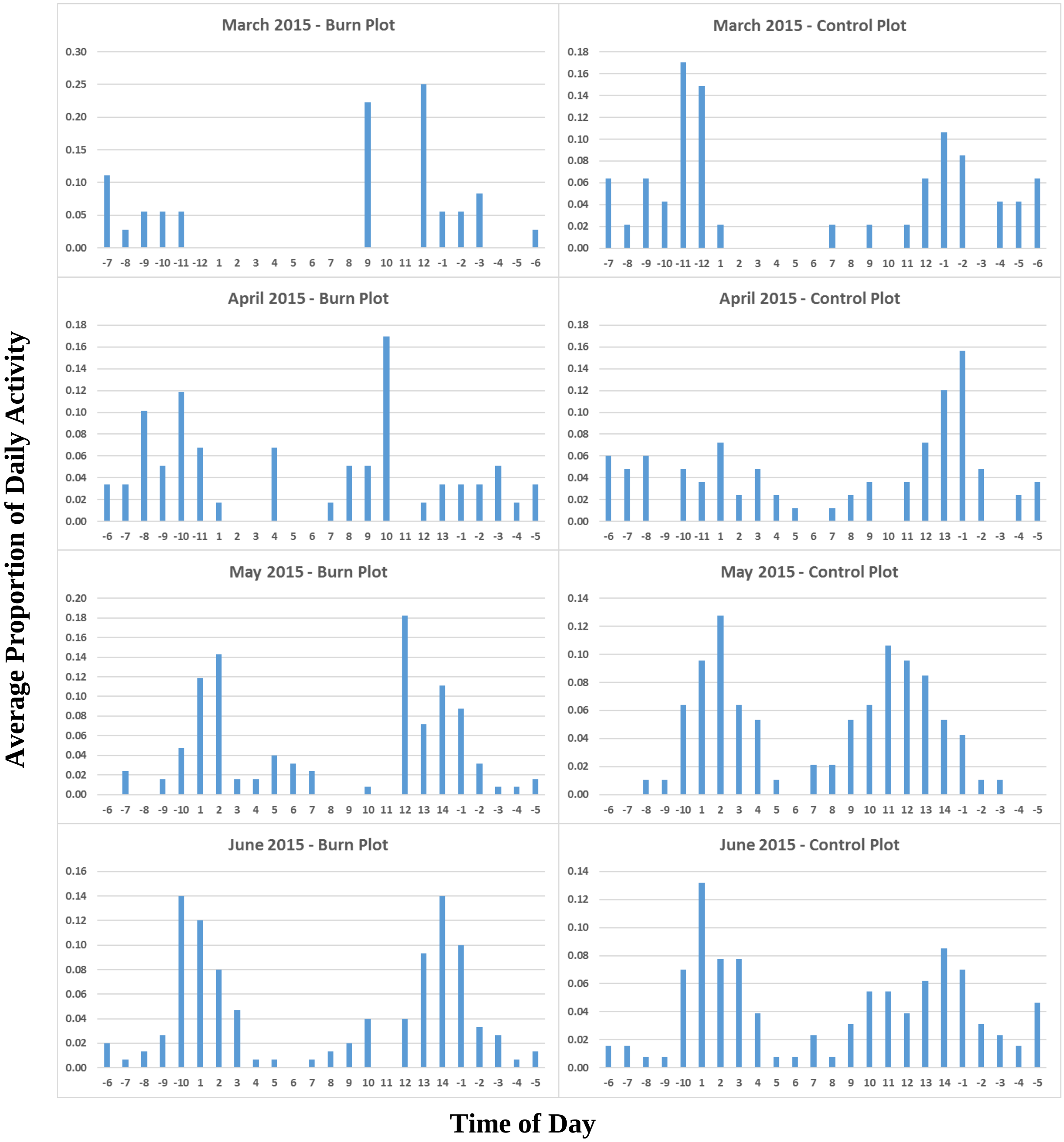
