5-1995

Fire Occurrence, Behavior and the Effect of Fire on Deer Mouse Density in Oakbrush at Camp Williams National Guard Base, Utah

Joel E. Godfrey

Follow this and additional works at: https://digitalcommons.usu.edu/etd

Part of the Forest Sciences Commons

Recommended Citation
Godfrey, Joel E., "Fire Occurrence, Behavior and the Effect of Fire on Deer Mouse Density in Oakbrush at Camp Williams National Guard Base, Utah" (1995). All Graduate Theses and Dissertations. 3626.
https://digitalcommons.usu.edu/etd/3626

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Theses and Dissertations by an authorized administrator of DigitalCommons@USU. For more information, please contact dylan.burns@usu.edu.
FIRE OCCURRENCE, BEHAVIOR AND THE EFFECT OF FIRE ON DEER MOUSE DENSITY IN OAKBRUSH AT CAMP WILLIAMS NATIONAL GUARD BASE, UTAH

by

Joel E. Godfrey

A thesis submitted in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE
in
Forestry

UTAH STATE UNIVERSITY
Logan, Utah
1995
ABSTRACT

Fire Occurrence, Behavior and the Effect of Fire on Deer Mouse Density in Oakbrush at Camp Williams National Guard Base, Utah

by

Joel E. Godfrey, Master of Science
Utah State University, 1995

Major Professor: Dr. Michael J. Jenkins
Department: Forest Resources

Fire occurrence and behavior were determined by collecting and analyzing fuel, weather, and fire history data. Fuel plots were used to measure average fuel loading by vegetation type and integrated with weather to make worst-case fire behavior predictions. A fire history was developed using oakbrush (Quercus gambelli Nutt.) sprouts to determine age and the Global Positioning System (GPS) for mapping the burned areas. Average fuel loading was highest in the oakbrush fuel type with 16.8 t/ha, then juniper (Juniperus osteosperma Torrey) with 6.72 t/ha, and the lowest was in sagebrush (Artemisia tridentata Nutt.) with 4.93 t/ha. Fire behavior predictions were similar for all fuel types. The fire rotation for the study area was
calculated to be 130 years. The fire history showed the most hectares burned were in the oakbrush fuel type due to fuel loading and horizontal continuity. Prescribed burns and vegetative fuel breaks were suggested as management alternatives.

The effect of fire on deer mouse (Peromyscus maniculatus) density in oakbrush was determined by using a trapping web design with distance sampling techniques. Webs were set in four pairs with one web of each pair being in 7-year-old burned oakbrush and the other web in unburned oakbrush. Variables such as shrub height and litter depth were recorded in order to reduce variance. Trapping occurred in June 1994 with each web set for two consecutive nights using 80 Museum Special snap traps spaced 6 m apart on eight lines. Density estimates were determined by using a computer program called DISTANCE and then analyzed using analysis of variance with a randomized block design. No significant differences between deer mouse densities were detected between burned and unburned oakbrush. Although litter depth and shrub height were both significantly less in burned sites, it did not affect deer mouse density. The conclusion from these results was that after 7 years oakbrush had recovered to a point that the effect of fire on deer mouse density was negligible.
ACKNOWLEDGMENTS

I would like to thank Dr. Michael Jenkins for the guidance and input that led to the successful completion of this project. I would also like to thank Dr. James Long, Dr. Mike Wolfe, and Dr. Leila Shultz for their time and assistance. The personnel at Camp Williams National Guard Base along with Dr. John Crane of the Utah National Guard provided generous assistance as well as use of their facilities through the course of this project. My thanks also go out to the graduate students involved with this project, especially Mr. Tom Van Niel, for all their help.

I would like to give special thanks to my friends and family for their patience and understanding. My parents, John and Jackie Godfrey, deserve special mention for their years of unfailing support.

Joel E. Godfrey
# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
<td>ii</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>iii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>iv</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>v</td>
</tr>
<tr>
<td>CHAPTER</td>
<td></td>
</tr>
<tr>
<td>I.  INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>FIRE IN ECOSYSTEMS</td>
<td>1</td>
</tr>
<tr>
<td>FUELS AND FIRE BEHAVIOR</td>
<td>15</td>
</tr>
<tr>
<td>OBJECTIVES</td>
<td>19</td>
</tr>
<tr>
<td>II. FIRE OCCURRENCE AND BEHAVIOR AT THE CAMP WILLIAMS NATIONAL GUARD BASE, UTAH</td>
<td>21</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>22</td>
</tr>
<tr>
<td>STUDY AREA</td>
<td>25</td>
</tr>
<tr>
<td>METHODS</td>
<td>25</td>
</tr>
<tr>
<td>RESULTS</td>
<td>30</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>33</td>
</tr>
<tr>
<td>III. THE EFFECT OF FIRE ON DEER MOUSE DENSITY IN OAKBRUSH AT CAMP WILLIAMS NATIONAL GUARD BASE, UTAH</td>
<td>41</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>42</td>
</tr>
<tr>
<td>METHODS</td>
<td>46</td>
</tr>
<tr>
<td>RESULTS</td>
<td>50</td>
</tr>
<tr>
<td>DISCUSSION</td>
<td>57</td>
</tr>
<tr>
<td>IV. SUMMARY</td>
<td>61</td>
</tr>
<tr>
<td>LITERATURE CITED</td>
<td>65</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>79</td>
</tr>
</tbody>
</table>
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1   Average fuel loading by vegetative type</td>
<td>31</td>
</tr>
<tr>
<td>2   BEHAVE output for the 2 fuel models using average weather inputs from August 1-7, 1994 for Camp Williams National Guard Base, Utah (temp-38°C, fine dead fuel moisture-3%, midflame windspeed-1.8m/sec, live herbaceous fuel moisture-90%, average slope for the base-12%)</td>
<td>32</td>
</tr>
<tr>
<td>3   BEHAVE output for the 2 fuel models using average weather inputs from Table 1 and a midflame windspeed of 3.6m/sec</td>
<td>32</td>
</tr>
<tr>
<td>4   Size and year of recent fires at Camp Williams National Guard Base, Utah</td>
<td>35</td>
</tr>
<tr>
<td>5   Analysis of variance with a randomized block design for average shrub height</td>
<td>53</td>
</tr>
<tr>
<td>6   Analysis of variance with a randomized block design for average litter depth</td>
<td>53</td>
</tr>
<tr>
<td>7   Analysis of variance with a randomized block design for the number of juvenile deermice trapped</td>
<td>54</td>
</tr>
<tr>
<td>8   Density estimate of deermice per hectare with corresponding P-value and estimation model used for each pair</td>
<td>54</td>
</tr>
<tr>
<td>9   Analysis of variance with a randomized block design for deermouse density</td>
<td>57</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Distribution of fuel plots</td>
<td>27</td>
</tr>
<tr>
<td>2</td>
<td>Boundaries of past fires</td>
<td>34</td>
</tr>
<tr>
<td>3</td>
<td>Trapping web plot centers and their orientation to fire boundaries</td>
<td>49</td>
</tr>
<tr>
<td>4</td>
<td>Average shrub height and litter depth for burned and unburned webs</td>
<td>52</td>
</tr>
<tr>
<td>5</td>
<td>Density estimates for deermice in burned and unburned webs</td>
<td>55</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

FIRE IN ECOSYSTEMS

Fire has shaped and regulated ecosystems for millions of years with few terrestrial ecosystems remaining unaffected (Kimmins 1987, Pyne 1982). Disturbances such as fire are an integral part of the natural environment (Heinselman 1978, Agee 1993). By the beginning of the Pleistocene period early man had distinguished himself through language, stone tools, and fire control. Fire had many uses, such as a tool for clearing land, and driving game (Stewart 1955, Pyne 1982). In addition to lightning, man's use of fire has intensified the effect of fire on the landscape (Wright and Bailey 1982). Fires and ecosystems have long interacted, with fire playing a role in maintaining biological diversity, nutrient cycling, affecting insects and diseases, plant succession, wildlife habitat, and biomass reduction (Mutch 1994).

Biodiversity

The plants, animals, and microorganisms that inhabit the earth comprise biological diversity or biodiversity (Ehrlich 1990). Biodiversity includes genotypes or alleles
within a population, species within a community, and species or ecosystems in relation to the landscape or the biosphere (Burton et al. 1992).

Biodiversity has been reduced worldwide by five great periods of extinction in the past 600 million years. The first four were attributed to climatic cooling. The fifth was the result of a huge meteorite, volcanic eruptions, or a combination of the two and resulted in the extinction of the dinosaurs (Wilson 1994). In recent times man has contributed to the loss of diversity by altering the landscape. Agricultural practices such as plowing fields and planting monocultures have resulted in the loss of many prairie ecosystems. Other practices that can have a negative impact on diversity are some logging practices and dam and road building (Ehrlich 1990).

