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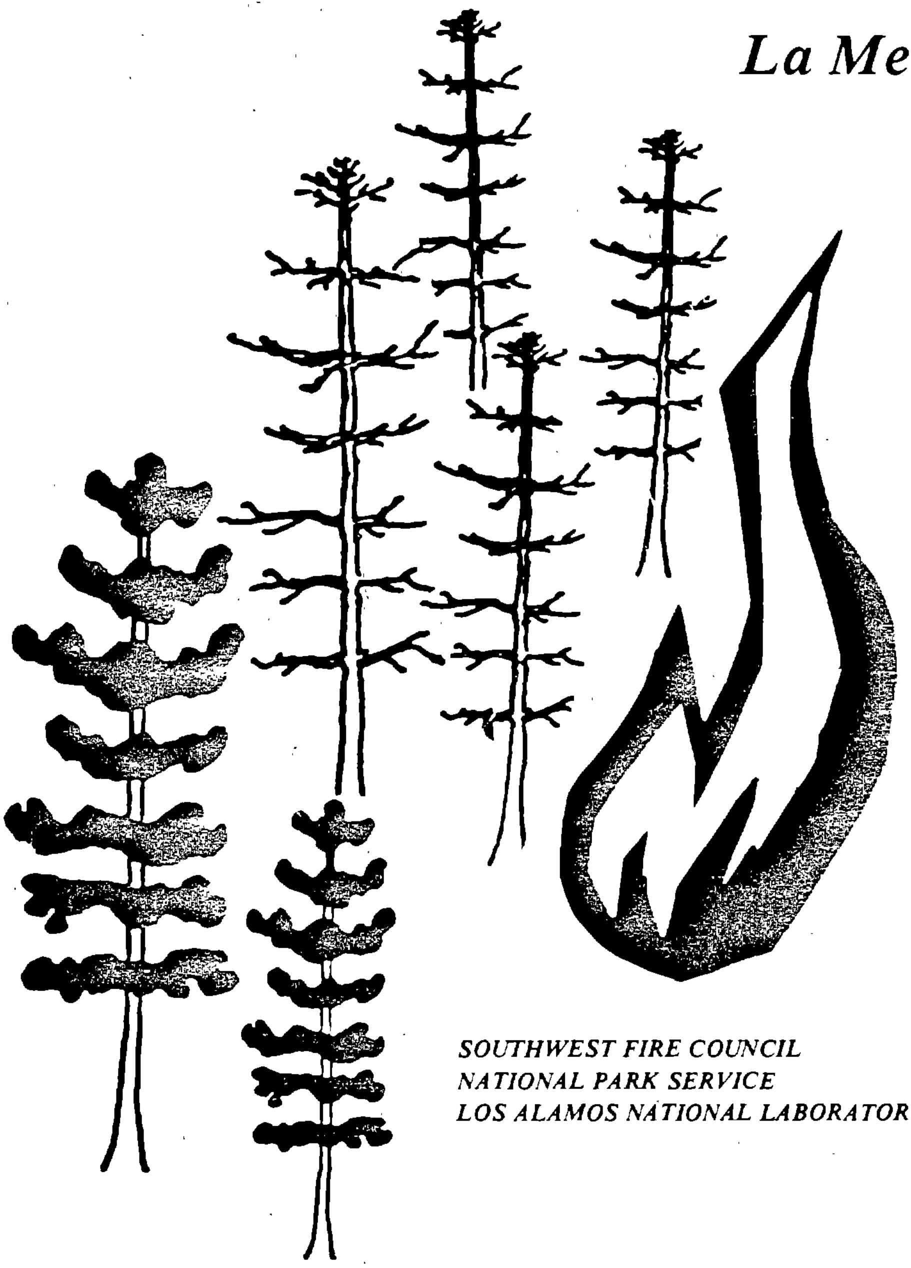
La Mesa Fire Symposium

Los Alamos, New Mexico
October 6 and 7, 1981



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Los Alamos

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REPRODUCED BY: NTIS
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

This work was partially supported by the National Park Service and the Eisenhower Consortium of the US Forest Service.

LA-9236-NERP

UC-11
Issued: February 1984

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PREFACE

Funding for studies presented at this symposium was furnished by three sources: Los Alamos National Environmental Research Park (LA/NERP), a program of Los Alamos National Laboratory funded by the Department of Energy, Office of Health and Environmental Research; Division of Natural Resource Management, Southwest Regional Office, National Park Service, Department of Interior; US Forest Service, Department of Agriculture through the Eisenhower Consortium for Western Environmental Forestry Research.

The symposium was held at Los Alamos National Laboratory and co-sponsored by the LA/NERP, National Park Service, and Southwest Fire Council. In addition to the papers presented in this document, two papers on elk diet and movement are published in the Journal of Wildlife Management. The LA/NERP-sponsored movie "Elk Biotelemetry at the Los Alamos National Environmental Research Park" is available from Group LS-6, Los Alamos National Laboratory, Los Alamos, NM 87545.

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ABSTRACT

This report presents edited versions of papers given at the La Mesa Fire Symposium. The papers contain results of numerous studies made after the fire and results of some studies that were in progress when the fire started.

I. INTRODUCTION

The following sections provide descriptions of the physiography and climatology of the fire location, followed by a description of the fire's growth, and finally, containment, 8 days later. The symposium papers follow, and, in the interest of a concise and useful report, repetitions of the above descriptions have been omitted.

II. PHYSIOGRAPHY OF LA MESA FIRE AREA

Bandelier National Monument is situated at the base of the eastern slopes of the Jemez Mountains in an area called the Pajarito Plateau. In the deep and precipitous canyons and on mesa tops of this plateau, early prehistoric inhabitants made their homes and used the land. The area contains one of the largest concentrations of prehistoric Indian ruins of the Southwest—over 600 ruins are recorded at present (National Park Service 1976).

The plateau was formed by an ash flow from volcanic activity, which resulted in the formation of the giant caldera called the Valle Grande, or Great Valley, 19 miles west of the Bandelier National Monument entrance station. This giant depression, approximately 12 miles in diameter, was formed as a by-product of the volcanism resulting from tectonic disturbances that formed the mountains of the Rockies, Sangre de Cristo, Sierra Nacimiento, and San Pedros ranges. Since then, erosion has carved generally narrow precipitous canyons from the plateau (Olinger 1974).

As a result of this volcanic activity, the soils of the area are derived from rhyolite, tuff, ash, and other volcanic debris. Soils generally can be classified into three groups: (1) extremely stony, rocky shallow soils, less than 20 in. deep, on extremely steep canyon side slopes; (2) moderately deep (20-36 in.) soils on mesa tops; and (3) sandy soils of the alluvial bottoms of the canyons (Wade 1965, Earth Environmental Consultants 1974).

The Monument comprises approximately 51 square miles, or 32 737 acres, bordered on the eastern edge by the muddy Rio Grande. The elevation varies from 5 312 ft near the Rio Grande to approximately

10 000 ft at the top of the highest peak, Cerro Grande. Tsankawi, a separate portion of the Monument, is situated approximately 10 miles north of the Bandelier National Monument entrance station.

The area is transected by three main canyons and a system of smaller secondary canyons. The terrain is rough, and in some places, virtually inaccessible. The Monument headquarters are situated in Frijoles Canyon, where the major ruins are located. All other canyons, as well as the upper portion of Frijoles, are located in the back country, a wilderness area with many hiking trails. Although the upper portions of the canyons have water nearly year round, the streams are intermittent in the lower canyons, being swollen with water only during the rainy season or spring snow melts. Los Ritos de los Frijoles, located in Frijoles Canyon, is the only stream with year-round water.

Piñon-juniper, ponderosa pine, and mixed conifer forests dominate the mesa tops and sometimes extend into the canyons. Canyon bottoms have riparian communities that include narrowleaf cottonwood, boxelder, and numerous shrubs. The high peaks are dominated by spruce-fir and open meadows.

Pure juniper stands at low elevations near the Rio Grande intergrade into piñon-juniper forest, which extends upward to approximately 6 500 ft. Then the latter forests intergrade with ponderosa pine at elevations of approximately 7 500 ft. This type merges with mixed conifer at 8 500-9 000 ft. The mixed conifer includes Douglas fir, white fir, ponderosa pine, and limber pine. At higher elevations, spruce-fir and aspen border high meadows composed of many grasses and forbs. Aspen also occurs within the mixed conifer, mostly on large burns, areas of previous logging, areas of blowdown, and moist north slopes at the heads of narrow, shaded canyons.

III. CLIMATOLOGY

Climatological records for the Monument are limited to file records, dating from 1933, of precipitation and temperature readings from the headquarters area. More extensive records have been maintained at Los Alamos, approximately 10 miles north of Bandelier National Monument.

A rainfall station was established at Alamos Ranch in November 1910, and temperature records were begun in October 1918. In 1942, the name of the ranch was changed to Los Alamos. In January 1943, the station was taken over by the Corps of Engineers and later operated by various divisions of the Atomic Energy Commission. Several changes in the location of the measurement equipment have been made since 1943. The instruments were removed from roof-top levels to ground exposure in 1956. There is now a network of 72 rain gauges distributed throughout the county (Schiager and Apt 1973; Von Eschen 1961). Thus, the information here is a summary of data from both Los Alamos National Laboratory and the Monument headquarters (Von Eschen 1961; Schiager and Apt 1973; Clements and Barr 1976; and Los Alamos Scientific Laboratory 1972).

Summers on the Pajarito Plateau are cool with maximum temperatures reaching 90°F generally only 2 days of the year. The maximum temperature recorded at the Monument headquarters was 106°F. The nighttime summer temperatures average in the 50s. Freezes have been recorded for all months except July and August. Winter days are typically clear and sunny. Daytime shade temperatures, even in January, the coldest month, may reach the high 30s under cloudless skies. The average winter has approximately 18 days when the mercury fails to rise above 32°F. Winter night temperatures drop below freezing from November through mid-April, but below zero readings occur, on the average, once a year. The minimum temperature recorded for the Monument is −23, and at Los Alamos −18°F.

The Bandelier area has a semiarid continental mountain climate. Annual precipitation for the Los Alamos area averages slightly more than 18 in. and at the Monument headquarters, 15 in. The most precipitation received in one year was 30.3 in., the least 6.80 in. Seventy-five percent of the precipitation is received during the months of July and August—the monsoon season. The maximum 24-h rain recorded for Los Alamos is 3.48 in. On the average, a trace or more of precipitation occurs on 140 days of the year.

Shower activity reaches its peak in August, when rainfall of 1/10 in. or more can be expected one day out of four. These convective showers normally develop in the afternoon or early evening and are relatively brief. Hail may accompany the more severe thunderstorms. Most of the winter precipitation falls as snow, with an average snowfall of 50 in. As much as 6 in. has been reported in 24 h.

The precipitation patterns are indicated in studies done at Los Alamos Scientific Laboratory (Schiager and Apt 1973). Two primary thunderstorm tracts were recorded from June through October. The most common tract was the west-to-east movement of a convective cell originating in the Jemez Mountains, probably near Redondo Peak. These cells diminish as they travel eastward. The second tract led up the Rio Grande Valley from the south and often accounted for very heavy rains. This precipitation diminished as it moved west. Total precipitation isohyets for June through October 1973 indicate a storm cell tract along Frijoles Canyon.

A summary of thunderstorm activity from 1965-1974 done at Los Alamos Scientific Laboratory shows the daily thunderstorms occurring with the greatest frequency during August, followed by July, June, and September. The first thunderstorm of the day generally occurs around 11:00 a.m. to 1:00 p.m., with another peak time from 5:00 to 6:00 p.m. Apparently, no studies were made to determine lightning strike frequency.

No records of wind velocity or turbulence have been kept at the Monument; however, observations of wind have been maintained at a number of Los Alamos locations for approximately 20 years. These show significant variation in wind with location. Locations nearest the mountains have a greater downslope component, whereas those at the lower end of the plateau reflect the channeled Rio Grande flow and mountain-valley wind influence (Los Alamos Scientific Laboratory 1972).

Observations made at the Los Alamos Airport show that the average wind speed is less than 10 mph about 75% of the time and over 30 mph less than 0.1% of the time, usually in gusts. Highest wind speeds generally have been recorded in the spring. Winds 86 mph were recorded February 24, 1956, with some resultant damage to Los Alamos buildings. In May 1956, there were 7 consecutive days with wind speeds over 40 mph. These winds may have contributed to several blowdowns in the Monument area. Homer Pickens, retired forester of the area, recalls another major blowdown in the early 30s, possibly May 30, 1934, when hard winds were recorded.

The complex wind flow patterns produced by the canyons have been studied by Clements and Barr of Los Alamos Scientific Laboratory (1976).

IV. DESCRIPTION OF LA MESA FIRE

The following information is summarized from Forest Service notes on fire behavior and weather prediction. La Mesa fire was first reported at 1556 hours, June 16, 1977, by personnel at the St. Peter's Dome Lookout, and within 20 min of the original sighting, flames and heavy smoke were noted. The initial attack on the fire was by a Forest Service helitack crew. The location and spread of the fire is given in Fig. 1.

The fire began in a pile of slash on Mesa del Rito, approximately 2 miles from the western boundary of the Monument. Investigations by Forest Service personnel deemed it to be man-caused, either deliberate or accidental. The area was dense ponderosa pine that had been logged 20 years previously. The slopes were 10-15%, but steep in the draws and precipitous to the edge of the mesa, which drops into Alamo Canyon. At 1730, an aerial reconnaissance flight revealed the fire to cover approximately 50 acres.

Hot, dry, windy weather, plus heavy fuel loads (16-20 tons/acre)(Forester 1976), produced prime conditions for a holocaust. The fire season had begun exceptionally early with a fire on April 10, 1977. In the 39-year fire history, only three other fires had been reported for April—the prime fire season is June and July. Although the total precipitation for the previous year was not below normal, the snow pack had been very thin and the general precipitation for the first 6 months of the year was below normal. The day before La Mesa fire began, the relative humidity had dropped to 6%, whereas the mean for the first 13

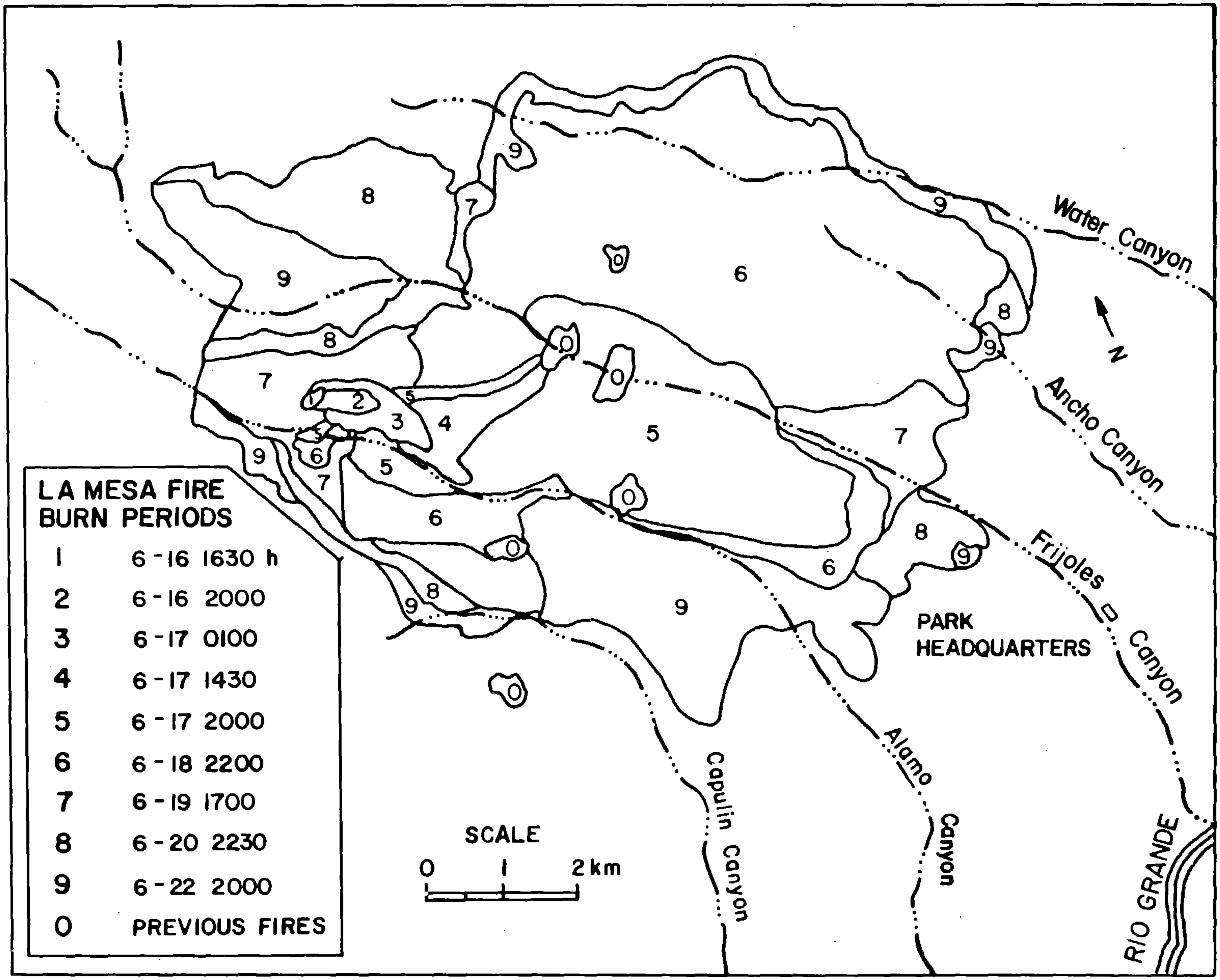

Fig. 1. Rate of spread of the June 1977 La Mesa fire.

days of the month was 43.4%, and 2 months prior was 39.4%. The average temperature for June was recorded as 81.2°F, with an extreme of 90° recorded the day of the fire. In the previous 31 days, only about 0.18 in. of rain had fallen, which was spread over 4 days. The rain had been accompanied by thunderstorms, which contributed to the seven reported fires. The fire fuel moisture had reached a low of 4% and the 1-h time lag was 1. These exceptionally dry, hot conditions at the start of the fire and during the following 4 days probably contributed to the fire spread.

Although from 1730-1800 the fire was estimated to have increased from 50 to 100 acres with a spreading rate of 24 chains/h (1 chain = ~ 60 ft/h), it was believed that the fire would be contained soon. However, because of burning debris falling into Alamo Canyon and causing re-ignition as well as long-range spotting, by midnight Friday, June 17, 1977, the fire had escaped Mesa del Rito and spread approximately 3 miles into Bandelier National Monument. At that time, the total burn acreage was set at 740, but it was probably double that amount. The perimeter extended north across Frijoles Canyon to Escobas Mesa.

On Saturday, June 18, tractor lines 20 to 40 ft wide were constructed on Escobas Mesa in the hope of containing the fire. (Part of this line ran directly through the 1976 Escobas Mesa Fire.) However, the fire began to spread rapidly in a northeasterly direction at 1100 hours and there was nothing to hamper its spread until it reached State Road 4. The fire reached and crossed the highway on a mile-wide front at 1230. The forward rate of spread at this time was estimated at 38 chains/h. Long-distance spotting from 0.5 to 2 miles caused numerous spot fires. During the day and evening, the smoke levels were high and cinders were falling in White Rock, 8 miles away; occupants were warned of burning embers, and the headquarters families were evacuated. By the end of the night shift on June 18, the northern flank within Federal property was basically contained. The suppression activity had not commenced on the southwestern flank of the fire and it had extended just south and west of Rabbit Hill.

June 19, 1977, the fire spread rapidly to the west on Mesa del Rito and it continued within Frijoles Canyon. The weather forecast called for the possible development of a convection column to 23 000 ft in the afternoon. This would cause extreme rates of fire spread and sustained fire crowning. It was estimated at that time that the fire line intensity would be approximately 500-700 Btu ft/s. At 1300 hours, the estimated rate of spread for closed timber type with litter and understory was 12 chains/h, with a fireline intensity of 350 Btu ft/s. Timber with moderate logging slash and loadings of downed fuels was projected to produce a rate of spread of 20 chains/h and a fireline intensity of 900 Btu/s.

At approximately 0100 hours June 19, 1977, backfiring was initiated along State Road 4 to Frijoles Canyon Bluffs to stop the spread north of and west along Frijoles Canyon, and the possible spread into Los Alamos. The firing was completed by 0900 hours but was not particularly clean. In addition to the backfiring, a hand line was constructed from the Sandoval County line along the rim of Frijoles Canyon. It was approximately 0.5 to 1.5 chains wide.

June 20, 1977, the weather forecast called for increasing winds throughout the day and a low relative humidity. The fire was expected to make rapid advances with long-distance spotting. At 1200 hours, the rate of spread for timber litter and understory with no slope was expected to be 18 chains/h, with a fireline intensity of 400 Btu ft/s and a flame length of 7 ft; for 80% slopes, with effective wind speeds of 20 mph, the rate of spread was estimated to be 28 chains/h with a fireline intensity of 850 Btu ft/s and a flame length of 11 ft. For fuels composed of medium logging slash, or areas of heavy loading of natural accumulation of dead fuel, flat slopes, and effective wind speeds of 14 mph, the rate of spread was estimated to be 29 chains/h, with a fireline intensity of 1700 Btu ft/s and a flame length of 13 ft. Areas with at least 80% slope and an effective wind speed of 20 mph were estimated at 45 chains/h, with a fireline intensity of 1800 Btu ft/s and a flame length of 15 ft. It was noted that logging slash would probably not be encountered on 80% slopes but the natural downed fuels in La Mesa fire area could equal such loadings.

By the night shift on June 19, the fire weather forecast called for northwesterly winds of 4 to 8 mph, minimum temperature of 60°F, and a relative humidity of 50%. Since the fire behavior depended to a large extent on the moisture in ground fuels and the increase in the relative humidity, fast fire movements experienced on the previous night were not expected.

On Monday, June 20, at 0200, the fire behavior forecast predicted winds with gusts up to 35-40 mph. Because of the unstable air, a convection column was predicted to reach 20 000 ft with a high probability of spot fire and long-distance spotting (1-2 miles). Torching of individual tree crowns was expected to be common, with the likelihood of sustained crown fires. The possibility of reburn through areas where only surface fires had been was noted. The fuel loadings in the area were reportedly extremely high (60-80 tons per acre) from logging slash and natural accumulations. At that time the rate of spread for timber type with ground litter and understory was estimated to be 23 chains/h, and for a timber type with logging slash or areas of heavy natural accumulations, 37 chains/h. At 1300 hours, the rate of spread for timber with litter and understory was predicted to be 10 chains/h, and in timber with slash or downed natural fuels, 19 chains/h.

Thunderstorms and higher relative humidities were predicted. It was indicated that if the precipitation reached the ground fuels, the rate of spread in timber with litter and understory would be 2 chains/h, with a fireline intensity of 60 Btu and a flame length of 2.5 ft. In timber with slash or downed natural fuels, the prediction was 6 chains/h, with a fireline intensity of 200 Btu ft/s and a flame length of 5 ft.

On June 21, cumulus clouds began to form around noon. The projected fire behavior at noon was 12-16 chains/h, with a fireline intensity of 300-400 Btu ft/s and a flame length of 6-7 ft for timber type with litter and understory. Timber with slash or fuel accumulations had a predicted rate of spread of 18-22 chains/h, with fireline intensity of 800-860 Btu/s and a flame length of 9-10 ft. The moisture of large dead fuels remained critically low, although the weather had improved. Torching and intermittent crowning was probable on steeper slopes. At this time, the perimeter was estimated to be 1770 chains and a total area of 11 000 acres.

By the evening of June 21, 1977, the minimum temperature was expected to be 48°F and the maximum humidity, 70%. Due to this projection, the rates of spread were reduced to 2-4 chains/h, with fireline intensity of 50-70 Btu/s and a flame length of 2-4 ft in the timber with litter and understory. Timber with slash and/or fuel accumulations was expected to produce rates of 6-8 chains/h, with a fireline intensity of 200-300 Btu ft/s and a flame length of 4-6 ft.

The fire weather forecast called for cumulus clouds to form in the late morning hours with isolated thunderstorms in the fire vicinity during the afternoon. The relative humidity had dropped to 20%.

Because of the lowering of the relative humdity and the low fuel moisture content, fast fire runs and spotting were again expected. By this time the manpower and equipment were 1370 men, 9 bulldozers, 23 ground tankers, 5 helicopters, and 5 air tankers. There were enough firefighters to man the entire perimeter, and approximately 3 miles of open line were backfired to the edge of Frijoles Canyon. This proved to be a good backfire.

Thundershowers began at about 1500 hours and ended about 2100 hours, with winds nearly calm. The minimum temperature was 54°F and the relative humidity, 75%. This reduced the probability of fast fire runs and minimized the chances of spotting. At the end of this shift, the perimeter was approximately 38 miles (a conservative estimate) and a total area of 15 000 acres. The fires was considered contained at 1600 hours.

On June 23, 1977, scattered thunderstorms produced heavy rains during the night and temperatures were in the 30s. The fire was declared controlled at 1600 hours.

La Mesa fire had consumed approximately 15 270 acres of forested land in the Santa Fe National Forest, Bandelier National Monument, and Los Alamos National Environmental Research Park. Approximately 33% of the forested land of Bandelier had been subjected to the fire, a total of 10 630 acres.

V. IMPORTANCE OF FIRE IN PONDEROSA PINE

Ponderosa pine and ponderosa pine-piñon-juniper mixture compose 28% of Bandelier National Monument and by virtue of the experimental design, ponderosa pine is the dominant tree species in this study. No major fires before 1977 were found in mixed conifer and the new accession was added in 1977.

Ponderosa pine, occurring at elevations of 7000-8500 ft, is the most drought-tolerant of the major coniferous forest trees of the Southwest. It is also a shade-tolerant, fire-climax species; however, it will not disappear without fire (Dieterich 1976; Foiles and Curtis 1973; Schubert 1974).

Ponderosa pine forests of the Southwest were subjected to frequent and periodic fires before 1918. Evidence gained through dating of fire scars has shown that, before modern fire suppression, trees burned every 8 to 12 years (Weaver 1951a,b; Weaver 1955). Ponderosa forests of the Southwest are in a lightning bioclimate (Komarek 1968, 1969). These forests are subject to high lightning frequency. In a 22-year period from 1945 to 1966, Komarek (1969) reported 33 965 lightning-set fires on the 204 407 885 acres composing the national forests of Arizona and New Mexico. That averages one lightning-set fire per 601 acres during that period. During the same period, the Santa Fe National Forest, which is adjacent to Bandelier National Monument, recorded 1431 lightning-set fires on 1 440 511 acres. Although man has been able to change the general nature of the forest through fire suppression, he cannot have changed the main source of ignition of historic and prehistoric fires.

Sixty years of fire suppression have changed the composition and character of the ponderosa forest. Early explorers described the forests as open and unencumbered by underbrush (Beal 1858; Dutton 1881; Muir 1894; Muir 1901). King (1871) gives an account of running his horse through the forests of Sierra Nevada. Fires in those environments were not as destructive as those seen today. They also crept along the ground and only occasionally ignited treetops. Those fires reduced the pine needle accumulations, culled diseased trees, and thinned young stock, resulting in a forest with a more park-like appearance (Muir 1901).

Major changes in the Southwestern forests began in the late 1800s with logging, accumulations of slash, and suppression of fire in the 1900s. Grazing also had its impact. Livestock, first introduced by Coronado in the 1500s, grazed freely. Severe range deterioration did not begin, however, until the 1880s and early 1900s. Exposure of mineral soils and reduced stocking rates accompanied by fire suppression have resulted in dense, stagnant stands seen throughout the southwestern ponderosa pine forests (Komarek 1969; Weaver 1974; Cooper 1960).

Exclusion of fire from these forests has resulted in heavy fuel accumulations. Dieterich (1976a) collected samples in various areas of Arizona and New Mexico from 54 stands of mature ponderosa, which indicated an average of 12.7 tons/acre of ground fuel and 10.6 tons/acre of down, dead, woody material. Fuel loadings of this magnitude can produce extremely hot fires. It is estimated that 12.5 tons/acre of accumulated fuel consumed by the fire front is 1433 Btu/s/fireline ft. Excessive damage to mature overstories can be expected from 700 Btu (Sackett 1976).

Biswell et al. (1966) found that 2.2 to 6.9 tons of litter per hectare are accumulated on the forest floor each year. This becomes a serious problem in the warm dry climates of the Southwest, where decay is slow. All these fuels are available to produce disastrous wildfires. Dodge (1972) indicates that the effectiveness of an exclusion policy has been that 95% of the wildfires are extinguished while small; however, the 3 to 5% that get out of control cause 95% of the damage.

The accumulation of fuels and the closing of the forest canopy have had an important effect on the understory composition. Moir (1966) found a reduction of herbaceous material in closed canopy forests. This alteration of the understory has reduced the available habitats for deer, elk, antelope, and turkey, as well as other wildlife that inhabit ponderosa pine forests. However, Moir found that fire increased the production of grasses such as *Festuca*. Other investigators have found an increase in the reproduction of various browse shrubs such as *Ceanothus* sp. in areas that have been burned (Went, Juhren, and Juhren 1952; Gratkowski 1962).

Studies in recent years have shown that fire is necessary to perpetuate as well as to produce healthy ponderosa pine forests (Weaver 1974; Vlamis et al. 1956). Fire provides the bared soil necessary for the shade-intolerant ponderosa seedling (Foiles and Curtis 1973). Although prehistoric fires were generally cool, they provided some severely burned areas where windfalls and snags were consumed. The increased nutrification and fungal sterilization of these areas probably provided excellent seedbeds. Wagle and Kitchen (1972) found that this increased nutrification can help override other environmental factors that often result in death of ponderosa seedlings. Ffolliott et al. (1977) saw an increase in seedlings on burned vs unburned areas, although many were short-lived.

Fire is a natural thinning agent. Ponderosa pine needs full sunlight for maximum photosynthetic activity. Young trees are susceptible to fire, but older and more mature trees are protected by thick bark. The thinning reduces competition and over-stocking. In the dense, stagnant stands produced because of fire exclusion, trees are also weakened and more susceptible to disease and insect attack. Thinning of the forest, either mechanically or through prescribed burning, produces a more vigorous, rapidly growing stand of trees. This means fewer trees are killed by such diseases as dwarf mistletoe (Wicker and Leaphart 1976). There is also some indication that smoke produced by fire may have a sterilizing effect on the forest—thus reducing certain disease organisms (Parmeter and Uhrenholdt 1976).

Researchers warned against the "Smokey the Bear" policy of total fire exclusion soon after its inception; however, the problem has only recently been of increasing concern. Weaver (1943, 1951a,b, 1955, 1957, 1959, 1961, 1967a, 1967b) experimented early with prescribed burning—a technique of controlled fires. The principle of fuel reductions by this technique is recongnized as being useful to the forest manager; however, a number of questions still must be answered before such a plan can be initiated in any specific area.

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FIRE ECOLOGY AT BANDELIER NATIONAL MONUMENT

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Before the coming of white man to the North American continent, the forests of the Southwest were subjected to frequent and periodic fires. Evidence gained through dating of fire scars (pyrodendrology) has shown that, before modern fire suppression, ponderosa forests burned every 8-12 years (Arno 1976, Laven et al. 1980, Show and Kotok 1924, Wagener 1961, Weaver 1951, Weaver 1955). These frequent creeping fires were important in keeping the forest a mosaic of even-aged stands in an uneven-aged forest (Cooper 1960). Years of fire suppression, however, have changed the composition of the forest and increased fuel loads such that wildfire is now often intense and destructive.

In 1975, as a result of many years of fire suppression, the management of Bandelier National Monument adopted a policy of controlled or management fires to reduce fuel loads and thereby reduce the potential destruction by wildfire. Before establishing a prescription for management fire, basic data as to succession, previous fire history, and fuel loadings were necessary. A study was undertaken in 1976 to provide some of these data, but before the study was completed, a major wildfire (La Mesa fire, 1977) changed the nature and complexity of the research.

Before the fire, two approaches were used to collect the necessary data. To determine fire history, both historic records and dendrochronology were used. To determine succession, vegetational analyses were conducted on areas known to have burned at specific times. With these baseline data, postfire studies were also more experimental and less conjectural.

This paper is a composite of two major parts of the study that are separate but related—the fire history and the fire damage of various sites as related to their fire history.

I. FIRE HISTORY AND FIRE INTERVALS

A. Introduction

Among the various methods that can be used to determine fire history and frequency are historic searches of fire records, interviews of witnesses, and pyrodendrology. Historic records are often very limiting because they were compiled after 1900, when organized fire suppression began. Witness accounts are often unreliable in specifics and are limited to the lifetime of one person.

To obtain pre-fire-suppression fire frequencies, the most reliable method is pyrodendrology or fire-scar analysis. This technique is based upon the fact that various tree and shrub species have annual rings that can be used in dating. In addition, a fire can affect a tree bole in different ways from complete to partial destruction. Partial destruction causes wounds that become fire scars, which provide a lasting record of fire. A fire-scarred tree is more susceptible to additional scarring and, therefore, can be a record of fire frequencies.

The technique is limited, in that not every fire will burn intensely enough to produce scarring. Arno (1976) found that trees growing just a few yards from each other had scars of different fires. The technique does, however, provide an indication of general frequency of fires within an area.

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B. Materials and Methods

1. **Historic Fire.** Information about historic fires was obtained from fire atlases and fire reports maintained at Bandelier until 1969. After 1969, fire atlases were not maintained and little specific information about fire was found.

2. **Dendrochronologic Samples.** During the summer of 1976, wedges were collected from fire-scarred standing snags that appeared to be sound. Collections were made on Escobas Mesa and the rim of Frijoles Canyon. At this time no living trees were sampled.

After the 1977 La Mesa fire, fire-scarred trees or those killed by the fire were felled and complete cross sections were collected from Burnt Mesa, Escobas Mesa, and the rim of Frijoles Canyon. Samples were obtained in areas of known fire history and/or near archeological sites. Specimens were gathered from both lightly and severely burned areas.

Twenty-five samples were used in this study. Each sample was sanded, rings were counted, and, when possible, dated. Only 19 samples were dated; the remaining specimens were counted for frequency between fire scars. Ten of the 25 samples were dated by the Tree Ring Laboratory at the University of Arizona (Robinson, 1978). I dated the remaining 15. Samples were cross-dated and compared with tree-ring chronology for the area compiled from growth rate studies by Potter and Foxx (1978) and with information from the Tree Ring Laboratory.

C. Results and Discussions

1. **History of the Collection Sites.** Burnt Mesa, Escobas Mesa, and the rim of Frijoles canyon are located in a portion of land obtained by the National Park Service in 1963 as a trade for the Otowi Section located in Bayo Canyon east of Los Alamos. The history of these mesas is closely tied to the history of the Ramon Vigil Grant, of which it was part.

Apparently, these mesas did not have permanent human habitation until the late 1100s, at which time settlement of the Tewa and Tiwa speaking peoples began (Steen 1977). Large pueblos developed in Frijoles Canyon and Pajarito Canyon but many outlying sites have also been found. Fire as a tool for hunting or increasing food supplies does not appear to have been used by the pueblo people. Bandelier (1892) indicates that the Cochiti (decendents of these early peoples) practiced communal hunts by rounding up animals and forcing them off precipices near the Rio Grande, but there is no mention of fire. Although the pueblo Indian may not have used fire as a hunting tool, he did recognize it as a natural phenomenon. In a letter to Southwestern National Monuments, C. A. Thomas (1940) quotes an old Taos Indian as having said, "Before the White Man came to the mountains, bugs and disease seldom killed the forest, because when bugs attacked the trees, a few (trees) died, and the gods seeing the dead trees sent the lightning to set them afire. The fire burned up the dead trees and the bugs and no more trees were harmed for a long time." Abandonment of the plateau by these prehistoric peoples began in the 1500s, and by the time the Spanish arrived in New Mexico in 1597, these Indian groups lived in the valley areas near the Rio Grande.

There is no historical evidence of use or habitation on the mesa until 1742 when Pedro Sanchez was given a Spanish Land Grant, which later became known as the Ramon Vigil Grant. For nearly 100 years, the Grant remained within the Sanchez family and the area was used for grazing small pastoral herds. It is even doubtful that the fire study areas were used because they are miles from old habitation sites of the Española valley. In 1851, Antonio Sanchez sold 8 interests of the land to Ramon Vigil, and for the next 28 years, this family used the Grant for grazing herds of sheep, goats, and cattle (Chambers 1974).

The biggest changes for the Grant began to occur in the late 1800s. The ecomony after the Civil War, laws made in Texas to prevent overgrazing, the opening of northern New Mexico to the railroad and lumbering, and the Homestead Act all provided massive land use changes for the area. In 1883, Winfield

Smith and Edward P. Sheton bought the grant and opened it to grazing and lumbering. From 1885-1887, W. C. Bishop (a Texas cattleman) ran 3000 head of cattle on the 32 000-acre Grant. In 1897, the owners of the Grant sold the timber rights to H. S. Buckman, who removed 36 000 000 board feet of lumber. Homesteading began in 1894, but much of the area was still used only as a summer grazing area for Española valley families (Chambers 1974).

In the early 1900s, Frank Bond, sheep and cattleman from Española, bought the Grant as a way station for cattle and sheep being shipped from Buckman on the Rio Grande and from the summer ranges of the Valle Grande. He continued to graze sheep and cattle in the area until the 1940s, when the area was taken over for the secret Manhattan Project (development of the first atomic bomb). From 1940-1963, the study mesas were under the jurisdiction of the Atomic Energy Commission, which provided necessary fire suppression efforts. In 1963, the National Park Service obtained the area and has had a policy of total fire suppression since then.

In this paper, fire history will be related to two long land use periods: from 1786 to 1893, and from 1894-1977, a period of logging, grazing, and organized fire suppression.

2. **Fire History Obtained from Historic Records.** Although the area became a National Monument in 1916 by Presidential proclamation for the "preservation, protection, and study of its archeological resources," there is no record of fire and its management until 1932, when the managment of the land was changed from the Forest Service to the National Park Service. Additional land was added to the Monument in 1961, 1963, and 1977. Fire records are not available for the areas of those accessions. Thus, the fire history is based on information gained from fire atlases and fire reports maintained at the Monument from 1932 to 1976. After 1969, fire atlases were not maintained, and until the present administration of the Monument, minimal records of fire occurrences were kept. As a result, there are a number of years for which no records could be located. All fires and their locations as recorded in the fire atlases are summarized in Fig. 1.

Records for approximately 39 years (1931-1977) were partially or wholly found. These records are summarized in Table I by classes of fire size, causes, and month, as well as the annual precipitation at Bandelier headquarters. As seen in Table I, during the past 39 years, 224 fires were recorded. Of these, 72% were less than 0.25 acre (Class A), 25% were 0.25 to 9 acres (Class B), and 3% were 10 or more acres (Class C). This is an average of approximately 6 fires per year, of which 86% were lightning caused. More than 30% of the fires occurred during July, which is considered the peak fire month, followed by June, then August. Most of the fires occurred between May and September.

The data indicate that the number of lightning fires within the Monument has increased in the past 40 years (Fig. 2). In contrast, even though visitation has increased substantially since 1932, the numbers of man-caused fires have remained nearly the same.

Increase in lightning-caused fires is not a phenomenon unique to Bandelier National Monument but has been reported by Komarek (1968, 1969) for all of the West. Ponderosa pine forests are in a lightning bioclimate and are subject to high lightning frequencies.

Because of increased land acquisition, resulting in better reporting, a current data base seems to indicate an increase in lightning-caused fires; however, the most important factor appears to be the condition created by years of fire suppression. Fuel loads up to 24 ton/acre have been reported for the Monument (Forester 1976). The most important kindling material for lightning fire is accumulated needles and duff on the ground, then trees, and finally, dead trees (Morris 1934, Komarek 1967, Taylor 1969). The increasingly heavy fuel loads combined with appropriate climatic conditions may produce ideal circumstances for lightning ignition. Such conditions have existed in the Jemez Mountains, and in the past 10 years, three destructive wildfires have occurred there: the Cebollita fire, June 1971, 4380 acres; the Porter fire, June 16, 1976, 4000 acres; and La Mesa fire, June 16, 1977, 14 000 acres.

3. **Fire History from Fire-Scar Analysis.** Twenty-five fire-scarred trees were sampled on several mesa tops on Burnt Mesa, Escobas Mesa, and the rim of Frijoles Canyon in areas of varying burn intensity.

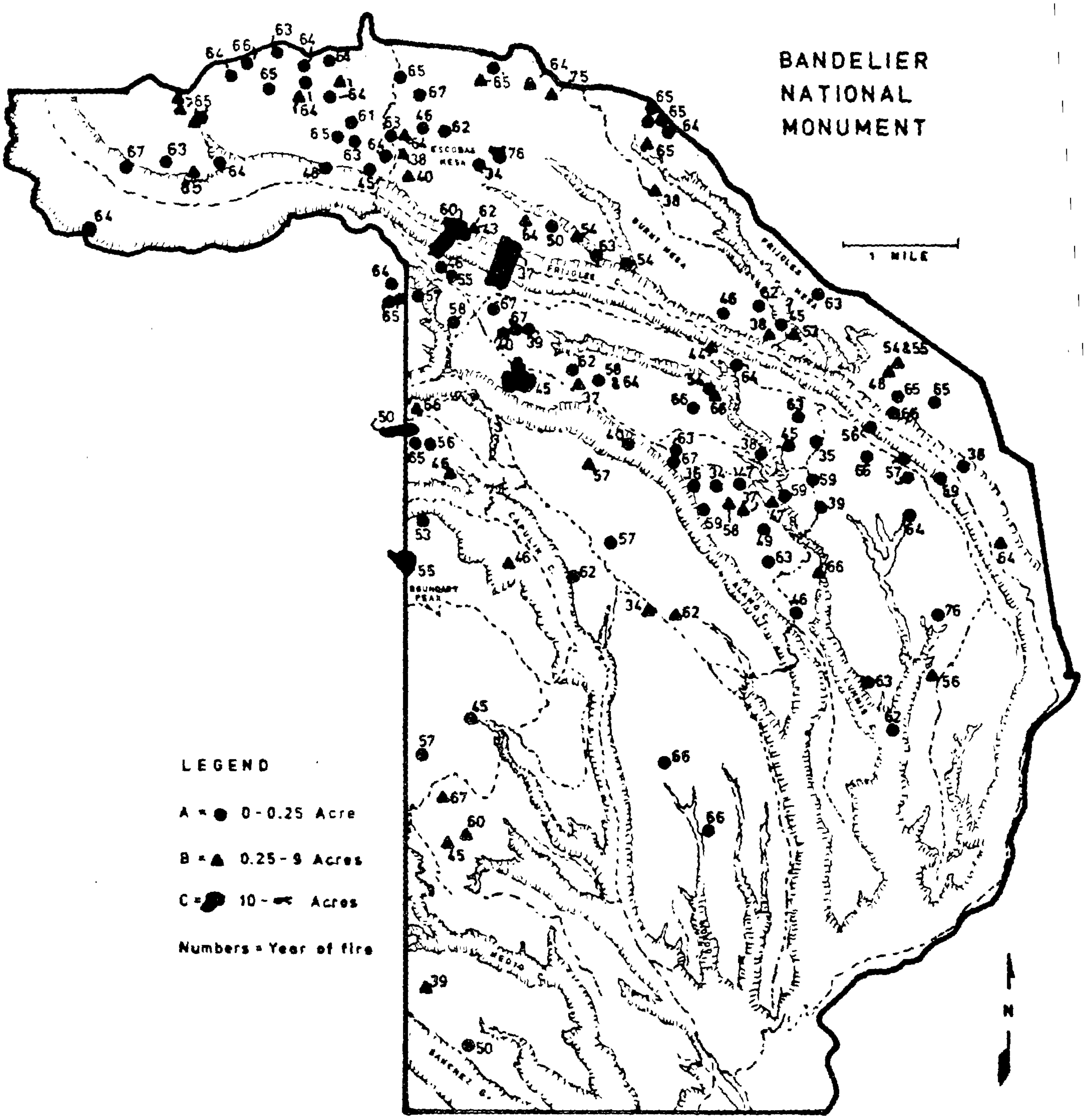

Fig. 1. Location and date of fires recorded in the fire atlas at Bandelier National Monument before La Mesa fire.