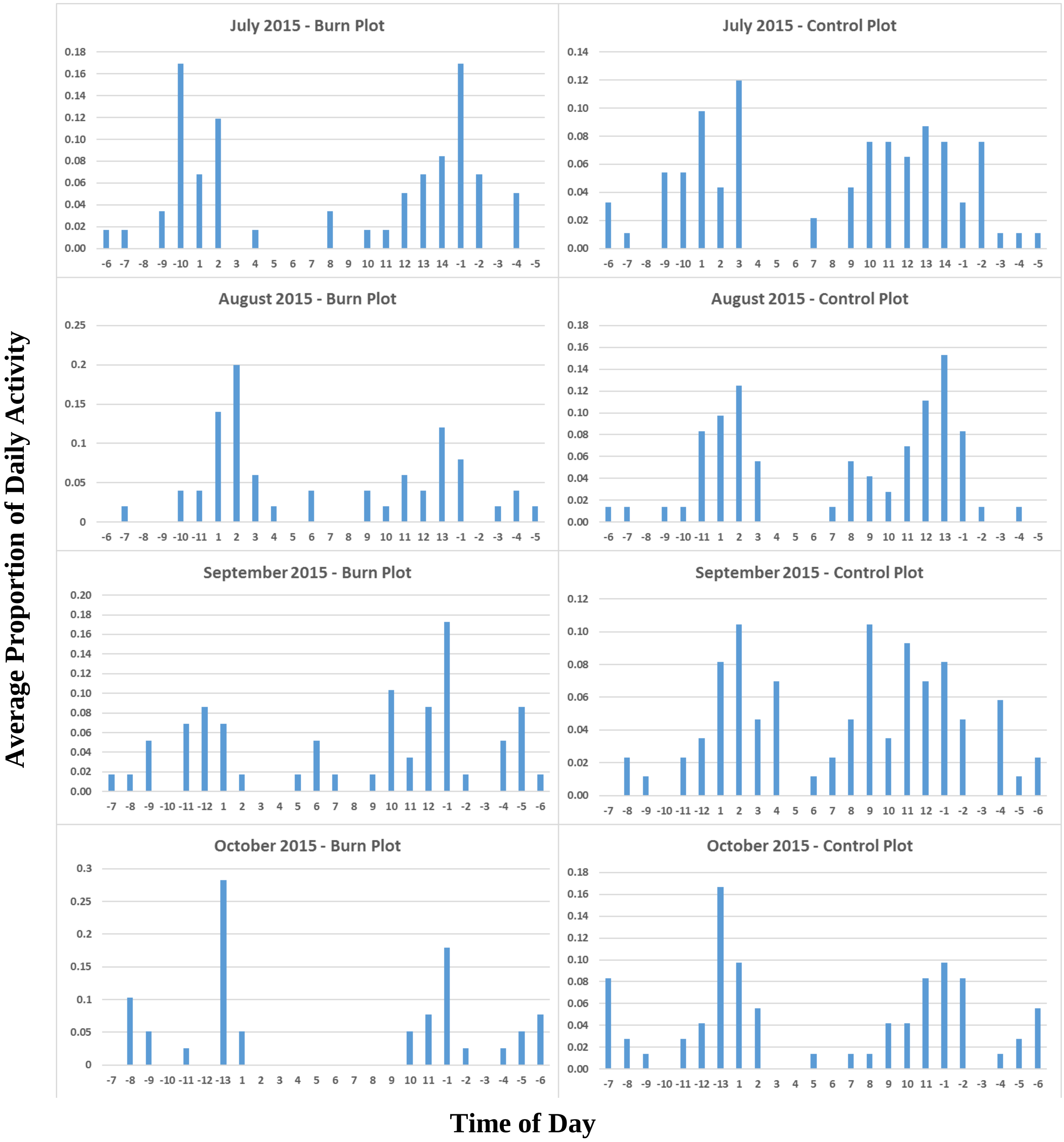


