Five Years of Fire Recovery in Mesa Verde National Park

The five-year study followed a 1989 lightning-caused burn on Long Mesa within Mesa Verde National Park.

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ABSTRACT

Given the significant influence of wildfire on the landscape of Mesa Verde National Park, it is important for land managers to have access to detailed documentation of post-fire plant succession. This five-year study, following a 1989 lightning-caused burn on Long Mesa within Mesa Verde National Park, reports the post-fire vegetation recovery in pinyon-juniper (*Pinus edulis* Englem.-*Juniperus osteosperma* [Torr.] Little) woodland and sagebrush-bitterbrush (*Artemisia tridentata* Nutt., *A. nova* A. Nelson-*Purshia tridentata* [Pursh.] DC.) shrubland as compared to adjacent unburned control plots missed by the fire. Observations of unburned pinyon-juniper control plot suggest that juniper was a relatively healthy species, but that pinyon was losing the ability to maintain a balanced age-class structure on Long Mesa. For both vegetation types, tree and shrub species that were dominant in the unburned plots were replaced by crown-sprouting shrubs in the burned areas; dominant members of unburned plots (pinyon, juniper, sagebrush) had not returned at all or had only arrived by seed during the fifth year of the study. Many annuals and herbaceous perennial species were unique to either the burned or unburned plots, and many of those shared in common between burned and unburned plots varied notably in coverage and frequency. Fremont's goosefoot (*Chenopodium fremontii* S. Watson) and coyote tobacco (*Nicotiana attenuata* Torr. Ex S. Watson) displayed interesting recovery trajectories by peaking in individual plant size one year and then increasing in population during following year(s). Four non-native species had only minor influence on any of the four study plots, and the burn resulted in a higher diversity of plant communities on Long Mesa than before

the fire. These results supported and quantified some observations of earlier studies, but contrasted with others. Differences in conclusions may be due to nature of individual fire events, and the presence/absence of post-fire reseeding or of feral horse grazing. Land managers in Mesa Verde National Park now have two studies of pinyon-juniper woodland fire recovery, their first study of the immediate recovery of a burned sagebrush-bitterbrush shrubland, and previous information to suggest that oaks (*Quercus* spp. L.) re-establish themselves remarkably well by crown-sprouting immediately following an oak shrubland fire.

Keywords: age-class structure, *Artemisia*, Colorado Plateau, fire effects, *Juniperus*, Mesa Verde, *Nicotiana*, *Pinus*, pinyon-juniper woodland, *Purshia*.

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INTRODUCTION

Wildfires are a significant influence on the landscape of Mesa Verde National Park in southwest Colorado. Lightning-caused burns typically occur during hot and dry springtime weather or during summer thunder storms. There have been twelve major lightning-caused wildfires within the park since 1930, all burning at least thirty acres (National Park Service 2012). Such major burns threaten both park infrastructure and cultural resources. However, the effects of fire on natural habitats are variable and depend on the type of vegetation community, on the severity of the fire, and on the environmental conditions following the burn. Close observation of the plant communities that develop after fire in Mesa Verde is important to inform land management practices enacted following a fire.

Pinyon-juniper woodland and the sagebrush-bitterbrush shrub community are major plant communities throughout the American West as well as within Mesa Verde National Park (Floyd *et al*. 2000). Both communities have been named for their dominant woody plants, *Pinus edulis* Englem.-*Juniperus osteosperma* [Torr.] Little and *Artemisia tridentata* Nutt., *A. nova* A. Nelson-*Purshia tridentata* [Pursh.] DC. These dominant woody species are often eliminated by fire, which can: a) radically change the composition of the community; b) increase light availability; c) alter soil composition; d) eliminate competitive species; and e) encourage weedy native and introduced species to become established. Crown cover, number of individual trees, litter cover, and percentage of bare soil are conditions that change rapidly over the course of succession after fire. For these plant communities, post-fire recovery is a sensitive time when non-native pioneer species like cheatgrass (*Bromus tectorum* L.) may invade (Getz and Baker 2008).

In 1990 Crow Canyon Archaeological Center, in cooperation with Mesa Verde National Park, initiated a five-year study of the effects of fire on vegetation following a July 1989 lightning-caused burn on Long Mesa. The objective of this research was an ecological study of post-fire vegetation recovery of two mature plant communities, a pinyon-juniper woodland and a sagebrush-bitterbrush shrubland, including comparison to two nearby unburned communities spared by the burn. No intentional seeding with introduced or native species followed the fire, although a small herd of feral horses may have affected vegetation recovery to some unknown extent. Data and results represent the period July 1990 through June 1994. The Long Mesa study area, including the burned and unburned study plots, is depicted in Fig 1.

METHODS

Study Site

The study site is a cuesta, a geologic formation created by gently tilted strata of rock (Anonymous 2012). Mesa Verde is composed of a series of these mesas, all sloping gradually from 2485 m in the north to 2060 m in the south (Erdman *et al*. 1969). The mesas, composed of Cretaceous sandstones inter-bedded with shale layers, are mantled with Aeolian deposits on top and abut deep canyon bottoms filled with rock and alluvium. Mean annual precipitation (1923-1994) is 47 cm, with a dry season in May and June and a wet period in July and August. Annual growing season averages 140 days to 170 days (Floyd *et al*. 2000).

Long Mesa and the surrounding area burned several times in the recorded history of Mesa Verde National Park. The northern portion of Long Mesa was burned in July of 1934 by both the Wickiup Point Fire and the Wildhorse Mesa Fire. The Rock Springs Fire burned the mesa and canyon around Rock Springs in the summer of 1972, and this area was partially re-burned by

the Long Mesa Fire of 1989, the after-effects of which are discussed here. All these burning events were ignited by lightning during the summer months.

Observations for this study began shortly after the fire in 1989 with the examination of burned and unburned locations. Researchers established study plots the next year. Previous fire history records indicate that three of these locations last burned in the Wildhorse Mesa Fire of July 1934; only the unburned pinyon-juniper woodland location appears to have been missed by the 1934 fires. For comparability, the descriptive methods and techniques utilized in this research parallel those of an earlier post-fire analysis at Mesa Verde National Park (Erdman *et al*. 1969; Erdman 1970).

Researchers established four permanent study plots. Each measured 68.6 x 15.2 m, and within each permanent plot, ten parallel 15.2 m lines, each subdivided into 3.04 m sublines, were laid out at 7.6 m intervals along a base line. We employed the analytical concepts of canopy coverage, frequency, and density to characterize vegetation in the study plots during numerous visits throughout each growing season.

Canopy coverage expresses the dominance (size, bulk) of a taxon as a measure of its relative impact (Daubenmire 1968:41). Tree and shrub canopies that overlapped above or below the plot lines via the line intercept method (Canfield 1941) were summed, and that total canopy sum was converted to a percent of the total 15.2 m of line monitored. We estimated canopy coverage for understory herbaceous plants within movable 30.5 cm by 61 cm metal frames placed at 3.04 m intervals along each line. Total canopy coverage was converted to a percent of the total area of the 50 subplots monitored. We estimated the coverage of abiotic components of rock, litter, and bare soil in the same way.

Frequency documents whether a plant is broadly or narrowly distributed in the study plot, and is expressed as the percentage of uniformly-sized samples in which a species occurs (Daubenmire 1968:53). For trees and shrubs, we calculated frequencies by dividing the number of sublines along which each taxon was recognized by the total number of sublines (50), and converting to percentage. We calculated frequencies for herbaceous taxa by dividing the total number of canopy coverage plots in which each taxon occurred by the total number of canopy coverage plots (50) monitored, and converting to a percentage.

Density is usually understood as the number of individuals of a species per unit area (Daubenmire 1968:40). For this study, we determined the density of pinyon and juniper trees per 0.4047 hectare in the unburned pinyon-juniper woodland, the only study plot in which they grew. We measured trees greater than 10 cm dbh (diameter at breast height) using the Point Quarter Method (Cottam and Curtis 1956), which focused on 10 individual data points spaced at 15.2 m intervals; we also accumulated data on the basal diameter of the nearest tree in all four quadrants around each data point.

For pinyon and juniper trees in the unburned pinyon-juniper plot, we produced an Importance Value (Cottam and Curtis 1956) to judge these two conifers against each other. As the sum of relative coverage (dominance), frequency (distribution), and density (numbers), the Importance Value provides a way to compare and contrast the relative importance or impact each has on the unburned pinyon-juniper study plot.

Age-class data, again accumulated only for pinyon and juniper trees in the unburned pinyon-juniper study plot, reveal the relative abundance and reproductive status of each species. Individuals present within ten 1.2 m by 15.2 m belt transects adjacent to each line were

characterized as seedlings (less than 30.4 cm in height), saplings (greater than 30.4 cm in height and less than 5.08 cm in diameter), or trees (greater than 5.08 cm in diameter).

Researchers collected formal herbarium specimens to support the field observations of trees, shrubs, and herbaceous plants in the four study plots. We verified these specimens against permanent collections curated in the University of Arizona Herbarium (Tucson) and then donated them to Mesa Verde National Park. Scientific plant names referred to in this report (Table 1) conform to those of *A Utah Flora* (Welsh *et al*. 1987).