The earth is well adapted to natural perturbations, such as fire, which has few lasting effects on diversity. Fire can, in fact, increase diversity by creating space for early successional species, guiding changes in life cycles, and enhancing variety and resilience (Wilson 1994). In the past, fires have occurred on different spatial and temporal scales ranging in orders of magnitude. This diversity in fire regimes promotes biodiversity (Martin and Sapsis 1991). Natural landscapes subject to disturbance are characterized
by a patchy structure and can be altered by fire suppression (Baker 1992). A study conducted at Yellowstone National Park by Romme (1982) found that biodiversity was significantly increased after fire. Romme attributed an increase in biodiversity to the occurrence of large fires in the 1700s and the subsequent decline in biodiversity during the late 1800s to a relatively fire-free interval (Romme 1982).

Nutrient Cycling

Fire is a major factor in nutrient cycling, especially within fire-dependent ecosystems. Rates of recycling can be influenced by fire intensity and frequency. Fire suppression impedes biomass decomposition and can result in an accumulation of nutrients (Heinselman 1978).

The effects of fire on nutrient cycling are reflected in the subsequent change in soil productivity and varied based on soil type, plant species, and region (Ahlgren and Ahlgren 1960). Fire results in decreased organic matter, lower soil moisture-holding capacity, and increased nutrients in the surface layers of soil (Wagle and Kitchen 1972). Burning releases nutrients held in litter, which can then be rendered volatile, water soluble, or easily suspended in air as particulate matter. Moisture retention
is reduced in burned litter, which results in increased runoff and leaching of nutrients (Ahlgren and Ahlgren 1960, Lewis 1974). Fire increases the probability of nutrient loss by wind by opening up the understory and lowering litter density (Lewis 1974). However, nutrients from ash can result in increased plant and microorganism growth (Ahlgren and Ahlgren 1960).

A study conducted by Smith (1970) on a site comprised mainly of jack pine (Pinus banksiana Lamb.) in Ontario showed the effect of fire on nutrient cycling. The study showed that organic matter consumed by fire resulted in a higher soil pH level and increased levels of soluble salts in the partially burned organic matter and ash. The study found that the majority of nutrients released were in easily dissolved forms that are highly susceptible to leaching. After the initial increase, leaching was presumed to be the cause of nutrient loss 15 months after the fire. Levels of potassium and calcium were lower at the surface level as early as 5 weeks after burning. Cation levels decreased at surface depths, which resulted in a decrease in pH and soluble salt levels (Smith 1970).

A study conducted by Lewis (1974) in a South Carolina pine forest showed a slow increase in nitrates and phosphates after burning. The majority of nitrogen is
generally lost to factors such as volatilization while a slight increase was attributed to biological processes (Lewis 1974). Grier (1975) found in his Washington state study of coniferous ecosystems large nutrient losses during the fire, leaching of mineralized cations into the soil, and a high retention of these cations in the soil. Cations leached from the ash and retained in the soil were calcium, magnesium, potassium, and sodium.

A study on ponderosa pine (Pinus ponderosa Doug. ex Laws) in Arizona compared nutrient availability in different aged burns (Wagle and Kitchen 1972). The old burn was over 15 years old and the new burn was over 3 years old at the time of this study. Wagle found that the old burn was low in nutrients such as phosphorus and nitrogen at three different soil levels; however, the new burn had higher nutrient availability at the surface layer of soil (Wagle and Kitchen 1972).

Insects and Diseases

Periodic fires can help maintain insect and disease populations at endemic levels. Insects and diseases create residue that increases the likelihood of fire. Fire in turn creates residue that can be attractive to insects and disease (Fellin 1979). Bark beetles (Dendroctonus
spp. [Coleoptera: Scolytidae]) are an example of insects that create a large amount of residue in a relatively short period of time (Fellin 1979, Dahlsten and Rowney 1983). The major effects of insects on a forest are on stand composition, age, and stand density. This can alter plant succession, which in turn affects the flora and fauna (Dahlsten and Rowney 1983).

For fire to be used effectively in forest insect management, it is important to understand the insect life cycle (Fellin 1979). Surface fires may be effective in managing forest insects that spend part of their life cycle on the forest floor. Insects susceptible to this type of fire include defoliators, seed and cone insects, and beetles associated with logging slash that live under the bark (Mitchell 1990). For example, engraver beetles (Ips spp. [Coleoptera: Scolytidae]) spend part of their life cycle in logging slash and prescribed burns can generate enough heat to kill them (Mitchell 1990).

Fire can indirectly affect insect populations by changing their environment, especially through alteration of forest structure and composition. Fire suppression and selective logging have been factors in changing forest composition in favor of tree species more susceptible to insects (Mitchell 1990). For example in ponderosa pine
forests, fire suppression and logging have combined to convert ponderosa pine stands to more shade-tolerant species such as true firs (Abies spp.), which are more susceptible to defoliators such as western spruce budworm (Choristoneura occidentals [Lepidoptera: Tortricidae]) (Fellin 1979, Mitchell 1990).

Fire also affects the occurrence and severity of pathogen outbreaks (Thies 1990). A study conducted by Irving and French (1971) found fire to be effective in controlling dwarf mistletoe (Arceuthobium pusillum Peck) in black spruce (Picea mariana B.S.P.). At the study site, mortality in black spruce increased as a result of dwarf mistletoe. Selective cutting was ineffective because not all of the mistletoe was removed, but Irving and French (1971) observed that fire with sufficient intensity would eliminate dwarf mistletoe.

Fire has been used successfully to control for brown spot needle blight (Scirrhia acicola Dearn) in a study on longleaf pine (Pinus palustris Mill) conducted by Hardison (1976) in the southern U.S. The study found that surface fires were sufficient to reduce brown spot needle blight for the 2 years needed for longleaf pine seedlings to become established (Hardison 1976).
When using prescribed fire to manage insects and diseases, care should be taken to avoid damage to residual trees, which may increase the likelihood of infection. Fire scars make trees susceptible to fungi, which cause butt, stem, and heart rots (Thies 1990).

Fire Effects on Flora

Fire affects plant succession and wildlife habitat and generally returns ecosystems, such as forests, to an earlier successional state (Heinselman 1978). Fire effects on plant succession are dependent on numerous factors, including how well plant species have adapted to fire by mechanisms such as thick bark and sprouting (Wright and Bailey 1982).

Gambel oak (*Quercus gambeli* Nutt.) is widely distributed over the Rocky Mountain West, including Utah, Colorado, Arizona, and New Mexico (Wright and Bailey 1982, Clary and Tiedemann 1986). Gambel oak ranges from a medium-sized shrub, 1 to 3 meters, to a medium-sized tree, 5 to 15 meters (Tiedemann et al. 1987). It is very fire tolerant, suckering prolifically after a fire, resulting in increasingly dense stands merging into continuous thickets over time (Wright 1971). Research conducted in Utah by McKell (1950) found that oakbrush grows very rapidly the first two growing seasons after a burn, sprouting within 10
...days (Tiedemann et al. 1967). McKell found after 18 years that only 75 percent of the stand's original cover had been reached. This same study indicated that the number of shoots increased four times after a burn, but decreased to preburn levels after 18 years (McKell 1950). Oak brush tends to become less dense over time when protected from fire (Brown 1958).

Utah juniper (*Juniperus osteosperma* Torrey) is found in Arizona, Utah, Nevada, and parts of California. The effects of fire on juniper depend on tree height, surface fuel loading, and burning conditions. Trees taller than 1.2 meters are hard to kill in open stands due to the relatively low fuel loading under individual trees (Wright et al. 1979); however, dense stands of juniper have a greater potential for fire spread (Aro 1971).

Big sagebrush (*Artemisia tridentata* Nutt.) often borders pinyon-juniper and oakbrush zones at elevations from 610 to 2,134 meters above sea level. Big sagebrush is a nonsprouter, from 0.45 to 0.76 meters in height, and is damaged by fire (Wright et al. 1979). However, it will reestablish in burned areas over a period of time by seed (Harniss and Murray 1973, Wright et al. 1979).
Fire Effects on Fauna

Fire changes an ecosystem, affecting both flora and fauna. Birds and mammals are adapted to their environment and react to disturbances such as fire (Bendell 1974). Frequent forest or range fires maintain the number and variety of plants that provide cover and food for wildlife (Wright and Bailey 1982, Gruell 1984). Wildlife can modify fire occurrence by reducing fuel loading through grazing. Materials in trees from nest-building fauna may increase the chances of ignition (Bendell 1974). The effects of fire on animals depend on variables such as the animals' mobility, size of the fire, rate of spread, fuel type, and fire frequency (Buech et al. 1977, Peek 1986). Mobile animals can move away from the fire and take shelter in unburned areas; animals that burrow can find protection within the soil (Handley 1969). Komarek (1969) observed little mortality in reptiles, such as snakes, which were seen sunning themselves directly after a fire on burned over sites (Komarek 1969). Komarek (1969) also observed cotton rats (Sigmodon spp.) carrying their young while running away from the fire.