Figure 4.2. Shows the proportion of nocturnal activity between sunset and sunrise per survey period over the course of a year; differences among months were not significant (P=0.171).


Average Proportion of Daily Activity
Time of Day
March 2015 - Burn Plot
0.00 0.05 0.10 0.15 0.20 0.25 0.30
-7 -8 -9 -10 -11 -12 1 2 3 4 5 6 7 8 9 10 11 12 -1 -2 -3 -4 -5 -6
March 2015 - Control Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
-7 -8 -9 -10 -11 -12 1 2 3 4 5 6 7 8 9 10 11 12 -1 -2 -3 -4 -5 -6
April 2015 - Burn Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
-6 -7 -8 -9 -10 -11 1 2 3 4 5 6 7 8 9 10 11 12 13 -1 -2 -3 -4 -5
April 2015 - Control Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
-6 -7 -8 -9 -10 -11 1 2 3 4 5 6 7 8 9 10 11 12 13 -1 -2 -3 -4 -5
May 2015 - Burn Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20
-6 -7 -8 -9 -10 1 2 3 4 5 6 7 8 9 10 11 12 13 14 -1 -2 -3 -4 -5
May 2015 - Control Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14
-6 -7 -8 -9 -10 1 2 3 4 5 6 7 8 9 10 11 12 13 14 -1 -2 -3 -4 -5
June 2015 - Burn Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16
-6 -7 -8 -9 -10 1 2 3 4 5 6 7 8 9 10 11 12 13 14 -1 -2 -3 -4 -5
June 2015 - Control Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14
-6 -7 -8 -9 -10 1 2 3 4 5 6 7 8 9 10 11 12 13 14 -1 -2 -3 -4 -5


Average Proportion of Daily Activity
July 2015 - Burn Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
-6 -7 -8 -9 -10 1 2 3 4 5 6 7 8 9 10 11 12 13 14 -1 -2 -3 -4 -5
July 2015 - Control Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14
-6 -7 -8 -9 -10 1 2 3 4 5 6 7 8 9 10 11 12 13 14 -1 -2 -3 -4 -5
August 2015 - Burn Plot
0 0.05 0.1 0.15 0.2 0.25
-6 -7 -8 -9 -10 -11 1 2 3 4 5 6 7 8 9 10 11 12 13 -1 -2 -3 -4 -5
August 2015 - Control Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
-6 -7 -8 -9 -10 -11 1 2 3 4 5 6 7 8 9 10 11 12 13 -1 -2 -3 -4 -5
September 2015 - Burn Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18 0.20
-7 -8 -9 -10 -11 -12 1 2 3 4 5 6 7 8 9 10 11 12 -1 -2 -3 -4 -5 -6
September 2015 - Control Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12
-7 -8 -9 -10 -11 -12 1 2 3 4 5 6 7 8 9 10 11 12 -1 -2 -3 -4 -5 -6
October 2015 - Burn Plot
0 0.05 0.1 0.15 0.2 0.25 0.3
-7 -8 -9 -10 -11 -12 -13 1 2 3 4 5 6 7 8 9 10 11 -1 -2 -3 -4 -5 -6
October 2015 - Control Plot
0.00 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
-7 -8 -9 -10 -11 -12 -13 1 2 3 4 5 6 7 8 9 10 11 -1 -2 -3 -4 -5 -6
Time of Day