RESULTS

Trees, shrubs, herbaceous plants, and abiotic components of each study plot are discussed below for the five-year study period. The vegetation in the two burned plots contrasted notably with that of the unburned control plots, as did the two plant community types, pinyon-juniper vs. sagebrush-bitterbrush. Changes in vegetation from year to year were most dramatic in the burned plots. Complete coverage and frequency data for all plants observed over the five years are available for the pinyon-juniper woodland study plots (Appendix 1) and for the sagebrush-bitterbrush study plots (Appendix 2). Result highlights are presented below, and the reader is referred to the appendices for the details.

Unburned Pinyon-Juniper Study Plot

The unburned pinyon-juniper woodland was occupied by pinyon and juniper trees, with an understory of shrubs and herbaceous vegetation (Fig 2). Coverage and frequency data reveal that both pinyon and juniper were co-dominant members of this community on Long Mesa (Table 2). Additional analysis provided a look at these two taxa relative to each other. Age-class data tallied in 1990 and 1994 suggested that juniper was a healthy species replacing itself, represented by all size classes, especially saplings (Table 3). In 1990 older pinyon trees

outnumbered pinyon seedlings and saplings, suggesting that pinyon may have been aging in this locality; by 1994 pinyon saplings and trees were even further reduced (Table 3).

Density assessments in 1990 and 1994 via Point Quarter Analyses provided another way to view these trees in the unburned pinyon-juniper study plot, relative to one another (Table 4). In 1990, the density of pinyon trees in a 0.4047 hectare study plot was over twice that of juniper trees. By 1994, the density of pinyon had dropped notably, with a relatively slight decline in juniper tree density. When relative density, frequency, and dominance (coverage) values were added to arrive at an overall "Importance Value", the result suggested that juniper trees increased in importance and pinyon trees decreased in importance between 1990 and 1994 (Table 4). This is despite the relatively higher density of pinyon trees. Overall, it appears that juniper was the dominant conifer during the five-year study. Pinyon played an important, but less conspicuous and possibly fading role.

Shrubs in the unburned pinyon-juniper study spot revealed some variability over the five-year observation period (Table 2). Four of them, including serviceberry (*Amelanchier utahensis* Koehne), sagebrush, mountain mahogany (*Cercocarpus montanus* Raf.) and bitterbrush displayed coverage between 0.0 % and 10.9 % and frequencies ranging between 0.0 % and 34 %. Three additional shrubs, fendlerbush (*Fendlera rupicola* A. Gray), Gambel oak *(Quercus gambelii* Nutt.), and banana yucca (*Yucca baccata* Torr.) were present, but not prominent.

Three annuals and 19 herbaceous perennials were observed in the unburned pinyon-juniper plot during the five-year study (Appendix 1). Absence of annuals in 1990 suggests a relatively undisturbed landscape; in succeeding years, a few more annuals moved into the plot, but coverage of annual species remained below 1 %. Increasing frequency was apparent for a number of perennials over the study period, such as toadflax (*Comandra umbellata* [L.] Nutt.)

and muttongrass (*Poa fendleriana* [Steud.] Vasey). Park Service efforts to reduce the number of wild horses that graze in the area may be partly responsible for these upward trends. Other herbaceous species with notable frequencies included additional grasses (*Elymus elymoides* [Raf.] Swezey, *Koeleria macrantha* [Ledeb.] Schult.), knotweed (*Polygonum douglasii* Greene), toadflax penstemon (*Penstemon linarioides* A. Gray), and two species of lupine (*Lupinus* spp. L.). The fact that the number of herbaceous taxa increased from eight in 1990 to 14 in 1994 may be in part due to close proximity to botanically diverse burned areas.

Abiotic plot components in the unburned pinyon-juniper community were consistent over the five year study (Table 2). Bare soil consistently remained below 10 % coverage. Litter, primarily in the form of decomposing foliage, was a predominant component of this mature community, displaying high coverage and relatively high frequency between 1990 and 1994. Rocks were present, but generally not a major community component.

Burned Pinyon-Juniper Study Plot

The burned pinyon-juniper study plot appeared stark with its dead trees and high incidence of bare ground (Fig 3). No seedlings of pinyon or juniper trees returned during the five-year study. Only standing dead timber was observed, easily identified on the basis of bark and morphological and anatomical traits.

By the first year following the fire, five shrubs regenerated via crown-sprouting, producing long, flexible and leafy stems from still-living underground parts (Table 2). The first shrub observed was Gambel oak (Fig 4), responding to late summer and fall rains almost immediately following the 1989 fire. Banana yucca, bitterbrush, snowberry (*Symphoricarpos oreophilus* Gray) and mountain mahogany all began recovery from the base the following summer. Two additional shrubs, serviceberry and fendlerbush, joined the group by 1991. There

was a trend of increasing coverage and frequency for most shrubs in the study period (Table 2). Gambel Oak increased in coverage from 8.3 % to 13 % between 1990 and 1994, and retained high frequency (25 % to 26 %) over the study period.

Eight annuals and 25 herbaceous perennials were observed in the burned pinyon-juniper study plot during the five-year study. Many of these became established in the burned plot within the first two years following the fire. The 11 herbaceous annuals and perennials observed in 1990 nearly doubled by 1991, and remained at this level. Non-native Russian thistle (*Salsola iberica* Sennen & Pau), prickly lettuce (*Lactuca serriola* L.), and goatsbeard (*Tragopogon* sp. L.) entered the plot in 1991, and cheatgrass by 1993; coverage was consistently low for these adventive taxa, and only prickly lettuce displayed elevated frequencies between 12 % and 56 %. Numerous native species generally increased in both coverage and frequency over the study period, including: bastard toadflax, tansyaster (*Machaeranthera canescens* [Pursh] A. Gray), toadflax penstemon (*Penstemon linarioides* A. Gray), showy goldeneye (*Viguiera multiflora* Nutt.), and various grasses.

Coyote tobacco and Fremont's goosefoot experienced interesting population trajectories. In October of 1990, researchers counted a total of 86 healthy tobacco plants that measured up to 1 m in height and 1 m in width (Fig 5). These tobacco plants flowered and produced ripe fruit capsules, each containing hundreds of seeds, until the first hard frost in November. By 1991, the tobacco population had increased in numbers to 174 plants, but had diminished noticeably in stature to an average of 41 cm in height and 9 cm in width. By 1992, no tobacco plants were observed within the burned pinyon-juniper plot. As for Fremont's goosefoot, an estimated 811 plants averaged 1.17 m in height and 0.57 m to1.6 m in width in 1990 (Fig 6). As the estimated number increased to 6820 plants in 1991, the stature of this taxon decreased to 0.12 m in height

and 0.03 m in width. This upward trend in population size continued into 1992, but not into the fourth and fifth year following the fire, when population size decreased dramatically.

Other herbaceous species, low in both coverage and frequency, flowered and fruited during the five-year study. By 1991 these included: showy goldeneye, ricegrass (*Stipa hymenoides* [Roem. & Schult.] Barkworth), squirreltail grass (*Elymus elymoides* [Raf.] Swezey), toadflax penstemon, sulpher-flower buckwheat (*Eriogonum umbellatum* Torr.), narrowleaf goosefoot (*Chenopodium leptophyllum* [Moq.] Nutt. Ex S. Watson), muttongrass, hairy false goldenaster (*Heterotheca villosa* [Pursh] Shinners), knotweed, plainsmustard (*Schoenocrambe linifolia* [Nutt.] Greene), bird's beak (*Cordylanthus wrightii* A. Gray), spreading fleabane (*Erigeron divergens* Torr. & A. Gray), and stickseed (*Lappula occidentalis* [S. Watson] Greene). By 1992, bastard toadflax and rock goldenrod (*Petradoria pumila* [Nutt.] Greene) had joined this list of actively reproductive plants.

Immediately following the fire, the burned plot displayed moderate coverage and frequency of bare soil, as one might expect of an area covered by charred plant materials (Table 2). By 1991 there was an increase in the amount of litter present, first composed of ash and charcoal from the fire, and later including decomposing vegetation from living plants. Rocks were consistently low in coverage (less than 1 %) and frequency (8 % to 40 %).

Comparison of the Two Pinyon-Juniper Study Plots

There are sharp contrasts in vegetation between the unburned and burned pinyon-juniper plots over the five-year observation period. The recovering burned plot lacked any living pinyon or juniper trees. The shrubs shared in common between the two plots differed significantly in coverage and frequency. For example, Gambel oak displayed a much higher coverage and frequency in the burned plot. In contrast, serviceberry, mountain mahogany, fendlerbush, and

bitterbrush were all well-represented in the unburned plot but not so in the burned plot. Banana yucca was the only species with similar representation in both locations. Despite seed availability in the surrounding area, a predominant shrub (sagebrush) of the unburned plot had not returned to the burned plot by 1994. Snowberry was a minor crown-sprouting component of the burned plot only.