The short-term effects of fire on animals can result in injury, death, loss of food and cover, and increased predation. The long-term response for some animal species,
however, includes increased population density (Ream 1981, Kimmins 1987). Whether fire benefits wildlife habitat is dependent on the habitat needs of a given species (Miller 1963, Peek 1986). Fire can modify habitat by removing trees and shrubs, which increases open areas, and can result in increased temperatures at that site. Fire burns unevenly, leaving a patchwork of unburned vegetation, open areas, and burned fuels such as logs and stumps. The amount of edge created by fire benefits a number of wildlife species (Miller 1963, Bendell 1974, Wright and Bailey 1982). Both the size and shape affect the amount of edge, with larger burns having a lower proportion of edge to open area than smaller burns (Bendell 1974).

Large herbivores such as deer (*Odocoileus* spp.) benefit from the increased browse and openings created by burning. Population densities of mule deer (*O. hemionus*) have been found to be higher on burned than unburned sites (Handley 1969, McCulloch 1969). Deer have also been seen feeding on ash directly after a fire, having been attracted to the nutrients found in the ash (Komarek 1969).

Species of some small mammals are known to increase in postburn sites due to increased growth of herbaceous and seed-producing plants (Beck and Vogl 1972, Bendell 1974, Ream 1981). An example of this is the deer mouse,
*Peromyscus maniculatus.* Due to its adaptability the deer mouse is found over most of North America in a variety of habitats, including forested and disturbed areas (Jameson 1955, Hall 1981). Deer mice nest in burrows made in a variety of places including in trees, on the ground, and in dwellings. They feed on seeds, acorns, berries, and insects. Their home range is from 0.2 to 1.2 hectares or greater with a high summer population of 25 to 37 per hectare (Burt and Grossenheider 1980). Deer mice are a pioneer species favoring early successional stages created by disturbance (Ream 1981, Kaufman et al. 1990). Deer mice population densities increase on burned areas because they feed on seeds which survived in soil after burning (Beck and Vogl 1972, Bendell 1974). Foraging in burned areas where there is less plant litter is preferred (Kaufman and Kaufman 1990). Their nocturnal habit and erratic movements help protect them from predators in open postfire environments (Ream 1981).

Fire impacts bird species through modifying their habitat by increasing openings and reducing the number of trees and shrubs (Bendell 1974). In terms of abundance most bird populations remain the same before and after a fire (Emlen 1970, Bendell 1974). However, species composition may change as a result of fire. Birds that are attracted to
burn areas are the mourning dove (*Zenaida macroura*), robins (*Turdus migratorius*), and some species of woodpecker, which all feed on the insects and seeds found on a fresh burn (Stoddard 1963, Wright and Bailey 1982). Some species of hawks are attracted while the fire is still burning to feed on escaping insects (Stoddard 1963).

**Fire History**

Fire histories can be used to better understand the historical role of fire on ecosystem processes. A variety of methods for fire histories can be used, including dates obtained from fire scars and by aging sprouts that are produced by certain species after a fire. A variety of terms is used in fire history studies, including fire frequency, fire rotation, and fire return interval. Fire frequency refers to the occurrence of fire in a given area over time. Fire rotation or natural fire rotation (NFR) is defined as the number of years required to burn over and reproduce an area equal in size to the study area (Heinselman 1973). A fire return interval is the term used for the period of time between two successive fires in a given area. A mean fire return interval is the average of all fire return intervals for a given area (Romme 1980). Fire return intervals or mean fire return intervals are most
commonly used when describing the fire history of a given area because data can be gathered through point sampling or through a past record of fire occurrence for the study area. Examples of fire return intervals can be given for three fuel types: sagebrush, juniper, and oakbrush. The fire return interval for sagebrush was estimated from a study site in Yellowstone National Park at 32 to 70 years with smaller fires occurring every 17 to 41 years (Houston 1973). Fires have been estimated to occur in juniper about every 10 to 30 years (Leopold 1924). However, since settlement and the introduction of grazing, fine fuels in juniper stands have been greatly reduced, which in turn reduces fire frequency (Nabi 1978). The fire return interval for oakbrush has been estimated at once or twice every 100 years during prolonged dry conditions (Wright and Bailey 1982).

Natural fire rotation is not a common descriptor because the actual size of the burned area, as well as the size of the study area, is required for the calculation. The formula for NFR is the total time period divided by the proportion of the area burned (Heinselman 1973). If the size of the burn area is unknown, which is often the case when dealing with past fires, then NFR cannot be calculated.
One other effect of fire on the ecosystem is biomass reduction. The National Wildfire Coordinating Group (NWCG) (1981) defined fire behavior as the way in which fuels ignite, flames develop, and fire spreads and exhibits other phenomena. The amount of biomass, or fuels, reduced by fire is directly related to the behavior of a given fire. Fire behavior predictions are based on three stages as discussed in Rothermel (1983). The first stage includes evaluating inputs such as fuels, fuel moisture, weather, topography, and slope; second is calculating rate of spread and intensity from these inputs; and third is interpreting rate of spread and intensity to obtain other outputs such as fire perimeter, area, flame length, spread distance, and identifying spotting and crowing conditions (Rothermel 1983).

Fuel can be described as all living and dead plant material from the bare mineral soil up to the top of the vegetation canopy that will ignite and burn (NWCG 1981). There are a number of factors that determine how fuels will affect fire behavior. Fuel compactness affects the spread of fire because it influences air supply and heat transfer. Optimum spread and intensity are observed when compactness is between the two extremes. If fuel is very tightly
compacted, the air supply is low and heat penetration is poor. When fuels are extremely loose, heat transfer is lost because the fuels are too widely spaced (Rothermel 1972).

Fuel continuity is another factor that greatly affects fire behavior. Fuels can be broken up into three vertical strata: ground, surface, and aerial (Brown and Davis 1973, Anderson 1982). Ground fuels, the first stratum, are all burnable material below the loose surface litter, including duff and roots lying underneath the ground. Materials within this stratum are usually tightly compacted and partially decomposed. Surface fuels include fallen leaves or needles, twigs, bark, cones, and small branches. Also included are grasses, forbs, low shrubs, saplings, heavier branchwood, downed logs, and stumps. Aerial fuels are all burnable material, live or dead, 1.5 to 2 m above the ground. Aerial fuels are partially comprised of branches and twigs of trees and shrubs and dead standing trees (Brown and Davis 1973, Anderson 1982, NWCG 1981).

Horizontal continuity is important to fire behavior and the ability of the fire to move from surface to aerial fuels. Both vertical and horizontal continuity are relative terms and depend on burning conditions and the heat energy produced by a given fire (Brown and Davis 1973, Anderson 1982).
Fuel moisture is the amount of moisture a particle of fuel contains as a percentage of its oven dry weight. Fuel moisture is a limiting factor for fire ignition and spread and varies according to current weather conditions. When fuel moisture is high, ignition is poor and rate of spread is low; however, low fuel moisture results in high ignition and spread components (Shroeder and Buck 1970).

Fuel loading is important to fire behavior and is expressed in terms of weight per unit area (Brown et al. 1982). The planer intersect technique of fuel inventory outlined by Brown et al. (1982) measures duff and litter depth, herbaceous vegetation, shrubs, small conifers, and dead and downed woody debris. The fuel plot is a randomly placed 17-m line transect for downed woody material, duff depth, and litter depth, with two 36.4 sq m circular plots for shrubs and one 121.4 sq m circular plot for small trees (Brown et al. 1982). Downed woody material is measured by counting the number of 0 to 0.6 cm and 0.6 to 2.5 cm particles intersected by the vertical sampling plane between 0 to 2 m from the sampling point. Particles from 2.5 to 7.6 cm are counted from 0 to 3 m from the sampling point. Pieces greater than 7.6 cm in diameter are sampled from 0 to 17 m with individual diameters and whether sound or rotten being recorded for each sample (Brown 1974, Brown et al.).
Duff depth is measured at 0.3 and 1 m from the sampling point. Shrubs are recorded on the two 36.4 sq m plots by diameter class for each stem by species. An average shrub height is given for each plot as well as an ocular estimate of percent cover both live and dead. The number of trees shorter than 3 m and within the 121.4 sq m plot is recorded by height and species (Brown et al. 1982). BIOMASS, a computer program, was developed for analyzing fuel inventory data (Brown et al. 1982).

Fire weather is the most important factor affecting fire behavior. Changes in fire weather values affect ignition, spread, and intensity of wildland fires (Fischer and Hardy 1972). Fire weather variables include wind speed and direction, air temperatures, relative humidity, precipitation, and cloudiness (Fischer and Hardy 1972).