TABLE I. Fire History from 1931 to 1977 According to Fire Size, Causes, and Month, Plus the Annual Precipitation at Bandelier Headquarters

Year	Class of Fires				Light-ning	Man-caused	Month										Annual Precip-itation
	A[a]	B[a]	C[a]	Total			Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Undated	
31	No fires recorded						---	---	---	---	---	---	---	---	---	---	---	23.68
32	No fires recorded						---	---	---	---	---	---	---	---	---	---	---	14.26
33	No fires recorded						---	---	---	---	---	---	---	---	---	---	---	14.61
34	1	2	0	3	1	2	---	---	---	---	---	---	3	---	---	---	---	(9.42)[b]
35	2	0	0	2	1	1	1	---	---	---	1	---	---	---	---	---	---	14.83
36	1	0	0	1	1	0	---	---	1	---	---	---	---	---	---	---	---	14.48
37	0	2	1	3	2	1	---	---	---	2	---	1	---	---	---	---	---	14.78
38	0	4	0	4	2	2	---	---	---	---	---	---	---	---	---	---	4	12.20
39	No information						---	---	---	---	---	---	---	---	---	---	---	18.03
40	3	1	0	4	3	1	---	---	---	1	2	1	---	---	---	---	---	20.45
41	0	0	0	0	0	0	---	---	---	---	---	---	---	---	---	---	---	25.96
42	0	0	0	0	0	0	---	---	---	---	---	---	---	---	---	---	---	13.92
43	2	2	0	4	2	2	1	---	1	1	---	---	1	---	---	---	---	14.06
44	1	0	0	1	1	0	---	---	---	---	---	1	---	---	---	---	---	18.31
45	4	4	1	9	7	2	---	---	1	3	3	---	1	---	---	1	---	11.58
46	5	4	0	9	9	0	---	---	---	---	6	2	1	---	---	---	---	10.80
47	2	1	0	3	3	0	---	---	---	---	---	3	---	---	---	---	---	13.04
48	2	0	0	2	2	0	---	---	---	1	---	1	---	---	---	---	---	15.16
49	1	0	0	1	1	0	1	---	---	---	---	---	---	---	---	---	---	19.01
50	1	2	0	3	2	1	---	---	3	---	---	---	---	---	---	---	---	8.98
51	No information						---	---	---	---	---	---	---	---	---	---	---	14.43
52	No information						---	---	---	---	---	---	---	---	---	---	---	16.10
53	2	0	0	2	2	0	---	---	---	---	2	---	---	---	---	---	---	14.00
54	3	1	0	4	3	1	---	---	1	1	2	---	---	---	---	---	---	11.78
55	1	1	1	3	3	0	---	---	---	---	2	1	---	---	---	---	---	9.64
56	2	1	0	3	2	1	---	---	1	1	1	---	---	---	---	---	---	4.94
57	5	1	0	6	6	0	---	---	---	---	2	4	---	---	---	---	---	21.12
58	2	1	0	3	3	0	---	---	---	---	1	2	---	---	---	---	---	16.59
59	5	0	0	5	5	0	---	---	1	---	4	---	---	---	---	---	---	20.47
60	0	1	1	2	1	1	---	---	1	---	---	---	1	---	---	---	---	18.05
61	No information						---	---	---	---	---	---	---	---	---	---	---	15.61
62	6	0	0	6	6	0	---	---	---	1	3	2	---	---	---	---	---	12.37
63	11	0	0	11	11	0	---	---	---	3	3	2	3	---	---	---	---	13.96
64	16	4	0	20	17	3	---	---	2	4	9	5	---	---	---	---	---	11.52
65	14	8	0	22	16	6	---	1	3	5	10	3	---	---	---	---	---	24.46
66	7	4	0	11	11	0	---	---	2	5	2	1	1	---	---	---	---	11.41
67	10	1	0	11	11	0	---	---	3	2	2	4						

TABLE I. (cont)

Year	Class of Fires				Light-ning	Man-caused	Month											Annual Precip-itation
	A[a]	B[a]	C[a]	Total			Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Undated	
68	No information																	
69	13	0	0	13	13	0	---	---	1	6	2	4	---	---	---	---	---	24.14
70	2	0	0	2	2	0	---	---	---	---	---	2	---	---	---	---	---	11.24
71	10	7	0	17	14	3	---	2	1	2	6	6	---	---	---	---	---	17.98
72	3	0	0	3	3	0	---	---	---	2	1	---	---	---	---	---	---	18.61
73	2	0	0	2	2	0	---	---	---	---	1	1	---	---	---	---	---	16.02
74	4	0	0	4	4	0	---	---	---	1	3	---	---	---	---	---	---	15.33
75	5	1	1	7	6	1	---	---	---	1	3	---	2	1				
76	8	1	1	10	8	2	---	---	---	4	5	---	1					
77	6	1	1	8	7	1	---	1	4	3								
Total (39 yr)	162	55	7	224	193	31	3	4	26	49	76	46	14	1	---	1	4	637.9 (41 yr)
Yr mean	4.2	1.4	0.2	6.0	5.1	0.8	0.08	0.1	0.7	1.3	1.9	1.2	0.4	0.03		0.03	0.1	15.6
% Total	72	25	3		86	14	1.3	1.8	11.6	21.9	33.9	20.5	6.3	0.4		0.4	1.8	---

[a] A = 0-0.25 Acres; B = 0.25-9 Acres; C = 10-∞ Acres

[b] May-Oct—precipitation only

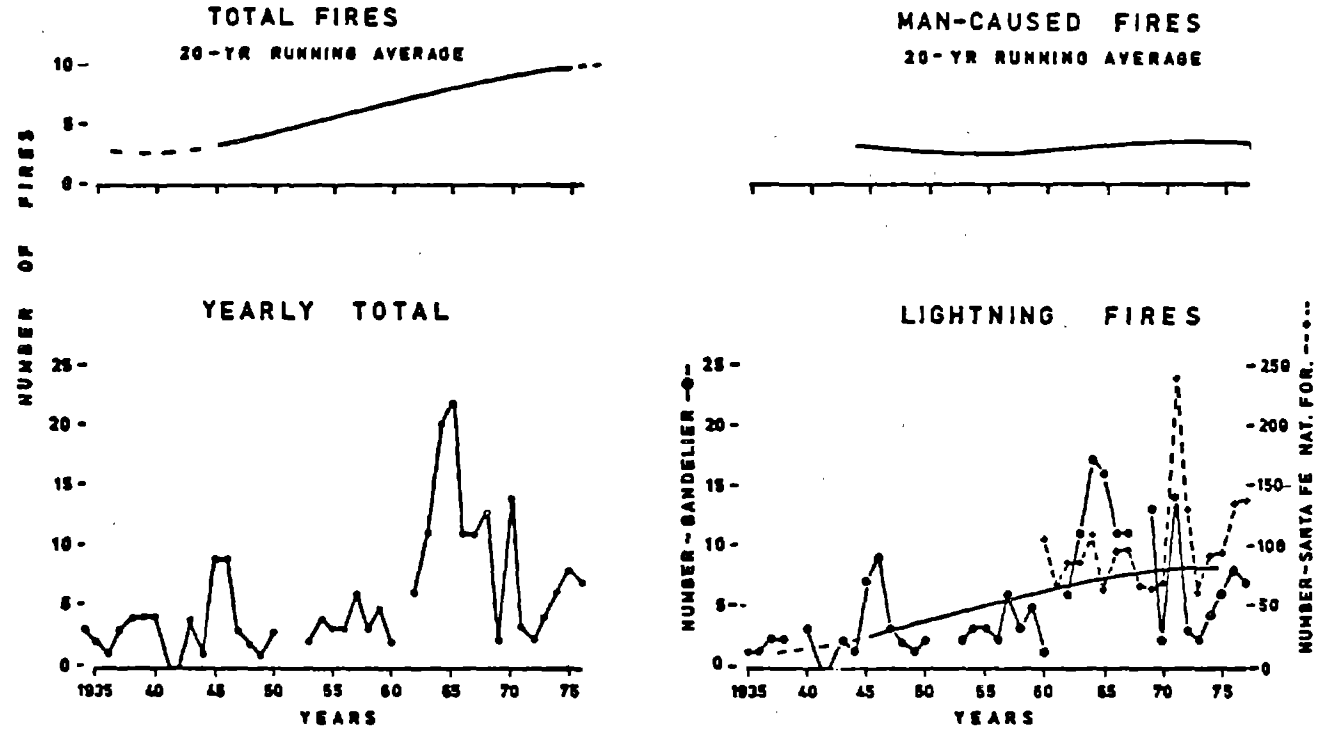

Fig. 2. Fire history at Bandelier, total, man-caused, and lightning.

Data were obtained from 109 fire-scarred annual rings from these 25 ponderosa pine wedges or cross sections. A total of 44 fire years were recorded on the samples from 1786 to 1962. Two-thirds of the fire scars occurred before 1900 and only one-third after 1900. Most of the cross sections dated to the late 1700s and early 1800s. Only two samples were limited to the early 1900s.

Fire-scar data can be treated in various ways. Each treatment of data analyses needs to be specified to eliminate confusion. We analyzed the data for fire frequencies, mean fire frequencies (interval), and composite fire intervals. Arithmetic averages for all data also were found for periods of 1786-1894, the pre-fire-suppression era, and 1895-1977, the period of organized fire suppression, grazing, homesteading, and lumbering. Terms are defined below (Romme 1980).

- Fire interval, fire frequency: the number of years between two successive fires documented in a designated area or on a designated tree.
- Mean fire interval, mean fire frequency: arithmetic average of all fire intervals determined in a designated area during a designated time period.
- Composite fire interval: a chronological listing of the dates of fires documented in a designated area.

Fire intervals for the 25 samples we examined are shown in Tables IIa and IIb. Unless otherwise specified, these intervals are based on the last recorded fire scar. Fire scars were dated from 1786 to 1962. When examining this time period, the shortest fire interval recorded on the samples was 3 years and the longest was 78 years. However, the interval since the last recorded fire scar on the samples ranged from 17 to 119 years.

Mean fire intervals for individual samples are found in Table III. The longest mean fire interval for an individual sample was 34.3 years and the shortest was 9.3 years. Numbers of fire scars per sample ranged from 1 to 11. The calculated mean fire interval for all samples between 1786 and 1962 was 17.4 years. An average of 63.1 years since the last fire was found on the 19 datable samples.

To substantiate the differences in fire frequency before and after major land use changes and organized fire suppression, the data were divided into two time periods, using only the 15 fire-scarred samples that had a complete history from 1797 to 1977: 1797-1894 (pre-fire-suppression) and 1884-1977 (organized

Table IIa. Fire History of Bandelier National Monument Based on Datable Dendrochronological Samples Collected on Burnt Mesa, Escobas Mesa, and Rim of Frijoles Canyon

Sample Number	Location	Severity of Burn	Fire Dates	Year Interval	Years Since Last Fire
1	Burnt Mesa	Severe	1797-1806	9	77
			1806-1822	16	
			1822-1900	78	
2	Burnt Mesa	Severe	1797-1806	9	119
			1806-1847	41	
			1847-1858	11	
3	Burnt Mesa	Severe	1806-1814	8	99
			1814-1822	8	
			1822-1842	20	
			1842-1870	28	
			1870-1878	8	
4	Esobas Mesa	Severe	1797-1822	25	58
			1822-1833	11	
			1833-1842	9	
			1842-1847	5	
			1847-1858	11	
			1858-1870	12	
			1870-1878	8	
			1878-1883	5	
			1883-1893	10	
			1893-1900	7	
			1900-1919	19	
5	Escobas Mesa	Severe	1797-1806	9	84
			1806-1814	8	
			1814-1822	8	
			1822-1842	20	
			1842-1870	28	
			1870-1878	8	
			1878-1893	15	
6	Escobas Mesa	Severe to moderate	1798-1822	24	84
			1822-1830	8	
			1830-1842	12	
			1842-1878	36	
			1878-1883	5	
			1883-1893	10	
7	Burnt Mesa	Severe	1806-1814	8	99
			1814-1822	8	
			1822-1830	8	
			1830-1870	40	
			1870-1878	8	
8	Escobas Mesa	Severe to moderate	1797-1801	4	84
			1801-1842	41	
			1842-1845	3	
			1845-1858	13	
			1858-1878	20	
			1878-1893	15	
9	Escobas Mesa	Light	1797-1814	17	N. A.[a]
			1814-1822	8	
			1822-1833	11	
			1833-1842	9	
			1842-1850	8	
			1850-1870	20	
			1870-1893	23	

Table IIa. (cont)

Sample Number	Location	Severity of Burn	Fire Dates	Year Interval	Years Since Last Fire
10	1878 plot	Severe	1850-1861	11	99
			1861-1867	6	
			1867-1878	11	
11	1976 plot	Light	1941-1962	21	1
			1962-1976[b]	14	
12	1976 plot	Light	1940-1976[b]	36	1
13	1976 plot	Light	1960-1976[b]	16	1
14	Escobas Mesa	Light to	1809-1827	18	17
	(logged)	moderate	1827-1833	6	
			1833-1842	9	
			1842-1860	18	
			1860-1896	36	
			1896-1922	26	
			1922-1940	18	
			1940-1949	9	
			1949-1960	11	
15	Escobas Mesa	Severe	1907-1927	20	37
	(unlogged)		1927-1940	13	
16	1960 plot	Light	1859-1867	8	17
			1867-1878	11	
			1878-1897	19	
			1897-1944	47	
			1944-1960	16	
17	1878 plot	Severe	1827-1833	6	
			1833-1844	11	
			1844-1868	24	
			1868-1893	25	
18	1937 plot	Severe	1786-1793	7	40
			1793-1850	57	
			1850-1878	28	
			1878-1908	30	
			1908-1921	13	
			1921-1937	16	
19	Escobas Mesa	Severe	1797-1824	27	69
	(unlogged)		1824-1831	7	
			1831-1850	19	
			1850-1908	58	

[a] Stump logged 1907.
[b] Samples collected after 1976 fire.

Table IIb. Fire History Based on Undatable Dendrochronological Samples Collected on Burnt Mesa, Escobas Mesa, and Rim of Frijoles Canyon.

Sample Number	Location	Interval	Years	Years Since Last Fire
20	Escobas Mesa	1-2	10	65
		2-3	18	
		3-4	18	
		4-5	19	
21	N. Rim Frijoles	1-2	40	49
		2-3	8	
		3-4	10	
		4-5	42	
22	Escobas Mesa	1-2	10	42
		2-3	12	
		3-4	7	
23	Escobas Mesa	1-2	9	0
		2-3	21	
24	N. Rim Frijoles	1-2	35	39
		2-3	23	
		3-4	19	
		4-5	9	
25	Escobas Mesa	1-2	17	60
		2-3	18	
		3-4	24	
		4-5	20	
		5-6	15	

fire suppression and land use). These mean fire intervals are shown in Table IV. For the pre-fire-suppression period, a mean fire interval of 15.1 years was found, whereas the period of organized fire suppression showed a mean interval of 41.9 years. Figure 3 shows the difference in fire frequencies during the two time periods.

Fire dates on more than one sample may indicate one extensive fire or many small fires. The data were examined for fire dates that occurred on at least 20% of the samples (Table V). The frequency of fires recorded on at least 20% of the samples was 12.0 years; on 30%, it was 24.0 years. This indicates that fire that produced multiple fire scarring occurred at least once every 12-24 years before 1894. It is interesting to note that after 1893, fire dates recurred only on one or two samples (Fig. 3). This indicates that no major fires occurred within the sampled area until La Mesa fire—a period of 84 years. This certainly reflects the land-use changes and organized fire suppression of the 20th century and explains the intensity of La Mesa fire.

Finally, examination of the fire history in relation to the condition of the stand where the samples were collected (Table II), shows that severely burned areas had not had a recorded fire for a period of 37-119 years. Lightly burned areas had had a fire in the past 1-17 years, which further substantiates the importance of the pre-fire-suppression mean fire intervals found on the dendrochronology samples.

The composite fire interval describes how frequently any one area may be subjected to fire. All fire dates for the area are summarized and the arithmetic average taken. The composite fire interval developed for the sampled area showed the frequency to be one fire every year (Table VI); that is,

TABLE III. Fire Frequencies for Recorded Fire Scars of 25 Samples Collected From Burnt Mesa, Escobas Mesa, and Rim of Frijoles Canyon.

Sample Number	Frequency (yr)	Years Since Last Fire Scar
1	34.3	77
2	20.3	119
3	14.4	99
4	11.1	58
5	13.7	84
6	15.8	84
7	14.4	99
8	16.0	84
9	13.7	NA
10	9.3	99
11	17.5	15
12[a]	---	37
13[a]	---	16
14	16.8	17
15	16.5	37
16	20.2	17
17	16.5	84
18	25.2	40
19	27.8	69
20[b]	16.3	
21[b]	25.0	
22[b]	25.0	
23[b]	9.7	
24[b]	15.0	
25[b]	21.5	
25[b]	18.8	
Mean	17.4	63.1

[a] One fire scar only.

[b] Not datable.

somewhere within the sampled area a fire was recorded that often. The composite fire interval for the period 1797-1894 revealed an average of 4.3 years, and that for the period 1895-1977, 3.0 years. The increased fire interval since 1900 again reflects the effect of 20th century organized fire suppression and increased ignitability of fuels.

II. VEGETATIONAL SUCCESSION AND FIRE DAMAGE AS RELATED TO FIRE HISTORY

A. Introduction

The second purpose of the original study funded by the National Park Service was to determine by inference the successional vegetational recovery and to predict future postfire succession. Field work was nearly completed when the area was burned by the 1977 La Mesa fire. Because the areas had previously

TABLE IV. Fire Frequency for Periods from 1797-1893 and from 1894-1977

Sample	1797-1893	1894-1977
1	12.5	77
2	20.3	83
3	14.4	83
4	10.7	28
5	13.7	58
6	15.8	83
7	14.4	83
8	16.0	83
10	9.3	83
14	17.4	16.2
16	12.7	26.7
17	16.5	83
18	30.6	24.8
19	17.7	69.0
Mean Frequency	15.1	41.9

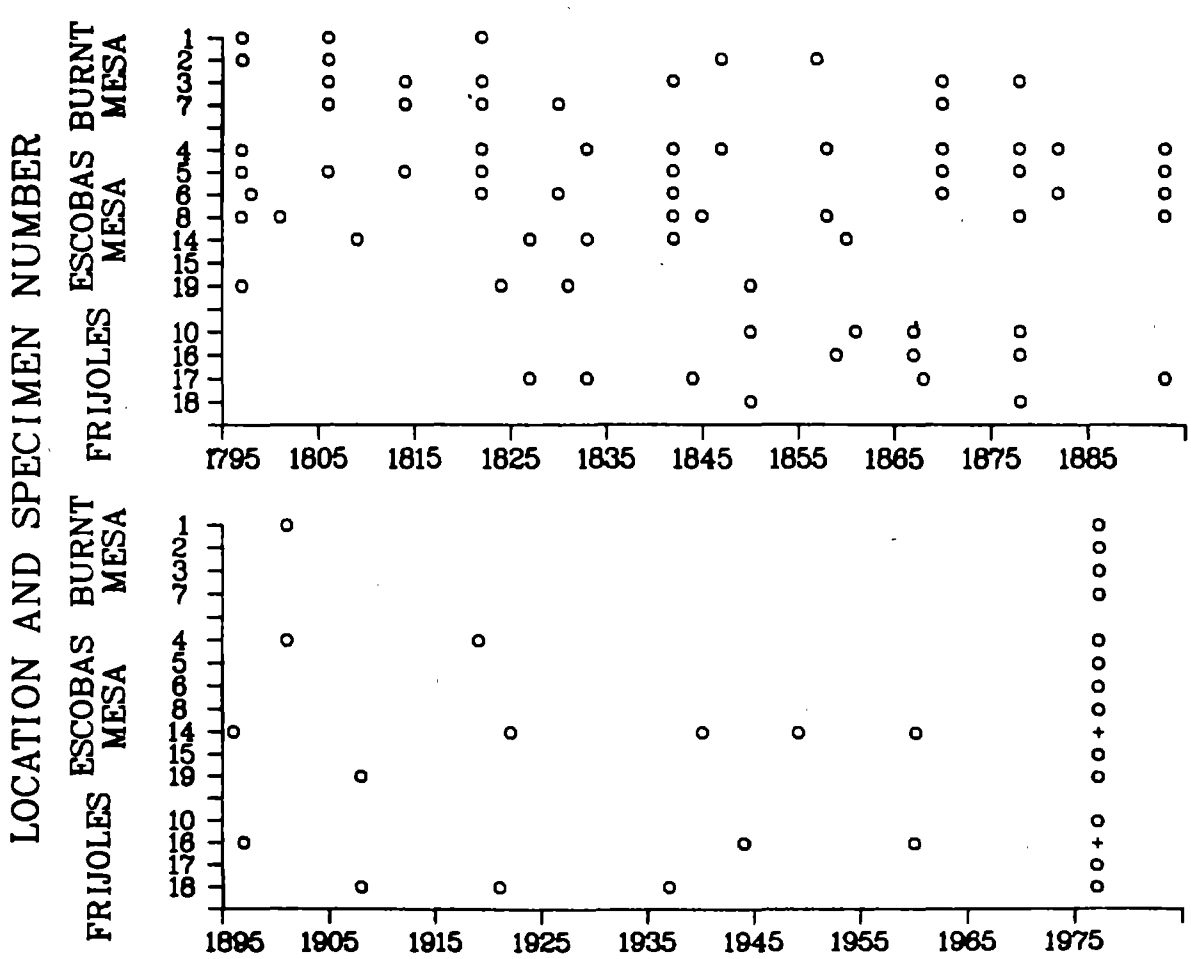

Fig. 3. Fire frequency of fifteen fire-scarred trees.

TABLE V. Fire Frequency.

Dates	Fire Interval (yr)	
Fire Dates Occurring on 20% of the Samples		
1797-1806	9	
1806-1814	8	
1814-1822	8	
1822-1833	11	
1833-1842	9	
1842-1850	8	
1850-1870	20	
1870-1893	23	Mean, pre-1900=12.0 yr
1893-1977	84	Mean, post-1900=77.0 yr
Fire Dates Occurring on 30% of the Samples		
1797-1822	25	
1822-1842	20	
1842-1870	28	
1870-1893	23	Mean, pre-1900=24.0 yr
1893-1977	84	Mean, post-1900=77 yr

been delineated, it was possible to return to locations of known fire history and examine the extent of damage and recovery of the individual sites as related to fire history. The rest of this paper discusses the data acquired during the 1976 field season (before La Mesa fire) and that collected immediately after the fire.

1. Site Selection. During 1976, previously burned areas of various ages were selected from information gained through fire atlases. Sites chosen were more than 10 acres because preliminary field examination showed that fires of smaller acreage were difficult to relocate. Study of the fire atlas maintained at the Monument headquarters from 1931 to 1969 revealed only five fires larger than 10 acres. All recorded fire locations are shown in Fig. 1. The five studies, indicated by irregularly shaped darkened areas, were Frijoles Canyon 1937, Upper Alamo Crossing 1945, Bear Mesa 1950, Boundary Peak 1955, and Frijoles Canyon 1960. Aerial maps dating from 1935 to 1963 were used to locate the study areas as accurately as possible, then the location was confirmed by field examination. A control area adjacent to each burned area was selected for comparison, and was as similar to the burned area as possible in regard to topography, slope, and exposure.

Initially, 12 study areas were established, including the five burned areas and adjacent controls. The 1937 and 1960 Frijoles Canyon burns involved both the inner, north-facing slope of the canyon and the canyon rim; thus, burn plots and controls were established both within the canyon and on the rim.

During the study, the site of a 3-acre fire burned in 1975 on Burnt Mesa was relocated by the Monument staff. This site and two others burned during the 1976 field season (the 5-acre Alamo Canyon fire and the 14-acre Escobas Mesa fire) were added to the study to establish photo stations to be used later to study the succession.

TABLE VI. Composite Fire History for Burnt Mesa, Escobas Mesa, and North Rim of Frijoles Canyon

Sample Year	Interval	Sample Year	Interval
1786-1793	7	1870-1878	8
1793-1797	4	1878-1883	5
1797-1798	1	1883-1893	10
1798-1801	3	1893-1896	3
1801-1806	5	1896-1897	1
1806-1809	3	1897-1900	3
1809-1814	5	1900-1907	7
1814-1822	8	1907-1908	1
1822-1827	5	1908-1919	11
1827-1830	3	1919-1921	2
1830-1833	3	1921-1922	1
1833-1842	9	1922-1927	5
1842-1844	2	1927-1937	10
1844-1845	1	1937-1940	3
1845-1847	2	1940-1941	1
1847-1850	3	1941-1944	3
1850-1858	8	1944-1949	5
1858-1859	1	1949-1960	11
1859-1860	1	1960-1962	2
1860-1861	1	1962-1976	14
1861-1867	6	1976-1977	1
1867-1870	3		

2. **Site Analyses.** The vegetational analysis was done by modification of the Lindsey's (1955) line intercept method. This method provides a measure of foliage cover of tree, shrub, and herb strata; the species composition in all strata; the density (number per area) of trees and shrubs; and the trunk diameters of mature trees. Measures of standing biomass of all understory plants less than 3 ft tall were also obtained with clip plots.

The sampling unit was a 1000-ft line with a 10-ft strip on each side. A right angle, or elb, was made every 200 ft to account for variations in terrain. Where it was impossible to remain within the burned area, an elb was made at 100 ft. The 1000-ft by 20-ft strip was divided into 50- by 20-ft plots so that frequencies could be calculated. A steel tape formed the line along which foliage intercept of mature and reproductive stock over 3 ft tall could be measured. The percentages of foliage cover of herbs, shrubs, and trees less than 3 ft tall were estimated by the use of a one-meter by one-half-meter quadrat placed every 50 ft along the line. Every 100 ft along the line, all vegetation on the quadrat was clipped, separated as to species, and weighed.

From the data gathered, measures of total foliage cover, relative foliage cover by species, total basal area of mature trees, relative basal area, total density, relative density, frequency index, and relative frequency were determined. From relative cover, relative density., and relative frequency, a single measure-of-importance value was calculated for each species.

On June 16, 1977, La Mesa fire was ignited and eventually burned 11 of the 13 previously examined sites (Fig. 4). Although the vegetational studies of previously burned areas provided data to hypothesize

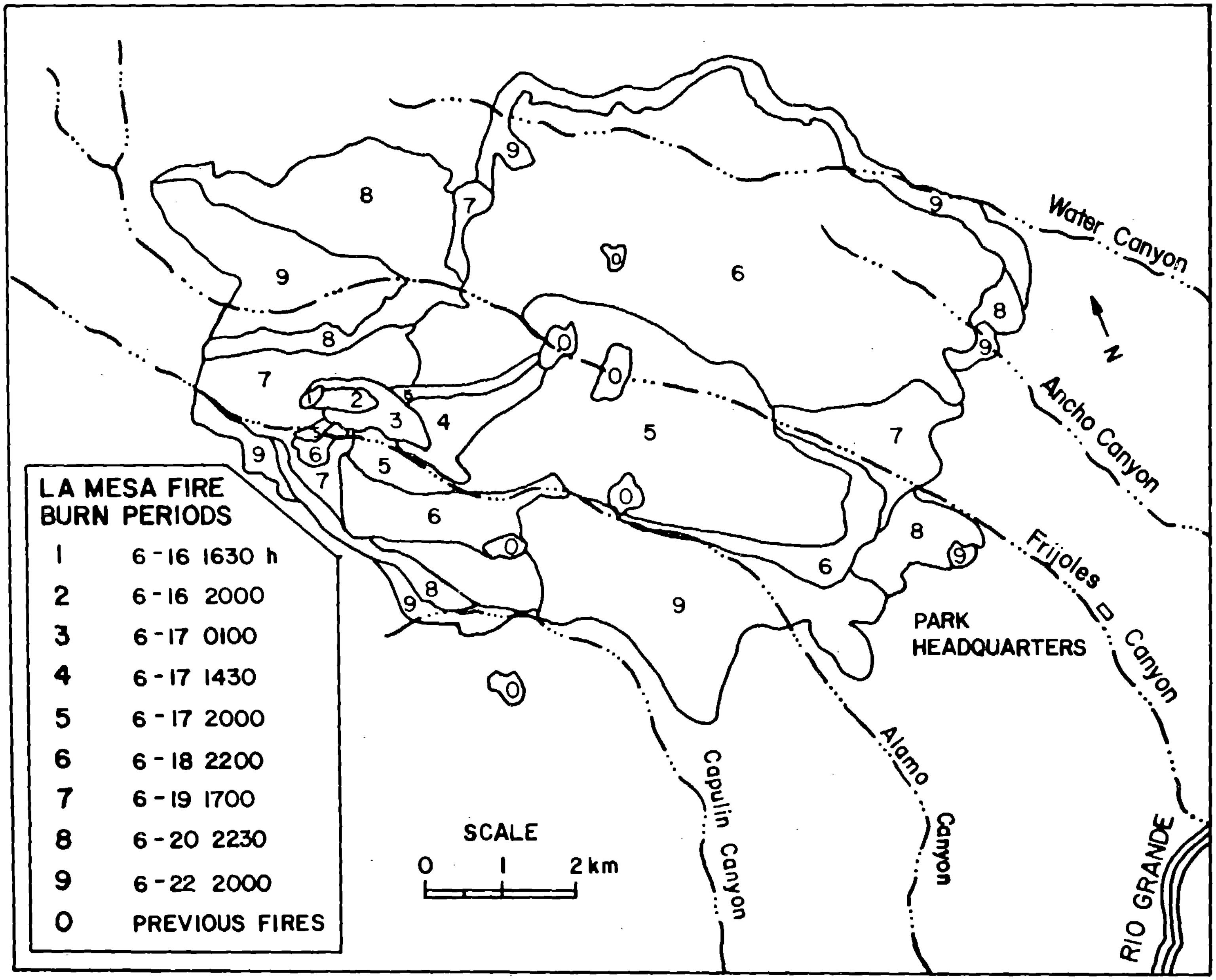

Fig. 4. Rate of spread of the June 1977 La Mesa fire, which burned 62 km^2 (14 000 acres).

the impact of wildfire and the nature of recovery, La Mesa fire (unfortunate as it may have been) turned the descriptive study and its hypotheses into an actual experiment. A re-examination of the study plots to determine varying degrees of damage and recovery response became imperative. Thus, the Upper Alamo Crossing 1945, Bear Mesa 1950, Frijoles Rim 1960, and the respective controls were re-examined. We tried to re-examine the inner Frijoles Canyon plots, but the steep terrain and lack of vegetation made it too dangerous. In addition, new line strips were run on the Escobas 1976 burn and an adjacent control, as well as an area adjacent to the 1960 Frijoles Rim burn, where dated samples indicated that the area had not been burned since 1878 (99 years). In addition to measures of species composition and size classes, the degree of foliage damage and trunk singeing were classified.

The following data were recorded for vegetation occurring within the study plots:

(I) Age classification of trees
  (A) Seedlings - 1 ft high and <1 in. in diameter
  (B) Sapling - 1-3 ft high and <2 in. in diameter
  (C) Pole - 3 ft high and 4 in. in diameter
  (D) Mature - >4 in. in diameter
(II) Damage assessment of the tree species
  (A) Crown damage categories modified from Wagle and Eakle*
    (1) 0-25% foliar damage
    (2) 26-50% foliar damage
    (3) 51-75% foliar damage
    (4) 76-99% foliar damage
  (B) Trunk damage
    (1) Trunk severely scorched all around, or bark mostly burned away
    (2) confined to first 2 ft
    (3) covering first 5 ft
    (4) covering over 5 ft of trunk
    (5) Trunk moderately scorched; cat faces formed in bark but generally bark not completely burned
    (6) Trunk lightly scorched or blackened; burned out new cat faces usually absent, bark structure generally well defined and easily visible.

B. Results and Discussion

A long discussion of the prefire phytosociological data will not be given here. Table VI gives a summary of general stand characteristics of four plateau stands of ponderosa pine type as they appeared before La Mesa fire. Stands are arranged in order of decreasing time since the last burn (34, 27, 22, and 17 years ago). This previous study is important because it allowed relocation of different aged burns after La Mesa fire. This permitted us to correlate fire history collected through pyrodendrology and that from the fire atlas with the amount of damage sustained in each stand for which the last fire was known. A discussion of each plot and condition of the stand after La Mesa fire follows.

1. Analysis of Plots after the 1977 Fire.

a. Alamo Rim 1945 Burn. This plot was examined July 13, 1977. It was burned between 1430 and 2000 hours on June 17, 1977, during which time the predicted rate of spread was 24 chains per hour. Total fuel loads within the area burned during this time were from 6.4 to 11.6 tons per acre (Forester

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*R. F. Wagle and T. W. Eakle, "Effect of Controlled Burn on Damage Caused by Wildfire," Final Report, Research Unit FS-RM-2108, Tempe, Arizona.

1976). Many areas along the trail, which provides access to the 1945 burn, were severely burned, with trees showing explosive popping of the bark. Fine fuel loads were 2.32 tons per acre within the area burned in 1945, and 9.06 tons per acre within the control.

The open meadow created by the 1945 fire was used as a heliport to supply men and materials for La Mesa fire and many small trees had been cut down. As shown in Fig. 5, there was very little difference in the low survival rate of the mature trees in either the 1945 burn or the control. Within the 1945 burn, 55% of the trees were in class 6, and 31% in class 5: within the control, 84% were in class 6, and 15% in class 5. Only 14% of the trees within the 1945 burn had foliar damage in classes 3 and 4, compared with 1% in the control.

The total relative foliage cover of herbaceous plants within the 1945 burn was reduced from 37% in 1976 to 8%, compared with the control, which was reduced from 5 to 1%. Sprouting of perennial grasses and herbs was seen within the 1945 burn, but within the control, only sprouting of deep-rooted shrubs was noted.

b. Bear Mesa 1950 Fire. This site was re-examined in September 1977. The area burned during the period from June 17, 2000 hours, to June 18, 2000 hours, during which time the predicted rate of spread was 38 chains per hour. Fuel loads within the area burned during that time and within the vicinity of these plots were from 6-8 tons per acre (Forester 1976). Fine fuel loads within the area burned in 1950 were 8.7 tons per acre, and 9.4 tons per acre within the control.

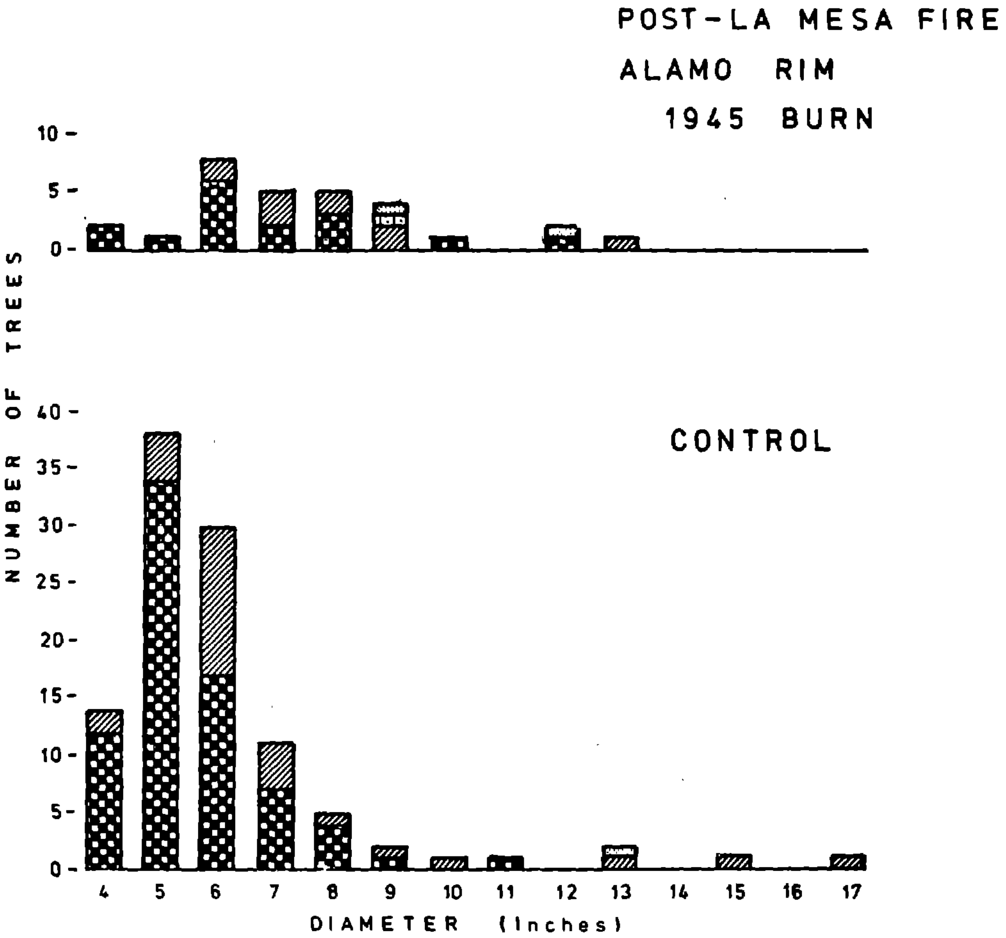

Fig. 5. Relative foliar damage in six categories to mature ponderosa pine on Alamo Rim based on the line-strip plots, 1977.

From the 1976 observations and from personal information communicated by Albro Rile, Chief, Los Alamos Fire Department (Ret). it was determined that the 1950 fire had been a relatively cool fire. This was reflected in the fuel loads, foliage cover, and densities obtained during the 1976 field season. The areas were very similar. However, extent of foliar damage was much more severe in the control area than in the burned area, as shown in Fig. 6. More than 66% of the trees within the control sustained foliar damage in classes 5 and 6, whereas only 6% sustained similar damage in the burn. Only 10% of the trees within the control sustained foliar damage less than 50%, but in the burn, 60% were in this category and prognosis for their survival was good. The more dense stands will probably be substantially thinned.

c. Frijoles Rim 1960 Burn. This plot was re-examined June 30, 1977. It burned during the period 1430 hours and 2000 hours on June 17, 1977, during which time the predicted rate of spread was 24 chains per hour. The site is located on the rim of Frijoles Canyon where the fire jumped the canyon. Fine fuel loads within the control area were 12.3 tons per acre. Unfortunately, fuel loads for the burn area had not been collected by the time of La Mesa fire; the collection was to be done during the 1977 field season. The remains of a vehicle were found just north of the 1960 burn and the chrome had been melted into pools, which evidences a hot fire.

The contrast between the control area and the 1960 burn was striking (Fig. 7). The control area was completely devastated, but the burn area had no trees in classes 5 and 6 (Fig. 7), and 64% of the trees were in classes 1 and 2. It appeared to be an island of green in a sea of black. The 1937 fire was situated

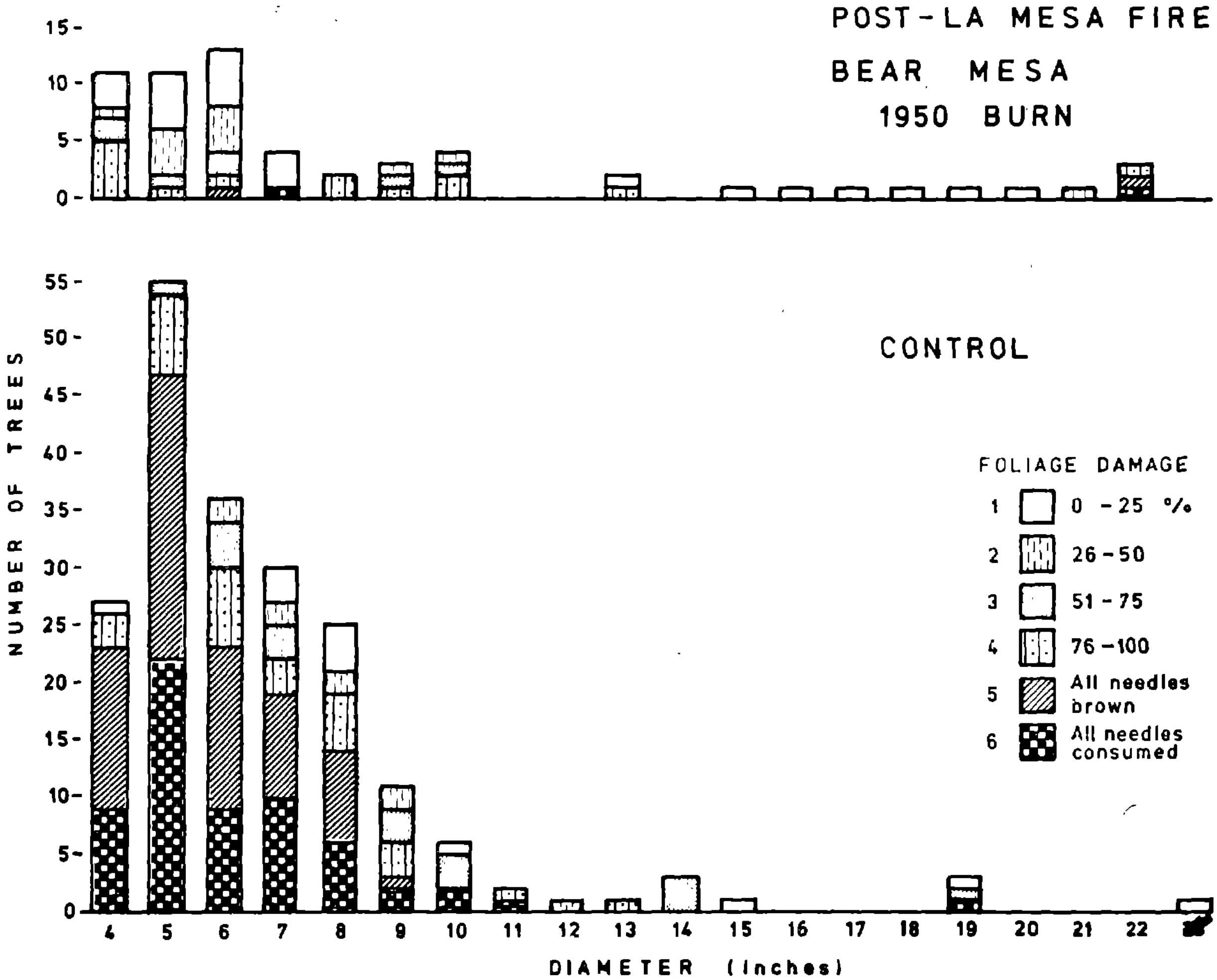

Fig. 6. Relative foliar damage in six categories to mature ponderosa pine on Bear Mesa based on the line-strip plots, 1977.

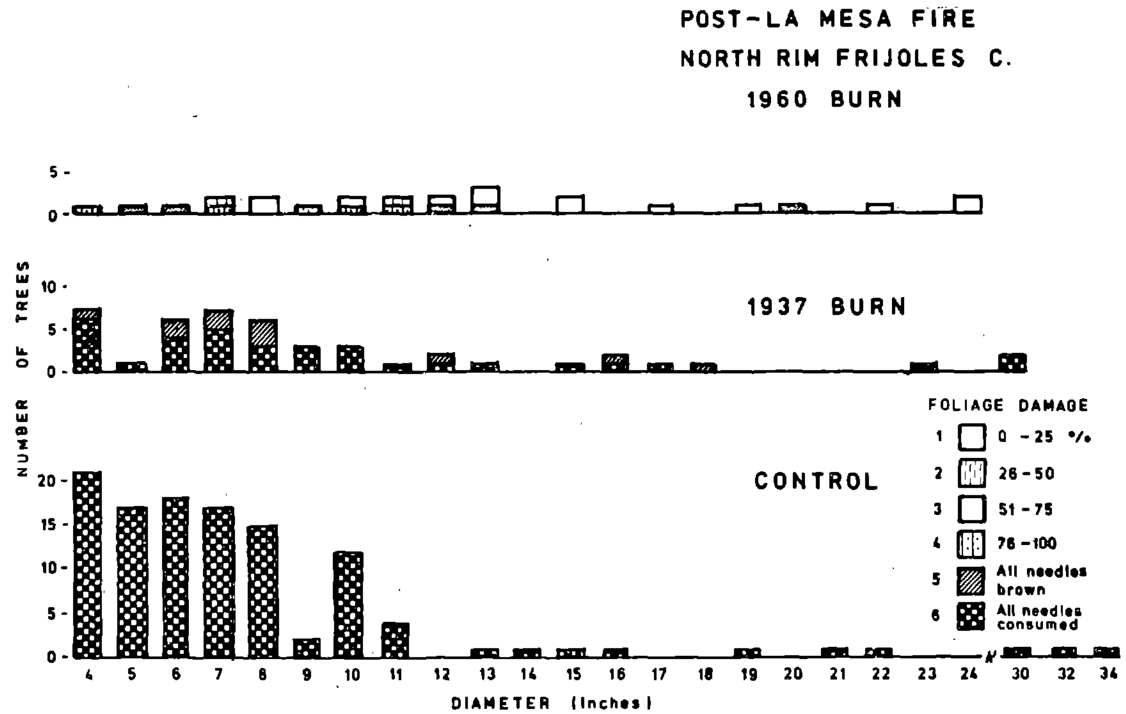

Fig. 7. Relative foliar damage in six categories to mature ponderosa pine on North Rim Frijoles Canyon based on the line-strip plots, 1977.

east of the 1960 fire, and the control was west. As Fig. 7 shows, destruction of the trees within the 1937 burn was very extensive. This area provides an excellent comparison of minimal damage in an area burned 17 years previously (near the average pre-Monument fire frequency) with the severe loss of an area not burned for 40 years.