The herbaceous vegetation in the burned pinyon-juniper plot also contrasted sharply with that of the unburned study plot. The burned plot contained over 40 % more herbaceous taxa (n=33) than the unburned plot (n=19). Of 14 species common to both plots, few displayed similar coverage and frequency (Appendix 1). Nineteen herbaceous plants were unique to the burned plot, and eight to the unburned plot, increasing the general diversity of plant resources in the local area. Populations of Fremont's goosefoot, tobacco, and knotweed, present in a small population in the unburned plot, peaked early in the burned plot and then rapidly declined. Herbaceous plants in the unburned plot were continuously reproductive; many of these same plants in the burned plot became fully reproductive by the first and second years following the fire.

Differences in abiotic components between the two plots were also notable. In the unburned plot, litter coverage was high and bare soil low. The coverage of bare soil in the burned plot decreased in the years following the fire, as presence of litter remained moderate. Rocks in both locations were encountered on occasion, reflecting their presence in shallow soils overlying a sandstone mesa top.

Unburned Sagebrush-Bitterbrush Study Plot

The unburned sagebrush-bitterbrush plot changed little in outward appearance during the study (Fig 7). The distribution of woody vegetation in the unburned plot revealed relatively high

coverage and frequency for both sagebrush and bitterbrush (Table 5). Other shrubs, including serviceberry, rabbitbrush (*Chrysothamnus depressus* Nutt.), snowberry and horsebrush (*Tetradymia canescens* L.) displayed relatively low to moderate coverage and frequency. Most shrubs displayed minor variability in these traits during the five study years.

Six annuals and 32 herbaceous perennials were documented. Presence of only two annuals in 1990 suggests a relatively undisturbed landscape (Table 5). Over the study period as many as six different annual species were documented, and although their coverage remained low their frequencies were quite variable (Appendix 1). By 1994 only a single annual was recorded (knotweed). Generally, most herbaceous perennial species experienced relatively minor changes in coverage or frequency during the study years. The most predominant perennial plants in terms of coverage and frequency in this plot included grasses such as squirreltail grass, prairie Junegrass (*Koeleria macrantha* [Ledeb.] Schult.), muttongrass, needle-and-thread grass (*Stipa comata* Trin. & Rupr.), and others, along with rock goldenrod, buckwheats (*Eriogonom* spp. Michx.), biscuitroot (*Lomatium triternatum* [Pursh] J.M. Coult. & Rose), and members of the *Asteraceae* family (Appendix 2). The remaining perennials were generally low in both coverage and frequency. The only non-native plant in this plot was prickly lettuce, recorded in 1992.

Abiotic components displayed some variability over the five-year study. Bare soil coverage ranged as high as 11 % to 25 % in the five-year study. Litter was ubiquitous, varying in coverage from year to year, but almost always occurring with 100 % frequency (Table 5). Few rocks were encountered in this plot, which is located in deeper soils some distance from the mesa edge.

Burned Sagebrush-Bitterbrush Study Plot

Shrubs in the burned sagebrush-bitterbrush plot underwent notable changes between 1990 and 1994 (Table 5). In 1990 serviceberry and snowberry shrubs crown-sprouted during the first year following the fire; snowberry was the first shrub to flower and fruit by 1991. Bitterbrush plants crown-sprouted in 1992 (Fig 8), and then increased in coverage and frequency during the study. Two additional crown-sprouting shrubs (rabbitbrush and fendlerbush) also entered the plot in 1992. Sagebrush plants returned to the plot during the fifth year of observation, re-established from seed.

The herbaceous annuals and perennials also changed over the five-year study. Four annuals present in 1990 increased to five by 1991 then decreased to two by 1994. The ten herbaceous perennial plants established in 1990 had nearly tripled by the following year, then the number stabilized between 23 and 25 taxa. In the first year following the fire, coverage was consistently low and frequency of any given species was rarely above 20 %. In the second and third years, a number of plants (goosefoot species, squirreltail grass, Junegrass, muttongrass, needle-and-thread grass, buckwheat species, lupine species, slender phlox [*Microsteris gracilis* (Hook.) Greene], knotweed, showy goldeneye, biscuitroot, rock goldenrod, and globemallow [*Sphaeralcea coccinea* (Nutt.) Rydb.]), first increased then decreased in frequency, while coverage for these plants remained low. The highest coverage of the five-year study was displayed by the grasses (Fig 9), including squirreltail grass and muttongrass, and the legume tailcup lupine (*Lupinus caudatus* Kellogg), all of which achieved 4 % to 10 % cover; a limited number of additional herbaceous perennials reached 1 % to 4 % cover, especially in the last two years of the study period (Appendix 2). Early in recovery (1991) a number of herbaceous plants were fully reproductive (biscuitroot, squirreltail grass, needle-and-thread grass, Junegrass,

toadflax penstemon, buckwheat species, goosefoot species, muttongrass, plainsmustard, fleabane species (*Erigeron* spp.), stoneseed (*Lithospermum ruderale* Douglas ex Lehm.), yarrow (*Achillea millefolium* L.), and lupine species.

Bare soil distributed throughout the plot decreased in coverage from 34 % to 50% (1990) to 11 % to 25 % (1994), though frequency remained very high (90 % to 100 %). There was also a consistent increase in the amount of litter present from 1 % to 4 % (1990) to 51 % to 75 % (1994). Rocks were encountered on occasion.

Comparison of the Two Sagebrush-Bitterbrush Study Plots

The dominant vegetation in the recovering burned sagebrush-bitterbrush plot was notably different from its unburned counterpart. The unburned plot was dominated by both sagebrush species and bitterbrush, giving the plot its name. In contrast, the burned plot was dominated by serviceberry and snowberry, contained relatively little bitterbrush, and sagebrush plants returned only in 1994. Of the shrubs shared in common between the two plots, coverage and frequency were higher in the burned plot for serviceberry and snowberry and lower in the burned plot for sagebrush, rabbitbrush, and bitterbrush. Fendlerbush occurred only in the burned plot, and horsebrush had barely returned to both burned and unburned plots by the end of the study in 1994.

The herbaceous vegetation was also divergent. Thirty-six herbaceous species were common to both plots, and by 1992, researchers had recognized three taxa unique to the unburned plot, and five taxa unique to the burned plot (Appendix 2). Narrowleaf goosefoot, not present in the unburned plot, experienced a frequency peak in the burned plot in 1991. The major differences between herbaceous plants in the two plots lies in the coverage and frequency data for many species; however, differences between the two plots for other species seem

negligible (Appendix 2).

Differences existed in abiotic components in the two plots. In the unburned plot, litter and bare soil were common. Bare soil in the burned plot decreased in the years following the fire, accompanied by a corresponding increase in litter. Rocks occur in both plots.

DISCUSSION

There are notable differences between each Long Mesa burned plot and its adjacent unburned control. By the end of the five-year study, the burned pinyon-juniper study plot contained no pinyon or juniper seedlings. Crown-sprouting Gambel oak was clearly the dominant woody member during this initial recovery period. Of the nine shrubs observed, only rabbitbrush (*Chrysothamnus depressus* Nutt.) flowered following its establishment via seed in 1992. Observations of the unburned pinyon-juniper control plot suggest that juniper was a relatively healthy species, but that pinyon was experiencing replacement difficulties even prior to the early 2000s, when pinyon trees suffered widely from drought and bark-boring beetles (Floyd *et al*. 2009). Herbaceous vegetation contrasted sharply between plots, with twice the number of annual and perennial species observed in the burned plot; many of these species were found only in the burned or unburned plot. The annuals goosefoot and coyote tobacco displayed interesting recovery trajectories by peaking in individual plant size one year, then increasing in population the following year(s). Over the five-year study period, the plot went from one with a fair amount of bare ground (Fig 10) to one covered in both crow-sprouting shrubs and herbaceous vegetation filling in between the fire-blackened trees (Fig 11).

The recovery of the burned sagebrush-bitterbrush plot was dominated by crown-sprouting serviceberry and snowberry. Of the seven shrubs observed within this plot, only snowberry reproduced. Both sagebrush and bitterbrush had become established in the burned plot by the

end of the five-year study, but played relatively minor roles. Herbaceous annuals and perennials differed in composition, coverage and frequency between the two plots. At the final year of the study, the differences in appearance between the unburned sagebrush-bitterbrush plot (Fig 12) and the burned one (Fig 13) were becoming less and less obvious.

For both vegetation types, shrubs were initially more diverse in unburned plots than in burned ones, but by the end of five years the balance had returned. While generally the coverage and frequency of individual shrub taxa were greater in the unburned plots, burning greatly enhanced both the coverage and frequency of Gambel's oak in the burned pinyon-juniper plot and the coverage and frequency of serviceberry in the burned sagebrush-bitterbrush plot during the first year following the fire. The growth mode noted first for all the shrubs in the burned plots was crown-sprouting. Only rabbitbrush (in pinyon-juniper) and snowberry (in sagebrush-bitterbrush) had matured enough to become reproductive during the five-year study. In contrast, the shrubs in the unburned control plots varied in age, with larger ones flowering and fruiting throughout the study.