Topography includes the physical features of an area and also affects fire behavior. Steep slopes increase fire spread by aided convective heat transfer preheating fuels ahead of the flaming front. Topography can alter fire weather through factors such as elevation and aspect (Heinselman 1978, NWCG 1981).

Fuels, weather, and topography are all factors that affect fire behavior. There are a number of variables used for describing fire behavior and they are rate of spread,
heat per unit area, fireline intensity, and flame length. Rate of spread is used to describe the rate of advance at the fire head. Heat per unit area is the amount of heat released per square foot while that area is within the flaming front. Fireline intensity is the amount of heat released per foot of fire front per second. Fireline intensity is directly related to containment and is based on rate of spread and heat per unit area. Flame length is the average length of flame at the projection point. Flame length can be used as an indicator of fireline intensity (Rothermel 1983).

Today, wildland fires are an increasing concern for both public and private land managers. The effect of fire on both flora and fauna in terms of ecosystem health and management is an important issue for land managers. Land managers need an understanding of how an ecosystem reacts or adapts to fire before they can start working towards establishing a better balance between resource objectives.

OBJECTIVES

The purpose of this project was to provide Camp Williams personnel with fire occurrence and behavior information that would be useful in evaluating possible management alternatives and the affects of fire on specific
Management alternatives considered base objectives, which include training missions, public safety, and ecosystem health. The objectives of this study at Camp Williams were as follows:

1) to determine fuel loading by vegetative type;
2) to monitor and record fire weather and make worst case fire behavior predictions;
3) to develop a fire history for areas outside of the impact area;
4) to compare deer mice population densities in burned and unburned oakbrush stands.
CHAPTER II
FIRE OCCURRENCE AND BEHAVIOR AT THE CAMP WILLIAMS
NATIONAL GUARD BASE, UTAH

ABSTRACT.—Fire occurrence and behavior were determined by collecting and analyzing fuel, weather, and fire history data. Fuel plots were used to measure average fuel loading by vegetation type and integrated with weather to make worst-case fire behavior predictions. A fire history was developed using oakbrush (*Quercus gambelli* Nutt.) sprouts to determine age and the Global Positioning System (GPS) for mapping the burned areas. Average fuel loading was highest in the oakbrush fuel type with 16.8 t/ha, then juniper (*Juniperus osteosperma* Torrey) with 6.72 t/ha, and the lowest was in sagebrush (*Artemisia tridentata* Nutt.) with 4.93 t/ha. Fire behavior predictions were similar outputs for all fuel types. The fire rotation for the study area was calculated to be 130 years. The fire history showed that the most hectares burned were in the oakbrush fuel type due to fuel loading and horizontal continuity. Prescribed burns and vegetative fuel breaks were suggested as management alternatives.
INTRODUCTION

Fire has shaped and regulated ecosystems for millions of years with few terrestrial ecosystems remaining unaffected (Kimmins 1987, Pyne 1982). Disturbances such as fire are an integral part of the natural environment (Heinselman 1978, Agee 1993). By the beginning of the Pleistocene period early man had distinguished himself through language, stone tools, and control of fire. Fire had many uses, such as a tool for clearing land, and driving game (Stewart 1955, Pyne 1982). Man's use of fire along with lightning has intensified the effect of fire on the landscape (Wright and Bailey 1982). Fires and ecosystems have long interacted, with fire playing a role in maintaining biological diversity and nutrient cycling, and in affecting insects and diseases, plant succession, wildlife habitat, and biomass reduction (Mutch 1994). In the past, fires have been suppressed to achieve certain management objectives. These objectives, however, have not always correspond with ecosystem health (Mutch 1994). Natural landscapes subject to disturbance are characterized by a patchy structure and can be altered by fire suppression (Baker 1992).

Today, wildland fires are an increasing concern for both public and private land managers. The effect of fire on
both flora and fauna in terms of ecosystem health and management is an important issue for land managers. Land managers need an understanding of how an ecosystem reacts or adapts to fire before they can start working toward establishing a better balance between resource objectives.

Camp Williams experiences frequent high-intensity fires commonly associated with military training. These fires are usually contained by bulldozed fire breaks within a specified target zone called the impact area. When fires do occur outside of the impact area, they can pose a serious problem for containment. Fire-fighting tactics for the base can be aided by fuel inventories and fire behavior predictions based on fuel type and fire weather. A study of past fire can assist base personnel in identifying areas where fires occur historically. Fires can be dated using fire scars and by aging sprouts that are produced by certain species after a fire.

A common species at Camp Williams that sprouts vegetatively in this manner is gambel oak (*Quercus gambelii* Nutt.). Gambel oak is widely distributed over the Rocky Mountain West, including Utah, Colorado, Arizona, and New Mexico (Wright and Bailey 1982, Clary and Tiedemann 1986). Gambel oak ranges from a medium-sized shrub, 1 to 3 meters, to a medium-sized tree, 5 to 15 meters (Tiedemann et al.)
2 4

1987). It is very fire tolerant, suckering prolifically after a fire, resulting in increasingly dense stands merging into continuous thickets over time (Wright 1971). Research conducted in Utah by McKell (1950) found that oakbrush grows very rapidly the first two growing seasons after a burn, sprouting within 10 days (Tiedemann et al. 1987). McKell (1950) found after 18 years that only 75 percent of the stand's original cover had been reached. This same study indicated that the number of shoots increased four times after a burn, but decreased to preburn levels after 18 years (McKell 1950). Oak brush tends to become less dense over time when protected from fire (Brown 1958).

The purpose of this study was to provide Camp Williams personnel with a better understanding of fire occurrence and behavior on the base. Management alternatives were then developed to best suit base objectives, which include training missions, public safety, and ecosystem health. The specific objectives were to (1) determine fuel loading by vegetative type, (2) monitor and record fire weather and make worst case fire behavior predictions, and (3) develop a fire history for areas outside of the impact area at Camp Williams.
Camp Williams is a Utah National Guard training site located 47 kilometers south of Salt Lake City on the west side of the Salt Lake Valley. The base is approximately 10,125 hectares and ranges in elevation from 1281 to 2196 meters above sea level. The base is located in upland and mountain zones with vegetation common to these areas. Wheatgrass (Elymus spp.), big sagebrush (Artemisia tridentata Nutt.), bluegrass (Poa spp.), and Utah juniper (Juniperus osteosperma Torrey) are most commonly found in the lower elevation upland zone. In the upper mountain zone, gambel oak (Quercus gambelii), bitterbrush (Purshia tridentata Pursh), wheatgrass, and forbs are found (Shultz and Crane pers. com. 1992).

METHODS

Fuel Inventories

Fuel inventories, as outlined by Brown et al. (1982), measure duff and litter depth, herbaceous vegetation, shrubs, small conifers, and dead and downed woody debris. The fuel plot is a randomly placed 17-m line transect for downed woody material, duff depth, and litter depth, with two 36.4 sq m circular plots for shrubs and one 121.4 sq m
circular plot for small trees (Brown et al. 1982). Downed woody material is measured by counting the number of 0 to 0.6 cm and 0.6 to 2.5 cm particles intersected by the vertical sampling plane between 0 to 2 m from the sampling point. Particles from 2.5 to 7.6 cm are counted from 0 to 3 m from the sampling point. Pieces greater than 7.6 cm in diameter are sampled from 0 to 17 m with individual diameters and whether sound or rotten being recorded for each sample (Brown 1974, Brown et al. 1982). Duff depth is measured at 0.3 and 1 m from the sampling point. Shrubs are recorded on the two 36.4 sq m plots by diameter class for each stem by species. An average shrub height is given for each plot as well as an ocular estimate of percent cover both live and dead. The number of trees shorter than 3 m and within the 121.4 sq m plot is recorded by height and species (Brown et al. 1982). A computer program called BIOMASS was developed for analyzing fuel inventory data (Brown et al. 1982). There were 113 fuel plots distributed by vegetation type (Fig. 1). The relative abundance of the three vegetation types was determined, sagebrush being the most abundant than oakbrush and juniper, and the fuel plots were placed proportionately.
Fig 1. Distribution of fuel plots at Camp Williams National Guard Base, Utah with each point representing 2 fuel plots superimposed on a false color composite of a Landsat satellite image for July 1993.
A National Fire Danger Rating System (NFDRS) fire weather station was constructed and equipment was put in place July 1993 (Deeming et al. 1972). Fire weather was taken daily and recorded wind speed and direction, minimum and maximum temperatures, wet and dry bulb temperatures, precipitation, state of the weather, and fuel moisture (Fischer and Hardy 1972). Changes in fire weather values affect ignition, spread, and intensity of wildland fires (Fischer and Hardy 1972).