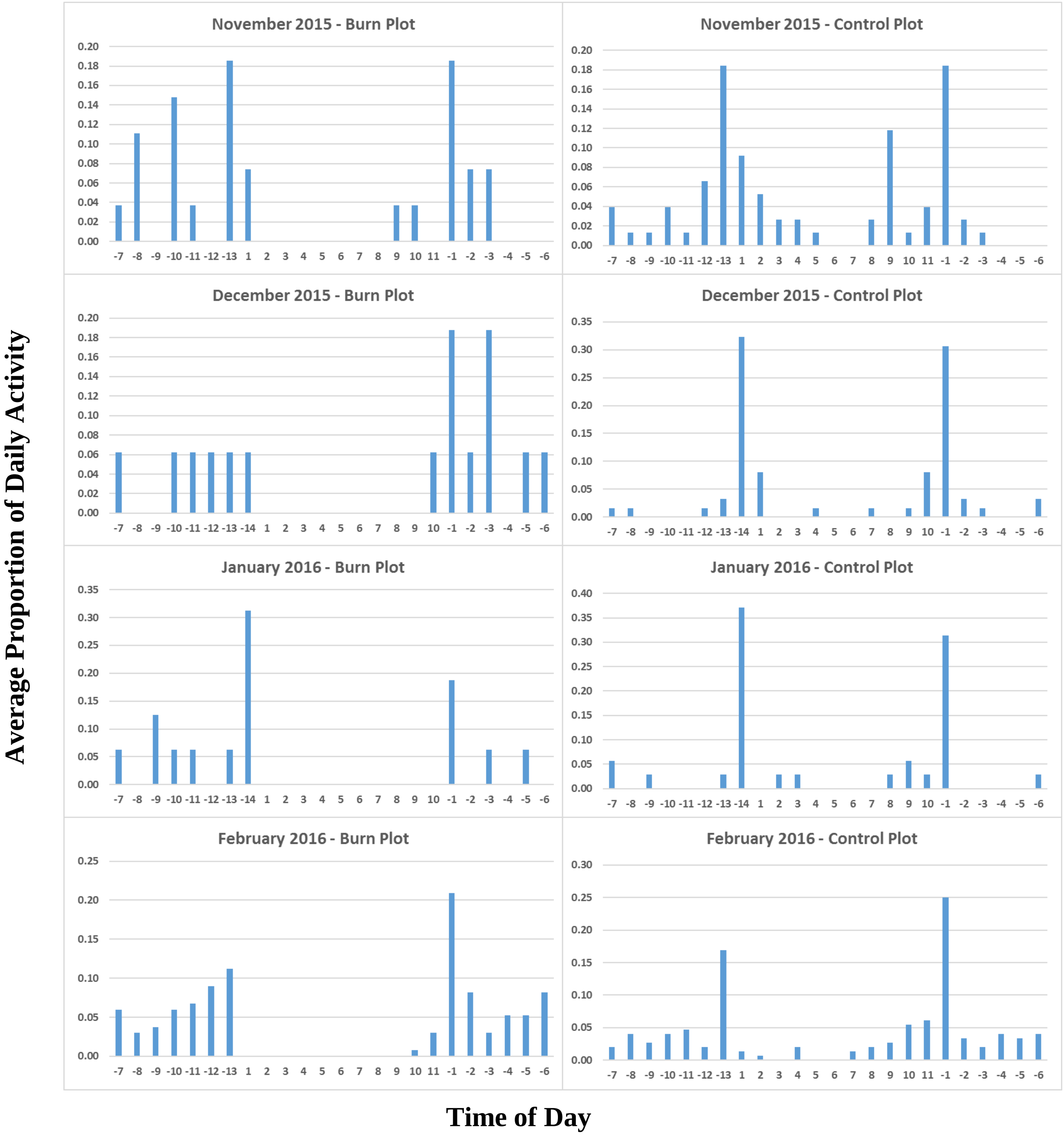


Figure 4.3. Displays the average 24 hour proportional distribution of *Sigmodon hispidus* activity for each month and treatment. Burn activity is on the left and control activity is on the right. Positive numbers represent daylight hours and negative numbers represent nighttime hours.

CHAPTER 5

GENERAL CONCLUSIONS

Cotton rat (*Sigmodon hispidus*) populations recovered quickly following the burn, which was confirmed by cameras visitation rates and live trapping population estimates. Estimated population sizes in winter were equal in size for burn and control plots which was also confirmed by camera visitation rates. Biomass was comparable in the summer between burn and control plots, but leading up to or during winter, sub-lethal behavioral effects likely resulted in reduced biomass for the burn population that most likely was a result of predation risks, reduced temperatures, or both. There is likely a strong relationship between cotton rats and their predators that influences seasonal activity. Visitation rates were significantly different between treatments, which may reflect population density changes, or possibly reduced activity due to predation risks in burned plots. Cohort survival was comparable in both plots, indicating that behavioral changes may have resulted in reduced visitation, or that individuals that were marked in the summer exercised vigilance and younger size classes were depredated more.