The herbaceous vegetation in both vegetation types was also clearly affected by burning, especially in the first years after the fire. For example, herbaceous plant diversity doubled in the burned pinyon-juniper plot between 1990 and 1991, with some pioneer species (Fremont’s goosefoot, knotweed) expressing significant frequency in 1990. Herbaceous plant diversity in the burned sagebrush-bitterbrush plot was also high, and although a number of species were also present in its unburned control plot, coverage and frequency of species were quite different. Fire clearly fostered a high diversity of plant communities on Long Mesa. Four non-native plants had only minor influence in any of the four study plots.

The abiotic components also varied between the unburned and burned plots. All plots

contained moderate to high amounts of litter, which included charred plant remains in the burned plots and decomposing plant litter in the unburned plots. Bare soil was generally low in the unburned plots, relative to burned plots.

Previous Fire Research in Mesa Verde National Park

Previous Mesa Verde National Park research in Morefield Canyon and on Long Mesa focused on the role of fire, the changing nature of plant communities, and the average interval between major fires in different vegetation types. A lightning-caused fire in Morfield Canyon in July of 1959 allowed James Erdman to evaluate the earliest stages of vegetation recovery within a pinyon-juniper woodland over a four year period (1970). The Morfield Canyon burn site was located approximately 12.2 km to the southeast (Erdman 1970, Figure 1) of the Long Mesa study area. A mixture of commercial seed (intermediate wheatgrass [*Agropyron intermedium* (Host) Barkworth & D.R. Dewey] non-native desert wheatgrass [*A. desertorum* (Fisch. ex Link) Schult.] and smooth brome [*Bromus inermis* Leyss.]) was air-dropped over the Morfield Burn in October 1959 (Erdman 1970:5). As unburned control plots, Erdman documented two locations on Long Mesa: 1) a pinyon-juniper woodland that had burned in 1873, located roughly 2 km south of our burned pinyon-juniper plot; and 2) a patch of over 400 year old climax pinyon-juniper woodland located just to the north of our burned pinyon-juniper study plot. Neither of Erdman's unburned Long Mesa study plots of the 1960s appears to have fallen inside the area affected by earlier 20th century fires. All of the four 1989 Long Mesa Fire study plots reported here were in the area affected by the 1934 Wildhorse Mesa Fire (Anonymous 2012b). Wildfires do not burn all areas evenly, and the Long Mesa Fire of 1989 left unburned patches in the midst of burned vegetation that served as control plots in this study. It is reasonable to suppose that past fires may have affected the landscape in a similarly heterogeneous way. In the burned

Morefield Canyon plot to the southeast, Erdman (1970) recorded the dominance of native sunflower (*Helianthus annuus* L.) and goosefoot (*Chenopodium pratericola* Rydb.) plants in the first two years following the fire, accompanied by domesticated wheat, an introduced brome grass (*Bromus japonicas* L.), and a native brome grass (*B. carinatus* Hook. & Arn.). In the third year, the plot was dominated by introduced and native grasses (Indian ricegrass, squirreltail grass, muttongrass), and in the fourth year the prominent species were grasses, non-native prickly lettuce and tansyaster.

The Long Mesa and Morefield Canyon burned study plots shared a similar history of woody plant recovery. No trees were observed in the early years following the fire (Table 6). In both locations, a few species of shrubs crown-sprouted and grew vigorously within the first year. Gambel's oak sprouted and was in leaf within weeks of the burn, revealing an impressive adaptability to fire. The same was true for banana yucca on Long Mesa. By the fifth year on Long Mesa, six different shrubs and yucca had all crown-sprouted; in the Morfield Canyon burn area three shrubs had crown-sprouted by year four (Table 6). Notably, the coverage and frequency of some of the shrubs monitored in the Long Mesa burn plot were consistently higher, and in some cases much higher, than those in the Morfield Canyon plot; this might be explained in part by differences between a mesa top setting (Long Mesa) and a canyon bottom setting (Morfield) where cold-air drainage may limit plant growth and abundance.

In some ways, the results of this study differ from those of the Morfield Canyon burn. Following the 1989 Long Mesa Fire, the burned pinyon-juniper study plot was occupied by a different pioneer species of goosefoot (*Chenopodium fremontii* Wats.), and lacked evidence of sunflower. If goosefoot and sunflower together represent an early stage of vegetation recovery on Mesa Verde (Erdman 1970:5), that stage was not apparent following the Long Mesa burn.

The ability of feral horses to keep wild sunflower populations completely in check should be considered. According to this study on Long Mesa, other pioneer plants with early vigorous populations included knotweed and coyote tobacco.

A number of native herbaceous plants displayed similar representation in the burned pinyon-juniper plots of both Long Mesa and Morfield Canyon, despite the spread of commercial seed following the Morfield Fire (Erdman 1970:5). These taxa included tansyaster, showy goldeneye, ricegrass, stickseed, species of lupine, and toadflax penstemon. Bare soil, litter and rock were similar in coverage and frequency as well.

The unburned pinyon-juniper woodland control plots for both studies were located on Long Mesa. Erdman's unburned plots included one that had burned approximately 90 years earlier in 1873, as determined by tree-ring dating of living pinyon trees, (Erdman 1970:10-15). In this plot the first tree seedlings were established by the early 1900s. Some of these trees were 4.6 m to 6.1 m in height by 1963, and shared the plot with bitterbrush and fendlerbush (Erdman 1970:10-11). Erdman's second unburned study plot was a small patch of pinyon-juniper woodland considered to be a 400 or more year-old remnant of a climax forest, based on tree-ring dating of the living trees (Erdman 1970:13-15). This 400+-year-old forest and the unburned pinyon-juniper study plot reported here shared characteristics in common (Table 7). In both studies, co-dominant pinyon and juniper trees displayed similar coverage and frequency values. In addition, when Point Quarter analysis (a measure of density) and Importance Value (the sum of relative density, frequency, and coverage [dominance]) were calculated, both studies suggested juniper trees were clearly dominant. In contrast, age class data varied in that pinyon trees were more abundant in the Long Mesa Climax forest, with more seedlings and saplings (n=16) than those of juniper (n=5); the findings of our Long Mesa study were just the reverse

(Table 3), with more seedlings and saplings of juniper (n=27) than of pinyon (n=4) by the end of the five-year study period. The age class data of these two projects suggest that between 1963 and 1994 pinyon trees were losing the ability to maintain a balanced age-class structure on Long Mesa.

The Role and Status of Non-Native Plants

Non-native invasive plants, especially annuals with a tendency to increase under conditions of disturbance, played a small role in plant community recovery on Long Mesa following the 1989 fire. Four adventive species, including cheatgrass, prickly lettuce, Russian thistle, and goatsbeard were noted in the study plots (Appendices 1-2). All four of these introduced plants were observed only rarely in the burned pinyon-juniper study plot, where they displayed extremely low coverage and frequency. Cheatgrass invasion into pinyon-juniper woodlands in western Colorado is uncommon unless the burned plot has been seeded (Getz and Baker 2008). Only prickly lettuce occurred in a single year in the unburned sagebrush-bitterbrush plot. In the early 1990s, fire recovery on Long Mesa was dominated by native plants.

Non-native vegetation played a much more significant role following more recent burns. In particular, post-fire conditions following the Chapin 5 Fire in 1996 encouraged high density stands of the nonnative musk thistle (*Carduus nutans* L.) (Floyd *et al*. 2006). This species was not observed in significant frequency or coverage following the 1989 Long Mesa Fire. A comparison of burned and unburned plots three years after the Pony and Bircher fires of 2000 showed a significantly greater density of non-native plants in the burned plots than the unburned ones (Floyd *et al*. 2006). The increased influence of non-native vegetation following these more recent Mesa Verde fires demonstrates a significant change in post-fire succession in the past two

decades, and emphasizes the need for continued attention to the influences of invasive plants on the regrowth of burned areas.

Patterns of Germination

This study documents a unique pattern of post-fire response for goosefoot and coyote tobacco. Coyote tobacco can be found in small numbers in arroyos and along roadsides in previously undisturbed areas, but germinate in large numbers for a maximum of three growing seasons following a fire (Barney and Frischnecht 1974; Baldwin and Morse 1994; Preston and Baldwin 1999; Colyer, Mesa Verde National Park, personal communication 1987). This tobacco species demonstrates a sophisticated germination response to post-fire conditions. The increase of water-soluble, smoke-derived compounds in the soil, a result of the combustion of cellulose, increases germination of dormant seeds (Baldwin and Morse 1994; Preston and Baldwin 1999, Schwachtje and Baldwin 2004). Abscisic acid and terpenes leached from the unburned litter of sagebrush and pinyon and juniper trees inhibit germination (Preston and Baldwin 1999; Krock *et al.* 2002). The interaction of these positive and negative cues explain wild tobacco's germination pattern, which allows it to take full advantage of increased light and nutrients and decreased competition after a fire (Preston and Baldwin 1999). No such germination patterns or chemical responses have been previously reported for goosefoot, which also experienced a population rise and decline during the first three years following the pinyon-juniper woodland fire.