A computer program called BEHAVE was used for predicting worst-case fire behavior. BEHAVE was developed by the Fire Behavior Research Work Unit at the Intermountain Fire Sciences Laboratory, Missoula, Montana (Burgan and Rothermel 1984). BEHAVE utilizes mathematical models to estimate rate of spread, intensity, flame length, suppression requirement, and potential for extreme fire behavior, and can be used for initial attack, real-time assessment of large fires, and prescribed burn planning (Andrews and Rothermel 1982). For the purposes of data input, fuel model 2 was used to represent sagebrush and juniper (timber, grass, and understory) and fuel model 6 for oakbrush (dormant brush, hardwood slash) as outlined by Anderson (1982). There are 13 fuel models used to represent
fuel loading for different vegetation types. Fuels are classified into four groups, which are grass, brush, timber, and slash (Anderson 1982). In fuel model 2, grass is the primary carrier of fire, in this case either under sagebrush or juniper. Fuel model 6 represents dormant brush, the state best representing oakbrush late in the fire season when live fuel moisture is low and fire spread most likely.

Fire History

The base can be divided into three major vegetation types: juniper, sagebrush, and oakbrush. There is a degree of intermix between the vegetation types with oakbrush present in all three. Oakbrush reproduces primarily vegetatively by suckers or stool shoots (Brown 1958). Prolific sprouting occurs in the year following a disturbance by fire. By counting the rings taken from sprout samples, age can be determined and used to estimate number of years since the fire for each of the burned areas.

Fires were located through knowledge of base personnel or by direct observation. Fire scaring and kills were used to verify that fire was the source of disturbance. The perimeter and size of past fires were determined using the Geographical Positioning System (GPS). GPS operates by a system of satellites, ground facilities, and a computer.
interface and GPS receiver with antenna, allowing the user to calculate precise location data (Boston 1990, Greer 1993). For each burned area, GPS points were taken while hiking around the perimeter. At each change of direction a new series of points was taken. The points were then corrected and averaged using a computer software package (PFINDER) designed for use with the GPS. The corrected and averaged points gave an estimation of the receiver's position to within 1 to 3 meters. When points were connected, an outline of the burn area was used to produce a map overlay. The process of actually connecting the points and putting them on the base map was done by loading the points into a computer-based Geographical Information System (GIS). GIS is designed for inputting, storing, exhibiting, manipulating, and examining spatial or geographic data (Fisher and Lindenberg 1989, Congalton and Green 1992). The map generated by the GIS recorded the year and size of the fire for the mapped areas.

RESULTS

Fuel Inventories

Fuel loading was averaged by vegetation type and given in metric tons/hectare (Table 1). Sagebrush had a total of 4.93 metric tons/hectare, juniper had 6.72 metric
TABLE 1. Average fuel loading (metric tons/hectare) by vegetative type for Camp Williams National Guard Base, Utah.

<table>
<thead>
<tr>
<th>Size</th>
<th>Sagebrush</th>
<th>Juniper</th>
<th>Oakbrush</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-0.6cm</td>
<td>0.18</td>
<td>0.23</td>
<td>0.33</td>
</tr>
<tr>
<td>0.6-2.5cm</td>
<td>1.64</td>
<td>2.38</td>
<td>2.54</td>
</tr>
<tr>
<td>2.5-7.6cm</td>
<td>0.62</td>
<td>0.41</td>
<td>0.93</td>
</tr>
<tr>
<td>Total</td>
<td>4.93</td>
<td>6.72</td>
<td>16.80</td>
</tr>
</tbody>
</table>

tons/hectare, and oakbrush had the highest at 16.8 metric tons/hectare. Oakbrush had the highest amount of 1-hour, 10-hour, and 100-hour fuels in relation to the two other vegetation types. Fuels in oakbrush were also the most horizontally continuous.

Fire Weather and Behavior

Worst-case fire behavior predictions were made for weather readings from the first week of August 1994 using the BEHAVE program (Table 2). A second run was made to give fire behavior predictions when midflame windspeed was increased from 1.8 m/sec to 3.6 m/sec (Table 3). Behavior was similar between the two fuel models for both runs.
average weather inputs from August 1-7, 1994 for Camp Williams National Guard Base, Utah (temp-38C, fine dead fuel moisture-3%, midflame windspeed-1.8m/sec, live herbaceous fuel moisture-90%, average slope for the base-12%).

<table>
<thead>
<tr>
<th>Fire Behavior Outputs</th>
<th>Fuel Model 2</th>
<th>Fuel Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of spread, M/MIN</td>
<td>13.0</td>
<td>14.0</td>
</tr>
<tr>
<td>Heat per unit area, KJ/SQM</td>
<td>7596.0</td>
<td>7575.0</td>
</tr>
<tr>
<td>Fireline intensity, KW/M</td>
<td>1633.0</td>
<td>1806.0</td>
</tr>
<tr>
<td>Flame length, M</td>
<td>2.3</td>
<td>2.4</td>
</tr>
</tbody>
</table>

**TABLE 3.** BEHAVE output for the 2 fuel models using average weather inputs from Table 1 and a midflame windspeed of 3.6m/sec.

<table>
<thead>
<tr>
<th>Fire Behavior Outputs</th>
<th>Fuel Model 2</th>
<th>Fuel Model 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of spread, M/MIN</td>
<td>44.0</td>
<td>35.0</td>
</tr>
<tr>
<td>Heat per unit area, KJ/SQM</td>
<td>7596.0</td>
<td>7575.0</td>
</tr>
<tr>
<td>Fireline intensity, KW/M</td>
<td>5550.0</td>
<td>4462.0</td>
</tr>
<tr>
<td>Flame length, M</td>
<td>4.1</td>
<td>3.7</td>
</tr>
</tbody>
</table>
The increased midflame windspeed affected both models by increasing behavior variables such as rate of spread, intensity, and flame length.

Fire History

A GIS overlay of the GPS points produced a map of the fire perimeters (Fig. 2). From this map the size of each fire was approximated (Table 4). It appeared that fire F experienced multiple burns between 1976 to 1978. Two of the larger fires, A and D, occurred primarily in the oakbrush vegetation type; fire B was mixed sagebrush and oakbrush vegetation types; fire C occurred in the sagebrush vegetation type; and both E and F occurred in the juniper vegetation type.

DISCUSSION

Of the major vegetation types at Camp Williams, oakbrush had the highest average fine-fuel loading for dead and downed woody debris, enabling fires to ignite and spread more rapidly. Fine-fuel loading in juniper was only slightly lower than oakbrush, as indicated in Table 1. However, of the three vegetative types, oakbrush had the highest total average fuel loading and greatest fuel
Fig. 2. Boundaries of past fires at Camp Williams National Guard Base, Utah superimposed on a false color composite of a Landsat satellite image for July 1993.
TABLE 4. Size and year of recent fires at Camp Williams National Guard Base, Utah.

<table>
<thead>
<tr>
<th>Fire</th>
<th>Size (hectares)</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>95.44</td>
<td>1987</td>
</tr>
<tr>
<td>B</td>
<td>30.59</td>
<td>1990</td>
</tr>
<tr>
<td>C</td>
<td>7.25</td>
<td>1992</td>
</tr>
<tr>
<td>D</td>
<td>718.67</td>
<td>1987</td>
</tr>
<tr>
<td>E</td>
<td>22.34</td>
<td>1988</td>
</tr>
<tr>
<td>F</td>
<td>203.92</td>
<td>1976 and 1978</td>
</tr>
</tbody>
</table>

continuity. These variables combined to make oakbrush the most likely to sustain a large fire.

Although not part of the fuel inventory, annual grass species play an important role in fire spread and behavior. One introduced annual species that is very prolific and in great abundance at Camp Williams is cheatgrass (*Bromus tectorum* L.). Cheatgrass is a fine-fuel, easily ignited, and increases the chance of fire spread where it is in abundance and provides a fine fuel continuum (Klemmendson and Smith 1964). An example of this was given for Idaho shrublands, where before cheatgrass invasion the fire return interval was estimated at 60-110 years, but since the introduction of cheatgrass is now every 3-5 years (Whisenant
fire is a factor in developing future management plans.

Fire behavior is highly variable depending upon weather and fuels. Weather conditions at the base can be extreme during summer and early fall. During this period, fire in oakbrush is most likely to burn through the shrub layer but may drop to the ground in openings or when midflame windspeed drops below 3.6 m/sec (Anderson 1982). By late fall, temperatures decrease and humidity increases, resulting in higher fuel moisture content and a reduction in the likelihood of ignition and spread. From Table 3, fireline intensity and flame length can be directly related to fire suppression (Andrews and Rothermel 1982). These two variables in Table 3 are high for both fuel models and would preclude control efforts at the head of the fire. In Table 2, fireline intensity and flame length are lower for both fuel models and indicate that handlines would be ineffective, but that tractors and engines could be effective means of controlling these fires (Andrews and Rothermel 1982). Fire behavior for fires A and D was likely to be extreme with traits possibly similar to those given in Table 3. This allowed the fire to spread through the shrub layer, killing the existing oakbrush and covering a large area where the fuels were continuous. The large area burned
in fire F likely occurred under similar extreme weather conditions as fires A and D.