Total relative foliage cover of herbaceous plants within the 1960 burn was reduced from 44% in 1976 to 14% after La Mesa fire.

d. Frijoles Rim 1878 Burn. This area was not measured during the 1976 field season. In an attempt to establish fire frequency, a tree, which was atop a ruin in this area, was cut down by the Monument staff just before La Mesa fire. Dating of this section indicated that the last fire was in 1878. The site was examined on September 21, 1977. It had burned during the period of 1430 hours and 2000 hours on June 17, 1977, during which time the predicted rate of spread was 24 chains per hour. Although fuel loads were not measured during the 1976 field season, fuel loads in the 1960 control, immediately south of the 1878 site, were measured at 12.3 tons per acre.

The site was not examined until September, but burning in the area had been so severe that little or no vegetation was coming back (~1% relative foliage cover). All the trees were in categories 5 and 6, with 99% in class 6 (Fig. 8). The area was devoid of any litter or duff and the mineral soil had been contracted and dried into polygons. *Andropogon gerardii* (big bluestem) was the only grass species evident in the area. It appears that the accumulation of fuels from a lack of burning for 99 years combined with the fire behavior provided the factors necessary for complete destruction of trees and the understory in this area, leaving it completely blackened and devoid of living vascular plants, except several inches below the ground surface.

e. Frijoles Rim 1937 Burn. This area was not measured during the 1976 field season and was to be examined during the 1977 field season. However, the studies were interrupted by La Mesa fire. This plot was examined September 21, 1977. The site burned during the period of 1430 hours and 2000 hours on

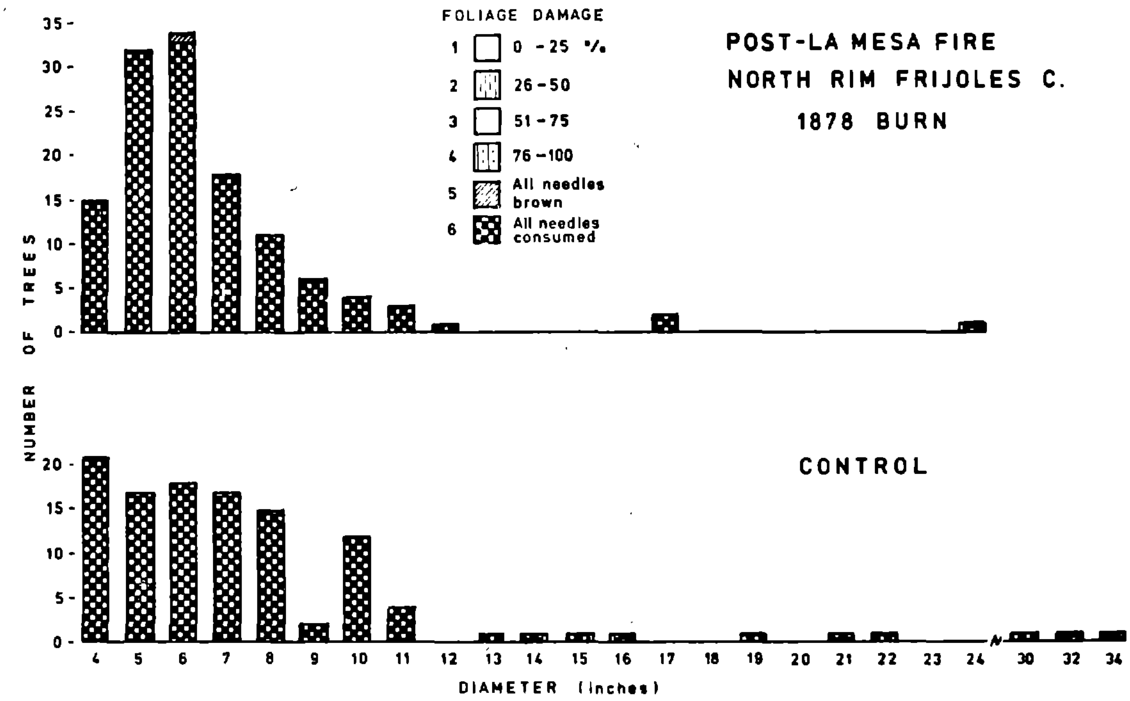

Fig. 8. Relative foliar damage in six categories to mature ponderosa pine on North Rim Frijoles Canyon based on the line-strip plots, 1977.

June 17, 1977, during which time the predicted rate of spread was 24 chains per hour. It is in the immediate vicinity of the area where the fire jumped the canyon. There are no recorded fuel loads before La Mesa fire but the control area west and separated by the 1960 burn was 12.3 tons per acre.

Although the area burned in 1937 had been opened into a meadow, damage to mature and reproductive trees was severe, with all trees in classes 5 and 6. This was slightly less than the damage in the control, where all trees were in class 6. Figure 7 illustrates the extent of damage to this area.

Total relative foliage cover for herbaceous plants was 2%, compared with the 1960 burn of 14% and the 1878 burn of 1%. Perennial grass and herbs were regenerating. Large quantities of *Andropogon gerardii* were found and there was evidence that turkeys had returned to the area. It is evident that 40 years of fuel accumulation provided the conditions necessary for fairly complete destruction of the overstory, but the severity of fire did not completely destroy the rootstocks of perennials.

f. ***Escobas Mesa 1976 Burn.*** This area was burned during the 1976 field season. At that time, photo stations were established but measurements were not taken. The site reburned June 18, 1977, between 1100 and 2200 hours, during which time the predicted rate of spread was 38 chains per hour. Immediately after the 1976 burning on Escobas Mesa, fuel loads were 1.3 tons per acre, whereas an adjacent control measured 3.5 tons per acre. Unfortunately, the fireline established on Escobas Mesa ran directly through the 1976 burn, which caused substantial bulldozer damage.

This area was measured July 7, 1977. It was easy to relocate the boundary of the 1976 fire because La Mesa fire had jumped the narrow, barren 1976 hand lines. The area apparently had been logged approximately 50 years ago, so an adjacent control that also had been logged was selected, but it had not been subjected to recent fire. As can be seen in Fig. 9, all trees within the area burned in 1976 were in classes 1-4, but 92% of those of the control were in classes 5-6. There also is considerable difference in relative cover of herbaceous plants. Within the 1976 burn, the total relative cover was 12%, and only 1% in the control.

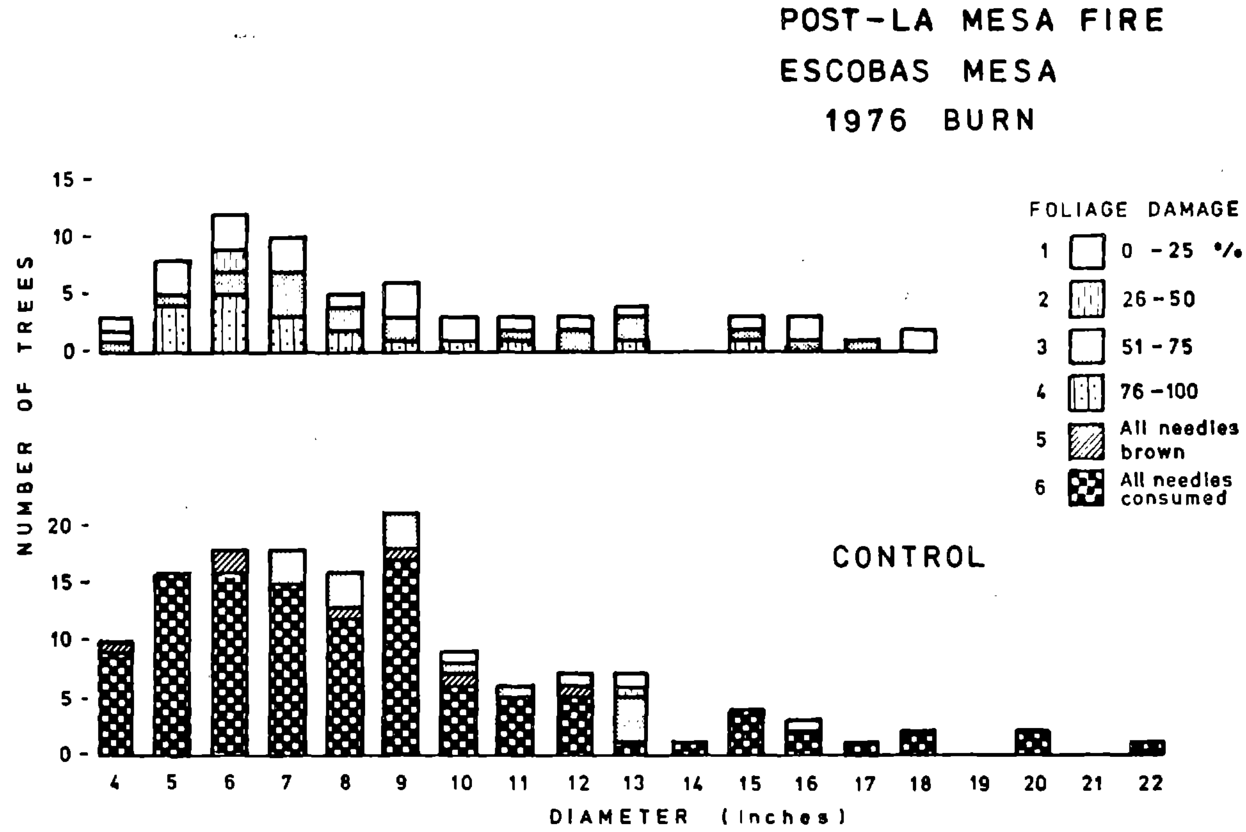

Fig. 9. Relative foliar damage in six categories to mature ponderosa pine Escobas Mesa based on the line-strip plots, 1977.

Because both the 1976 burn and the control had been logged, it is quite evident that the reduced fuel load in this area from the 1976 fire was responsible for the high survival of these trees. There will probably be considerable thinning in the area of the 1976 fire, but the prognosis for survival of many of the trees is good. Although the control was logged, a high degree of foliar damage was sustained and most of the trees must be considered dead.

*g. **Reproductive Ponderosa Pine.*** Damage to ponderosa pine less than 4 inches in diameter was very dependent on the length of time since the last burn. As can be seen in Fig. 10, there was extensive damage to reproductive trees in all plots except the Escobas 1976 burn, where 96% of the reproductive trees were in classes 1 and 2. Apparently, fuel loads in this area were high enough to produce a damaging fire. Reproductive trees in all other plots, with the exception of the 1950 burn, are not expected to survive. Only 25% of the reproductive trees in the 1950 burn have sufficient foliage remaining for survival; thus, it is expected that considerable thinning of this area will occur.

2. Summary of Fire Damage to Ponderosa Pine After the La Mesa Fire. Table VII summarizes the principal features of a series of stands representing no burning before La Mesa fire, for periods from 99 years to 1 year. Because these stands are of the ponderosa pine type and are completely dominated by this species, only the data for pines are given. Total densities and basal areas for the pine versus all species vary by minor percentages for the mature stratum.

The density of mature pine in the unburned controls varies from 235 to 440 trees per acre. Except for the area burned in 1878, which had a dense stand of 342 trees per acre, all other previously burned stands had greatly reduced density of stand. The variations did not correspond with time since the last burn, but

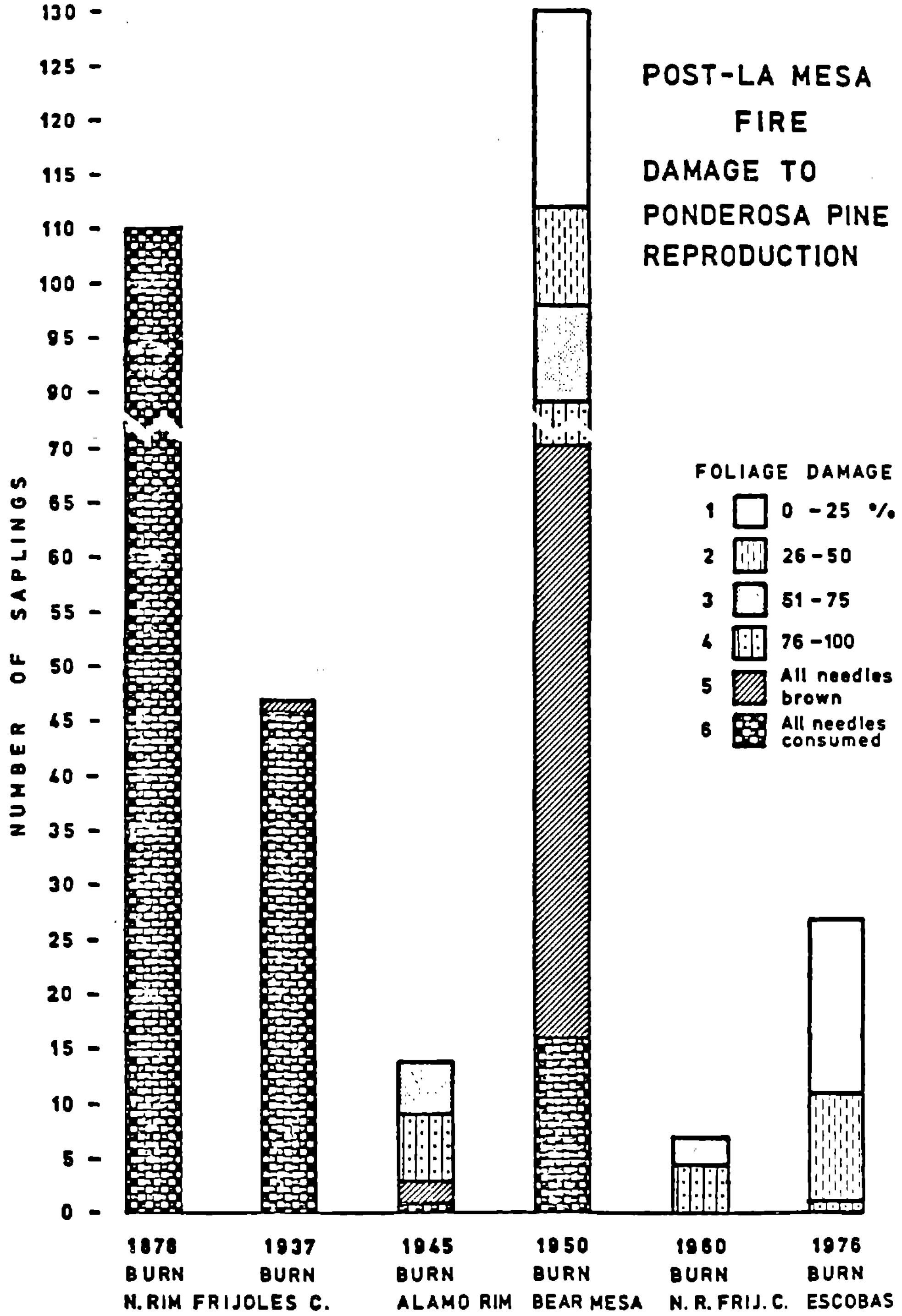

Fig. 10. Summary of relative foliar damage of La Mesa fire in six categories to reproductive ponderosa pine at six sites.

TABLE VII. Summary of Post-La Mesa Fire Damage and Stand Conditions, 1977, on Ponderosa Pine Type

	1878 Burn	1878 Control	1937 Burn	1937 Control	1945 Burn	1945 Control	1950 Burn	1950 Control	1960 Burn	1960 Control	1976 Burn	1976 Control
Fire Interval (years)	99		40		32		27		17		1	
Stand Conditions												
Mature												
Pine Density (No./A)	342	(235)	98	(235)	63	(231)	131	(440)	55	(235)	150	(288)
Pine Basal Area (Sq ft/A)	91	(118)	41	(118)	20	(50)	75	(114)	51	(118.)	52	(148)
Pine Mean dbh (in.)	7.0	(9.6)	8.8	(9.6)	7.6	(6.3)	10.2	(6.9)	13.1	(9.6)	7.9	(9.7)
Fuel Load												
Litter (tons/A)	–	–	–	–	1.9	(8.0)	8.1	(9.0)	–	(8.3)	–	–
Sticks (tons/A)	–	–	–	–	0.0	(1.1)	0.5	(0.4)	–	(3.8)	–	–
Herbs (tons/A)	–	–	–	–	0.5	(0.0)	0.1	(0.1)	–	(0.2)	–	–
Total (tons/A)	–	–	–	–	2.4	(9.1)	8.7	(9.5)	–	(12.3)	–	–
Fire												
Ratio of Spread (chains/hr)	24	(24)	24	(24)	24	(24)	12	(12)	24	(24)	38	(38)
Mature Foliage Damage (%)												
0 – 25							40	(5)	52		36	(2)
26 – 50							20	(5)	12		3	(1)
51 – 75					7	(1)	10	(9)	20		31	(5)
76 – 100					7		23	(15)	16		30	
All Brown	1		75		31	(15)	3	(35)				(69)
Consumed	99	(100)	25	(100)	55	(84)	3	(31)		(100)		(23)
Mean Damage Class	5.99	(6.00)	5.25	(6.00)	5.35	(5.82)	2.40	(4.64)	2.96	(6.00)	2.49	(5.03)
Reprod. Foliage Damage												
0 – 25							14	(2)			59	
26 – 50							11				37	
51 – 75					36		7		43			
76 – 100					43		15	(2)	57		4	
All Brown			2		14	(97.)	41	(37)				
Consumed	100	(100)	98	(100)	7	(3)	12	(59)		(100)		
Mean Damage Class	6.00	(6.00)	5.98	(6.00)	3.93	(5.03)	3.96	(5.52)	3.57	(6.00)	1.48	(–)

most likely were dependent upon the severity of the burn at that time, a phenomenon for which good data are not available.

Calculated basal areas indicate the 1878 burn plot had a high stand composed of size classes greater than 4 inches in diameter. Of the stands previously burned, the 1878 stand had the lowest average diameter, 7.0 inches. Two adjacent stands burned in 1937 and 1960 had average diameters of 8.8 and 13.1 inches, apparently indicating the removal of small-diameter trees by fire. Given enough time for successful germination, seedling establishment, and growth, a population of young mature trees becomes reestablished. This high density and small size would result in a stand with trees close together, much total foliage, and with many branches close to the ground—a situation conducive to severe burn damage by wildfires.

The limited amount of data on fuel loads indicates a considerably higher total amount for the control areas than for the burned stands. Again, the amount of litter and sticks in the fuel load is probably more a factor of fire intensity than the time since the last burn. Several stand conditions such as mature tree density, reproductive density, and high fuel load in the Bear Mesa stand indicate a relatively cool fire there in 1950.

The rate of fire spread was derived from information obtained from the US Forest Service. As a comparison, rates were slower in the Bear Mesa stand and faster in the Escobas Mesa 1976 burn.

The data in Table VII on fire damage to foliage of mature trees provide the best evidence of the relation of time since the last burn to severity of damage produced by wildfire. Trees having foliage damage classifications of 3 or greater are generally considered unlikely to recover. Note the complete loss of trees in the areas not burned since 1878 and 1937. The Alamo Rim stand, not burned for 31 years, has no trees with less than 50% foliar damage, and probably none of the trees will survive. The Bear Mesa stand, burned by a cool fire in 1950, has a low percentage of trees in classes 5 and 6, and 60% in classes 1 and 2. Trees in the 1960 Frijoles Rim burn and the 1976 Escobas Mesa burn have no trees in classes 5 and 6. The number of trees in classes 3 and 4 within the Escobas Mesa stand may reflect damage from the 1976 fire, from which there was no time for recovery. Note the contrast between the burned stands and the adjacent controls. The latter always have higher mean damage values. This set of data indicates that an interval between wildfires of more than 25 years results in nearly complete loss of all mature trees when a fire does occur. This time interval is nearly a decade longer than the naturally occurring fire interval recorded by fire-scarred trees on Burnt Mesa, Escobas Mesa, and rim of Frijoles Canyon. Obviously, the damage produced by prescribed burning would be less severe than that of a wildfire. With prescribed burning, the survivorship after wildfire of only 60% of the mature trees, as in the case of the 1950 Bear Mesa burn and the 1960 Frijoles Rim burn, might not be acceptable. The above examples represent fire intervals of 27 and 17 years.

The set of data for the damage to the foliage of pine reproduction indicates similar damage to the mature trees. The mean damage decreases with the decreased interval of time since the previous fire.

Figure 11 summarizes the effect of wildfire on six plateau stands of ponderosa pine relative to the length of time (ranging from 1 to 99 years) since the site had burned before La Mesa fire. The classes of foliar damage range from 1 (0.25% foliar scorching) to 6 (complete needle consumption). It is seen that if the area had not burned in the last 27 years, foliar loss was complete. This is consistent with the fire history data that indicated an individual sample interval from 9-34 years. Other data indicated that major fires occurred on the plateau from 12-25 years. The average fire interval or fire frequency for all samples was 18 years. Therefore, a fire frequency of 17 years appears to be optimum for tree survival in the ponderosa pine forest of Bandelier National Monument.

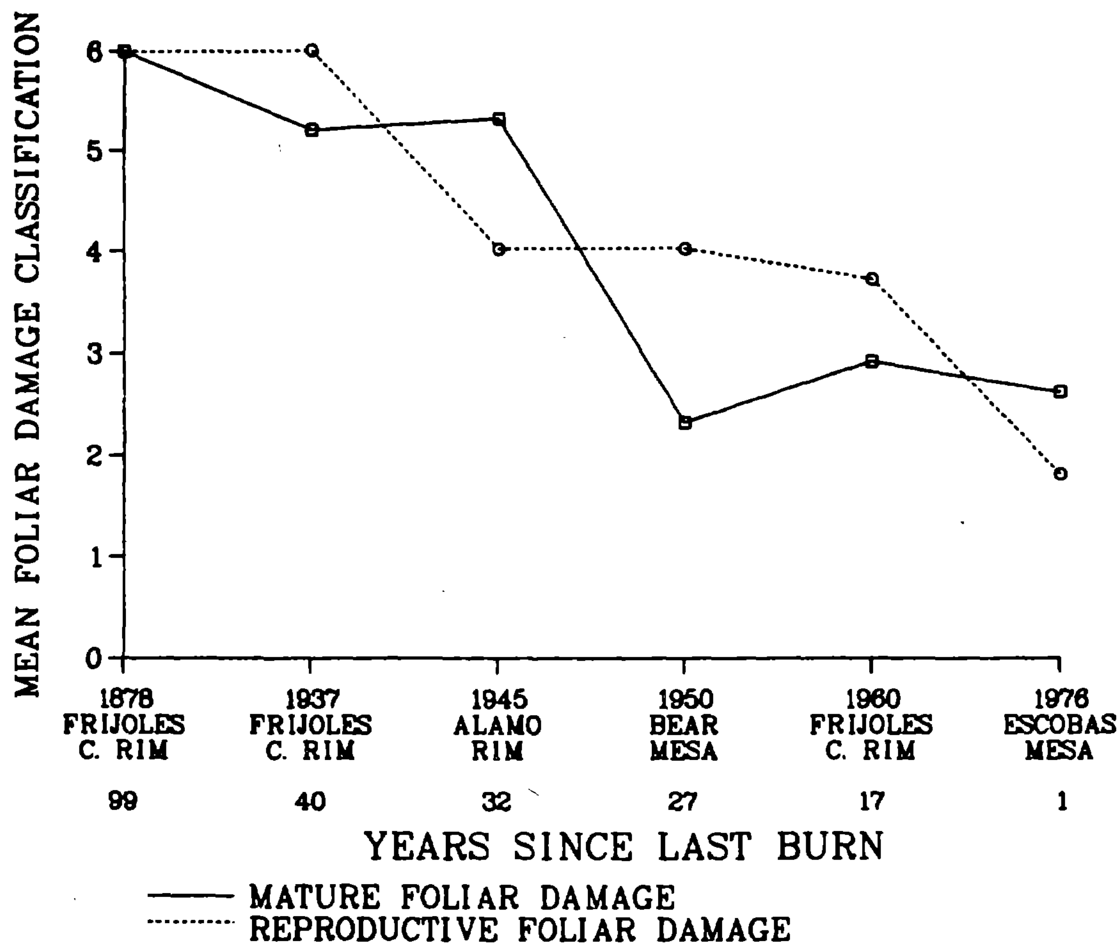

Fig. 11. Effect of fire interval on foliage in six plateau stands of ponderosa pine.

C. Conclusions

With the recognition of the serious fire hazard resulting from over 80 years of fire suppression, the National Park Service instigated a study of fire ecology. The locations and dates of local fires were determined and study plots were located on sites presenting different intervals of time since the last burn, namely, 1937, 1945, 1950, 1955, and 1960. Using the modified line-strip method of vegetational analysis, phytosociological measures of mature tree density, coverage, frequency, and importance values were determined for burn areas and adjacent controls. Analyses also included density, coverage, and frequency of reproductive classes and shrubs. Herbs and seedlings were sampled by quadrats as well as fuel loads.

Fire records for 39 years indicate an average of six fires per year, 86% of which were lightning caused. The incidence of man-caused fire has remained fairly stable. The frequency of extensive, destructive fires has increased and it is suggested that this is principally due to accumulated fuel loads after 80 years of major land use changes and organized fire suppression.

Analyses of tree rings from Burnt Mesa, Escobas Mesa, and the rim of Frijoles Canyon indicate mean fire frequency of 17.4 years between 1786 and 1962. The pre-fire-suppression period (before 1894) shows a fire frequency of 15.1 years, whereas the period from 1894 to 1977, a period of organized fire suppression and major land use changes, shows a fire frequency of 41.9 years. The data also indicated that there had been no major fires on the mesa for 84 years, and that before then, a fire burned over more than one mesa every 12-25 years. No severely burned site had had a previous fire for 119 to 37 years, whereas lightly burned areas had been burned within the past 1-7 years. The data further emphasize the effect on the plateau of fire suppression since 1900.

La Mesa wildfire of June 1977 burned about 14 000 acres, including the 1976 study plots, converting a descriptive study into an actual demonstration and experiment. Within the burn area there were variations in the degree of damage.

Having just completed the study of fire history, location, and stand conditions of sites not burned for 40 and fewer years, it was possible to revisit the same stands after La Mesa fire and compare the burn damage. Other stands not burned since 1878 and comparative stands of previous thinning by logging versus unthinned were also examined. All stands previously burned had lower densities of trees but the trees were larger than those on the adjacent control stands. The 1878 burn had recovered with a high density of many small trees. Its fire damage was extreme in all regards. After La Mesa fire, trees were classified as to degree of foliar scorching from 1 to 6. Trees in classes 3 and greater (3 = 51-75% foliar singeing) are often considered not likely to recover. Stands not burned for 99 and 40 years were completely lost (classes 5 and 6). The Alamo Rim stand, not burned for 31 years, had no trees with less than 50% of foliar damage and few will survive. The Bear Mesa stand, burned by a cool fire 27 years ago, had very few trees in classes 5 and 6 but 60% in classes 1 and 2, which are expected to survive. Stands not burned for 17 and 1 years had no trees in classes 5 and 6. The mean damage values for control stands were always higher than those for stands previously burned, with an increasing contrast for recently burned stands. Intervals of more than 25 years between wildfires in this area apparently result in nearly complete loss of all mature trees. To obtain survivorship percentages less than 60%, wildfire frequency would have to occur more often than 25 years, which approaches the natural interval of 15-18 years. Prescribed burning under correct conditions would produce less damage.

ACKNOWLEDGMENTS

This study would not have been completed without the support and help of many individuals. Appreciation is expressed to the National Park Service for their financial support. R. Wauer and J. D. Hunter initiated the study. Members of the staff of Bandelier National Monument rendered assistance. J. Lissoway helped in collecting samples and J. Wobbenhorst assisted in obtaining information. J. Schmidt of the Forest Service supplied information about La Mesa fire.

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POSTFIRE RECOVERY AND MORTALITY OF THE PONDEROSA PINE FOREST AFTER LA MESA FIRE*

Loren D. Potter** and Teralene Foxx†

I. INTRODUCTION

In the wake of all except the most severe fires, a number of trees are not killed outright but retain an unsinged portion of the crown. The health, vigor, and recovery of these trees can determine which trees are to be salvaged (Connaughton 1936, Herman 1954). Accurate prediction of which trees will live is essential because these trees provide the seed source for natural regeneration (Rietveld 1976).

A few studies have examined postfire mortality in fire-damaged trees. Herman (1954) found that trees of sawtimber size with 40% or more of the canopy singed did not survive 6 years. In a study in Idaho, Connaughton (1936) found that 57% of the trees with 50% or more of the crown singed were dead after 3 years, compared with 26% mortality of trees with less than 50% of the crown singed.

As a result of the man-caused La Mesa fire in north-central New Mexico and a previous investigation of the fire history of several stands of ponderosa pine before La Mesa fire, it was possible to examine postfire mortality as well as recovery of ponderosa pine stands two growing seasons after a fire. Factors examined included fire history, stand density of living trees after the fire, crown damage, and competition of herbaceous vegetation.

II. THE STUDY

In June 1977, La Mesa fire consumed 14 361 acres of Bandelier National Monument, Santa Fe National Forest, and Department of Energy land in Los Alamos. The fire burned predominantly in the ponderosa pine zone, but acreage containing piñon-juniper and mixed conifer were also flamed. Before the fire, we were conducting a fire ecology study to determine the fire history and related plant succession of the area (Foxx and Potter 1978). The information accumulated provided baseline data so that, after the fire, it was possible to scrutinize established plots and to determine the extent of damage to mature and reproductive ponderosa pine stock as related to previous fire history and phytosociology. In addition, plots in areas of light, moderate, and severe damage were established immediately after the fire.

Soon after the fire, we established six categories of foliar damage from nearly all the crown remaining to all needles having been consumed by the fire (Fig. 1). Categorized trees were labelled with aluminum number tags. Two growing seasons (15 months) after the fire, each tree in these permanent plots was reexamined to determine inprovement or decline in the foliar classification. The coloration of leaves killed by the fire was substantially different from those that died subsequently, so we were able to include data concerning vigor of the tree as indicated by the needle condition. Height of trunk scorch and the presence

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*This research was supported in part by the Forest Service, US Department of Agriculture, through the Eisenhower Consortium for Western Environmental Forestry Research, and is published as Eisenhower Consortium Journal Series No. 55. Funding for part of the research was from Grant No. 4-L40-8716N-1, Los Alamos National Laboratory, Department of Energy, Los Alamos, New Mexico.

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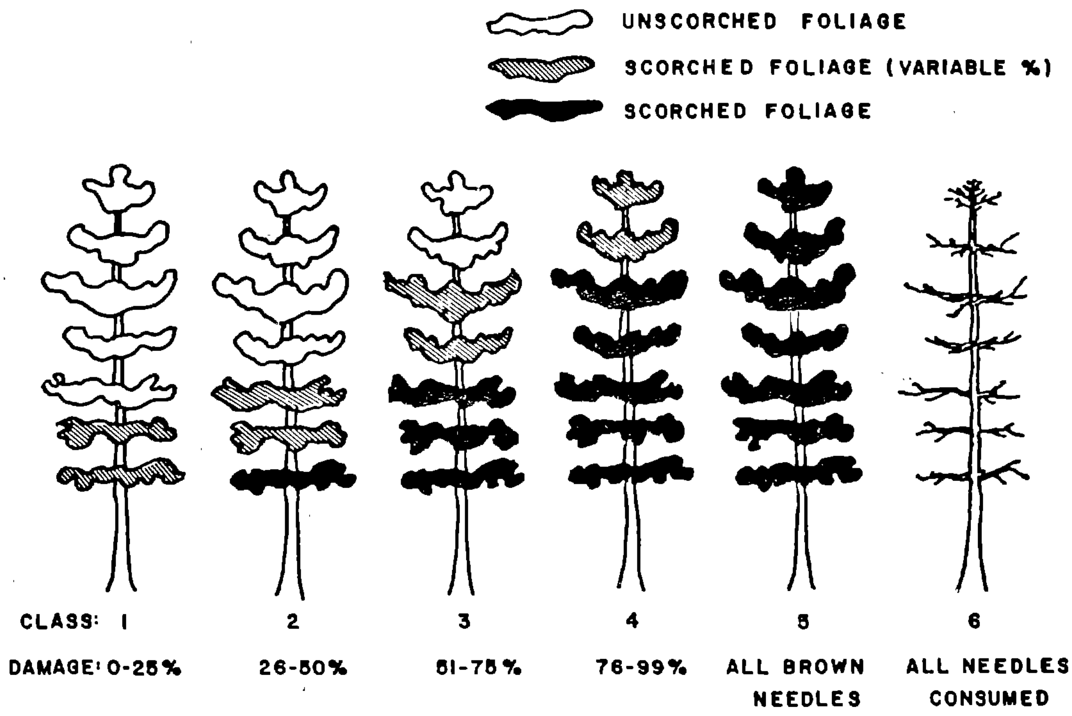

Fig. 1. Foliar damage categories.

of stump burn-outs, insects, mistletoe, and oozing of pitch were also noted. The amount of new growth within the scorched area was also determined.

III. RESULTS AND DISCUSSION

Improvement or deterioration of foliage condition in fire-damaged trees in relation to the following factors was examined: (1) extent of fire damage to the crown, (2) length of time since the area had burned before La Mesa fire, (3) density of living trees in the stand, (4) growth of herbaceous vegetation, particularly aerially seeded grass, and (5) such other factors as beetle infestation.

Figure 2*shows the extent of La Mesa fire and the distribution of stands in various foliar classifications. Of the total area, the unburned patches amount to 211 acres (1.5%); classes 1-4 combined are 8941 acres (62.3%); class 5 is 2534 acres (17.7%); and class 6 is 2675 acres (18.6%). Thus, an area of 5209 acres (36.3%) has few or no seed trees with which to naturally regenerate the area (Potter, Foxx, Barnes 1981).

A. General Condition

The analyses were based on a total of 897 trees in nine plots, all of which were in similar topography. Trees in all size classes were included. Immediately after La Mesa fire, each tree within these plots was tagged and categorized according to foliar damage. Of the 897 trees examined immediately after the fire, 291 were in category 6 and certainly dead; 213 were in category 5 and, because all needles were singed, dry, and brown, we assumed they were dead or would soon die. Only 393 trees (44%) had green needles.

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*See envelope, inside back cover.

Of these, 93 had less than 25% of the canopy singed, 12 had 26-50% singed, 43 had 51-75% singed, and 245 had 76-99% singed. Thus, 288 of the 393 had more than 50% of the canopy singed (categories 3 and 4).

In 1978, two growing seasons after the fire, 357 (40%) of the 897 trees were in categories 1-4 and considered alive, a net loss of only 4% (Potter and Foxx 1979a). Of the 357 living trees, 206 (58%) had more than 25% viable crown, an increase of 58 trees in categories 1-3. Thus, 14% of the original population of 393 living trees showed a net improvement from class 4 to classes 1-3. Of the population of living trees (categories 1-4) immediately after the fire, 90% were alive after two growing seasons. Of the population having more than 50% singed canopy, 80% were still alive—a much higher survival than indicated in the studies by Connaughton (1936) and Herman (1954).

B. Recovery of Pine Related to Foliar Damage Classification

Within two growing seasons after the fire there were some general trends. Trees with more foliar damage showed an increasing mortality compared with those in the less severely burned categories (Fig. 3). The following percentages of trees were improved or remained in the same category: category 1, 91%; category 2, 83%; category 3, 74%; and category 4, 83%. Approximately 6% of the trees classified as having all brown needles (category 5) showed signs of recovery (Fig. 3). This is because some small trees (less than 6 feet tall and 2 inches dbh), which had only brown needles after the fire, showed partial to complete recovery after two growing seasons. Young trees that recovered were in less dense stands; trees of similar size in dense stands did not recover.

The exception to the general trend of recovery and foliar damage was the population of 245 trees in category 4 foliar damage (76-99% foliage singed). These showed the greatest improvement (indicated by the largest percentage change to better foliage classifications). Category 4 trees were examined in terms of the relative recovery of different sizes (Fig. 4). The smaller trees showed less improvement and greater mortality than larger trees. For all sizes in category 4, 26% improved, 54% remained the same, and 20% died. Previously published criteria (e.g., Connaughton 1936 and Herman 1954) predicted that all these trees would die because they had only 25% or less healthy foliage.

C. Recovery of Damaged Pine Foliage Related to Size

We determined the amount of regrowth in two seasons of trees in categories 1-4 and arranged recovery according to tree size. The total population of 354 trees was well distributed among the various sizes. Only 16% of the trees showed no recovery within the singed foliage, 63% showed up to 25% recovery, and only 3% of the trees showed 75-100% recovery of the damaged area. Recovery of 50% or more was greatest in the small trees ($\leq$4 in.) and in the large trees.

D. Recovery of Pine Related to Previous Fire History

Foxx and Potter (1978) found that severity of damage to the overstory, indicated by the mean foliar damage, depends on the length of time since the last fire (Fig. 5). Based on the estimates of Herman (1954) that all trees with less than 60% viable crown would die, the foliar damage data accumulated after La Mesa fire were converted to an anticipated survival curve and arranged according to the interval since each stand had been previously burned (Fig. 5). The mean foliar damage is given for both mature and reproductive sizes. The anticipated survival under this criterion was zero for trees in stands not burned within the last 27 years. The mean fire interval at Bandelier before fire suppression was 17-18 years (Foxx and Potter 1978).

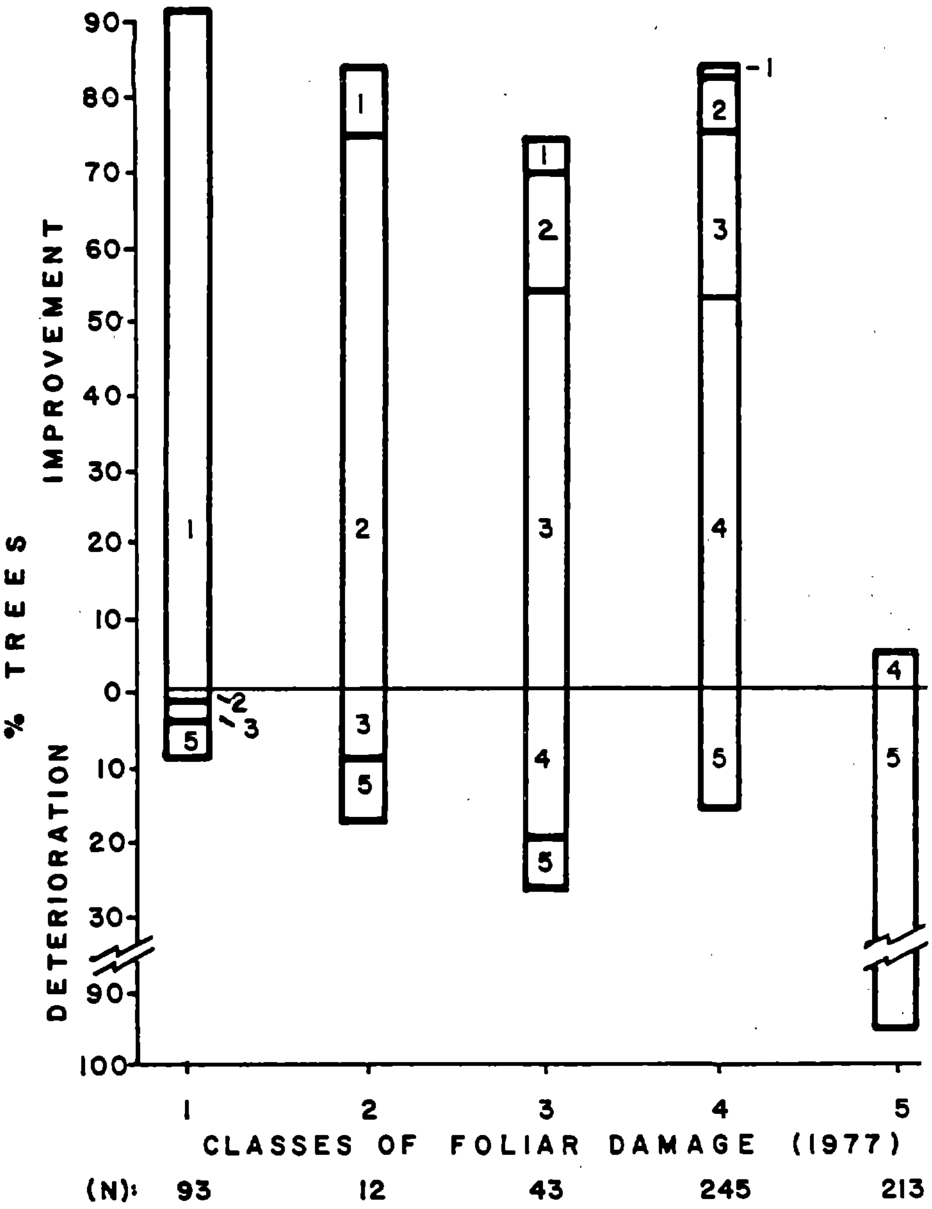

Fig. 3. Changes in foliar classification after 2 growing seasons of all trees of all plots in categories 1-5 soon after La Mesa fire.

When the trees in these areas were examined two growing seasons (15 months) later, we found that the actual survival was higher than that anticipated (Fig. 6). This was due to at least 2 factors: (1) the large number of category-4 trees (76-99% foliar singeing) that remained the same or showed recovery, and (2) the openness of the 1945 fire site where many of the small trees with less than 25% of the crown remaining recovered substantially. These trees were predicted to die because they had less than 60% of the crown intact.

E. Recovery of Pine Related to Density

Figure 7 shows the percentage of change in foliar classification for the living immature and mature trees in nine stands as related to stand density. Trees in the least dense stands show the best recovery. Among immature trees less than 4 in. dbh, 100% improvement of all trees occurred until the stand density

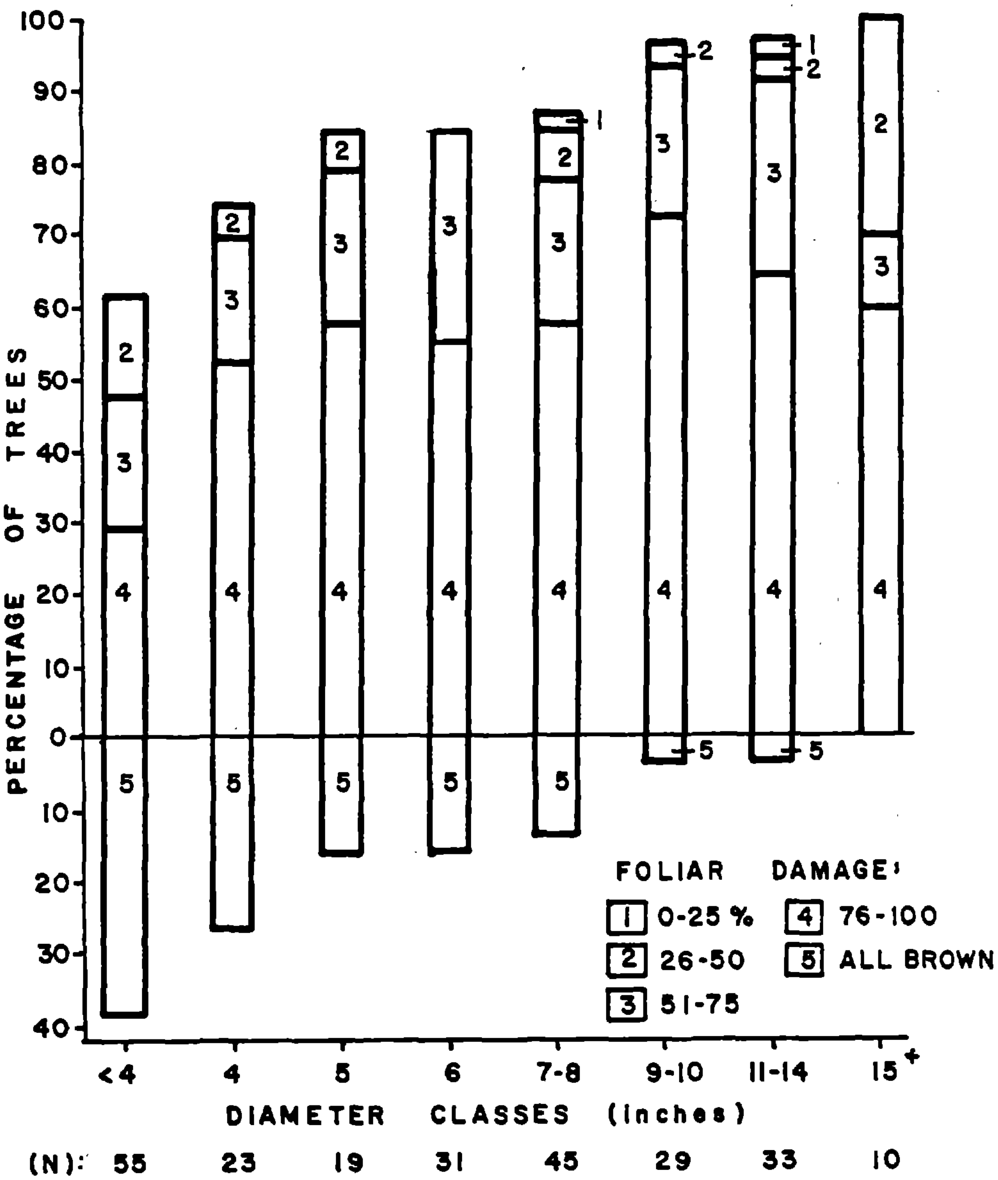

Fig. 4. Changes in postfire condition after two growing seasons of all 1977 trees of class 4 foliar damage according to diameter.

exceeded 93 trees per acre. At 133 trees per acre, very little improvement occurred. The effect of increased density over 133 trees per acre, is more dramatically demonstrated for the curve in the decline of foliar classification. As the stand density increases, a greater percentage of the trees deteriorated, which is expected to continue to mortality. Examination of mature trees over 4 in. dbh showed a progressive negative influence on recovery as the density increased from 16 to 133 trees per acre. The upswing of the curve for improvement in stand 9 (with the maximum number of living trees) may be related to the fact that this stand was lightly burned in 1976. In 1977, fuel loads were only 1.3 ton per acre so La Mesa fire did not cause serious damage and recovery was favorable.