The Issue of Large Fire Intervals in Shrublands and Woodlands

The average intervals between large fires vary widely in shrublands and woodlands. Following the Long Mesa Fire of 1989, researchers focused on shrub communities of Gambel's oak, a species well-known for its crown-sprouting capabilities following a fire (Floyd *et al*.

2000). Their aim was to develop a method to reconstruct fire history based on the observed age structure of oak shrublands. Floyd and her colleagues noted that oaks "sprouted prolifically" in the late summer of 1989 and spring of 1990 and that by two years after the fire in 1991 there was "no significant difference in shrub cover between burned and unburned areas" except for lower stature of plants in the burned plot (2000:1669). This clearly indicates a remarkable ability of oaks to recover after a devastating burn, although the time it takes for their associated woody and herbaceous floras to recover may be longer. They went on to evaluate the age structure of oak woodlands in numerous locations on Mesa Verde, and estimated that the interval between large fires within oak shrublands is approximately 100 years (Floyd *et al*. 2000:1676). Other researchers have estimated it would take from 35 up to 450 years for different sagebrush (*Artemisia*) communities in the American west to fully recover (Baker 2006), whereas one study reported that a sagebrush community developed in as few as 11 years (Barney and Frischknecht 1974).

Conifer woodland fires may require even more recovery time. Pinyon and juniper trees are extremely fire sensitive and killed by even small fires (Floyd *et al*. 2000; Morris *et al*. 2008). At least two decades passed after the Long Mesa Fire of 1873 before any pinyon and juniper seedlings became established; another woodland represented a climax forest estimated at 400 years of age (Erdman 1970:10, 15), although it is not known how much time was required for it to reach a climax condition. After analyzing the age structure of living pinyon and juniper woodlands located across the Mesa Verde, Floyd and her colleagues supported Erdman's conclusion. By counting tree-rings in hundreds of trees, as opposed to the more precise method of cross-dating, they were able to estimate the minimum interval since fire had affected various locations. They concluded that much of the Mesa Verde pinyon-juniper woodland had not been

subjected to severe fire for many centuries, generally more than 400 years (2000:1676). Elsewhere in west-central Utah, other researchers reported that juniper woodlands were well-developed 85 to 90 years following fire (Barney and Frischknecht 1974).

Fire is influential in landscapes dominated by pinyon, juniper and sagebrush because unlike other woody species present, the dominant woody plants do not crown-sprout. In the burned shrubland plot, sagebrush only became re-established from seed during the fifth year following the fire, and had not become re-established in the pinyon-juniper plot at all. No pinyon or juniper seedlings were observed in the burned pinyon-juniper plot during the entire study. Other woody and herbaceous species re-established, flowered and fruited in very few growing seasons following the fire, and the diversity of taxa increased in the course of post-fire succession.

The Value of Plant Community Mosaics

Fire clearly promotes plant community diversity on Mesa Verde. In contrast to a well-developed plant community, fire alters the overall plant composition and traits of individual plant taxa for some number of years during recovery. These differences can convert an area with a limited set of well-established plant communities into a mosaic pattern that includes all the communities affected by a fire. Some of the immediate effects include: release of nutrients from the burned biomass; less competition among plants for light, moisture, and pollinators; and stimulation of fire-adapted species. During recovery, some resources for animals are increased as others are diminished. When burned and unburned patches of different vegetation types occupy an area, the ecological implications can be felt for years and sometimes centuries.

The Value of These Studies for Land Managers

The more information land managers have on plant community recovery following a fire, the better they are able to make decisions about intervention and the time-frame of projected future plant composition. The Long Mesa study reported here provided detailed assessments of plant community composition during the first five years following a fire in two common vegetation types on Mesa Verde, pinyon-juniper woodland and sagebrush-bitterbrush shrubland. Simultaneously, the same data were gathered on two unburned control plots in the vicinity of the burned plots. The fact that the burned areas were not intentionally seeded with either native or non-native species allowed a natural sequence of vegetation recovery. Such detailed studies are rare, and often lack adjacent unburned controls.

This study provides a historic context for land managers to understand the ecological consequences of fires that completely consume the dominant woody plants in a pinyon-juniper woodland. A previous assertion that all Mesa Verde pinyon-juniper woodlands pass through a single seral stage following a burn (Erdman 1970) appears not to be supported. The interval before either pinyon or juniper trees are established as seedlings is longer than five years; previous Mesa Verde research suggests between 25 to 35 years are required (Erdman 1970). As this report shows, many differences exist in the shrub and herbaceous plant components of a heavily burned pinyon-juniper woodland and a nearby unburned counterpart. When combined with an earlier study (Erdman 1970) of Long Mesa areas spared by earlier 20th century fires, it appears that pinyon was a healthy population replacing itself in 1963, but by the early 1990s was losing ground; pinyon trees were subsequently devastated in the region by a combination of drought and bark-boring insects (Floyd *et al*. 2009).

This research presents the first Mesa Verde National Park case study of post-fire vegetation recovery of a sagebrush-bitterbrush shrubland, including comparison to a nearby unburned control plot. Crown-sprouting shrubs included bitterbrush and eventually sagebrush, but other shrubs such as serviceberry and snowberry dominated the early recovery. Differences in plant species and their characteristics were notable at five years following the fire, but perhaps less dramatic than those of burned and unburned pinyon-juniper woodland plots. These vegetative types contrasted sharply with the relatively rapid two-year recovery reported for oak trees in oak shrublands (Floyd *et al*. 2000).

Park managers now have basic information on short-term recovery of pinyon-juniper woodlands (Erdman 1970; this study), sagebrush-bitterbrush shrublands (this study), and on one-two year recovery of oak shrublands (Floyd *et al.* 2000). The early recovery trajectories clearly vary. The first to recover its dominant vegetation appears to be the oak shrubland, which is dominated by oaks by the second year. Sagebrush-bitterbrush vegetation at five years still varies from that of an unburned control, although many plant species are shared in common. The vegetation type that takes the longest to recover is burned pinyon-juniper woodland; when compared to an unburned control plot there are still many differences at five years, and pinyon and juniper seedlings are not expected for at least another two decades.

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Figure 1: Mesa Verde National Park, with plot locations

Figure 2. Unburned pinyon-juniper plot 1991

Figure 3. Burned pinyon-juniper plot 1990

Figure 4. Crown-sprouting Gambel oak in burned pinyon-juniper plot, 1992

Figure 5. Large, healthy coyote tobacco plant, 1990

Figure 6. Healthy goosefoot plant with researchers for scale, 1990

Figure 7. Unburned sagebrush-bitterbrush plot 1992

Figure 8. Crown-sprouting bitterbrush in burned sagebrush-bitterbrush plot, 1991

Figure 9. Grasses and herbaceous plants in burned sagebrush-bitterbrush plot, 1991

Figure 10. Burned pinyon-juniper plot, 1991

Figure 11. Burned pinyon-juniper plot, 1994

Figure 12. Unburned sagebrush-bitterbrush plot, 1994

Figure 13. Burned sagebrush-bitterbrush plot, 1994

Table 1. Plants observed in the study plots. Scientific names primarily correspond to *A Utah Flora* (Welsh et al. 1987). Life forms are T (trees), S (shrubs), HP (herbaceous perennials) and A (annuals). *Plants introduced from other continents.

Scientific Name	**Common Name**	**Life Form**
Achillea millefolium L.	Yarrow	HP
Amelanchier utahensis Koehne	Serviceberry	S
Arabis holboellii Hornem var. *secunda* (Howell) Jeps.	Rockcress	HP
Artemisia ludoviciana Nutt.	White sagebrush	HP
Artemisia nova A. Nels.	Black sagebrush	S
Artemisia tridentata Nutt.	Big sagebrush	S
Astragalus scopulorum T.C. Porter	Milkvetch	HP
Balsamorhiza sagittata (Pursh.) Nutt.	Balsamroot	HP
**Bromus tectorum* L.	Cheatgrass	A
Bromus spp.	Brome grass	A or HP
Calochortus nuttallii T.&G. in Bechwith	Mariposa lily	HP
Cercocarpus montanus Raf.	Mountain mahogany	S
Chenopodium fremontii Wats.	Fremont's goosefoot	A
Chenopodium leptophyllum (Moq.) Wats.	Narrowleaf goosefoot	A
Chrysothamnus depressus Nutt.	Rabbitbrush	S
Cirsium undulatum (Nutt.) Sprengel	Thistle	HP
Cirsium sp. Mill.	Thistle	HP
Comandra umbellata (L.) Nutt.	Toadflax	HP
Cordylanthus wrightii Gray	Birdbeak	A
Crepis acuminata Nutt. var. Johnstonii	Hawksbeard	HP
Cymopterus purpureus Wats.	Springparsley	HP
Delphinium nuttallianum Pritz.	Delphinium	HP
Dracocephalum parviflorum Nutt.	Dragonhead	HP
Elymus elymoides (Raf.) Swezey	Squirreltail	HP
Elymus smithii (Rydb.) Gould	Western wheatgrass	HP
Erigeron divergens T.&G.	Spreading fleabane	HP
Erigeron engelmannii A. Nels.	Engelmann's fleabane	HP
Erigeron pumilus Nutt. ssp. *concinnoides* Cronq.	Shaggy fleabane	HP
Erigeron speciosus (Lindl.) D.C.	Aspen fleabane	HP
Eriogonum racemosum Nutt.	Redroot buckwheat	HP
Eriogonum umbellatum Torr. Va. *suibaridum* Stokes	Sulpher-flower buckwheat	HP
Fendlera rupicola Gray	Fendlerbush	S
Gayophytum ramosissimum T.&G.	Pinyon groundsmoke	A
Gramineae	Grass	A or HP
Grindelia arizonica A. Gray	Gumweed	HP
Heterotheca villosa (Pursh.) Shinn.	Hairy false goldenaster	HP
Juniperus osteosperma (Torr.) Little	Juniper	T
Koeleria macrantha (Ledeb.) Schultes	Junegrass	HP
**Lactuca serriola* L.	Prickly lettuce	A or HP
Lappula occidentalis (Wats.) Greene	Stickseed	A
Lithospermum ruderale Dougl. Ex Lehm.	Stoneseed	HP