Fire perimeters mapped at Camp Williams contain pockets of unburned vegetation as well as fingers of burned vegetation extending out from the main burn. Using the GPS to map this variability was difficult. However, the combination of GPS and GIS used in this study was time effective and provided a more accurate estimate of area than other survey methods.

Fire rotation or natural fire rotation (NFR) is defined as the number of years required to burn over and reproduce an area equal in size to the study area (Heinselman 1973). The fire rotation for Camp Williams excluding the impact area was calculated to be 130 years. Due to the high probability of man-caused ignitions, this is not an indicator of the true natural fire rotation. Rather, this fire rotation reflects the impact training has had on the base. Natural fire rotation is not a common description due to the fact that the actual size of the burned area as well as the size of the study area is required for the calculation. As a result, there was no point of comparison found in the literature search for the three fuel types found at Camp Williams. However, when in the future NFR calculations are made for these fuel types, they can be used
to help assess the impact of training on the natural fire rotation at the base.

Understanding fire occurrence and behavior can provide Camp William personnel with fire management alternatives. To reduce the risk of recurring large fires in oakbrush, a series of prescribed burns and mechanical treatments can be implemented for fuel reduction. Vegetative fuel breaks could be used for added safety around the impact area and to break up fuel continuity in sagebrush and juniper fuel types. Vegetative fuel breaks are used to reduce the occurrence and size of wildfires (Pellant 1990). Plant species used in vegetative fuel breaks are effective insofar as they remain green through the fire season, have low residual amounts of fuel, are able to persist and compete with annual species, and have low fire susceptibility (Pellant 1990). The ability of greenstrip species to compete with annuals is essential for controlling cheatgrass and breaking up the fine-fuel continuum. Placement is critical for these fuel breaks to be effective. Vegetative fuel breaks must be continuous with each other or with preexisting fuel breaks, such as roads or rock outcrops, to keep fires contained. Vegetative fuel breaks would be ineffective in oakbrush due to sprouting. By monitoring fire weather, fire danger can be reported to training
personnel and activities modified accordingly. Fuel inventory information can be used to select sites for training where the risk of fire ignition and spread are the lowest. These management alternatives are not an attempt to completely remove fire, a natural part of the ecosystem, from the base. Rather, the objective is to limit the size and intensity of these fires to better mimic the patchy structure of fire-adapted systems and also to facilitate containment in order to protect training facilities.

With increasing suburban encroachment into wildland areas, containment of wildfires is a growing concern for both the public and land managers. The juncture of vegetative fuels and man-made structures is called the wildland/urban interface (University Research Corp. 1989). A census conducted by the USDA Forest Service showed that between 1970 and 1980 there was a 23.4 percent increase in population for rural counties in wildland areas, compared to a 11.4 percent population increase nationwide (University Research Corp. 1989). The value of 0.4 ha of oakbrush may be $50.00 when used for recreation, watershed, livestock forage, and wildlife habitat; build a home and this same 0.4 ha could be worth $100,000.00 (Utah Division of State Land and Forestry 1986). This increasing pressure to develop rural areas helps stress the importance of wildfire
management not only for Camp Williams but also for all lands in the wildland/urban interface.
CHAPTER III

THE EFFECT OF FIRE ON DEER MOUSE DENSITY IN OAKBRUSH AT CAMP WILLIAMS NATIONAL GUARD BASE, UTAH

Abstract.—The effect of fire on deer mouse (*Peromyscus maniculatus*) density in oakbrush was determined by using a trapping web design with distance sampling techniques. Webs were set in four pairs with one web of each pair being in 7-year-old burned oakbrush and the other web in unburned oakbrush. Variables such as shrub height and litter depth were recorded in order to reduce variance. Trapping occurred in June 1994 with each web set for two consecutive nights using 80 Museum Special snap traps spaced 6 m apart on eight lines. Density estimates were determined by using a computer program called DISTANCE and then analyzed using analysis of variance with a randomized block design. No significant differences between deer mouse densities were detected between burned and unburned oakbrush. Although litter depth and shrub height were both significantly less in burned sites it did not affect deer mouse density. The conclusion from these results was that after 7 years oakbrush had recovered to a point that the effect of fire on deer mouse density was negligible.
INTRODUCTION

Fire changes an ecosystem, affecting both flora and fauna. Birds and mammals are adapted to their environment and react to disturbances such as fire (Bendell 1974). Frequent forest or range fires maintain the number and variety of plants that provide cover and food for wildlife (Wright and Bailey 1982, Gruell 1984). Wildlife can modify fire occurrence by reducing fuel loading through grazing. Materials in trees from nest-building fauna may increase the chances of ignition (Bendell 1974). The effects of fire on animals depend on variables such as the mobility of the animals, size of the fire, rate of spread, fuel type, and fire frequency (Buech et al. 1977, Peek 1986). Mobile animals can move away from the fire and take shelter in unburned areas; animals that burrow can find protection within the soil (Handley 1969).

The short-term effects of fire on animals can result in injury, death, loss of food and cover, and increased predation. The long-term response for some animal species, however, includes increased population density (Ream 1981, Kimmins 1987). Whether fire benefits wildlife habitat is dependent on the habitat needs of a given species (Miller 1963, Peek 1986). Fire can modify habitat by removing trees and shrubs, which increase open areas and can result in
increased temperatures at that site. Fire burns unevenly, leaving a patchwork of unburned vegetation, open areas, and burned fuels such as logs and stumps. The amount of edge created by fire benefits a number of wildlife species (Miller 1963, Bendell 1974, Wright and Bailey 1982). Both the size and shape affect the amount of edge, with larger burns having a lower proportion of edge to open area than smaller burns (Bendell 1974).

Today, wildland fires are an increasing concern for both public and private land managers. The effect of fire on both flora and fauna in terms of ecosystem health and management is an important issue for land managers. Land managers need an understanding of how an ecosystem reacts or adapts to fire before they can start working towards establishing a better balance between resource objectives.

Camp Williams is a Utah National Guard training site located 47 kilometers south of Salt Lake City on the west side of the Salt Lake Valley. The base is approximately 12,150 hectares and ranges in elevation from 1281 to 2196 meters above sea level. The base is located in upland and mountain zones with vegetation common to these areas. Wheatgrass (Elymus spp.), big sagebrush (Artemisia tridentata Nutt.), bluegrass (Poa spp.), and Utah juniper (Juniperus osteosperma Torrey) are most commonly found in
the lower elevation upland zone. In the upper mountain zone, gambel oak (*Quercus gambelii* Nutt.), bitterbrush (*Purshia tridentata* Pursh), wheatgrass, and forbs are found (Shultz and Crane pers. com. 1992).

Gambel oak is widely distributed over the Rocky Mountain West, including Utah, Colorado, Arizona, and New Mexico (Wright and Bailey 1982, Clary and Tiedemann 1986). Gambel oak ranges from a medium-sized shrub, 1 to 3 meters, to a medium-sized tree, 5 to 15 meters (Tiedemann et al. 1987). It is very fire tolerant, suckering prolifically after a fire, resulting in increasingly dense stands merging into continuous thickets over time (Wright 1971). Research conducted in Utah by McKell (1950) found that oakbrush grows very rapidly the first two growing seasons after a burn, sprouting within 10 days (Tiedemann et al. 1987). McKell found after 18 years that only 75 percent of the stand's original cover had been reached. This same study indicated that the number of shoots increased four times after a burn, but decreased to preburn levels after 18 years (McKell 1950). Oak brush tends to become less dense over time when protected from fire (Brown 1958). Oak brush covers 2089 ha at Camp Williams and is of special interest to this study.

Trapping done in September and October of 1993 in the various vegetation types found the predominant small mammal
to be the deer mouse, *Peromyscus maniculatus*. Due to its adaptability, the deer mouse is found over most of North America in a variety of habitats, including forested and disturbed areas (Jameson 1955, Hall 1981). Deer mice nest in burrows made in a variety of places, including in trees, on the ground, and in dwellings. They feed on seeds, acorns, berries, and insects. Their home range is from 0.2 to 1.2 hectares or greater with a high summer population of 25 to 37 per hectare (Burt and Grossenheider 1980). Deer mice are a pioneer species favoring early successional stages created by disturbance (Ream 1981, Kaufman et al. 1990). Deer mice population densities increase on burned areas because they feed on seeds that survived in soil after burning (Beck and Vogl 1972, Bendell 1974). Foraging in burned areas where there is less plant litter is preferred (Kaufman and Kaufman 1990). Their nocturnal habit and erratic movements help protect them from predators in open postfire environments (Ream 1981).

The objective of this study was to test the null hypothesis that there is no difference in deer mouse densities between burned and unburned stands of oakbrush. The alternative hypothesis was that deermouse density is higher in burned than unburned sites.
METHODS

Trapping was done in two areas where large fires occurred in 1987. These areas were chosen because they were large enough for the amount of sampling done for this study.