Examination of plots with known fire history showed no strong relationship between either recovery or decrease in foliar classification and the interval between the last fire and La Mesa fire, or to the fuel loadings. However, the trees in the least dense plots that had previously had low fuel loads (mostly flash fuels) showed the highest percentage of improvement.

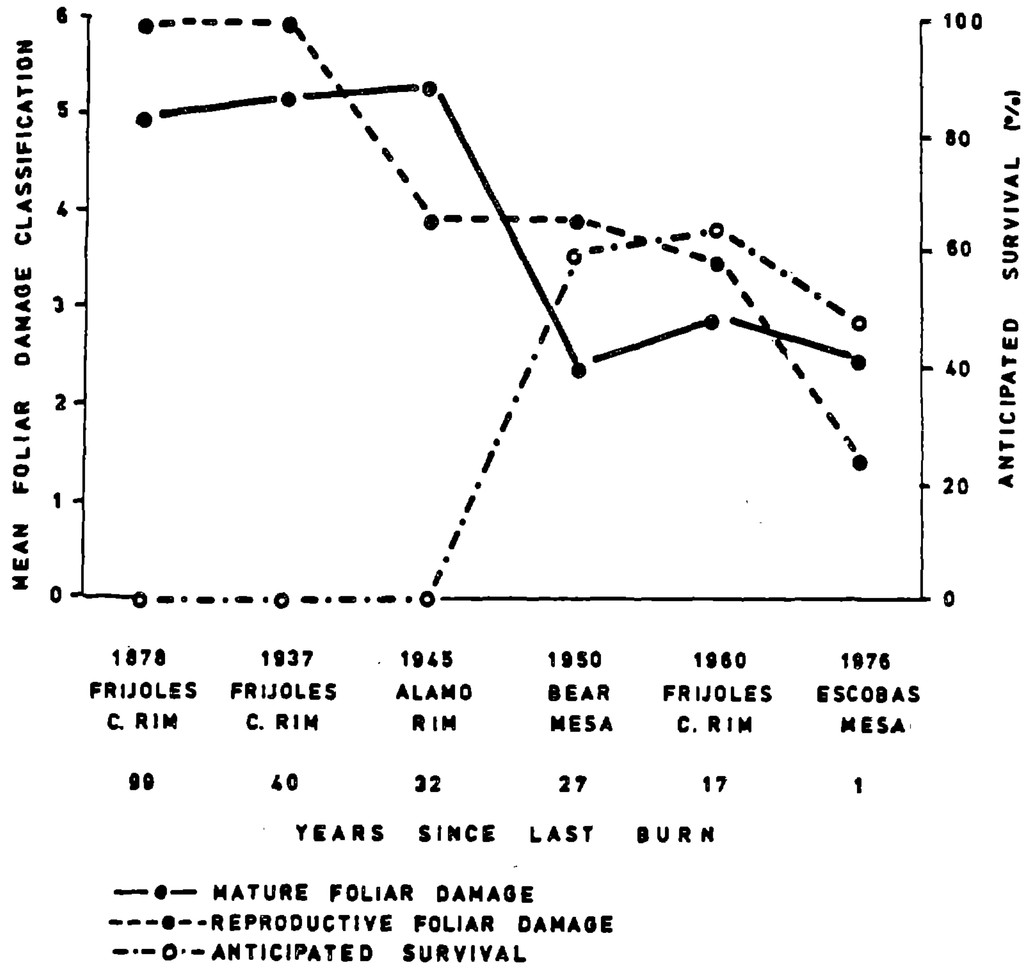

Fig. 5. Foliar damage and anticipated survival after La Mesa fire.

F. Shrub Sprouting

The results of analyzing the sprouting of shrubs two seasons after La Mesa fire are summarized in Table I. These data were obtained by counting the number of clumps and sprouts in 20 plots of 0.01 acre distributed across the area of each stand. The maximum number of clumps and sprouts occurred in the Frijoles Rim stand, which had been burned in 1960 (17 years earlier, which was the mean fire interval before fire control). This stand was relatively open and damage from La Mesa fire was slight (most trees were in foliar classes 1-3). During the 17 years since the last fire, the shrubs had become well established and La Mesa fire was not severe enough to cause deep soil penetration of the heat and concomitant root kill. In contrast, all of the trees in the severely burned Frijoles Rim stands, burned in 1937 and 1878, were in foliar classes 5 and 6, root burn-outs were much deeper, the soils were hotter, and there was greater kill of shrub roots. Excavation of some roots indicated that only the lower sides of some large roots, from which sprouts were developing, remained viable. The Burnt Mesa dense stand revealed similar severe damage: all trees were in foliar classes 5 and 6 after the fire. However, in contrast to the severely burned Frijoles Rim stands, most of the new sprouts were clumped around charred bases of trees that had been completely burned, and it was suggested that the uneven topography and perhaps heavier soil permitted less heat penetration and root kill. The minimum number of clumps and sprouts occurred in the very open and meadow-like Burnt Mesa stand. Also, a good cover of native grass recovered quickly after the fire.

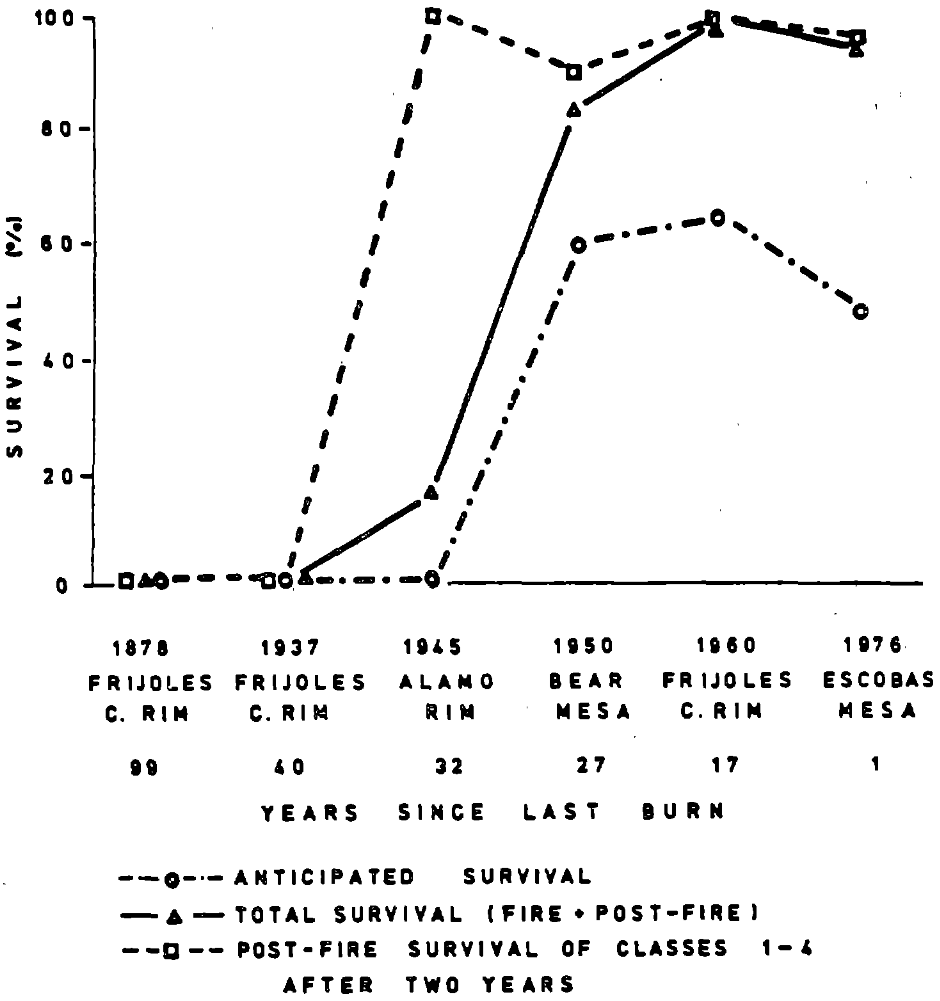

Fig. 6. Anticipated survival of postfire living trees and actual survival of all living trees and those in classes 1-4 after two growing seasons.

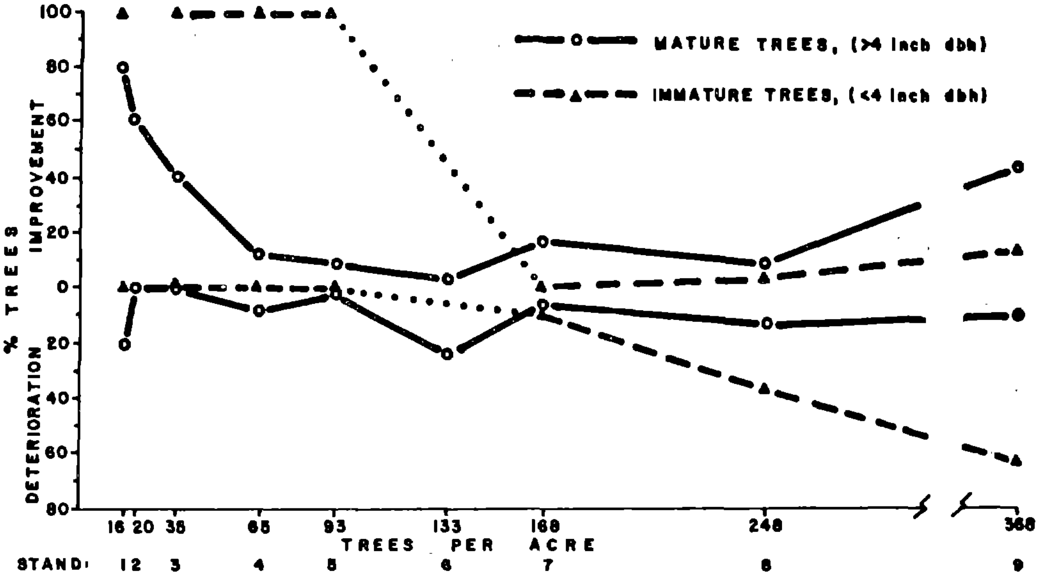

Fig. 7. Percentages of change in foliar classification of mature and immature trees living after La Mesa fire as related to density of stand.

TABLE I. Density and Average Height of Shrub Clumps and Individual Sprouts Per Acre

Stand	Species	Clumps/ Acre	Sprouts/ Acre	Av Height (cm)
Frijoles Rim 1960 burn (moderate)	*Ceanothus fendleri*	340	1790	42
	Quercus gambellii	180	2250	91
	Quercus undulata	50	645	59
	Robinia neomexicana	1535	2350	71
	Rosa sp.	35	60	25
		2140	7095	
Frijoles Rim 1878 burn (severe)	*Cercocarpus montanus*	70	75	38
	Quercus gambellii	395	1840	77
	Robinia neomexicana	30	45	101
		495	1960	
Frijoles Rim 1937 burn (severe)	*Ceanothus fendleri*	15	20	52
	Cercocarpus montanus	20	130	62
	Fallugia paradoxa	220	900	39
	Quercus undulata	40	505	75
		295	1555	
Burnt Mesa dense stand (severe)	*Ceanothus fendleri*	45	85	48
	Cercocarpus montanus	5	20	83
	Quercus gambellii	1355	5405	83
	Quercus undulata	15	55	90
	Rosa sp.	10	75	55
		1430	5640	
Escobas Mesa 1976 burn (light)	*Fallugia paradoxa*	10	20	26
	Robinia neomexicana	240	295	38
	Rosa sp.	50	50	25
		300	365	
Burnt Mesa open meadow (light)	*Quercus gambellii*	5	70	110
		5	70	

The species *Quercus gambellii, Robinia neomexicana* and *Ceanothus fendleri* are the dominating shrub covers.

G. Growth of Grasses

Because of the severity and extent of La Mesa fire, there was a need to prevent severe erosion of the highly erodable volcanic soil to reduce flash flooding and to protect valuable archeological resources. The area was reseeded by helicopter with a mixture of six grass species including sand dropseed (*Sporobolus* *cryptandrus*), spike muhly (*Muhlenbergia wrightii*), western wheatgrass (*Agropyron smithii*), slender wheatgrass (*Agropyron trachycaulum*), sheep fescue (*Festuca ovina*), and blue grama (*Bouteloua gracilis*). The seed was applied at rate of 9.63 lbs/acre (8.7 lbs/acre of which was pure grass seed). This application averaged 50-60 seeds per square foot (538-646 seeds per square meter). The species were selected for (1) natural occurrence, (2) soil-holding properties, (3) availability of seed, (4) ease of seeding, and (5) the desire of the National Park Service not to introduce exotics. Because most of the acreage was severely burned, all of the burned area was seeded except a control plot of 180 acres on Department of Energy land. Immediate postfire seeding was delayed by heavy rains; however, the total seeding of the area was completed by July 17, 1977, approximately one month after the fire.

Two types of plots were examined in this study (Potter and Foxx 1979b). Before La Mesa fire, areas of known fire history had been selected and phytosociologically sampled with a modified Lindsay line-strip sampling unit 1000 by 20 feet, divided into 50-foot units, each with a quadrat 1.0 by 0.5 m for seedling and herbaceous cover. After the fire, we re-examined the plots. In addition, we laid out plots 20 by 50 m, each of which included 50 shrub plots 1 by 2 m, and 100 herbaceous plots 5 by 5 dm, in areas of severe, moderate, and light burn damage (Foxx and Potter 1978).

Relative foliage cover of species was determined in herbaceous plots and, in selected areas, density was determined by counting individual seedlings. Biomass studies were based on 10 quadrats 1 by 1 m within each study plot. Plants were clipped within 1 in. of the soil level, oven-dried, and weighed.

Of the six grasses, slender wheatgrass and sheep fescue germinated the best. Slender wheatgrass is a short-lived perennial bunchgrass, which is high in seed production and yields well up to 5 years, then declines (Flory and Marshall 1942). It has a deep, wide-spreading, fibrous root system occupying all levels down to 40 cm. Recent studies at Bandelier (Potter, Foxx, and Barnes 1981) showed it to have excellent drought resistance and to have an extended growth period during the season.

Sheep fescue is a fine-leaved and densely tufted perennial. It has a dense root system principally in the top 10 cm of soil. It is a cool-season grass, developing on winter moisture supply and completing its growth early in the season and during the early summer drought, which is a critical growth period for pine seedlings. Thus, the timing and shallow roots of sheep fescue make it highly competitive with pine seedlings.

The other four species of grass showed negligible germination. The success of germination of the seeded grasses was inversely related to the amount of native grass, which recovered rapidly and provided good ground cover in lightly burned areas. Figure 8 shows the relationship between the success of germination of two species of seeded grasses and the amount of native grass cover, which already had a good root mass and was well established. Where the native grasses were not destroyed and recovered rapidly after the fire, the seeded species did not germinate or become well established. Where the plots were virtually covered with native grasses, only in the severely burned pockets did the seeded grasses germinate. Such local sites include areas around pine trees or dead trunks, formerly devoid of grasses because of the litter of pine needles. The grasses seeded into the ash following the fire show excellent germination and growth.

The best stands of seeded grass occurred in areas with the longest recent fire interval, with the densest tree stand, and with greatest severity of damage as measured by foliar classification. The recovery of native grasses showed the opposite relationship. Therefore, the two groups of grasses complemented each other in providing erosion protection.

McConnell and Smith (1971) observed that litter on bare soil improved the production of hard fescue, but removal of all litter did not enhance production. At Bandelier, two adjacent plots provided excellent contrast of the effect on grass seed germination of pine needlefall. The first area, with 190 trees per acre, had been selectively logged 60 years previously and most trees had more than 50% of the crown singed, which resulted in considerable needlefall. The adjacent plot, with 918 trees per acre, had not been logged, and all trees were killed and most needles were completely consumed. Measurements on September 27, 1977, showed that the success of seeding, based on the number of grass seedlings per average rate of seeding, was 52% in the area with needlefall and only 8% in the area with no needlefall.

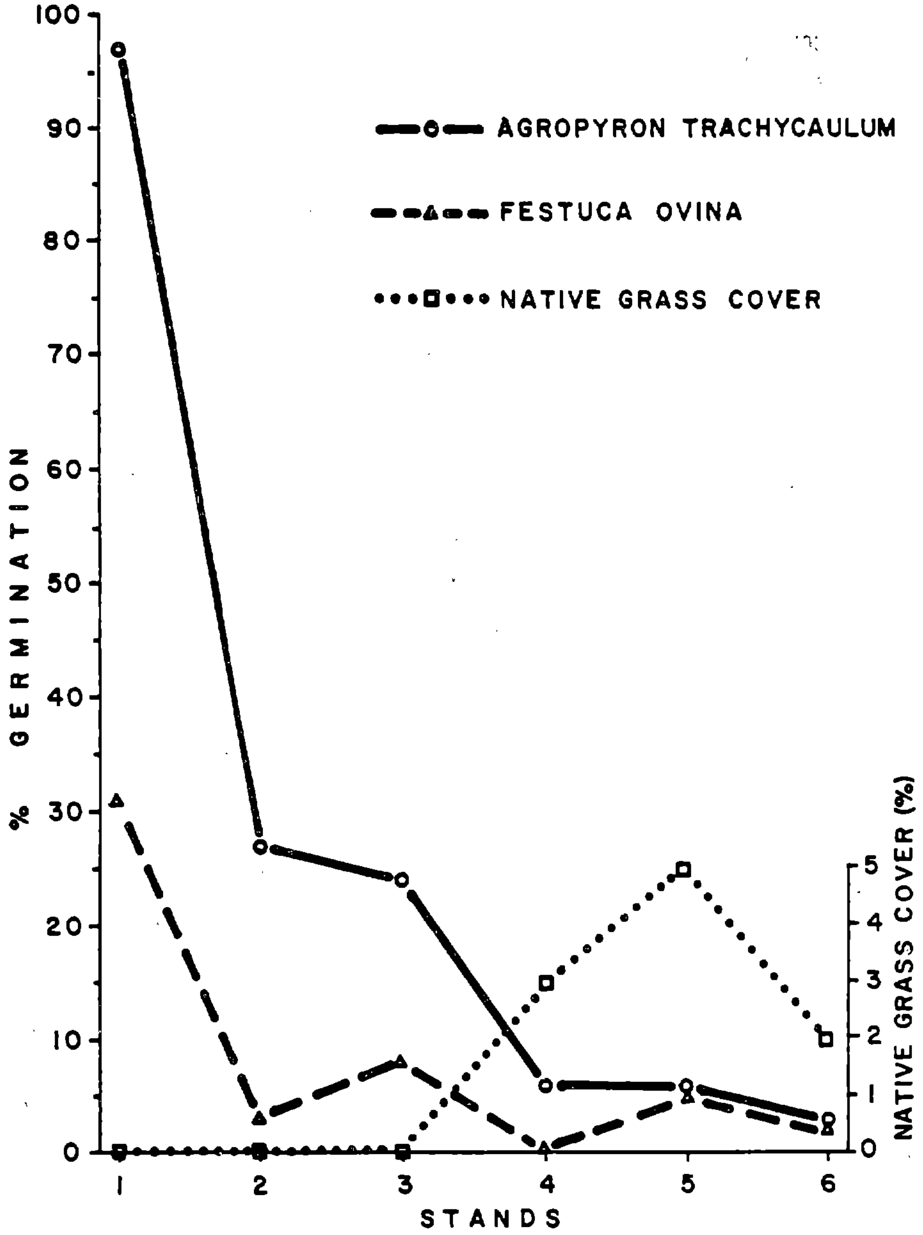

Fig. 8. Comparison of percentage germination of slender wheatgrass *(Agropyron trachycaulum)* and sheep fescue *(Festuca ovina)* with cover of native grass species.

In June 1978 (1 year after La Mesa fire), these plots were re-examined and seedlings were separated by species. In an area where the needle mulch had held the soil, prevented erosion, and retained moisture and seeds, 97% of the slender wheatgrass germinated. Where there was no needle mulch and the soil was not protected from erosion and seed loss, germination was only 24% for slender wheatgrass. The same relative trend in germination rate was observed for sheep fescue.

In a comparison of different plots, several factors were considered to be principal causes of the relative success of slender wheatgrass. The best correlation was between the seedling establishment and the percentage of trees in foliar damage class 5 (all needles brown, which would result in the maximum amount of needlefall).

In contrast to the differences in germination percentages and the resulting densities of grass plants in the comparative plots, the biomass data are surprisingly very similar. Table II shows that in the Bandelier logged and unlogged plots, the biomass weights of native grasses and *Carex* spp., reseeded grasses and introduced grasses are essentially identical in the two plots after two seasons. Even though there were 6.5 times more seedlings in the needle mulch area, the fewer seedlings in the unmulched area had grown more robust so that total biomasses were equal. This is an ecological tribute to the similar use of available nutrients and water by dissimilar densities of the same species. Interestingly, the balance was reached in approximately two seasons of growth. The coverage was 13% in the mulched area vs 9% in the unmulched area.

Within a burned area of the National Environmental Research Park of Los Alamos National Laboratory, an area of 180 acres was not reseeded. Comparative plots seeded and unseeded within the ponderosa pine zone were established. Plots in the seeded area had 7% total foliage cover. Grass composed 57% of the total foliage cover; 42% of the foliage cover was slender wheatgrass. The unseeded plots had an average of 6% total cover. Less than 1% of the cover was grass and more than 99% was forbs. *Chenopodium* species made up 79% of the total foliage cover. Biomass in the seeded area amounted to 850 g/m^2, and in the unseeded area, 810 g/m^2. Grass represented 31% of the total biomass on the seeded side, whereas it represented only 6% on the unseeded side. Forbs made up 94% of the total biomass on the unseeded side and only 69% on the seeded plots. Seeded grasses made up 69% of the total biomass on the seeded plots and 0% on the unseeded side.

When the total biomass of contrasting areas recovering from La Mesa fire (seeded vs unseeded and needlefall vs no needlefall) are compared with an area in which native grass recovery was good (burned in 1960), the total biomass was about 2.5 times that of the predominantly native grass cover of an open pine stand (Table II).

H. Recovery of Pine Related to Grass Competition

A factor that seems to affect recovery of ponderosa pine in stand 6 is the herbaceous cover of seeded grasses. The highest cover of seeded grass occurs at the lowest point of improvement in foliar

TABLE II. Comparison of Biomass of Native Grass, Seeded Grass, Exotic Grass, and Forbs in Five Stands (Based on 10 Subplots Each)

	Grasses												
	Native Grass		Reseeded Grass		Exotic Grass		Total			Forbs			Total Biomass
	g/m^2	(%)	g/m^2	(%)	g/m^2	(%)	g/m^2	S.D.	Biomass (%)	g/m^2	S.D.	Biomass (%)	g/m^2
Los Alamos													
Seeded	4.0	15	18.5	69	4.2	16	26.7	±2.4	31	58.4	±6.6	69	85.1
Unseeded	0	0	0	0	4.6	100	4.6	±1.0	6	76.4	±13.0	94	81.0
Bandelier													
Logged, needle mulch	0.2	<1	79.3	100	0	0	79.5	±5.4	100	0.3	±0.9	<1	79.8
Unlogged, no needle mulch	0.1[a]	<1	76.2	100	0	0	76.3	±6.1	100	0	±0	0	76.3
1960 burn	24.4	100	0	0	0	0	24.4	±0.7	84	4.6	±0.4	16	29.0

[a] *Carex* sp.

classification. We believe that the rapidly growing seeded grass competes with the trees for moisture and nutrients and is a factor in the poor improvement of this stand. In other stands with as great or greater herbaceous cover, mostly native grass, tree improvement does not seem to be inhibited.

I. Recovery Related to Other Factors

Another factor that affected the health and vigor of the surviving tree population was the beetle infestation, which developed rapidly after the fire. We attempted to determine the influence of insects on the tree population in two ways. The first was to determine the relative number of beetles, either by noting entrance holes or seeing the insects. The second was to note the amount of pitch produced by a tree. There was a negative ralationship between the vigor as expressed by the color of the foliage of the tree and the insect invasion. There was a positive relationship between the exuding of pitch and the infestation of insects. We found that, after the fire, 12% of the 354 trees considered viable had evidence of insect infestation. Over 40% of the viable trees exuded pitch as a negative or positive response to damage by insects or the fire.

We found no relationship between the height of trunk scorching, presence of root burns, or disease conditions such as mistletoe with improvement or lack of improvement in the stands. Neither did we find a relationship between the amount of regrowth within the singed area during the first two growing seasons and factors such as crown damage, density of stand, or insect infestation.

Conditions before and after each fire are quite different, as are the conditions during each fire. In the recovery of a burned pine stand, climatic conditions after the fire are important, especially precipitation and temperature. Drought may cause water stress in already stressed trees and contribute to delayed mortality. The Pajarito Plateau has summer monsoons. Thunderstorms occur almost daily beginning in early July and continue into August. This is not the peak growing season for the pines, but moisture during this period is important—especially to fire-damaged trees. La Mesa fire occurred in late June 1977. Average to above-average precipitation fell during the two months after the fire. During the second growing season, however, there was considerably less precipitation than normal. Temperatures during the winter months were not extreme. If the fire had occurred in late June 1978, greater moisture stress and less recovery would have been expected.

J. Continued Change in Condition

Cursory examination of the trees in several of the stands after the third growing period (September 1979) showed additional mortality. Practically all of the loss was in trees of class 4, which in 1978, after two growing seasons, had remained in that original classification. Of a population of 150 class-4 trees in 1978, distributed in five stands, an average loss of 14% occurred in the third year. The other 86% of this population remained very green and healthy in appearance, which might indicate that the peak of mortality is past.

K. Ponderosa Pine Regeneration

Sims and Mueller-Dombois (1968) showed that root competition occurs between grasses and northern conifer species. Under moderate-to-dry conditions, successful conifer seedling growth was attained only when the tap root passed through the surface mat of grass roots into the soil below, with concomitant expansion of pine seedling lateral and tap roots into the soil. Another study (Larson and Schubert 1969) showed that grass roots produce several "flushes" of new growth during a season, but ponderosa pine seedlings only produce a few additional roots after the initial spring growth period.

A recently completed study (Potter, Foxx, and Barnes 1981) concerned microsite conditions that might favor ponderosa pine seedling establishment. One of the apparent factors was the environment produced by three common species of grass: slender wheatgrass, sheep fescue, and mountain muhly. The first two are seeded in the area. Fescue, with its fine, shallow, fibrous root system and its early growth from winter moisture is the most detrimental to initial establishment of ponderosa pine seedlings. Slender wheatgrass has deep wide-spreading roots, high drought resistance, and grows throughout much of the summer. It would be most competitive with second- and third-year pine seedlings. Mountain muhly, the principal native grass, is intermediate in depth and spread of root system, but its period of growth is in late summer and fall; therefore, it is the least competitive of the three grasses. As Daubenmire (1943) has shown, soil drought is a frequent limiting factor in the lower elevational distribution of pine and grasses, and both are highly competitive for that moisture.

In a population of 1431 seedlings of 1- to 150-cm height examined for microsite characteristics, 18% were current-year seedlings. Frequency of seedlings according to soil texture was 89% in soil finer than sand and 9% in sand. About 48% of the seedlings were in litter ≤1 cm deep, and 25% were in litter 1.5 to 2 cm deep. About 95% of the pine seedlings were associated with conifer litter.

The relationship of seedlings to living ground cover is illustrated in Fig. 9. The 30% that was in the highest category of ground cover was due almost entirely to seedlings within a cover of mountain muhly and bearberry (*Arctostaphylos uva-ursi*). Species of ground cover having the highest association with pine seedlings were mountain muhly, 14%; bearberry, 11%; sedges, 8%; and squirreltail bottlebrush (*Sitanion hystrix*), 8%. Regardless of the ground-cover vegetation at the time of seedling establishment, within a few years, 57% of the seedlings are associated with grass species.

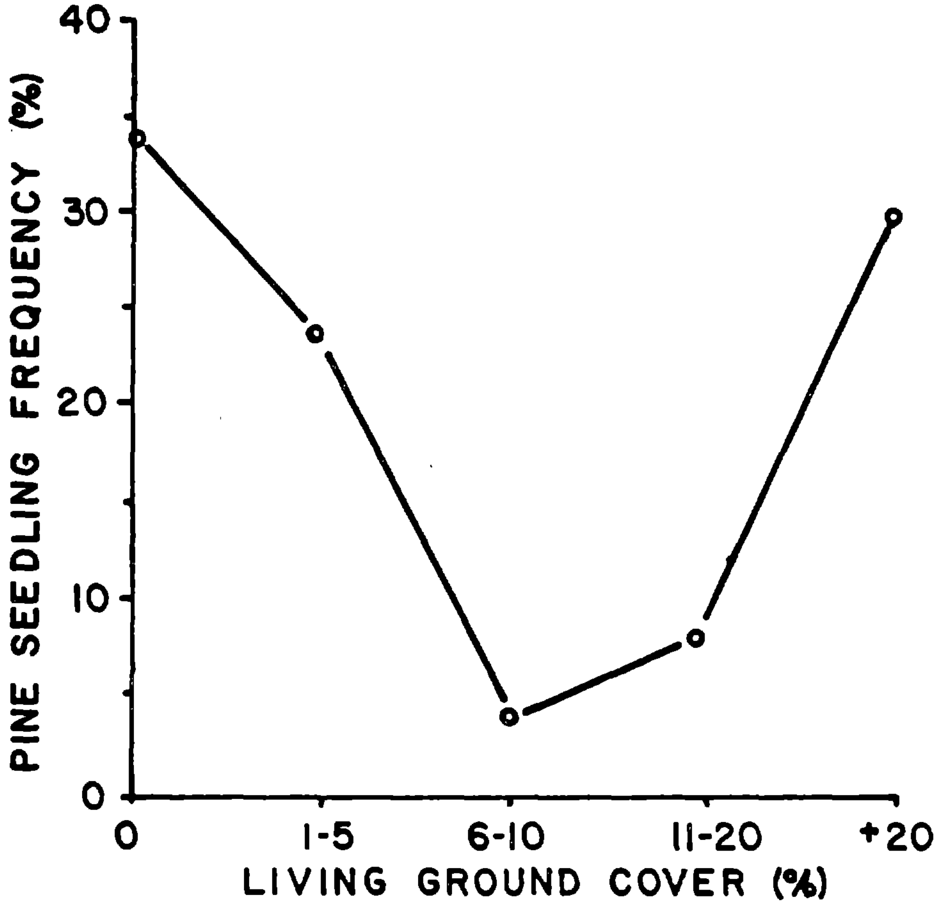

Fig. 9. Frequency of pine seedlings in relation to percentage classes of living ground cover.

Concerning canopy and shade, 58% of the pine seedlings had no canopy vertically above them. The potential shade was measured by canopy interception of an arc from the horizon east to west and a 60° angle at the south. Only 8% of the seedlings occurred in 80-100% potential shade. An interesting relationship between potential shade and ground cover is illustrated in Fig. 10. To compile the contingency table used as a basis for the plotting, the intermediate shade classes were combined. It appears that with no ground cover, some shade is needed. As the ground cover increases, it seems to replace the need for shade from the tree canopy, although few seedlings are found under the maximum ground cover and maximum shade. Some litter around seedlings or minimal competitive ground cover seems to be desirable.

Measures of relationships between seedlings and a protective object (log, rock, or tree trunk) revealed that 71% of the seedlings were in the open and 24% were near a log. In a replanting program, the use of fallen logs as protection is suggested both for soil moisture relations and as protection from trampling.

No significant relationships were obtained from a variety of other factors, such as direction from protective object, distance to nearest neighbor seedling or to nearest tree trunk, direction or degree of slope, or relation to local natural depressions.

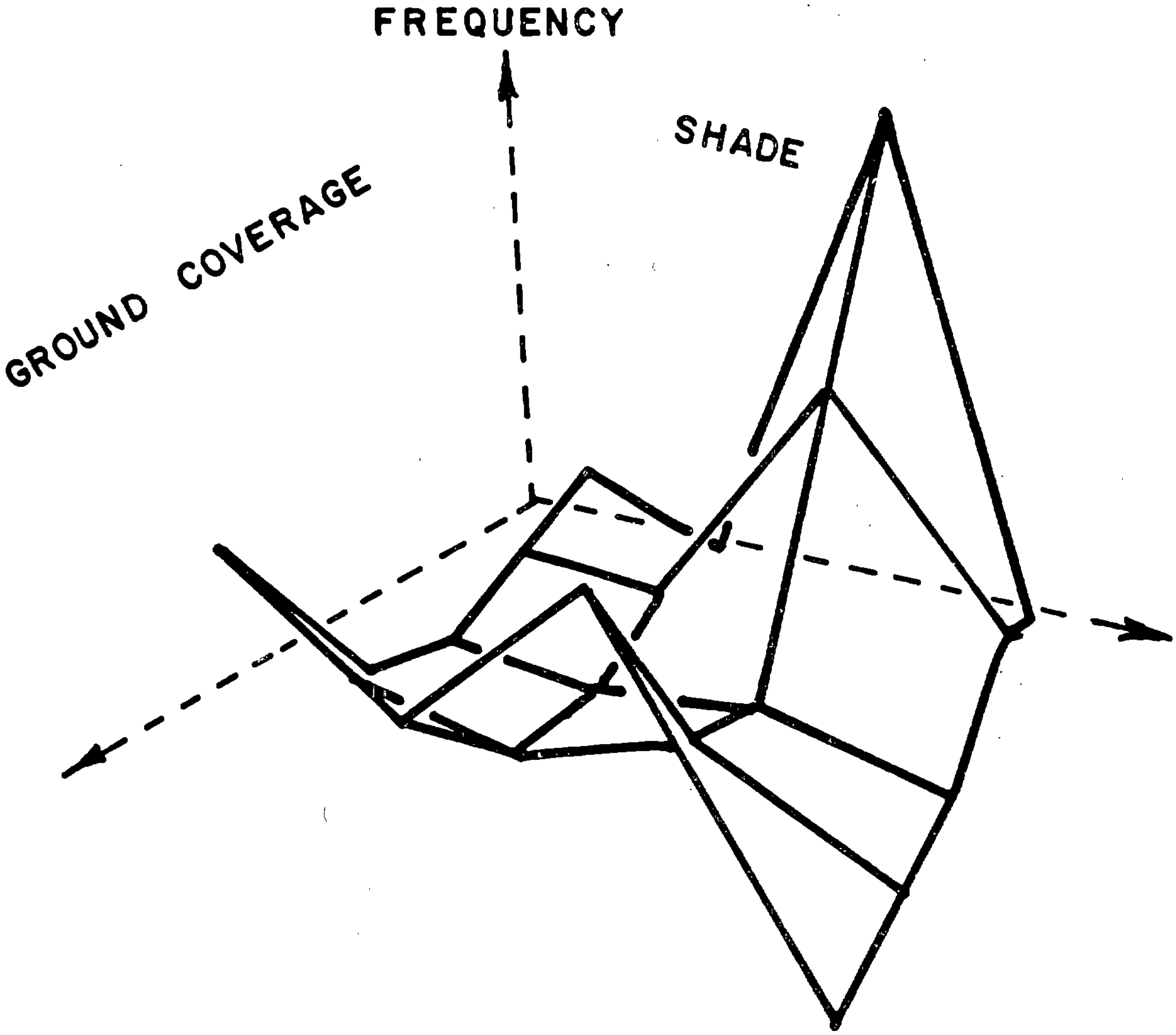

Fig. 10. Relationship between potential shade, ground cover, and ponderosa pine seedling frequency.

The confirmation of the observation that pine seedlings were often clustered within mats of bearberry seemed unusual because Fisher (1980) reported that several species of *Arctostaphylos* produce allelopathic substances that inhibit pine growth. Possible benefits of the shrub may be to provide a trap for seed, to hide seedlings from rodents and birds, to trap and hold snow, to protect the soil from evaporation, to provide seed for young seedlings, and to be less competitive for moisture in the surface soil layers. Other shrubs have been reported to serve as "nurse plants," for example, *Ceanothus* spp. (Wahlenberg 1930, Cronemiller 1959) and *Purshia* sp. (Youngberg 1966), because of their nitrogen-fixing properties.

Indicative of the influence of climatic factors was the observation of a flush of pine seedling following a week of steady rain in early August 1980. In contrast to spring germination, a very low percentage of this late crop of seedlings can be expected to survive.

IV. SUMMARY

The recovery of ponderosa pine after a fire is complex and depends on a variety of factors during and after the fire. Of the 14 361 acres burned in La Mesa fire, the area of stands in categories 5 and 6, within which few or no seed trees were found, amounts to 5209 acres or 36% of the total. Except for about 211 acres of unburned patches, the rest of the area consists of trees with foliar damage classifications of 1-4 (1% to 99% foliage singed).

After the fire, 897 trees, 393 of which were in categories 1-4, were tagged and their foliar classifications were recorded. Observations after one, two, and three growing seasons provided the information for improvement or deterioration. Category-1 trees had 1-25% foliar singeing; category 2, 26-50%; category 3, 51-75%; and category 4, 76-99%. Category-5 trees had all needles singed, and category-6 trees were all consumed.

In the various categories, the following percentages of trees improved or remained the same: category 1, 91%; category 2, 83%; category 3, 74%; and category 4, 83%. Approximately 6% of category-5 trees improved, mostly sapling trees in open stands. All trees in categories 3 and 4 had less than 50% green foliage after the burn and, according to previous reports, most or all of these trees would be expected to die; however, after two growing seasons, 80% were still alive. Perhaps the slightly-above-average rainfall after the fire and the deep snowfall of 1978-79 resulted in excellent recovery. Among the category-4 trees, the larger trees showed greater recovery percentages. In general, the severity of foliar damage decreased with decreasing time since the last burn, and was negligible in areas burned 27 years earlier (the mean fire interval for the area before fire control is 17 years). The actual recovery percentage was much greater than that anticipated based on previously published data for ponderosa pine.

Recovery of immature trees damaged by the fire was little affected by density of trees in the stand until the density reached about 100 trees per acre. There was a rapid decline in the percentage of recovery of mature trees as the density increased from 16 to about 100 trees per acre.

Although there was a positive relationship between severity of foliar damage and length of time since the previous burn, the relationship was negative between recovery of surviving trees and the last fire interval. However, the trees in the plots that were least dense, which previously had low fuel loads (mostly flash fuels), showed the maximum percentage improvement.

The largest number (7095 per acre) of shrub sprouts occurred in the forest stand burned 17 years previously. The severity of burn in stands of longer fire interval apparently caused more root kill, especially in the porous tuff soils. Some oak roots at a 3-in. depth were alive only along the bottom side. A small number of sprouts also occurred in light burns of opens stands that had a dominant ground cover of grass. Sprouts were principally of Gambel oak and New Mexico locust.

Of six species of grasses aerially seeded on the burn, only slender wheatgrass and sheep fescue were very successful. The seeding was done to reduce erosion, to prevent flash floods downstream, and to protect archeological sites. The seeded grasses were generally most successful in the areas of most severe burn damage. However, higher densities of grass occurred in areas that had a needlefall layer from a stand of category-5 trees than on the completely bare soil under class-6 trees. After two growing seasons, however, the smaller number of plants (about 1/6) in the areas without needle mulch had increased in size enough that the total biomass production of the two areas was essentially equal. This is a tribute to similar total production from use of available nutrients and water by dissimilar densities of the same species. Comparative plots on seeded and unseeded areas on Los Alamos National Laboratory land showed similar cover and biomass production, even though the former was 57% grass cover and the latter was less than 1% grass cover. *Chenopodium* species made up 79% of the total foliage cover of the unseeded plots. All of the seeded or unseeded burn plots produced more biomass than the native grass cover of open pine stands. The seeded grasses were least successful in the stands of native grass, but in contrast, dense stands occurred around living or killed trees in the area originally occupied by a dense mantle of needles and unoccupied by grass. The inhibition of the needle to grass growth was completely removed by the fire.

The study included an examination of the leaf water potential, morphology of root system, and soil moisture regime of three species of grasses. Slender wheatgrass, seeded in the burn, is a dense, tall, but short-lived bunchgrass, with a deep wide-spreading root system. It is drought resistant and its seasonal growth is of long duration. Sheep fescue is shallow rooted, cool season, and rapid in its growth in the spring. The native mountain muhly is intermediate in its root development and drought resistance, but completes most of its growth later in the growing season. Pine seedlings would be in greatest competition with sheep fescue and then slender wheatgrass. Thus, the success of reseeding to prevent erosion will be a major factor in deterring the natural regeneration of ponderosa pine or the success of replanting unless the grasses are removed.

There was an apparent negative relationship between vigor of trees as expressed by foliage color and the amount of insect invasion, principally bark beetles. There was a positive relationship between pitch exudation and insect infestation. About 12% of postfire living trees were evidently insect infested, 40% were exuding pitch. We found no relationship between the percentage of recovery of ponderosa pine and the height of trunk scorching, presence of root burns, or disease conditions such as mistletoe.

Results of a study on microsite factors related to ponderosa pine regeneration in the area indicated a favorable relationship with stands of mountain muhly and patches of the low-growing, shrubby bearberry. Seedlings occur either in thin-litter and low-percentage ground cover, or principally with the above two species. In bare areas some shading seems advantageous. Under shade of the above species it is not required.

Local sites of successful pine regeneration included the compressed meadow soils of elk hoof prints. The possible erratic germination of ponderosa pine was illustrated by a flush of seedling which suddenly germinated after a week-long drizzle in early August 1980. The successful over-wintering of this population is highly questionable, especially because of the open winter of 1980-1981 and the resulting spring drought.

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WATER RELATIONS OF THE DOMINANT GRASSES ON LA MESA BURN

Fairley J. Barnes

I. INTRODUCTION

La Mesa Fire burned 60 km^2 of Bandelier National Monument and adjoining US Forest Service lands. One month after the fire, the burned areas of Bandelier were seeded with a mixture of native and nonnative grass species. The seeding operation was undertaken in an effort to reduce erosion and subsequent damage to the numerous important archeological ruins in the Monument.

Studies on the recovery of mature ponderosa pines *(Pinus ponderosa)* and on the success of the seeding operation on La Mesa burn suggested that the high density of two of the seeded grasses *(Festuca ovina* and *Agropyron trachycaulum)* may have contributed to the reduced viability of fire-damaged mature trees in areas where the grass density was especially high. In addition, it was hypothesized that the dense grass stands may interfere with the natural regeneration of ponderosa pine in those areas where seed trees survived (Foxx and Potter 1978, Potter and Foxx 1979).

Other studies have demonstrated severe competition between coniferous tree seedlings and established grasses. Pearson (1942) concluded that dense herbaceous vegetation will retard and may prevent the natural regeneration of forest trees. In particular, he noted that ponderosa pine seedlings had greatly reduced shoot and root development when grown in competition with a grass sward of predominantly *Festuca arizonica* (a cool-season grass), but less growth inhibitation when grown with *Muhlenbergia montana, Bouteloua gracilis,* and *Blephaneuron tricholepis,* all warm-season grasses. A later study by Larson and Schubert (1969) quantified the effect on ponderosa seedlings of competition with *F. arizonica* and *M. montana.* They found that net gain in dry weight of seedlings growing with *M. montana* was about 4 times that of pines growing with *F. arizonica.* Seedlings grown without grass competition had dry weight gain up to 11 times that of seedlings competing with grass. Sims and Mueller-Dombois (1968) concluded that root competition with grasses can be a major contributing factor in limiting shoot height of coniferous seedlings, particularly at intermediate levels of soil moisture. When an extremely dense, thick (6-8 cm) grass root sod was present, conifer seedlings had very limited lateral root development near the surface and a reduced ability to penetrate the grass root mass with tap roots.

When attempting to revegetate an impacted area, a knowledge of the competitive interactions between species is essential for making management decisions. With limited resources, competition is intense and coexistence of species in a habitat can only occur when the species have some degree of spatial or temporal niche displacement (Parrish and Bazzaz 1976, Kemp and Williams 1980).

This study was made to determine whether there is significant niche overlap between the grasses on La Mesa burn and ponderosa seedlings. From previous reports (Pearson 1942, Larson and Schubert 1969), it seemed likely that the dominant native grass, *M. montana*, would compete less with ponderosa pine seedlings than would the introduced *F. ovina.* In addition, we can conclude availablity of water is the most important factor in ponderosa seedling establishment in the Southwest (Schubert 1974, Sims and Mueller-Dombois 1968, Pearson 1942). Thus, field observations were made on root structure and seasonal patterns of plant water status and soil moisture in order to investigate the partitioning of the soil water resource among coexisting species. Because too few pine seedlings for study could be found in the severely burned areas, the water relations study was confined to the three dominant grasses, and inferences were made about the possible competition with pine seedlings.