Lomatium triternatum (Pursh.) Coult. & Rose ssp. *platycarpum*	Biscuitroot	HP
Lupinus caudatus Kellogg	Tailcup lupine	HP
Lupinus polyphyllus Lindl. var. *ammophilis* (Greene) Barneby	Bigleaf lupine	HP
Machaeranthera canescens (Pursh.) Gray var. *aristata* (Eastw.) B.	Tansyaster	HP
Microsteris gracilis (Hook.) Greene	Slender phlox	A
Monocotyledon	Monocotyledon	HP
Nicotiana attenuata Torr. Ex Wats.	Coyote tobacco	A
Opuntia Miller	Prickly pear cactus	HP
Orthocarpus purpureoalbus Gray	Owlclover	A
Pedicularis centranthera Gray	Pinyon/juniper lousewort	HP
Penstemon linarioides Gray ssp. *coloradoensis* (A. Nels.) Keck	Toadflax penstemon	HP
Penstemon strictus Benth.	Rocky Mountain penstemon	HP
Petradoria pumila (Nutt.) Greene	Rock goldenrod	HP
Phacelia heterophylla Pursh.	Phacelia	HP
Pinus edulis Engelm.	Pinyon	T
Poa fendleriana (Steudel) Vasey	Muttongrass	HP
Poa pratensis L.	Kentucky bluegrass	HP
Polygonum douglasii Greene var. *johnstonii* Munz	Knotweed	A
Purshia tridentata (Pursh.) D.C.	Bitterbrush	S
Quercus gambelii Nutt.	Gambel's oak	S
**Salsola iberica* Sennen & Pau	Russian thistle	A
Schoenocrambe linifolia (Nutt.) Greene, Cruciferae	Plainsmustard	HP
Sphaeralcea coccinea (Nutt.) Rydb.	Globemallow	HP
Stipa comata Trin. & Rupr.	Needle-and-thread grass	HP
Stipa hymenoides R. & S.	Ricegrass	HP
Symphoricarpos oreophilus Gray	Snowberry	S
Tetradymia canescens L.	Horsebrush	S
**Tragopogon* L.	Goat's beard	HP
Viguiera multiflora (Nutt.) Blake var *multiflora*	Showy goldeneye	HP
Viguiera multiflora (Nutt.) var *nevadensis* (A. Nels) Blake	Nevada goldeneye	HP
Wyethia arizonica Gray	Mulesears	HP
Yucca baccata Torr.	Banana yucca	HP

Table 2. Coverage (%) and frequency (%) data for pinyon-juniper plots in Mesa Verde, Colorado USA, 1991 through 1994

Plot	Trees				Shrubs		Herbaceous plants		Abiotic components			
Unburned	Pinyon		Juniper		*Amelanchier, Artemisia* spp., *Cercocarpus, Purshia*		Annuals	Perennials	Litter		Bare Soil	
	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	No.	No.	Cover.	Freq.	Cover.	Freq.
1990	26.4	52	20.1	32	5.1-8.1	18-26	0	8	51-75	92	1-4	46
1991	37.6	68	32.6	58	3.7-10.9	24-34	2	12	76-90	100	4-10	68
1992	32.7	56	28.0	52	0.0-6.5	0-28	2	12	76-90	100	1-4	58
1993	29.9	52	27.3	46	4.8-7.8	16-32	2	12	76-90	100	1-4	52
1994	30.7	52	28.3	50	4.5-10	12-32	3	14	76-90	100	1-4	42
Burned	No trees established during the study period.				*Quercus, Yucca, Purshia, Symphoricarpos, Cercocarpus*							
	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	No.	No.	Cover.	Freq.	Cover.	Freq.
1990	na	na	na	na	0.1-8.3	2.5-25	5	6	4-10	84	51-75	94
1991	na	na	na	na	0.0-11.9	0-28	5	15	26-33	100	34-50	100
1992	na	na	na	na	0.1-12.9	2-26	6	15	34-50	100	11-25	92
1993	na	na	na	na	0.2-14.4	2-80	4	16	34-50	100	11-25	90
1994	na	na	na	na	0.2-13.0	2-26	2	16	34-50	92	26-33	88

Table 3. Age class analyses of pinyon and juniper trees in unburned pinyon-juniper study plot, Mesa Verde, Colorado USA, in 1990 and 1994.

Species	Year	No. seedlings[a]	No. saplings[b]	No. trees[c]	Total
Juniperus osteosperma	1990	7	16	14	37
	1994	5	22	4	31
Pinus edulis	1990	1	9	16	26
	1994	1	3	3	7

[a] seedlings: height <30.4 cm

[b] saplings: height >30.4 cm, diameter <5.0 cm

[c] trees: diameter >5.0 cm

Table 4. Point Quarter Analysis of pinyon and juniper trees in unburned pinyon-juniper woodland study plot in Mesa Verde, Colorado, USA, 1990 and 1994.

Species and year	Observation/Measurement							
Juniperus osteosperma	No. of trees	Mean distance (m)	Basal area (cm^2)[a]	Density (No./0.4047 hectares)	Relative density (%)	Relative frequency (%)	Relative dominance (%)	Importance value[b]
1990	26	6.71	22,332	90	29	56	87	172
1994	25	7.24	73,094	77	39	60	96	195
Pinus edulis								
1990	14	4.33	3,262	216	71	44	13	128
1994	15	5.96	3,022	114	61	39	4	104
All trees								
1990	40	5.877	25,594	306	100	100	100	300
1994	40	13.2	76,116	191	100	100	100	300

[a] Basal areas for all trunks of multiple-trunked individuals have been summed to find the total basal area for each individual.

[b] Sum of the relative density, frequency, and dominance.

Table 5. Coverage (%) and frequency (%) data for sagebrush-bitterbrush plots in Mesa Verde, Colorado, USA, 1990 through 1994

Plot	Major shrubs				Other shrubs	Herbaceous plants		Abiotic components			
Unburned	Sagebrush		Bitterbrush		*Amelanchier, Chrysothamnus, Fendlera, Symphoricarpos, Tetradymia*	Annuals	Perennials	Litter		Bare soil	
	Cover.	Freq.	Cover.	Freq.	No.	No.	No.	Cover.	Freq.	Cover.	Freq.
1990	17.3	84	24.1	76	3	2	13	26-33	88	4-10	90
1991	11.5	92	15.6	92	3	3	24	34-50	100	11-25	100
1992	12.4	74	14.7	72	3	5	22	34-50	100	11-25	100
1993	11.1	76	18.6	78	4	3	19	76-90	100	4-10	92
1994	10.6	72	18.1	74	4	1	20	51-75	100	4-10	88
Burned											
	Cover.	Freq.	Cover.	Freq.	No.	No.	No.	Cover.	Freq.	Cover.	Freq.
1990	0.0	0	0.0	0	2	4	10	1-4	75	34-50	95
1991	0.0	0	0.6	6	2	5	28	26-33	100	26-33	100
1992	0.0	0	0.6	8	4	4	23	34-50	100	11-25	100
1993	0.0	0	0.8	6	4	3	25	34-50	100	4-10	98
1994	0.3	4	1.2	10	5	2	25	51-75	100	11-25	90

Table 6. Early vegetation recovery of a burned pinyon-juniper woodland compared to a previous fire study in Mesa Verde National Park, USA (Erdman 1970)

Research		This study		Erdman (1970)
Fire location		Long Mesa		Morefield Canyon
Fire date		1989		1959
Study period		1990-1994		1960-1963
Seeded?		no		yes
Trees		No pinyon or juniper trees returned		No pinyon or juniper trees returned
Initial shrubs		*Quercus* gambelii and *Yucca baccata* crown-sprouted		*Quercus gambelii* crown-sprouted
Shrubs that followed		*Cercocarpus, Purshia, Symphoricarpos, Amelanchier,* and *Fendlera* also crown-sprouted		*Amelanchier* and *Fendlera* also crown-sprouted
Dominant pioneer vegetation		*Chenopodium fremontii, Polygonum douglasii, Nicotiana attenuata*		*Helianthus annuus, Chenopodium pratericola*
Herbaceous annuals and perennials that followed		At least twenty species occupied the burned study plot during years two through five.		Grasses were especially prominent by the third year following the fire. At least seventeen species occupied the burned study plot by year four.