In this study the proposed trapping design was a trapping web (Anderson et al. 1983). A trapping web is a field procedure used for direct density estimation. Data from a trapping web can be used as distance sampling data, a type of plotless sampling. Unlike traditional trapping methods, density is estimated directly rather than from separately estimating population size and geographic area (Buckland et al. 1993). The design consists of 16 lines radiating out from a central point. Each line is 60 m in length with 20 equally spaced traps per line covering 1 hectare in area. Variables such as the number of lines and traps can be modified to meet the needs of the researcher. In this study there were eight lines with 10 Museum Special snap traps per line spaced 6 meters apart. The web design assumed that all trappable animals at the center of the web are trapped over the course of 7 days of trapping (Anderson et al. 1983). Trapping occurred over two consecutive nights to meet this assumption.

Based on the results of trapping design simulation models, Wilson and Anderson (1985) concluded that the
trapping web design is a reliable means of determining densities of small mammal populations. An advantage of the web design is that it rests on relatively few assumptions when compared to other methods such as the nested grid (Wilson and Anderson 1985). A field comparison of trapping web and nested grid designs showed both to be reliable, with the trapping web design yielding a slightly more precise estimate (Jett and Nichols 1987). This lends support to the results obtained by the simulation models of Wilson and Anderson (1985). Another advantage of the trapping web design is that no new captures at the center of the web indicates a high capture probability and large numbers in the outer rings may indicate animals were being attracted from outside the web (Jett and Nichols 1987).

The use of Museum Special snap traps over other traps was based on ease of use and efficiency. When comparing Museum Special snap traps with live traps, there have been some conflicting conclusions in terms of efficiency (Drickamer and Mikesic 1993). In one study the Museum Special snap trap was found to be more efficient than a variety of snap or box-type live traps (Weiner and Smith 1972). Another study found not much difference in trapping efficiency between Museum Special snap traps and pitfall traps. The pitfall trap, however, is not as susceptible to
weather conditions and is more suitable for year round use (Mengak and Guynn 1987). The choice of Museum Special snap traps over Victor mouse traps or Victor rat traps was based on the size of the small mammals in this study.

The actual estimation of density was done through a distance sampling computer program called DISTANCE. The program was developed by Laake et al. (1993) and has the advantage of being able to analyze various forms of distance sampling, including line transect, point transect (variable circular plot), and cue count. Past programs were limited in their design to analysis of line transect data only (Laake et al. 1993).

There were eight webs set over 3 weeks. Four were in the burned and four in the unburned areas, and were assigned odd and even numbers, respectively. Web centers were recorded using a Geographical Positioning System (GPS). The webs were divided into four pairs with an attempt to make the burned and unburned web in each pair similar by setting the web in the burned and unburned portions of the same stand where possible (Fig. 3). To minimize edge effect, there was a 25-m buffer around the trapping webs. Litter depth was measured in each web using a 120-m line transect with 20 measurements taken at 6-m intervals. Variables such as shrub height, stand age, and ocular estimates of percent
Fig. 3. Trapping web plot centers and their orientation to fire boundaries at Camp Williams National Guard Base, Utah. Burned plots are odd numbered and unburned are even numbered. Background is a false color composite of a Landsat satellite image for July 1993.
cover were recorded and monitored to reduce variance. Small mammals were recorded by species, sex, and whether adult or juvenile (Appendix A). Analysis of variance (ANOVA) with a randomized block design (RBD) was used to determine if densities of deer mice between burned and unburned webs were significantly different. ANOVA using an RBD was used for the statistical analysis of data because the results would have been analogous to a paired comparison t-test. A two sample t-test was unsuitable because it ignores the blocking effect between pairs (Ostle and Malone 1988).

RESULTS

Plot locations were chosen in order to reduce the variance between and within pairs. All webs were a minimum of 70 percent oakbrush and the predominant vegetation in stand openings was sagebrush. The number of years since fire in the burned areas was 7 and an average of 36 years in the unburned areas with the shortest period since disturbance being 20 years. Vegetative samples revealed within-pair similarity for grass and herb species at each web location. The predominant undergrowth was Japanese brome (Bromus japonicus Thunb.), cheatgrass (Bromus tectorum L.), Kentucky bluegrass (Poa pratensis L.), Sandbergs bluegrass (Poa secunda Presl.), and common yarrow (Achillea
Litter depth and shrub height were averaged from the 20 samples taken for each web (Fig. 4). Both shrub height and litter depth values were significantly lower for the burned sites than the unburned sites (Table 5, Table 6). In Tables 5 and 6, treatments represent the burned versus unburned webs and blocks are the pair-by-pair interaction. The number of small mammals trapped in each web was recorded, with deer mice being the predominant species. Other small mammals such as the great basin pocket mouse (*Perognathos parvus*), mountain vole (*Microtus montanus*), and least chipmunk (*Eutamias minimus*) were trapped, but numbers were too small to be used in density estimates. Out of 372 mammals trapped, 14 were mountain voles, 6 were great basin pocket mice, 2 were least chipmunk, and 350 were deer mice. The difference in the number of juvenile deer mice trapped between burned and unburned webs and between web pairs was not significant (Table 7).

Estimates of deer mouse density were derived by entering the number of deer mice, both adult and juvenile, caught in each of the 10 rings into DISTANCE (Table 8, Fig. 5). The type of model for detection probability to estimate density used for each set of data was determined by the DISTANCE program and was based on the best fit for each data
Fig. 4. Average shrub height and litter depth for burned and unburned webs.
TABLE 5. Analysis of variance with a randomized block design for average shrub height.

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>1</td>
<td>2.1239</td>
<td>0.007</td>
</tr>
<tr>
<td>Block</td>
<td>3</td>
<td>0.0497</td>
<td>0.5</td>
</tr>
<tr>
<td>Error</td>
<td>3</td>
<td>0.0496</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 6. Analysis of variance with a randomized block design for average litter depth.

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>1</td>
<td>3.2512</td>
<td>0.027</td>
</tr>
<tr>
<td>Block</td>
<td>3</td>
<td>2.0737</td>
<td>0.166</td>
</tr>
<tr>
<td>Error</td>
<td>3</td>
<td>0.5937</td>
<td></td>
</tr>
</tbody>
</table>
### TABLE 7. Analysis of variance with a randomized block design for the number of juvenile deermice trapped.

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>1</td>
<td>3.13</td>
<td>0.677</td>
</tr>
<tr>
<td>Block</td>
<td>3</td>
<td>3.79</td>
<td>0.853</td>
</tr>
<tr>
<td>Error</td>
<td>3</td>
<td>14.79</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 8. Density estimate of deer mice per hectare with corresponding P-value and estimation model used for each pair (odd numbers are burned and even numbers are unburned).

<table>
<thead>
<tr>
<th>Web number</th>
<th>Density/ hectare</th>
<th>P-value</th>
<th>Estimation model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Uniform/ cosine</td>
</tr>
<tr>
<td>1</td>
<td>37</td>
<td>1.0</td>
<td>Neg. exp/ cosine</td>
</tr>
<tr>
<td>2</td>
<td>42</td>
<td>1.0</td>
<td>Neg. exp/ cosine</td>
</tr>
<tr>
<td>3</td>
<td>87</td>
<td>.34</td>
<td>Neg. exp/ cosine</td>
</tr>
<tr>
<td>4</td>
<td>78</td>
<td>.37</td>
<td>Neg. exp/ cosine</td>
</tr>
<tr>
<td>5</td>
<td>185</td>
<td>.33</td>
<td>Uniform/ cosine</td>
</tr>
<tr>
<td>6</td>
<td>105</td>
<td>.51</td>
<td>Uniform/ cosine</td>
</tr>
<tr>
<td>7</td>
<td>33</td>
<td>1.0</td>
<td>Uniform/ cosine</td>
</tr>
<tr>
<td>8</td>
<td>23</td>
<td>1.0</td>
<td>Uniform/ cosine</td>
</tr>
</tbody>
</table>
Fig. 5. Density estimates for deermice in burned and unburned webs.
set. Each data set can be represented by a curve and the best fit for that curve is determined by finding the closest match between the curves of an estimation model and data set. The p-value within the DISTANCE program represents the probability of rejecting the null hypothesis that the data set and estimation model have relatively the same curve. Therefore, a high p-value is desirable because it results in a failure to reject the null hypothesis, meaning the estimation model is the best statistical fit for the data set and will give a reliable estimation of density. A uniform cosine model type was used for webs 1-2 and 7-8. Webs 3-4 and 5-6 used a negative exponential cosine model type. The p-values for estimates using the negative exponential cosine model were comparatively low. This was due to the high number of captures in the center of the webs.