Summary of Research Findings

1. Cotton rats in burn plots following a prescribed burn in mid-February 2015 outnumbered populations in control plots by late June 2015. In February 2016 populations were nearly identical in size.
2. Average biomass in burned and control plots was nearly identical June 2015, but in February 2016, average biomass was significantly less in burned plots.

3. Total estimated biomass in burned and control plots did not significantly differ between treatment or season.
4. Cotton rat populations experience a small decline in winter.
5. Game cameras are able to record recaptures of small mammals, allowing for survival studies of at least two cohorts. Populations were reduced in burn plots but survival was comparable to control plots.
6. Camera CDRs and detection probabilities according to Program MARK are comparable and do not differ significantly. Additionally, camera visitation rates reflect population estimates.
7. Cameras efficiently produce accurate behavioral information on small mammals that does not require much effort or removal of small mammals by live traps.
8. Behaviorally, cotton rats are most active crepuscularly, but demonstrated some activity at all times of day.
9. Cotton rat populations did exhibit a shift in activity distribution from mostly diurnal in warmer months to mostly nocturnal in colder winter months.
10. Individuals in burned plots experienced sub-lethal behavioral effects that likely reduced fitness, and required them to be more active throughout the night in the winter than individuals in control plots that exhibited reduced activity.

Management Implications

According to camera visitation rates, a little over a month following prescribed burns cotton rat populations not only recovered, but outnumbered visitations of cotton rats in control plots, which was confirmed by summer population estimates based on trapping. Cotton rats faced temporary declines that likely provided a short-term benefit to predators that use the plots, as vegetation was reduced, but recovered quickly, indicating no long-term negative consequences to cotton rat population sizes. By the following winter, populations in burned plots experienced reduced biomass, but not reduced population sizes, indicating some long-term behavioral consequences. Dormant season fires can remove vegetation cover for extended periods of time, so growing season fires likely provide a better outcome where forage and vegetation cover for protection from predation is concerned.

Burns were initiated at the beginning of the growing season. Vegetation began growing immediately, which likely benefitted cotton rats by providing forage, however the loss of dense ground cover likely had negative behavioral impacts due to predation risk. Burning in the future should be done in a way that maximizes reduction of trees and shrubs that diminish the maritime grasslands in order to maintain the habitat. However, where it is possible, leaving patches of grass behind may provide a number of benefits to cotton rats including reduction of predation risk. Burning was conducted using a carefully planned grid ignition in which all above ground vegetation was burned. Using the same strategy, land managers could intentionally leave behind more patches of muhly grass and accomplish the goal of reducing succession of shrubs and trees. Cotton rat nests were commonly observed inside the remnants of large muhly clumps post-burn. When ground cover is reduced completely, it takes up to three years for above ground biomass to reach pre-burn equilibrium (Herndon and Taylor 1986), meaning that nests inside of muhly clumps may not be an option for cotton rats for several years following burns. Given the recovery time, and the value of well-developed muhly in winter control plots, burning no more than every five to seven years is recommended. Additionally, a patchier burn may provide a solution to land managers who only have the option to burn in the winter during the dormant season. Leaving some densely vegetated patches may offer refuge and forage to some individuals and compensate for the delayed growth of vegetation until the growing season begins again. Leaving behind some of this above-ground material during any season prescribed fire is employed, may prevent the reduced biomass experienced by cotton rats in the winter burn plots by providing access to dense vegetation cover to mitigate predation risk. It was not a particularly cold winter comparatively, and reduced biomass could possibly result in increased mortality on colder years. Also, no empirical data were collected on the seed production of muhly, but I saw that burning had a noticeable positive impact on seed production which may be an additional benefit for managers wishing to promote the habitat, as muhly is not a rhizomatous grass and requires seed to propagate (see also Main and Barry 2002).

Management that promotes this rare and declining habitat type benefits a number of organisms ranging from vegetation to predators. Cotton rats comprised a significant amount of biomass in maritime grasslands, along with other herbivores that were observed, such as marsh rabbits. Cotton rats prosper in grasslands comprised of dense ground cover. Using prescribed fire as a management tool maintains the habitat and does not have long-term consequences to population sizes. Maintaining and enhancing these grasslands provides a significant source of vegetation for herbivores and prey to any predator occupying the habitat, particularly to those of management concern. In the future, coastal land managers should prioritize the maintenance, enhancement, and where necessary, the restoration of maritime grasslands, as it is one of the most productive wildlife habitats found in coastal dune systems.