The importance of different soil layers in supplying water to the roots is usually estimated by one of three methods. First, root uptake patterns are often inferred from water content changes in the various parts of the soil profile (Sturges 1977, Cable 1969). Most of these inferred patterns neglect downward drainage and result in an overestimation of the importance of the upper layers of soil (Baver *et al.* 1972). The second method is to measure root biomass in the soil layers and to estimate importance from the percentage of biomass at each depth (Bartos and Sims 1974). Biomass in a particular layer is undoubtedly an indication of which layer is supplying water to the shoots, but it may not predict the importance of different layers under water stress or show the shift in water origin during seasonal changes in water availability at different depths. A third method is to record root initiation and growth rates of new roots as seen in glass-fronted planter boxes, and to infer areas of active nutrient and water withdrawal from such data (Parrish and Bazzaz 1976). It has been suggested that new roots, having a higher absorption rate per unit length than older suberized roots, may not be essential for either water or nutrient uptake. Under some conditions, suberized roots may account for up to 75% of the water uptake because the proportion of old roots to new roots increases with age of the plant (Parrish and Bazzaz 1976, Caldwell 1979). Species also differ in permeability of roots to water and nutrients, as well as in the magnitude of annual root system turnover and the longevity of rootlets and root hairs.

From observation of excavated root systems, or even more quantitative studies of root biomass per unit volume of soil, or total root length per unit volume of soil, it is not possible to accurately assess which soil layer provides a species with its primary source of water. Such assessment is further complicated by the possibility that a plant with both deep and lateral root proliferation might well use different layers under different water stress conditions, perhaps by using new surface roots after a flush of growth stimulated by precipitation, but relying on the much larger biomass of older roots in deeper layers when surface conditions are dry.

In this study, plant water potential is statistically correlated with soil moisture at successive depths. This method may provide accurate determination of the important soil layers for water withdrawal, and it is useful for comparing the underground niche spaces of different species.

II. METHODS

A. Study Areas

Five areas of study were selected in burned areas of ponderosa pine forest in Bandelier (Section 6, T18N R6E), adjacent to plots studied by Foxx and Potter (1978) on Escobas Mesa. Escobas Mesa generally slopes gently eastward, although a variety of slopes and exposures are found on the mesa top because of the numerous gullies and washes that connect with Frijoles Canyon and its branches.

As the 1980 growing season progressed, measurements were performed mainly at two sites (4 and 5) judged to be most similar in species composition, soil type, slope, and aspect. Site 4 was in a lightly burned area where native grass (*M. montana*) survived well, but it also included dense stands of both seeded grasses *(F. ovina* and *A. trachycaulum).* Site 5 was in a moderately burned area near an open meadow and adjacent to a severely burned area. All three grass species were present at site 5.

B. Water Relations Study

Leaf water potential (LWP) of the three grass species *(A. trachycaulum, F. ovina, and M. montana)* was measured between 1200 and 1400 on sunny days (cloud cover less than 10% from 1000 to 1200). The most recently fully emerged leaves were used for measurements. This was difficult to determine on *F. ovina* so, instead, we selected a leaf that was bright green, turgid, and of average or above-average length.

One leaf from each of 5 to 10 clumps of a species was cut with a razor blade and the xylem sap tension was measured using a Scholander type pressure chamber (PMS model 1000) (Scholander *et al.* 1965).

Within one day of the LWP measurements, soil samples were taken at 10-, 20-, 30-, and 40-cm depths from each of two sampling locations at each study site. The soil samples were weighed, dried at 105°C for 24 h, reweighed, and the soil moisture was calculated as a percentage of the dry weight.

In September and October 1980, two specimens of each grass species and one seedling *P. ponderosa* were excavated using a modified monolith method (Bohm 1979). Each specimen was dug as an intact cylindrical soil block 30 cm in diameter and 30 cm in depth. The soil block was carefully wrapped and taken to the laboratory where it was supported on a heavy wire grid. The soil was washed from the roots with a fine water jet. After most soil was removed, the root mass (still attached to the crown and shoot) was floated in many successive water baths, and debris and remaining soil removed by hand. Several specimens of newly germinated ponderosa seedlings were excavated approximately 2 and 6-8 weeks after heavy rains in August had resulted in a crop of seedlings. The cleaned root-shoot systems were spread on a sheet of white paper, photographed, and allowed to air dry.

C. Data Analysis

There is a possibility that significant differences might exist between the responses of LWP to soil water at different depths, as indicated by linear plots of LWP vs soil water. Accordingly, regression analyses were performed on different models of the relationship between LWP and soil water, using a computer package (Nie *et al.* 1975). Linear, semilogarithmic, log-log, and nonlinear models were tested. The model of best fit was

$$Y_i = -B_3 - B_2 e^{-B_1 X_j} ,$$

where Y_i is the LWP of species i, X_j is the percent of soil water at depth j, and B_1, B_2, and B_3 are regression constants. Regression statistics are given and discussed below.

III. RESULTS

A. Seasonal Patterns of Soil Moisture

The seasonal courses of soil moisture (Figs. 1 and 2) show that, in general, site 4 was drier than site 5 (average minimum soil moisture 4.9%, average maximum 11.4% at site 4, compared with 6.0 and 18.1% at site 5). Soil moisture and the 10-cm depth shows a typically fast response to precipitation, whereas the deeper layers are slower to recharge. There is a major difference between the sites in the characteristics of the deeper layers: site 4 shows considerable differences in the soil moisture at 20-, 30-, and 40-cm depths, probably caused by distinct layers in the soil horizon and slow water conductivity between the layers; at site 5, the deeper layers have remarkably similar soil moistures and may indicate a more homogeneous soil profile or greater conductivity between the layers.

B. Seasonal Patterns of LWP

The seasonal changes in LWP (Figs. 3 and 4) show that, for the three grass species studied, the average minimum LWP was lower at site 4 than at site 5 (–52.8 bars vs –32.7 bars) confirming that, in general, site 4 was drier than site 5 (Table I). Species differences in the response to drought can be seen under the more severe conditions at site 4 (Fig. 3). These unique responses can be correlated with the phenology of the species as reported in the literature and as casually noted during the study.

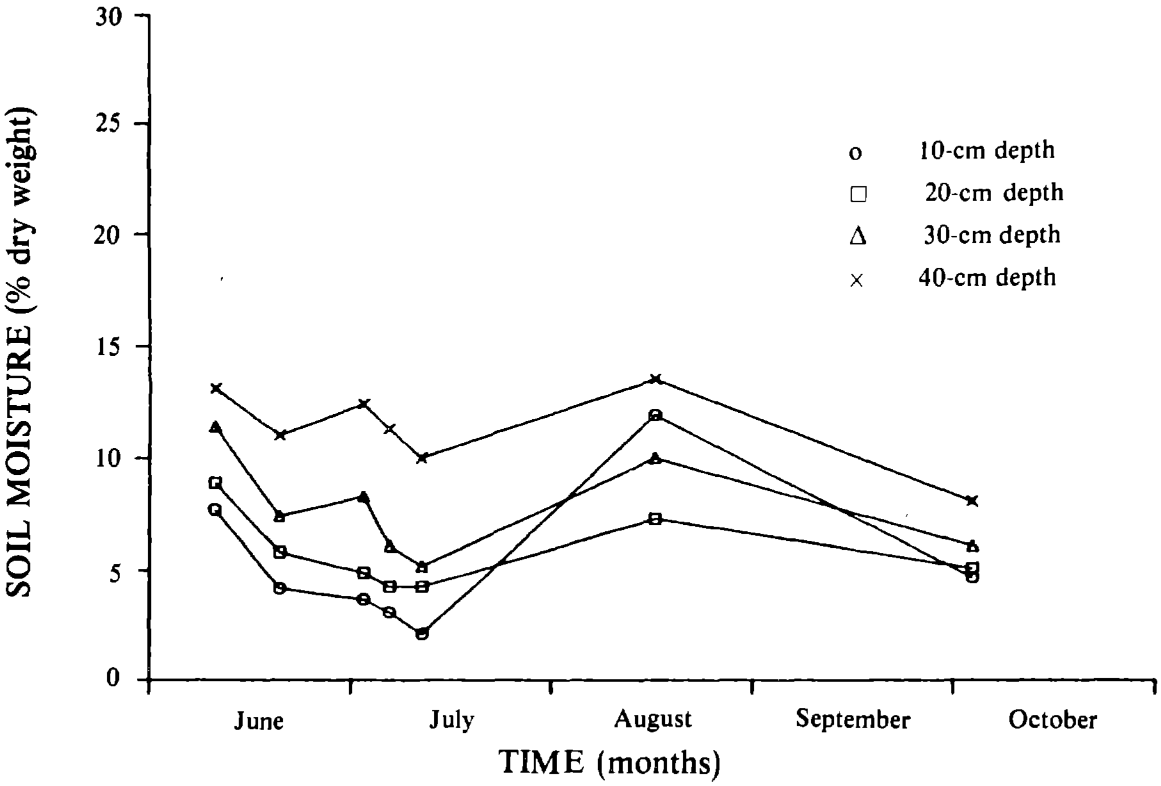

Fig. 1. Seasonal course of soil moisture at site 4.

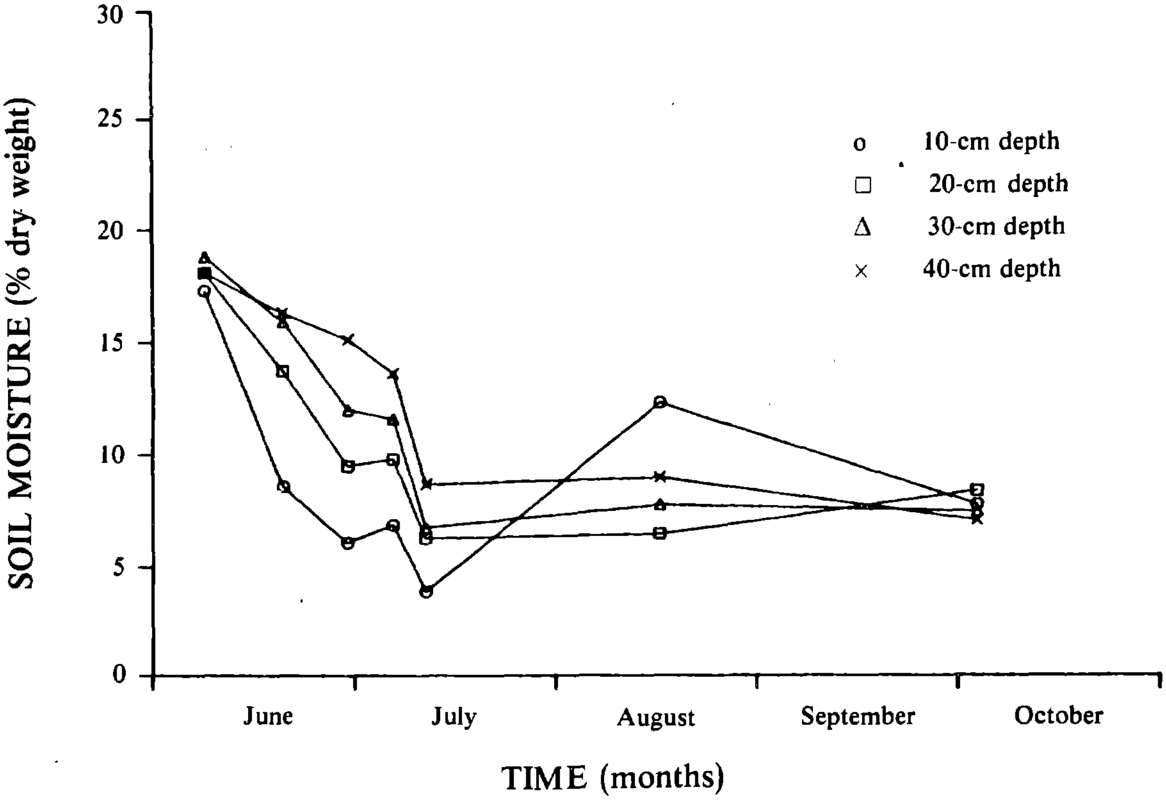

Fig. 2. Seasonal course of soil moisture at site 5.

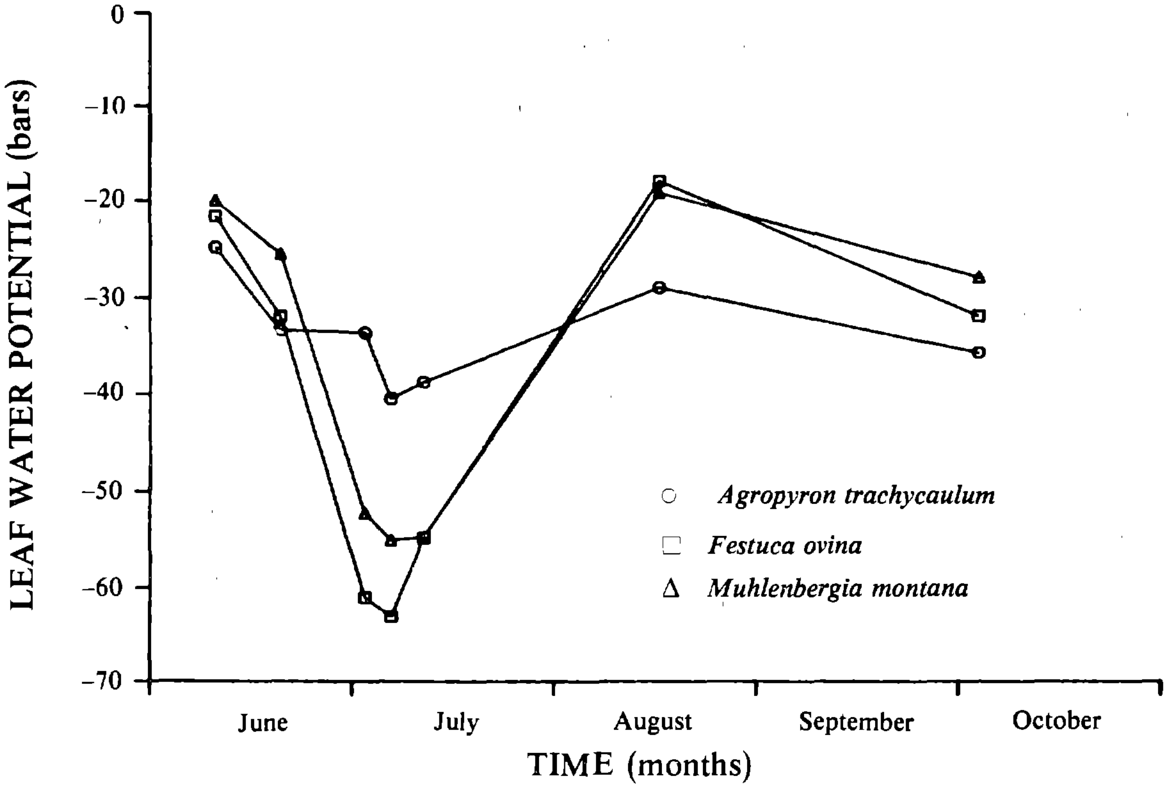

Fig. 3. Seasonal changes in LWP at site 4.

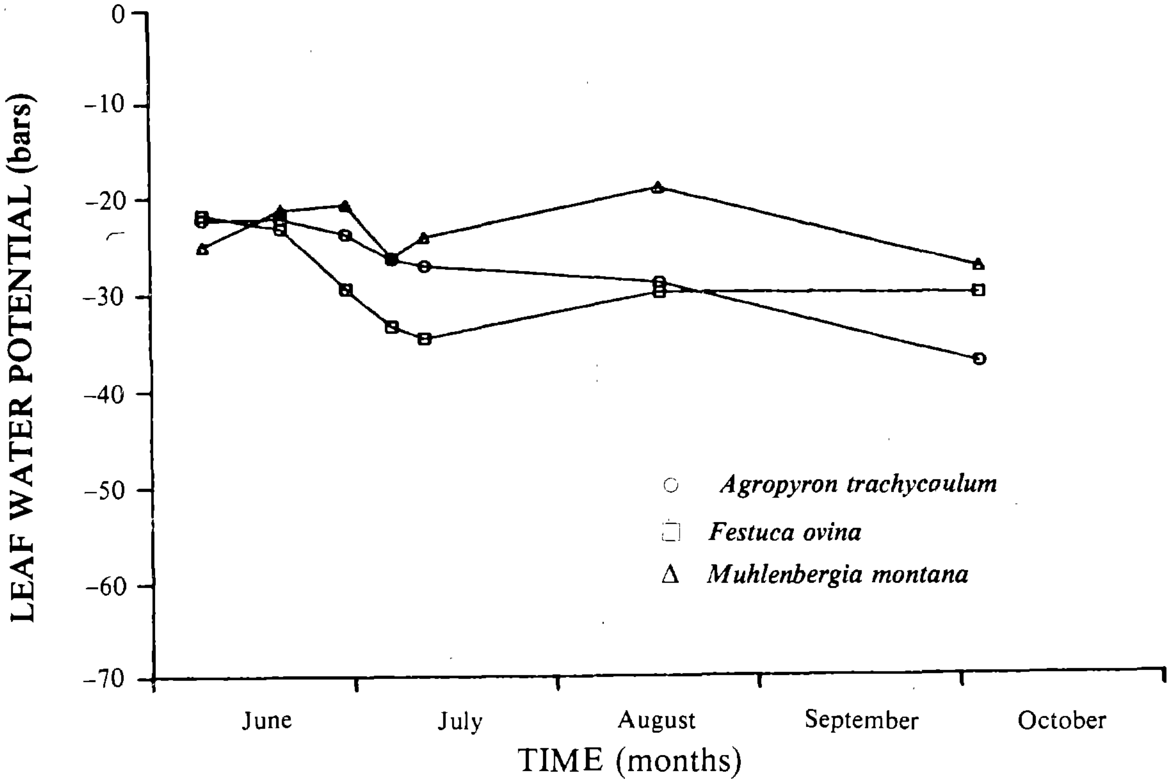

Fig. 4. Seasonal changes in LWP at site 5.

TABLE I. Comparison of LWP at Sites 4 and 5

Species	Site	Maximum Leaf Water Potential (bars)	Minimum Leaf Water Potential (bars)
A. trachycaulum	4	–40.5	–24.8
F. ovina	4	–63.0	–18.0
M. montana	4	–55.0	–19.2
A. trachycaulum	5	–37.2	–22.2
F. ovina	5	–33.4	–21.8
M. montana	5	–27.4	–19.2

F. ovina, a cool-season grass, had its major growth period early in the spring, and had completed flowering and seed set by the onset of the early summer drought. The LWP of this species decreased to very low levels during the drought in June and recovered to high levels with precipitation in August and September. Apparently, *F. ovina* completed its growth and reproduction while the LWP was still high in the early spring. This was followed by a period of dormancy during the summer, then another period of high LWP in the late summer when growth could have resumed, allowing the plant to accumulate carbohydrate reserves for winter survival.

The LWP of *M. montana*, a warm-season grass, followed the same general pattern as that of *F. ovina*, although its phenology is quite different. Field observations indicated that growth was minimal during the spring and summer, with flowering and seed set in late summer and early fall. Thus the species apparently grows slowly during summer drought (when the LWP is very low) and completes growth and flowering after late summer precipitation begins and LWP rises. *A. trachycaulum* had much less variation in LWP under drought stress than either *F. ovina* or *M. montana*. At site 4, this species maintained a LWP between -25 and -40 bars (Table I) during the driest period of the year. It flowered mid- to late summer, but growth seemed to be more or less continuous during the summer months.

C. Rooting Patterns

Specimens of *F. ovina* had an extremely dense mat of roots that covered the entire surface of the soil block and extended to 10-15 cm deep (Fig. 5). The roots were very fine and fibrous. *M. montana* (Fig. 6) had a more diffuse system of both coarse and fine roots that extended to 20 cm, whereas *A. trachycaulum* (Fig. 7) had a dense root system extending to 30 cm and, apparently, deeper. The latter species had an abundance of both fine fibrous roots and coarse roots, but did not have the almost impenetrable surface root mat that was characteristic of *F. ovina* specimens.

Newly germinated *P. ponderosa* seedlings (approximately 2 weeks after germination) had very short root systems that extended only 2-3 cm into the soil. One- to two-month-old seedlings had very sparse root systems from 5 to 15 cm deep with very little branching. The 3-year seedling had several lateral roots in the top 12 cm of soil, with two of these turning downwards about 15 cm from the shoot axis and extending to 25 cm deep (Figs. 8-10).

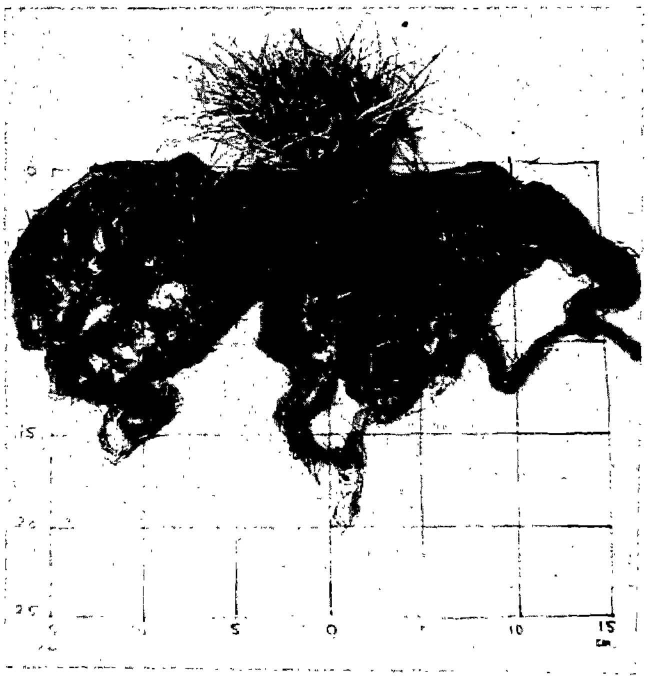

Fig. 5. Root structure of *F. ovina*.

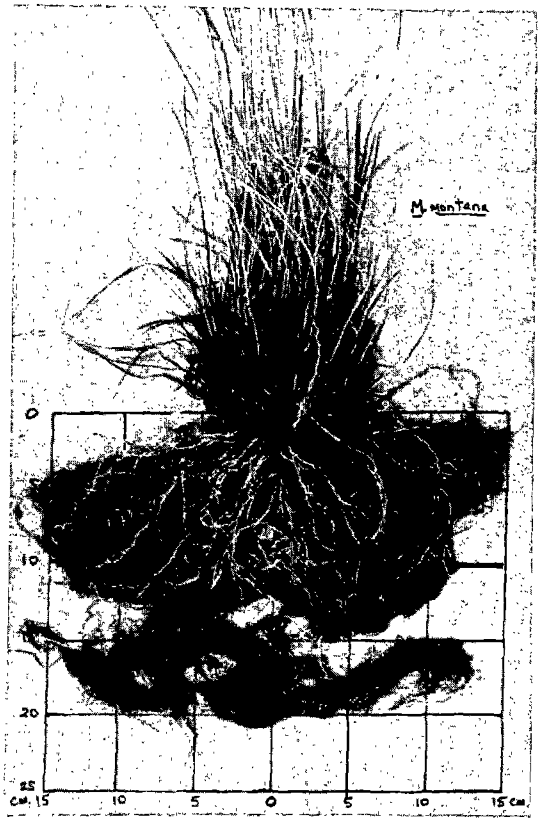

Fig. 6. Root structure of *M. montana*.

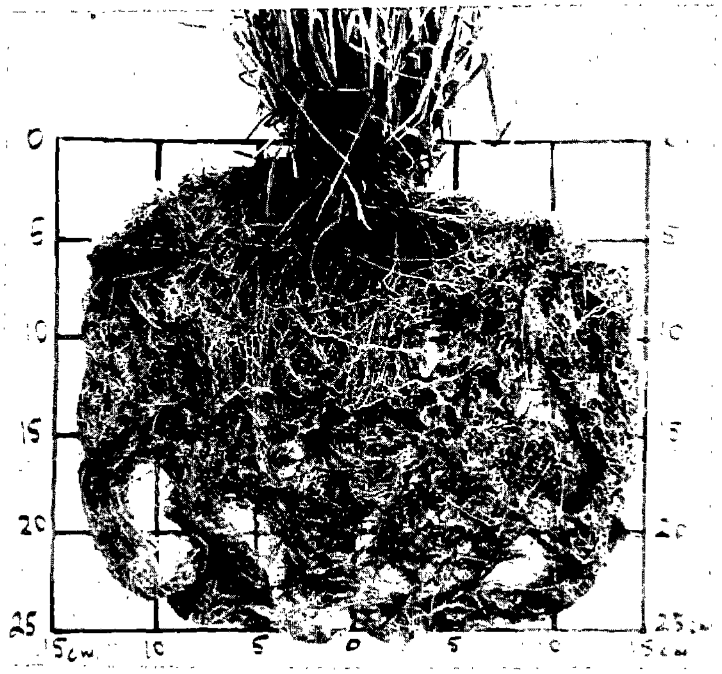

Fig. 7. Root structure of *A. trachycaulum*.

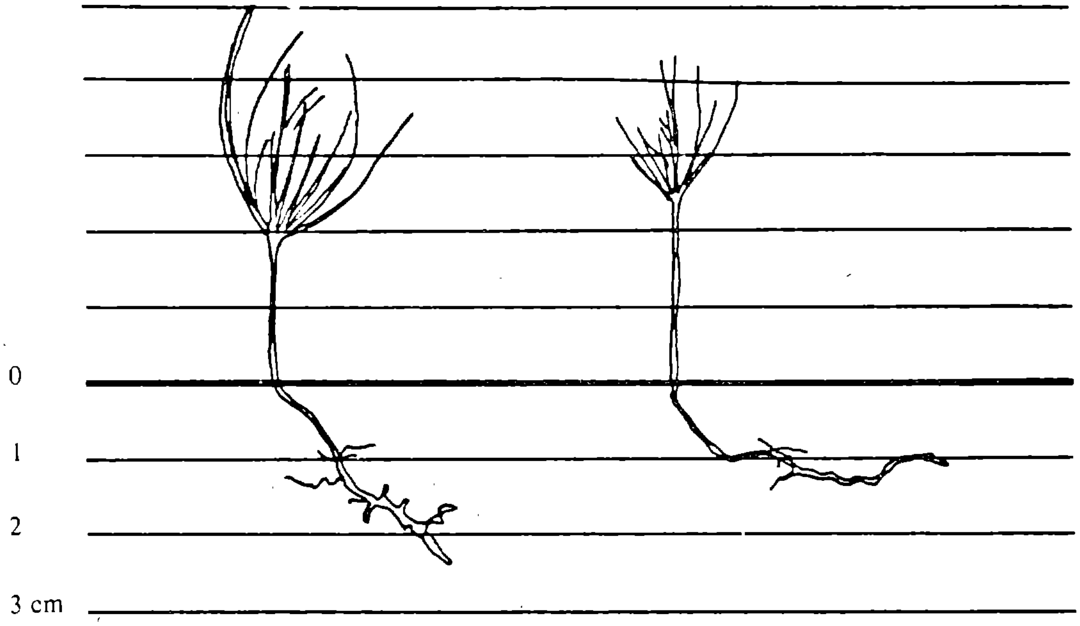

Fig. 8. Root structure of newly germinated *P. ponderosa* seedlings.

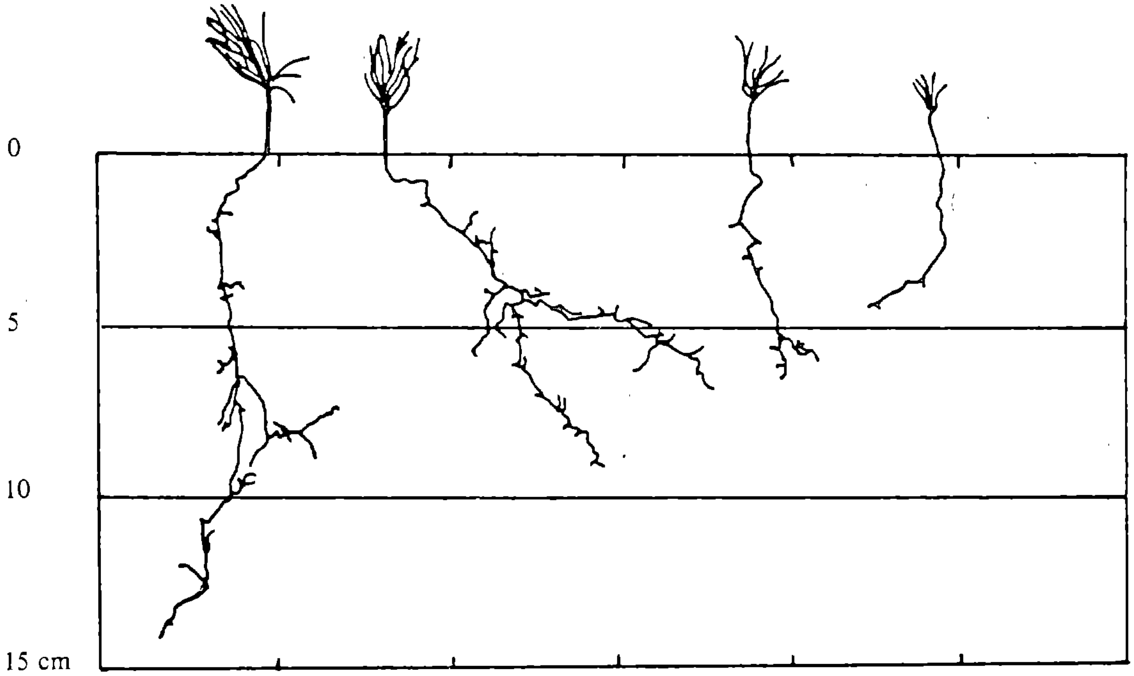

Fig. 9. Root structure of 4- to 8-week-old *P. ponderosa* seedlings.

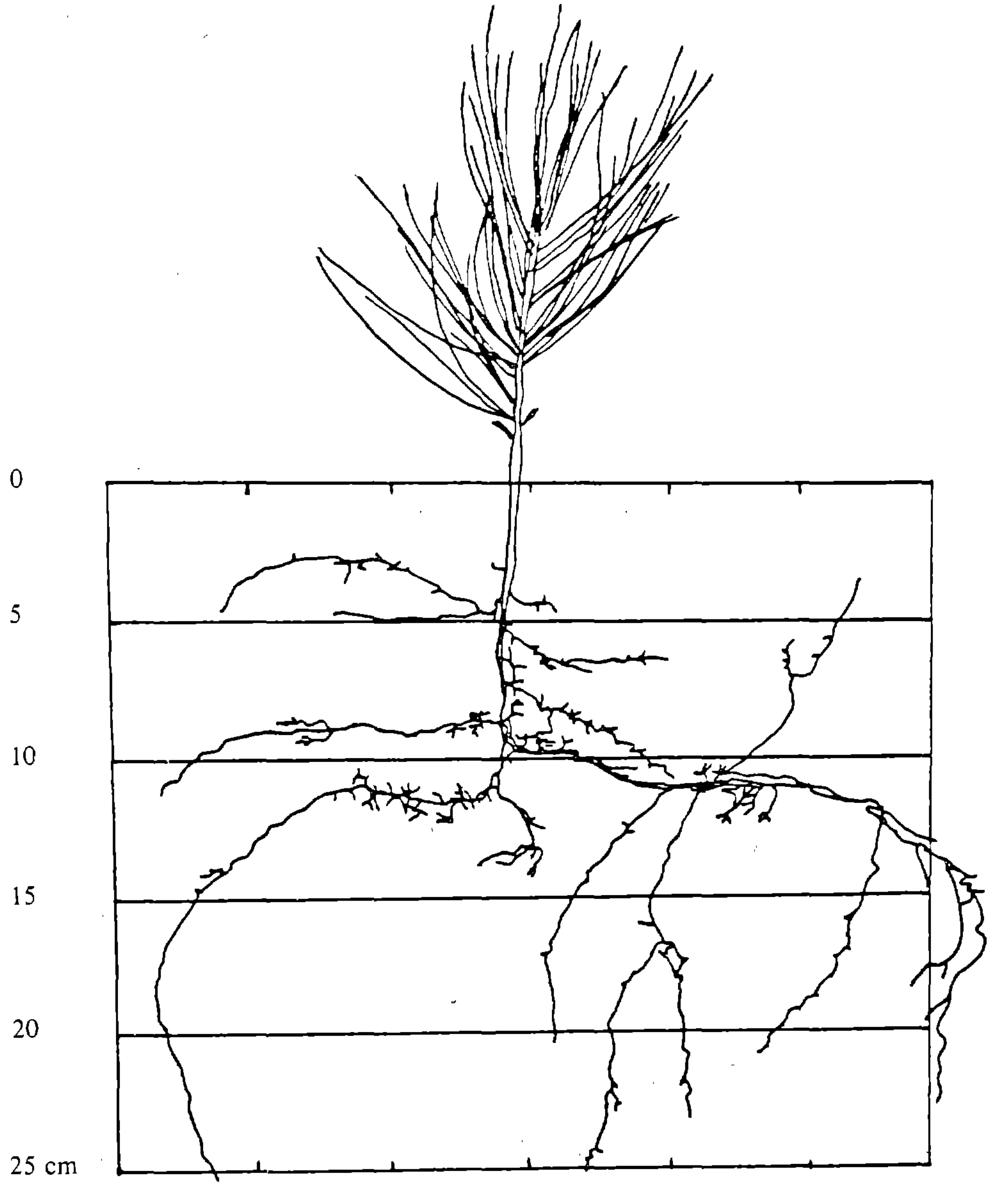

Fig. 10. Root structure of 3-year-old *P. ponderosa* seedling.

D. Prediction of Depth of Soil Water Withdrawal

From inspection of plots of plant osmotic potential vs soil moisture, Redmann (1976) concluded that *Agropyron dasystachyum* draws water primarily from the 0- to 15-cm soil layer. Our data, showing differences in rooting patterns and seasonal changes in LWP, suggest that a statistical analysis might reveal additional trends in the importance of different soil depths. As noted, the model of best fit was

$$Y_i = -B_3 - B_2 e^{-B_1 X_j} ,$$

where Y_i is the LWP of species i, X_j is the per cent soil moisture at depth j, and B_1, B_2, and B_3 are regression constants. B_3 is an estimate of the operational LWP of the species under midday conditions and low water stress. B_1 indicates the species' responsiveness to soil water, and B_2 indicates the decrease in LWP (below B_3) at 0% soil moisture. The evaluation of the constants and the coefficients of determination (r^2) for the different regressions are given in Table II.

Table II shows that for *F. ovina* and *M. montana,* over 70% of the variability in LWP is explained by regression on soil water at 10- and 20-cm depths. For both species, the regressions on 30- and 40-cm soil moisture explain less than 50% of the variability in LWP. We conclude that, statistically, the 10- and 20-cm soil layers are the most important sources of water for these two species. However, considering the confidence intervals of the regression constants (Table II), it is apparent that the relationships are weaker for the regressions on the 20-cm soil moisture than for the 10-cm soil moisture, even though the r^2 values

TABLE II. Summary of regression analyses using $Y = -B_3 - B_2 e^{-B_1 X_j}$

Species	j Soil Moisture Depth (cm)	B_1 (95% confidence interval)	B_2 (95% confidence interval)	B_3 (95% confidence interval)	r^2 [a]
Agropyron trachycaulum	10	0.241 (1.407 to 0.468)	26.48 (8.48 to 44.48)	23.29 (19.41 to 27.16)	0.596
	20	0.313 (0.105 to 0.521)	58.86 (2.15 to 115.6)	23.17 (20.68 to 25.67)	0.757
	30	0.283 (0.105 to 0.461)	74.37 (-4.06 to 152.80)	23.13 (20.71 to 25.56)	0.766
	40	0.148 (-3.72 to 0.333)	41.71 (-14.77 to 98.18)	22.58 (16.46 to 28.70)	0.506
Festuca ovina	10	0.335 (0.127 to 0.542)	80.23 (31.38 to 129.09)	21.64 (16.2 to 27.02)	0.739
	20	0.832 (0.326 to 1.339)	1291.78 (-161. 56 to 4199.13)	24.22 (20.42 to 28.02)	0.776
	30	0.351 (-0.033 to 0.735)	189.31 (-238.26 to 616.88)	23.30 (16.33 to 30.27)	0.493
	40	0.053 (-0.180 to 0.286)	37.47 (-0.47 to 75.40)	14.43 (-44.80 to 73.65)	0.202
Muhlenbergia montana	10	0.513 (0.109 to 0.917)	114.62 (-0.060 to 229.84)	20.39 (12.83 to 27.95)	0.717
	20	1.195 (-0.225 to 1.775)	5857.70 (-7797.5 to 11344.8)	21.94 (14.15 to 32.58)	0.851
	30	0.775 (-0.225 to 1.775)	1773.71 (-7797.5 to 11344.8)	23.36 (14.15 to 32.58)	0.455

[a] Coefficient of determination r^2 is a measure of the fraction of variability in Y that is explained by the regression equation.

have the opposite trend. For both species B_1 and B_2 are very high in these equations, suggesting a threshold-type reaction of LWP to soil moisture with little plant responsiveness, a model that has less biological validity than one where plant responsiveness over a range of soil moisture is apparent. Thus, a consideration of the values and confidence intervals of the regression constants leads us to suggest that the 10-cm soil layer is more important for these two species, although undoubtedly the 20-cm layer is also important. Additional statistical analyses or data might elucidate this further.

In contrast, the regression statistics for *A. trachycaulum* show that all soil depths are very important sources of water, with the regressions on 20- and 30-cm soil moistures having higher r^2 (Table II). This indicates that these two soil layers are possibly more important than the other layers. All the constants in the regression equations are of the same order of magnitude and have similar confidence intervals, thus supporting confidence in the results. Plots of regression equations for the three species are given Figs. 11-13.

IV. DISCUSSION

The LWP data seem to correlate well with observations of the root structures of the species. Figure 1 shows that at site 4 the surface soil layer dried out much more than the deeper layers. Thus it is likely that the very low LWP of *F. ovina* during the summer drought is due mainly to its shallow root system. The extensive root system of *A. trachycaulum* correlates well with its ability to maintain a relatively high LWP during drought, whereas the intermediate nature of the *M. montana* root system agrees with its intermediate LWP water status during the summer. Newman (1974) has noted that many species appear to have higher root density than needed for adequate water uptake. Wheat specimens *(Triticum aestivum)* with artificially pruned root systems had reduced transpiration rates when the soil water was at field capacity, and yet the pruning did not seem to increase drought susceptibility as the soil dried. This suggests that the dense root systems of *A. trachycaulum* and *F. ovina* may be particularly wasteful of water by comparison with *M. montana* and cause coexisting species to experience increased competition for water.

Observations on the phenology of *M. montana* agree with those reported by Pearson (1967) from sites in ponderosa pine forests in northern Arizona. He noted that maximum growth of *M. montana* occurred after the growth of pines ceased, with flowering and seed set not completed until late September. *F. ovina* has a phenology very similar to that of *F. arizonica*, a cool-season grass often abundant in ponderosa pine forests in northern Arizona and New Mexico, which has been found to compete strongly with ponderosa pine seedlings (Larson and Schubert 1969). *A. trachycaulum* is not native to Bandelier. Its range of abundance is the northwestern and north-central US and Canada, where there are more reliable summer rains. It is a late cool-season grass, growing throughout the driest portion of the year, unlike *F. ovina* and *M. montana*, which appear to be dormant during the period of greatest water stress.

Of the three grass species studied, *A. trachycaulum* and *F. ovina* appear to partition the soil water resource and coexistence of these two species could presumably be long term. *M. montana* and *F. ovina,* although having complementary phenologies, have conflicting patterns of water usage, and thus, it seems likely that the native *M. montana* experiences severe competition from *F. ovina*. *M. montana* might also experience significant competition from *A. trachycaulum*. *M. montana* has some roots that penetrate the soil profile quite deeply, probably giving the species increased survival during especially dry seasons. These deeper roots would come into direct competition with the very dense deep-root system of *A. trachycaulum.*

The observed root structures of ponderosa seedlings on La Mesa burn were shallower than those reported in the literature. Howells (1965) reported that 1-year seedlings commonly have a root penetration of up to 50 cm. Boldt and Singh (1964), studying ponderosa pine transplants in field test sites, reported that between the first and fourth growing seasons, lateral roots grew from about 25 to 300 cm, and vertical roots extended from 60 to 180 cm in depth. However, the configuration of the root system of

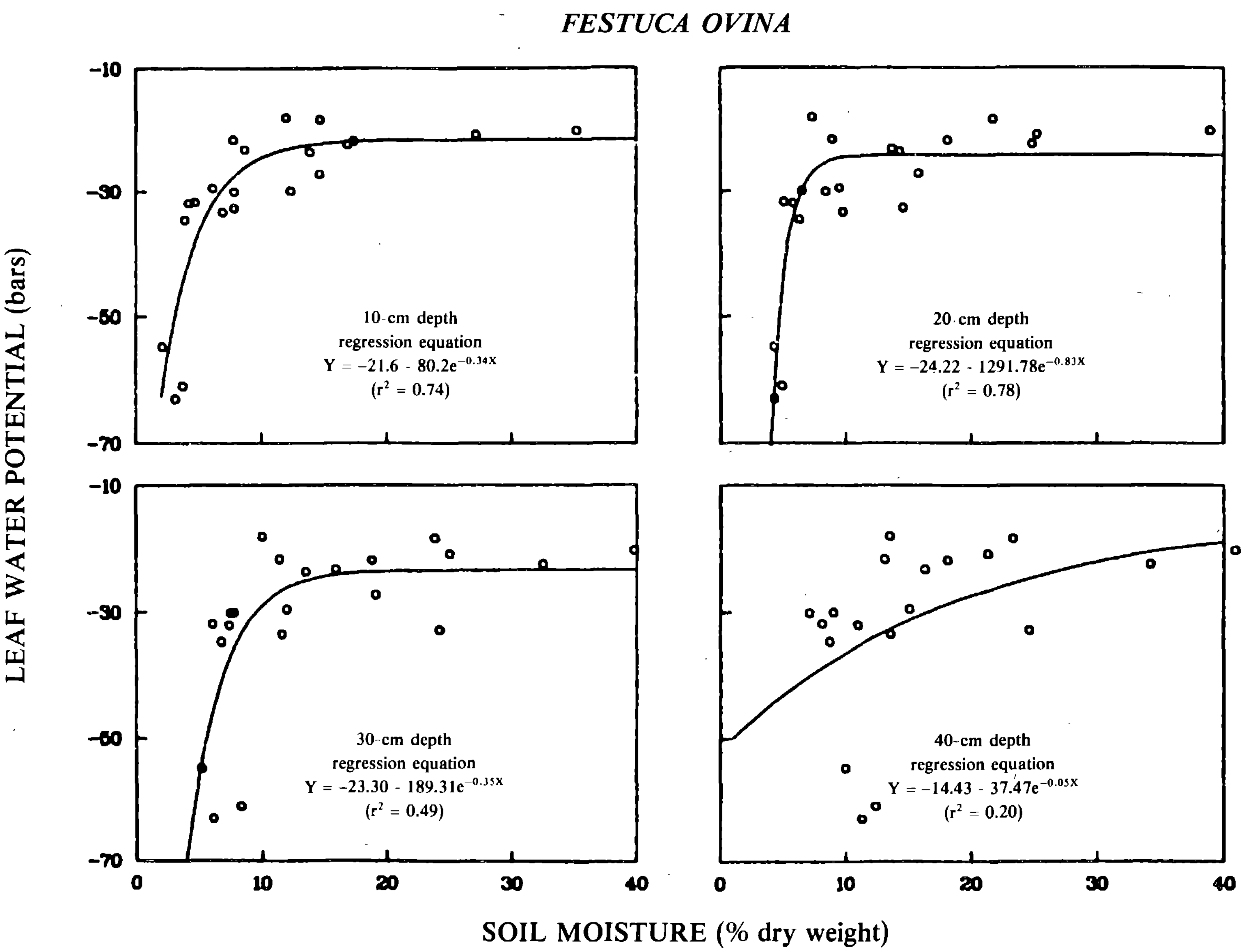

Fig. 11. Relationship between LWP (Y) of *F. ovina* and soil moisture (X) at 10-, 20-, 30-, and 40-cm depths. Regression equations for each relationship are plotted (Table II).