Table 7. Unburned pinyon-juniper control plot results compared to a previous study in Mesa Verde National Park, USA (Erdman 1970). All plots are on Long Mesa.

	This study				Erdman 1970				
Previous fire date	None known				1873		<= 1576 A.D.		
Observation year	1994 (study end)				1963 (study end)				
	Coverage (%)	Frequency (%)	Importance Value		Coverage (%)	Frequency (%)	Coverage (%)	Frequency (%)	Importance Value
Trees									
Pinyon	26.4	52	104		19	46	27	48	95
Juniper	28.3	50	195		6	12	31	50	205
Dominant shrubs									
Cercocarpus montanus	10	22			2	10	14	28	
Yucca baccata	0.5	4			13	40	2	14	
Fendlera rupicola	3.2	10			14	48	2	8	
Purshia tridentata	7.4	32			26	82	+	2	
Dominant herbaceous vegetation									
Poa fendleriana	4-10	84			<4	56	4-10	80	
Penstemon linarioides	<1	34					<4	24	
Commandra umbellata	1-4	28			n/a	n/a	+	14	
Polygonum douglasii	<1	18							
Lappula occidentalis, L. redowskii	n/a	n/a			<4	32	+	4	
Bromus tectorum	n/a	n/a			+	22	+	4	
Lupinus polyphyllus, L. ammophilus	1-4	50			n/a	n/a	+	4	
+ indicates presence but no significant cover value									

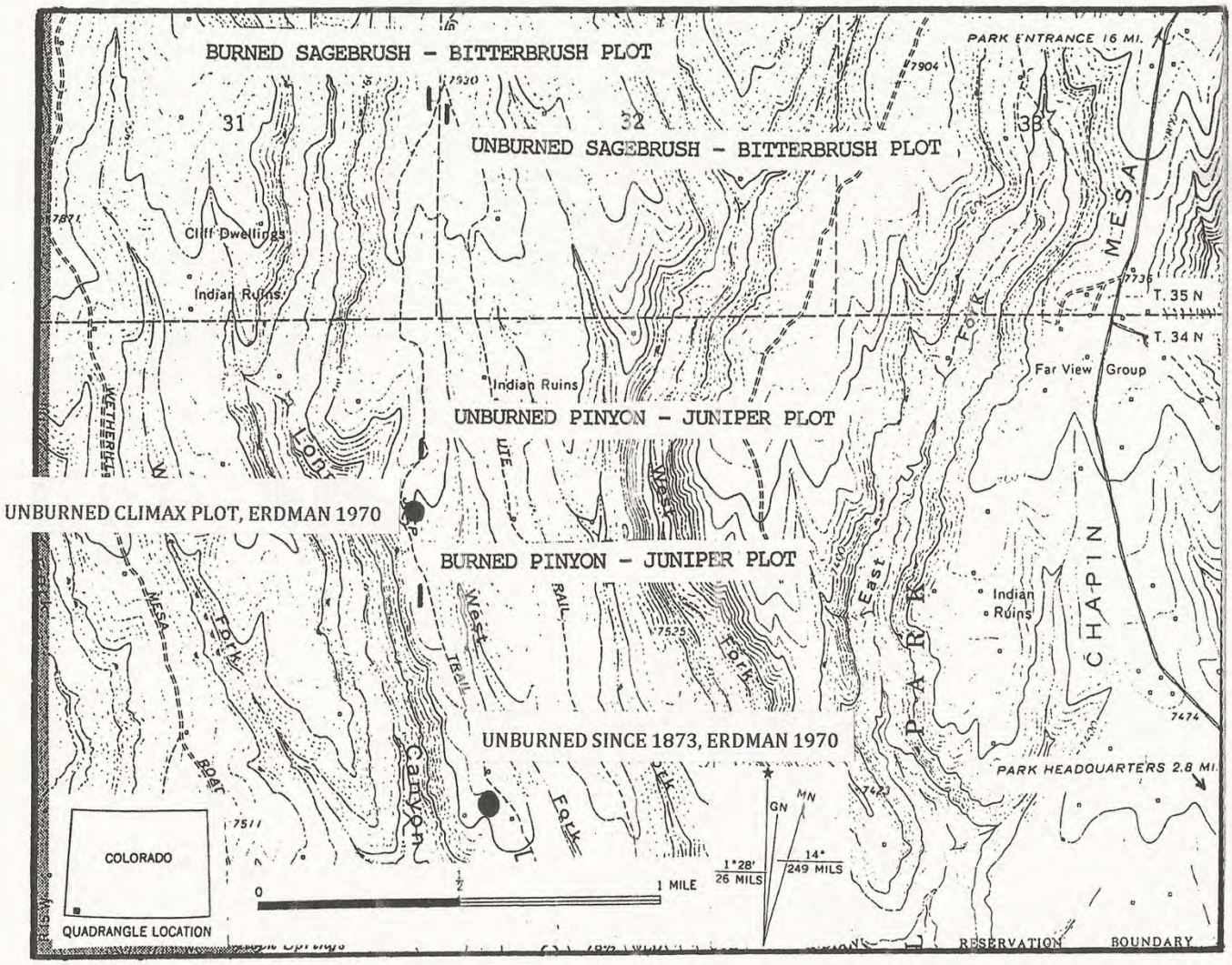

Figure 1. Plot locations in Long Mesa Study Area, T 34 and 35 N, R 15 W, Wetherill Mesa Quadrangle, Colorado - Montezuma County, 7.5 Minute Series.

Figures 2-5. Unburned and burned pinyon-juniper plots. (2) Unburned pinyon-juniper plot, general shot; (3) burned pinyon-juniper plot in August of 1990, covered with annual plants; (4) burned pinyon-juniper plot in September of 1992 highlighting crown-sprouting *Quercus* shrubs; (5) typical *Nicotiana attenuata* plant in August of 1990.

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Figures 6-9. (6) Burned pinyon-juniper plot, huge *Chenopodium* plant in August 1990; (7) general shot of the unburned sagebrush-bitterbrush shrubland in September of 1992; (8) crown-sprouting *Purshia tridentata* in August of 1991; (9) numerous grass species recovering in the burned sagebrush-bitterbrush plot in August of 1991.

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Figures 10-13. (10) General shot of burned pinyon-juniper plot with a high proportion of bare soil in Sept. of 1991; (11) burned pinyon-juniper plot at the end of the study in June 1994; (12) unburned sagebrush-bitterbrush plot in October of 1994; (13) burned sagebrush bitterbrush plot in June of 1994.

10	11
12	13

Appendix 1. Coverage and frequency of vegetation in the pinyon/juniper plots. *Plants introduced from other continents.

	1990				1991				1992				1993				1994			
	Unburned		Burned		Unburned		Burned		Unburned		Burned		Unburned		Burned		Unburned		Burned	
	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
TREES																				
Juniperus osteosperma	20.1	32			32.6	58			28	52			27.3	46			28.3	50		
Pinus edulis	26.4	52			37.6	68			32.7	56			29.9	52			30.7	52		
SHRUBS																				
Amelanchier utahensis	5.1	18			9.2	30	0.8	8	6.5	24	1	4	6.4	16	1.8	4	4.6	12	2	4
Artemisia tridentata/nova	6.6	26			3.7	24			5.9	26			4.8	20			4.5	18		
Cercocarpus montanus	8.1	18	0.2	2.5	9.8	30					0.3	4	7.8	18	1.1	6	10	22	1.5	8
Chrysothamnus depressus									0.3	4										
Fendlera rupicola	2.1	8			2.1	10	0.5	2	5.2	12	0.4	2	3.8	10	0.8	4	3.2	10	0.5	2
Purshia tridentata	6.2	20	1.1	7.5	10.9	34	2	10	5.5	28	2.7	16	7.1	32	2.7	18	7.4	32	0.3	16
Quercus gambelii	1.4	2	8.3	25	1.5	4	11.9	28	2.7	4	12.9	26	1.6	2	14.4	80	1.6	2	13	26
Symphoricarpos oreophilus			0.1	4			0.4	2			0.1	2			0.2	2			0.2	2
Yucca baccata	1	4	1.2	5	1.5	6	1.8	6	0.6	2	2.5	6	0.5	4	3.3	8	0.5	4	2.7	8
HERBACEOUS PLANTS																				
Annuals																				
*Bromus tectorum**															<1	2			<1	2
Chenopodium fremontii			<1	34			<1	56			<1	36			<1	2				8
Chenopodium sp.																	<1	2		
Cordylanthus wrightii			<1	2	<1	4			<1	18	<1	2	<1	14			<1	6		
Lappula occidentalis			<1	2			<1	14			<1	12			<1	6				
Microsteris gracilis											<1	4								
Nicotiana attenuata			<1	4			<1	4			<1	2								
Polygonum douglasii			<1	26	<1	4	<1	84	<1	42	<1	96	<1	10	<1	76	<1	18	<1	44
*Salsola iberica**							<1	6												
Perennials																				
Balsamorhiza sagittata					<1	8			<1	8			<1	4			<1	8		
Calochortus nuttallii															<1	2				
Cirsium sp.											<1	2							<1	2
Cirsium undulatum															<1	2			<1	8
Comandra umbellata	<1	18	<1	10	<1	26		22	<1	26	<1	22	<1	22		26	1-4	28	1-4	30
Crepis acuminata																	<1	2		