Density estimates were then compared by analysis of variance using a randomized block design (Table 9). The randomized block design tested the null hypothesis that there were no significant differences between densities in burned and unburned oakbrush. In Table 9, treatments compare the burned versus unburned webs, and blocks are the pair-by-pair interaction. The p-value for treatments was 0.304 and blocks was 0.061.
TABLE 9. Analysis of variance with a randomized block design for deermouse density.

<table>
<thead>
<tr>
<th>Source</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>1</td>
<td>1096.0</td>
<td>0.304</td>
</tr>
<tr>
<td>Block</td>
<td>3</td>
<td>5683.7</td>
<td>0.061</td>
</tr>
<tr>
<td>Error</td>
<td>3</td>
<td>715.6</td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

This study was limited to trapping in 7-year-old burns because they were the only burns large enough to fulfill the size requirements of the sampling design for this investigation. The number of webs was limited due to the scarcity of suitable unburned sites. Web centers for each pair were at least 280 m apart to insure that webs were not sampling the same population of deer mice. The difference in deer mouse densities between the pairs was most likely due to site-to-site variability. The very high densities recorded for webs 5 and 6 were the result of being checked the first and the third night. The webs could not be reached after the second night due to artillery training in that area.
The p-value can be defined as the probability, assuming the null hypothesis is true, of getting an outcome at least as extreme as the one observed. The smaller the p-value the stronger the evidence against the null hypothesis (Moore and McCabe 1989). The accepted p-value to reject the null hypothesis for most types of analysis is 0.05 or lower. The treatment p-value of 0.304 is too high to reject the null hypothesis. Therefore, the investigation fails to reject the null hypothesis that there is no difference in deer mouse density between 7-year-old burned and unburned stands of oakbrush. Although a p-value of 0.304 is high, it does indicate a trend in deer mouse densities of being higher in burned versus unburned sites. The block p-value of 0.06 is close enough to 0.05 to say that there is a difference between pair densities though not highly significant. Variability between pairs had an obvious effect on the number of deer mice trapped.

The variability in deer mouse density between pairs could be attributed to a number of factors. As stated in the results, grass and herb species were similar for the various trapping sites. Deer mice feed on a variety of items, including seeds. A reduction in grass or herb species could act as a limiting factor for deer mouse abundance by reducing seed availability. This loss in seeds
may not be a significant factor, however, due to the fact that deer mice supplement their diet with a variety of food sources (Wolff et al. 1985). A direct measure of seed abundance at each site was needed for further discussion on the effect of seed abundance on site variability.

Another source of variation may be due to what is called "edge effect." Edge is when two distinct vegetative forms come into contact and a boundary is formed. Some animal species benefit from edge while others are negatively impacted (Bendell 1974, Patton 1992). Edge can be quantified through a formula that relates the ratio of perimeter to area for a given site and is expressed as diversity index (Patton 1975). In this study, edge was created by fire. Of the two burn areas, one was 7 times larger than the other. Larger burns generally have less edge; however, the diversity index for the larger burn was 1.373. This value was relatively the same as the smaller burn, which was 1.349. More burn areas are needed to statistically test the variability of edge between different size burns for this study.

The main reason why no significant differences were found between burned and unburned sites was the length of recovery time since the fire. It has been stated that deer mice are attracted to the reduced litter associated with
Although litter depth and shrub height were significantly less in all four of the burned sites, it might not have been distinguishable to the deer mice from unburned sites. The 7 years since the fire allowed the oakbrush stands enough time to recover to a point where the effects of fire on deer mouse density was insignificant. Deer mice populations had recovered to prefire numbers within 7 years. This relatively short recovery time is important for Camp Williams, which experiences frequent high intensity fires due to military training. The results of this study would seem to indicate that fires in oakbrush resulting from possible training have no significant effect on deer mice populations after 7 years.
Fuel loading was averaged by vegetation type and given in metric tons/hectare (Table 1). Sagebrush had a total of 4.93 metric tons/hectare, juniper had 6.72 metric tons/hectare, and oakbrush had the highest at 16.8 metric tons/hectare. Oakbrush had the highest amount of 1-hour, 10-hour, and 100-hour fuels in relation to the two other vegetation types. Fuels in oakbrush were also the most horizontally continuous.

Worst-case fire behavior predictions were run for weather readings from the first week of August 1994 using the BEHAVE program (Table 2). A second run was made to give fire behavior predictions when midflame windspeed was increased from 1.8 m/sec to 3.6 m/sec (Table 3). Behavior was similar between the two fuel models for both runs. The increased midflame windspeed affected both models by increasing behavior variables such as rate of spread, intensity, and flame length.

A GIS overlay of the GPS points produced a map of the fire perimeters (Fig. 2). From this map, areas for each of the fires were approximated. The year the fire occurred was determined by analyzing the oakbrush specimens taken from each of the burned areas (Table 4). It appeared that fire F
experienced multiple burns between 1976 to 1978. Two of the larger fires, A and D, occurred primarily in the oakbrush vegetation type; fire B was mixed sagebrush and oakbrush vegetation types; fire C occurred in the sagebrush vegetation type; and both E and F occurred in the juniper vegetation type.

Understanding fire occurrence and behavior can provide Camp William personnel with fire management alternatives. To reduce the risk of recurring large fires in oakbrush, a series of prescribed burns and mechanical treatments can be implemented for fuel reduction. Vegetative fuel breaks could be used for added safety around the impact area and to break up fuel continuity in sagebrush and juniper fuel types. Vegetative fuel breaks are used to reduce the occurrence and size of wildfires (Pellant 1990). Plant species used in vegetative fuel breaks are effective insofar as they remain green through the fire season, have low residual amounts of fuel, are able to persist and compete with annual species, and have low fire susceptibility (Pellant 1990). The ability of greenstrip species to compete with annuals is essential for controlling cheatgrass and breaking up the fine-fuel continuum. Placement is critical for these fuel breaks to be effective. Vegetative fuel breaks must be tied into each other or preexisting fuel
breaks, such as roads or rock outcrops, to keep fires contained. Vegetative fuel breaks would be ineffective in oakbrush due to sprouting. By monitoring fire weather, fire danger can be reported to training personnel and activities modified accordingly. Fuel inventory information can be used to select sites for training where the risk of fire ignition and spread are the lowest. These management alternatives are not an attempt to completely remove fire, a natural part of the ecosystem, from the base. Rather, the objective is to limit the size and intensity of these fires to better mimic the patchy structure of fire-adapted systems and also to facilitate containment in order to protect training facilities.

When planning prescribed burns in oakbrush, many factors come under consideration, such as the effects of fire on wildlife. This study has shown that the most predominant small mammal, the deer mouse, recovers to prefire population densities within 7 years after a fire. This is due to the ability of oakbrush to recover by sprouting vegetatively after a disturbance such as fire. This relatively short recovery period reflects positively on the use of prescribed fire in oakbrush.

With the ever-increasing development of rural areas, containment of wildfires is a growing concern for both the
public and land managers. Where vegetative fuels and man-made structures meet is called the wildland/urban interface (University Research Corp. 1989). A census conducted by the USDA Forest Service showed that between 1970 and 1980 there was a 23.4 percent increase in population for rural counties in wildland areas, compared to a 11.4 percent population increase nationwide (University Research Corp. 1989). The value of 0.4 ha of oakbrush may be $50.00 when used for recreation, watershed, livestock forage, and wildlife habitat; build a home and this same 0.4 ha could be worth $100,000.00 (Utah Division of State Land and Forestry 1986). This increasing value of rural areas helps stress the importance of wildfire management not only for Camp Williams but all lands where wildland/urban interface occurs.


Fischer, W.C., and C.E. Hardy. 1972. Fire weather observers handbook. USDA Forest Service Intermountain Forest and Range Experiment Station, Ogden, Utah. 152 pp.


APPENDIX
Recently deer mice have come under the scrutiny of researchers because of a potentially deadly virus known as the hantavirus. Rodents are the primary host for hantavirus and data suggest that the deer mouse is the primary reservoir for the hantavirus strain recently discovered in the Southwestern United States. The host does not show any apparent illness from the hantavirus. Transmission can occur through inhaled, infected excreta aerosols; dried contaminated materials introduced directly into open breaks in the skin; by ingestion of contaminated food or water; or by being bitten by the animal (Centers for Disease Control 1993).

The Utah Department of Health (pers. comm.) has put out a series of recommendations for people working with deer mice in areas where the existence of the hantavirus has yet to be determined. When trapping deer mice the worker should periodically wash their traps in a bleach solution or any general household disinfectant which is effective due to the susceptibility of the lipid envelopes found in the hantavirus (Centers for Disease Control 1993). Workers should always wear rubber gloves when handling the specimens. If removal trapping is practiced, such as with snap traps, dead deer mice should be placed in a plastic bag.
with disinfectant during collection and disposed of by incineration or burial. Further precautions are needed if dissection of the specimens is planned.