AGROPYRON TRACHYCAULUM

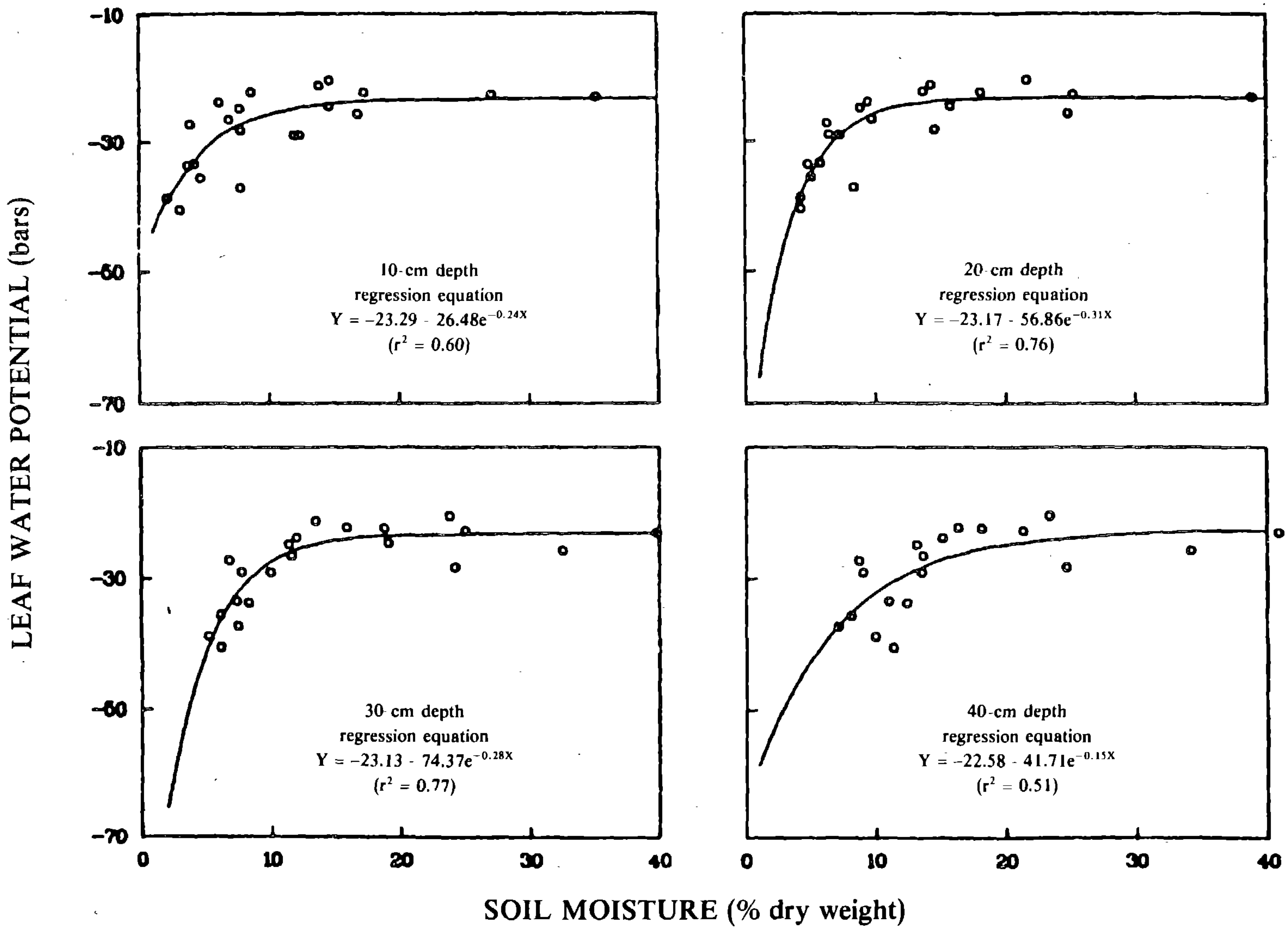

Fig. 12. Relationship between LWP (Y) of *A. trachycaulum* and soil moisture (X) at 10-, 20-, 30-, and 40-cm depths. Regression equations for each relationship are plotted (Table II).

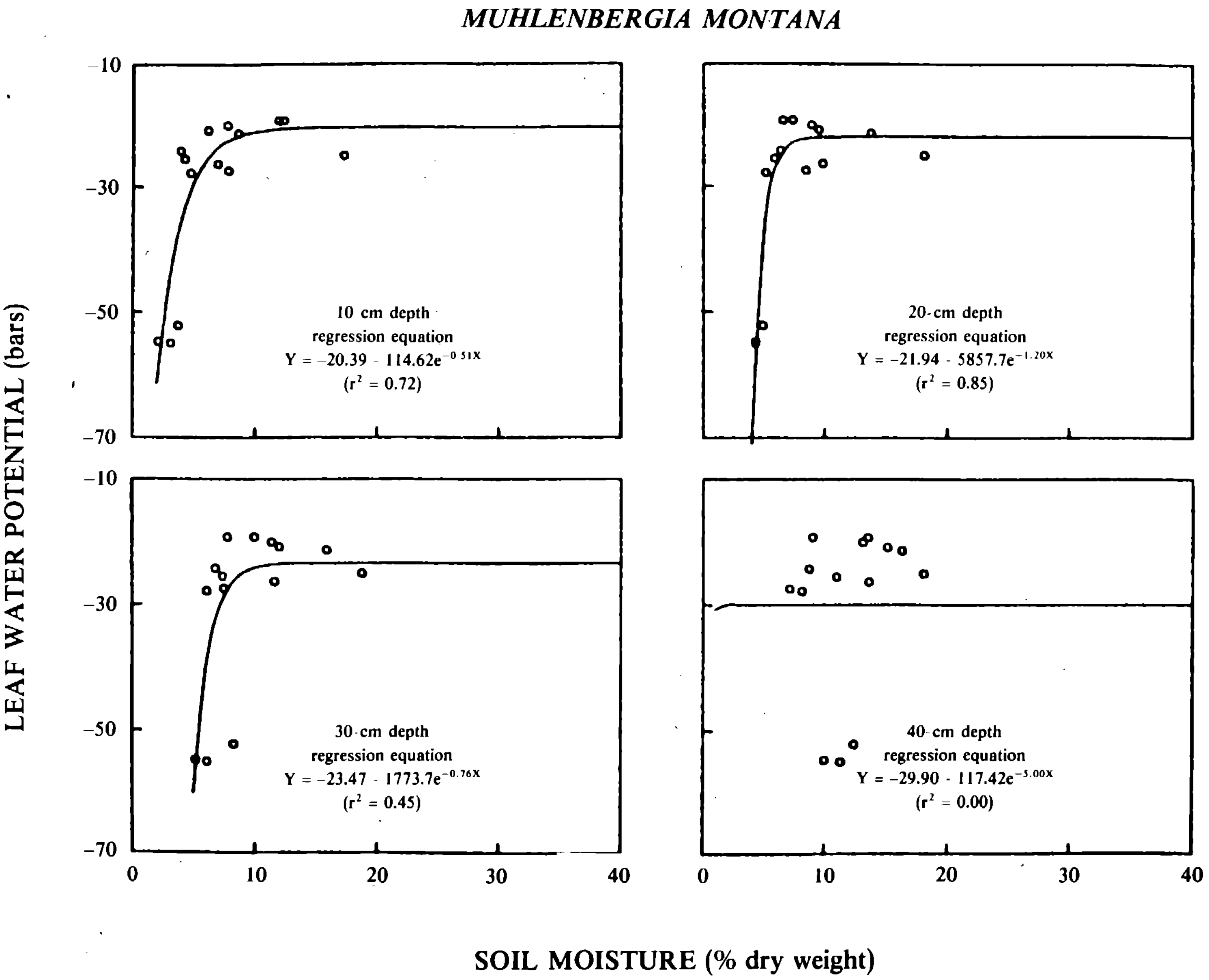

Fig. 13. Relationship between LWP (Y) of *M. montana* and soil moisture (X) at 10-, 20-, and 30-, and 40-cm depths. Regression equations for each relationship are plotted (Table II).

these transplants was similar to that noted in this study in that both lateral and vertical roots were present. All seedlings excavated in Bandelier were from sites with undisturbed soil profiles. Root extension in hard, unplowed soil is generally much less than in prepared soils, which no doubt accounts for the shallow root systems observed in this study.

Larson and Schubert (1969) showed that grass roots will produce several "flushes" of new growth during a season, but ponderosa pine seedlings will produce only a few additional roots after the initial spring growth period. Given our data on grass root distribution and water usage, this suggests that young pine seedlings would experience severe competition from *F. ovina* because this species has an extremely dense root mat that would be difficult for the roots of newly germinated seedlings to penetrate. In addition, the phenology of this grass conflicts with that of ponderosa pine in that both use winter precipitation during early spring growth. It also seems likely that older pine seedlings would experience considerable competition from *A. trachycaulum* because of its extensive deep root system and continued growth and water uptake during the summer drought.

Ponderosa pine seedlings would compete much less with the native *M. montana* than with the other two dominant grasses because it appears that the pine seedlings and *M. montana* have fundamental differences in niche space. The native grass has a phenology complementary to the growth patterns of ponderosa pine. In addition, it has a somewhat sparse root system, which is likely to result in less water withdrawal from the soil during the spring and summer, and allow root penetration of newly germinated pine seedlings. Unfortunately, the two seeded grasses are dominant in the severely burned areas of Bandelier. Any attempts to plant or seed ponderosa pine on the burn will have to consider ways to mitigate the severe competition the seedlings will experience from the dense stands of *A. trachycaulum* and *F. ovina* that currently exist.

For reclamation of impacted areas, the first priority is to identify the target overstory species that the reclamation project is designed to protect or encourage. For erosion control in such a project, seeding with locally common species is the first choice. However, the commercial nonavailability of particular species or the economics of seeding large areas may often require a manager to consider exotic species. In choosing such species, the choice should be restricted to those with phenologies complementary to the target species. This implies the existence of a data bank that could supply information on specific germination requirements and mature niche spaces of potential seed species. Managers of important forest resources should have similar information on the tree species. Following a natural or manmade disturbance, this information could allow managers to assess the competitive interactions between seeded grasses and the desired overstory species. Thus it would be possible either to retard or hasten the regeneration of normal climax vegetation by choosing to seed an area with species having conflicting or complemetary niche requirements with the climax vegetation.

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GEOMORPHIC EFFECTS OF LA MESA FIRE

William D. White* and Stephen G. Wells**

I. INTRODUCTION

The Rito de los Frijoles watershed, the northernmost portion of Bandelier National Monument, experienced the greatest areal extent of devegetation by La Mesa fire. Our study was made to assess the impact of devegetation by the fire on geomorphic processes in selected portions of the Rito de los Frijoles watershed. Those geomorphic processes of interest include hillslope erosion, channel sedimentation, and concomitant modification of the land. Assessing the impact of La Mesa fire involved four main aspects: (1) identification of sediment-source areas, (2) determination of rates and controls of sediment production (erosion rates), (3) characterization of the adjustments of the ephemeral channels to increased sediment supply, and (4) characterization of the morphologic adjustments of the perennial master stream (Rito de los Frijoles) to increased runoff and sediment supply. This study evaluates the geomorphic processes and adjustments to devegetated conditions for a 3-year period. Thus, results discussed herein are restricted to short time periods (several years) rather than periods of tens of years. A morphometric analysis of the Frijoles Canyon watershed provides baseline information on the spatial arrangement of hillslopes and channels. The geomorphic responses of noninstrumented, devegetated watersheds developed on the volcanic plateaus surrounding the Jemez Mountains may be predicted based upon a synthesis of field studies, morphometric analysis, and geomorphic mapping performed in this study.

A. Geologic Setting of Study Area

The Frijoles Canyon watershed is developed on a portion of the southeastern flanks of the Pleistocene Valles Caldera volcanic complex (Fig. 1). Bedrock geology of the study watershed includes the Bandelier Tuff, unnamed basalt flows, the Tshicoma Formation, and the Paliza Canyon Formation (Smith et al. 1970). The Bandelier Tuff composes approximately 75% of the areal extent of the Frijoles Canyon watershed. The uppermost headwater portion of the watershed (approximately 20% areal extent) is composed of two volcanic domes of the Tschicoma Formation. The lowest part of the Frijoles Canyon watershed consists of interfingering basalt flows and Bandelier Tuff, which overlie a maar feature (Eichelberger and Heiken, unpublished report). The middle of the Frijoles Canyon watershed is cut by three north-northwest-trending, high-angle normal faults (Fig. 1). These faults offset the Bandelier Tuff with the east blocks being downthrown.

The physiographic setting of the study area is a volcanic plateau incised by deep canyons with local relief of 60 to 240 m along these canyon walls. The mouth of the Frijoles watershed is at an elevation of 1640 m, receives 38 cm of precipitation (Earth Environmental Consultants, Inc. 1978), and has cholla and mesquite as its typical vegetation. The headwaters of the Frijoles watershed is at an elevation of 3050 m, receives 76 cm of precipitation (Earth Environmental Consultants, Inc. 1978), and has a spruce-fir

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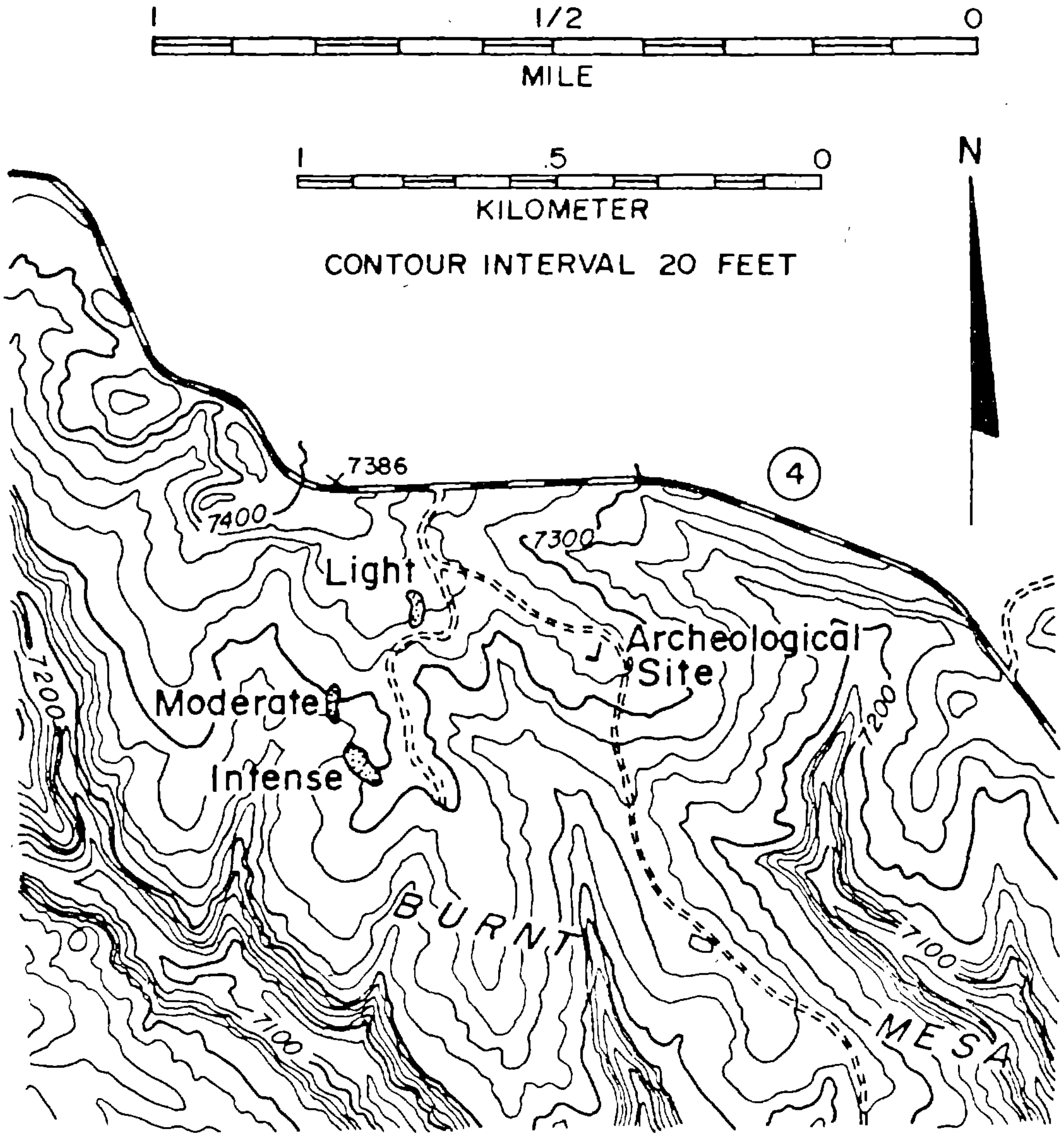


Fig. 1. Geology and topography of the Frijoles Canyon watershed. Study areas are indicated by △ and O.

forest type. The largest catchment areas of the Frijoles Canyon watershed are the mesas of the Pajarito Plateau. The mesas are formed primarily on the Bandelier Tuff, which is offset by the normal faults mentioned above. The resulting fault-line scarp is the physiographic boundary separating the upper and lower mesas of the Pajarito Plateau (Figs. 1-3).

II. DRAINAGE-BASIN CHARACTERISTICS AND INSTRUMENTATION

The selection of study basins within the mesa-top catchment areas of the Frijoles watershed involved locating small catchment areas (thousands of square meters) that represent different burn intensities of the fire. A qualitative estimate of burn intensity, given below, was recommended by the National Park Service (NPS) (this information provided by K. Newton, 1977):

(1) intense burn: complete destruction of all ground and tree foliage, leaving only charred trunks and branches;

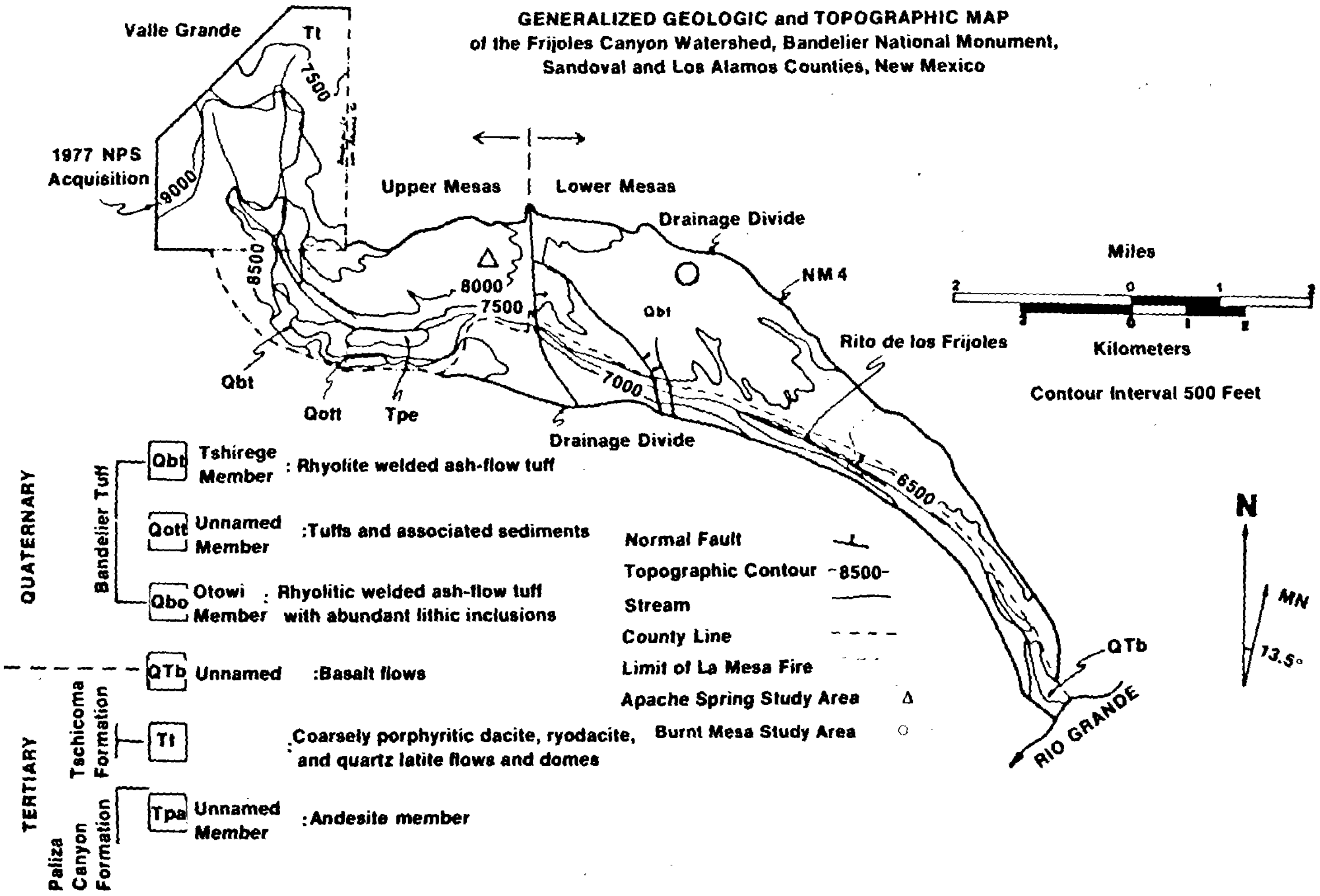


Fig. 2. Instrumented basins in the Burnt Mesa study area. Figure 1 shows this area within the Frijoles Canyon watershed. State Road 4 forms the northern boundary of the Monument.

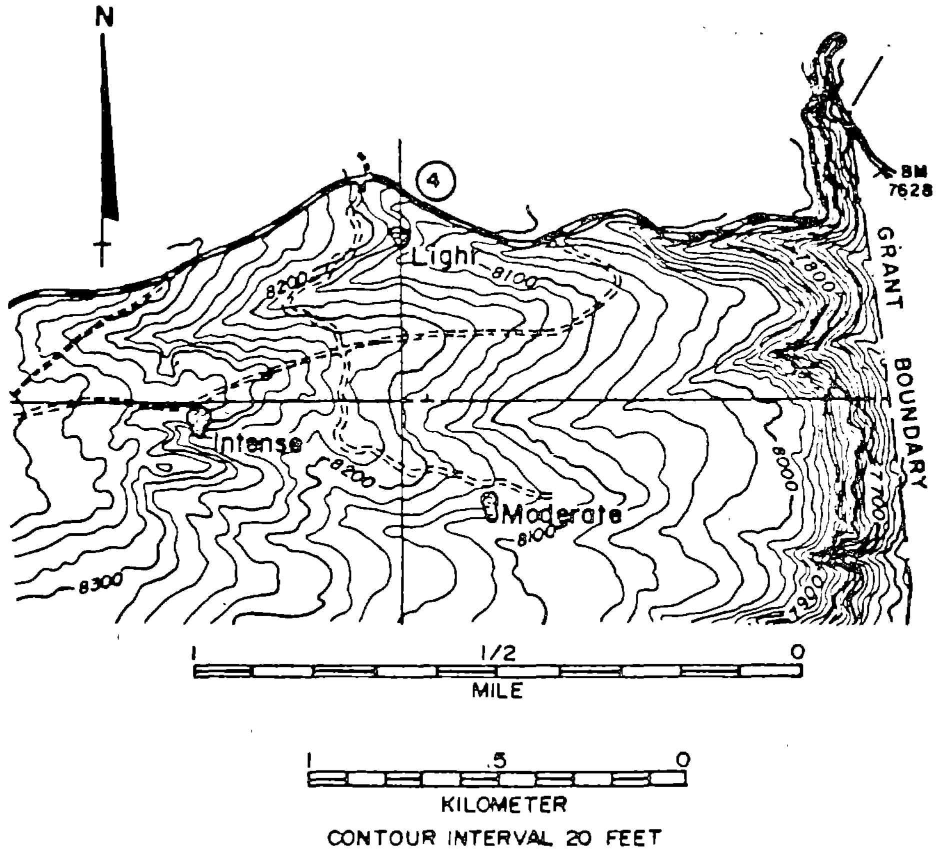


Fig. 3. Instrumented basins in the Apache Spring study area. Figure 1 shows this area within the Frijoles Canyon watershed. At the right is fault-line scarp separating the upper and lower mesas.

(2) moderate burn: destruction of ground foliage, leaving only the crowns of taller trees; and

(3) light burn: destruction of the ground foliage and small shrubs; larger trees and shrubs not destroyed.

A second selection criterion was to locate areas that differ in topographic and vegetative characteristics. Given the extent of La Mesa fire and the geology of the plateau, it was possible to instrument watersheds of different climatic settings and of relatively uniform bedrock geology. Finally, basins with similar aspects and without disturbance by roads or fire lines were selected for detailed studies.

Three months after La Mesa fire, three basins had been instrumented on the upper mesas in the Apache Spring area, and three basins on the lower mesas had been instrumented in the Burnt Mesa area (Figs. 2,3). In both areas, the three basins are small low-order headwater drainage basins that reflect the qualitative type of burn intensity (intense, moderate, light). Stream (or basin) order is a method of denoting certain stream segments within a drainage network (Strahler 1964). Unbranched stream segments are referred to as first order; the confluence of the two first-order streams forms a second-order stream segment, etc. Hence, low-order basins refer to small basins drained by first-, second-, or third-order streams. The Apache Spring study area is at an elevation of approximately 2530 m with a mixed conifer forest. The Burnt Mesa study area is at an elevation of approximately 2195 m and is characterized by a mosaic of ponderosa pine in dense stands of young trees, open park-like stands of mature trees, and open meadows of grasses.

The respective burn intensity at each elevation will be referred to in abbreviated form: BMINT refers to the intense-burn basin within the Burnt Mesa study area; BMMOD, the moderate-burn basin within the

Burnt Mesa area; BMLIGHT, the light-burn basin within the Burnt Mesa area; and BMARCH refers to the pin transect along an unexcavated ruin. ASINT refers to the intense-burn watershed within the Apache Spring study area; ASMOD, the moderate-burn basin within the Apache Spring area; and ASLIGHT, the light-burn basin within the Apache Spring area.

Low-order drainage basins of Burnt Mesa and Apache Spring differ in their geomorphic character (Table I). Drainage basins within the Burnt Mesa area are typically elongate because of their development on incised mesa tops (Fig. 2). The Apache Spring basins are characteristically circular because of their development on the side slopes of wide shallow valleys (Table I, Fig. 3). Drainage basins of the Apache Spring are steeper and shorter than those of Burnt Mesa, whereas relief in the drainage basins is similar in both areas (Table I). Bedrock outcrops are not extensive in the drainage basins. Rather, varying thicknesses of water-worked colluvium and alluvium cover the basins.

Hillslope segments and ephemeral channel reaches were instrumented in each study basin to monitor the amount, distribution, and seasonal variations in sediment contribution to the stream channel. Modifications of the ephemeral channel morphology were measured with erosion-chain transects (Leopold et al. 1966). Hillslope erosion was measured by two types of field instruments: (1) erosion-pin transects (Leopold et al. 1966) and (2) a portable contour-plotting frame (called an erosion grid), which permits 25 elevation measurements over a 1-m^2 area (Campbell 1974). Additional field methods used in this study are described by White and Wells (1979) and White (1981).

III. PREBURN GEOMORPHIC CONDITIONS

EECI (Earth Environmental Consultants, Inc., contracted by the NPS) prepared a soil survey of the Bandelier National Monument (Earth Environmental Consultants, Inc. 1978). This survey indicates that the upper mesas of the Monument are characterized by a well-developed soil profile. EECI (1978) further noted that the lower mesas are actively eroding, based upon the observation of pedestaled grasses. Estimating the average height of pedestaling (3.8 cm) and the average life span of blue grama grasses (seven years), the EECI concluded that the lower mesas experience an erosion rate of 5.3 mm/yr. EECI concluded that the well-developed soil profiles of the upper mesas are due to an apparent drying of the climate (Earth Environmental Consultants, Inc. 1978).

A control area, an unexcavated archaeological site on Burnt Mesa instrumented with an erosion-pin transect, shows an erosion rate of 5.7 mm/yr for an 18-month period. The control area is on the

TABLE I. Geomorphic Characteristics of Study Basins in Bandelier National Monument.[a]

Basin	Area (m^2)	Aspect	Order	Relief (m)	Length (m)	Perimeter (m)	Basin Circularity	Basin Slope
Burnt Mesa								
Intense	4116.5	WNW	3rd	11.86	129.97	298.09	0.582	0.091
Moderate	813.8	S	1st	8.65	67.06	146.30	0.478	0.129
Light	1426.0	S	1st	5.57	70.84	177.39	0.570	0.079
Apache Spring								
Intense	1431.5	S	2nd	11.16	51.51	143.26	0.876	0.217
Moderate	677.7	S	1st	8.12	49.07	124.05	0.553	0.166
Light	380.4	ESE	1st	5.41	25.97	67.36	0.776	0.208

[a] Basin circularity (R_c) is defined as $R_c = 4\pi A/P^2$, where A – area and P = perimeter. Basin slope is defined as relief/length.

uppermost portion of a lower elevation mesa, and therefore has no upslope component. The postburn erosion rate is in agreement with the EECI preburn estimate for the lower mesas. This is a general indication of a similar rate of erosion following La Mesa fire on the lower mesas of the Monument. There is no contribution to this erosion rate by feral burros. The burros, of concern in the lower portions of the Monument, are not present on the mesas north of Frijoles Canyon.

IV. TYPES AND DISTRIBUTION OF HILLSLOPE EROSION RELATED TO FOREST-FIRE DEVEGETATION

Erosional processes responsible for hillslope reduction in the devegetated portions of Bandelier National Monument are rillwash and sheetwash. In the study basins mapped in June and July of 1978, sheetwash is of greater areal extent than is rillwash. This is due to the shallow slopes of most of the hillslope segments within the study basins. The shallow gradient of these hillslopes (<10°) generally will not concentrate overland flow into areas of channelized flow (rilling). Rillwash is more common in the intensely burned study basins, relative to the other study basins. This is a result of a greater degree of devegetation within these study basins and the better developed impermeable ash layer associated with intensely burned areas. Both overland flow processes become increasingly effective in a devegetated setting because of the lack of the retarding influence of vegetation and the decreased infiltration capacity of forest soils associated with fire.

The decreased infiltration rates on exposed soils can be attributed to two processes: (1) rain-splash impact reducing the ground-surface porosity by plugging surface pores (Zwolinski 1971) and/or (2) a fire-induced water repellency of the ground surface (Krammes and Debano 1965). Campbell et al. (1977) observed that fire-induced water repellency was an important factor in reducing infiltration rates in their case study of an Arizona ponderosa pine ecosystem. In Bandelier National Monument, it was observed that the ash layer produced by the consumption of forest litter during La Mesa fire decreased the infiltration rate of the exposed soils. In the study basins, an ashed ground surface had a lower infiltration rate (mean = 30 cm/h) than did an unashed, or stripped, ground surface (mean = 42 cm/h)(White 1981).

To test the relative contribution of the reduction of surface porosity by rain-splash impact and the development of an impermeable layer on decreased infiltration capacity, bulk density was determined for the samples collected at the infiltration sites. It was found that ashed ground surfaces had lower bulk densities (0.56-1.09 g/cm^3) than did unashed ground surfaces (1.20-1.43 g/cm^3). The lower bulk densities of the ashed surfaces is a result of the combustion of organic debris in the ground surface producing void spaces. The lower infiltration rates associated with lower density, ashed ground surfaces appears to be due to the generation of an impermeable ash layer and not due to a plugging of surface pores by rain-splash impact. It is assumed that the water repellency of a burn layer is due to the organic resins that are concentrated in the ashed remains of the forest litter.

The decreased infiltration capacity of the forest soils as a result of La Mesa fire promotes an increase in overland flow. With greater overland flow, a corresponding increase will occur in runoff and sediment yield from a given basin. The length of overland flow influences the amount of sediment entrained on hillslopes and delivered to the drainage lines. The efficiency of sediment removal from hillslopes will be greatest where the length of overland flow is the least (White and Wells 1979). Thus, in the Bandelier area, the headwater and basin-mouth regions, being generally more dissected by drainage lines, are more susceptible to erosion because of the shorter lengths of overland flow.

The reduced infiltration capacity on burned hillslopes leads to greater volumes of overland flow. In a test plot, the infiltration rate on the rilled, impermeable ash was found to be 21.6 cm/h, whereas the infiltration rate on the unashed surface was measured at 64.8 cm/h. The decreased infiltration capacity of the ashed surface increases the surface runoff, which, in turn, promotes the development of rills and an increase in channelized flow.

A shallow gradient hillslope (<10°) with a relatively large upslope catchment and with a well-developed ash layer (prevalent in the intense-burn basins) will be susceptible to rill erosion. Rill systems will develop master (main stem) rills with tributary rills that fill and switch courses over the ground surface. The resultant ground surface along a given erosion-pin transect will exhibit variable amounts of gain and loss from pin to pin. Sheetwash is the dominant erosional process on a shallow gradient hillslope without a significant upslope catchment area. Changes in ground-surface elevation, along a given pin transect where sheetwash is operative, will be more evenly distributed, with minor variations. Steep, short side slopes adjacent to drainage lines are highly susceptible to postburn erosion due to the degree of slope and rapid removal of sediment via the drainage line. Complex hillslopes, slopes with both waxing (increasing slope) and waning (decreasing slope) segments, will experience erosion on the waxing segment and deposition on the waning segment.

In this study, those factors important in postfire hillslope erosion include (in decreasing order of importance)

(1) degree of ash development,
(2) amount of upslope catchment area,
(3) degree of slope, and
(4) type of slope.

V. RUNOFF, EROSION RATES, AND SEDIMENT YIELD IN DEVEGETATED DRAINAGE BASINS

Runoff calculations for the Burnt Mesa study basins show that runoff increases with increasing burn intensity (increasing devegetation) (Fig. 4). Table I indicates that the smallest basin in the Burnt Mesa study area (BMMOD) is also the steepest. Figure 4 shows that the BMMOD basin yields a smaller

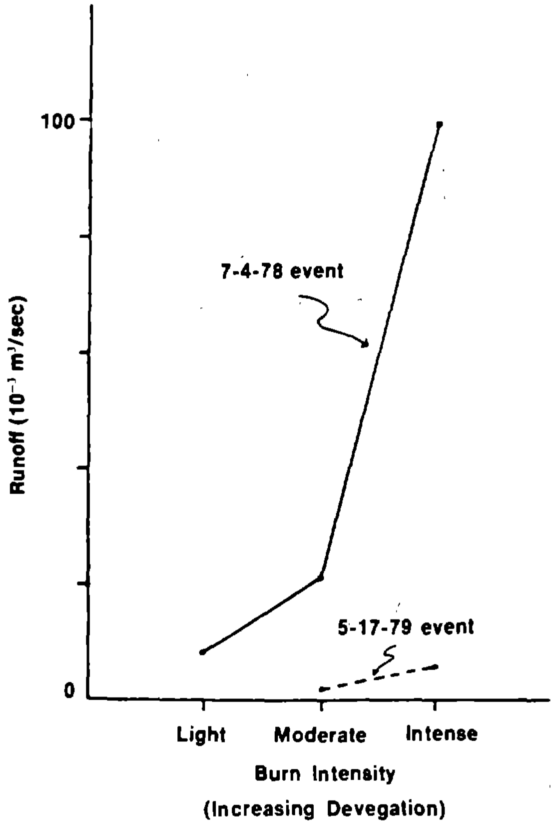


Fig. 4. Relationship between runoff and forest-fire devegetation for two precipitation events, Burnt Mesa study basins.

amount of runoff than the larger BMINT basin but a greater volume of runoff than the larger BMLIGHT basin. Therefore, drainage-basin area and slope may not be the significant factors in runoff in devegetated basins. Rather, basin relief and burn intensity may have a greater influence on runoff than basin area and slope.

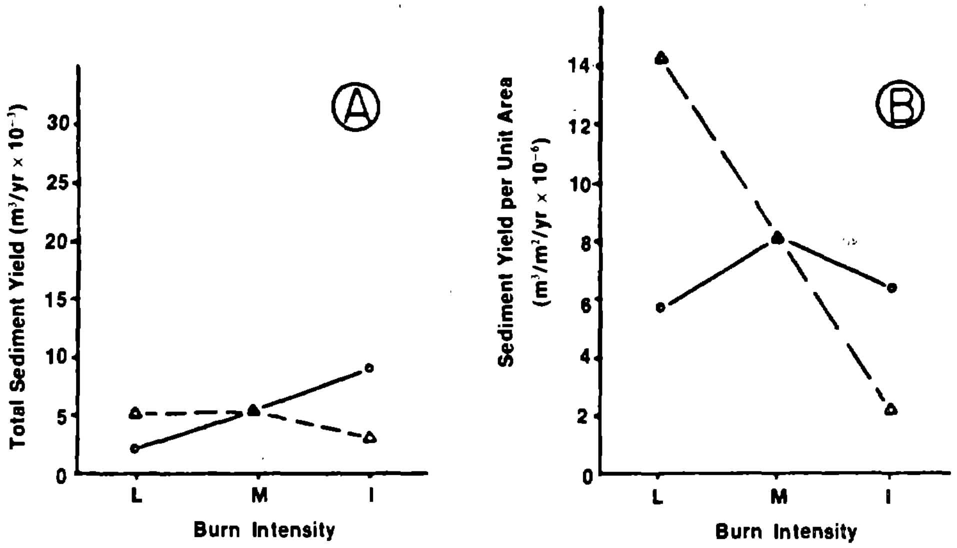
Table II is a summary of the calculated annual rates of mean surface-elevation change ($\bar{\Delta}$/yr) for each study basin. The $\bar{\Delta}$/yr values are calculated for each basin by summing the pin measurement values for each annual period and dividing by the number of pin transects per basin. Total sediment yield (m^3/yr) is computed for the first two annual periods by multiplying the $\bar{\Delta}$/yr values by the length and width (0.04 cm) of the erosion-pin transects. Sediment yield per unit area is computed by dividing the m^3/yr values by their respective basin areas. This allows the relative degree of erosion between study basins to be compared; the sediment yield values are calculated (not actually measured) volumes of sediment. Sediment yield is not computed for the third annual period because nearly all the basins experienced a net gain along erosion-pin transects. Although the study basins were yielding sediment, the total sediment yield must have been significantly decreased as the hillslopes and channels became revegetated.

Erosion rates ($\bar{\Delta}$/yr) were generally greater during the second year after La Mesa fire. However, precipitation was greater during the first year after the fire. The greater magnitude of erosion during the second year is attributed to the destruction of the ash layer. Directly after the fire, the ash layer was hard to wet [water repellency of organic resins in the ash (Debano et al. 1970)] and promoted overland flow. During the first year after the fire, the ash layer was only beginning to be incised locally and removed by rilling and sheetwash. During the second year, the extensive disruption of the ash layer by frost action and the expansion of rill systems led to widespread erosion of the ash layer. Even though the total amount of precipitation was less during the second year after the fire, the extensive destruction of the ash layer accounts for the higher erosion rates during this period. That is, less frequent precipitation events were more effective in erosional processes.

TABLE II. Summary of Mean Annual Surface Change and Sediment Yield for Each Study Basin

Study Basin (m^2)	Time Period	$\bar{\Delta}$/yr (mm/yr)	Total Sediment Yield ($m^3/yr \times 10^{-3}$)	Sediment Yield per Unit Area ($m^3/m^2/yr \times 10^{-6}$)
BMINT	9/77-6/78	−4.3	17.2	4.18
Area = 4116.5	6/78-6/79	−6.5	26.0	6.32
	6/79-4/80	+3.6		
BMMOD	9/77-6/78	−1.8	3.6	4.42
Area = 813.0	6/78-6/79	−1.1	2.2	2.70
	6/79-4/80	−0.4		
BMLIGHT	9/77-6/78	−4.6	12.1	8.50
Area = 1426.0	6/78-6/79	−7.7	20.2	14.2
	6/79-4/80	+6.2		
ASINT	9/77-6/78	−3.5	9.1	6.42
Area = 1421.4	6/78-6/79	−1.2	3.1	2.20
	6/79-5/80	+3.4		
ASMOD	9/77-6/78	−4.4	5.5	8.18
Area = 677.7	6/78-6/79	−4.4	5.5	8.18
	6/79-5/80	+2.5		
ASLIGHT	10/77-6/78	−3.2	2.2	5.85
Area = 380.4	6/78-6/79	−7.8	5.4	14.3
	6/79-5/80	+3.2		

Figure 5 illustrates total sediment yield (m^3/yr) and sediment yield per unit area ($m^3/m^2/yr$) compared with burn intensity for both the Apache Spring and Burnt Mesa study areas. It is evident from the plots that there is not a direct relationship between burn intensity and sediment yield (Fig. 5), as the runoff versus burn intensity plot seemed to indicate (Fig. 4). This is a result of factors other than burn intensity that may have an overriding effect on sediment production in a devegetated setting. These other factors are discussed in detail in the following section.



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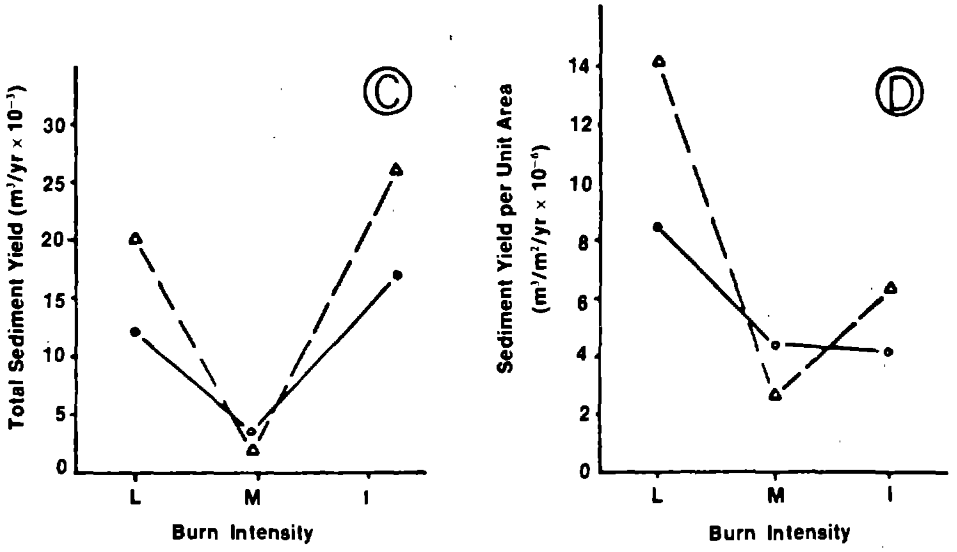

BURNT MESA

Fig. 5. Sediment yield vs burn intensity relationships for the Apache Spring and Burnt Mesa study basins. Solid line represents first year of data; dashed line represents second year.

A. Comparison of Drainage Basins in Differing Climatic and Topographic Settings

Figure 5B shows that during the second year of this study, the smallest basin (ASLIGHT) produced the greatest amount of sediment for the upper mesa study basins. The largest basin on the upper mesas produced the least sediment. However, the smallest basin on the lower mesas (BMMOD) produced the least sediment in the Burnt Mesa study area (Fig. 5D), whereas the largest basin (BMINT) produced a comparatively moderate amount of sediment (Fig. 5D). These relationships further illustrate the fact that the principal factors in erosion in a devegetated terrain are not necessarily burn intensity or drainage area size.

The total sediment yield (m^3/yr) for the Apache Spring study basins (Fig. 5A) is less than that for the Burnt Mesa basins (Fig. 5C) because the area covered by the erosion-pin transects within the Apache Spring basins is less. Figures 5B and D show that the range or magnitude of sediment yield per unit area ($\sim$2 to 14 $m^3/m^2/yr$) is similar between the study areas. This indicates that both areas are producing similar amounts of sediment following La Mesa fire. However, the axial drainage below ASINT ($\sim$30 m downslope from the basin mouth) exhibits very little fire-associated sediment. The axial drainage below the BMINT and BMMOD study basins ($\sim$5 m downslope from their basin mouths) exhibits large amounts of fire-associated sediment in the channel. The physiography of the upper mesas as compared with that of the lower mesas is a contributing factor as to why the upper mesa axial drainages exhibit less deposition of fire-associated sediment. The sediment produced from the Apache Spring study basins must traverse long valley-side slopes to reach the axial drainage (Fig. 6A), whereas the sediment produced from the Burnt Mesa study basins is delivered directly to the axial drainage (Fig. 6B).