Cymopterus purpureus																	<1	10				
Delphinium nuttallianum															<1	2						
Elymus elymoides	<1	28				<1	10	<1	4		<1	12	<1	8	<1	10	<1	6	<1	8	<1	14
Erigeron divergens			<1	2				<1	4				<1	2								
Erigeron engelmannii																					<1	2
Erigeron speciosus	<1	2				<1	2								<1	4			<1	4		
Eriogonum umbellatum	<1	2						<1	4												<1	2
Gramineae			<1	6		<1	12				1-4	70	<1	12			<1	4				
Heterotheca villosa													<1	6			<1	4			<1	4
Koeleria macrantha						<1	2				<1	12	<1	10	<1	18			<1	8		
*Lactuca serriola**								<1	36				<1	56			<1	12				
Lupinus caudatus						<1	20	<1	2		<1	16	<1	2					<1	4	<1	4
Lupinus polyphyllus						<1	24	<1	8		<1	34	<1	2	1-4	40	<1	12	1-4	50	<1	12
Machaeranthera canescens								<1	2				<1	38			<1	38	<1	4	1-4	56
Opuntia (p. pear)	<1	4				<1	6	<1	4		<1	4			<1	4			<1	4		
Pedicularis centranthera																	<1	4				
Penstemon linarioides	<1	22	<1	20		<1	44	<1	30		<1	38	<1	26	<1	28	<1	22	<1	34	<1	34
Petradoria pumila	<1	8				<1	30				<1	20			<1	20			<1	22		
Phacelia heterophylla																					<1	2
Poa fendleriana	<1	66				1-4	82	<1	22		1-4	58	<1	8	1-4	74	<1	22	4-10	84	<1	14
Schoencrambe linifolia			<1	2				<1	20				<1	24			<1	34			<1	24
Stipa comata																			<1	2		
Stipa hymenoides								<1	2												<1	2
*Tragopogon sp.**								<1	4								<1	4				
Viguiera multiflora			<1	4				<1	38				<1	52	<1	2	<1	60			1-4	64
Wyethia arizonica											<1	2										
ABIOTIC																						
Bare soil	1-4	46	51-75	94		4-10	68	34-50	100		1-4	58	11-25	92	1-4	52	11-25	90	1-4	42	26-33	88
Litter	51-75	92	4-10	84		76-90	100	26-33	100		76-90	100	34-50	100	76-90	100	34-50	100	76-90	100	34-50	92
Rock	<1	10	<1	10		<1	14	<1	40		<1	18	<1	26	<1	6	<1	10	<1	6	<1	8

Appendix 2. Coverage and frequency of vegetation in the sagebrush/bitterbrush plots. *Plants introduced from other continents.

	1990				1991				1992				1993				1994			
	Unburned		Burned		Unburned		Burned		Unburned		Burned		Unburned		Burned		Unburned		Burned	
	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.	Cover.	Freq.
	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
SHRUBS																				
Amelanchier utahensis	6.3	16	6.9	20	6.8	26	11.6	46	6.6	20	11.2	30	8	20	9.9	30	7.6	20	12.8	32
Artemisia tridentata/ nova	17.3	84			11.5	92			12.4	74			11.1	76			10.6	72	0.3	4
Chrysothamnus depressus	1.9	10			2	20			0.9	8	0.2	4	0.7	16	0.2	2	0.5	12	0.2	2
Fendlera rupicola											0.4	2			0.7	4			0.8	4
Purshia tridentata	24.1	76			15.6	92	0.6	6	14.7	72	0.6	8	18.6	78	0.8	6	18.1	74	1.2	10
Symphoricarpos oreophilus	2.3	6	1.7	6	3.3	8	4.4	22	4.2	14	4	28	5.1	14	7.3	28	3.5	8	4.4	26
Tetradymia canescens													0.4	10			0.5	6	0.4	4
HERBACEOUS PLANTS																				
Annuals																				
Chenopodium fremontii	<1	2					<1	62	<1	2			<1	2						
Chenopodium leptophyllum			<1	20			<1	50			<1	28								
Cordylanthus wrightii									<1	26	<1	2							<1	2
Gayophytum ramosissimum			<1	25			<1	2	<1	10										
Microsteris gracilis			<1	5	<1	8	<1	46	<1	38	<1	18			<1	2				
Orthocarpus purpurea-albus					<1	2							<1	8	<1	4				
Polygonum douglasii	<1	2	<1	40	<1	10	<1	96	<1	56	<1	98	1-4	64	<1	44	<1	26	1-4	38
Perennials																				
Achillea millefolium	<1	2			<1	2	<1	4	<1	2	<1	2	<1	2	<1	2	<1	6	<1	6
Arabis holboellii							<1	8												
Artemisia ludoviciana	<1	4					<1	2												
Astragalus scopulorum	<1	2			<1	6	<1	2	<1	4	<1	2	<1	4	<1	6	<1	4		
Balsamorhiza sagittata																			<1	2
Calochortus nuttallii									<1	34	<1	14	<1	2	<1	8	<1	10	<1	12
Cirsium undulatum			<1	20			<1	14	<1	2	<1	8			<1	2	<1	2	<1	2
Comandra umbellata							<1	2												
Compositae					<1	40			<1	42	<1	24					<1	8		
Crepis acuminata					<1	2	<1	22			<1	14	<1	4	<1	14	<1	28	<1	16
Cruciferae							<1	2	<1	2										
Delphinium nuttallianum					<1	2	<1	2												

Dracocephalum parviflorum			<1	5			<1	2													
Elymus elymoides	<1	28	<1	15	<1	68	1-4	74	1-4	74	1-4	68	1-4	62	1-4	42	1-4	62	4-10	86
Elymus smithii					<1	14							<1	8	<1	6	<1	12		
Erigeron divergens							<1	4					<1	2	<1	2				
Erigeron engelmannii	<1	6			<1	8	<1	12	<1	8	<1	44	<1	4	<1	8	<1	2	1-4	24
Erigeron pumilus					<1	8	<1	20							<1	4	<1	2	<1	4
Erigeron speciosus	<1	2			<1	4													<1	4
Eriogonum racemosum			<1	55	<1	82	1-4	80	<1	70	<1	64	1-4	66	1-4	34	1-4	62	1-4	64
Eriogonum umbellatum	<1	60			<1	64	<1	56	<1	34	<1	6			<1	2			<1	2
Gramineae					<1	60			<1	22			<1	2						
Koeleria macrantha			<1	25	1-4	84	1-4	66	<1	44	<1	52	1-4	54	1-4	40	1-4	68	1-4	74
*Lactuca serriola**									<1	10										
Lithospermum ruderale	<1	2			<1	22	<1	8	<1	8	<1	4	<1	6	<1	6	<1	18	<1	6
Lomatium triternatum					<1	22	<1	26	<1	34	<1	20			<1	4			<1	2
Lupinus caudatus			<1	10	<1	16	<1	60	<1	16	1-4	74	<1	30	1-4		1-4	52	4-10	90
Lupinus polyphullus																			<1	4
Machaeranthera canescens															1-4	40	<1	4	<1	26
Monocotyledon					<1	18														
Penstemon linarioides	<1	6			<1	24	<1	22	<1	28	<1	8	<1	8	<1	8	<1	12	<1	10
Penstemon strictus			<1	5	<1	4	<1	8	<1	2	<1	10			<1	8			<1	8
Petradoria pumila	1-4	62			4-10	90	<1	22	4-10	72	<1	24	4-10	72	<1	20	1-4	76	1-4	26
Phacelia heterophylla			<1	5			<1	4			<1	12	<1	2	<1	4	<1	2	<1	4
Poa fendleriana	1-4	80			4-10	90	<1	58	4-10	86	4-10	52	1-4	66	1-4	10	4-10	82	1-4	32
Poa pretensis											<1	16								
Sphaeralcea coccinea	<1	2	<1	20	<1	2	<1	32			<1	34			1-4	24			1-4	24
Stipa comata	<1	2			<1	54	<1	34	<1	50	<1	36	1-4	32	1-4	28	<1	2	1-4	20
Viguiera multiflora			<1	20			<1	42	<1	2	<1	44	<1	2	1-4	34			1-4	62
ABIOTIC																				
Bare Soil	4-10	90	34-50	95	11-25	100	26-33	100	11-25	100	11-25	100	4-10	92	4-10	98	4-10	88	11-25	90
Litter	26-33	88	1-4	75	34-50	100	26-33	100	34-50	100	34-50	100	76-90	100	34-50	100	51-75	100	51-75	100
Rock			<1	5	<1	10	<1	40			<1	14	<1	2	<1	12			<1	14