Future Directions and Recommended Research

Cotton Rats: Among the highest future research priorities are to develop spatially explicit models to increase the accuracy and reliability of population estimates, and pair this with the camera data. I observed substantial survival and winter reproduction in contrast to other studied populations in colder climates (Odum 1955, Goertz 1965a, Mabry et al. 2003, Clark et al. 2003, Bergstrom and Rose 2004, Green and Rose 2009, Reed and Slade 2010, Wright et al. 2010). Information gathered through cameras and trapping in this study can inform parameters to model cotton rat populations, including survival, fecundity, and proportion of juveniles, and may prove valuable when modeling changes from stochastic events or even predicting response to climate change. I will evaluate these data for time spent at bait stations as a measure of giving up densities to assess predation risks and, to pair with current behavioral data (see Chapter 4). Finally, it has been suggested that some degree of social territoriality may exist in large adults in order to restrict the effects of competition from conspecifics, that can result in activity shifts of younger age classes (Calhoun 1945, Spencer and Cameron 1983, Doonan and Slade 1995). I will also assess size classes related to activity times more closely to see if larger cotton rats are active at peak times, and younger subordinate size classes are active around the clock to avoid social competition in the wild as suggested by Calhoun's laboratory study (1945).

During summer trapping sessions, I did not capture any marsh rice rats (*Oryzymys palustris*), but I captured several in every plot during the winter trap session. I observed a few individuals on camera in the winter following the burn and began to see them again during the following winter. Winter rains partially flooded many areas within the plots, and marsh rice rats are known to prosper in wetland environments. Whether habitat requirements improve in the winter with flooding, resources were scarce in other habitats, or if cotton rats competitively displaced them in the summer but not winter is unknown and pose interesting research questions.

Also, there was a lot of evidence of fire ants found throughout the maritime grasslands, and the relationship to cotton rats and other small mammal species warrants future attention. Other studies have shown that fire ant presence can result in cotton rats altering habitat use or displacing other species of small mammals in the same habitat (Peterson et al. 2003, Holtcamp et al. 2010).

The Significance of Vegetation: The importance of vegetation cover density to survival or increased densities of cotton rats is mentioned frequently in the literature (Goertz et al 1964, Schnell et al. 1968, Guthery et al. 1974, Cameron et al. 2009, Layne 1974, Kirchner et al. 2011, Connor et al. 2011, and Morris et al. 2011). It is known that reduced cover does not negatively impact cotton rat foraging resources, but cover reduction in microhabitats does result in reduced time spent foraging by cotton rats compared to areas with dense vegetation (Hinkleman et al. 2012, Morris et al. 2012). These observations suggest that cotton rat fitness was negatively impacted in the winter by sub-lethal behavioral impacts. In the future a comparison of winter impacts to cotton rats where a patchy burn occurs, to an entirely burned area could determine if a different strategy improves cotton rat winter fitness.

Finally, I recorded vegetation presence and density that will be incorporated in future publications, in order to relate vegetation parameters to cotton rat predation risk. I did not record vegetation height, which may be of importance where predation risk and nest site selection is concerned, so I recommend taking this into consideration for future studies.

Prescribed Burning: While I can currently make recommendations based on my short-term observations and the literature available, it would be valuable to have empirically based evidence that demonstrated the optimal burn interval for wildlife fitness, reduction of trees, and maintenance of maritime grasslands. A long-term study examining plots with multiple burn intervals would be necessary. Additionally, such a long-term study could examine the impacts of season on vegetation and wildlife found in maritime grasslands. Finally, a study comparing the fitness of cotton rats in fully burned maritime grasslands to cotton rats in sites that were burned patchily could better inform management based on these recommendations, particularly in the winter, for land managers that only have the ability to burn during the dormant season.

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