Collectively, the Apache Spring study basins deliver less sediment to the Frijoles Canyon drainage net because the dense and rapid regrowth of vegetation on the valley-side slopes of the upper mesas traps fire-

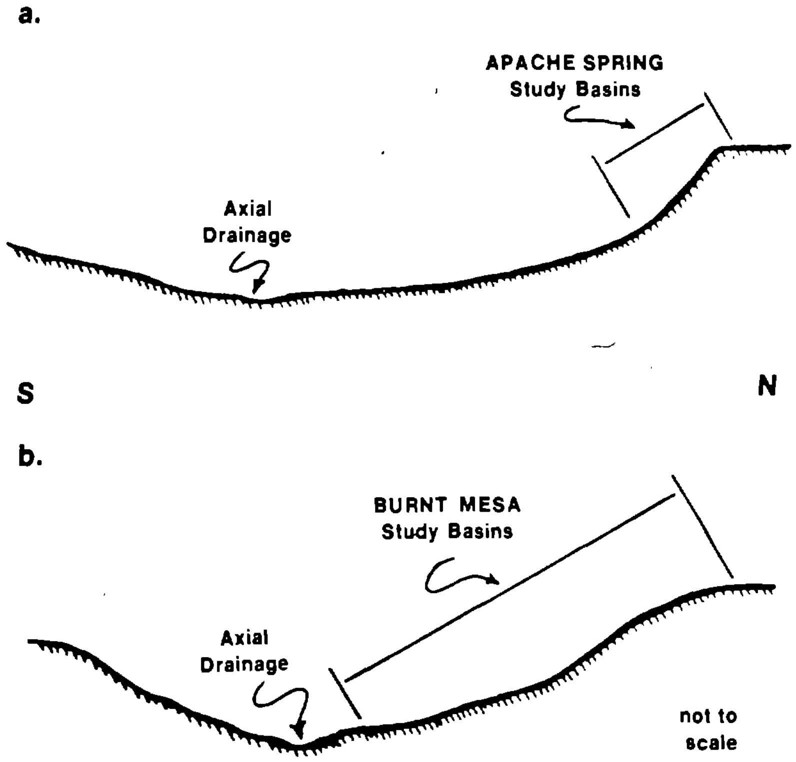

Fig. 6. Physiographic settings of study basins within each study area. Apache Spring basins are separated from axial drainage by shallow gradient valley-side slopes.

associated sediment before it reaches the axial drainages. Therefore, the combination of the physiography of the study areas, the location of the study basins within the upper and lower mesa study areas, and the success of the reseeding on the upper mesas, all combine to result in the upper elevation mesas being less affected by La Mesa fire.

B. Comparison of Drainage Basins of Differing Burn Intensity

The sediment yields within the BMMOD study basin are the lowest for all the study basins (Figs. 5C and D). The low erosion rates within the BMMOD basin are due to the protection of the denuded ground surface by postfire needle cast. Pine needles burned but not consumed on the upper portions of the trees were cast off by the trees. These needles provide a protective carpet that breaks the fall of rain drops and retards overland flow (Megahan and Molitor 1975). Throughout Bandelier National Monument, the postfire needle cast enhanced the success of revegetation of native grasses (Potter and Foxx 1979).

Burrowing by gophers produces mounds of fresh sediment at the ground surface without a protective cover of vegetation. These mounds of loose sediment are susceptible to rain splash and entrainment by overland flow (Imeson 1977). The BMLIGHT study basin, which is largely a meadow, supports a gopher population (this information provided by D. Guthrie, 1978). The high sediment yields (Fig. 5C,5D) of the BMLIGHT study basin are a result of the burrowing by gophers.

The high total sediment yield for the BMINT study basin is due to a number of factors (Fig. 5C). The most important factor contributing to the high erosion rates is the impermeable ash layer. The ash layer is most apparent in the headwaters of BMINT and is best developed in intensely burned areas. Also important is the lack of needle cast to protect the ground surface. Mechanical weathering is a significant factor in intensely burned areas, where the degree of devegetation is the greatest, and correspondingly, frost action is most effective (White and Wells 1979). The high drainage density, relative to the other study basins, of the BMINT basin allows rapid and efficient sediment removal from the basin.

In the Apache Spring area, the intense-burn basin experienced a relatively moderate sediment yield during the first year after the fire (Fig. 5B). During the second year, the ASINT basin experienced a relatively low sediment yield (Fig. 5B). The change from a moderate to a low yield in this intensely burned area can best be attributed to the rapid and dense regrowth of vegetation within the basin. The rapid regrowth of vegetation may be due to the better developed soils and greater amounts of precipitation on the upper mesas (Earth Environmental Consultants, Inc. 1978).

The large sediment yields in the ASMOD basin (Figs. 5A and B) may be due to the large headwater catchment area of the basin, relative to the other Apache Spring study basins. The large headwater catchment may have contributed larger volumes of runoff for sediment entrainment from the pin transects. Since the basin was protected by a dense needle carpet, the runoff could not channelize into rills and the sediment was removed by sheetwash. The fairly uniform change in ground surface elevation from pin to pin along the transects supports this explanation for the large erosion rates within this moderate-burn basin (White 1981).

The high sediment yields within the ASLIGHT study basin are due to its development on the waxing portion of a mesa-side slope (Figs. 5A,5B). The convex longitudinal profile distinguishes the ASLIGHT basin from all other study basins. Revegetation was not as successful within this study basin, which, in combination with its convex profile, resulted in a relatively high sediment yield during the second year of this study (Fig. 5B).

VI. CHANNEL PROCESSES AND MORPHOLOGIC ADJUSTMENTS IN DEVEGETATED WATERSHEDS

A. Ephemeral Channels in Mesa-Top Catchment Areas

The soils of the Frijoles Canyon watershed are better developed on the upper mesas than on the lower mesas because the upper mesas receive more precipitation (Earth Environmental Consultants, Inc. 1978). The degree of soil development in the study area influences the preburn ephemeral channel morphology. The axial ephemeral drainage on the upper mesas in the Apache Spring area has a shallow, parabolic cross section with a loamy bed and dense vegetation. On the lower mesas, bedrock outcrops influence the morphology of the ephemeral channels to a greater degree. The preburn morphology of the trunk ephemeral channel draining the upper and lower mesas can be described as a wide-to-confined, U-shaped, bedrock channel with varying densities of vegetation and thickness of sediment.

The postburn ephemeral channel morphology depends on the degree of revegetation. The upper mesas revegetated quickly, so there is no significant change in channel morphology. The ephemeral channels of the lower mesas have a distinctly different postburn morphology. Higher order channels (for example, the fourth-order channel draining the BMMOD and BMINT study basins) are choked with sediment resulting in wide, flat-bottomed, braided channels. High-order (greater than third order) ephemeral channels are areas of significant temporary storage of the excess sediment being produced as a result of La Mesa fire.

A secondary, but still significant, storage area of fire-associated sediment is the plunge pools marking the junction of trunk ephemeral canyons with the Rito de los Frijoles. Sediment delivered to the base of these nickpoints splashes to the margins of the plunge pool and builds high channel banks. The portion of sediment being discharged to the Frijoles Canyon valley floor is deposited along point bars and becomes overbank deposits on the floodplain.

B. Perennial Channel: Rito de los Frijoles

The preburn morphology of the Rito de los Frijoles varies along the length of its course. In general, the Rito de los Frijoles occupies an incised alluvial floodplain bounded by steep walls of Bandelier Tuff. The channel is meandering and flat-bottomed, with a shallow-to-deep, U-shaped cross section. The cut banks range from 0.4 to 2 m high, and point bars range from 0.1 to 0.6 m high. The width:depth ratio is low, indicating a high percentage of silt-clay in the channel banks (Schumm 1977). The channel bed is armored with cobbles.

The low-flow channel is transporting an increased bed load as a result of La Mesa fire. Shifting of bars of fine gravels and sand over the cobble-armored bed of the Frijoles channel indicates bed-load transport. According to a treatment of hydraulic geometry by Schumm (1977), a channel experiencing an increased bed load may adjust width, depth, meander wavelength, channel slope, and channel sinuosity to accommodate the increased bed load. The Rito de los Frijoles channel shows a distinct increase in bank undercutting since La Mesa fire (this information provided by J. Lissoway, 1979). This increase in channel width is the most pronounced change in morphology in response to the increased bed load. Channel depth likely decreases because of the observed formation of point bars composed of fire-derived sediment, but this channel adjustment is insignificant relative to the bank undercutting. The energy of the normal discharge of the Rito de los Frijoles is not enough to transport the cobbles coming from the banks. These cobbles provide additional armor to the channel bed. Down-cutting of the channel is thereby inhibited.

The US Geological Survey (USGS) operated a stream-gaging station on the Rito de los Frijoles in Bandelier National Monument from October 1963 to September 1969. The station was discontinued at the end of the period and was again made operational on July 7, 1977, 15 days after La Mesa fire.

The shapes of the postburn hydrographs are dramatically different from the preburn hydrographs (Figs. 7A, 7B). The hydrographs have been separated into surface-runoff and base-flow components by a simple visual separation, as described by Gregory and Walling (1973). The separation is intended to define the relative amounts of surface runoff and base flow in each hydrograph. Interflow has not been considered here. The hydrographs are of runoff events that occurred during the summer thunderstorm season of each period of record.

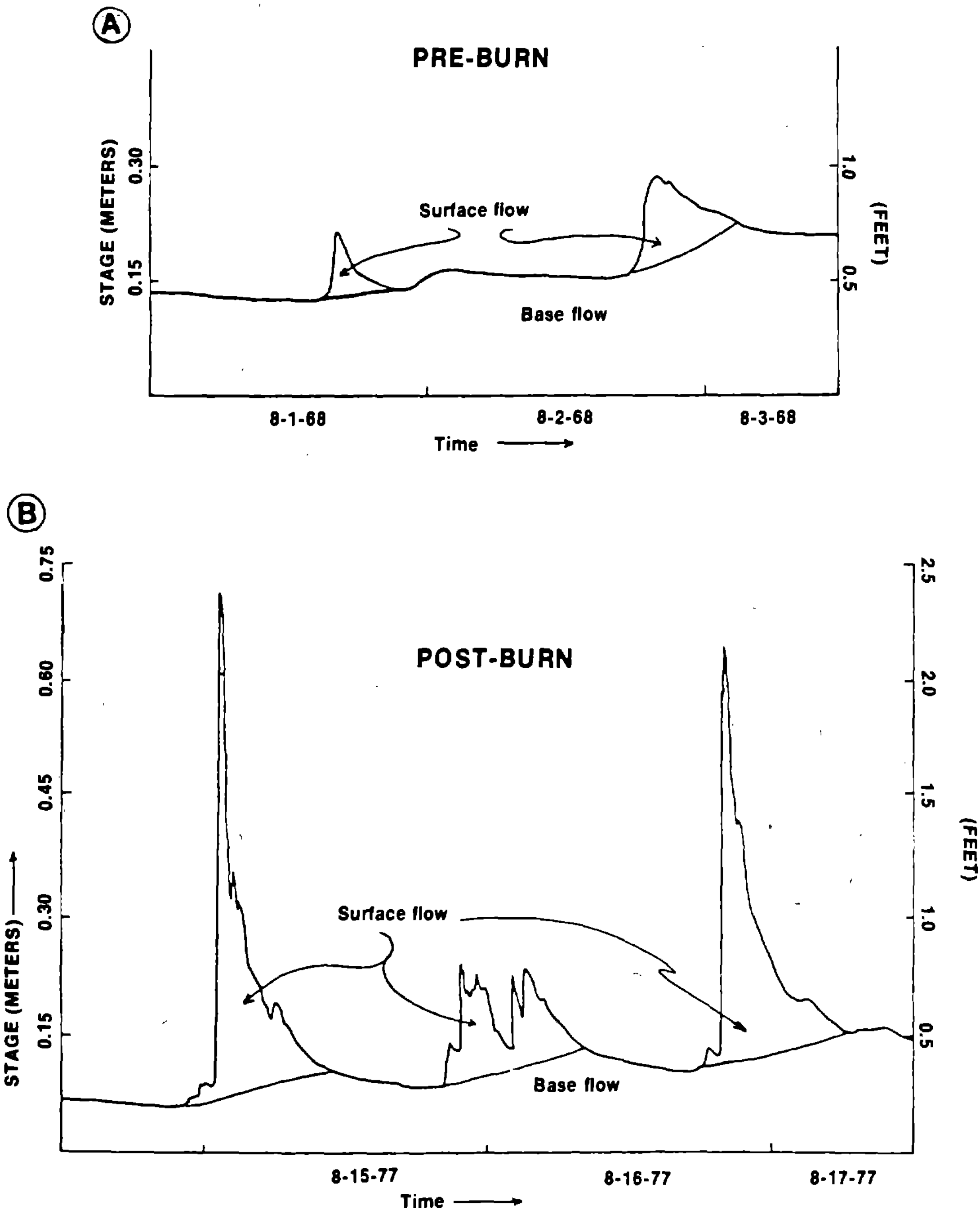

Fig. 7. Hydrographs of pre- and postburn streamflow for the Rito de Los Frijoles.

Postburn runoff is more flashy; that is, the flood peak is sharp, with steep limbs displayed on the hydrograph. The postburn hydrograph illustrates a much larger surface runoff component, whereas the preburn hydrograph has a greater base-flow component (Figs. 7A, 7B). Vegetation and forest litter retard overland flow and promote infiltration. Compared with the postburn case, the presence of vegetation in the preburn case gives rise to a reduced runoff peak and a large base flow that will recharge the stream for a longer period following the runoff event. In the postburn case, the removal of large areas of vegetation from the catchment areas produces a large surface-runoff component that results in a rapid rise and fall in stage. Without the retarding influence of vegetation, in addition to many other fire-induced factors, there is little infiltration.

The variability of the stream flow can be demonstrated by a flow-duration curve (Gregory and Walling 1973). The flow duration curve displays the frequency at which flows of various magnitudes are equaled or exceeded. Figure 8 is a plot of the preburn and postburn flow-duration curves.

The departure of the postburn trend from the preburn trend further illustrates the impact of La Mesa fire on the hydrology of the Frijoles Canyon watershed. Figure 8 indicates that 60% of the time the postburn discharge of the Rito de los Frijoles is greater than the discharge of the same frequency for the preburn record. Futhermore, 10% of the time the flow of the postburn record exceeds the 0.1% frequency event of the preburn record. Figure 8 indicates that the high-frequency events are smaller since La Mesa fire.

The 3 years of postburn stream-flow records exhibit distinct changes from the trend of the 6-year preburn record. With time, the difference between the lines in Fig. 8 should diminish. The postburn flow-duration curve will approach the preburn flow-duration curve based upon the fact that the study basins

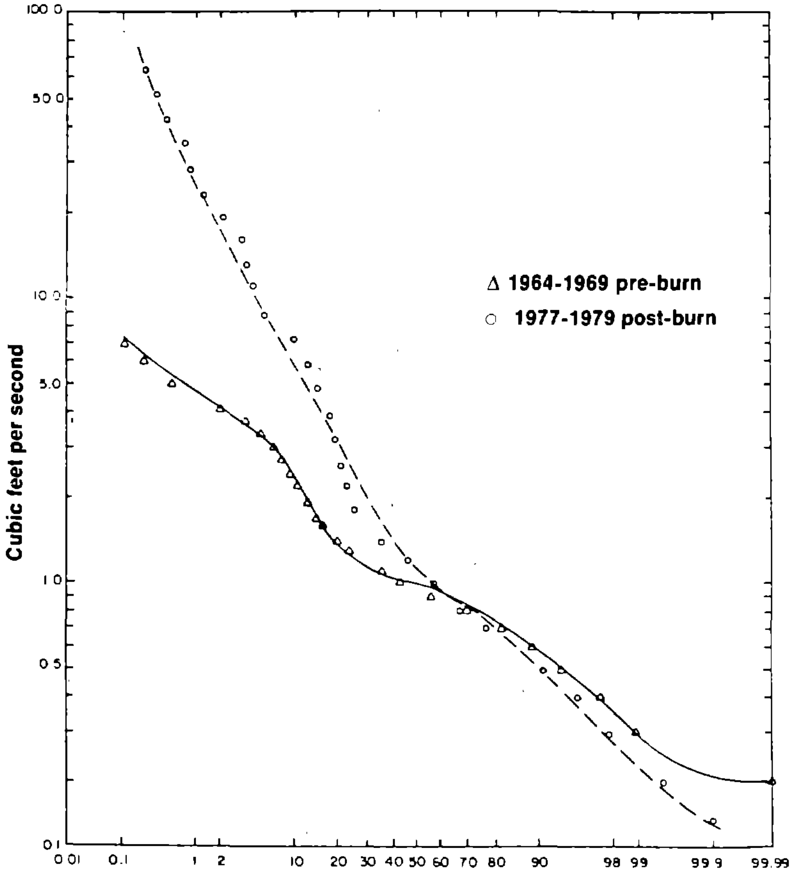

Fig. 8. Flow-duration curves for the pre- and postburn records of the Rito de los Frijoles.

have experienced a net aggradation during the third year after the fire ($\bar{\Delta}$/yr of Table II). The net aggradation is a result of the regrowth of vegetation. The vegetation will increase in density, providing greater obstruction to overland flow and promoting infiltration. A 5-year period is considered a minimum time required to accurately depict the long-term adjustments of the hydrologic behavior of a watershed to altered environmental conditions (this information provided by B. Dean, 1980). Irregularities of the postburn flow-duration curve may be a reflection of the brevity of the record.

VII. PREDICTION OF GEOMORPHIC ADJUSTMENTS IN NONINSTRUMENTED WATERSHEDS

A. Morphometric Analysis

Differences in drainage pattern, drainage density, and stream bifurcation permit the subdivision of the Frijoles Canyon watershed into physiographic sections (Fig. 9). The west and east forks of the headwater physiographic unit have developed a different drainage pattern than the mesa-top physiographic region (north and south canyon). The headwater region has a dendritic to subparallel drainage pattern because of the long slopes of the volcanic domes. The mesas have a dendritic to trellis pattern. The dendritic

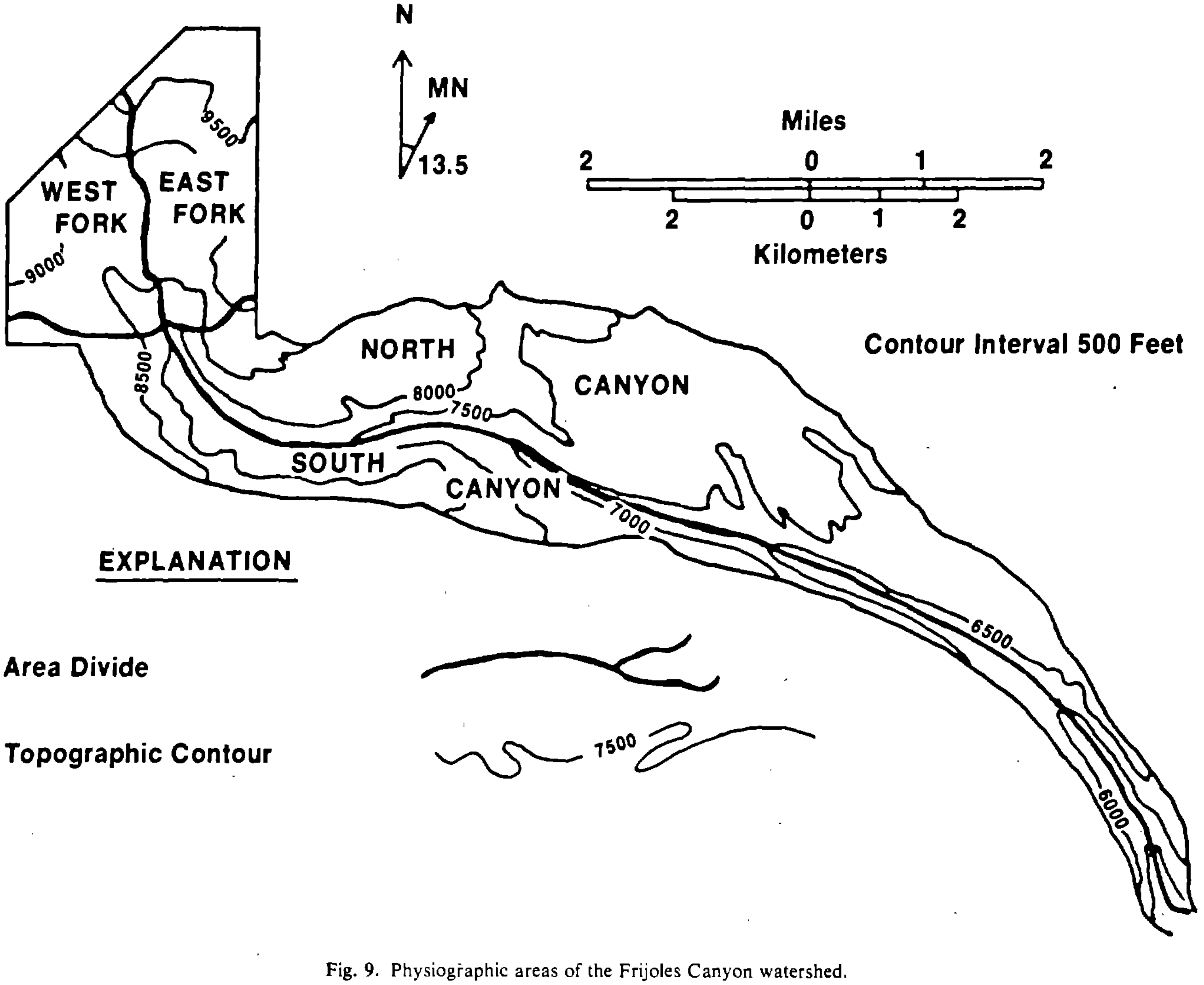

Fig. 9. Physiographic areas of the Frijoles Canyon watershed.

drainage pattern is a result of the homogeneity of the bedrock. The trellis drainage pattern is due to the numerous first-order stream segments draining the mesa-side slopes, joining trunk canyons at nearly right angles. The north canyon area (Fig. 9) can be distinguished from all other areas by (1) greater number of stream segments for all stream orders, (2) shorter first-order streams, and (3) longer high-order streams (Table III).

Table IV is a summary of the drainage density and bifurcation ratios [the ratio of the number of streams of given order (n) to the number of streams of the next highest order (n + 1)] for each area. The range in drainage density and weighted-mean bifurcation ratio is small because of the near homogeneity of the lithology of the watershed.

The headwater areas have high relative drainage densities and low bifurcation ratios because of the domal features of the caldera rim. The first-order drainages are closely spaced (subparallel) on the domal slopes and are elongate, giving rise to the low bifurcation ratios.

The mesa-top areas have relatively lower drainage densities and high bifurcation ratios. The low drainage densities are due to the low relief (relative to the headwater areas) of the mesa-top catchments, and larger areas of canyon wall with no mesa-top catchment contributing surface runoff to the canyon wall (south wall of Frijoles Canyon, especially in the lower basin). The high bifurcation ratios are a result of the low relative relief of the mesa tops and are a reflection of a high number of stream segments within the mesa-top catchments (Table III).

B. Landscape Susceptibility

Morphometric analysis yields relationships that define landform components that are most susceptible to erosion. The morphometric analysis of the Frijoles Canyon watershed indicates many first-order drainages dissecting the gently to moderately sloping mesa tops of the north canyon area. This is reflected by a high bifurcation ratio (Table IV). The high number of short first-order stream segments efficiently deliver sediment from hillslopes to higher order streams. At the scale with which the analysis was conducted, the axial drainage below the confluence of the BMMOD and BMINT study basins is a first-order stream segment. At the scale of field instrumentation, the drainage line is fourth order. Cut and fill processes are documented by the chain transect traversing the axial drainage. The cutting and filling of the channel indicates that the drainage network is efficient in delivering sediment to the trunk ephemeral drainage line.

TABLE III. Summary of Linear Parameters of Morphometric Analysis of the Rito de los Frijoles Watershed System

Drainage Area		Stream Order				
(km^2)		1	2	3	4	5
East Fork, 6.01	No. segments	204	48	12	3	1
	Total length	41.35	8.53	4.34	1.29	3.22
	Mean length	0.20		0.43	0.43	
North Canyon, 27.79	No. segments	1177	252	40	7	1
	Total length	164.44	50.21	29.6	10.94	6.6
	Mean length	0.12	0.20	0.74	1.56	
West Fork, 4.96	No. segments	178	40	11	3	1
	Total length	32.02	9.81	4.67	2.57	1.79
	Mean length	0.18	0.24	0.42	0.86	
South Canyon, 11.45	No. segments	32	73	16	2	
	Total length	56.79	18.35	7.07	2.25	
	Mean length	0.17	0.25	0.44	1.12	

TABLE IV. Drainage Density and Bifurcation Ratios for the Physiographic Areas of the Frijoles Canyon Watershed

Area	Drainage Density (km/km^2)	Weighted-Mean Bifurcation Ratio
East Fork	9.77	4.86
West Fork	10.22	5.13
North Canyon	9.42	5.97
South Canyon	7.38	5.54

The north canyon is the largest area (55%) of the Frijoles watershed and comprises upper and lower mesa segments. As discussed earlier, the upper mesas have stabilized within two growing seasons after La Mesa fire. The lower mesas are dissected by a high number of short first-order stream segments, which is an indication that the lower mesa of the north canyon area is the landform component most susceptible to erosion. The south canyon area contains segments of upper mesas only.

The north canyon area is cut by long trunk-drainage lines. The long trunk ephemeral drainages provide temporary storage of fire-associated sediment that is rapidly flushed to these drainage lines by short first-order stream segments. These trunk ephemeral drainages are, therefore, the second most susceptible landform component affected by La Mesa fire. Heavy precipitation in the north canyon area will produce large volumes of storm runoff and sediment yield. The confluence of the ephemeral tributaries draining the north canyon area with Frijoles Canyon occur primarily in the lower part of Frijoles Canyon, above the Monument headquarters. The concentration of large floods occurs in lower Frijoles Canyon, and correspondingly, the modern floodplain in lower Frijoles Canyon is the third most susceptible landform to fire-induced changes.

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THE EFFECT OF LA MESA FIRE ON TOTAL SOIL NITROGEN IN BANDELIER NATIONAL MONUMENT, NEW MEXICO

C. E. Freeman*

I. INTRODUCTION

Nitrogen availability in ecosystems is often a critical or limiting factor regulating plant growth and productivity on a site (Hellmers et al. 1955). Typically, nearly all (70-98%) ecosystem nitrogen is in the soil. This is true from deserts to the more mesic grassland and forest ecosystems (Welch and Klemmedson 1975, Rodin and Bazilevich 1967). Most of the rest of the nitrogen is in the standing crop of the producers. Any environmental factor that can cause substantial loss of nitrogen from an ecosystem, then, can greatly influence productivity and succession on a site. One such factor is fire.

Nitrogen in both the soil and standing crop is readily volatilized by heat and lost from the ecosystem (Debell and Ralston 1970, White et al. 1973). Significant amounts of nitrogen can be lost as gas at temperatures above 300°C, and temperatures above 700°C can easily volatilize substantial amounts (Debell and Ralston 1970). Because the largest concentrations of soil nitrogen are near the surface, a considerable portion of the total soil nitrogen may be lost during a fire. Large variations in maximum soil temperature and duration of soil heating can occur over small distances because of different fuel loadings and local burning conditions (Debano et al. 1979).

The large and destructive La Mesa fire swept through the ponderosa pine forests in Bandelier National Monument, New Mexico, between June 16, 1977, when the fire began in the adjacent Santa Fe National Forest, and June 23, 1977, when the fire was finally extinguished. This study estimated the effects of La Mesa fire on total soil nitrogen and gathered data on the nitrogen content of similar soils from unburned regions.

II. METHODS AND MATERIALS

The areas studied were Frijoles Mesa (a piñon-juniper community that did not burn), and Burnt and Escobas Mesas (which supported ponderosa pine communities). Within each major sampling area, several sample sites were located. These were designed in all cases to cover as many kinds of sites as were available in that area. Consequently, some sites were unburned, others moderately to severely burned. These latter categories were estimated by tree mortality. If there was appreciable survival, the site was classified as moderately burned. If there was no survival, it was severely burned.

Each sampling site was 10 by 10 m, and from this area, nine subsamples were collected. Subsamples were collected at the corners of the plot, at the center, and midway between the corners and the center. This was done to estimate variability within each site. Soil subsamples were from the upper 5 cm of the mineral soil (in the A horizon) and were obtained by pushing a cork-borer to that depth into the soil. Individual subsamples were placed in polyethylene bags for transport. Sampling dates were May 31 and June 1, 1978, approximately 1 year after the fire.

Samples were dried for 24 hours at 70°C and sieved through a #100 soil screen. Soils were analyzed for total soil nitrogen using a semimicro Kjeldahl technique modified to include nitrates (Bremmer 1965).

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Data were compared using one-way analysis of variance. All percentage data were transformed to arcsins for analysis.

III. SITE DESCRIPTIONS

A. Frijoles Mesa

The sampling sites on Frijoles Mesa are located in a gently rolling piñon-juniper community at an approximate elevation of 6600 feet. Occasional clearings and ponderosa pines occur in the woodland. All Frijoles Mesa sites were unburned.

Site A is located on the Tyuonyi Overlook trail in a clearing and is an abandoned field used by the paleo-Indian inhabitants of the cliff dwellings. The site is dominated by blue grama (*Bouteloua gracilis*), black grama (*Bouteloua eriopoda*), estafiata (*Artemisia frigida*), snakeweed (*Xanthocephalum* sp.) and Indian paintbrush (*Castilleja* sp.).

Site B also is in a clearing in the piñon-juniper woodland. A few ponderosa pines (*Pinus ponderosa*) are nearby. The sample area is dominated by blue grama, snakeweed, and mullein (*Verbascum thapsus*).

Site C, located on a south-facing slope, is higher in elevation than sites A and B. Vegetation is dominated by piñon (*Pinus edulis*), one-seed juniper (*Juniperus monosperma*), Gambel oak (*Quercus gambelii*), wavy leaf oak (*Quercus undulata*), and mountain mahogany (*Cercocarpus montanus*).

Site D, on the south edge of the mesa, is dominated by piñon, juniper, Gambel oak, and mountain mahogany. The soil is very rocky.

Site E is nearly level and dominated by piñon, juniper, blue grama, and snakeweed.

B. Burnt Mesa

The Burnt Mesa area, at approximately 7250 feet, is higher than Frijoles Mesa and is covered by ponderosa pine forest. This area, burned during La Mesa fire, contained sites ranging from unburned to severely burned.

Site A/u was unburned and along State Road 4. The vegetation at this site is dominated by ponderosa pine, blue grama, Indian paintbrush, annual sage (*Artemisia*), and peavine (*Lathyrus* sp.). The site is relatively level.

Site A/b is near A/u but was burned and nearly all trees were dead. The litter layer also had been consumed. Species found on this site were lupine (*Lupinus* sp.), Indian paintbrush, annual *Artemisia*, mullein, and blue grama.

Site B/b is in a lightly burned ponderosa forest. Most trees seemed likely to survive. Dominant species were ponderosa pine, Gambel oak, Indian paintbrush, fleabane (*Erigeron* sp.), peavine, and beardtongue (*Penstemon* sp.).

Site B/severe was severely burned. No trees survived and there is little growth of any kind on this site. A single Gambel oak had managed to sprout from the soil almost a year after the fire. The litter layer was consumed.

C. Escobas Mesa

Escobas Mesa also supports a ponderosa pine forest through which the fire swept, but, at approximately 7350 feet, is a bit higher in elevation than Burnt Mesa.

At site A/light burn, larger ponderosas survived the fire and some litter was left on the soil surface. Some grass (*Muhlenbergia* sp.) was growing on this site.

Site A/b, in a stand of nearly completely killed ponderosas, is a severe burn. The site was air-seeded with western wheatgrass (*Agropyron spicatum*) and fescue (*Festuca*).

At site B/severe, no trees survived and litter was consumed. Charcoal littered the surface of the mineral soil. The only plants present were the air-seeded grasses.

Site C/u was not burned in La Mesa fire, but it was lightly burned in 1976. This site represented an opportunity to see if nitrogen content had recovered significantly in 2 years.

Site D/u has not been burned in at least the last 30 years. It is an open grassland clearing in the forest with young ponderosa pines. This site is probably in a successional stage toward a ponderosa forest after a fire some time ago. Dominant vegetation included estafiata, grama grasses, fleabane, and lupine.

IV. RESULTS AND DISCUSSION

The raw data are summarized in Table I. Total soil nitrogen increased with elevation on the unburned sites, probably because of the higher organic matter content of soils in more mesic areas.

Sites B, C, D, and E on Frijoles Mesa were not significantly different; however, site A was significantly ($P < 0.001$) higher in nitrogen than the other Frijoles sites. This was a cliff-dweller field, and it is not clear whether this elevated nitrogen content is due to ancient fertilization, cultivation of nitrogen-fixing legumes (such as beans), or other factors.

Sites on Burnt and Escobas Mesas are very similar and, in general, showed the same trends. Unburned sites in ponderosa forests on both mesas contained about 0.16% nitrogen. Burning reduced total soil nitrogen by about 50 to 65%. These observations are in excellent agreement with the data of White et al. (1973) for soils under ponderosa forests in the Black Hills of South Dakota and those from the same locality heated in the laboratory to simulate forest fire conditions (above 200°C). These data also agree with the findings of Debano et al. (1974) and Knight (1966), and suggest the surface soil on many Bandelier sites must have been heated to about 700°C. Two other interesting observations are (1) Burnt Mesa sites A/u and A/b are not significantly different in total nitrogen and (2) other burned sites show about the same amount of nitrogen reduction, whether lightly burned or severely burned. In addition, the site lightly burned in 1976 was comparable in soil nitrogen with those sites burned in 1977. It is known that recovery of nitrogen content to prefire levels requires 15 years or more (Viro 1974).

I believe that these observations may be explained by the speed with which fire moves. A rapidly moving crown and surface fire might well consume the litter layer and kill all trees and still heat the mineral soil less than a slower moving surface fire that does not result in severe tree mortality because soil temperature is the critical factor in the volatilization of nitrogen.

The subsample variability in nitrogen on unburned sites is also interesting. In a small area, such as the 10- by 10-m study area used here, nitrogen levels might be expected to be rather uniform. Perhaps nitrogen content and availability are responsible for the vegetation mosaic commonly observed on the forest floor.

Fire is one of the basic abiotic factors that have influenced plant communities over long periods of time (Mutch 1970). Some plant communities even seem to require periodic fires to maintain themselves. Two such communities in the western United States are the chaparral community type of southern California (Debano et al. 1979) and the ponderosa pine forests of the southwestern mountains. The nutrient changes in soils after fires are critical in understanding the fertility of such soils. Total soil nitrogen is commonly greatly reduced after fire treatment. Site degradation is very important in ponderosa forests because they grow on relatively infertile soils. In addition, water balance problems and leaching of the remaining soil nutrients after fire damage complicate the successional process and site management.

On the other hand, removal of considerable amounts of litter helps release more nitrogen from the soil to the plants because conifer litter is generally 1-2% nitrogen but very carbon (carbohydrate)-rich. The carbon:nitrogen ratio in these situations is often above 20, which means that decay microorganisms compete with the vascular plants for available nitrogen, with the result that the plants show symptoms of nitrogen deficiency (leaf chlorosis and/or slow growth rates). Fires reduce the carbon:nitrogen ratio and help prevent nitrogen starvation. The input of inorganic nitrogen apparently is sufficient to cause greater

TABLE I. Total soil N on sites studied. Some material from Escobas Mesa was lost before analysis.

	Frijoles Mesa					Burnt Mesa				Escobas Mesa				
	A/u	B/u	C/u	D/u	E/u	A/u	A/b	B/b	B/s	D/u	C/b	A/b	A/1b	A/b
1	0.1053	0.0722	0.1344	0.0482	0.0882	0.1623	0.1576	0.1064	0.0860	0.1434	0.0638	0.0711	0.0504	0.1232
2	0.0872	0.0722	0.0918	0.0630	0.0784	0.1568	0.1823	0.0714	0.0714	0.1436	0.0638	0.0672	0.0392	0.098
3	0.1064	0.0631	0.0642	0.0638	0.0745	0.1708	0.1921	0.0756	0.0882	0.1532	0.0493	---	0.1036	---
4	0.1555	0.0939	0.1022	0.1000	0.0966	0.1364	0.1551	0.0644	0.0938	0.1719	0.0476	---	0.0515	---
5	0.1764	0.1008	0.0700	0.0734	0.0834	0.1750	0.1649	0.0784	0.0694	0.1840	0.0647	---	0.1126	---
6	0.1044	0.0854	0.0882	0.0678	0.0633	0.1655	0.1666	0.0834	0.0899	0.1932	0.0543	---	0.0630	---
7	0.1190	0.0714	0.0854	0.0756	0.0798	0.2010	0.1476	0.0784	0.0871	0.1935	0.0521	---	0.1064	---
8	0.1126	0.0748	0.1562	0.0658	0.0720	0.1201	0.1179	0.0882	0.1117	0.1845	0.0582	---	0.0812	---
9	0.1924	0.1263	0.0686	0.0876	0.0904	0.1518	0.1512	0.0588	0.0874	0.1344	0.0546	---	0.0812	---
$\bar{X}\%_N$	0.1288	0.0845	0.0960	0.0717	0.0807	0.160	0.159	0.0783	0.0872	0.1669	0.055	0.0692	0.0797	0.1110
var	0.00135	0.00039	0.0095	0.00023	0.00010	0.00054	0.00045	0.00019	0.00015	0.00055	0.00033	---	0.0085	---
std dev	0.0367	0.0198	0.0307	0.0151	0.0102	0.0231	0.0213	0.0139	0.0123	0.0234	0.0057	---	0.292	
std error	0.0122	0.0066	0.0102	0.0050	0.0034	0.0077	0.0071	0.0046	0.0041	0.0078	0.0019	---	---	---
Decrease in N after fire (%)	---	---	---	---	---	---	0	51	45.5	---	67	---	52.3	---

site productivity over the long run with periodic fires. Clearly, however, if these fires are confined to the ground, tree growth is improved, whereas destruction of the tree canopy by a crown fire makes the site susceptible to massive erosion.

Ponderosa has a quick-growing taproot that gives drought resistance (Fowells 1965) and is, therefore, a strong open-site competitor where it is an invader species of early successional stages (Lambert 1980). The evergreen habit, characteristic of stress-tolerant species occurring on infertile soils, allows the plants to store scarce nitrogen in the leaves and reduce loss of this critical nutrient through leaf fall. Perhaps these strategies allow ponderosa to dominate sites that are chronically nitrogen-poor because of fire.

Using a Markovian model based on potential replacement rates in the understory of mature ponderosa forests, Lambert (1980) predicted that without fire ponderosa would suffer a dramatic decrease in future importance on sites in the Sacramento Mountains of southern New Mexico.

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EFFECTS OF LA MESA FIRE ON BANDELIER'S CULTURAL RESOURCES

Diane Traylor

The worlds of firefighters and archeologists seem unrelated. Yet fire suppression and cultural resource preservation are compatible, and the means for integrating the two have been tested.

In June 1977, during a forest fire in Bandelier National Monument and adjacent Federal lands, archeologists attempted to assist firefighters in reducing or preventing damage to cultural resources. A hastily called team of archeologists, reminded of past destruction of archeological sites by firefighting machinery, organized a plan to monitor handline construction and bulldozer activities during La Mesa fire. This unique opportunity resulted in positive action during the fire and led to a follow-up study of the effects of fire and fire suppression on archeological sites.

Beginning on the second day of La Mesa fire, the Southwest Regional Office of the National Park Service sent archeologists from the Cultural Resources Center in Santa Fe to accompany bulldozer operators and handline crews and watch for structural and nonstructural archeological sites along the firelines. Whenever possible, we steered heavy equipment and hand tools away from the sites by using flagging and verbal signals.

A postfire survey showed that, although we succeeded in preventing damage to sites during initial line cuts, damage and destruction did occur during subsequent line widening, rehabilitation, and reseeding because we were not informed of these activities. This proved that timely communication with the fire command is essential, and that the archeologists must understand all procedures involving firefighting equipment.

To record just how the fire and fire suppression had affected archeological sites in Bandelier, five Park Service archeologists conducted a sample survey along a 37.5-m-wide corridor of all handlines and catlines, and in safety zones, fire camps, and heliports, as well as mop-up areas adjacent to them. Surface ceramic and lithic collections were made at several sites and examined later for fire damage.

The survey cut a meandering path across the Monument's three major canyons and the broad, gullied mesas that characterize the Pajarito Plateau, of which Bandelier is a part. Elevations range from 1950 to 2880 m. During the fire, handlines were used exclusively in the back country west of Frijoles Canyon. One extensive handline was cut from State Road (SR) 4 to the rim of Frijoles Canyon and up a rugged slope on the opposite side near the fire's origin. A few smaller handlines connected sections of catline or surrounded isolated burn areas. In more accessible areas, existing fire roads and highways were used or expanded with caterpillar tractors to create larger fire breaks. In addition to the firelines survey, two biological transects were made within the burn. Recording sites here helped complete an inventory of natural and cultural resources.

When the survey was complete, four sites were chosen for excavation to examine any subsurface damage to specific artifactual and ecofactual materials. Samples sent to consultants for examination included tree-ring, pollen, flotation, soil, faunal, archeomagnetic, carbon-14, thermoluminescent, and obsidian.

Of the 100 sites recorded during the survey, 44 were damaged by fire suppression. This damage ranged from erosion caused by removal of topsoil in or around a site (from handline construction) to total site destruction (by caterpillar tractors during line rehabilitation). Some of these effects were temporary, but three permanent effects were (1) destruction of architecture with resulting loss of internal information, (2) displacement of surface and subsurface artifacts, and (3) destruction of artifacts. Most hand operations avoided the first and third effects but displaced the location of site artifacts. Exact location of artifacts is important information in archeological surveys and excavations.

At a few sites, especially those in and around heliports and camps, some disruption of surface artifacts occurred when fire crews collected sherds and lithic materials. However, most materials were returned to the site when archeologists on the fireline explained the Antiquities Act and the importance of leaving artifacts *in situ*. Such collection is not uncommon in ordinary situations but was greatly intensified by the greater number of people present during the fire. The fire crews showed great interest in helping to preserve Bandelier's cultural sites and helped line archeologists spot and avoid them.

Occasionally, brush cleared from the lines had been piled directly on top of a site, making it difficult to see during the survey and increasing the chances of additional damage in another fire.

Some minor disruption of sites occurred while clearing heliports. In a few cases, small stones were collected from the sites and arranged as numbers to designate the landing spots. The stones were spray-painted orange to be more visible. In no case, however, were walls dismantled for this purpose.

The most serious damage to sites occurred during catline construction and rehabilitation. Many of the lines were built at night, which required the archeologist to walk ahead of the cat, his field of vision provided by its headlights, looking for sites, tagging them, and yelling their locations back to the operator, while choking from dust, trying not to trip into the blade's path, and hoping the fire would not suddenly change direction. Although this worked fairly well for the lead cats, the construction procedure had not been fully explained to the archeologists, and so cats followed along behind and widened the lines and bulldozed sites that had been marked. In the confusion, no one had thought to tell the other operators that the red flags marked archeological sites and not the line to be cut. Two important lessons were (1) archeologists must be present during all cat activity, and (2) distinct flags must be used for archeological sites and their significance made known to the whole operation.

After the fire, fire lines were rehabilitated and later reseeded. Material pushed out to form the fire line was pushed back in, and sites located on the perimeter were sometimes demolished by the cat blades. The main problem was that the fire archeologists did not have adequate information on procedures. Section c, nearest the residential area at Bandelier, underwent the most serious work because it was a new cut. Existing roads on Burnt and Escobas Mesas had been used for access and did not require as much rehabilitation as that in section c.

Other fire suppression techniques did not seem to have serious impact on archeological sites. Slurry left a temporary stain on artifacts and architecture but washed off in succeeding rainstorms. Mop-up, which was believed a major source of damage to sites before the survey, damaged only three sites by cutting out roots. Although the resulting holes did not destroy architecture, they did disturb the internal integrity of these sites. The postfire survey crew saw little damage caused by mop-up.

Fire damage to sites ranged from very light to severe. Surface indications noted during the survey were studied in more detail during the excavations.

Fire intensity and heat duration and penetration into the soil were seen as the major causes of damage, but these determinations were difficult to make by surface observations. Furthermore, some areas were not surveyed until almost a month after the fire, and vegetation had recovered in some of the lightly burned areas, making it hard to determine fire intensity. In lightly burned areas with grass fuel, fire temperatures probably ranged from 100-300°C. In moderately burned areas of mainly piñon-juniper fuel, the temperature may have reached 300-500°C. The most severely burned areas, where high concentrations of ponderosa occurred, may have reached 800°C. In very small areas where pitchy roots burned, the heat may have reached 1500°C. Exact temperatures were not recorded during the fire.

Beyond discoloring the exposed stone, the most severe damage to site architecture on the surface was spalling, fire cracking, and increased friability of the tuff construction blocks so that some crumbled when picked up. Although tree-ring evidence in the severely burned area showed that fire has occurred approximately once every 20 years, it is improbable that a fire as intense as La Mesa had ever occurred here. Years of fire suppression had built up a heavy fuel load. Further consequences to sites, artifacts, and ecofacts were not completely understood until results of the test samples from the excavation were returned. Other effects, such as soil erosion, may not be known for years to come.

Artifacts on the surface were directly affected by relative fire intensity. Ceramic surfaces were either carbonized or oxidized. Some had a shiny black residue burned onto their surfaces and others exhibited fireclouding. In severely burned areas, most sherds could still be identified as to type, but some surface designs were completely obliterated and the core interior color was changed. Heat caused some paint to spall. In some cases, natural weathering may have caused some of the effects, but because no prefire comparison exists, it is impossible to attribute all the changes to the fire.

There was surface residue on both basalt and obsidian that had been exposed to the fire. A dull carbon patina appeared more commonly on surface obsidian than on basalt. A shiny residue replete with bubbles occurred in crevices and flaked areas of basalt from the most severely burned site examined. Whether these effects were caused by heat exposure or the burning of pitchy forest litter is unknown.

Results of specific tests on these datable materials revealed the effects of heat on surface as well as subsurface artifacts. Thermoluminescent values were measured for basalt and pottery sherds from three excavated sites. Surface sherds registered ages 24% lower than expected, compared with relative pottery chronology at the most severely burned site, LA 16097. One of the two surface sherds fell within the 5% error tolerance, but a sherd from the second stratum produced a lower age than expected. Because this sherd was within the 5-cm penetration depth of probable heat damage (and the fire burned very hot here), this sample was also affected. It is not known why the surface sherd was seemingly unaffected unless it was somehow protected. In contrast, at LA 16114, where fire damage was much less severe, the thermoluminescence response was reduced by only 10%. Although some of the age reduction may have been caused by surface exposure, the fire moving over the ground surface apparently directly affected the samples.

Obsidian was likewise affected by heat, especially above 400°C. A comparison of pieces from the most severely burned site and a site not burned by La Mesa fire showed that only 35% of 110 edges in the first group had measurable rinds, whereas 70% of 138 edges of the second group could be measured. Both groups showed the effects of heat alteration. It was suggested that the high temperature occurring in LA 16097 had nearly obliterated the rinds from surface obsidian while the comparison group seemed to be recovering from a similar past incident.

Samples of subsurface obsidian from La Mesa fire sites and from sites excavated in Alamo Canyon in Bandelier showed few pieces affected by heat. Thus, this material shows the advantage of a more protected location. Ethnobotanical remains were virtually unaffected by La Mesa fire in the sense that they could still be separated from burned material. One means of separating archeological plant remains was by noting the condition of charcoal in the sample and the species composition. Archeological charcoal was thoroughly carbonized and more friable than recent charcoal, which was harder and varied in degree of combustion. The condition of masonry and artifacts and making a record of plants on the surface of a site and vicinity to compare with prehistoric samples helped determine past fires that may have affected a site.

The pollen analysis indicated two important points for archeologists: (1) pollen is destroyed at 300°C, and (2) surface samples should be collected before pollinating plants have a chance to deposit fresh pollen in the area. The latter was evident in the large amount of well-preserved pollen deposited on a surface sample from a severely burned site. None of these pollen grains was burned, which indicates that all previous surface pollen was destroyed. Of 14 samples submitted, only this surface sample, one from a hearth 40 cm below ground, and one from 10 cm below ground from another site, had adequate pollen counts. The other samples did not contain well-preserved pollen, a condition that was constant regardless of depth. These pollens were counted and identified for prehistoric evaluation.

Only two poorly preserved tree-ring samples were taken from the excavations. Both came from subsurface locations and were judged unaffected by La Mesa fire.

Radiocarbon samples could be dated but, because there were no comparative prefire samples, effects of the fire could not be determined. Results of soil and archeomagnetic analyses are unavailable as yet, and the one faunal sample recovered during the excavations provided very little data.

Although this study did not have previous survey information or comparative prefire data, it provided some interesting pioneer work. The results of the survey, excavations, and detailed accounts of the analyses are reported in a report in press. Much of the credit for completion of this report is due the other three authors who were also part of the field crew: D. Traylor, N. Wood, B. Fiedler, and L. Hubbell.

In addition to the evaluation of the effects of fire and fire suppression on cultural resources, the methods used by archeologists and resource managers were evaluated to assist them in future wildfires and prescribed fires.

The following recommendations, based on the La Mesa fire study, are made to mitigate fire's adverse effects on cultural resources and include proposed actions for resource managers in fire management programs.

1. The most important function is timely and accurate communication with all parties.

2. Each resource area manager should establish and inform all parties of policy and priority for his/her resource area. In the event of wildfire, fire bosses should be advised of area policy to avoid confusion and interference in fire fighting. Interagency managers should be invited to periodic symposiums so that current policy is explained.

3. Resource area managers should maintain resource base maps showing exact site locations to be provided to archeologists and fire bosses.

4. When cultural resources may be threatened by either wildfire or controlled burns, archeologists should be present to mitigate fire, fire suppression, and rehabilitation effects on those resources.

5. Bulldozer line construction must be monitored carefully because it can be the most destructive of the fire control functions. Handlines, heliports, fire camps, and mop-up areas should also be closely monitored.

6. All archeologists on fire duty should have completed a certified course on fire behavior and hold a current red card. They should also know basic first aid and be competent in the use of topographic maps.

7. Each area or agency should provide interested archeologists with the opportunity to receive fire training and should form a well-trained core of archeologists from all available institutions and agencies to serve on a stand-by basis during the fire season. The 27 000 lightning or man-caused fires occurring annually in the western states proves the need (Sanderson 1976). If qualified local archeologists are unavailable for duty, archeologists from neighboring areas or trained park personnel should be present during all fire suppression and rehabilitation activities.

8. An archeological liaison officer(s) should coordinate all activities of line archeologists with fire bosses, especially when more than one agency is involved.

9. A line archeologist should be briefed on his/her duty area and know his/her function on the line. He/she should communicate with the appropriate field boss at the beginning of each shift and know the function of the field boss. Archeologists should follow fire line rules and stay with assigned crews. If it is necessary to leave the line, the line official should be notified.

10. Communication with coordinating archeologist(s) should be maintained to provide adequate line coverage.

11. Special flagging and pin flags in a color other than the bright red and orange commonly used by fire crews should be used to mark sites, and everyone concerned with the fire should be aware of what that color means. During La Mesa fire, flagging during construction sometimes meant only initial avoidance of a site. Therefore, especially when heavy equipment is used, an archeologist should be present.

12. Line archeologists should be equipped with standard safety equipment including fire shirt, hard hat, goggles, leather gloves, Vibram-soled boots, fire shelter, headlamp, neckscarf, cotton underclothing, and a field notebook with the 10 standard firefighting orders.

13. When feasible, archeologists should photograph fire suppression activities to record both damage and avoidance of sites and to provide information for the fire record.

Fire control is the prime concern of the firefighter. Cultural resources may have to suffer surface impact from the fire, but little or no damage is necessary from fire suppression if archeologists are present during these activities. If there is no way to avoid a resource, the fire lines have priority, but usually damage can be averted. During La Mesa fire, Forest Service crews willingly cooperated in avoiding sites. On fire lines, some concessions may have to be made between the architectural part of a site and the cultural trash which may extend some distance away. This is especially difficult at night when many of the firelines are constructed. With handlines, avoidance is more feasible than with equipment that can create a 12-foot disturbance with one cut.

Removal of high-fuel-content vegetation from the tops of sites or their peripheries before a fire may help to avoid damage: frequently, clearance of overabundant trees and other plants on a site would leave little fuel to ignite during a fire.

Information on the impact of fire and fire suppression on cultural resources should become a routine part of a course at fire training centers so that firefighters will be aware of the possible encounter with archeologists and cultural resources. All agencies dealing with cultural resources should be informed of these problems and possible solutions.

The La Mesa fire study has made inroads into learning the effects of fire on surface and subsurface materials in the Bandelier area, but different problems may exist in other areas of the country. Prescribed burning may become a more common practice as a means of preventing large-scale fires such as La Mesa. Our study indicates a real need to develop specific guidelines regarding cultural resources in key National Park Service areas, and general guidelines for fire management throughout the Service. The following recommendations pertain only to prescribed fires.

1. In the development of a fire management program, consideration of all sensitive cultural resources within an area scheduled for prescribed burning is essential. Sample surveys, literature searches, assessments, or other mechanisms can provide baseline information with which the resource manager can predict how his cultural resources might be affected. Cultural resource base maps showing exact site locations should be maintained for planning prescribed fires or in case of wildfire. A complete inventory of cultural resources would be ideal, but any information that could be derived would be useful.

2. If a structure or site within a prescribed fire area is listed in the *National Register of Historic Places*, a Section 106 compliance procedure must be initiated before the prescribed fire. Discovery sites not listed in the *National Register* also must be protected.

3. During any fire, the four basic sources of damage to cultural resources are fire intensity, duration of heat, heat penetration into the soil, and use of fire suppression equipment. During prescribed burning these four elements will be minimized but the surface could be damaged depending on type and amount of vegetation located on an archeological site. The four elements will be minimized, using only minimal hand-lines for control, because fast-moving cooler fires burn only the understory vegetation. Also, postfire erosion that could alter the surface of prehistoric sites will be minimized during a prescribed fire. Use of heavy equipment and/or hand tools should be monitored to avoid direct impact on resources during construction of fire lines or in mop-up operations. During the testing period for prescribed fires, two possible approaches are (1) removing vegetation from the tops of archeological sites and their peripheries to lessen fire damage, and (2) surrounding specific sites with fire breaks. Security should be provided for above-ground historic resources, which are particularly vulnerable to both prescribed fires and wildfires. Surface wooden structures (log cabins, hogans, corrals, etc.) may be destroyed. During the tests for prescribed fires, wooden structures could be constructed and wet down before burning to see if this is a preventive measure.

4. Direct fire damage to artifacts appears to be mainly confined to surface materials. Ceramics are usually oxidized or carbonized by exposure to the fire, lithic materials (mainly basalt and obsidian) sometimes exhibit surface residues, and hydration factors can be affected. Surface pollen grains can be destroyed when temperatures are above 300°F. Further testing is needed on how to better preserve these and other surface materials.

5. Controlled testing during the prescribed fire testing program can determine surface temperatures, heat penetration, how to treat various surface materials, and how to minimize impacts to cultural resources. Evaluation/research funding for these tests should be included with that for initial prescribed fire testing programs. Ideally this should be an interagency-supported program for all the land-managing agencies (National Park Service, US Forest Service, Bureau of Land Management, and Bureau of Indian Affairs).

Until La Mesa fire, little attention was given to fire and fire suppression impact on cultural resources. La Mesa fire has shown that archeologists at a fire site can be a valuable asset. We hope that our experiences during this fire will provide the basis for useful ongoing research, and that policy can be established for all those involved with fire and fire management.

CHEMICAL QUALITY OF SURFACE WATER IN BANDELIER NATIONAL MONUMENT

by

William D. Purtymun

Perennial and intermittent streams have cut the surface of the Pajarito Plateau into a number of narrow southeast-trending mesas separated by deep canyons. Perennial surface flow occurs in Cañon de los Frijoles and in the upper and middle reaches of Alamo and Capulin Canyons (Fig. 1). Water quality data have been collected in Cañon de los Frijoles since 1957. After La Mesa fire, water quality data were collected in Cañon de los Frijoles and Alamo and Capulin Canyons to evaluate the effect of the fire on the quality of surface water (Purtymun and Adams 1980*).

I. CAÑON DE LOS FRIJOLES

Water samples have been collected from Cañon de los Frijoles at the Monument headquarters since 1957. The principal ions in the stream water are calcium and bicarbonate. The water is typical of mountain streams in the area with total dissolved solids (TDS) ranging from 80 to 170 mg/ℓ for samples collected before the fire in 1977. Variations in constituent concentrations occur with increased discharge from storm runoff, and the result is dilution of base flow (Fig. 2).

Debris washed into the stream after the fire caused a slight increase in calcium, bicarbonate, chloride, and TDS in base flow at the Monument Headquarters (Fig. 2). After the fire, TDS concentrations increased from 110 mg/ℓ in March 1977 to 215 mg/ℓ in July 1977. After July, the TDS concentrations declined slightly. Fluoride varied slightly, but showed no significant trend. These constituents in base flow have shown a general decline in concentration as the fire debris and ash are removed from the channel by continued runoff.

In July 1977, after the fire, water samples were collected from six stations above and below the burn (Fig. 1). These stations and one additional station were sampled again in June and July 1978. A graphic comparison by station of calcium, sodium, chloride, TDS, and bicarbonate of samples taken in 1977 shows a general increase in these constituents downgradient in the canyon. The largest increase occurs between Stations 5 and 6, where the stream enters the burn area (Fig. 3). Chemicals leached from the fire debris in the burn area enter the stream, increasing certain chemical concentrations. In 1978, the constituents increased at Station 6 (near Monument headquarters), then decreased slightly at the Rio Grande. A comparison of the samples taken in 1977 with those taken in 1978 shows considerable variation, but below Station 6 a general decrease in most concentrations is indicated.

Samples of base flow and storm runoff collected in Cañon de los Frijoles indicated that barium, calcium, iron, bicarbonate, manganese, lead, and phenol concentrations were elevated in storm runoff when compared to base flow (Fig. 4). Phenols are attributed to decay of vegetation. Other constituents,

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*William D. Purtyman and Howard Adams, "Geohydrology of Bandelier National Monument, New Mexico," Los Alamos Scientific Laboratory report LA-8461-MS (1980).

with the exception of lead, can be attributed to the runoff from the burn area. Lead could be from automobile emissions, as it was not reported in a similar runoff event in Capulin Canyon, which is remote from vehicle traffic (Fig. 3).

II. ALAMO CANYON

Three surface water samples were collected in Alamo Canyon in July 1977 and 1978 above, within, and downgradient from the burn (Fig. 1). The water contains principal ions of calcium and bicarbonate. A comparison of the water quality at the three stations in 1977 shows the effect of the burn, with a slight increase of calcium, sodium, bicarbonate, and TDS (Fig. 5). Analyses of samples collected in 1978 indicated a decrease in most of these constituents.

III. CAPULIN CANYON

Surface water below the burn in Capulin Canyon was sampled in 1977 and 1978 (Fig. 1). The base flow contains principal ions of calcium and bicarbonate. The concentrations of calcium, bicarbonate, and TDS generally increase downgradient in the canyon. The concentrations of these constituents decreased from 1977 to 1978 when compared at individual stations (Fig. 3).

Samples of base flow and storm runoff at Station 15 (Base Camp) were analyzed for barium, calcium, iron, bicarbonate, magnesium, manganese, lead, and phenols (Fig. 4). Barium, calcium, iron, and manganese concentrations were elevated during runoff events. Bicarbonate varied but showed no significant trend. Phenols and lead were below analytical limits.

IV. SUMMARY AND CONCLUSIONS

The chemical quality of surface water (base flow) in Cañon de los Frijoles changed slightly after La Mesa fire. The most noticeable change was an increase in calcium, chloride, bicarbonate, and TDS. Analyses taken over a 20-month period after the burn indicated a general decline in most of these constituents. Similar analyses of surface water in Alamo and Capulin Canyons indicated similar results over a 12-month period.

Analyses of samples of summer storm runoff compared with base flow samples from Cañon de los Frijoles and Capulin Canyon indicated that higher concentrations of barium, calcium, iron, bicarbonate, manganese, and phenols occurred in storm runoff than in base flow. The presence of lead in storm runoff in Cañon de los Frijoles may be attributed to lead in automobile emissions because it was not reported in a similar runoff event in Capulin Canyon, which is remote from vehicle traffic.

Precipitation and runoff from the burn area will remove the fire debris and the quality of water in the streams will return to normal. The past 2 years of data indicate that the water quality of base flow should return to normal within 3 to 5 years.

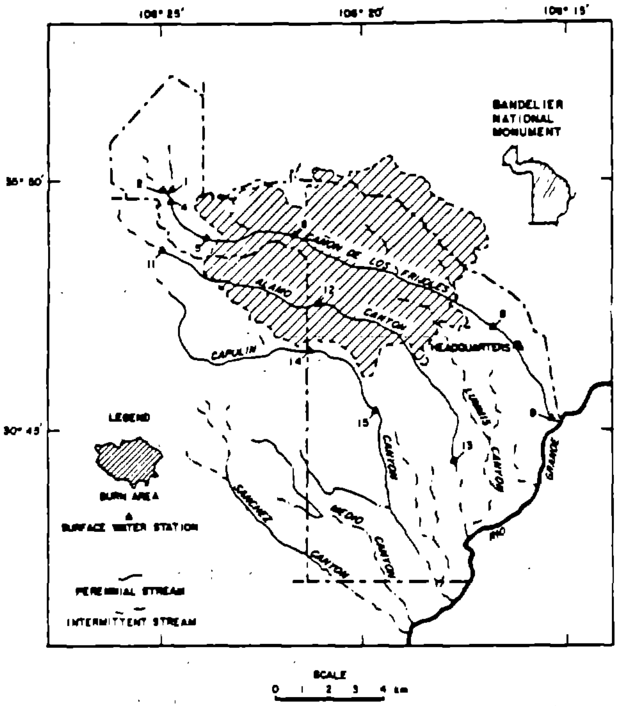

Fig. 1. La Mesa fire and surface water sampling stations.

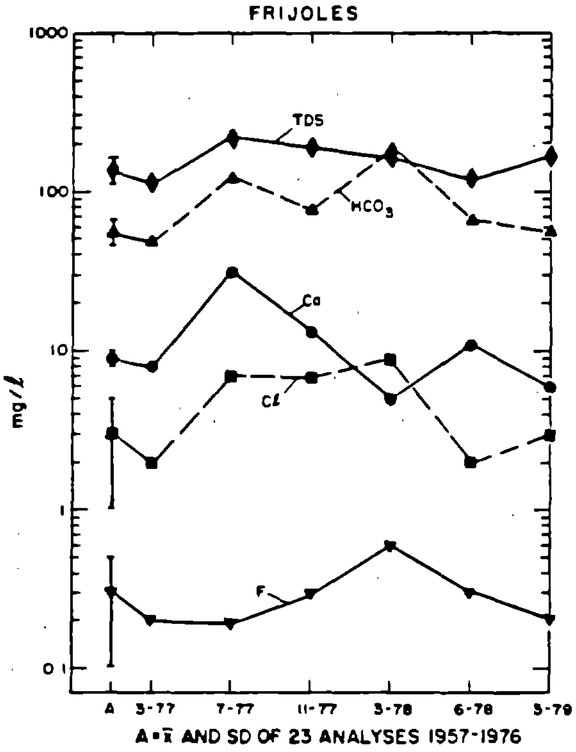

Fig. 2. Base flow chemical constituent variation in Cañon de los Frijoles before and after La Mesa fire.

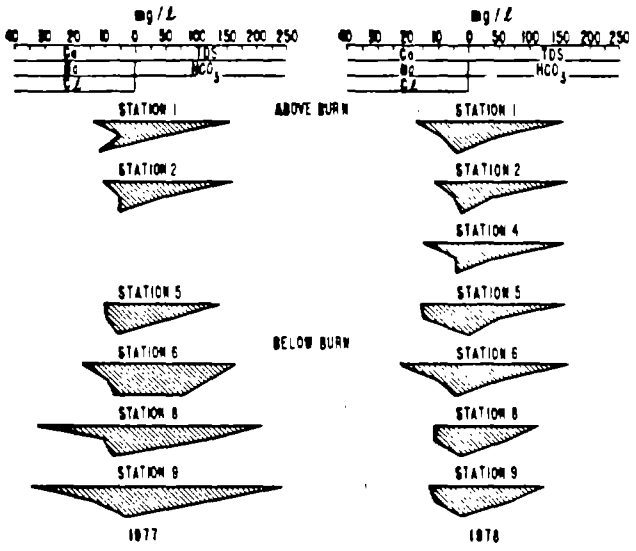

Fig. 3. Calcium, sodium, chloride, TDS, and bicarbonate in surface water from Cañon de los Frijoles.

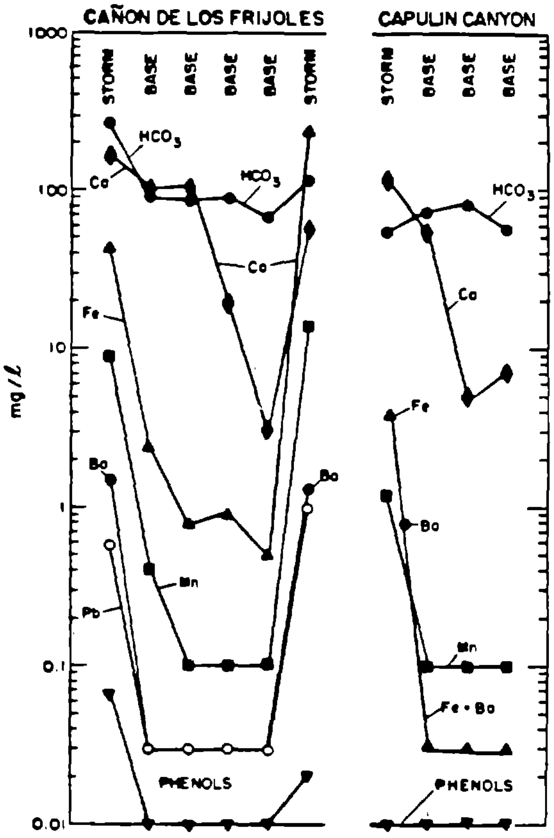

Fig. 4. Base flow and storm runoff chemical constituent variations in Cañon de los Frijoles and Capulin Canyon after La Mesa fire.

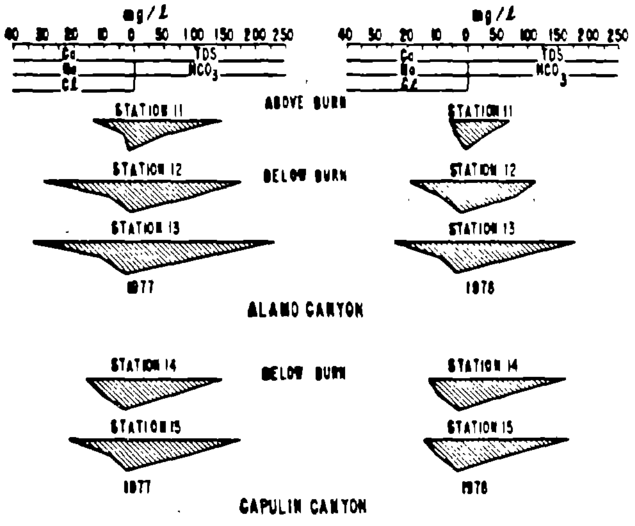

Fig. 5. Calcium, sodium, chloride, TDS, and bicarbonate in surface water in Alamo and Capulin Canyons.

AQUATIC INVERTEBRATES FROM CAPULIN CREEK, BANDELIER NATIONAL MONUMENT, NEW MEXICO*

Warren F. Pippin and Belle D. Pippin

I. INTRODUCTION

During the summer of 1980, a limited survey was made of the invertebrate fauna of Capulin Creek, within Bandelier National Monument. The stream originates in the Santa Fe National Forest, enters at the western edge of the Monument, and flows for approximately 11.5 km through Capulin Canyon into the Rio Grande. The stream flows steadily for approximately 6.4 km, then becomes intermittent or dry, especially in the summer months. The stream is small and shallow and varies in width according to the topography, but averages about 1 m. The flow varies with the seasons and time of day.

The purpose of the study was (1) to establish a preliminary check list of the invertebrate fauna of the stream, primarily macroinvertebrates of the Class Insecta, (2) to assess the relative abundance of various taxa between test sites, and (3) to compare the number and kind of taxa collected with those found in Rito de los Frijoles (Pippin 1980**).

II. MATERIALS AND METHODS

Three sites where the water flowed continually were selected for sampling. The sites, each 50 m long, were designated C-1, C-2, and C-3 (Fig. 1). Site C-1 was located approximately 1.2 km above Painted Cave at an elevation of about 1785 m. The stream in this area flows through piñon-juniper-ponderosa woodlands with scattered cottonwood and box elder. Site C-2 was located approximately 0.8 km below Base Camp at an elevation of about 1875 m. The stream in this area flows through predominantly ponderosa pine woodlands. Site C-3, at about 2100 m in elevation, was located where the stream enters the Monument from Forest Service land. The stream flows through riparian woodland, dominated by ponderosa pine and mixed conifers.

Once each month, June through September 1980 and in May 1981, the aquatics were collected with a Surber square-foot sampler and with a standard aquatic insect net when the stream was too low to use the Surber sampler. The 10 samples taken from each site were combined, placed in 70% alcohol, and returned to the laboratory for counting and processing. In counting specimens, numbers above 400 are indicated as 400+. Water temperatures were taken at each site by submerging a thermometer in flowing water for 10 minutes.

To obtain a more definitive collection of taxa, the stream was also surveyed at 1-mile intervals during the summer of 1980. In addition to the Surber sampler and other aquatic nets, a 28-mesh soil sieve was used to collect organisms that might not be collected in nets. Visual examination was also made of the stream and aquatics collected.

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*Work supported under National Park Service contract NPS-PX 7029-0-0296.

**Pippin, W. F., 1980. Aquatic invertebrates of Rito de los Frijoles, Bandelier National Monument, New Mexico, final report. National Park Service, Southwest Region, Santa Fe, New Mexico.

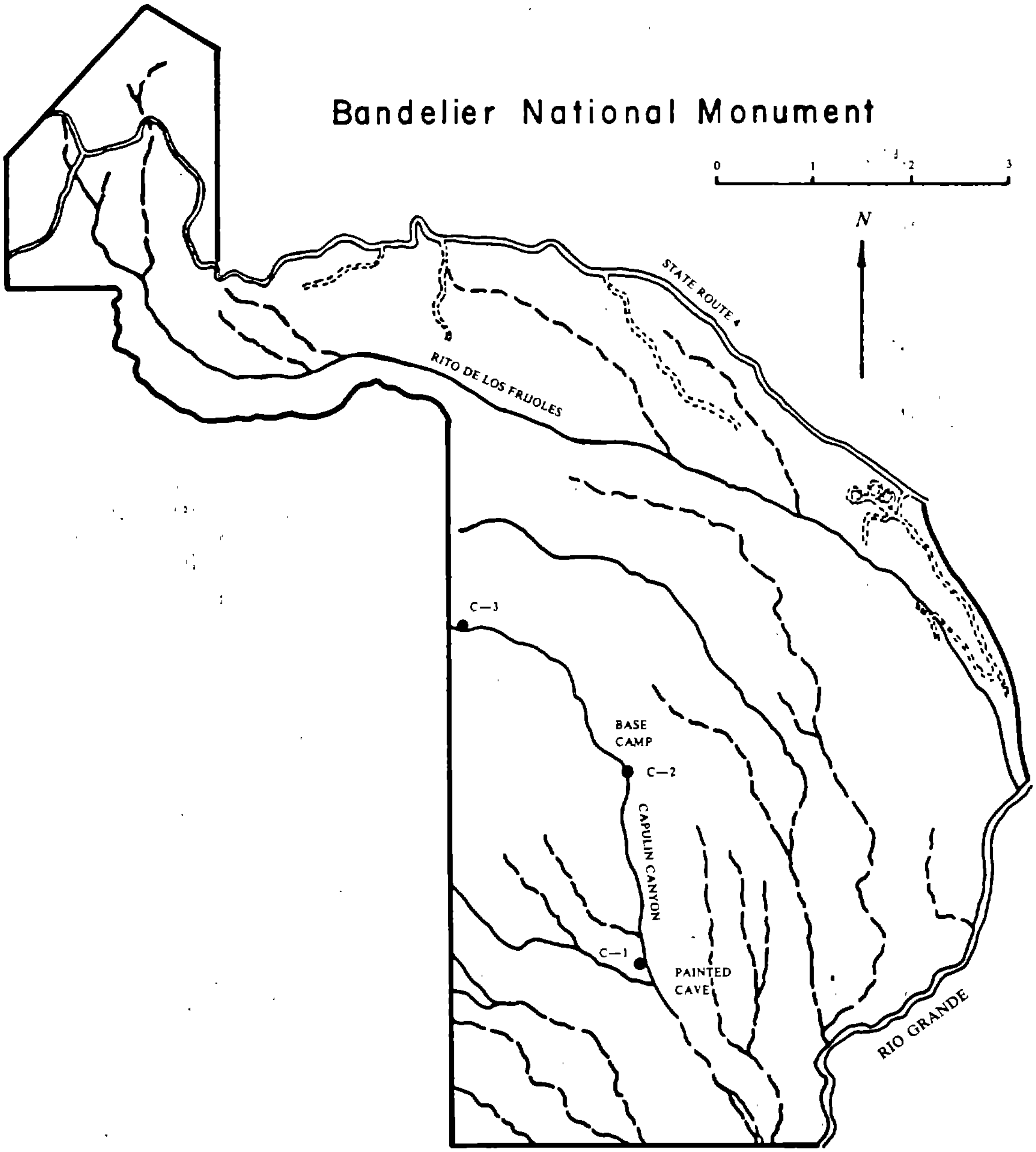

Fig. 1. Bandelier National Monument, with sampling sites on Capulin Creek.

III. RESULTS

A total of 65 taxa of macroinvertebrates were found in the various sampling sites (Table I), compared with 107 collected from Rito de los Frijoles (Pippin 1980). Nineteen taxa (28.8%) were common to all three sampling sites. The total number of taxa collected from site C-1 was 39 (59%); site C-2, 40 (60.8%); and site C-3, 44 (66.6%). The number of taxa collected only in site C-1 was 11 (16.6%); site C-2, 2 (0.03%); and site C-3, 13 (19.7%). The most families collected were in the Order *Diptera* (7) and *Ephemeroptera* (6). More genera (14) were collected in the Order *Diptera* than any other. Nine taxa were collected in Capulin Creek that were not found in Rito de Los Frijoles. These included one family (*Lepidostomatidae*) and four genera (*Ephemerella, Alloperla, Cultus,* and *Lepidostoma*) (Table II, Addendum).

TABLE I. Aquatic Invertebrates from Capulin Creek, Bandelier National Monument, New Mexico

Classification	Areas Collected
Class Insecta	
Coleoptera	
Dytiscidae	
Dytiscus sp.	1, 2, & 3
Hydroporus vilis	1 & 2
Agabus cordatus	2
Deronectes striatellus	1
Dryopidae	
Helichus suturalis	1, 2, & 3
Elmidae	
Zaitzevia parvula	1, 2, & 3
Optioservus divergens	1, 2, & 3
Optioservus castanipennis	1, 2, & 3
Narpus concolor	2 & 3
Heterlimnius corpulentus	3
Gyrinidae	
Gyrinus sp.	1
Hydrophilidae	
Ametor scabrosus	3
Berosus styliferous	3
Diptera	
Dixidae	
Dixa sp.	3
Muscidae	
Limnophora aequifrons	1, 2, & 3
Simuliidae	
Simulium sp.	1, 2, & 3
Syrphidae	
Tubifera sp.	1 & 2
Tipulidae	
Tipula sp	3
Pedicia sp.	1 & 2
Dicranota sp.	3
Stratiomyidae	
Eulalia sp.	1 & 2
Chironomidae	
Nanocladius sp.	1
Cardiocladius sp.	1
Cricotopus sp.	2 & 3
Procladius sp.	2
Chironomus sp.	1
Zavrelia sp.	3
Ephemeroptera	
Baetidae	
Baetis sp.	1, 2, & 3
Ephemerellidae	
Ephemerella (Drunella) sp.	1
Ephemerella sp.	1, 2, & 3
Heptageniidae	
Epeorus longimanus	1, 2, & 3
Epeorus sp.	1, 2, & 3
Cinygmula sp.	2 & 3
Heptagenia sp.	2
Siphlonuridae	
Siphlonurus sp.	1
Ameletus sp.	2 & 3
Leptophlebiidae	
Paraleptophlebia sp.	2 & 3
Tricorythidae	
Tricorythodes sp.	1, 2, & 3
Plecoptera	
Chloroperlidae	
Alloperla sp.	1
Sweltsa lamba	2 & 3
Sweltsa coloradensis	3
Pteronarcyidae	
Pteronarcella badia	2 & 3
Perlodidae	
Isoperla fulva	1
Isoperla mormona	1 & 2
Cultus sp.	3
Isoperla sp.	2 & 3
Isoperla quinquepunctata	3
Nemouridae	
Amphinemura banksi	1, 2, & 3
Amphinemura sp.	2 & 3
Trichoptera	
Lepidostomatidae	
Lepidostoma sp.	1 & 3
Glossosomatidae	
Glossosoma sp.	2 & 3
Rhyacophilidae	
Rhyacophilia sp.	2 & 3
Philopotamidae	
Wormaldia sp.	3
Dolophilodes sp.	3
Odonata	
Aeshnidae	
Aeshna sp.	1
Coenagrionidae	
Hyponeura sp.	1
Cordulegastridae	
Cordulegaster sp.	1 & 2
Hemiptera	
Veliidae	
Microvelia sp.	1, 2, & 3
Corixidae	
Sigara sp.	1 & 2
Gerridae	
Gerris marginatus	1 & 2
Gerris notabilis	1, 2, & 3
Class Oligochaeta	
Lumbricidae	
Eiseniella tetraedra	1, 2, & 3
Class Gordiacea	
Gordius sp.	1, 2, & 3
Class Nematoda	
several unidentified free-living sp.	1, 2, & 3
Class Plecypoda	
Pisiclium casertanum	3

TABLE II. Taxa Collected from Rito de los Frijoles and Capulin Creek

Classification	Frijoles	Capulin
Class Insecta		
Coleoptera		
Dytiscidae		
Agabus cordatus	X	X
Agabus tristus	X	
Dytiscus sp.	X	X
Deronectes striatellus	X	X
Hydroporus villis	X	X
Dryopidae		
Helichus suturalis	X	X
Helichus striatus	X	
Elmidae		
Zaitzevia parvula	X	X
Optioservus divergens	X	X
Optioservus castanipennis	X	X
Narpus concolor	X	X
Heterlimnius corpulentus	X	X
Cleptelmis addenda	X	
Rhizelmis sp.	X	
Cylloepus sp.	X	
Gyrinidae		
Gyrinus sp. c.f. *picipes*	X	X
Hydrophilidae		
Ametor scabrosus	X	X
Cymbiodyta dorsalis	X	
Crenitus sp.	X	
Berosus styliferous	X	X
Diptera		
Dixidae		
Dixa sp.	X	X
Dixa californica	X	
Muscidae		
Limnophora aequifrons	X	X
Syrphidae		
Tubifera bastardii	X	
Simuliidae		
Simulium sp.	X	X
Prosimulium sp.	X	
Tipulidae		
Tipula sp.	X	X
Pedicia sp.	X	X
Dicranota sp.	X	X
Limonia sp.	X	
Psychodidae		
Pericoma sp.	X	
Culicidae		
Culex sp.	X	
Aedes sp.	X	
Ptychopteridae		
undetermined genus & sp.	X	
Chironomidae		
Nanocladius sp.	X	X
Cardiocladius sp.	X	X
Cricotopus sp.	X	X
Procladius sp.	X	X
Cryptochironomus sp.	X	
Zavrelia sp.	X	X
Ablabesmyia sp.	X	
Chironomus sp.	X	X
Brillia sp.	X	
Microtendipes sp.	X	
Stratiomyidae		
Eulalia sp.	X	X
Ephemeroptera		
Baetidae		
Baetis tricaudata	X	
Baetis bicaudata	X	
Baetis sp.	X	X
Ephemerellidae		
Ephemerella sp.	X	X
Ephemerella inermis	X	
Ephemerella grandis grandis	X	
Heptageniidae		
Cinygmula sp.	X	X
Rhitrogena sp.	X	
Epeorus sp.	X	X
Tricorythidae		
Tricorythodes sp.	X	X
Leptophlebiidae		
Paraleptophlebia sp.	X	X
Siphlonuridae		
Siphlonurus sp.	X	X
Plecoptera		
Perlidae		
Hesperoperla pacifica	X	
Nemouridae		
Amphinemura sp.	X	X
Amphinemura banksi	X	X
Malenka coloradensis	X	
Nemoura sp.	X	
Chloroperlidae		
Paraperla prob. *frontalis*	X	
Paraperla sp.	X	
Chloroperla sp.	X	
Sweltza lamba	X	X
Sweltza coloradensis	X	X

TABLE II. (cont)

Classification	Frijoles	Capulin
Perlodidae		
Isoperla fulva	X	X
Isoperla quinquepunctata	X	X
Pteronarcidae		
Pteronarcella badia	X	X
Pteronarcella sp.	X	
Capniidae		
Capnia sp. prob. *turnida*	X	
Leuctridae		
Paraleuctra vershina	X	
Trichoptera		
Limnephilidae		
Limnephilus sp.	X	
Hesperophylax sp.	X	
Dicosmoecus sp.	X	
Hydropsychidae		
Hydropsyche sp.	X	
Brachycentridae		
Brachycentrus sp.	X	
Amiocentrus sp	X	
Philopotamidae		
Dolophilodes aequalis	X	X
Wormaldia sp.	X	X
Rhyacophilidae		
Rhyacophilia sp.	X	X
Rhyacophilia acropedes	X	
Helicopsychidae		
Helicopsyche sp.	X	
Glossosomatidae		
Glossosoma sp.	X	X
Polycentropidae		
Polycentropus sp.	X	
Calamoceratidae		
Phylloicus sp.	X	
Hydroptilidae		
Ochrotrichia sp.	X	
Hemiptera		
Veliidae		
Microvelia sp.	X	X
Corixidae		
Sigara sp.	X	X
Corisella sp.	X	
Notonectidae		
Notonecta undulata	X	
Gerridae		
Gerris marginatus	X	X
Gerris notabilis	X	X
Odonata		
Coenagrionidae		
Ischnura perparua	X	
Argia sp.	X	
Hyponeura sp.	X	X
Aeshnidae		
Aeshna sp.	X	X
Cordulegastridae	X	
Class Oligochaeta	X	
Lumbricidae		
Eiseniella tetraedra	X	X
Class Hirudinea		
Unidentified leeches	X	
Class Turbellaria		
Several unidentified sp.	X	
Class Gordiacea		
Gordius sp.	X	X
Class Nematoda		
Several unidentified sp.	X	X
Class Gastropoda		
Physa sp.	X	
Class Pelecypoda		
Pisiclium casertanum	X	X
ADDENDUM		
Class Insecta		
Diptera		
Syrphidae		
Tubifera sp.		X
Ephemeroptera		
Ephemerellidae		
Ephemerella (Drunella) sp.		X
Heptageniidae		
Epeorus longimanus		X
Plecoptera		
Chloroperlidae		
Alloperla sp.		X
Perlodidae		
Isoperla mormona		X
Cultus sp.		X
Isoperla sp.		X
Trichoptera		
Lepidostomatidae		X
Lepidostoma sp.		X

Table III compares the number of insect families and genera collected with those collected in the Frijoles; the number of families was 76% of those in the Frijoles, and the genera, 62.6%. Table IV lists numbers of specimens collected and water temperatures from the sites. The numbers collected from each site varied, but in general, as in the Frijoles, the numbers increased with progression upstream. The difference in number of taxa between sites was not as dramatic as that found in the Frijoles. The greatest number of specimens per site were found in May and June.

The water temperature, which varied considerably at each site, ranged from a low of 5°C at C-3 to a high of 18°C at C-1. The average water temperature at C-1 was 13°C; at C-2, 11.4°C; and at C-3, 8.8°C. The water temperature in Capulin creek varied, depending on exposure to sunlight, time of day, and flow rate.

TABLE III. Insect Families and Genera Collected from Capulin Creek and Rito de los Frijoles

	Capulin		Frijoles	
Order	Family	Genus	Family	Genus
Coleoptera	5	13	5	20
Diptera	7	14	10	25
Ephemeroptera	6	11	6	12
Plecoptera	4	11	7	16
Trichoptera	5	5	10	15
Hemiptera	3	4	4	6
Odonata	3	3	3	5
Total	33	61	45	99

TABLE IV. Specimens collected and water temperature (°C) at each site.

	Site			
Date	C-1	C-2	C-3	Total
1980				
June	126(18)	191(12)	400+(10)	717+
July	87(12)	123(11)	255(11)	465
August	50(12)	125(12)	383(10)	558
September	62(11)	119(10)	237(5)	418
1981				
May	289(12)	159(12)	369(8)	817
Total	614	717	1644	2975+

IV. DISCUSSION

During the survey, we collected 65 taxa, compared to 107 collected in the Frijoles. The difference in numbers may be attributed to the relatively short time devoted to the Capulin study. We believe a minimum of three seasons is required to properly accomplish a study of this type. The low percentage (0.03%) of taxa collected only at site C-2 probably indicates a closer association between sites C-1 and C-3 in Capulin than between sites on the Frijoles; indeed, some test sites on the Frijoles were at lower and higher elevations than those in Capulin. Also the Frijoles flows for a much longer distance through the Monument, providing more diversified habitats. As in the Frijoles, most specimens found were in the Orders *Plecoptera* (stoneflies), *Trichoptera* (caddisflies), *Ephemeroptera* (mayflies), and *Diptera* (blackflies). It was evident that the greater diversity of species and, in general, the overall population numbers occurred in the upper areas of Capulin creek. The same increase was noted in the Frijoles. Capulin creek from Base Camp to its headwaters is a relatively stable but fragile environment. Any human project that might upset this environmental balance should be vigorously resisted.

EFFECTS OF FIRE ON SMALL MAMMALS WITHIN BANDELIER NATIONAL MONUMENT

Daniel A. Guthrie*

I. INTRODUCTION

A study of the effects of fire and subsequent plant succession on small-mammal populations within Bandelier National Monument began in June 1977. The locations and sizes of past fires within the Monument were obtained from Monument personnel and trapping grids were planned for the largest burns. Soon after the start of this project, La Mesa fire occurred, burning much of the Monument, including most previous burn areas. Those sites not reburned by La Mesa fire were, in general, too small (less than 1 acre) for any differences in mammal populations independent of edge effects to be observed. Consequently, the study was redirected to an examination of the effects of La Mesa fire on small-mammal populations. This report on the initial changes in small-mammal populations after the fire is based on work during the summers of 1977, 1978, and 1979.

II. HISTORY

La Mesa fire, which burned over 10 000 acres within the Monument between June 16 and 23, 1977, affected several vegetational zones. Heaviest damage occurred within pure stands of ponderosa pine (*Pinus ponderosa*). In some areas, ground fire burned under ponderosa, leaving the trees undamaged. In most areas, however, the accumulation of underbrush and ground litter and the density of unthinned stands allowed the fire to crown and totally consume large patches of ponderosa. In these areas, all needles were burned or scorched and the trees, although left standing, were killed.

At lower elevations, where ponderosa is replaced by more open piñon-juniper woodland (*Pinus edulus, Juniperus monosperma*), less damage occurred. In this zone, the grasses between clumps of trees were ignited by blowing embers; other clumps were undamaged. The burn in this vegetational zone was spotty, leaving much of the ground cover and many clumps of trees intact. The fire was controlled at lower elevations soon after it passed into the piñon-juniper zone from pure stands of dense ponderosa.

At higher elevations, where ponderosa is replaced by Douglas fir (*Pseudotsuga taxifolia*) and aspen (*Populus tremuloides*), less fire damage occurred because the moistness of the vegetation did not sustain the burn as well as did ponderosa. Damage in this zone was caused mostly by ground fire, and was greatest where fallen logs sustained the burn. This burn pattern was also found in the riparian zones where most damage was confined to ground cover near logs and other fuel, with little damage to trees, except the more resinous ponderosa. Damage was spotty in both zones.

La Mesa fire occurred at the end of 2 years of abnormally dry conditions. In July and August 1977, summer rainstorms occurred in the area and the burnt areas were reseeded from the air with a mixture of wild grass seed. Much flood damage occurred in riparian zones during August 1977 because of heavy runoff and siltation.

Regrowth of ground cover in burned areas was extremely poor during the summer of 1977. Despite reseeding and rain, no significant ground cover developed on any burned areas. Large areas of ponderosa

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remained devoid of ground cover well into September. The only significant regrowth was in clumps of native bunch grass within the piñon-juniper woodland and on the meadow areas near Apache Spring. In both areas, ground cover in open areas appeared nearly normal by the end of the summer. Areas below bushes, trees, or pine needle cover, however, remained barren because of fire intensity.

By the summer of 1978, reseeding and good winter rains resulted in good growth of grasses and weedy annual species in burn areas. The summer of 1979 showed continual growth on the reseeded areas, but little change from the summer of 1978.

Climatic Conditions During This Study

There were 2 years of below-average rainfall before La Mesa fire. After the fire, little rain fell until late in the summer of 1977. The winter of 1977-78 was rather mild, and spring and summer rains in 1978 supported good annual plant growth during the summer of 1978. The winter of 1978-79 was more severe than usual, with several periods of lower-than-average temperatures. Excellent plant growth continued during the summer of 1979, because of spring and summer rain.

III. METHOD

Trapping sites were selected along New Mexico State Road (SR) 4 (which crosses the area of La Mesa fire) in such a way as to include a variety of elevations, including all major vegetational zones within the burn area. A riparian site at Upper Frijoles Crossing was also sampled.

Because of the problems in interpretation of small-mammal population changes, the best control information is contemporaneous trapping data from unburned sites. Such sites were established for each major vegetational zone, but a control area in riparian habitat, similar in elevation and vegetation to the burned area, could not be found.

Trapping began soon after the fire, with trapping grids established in all affected vegetational zones. Sherman live traps (3 by 3 by 9 in.), baited with a mixture of wild bird seed, peanut butter, and rolled oats, were used at 100-ft intervals, one per trapping station, and were examined daily for 5 days or until 70% recaptures occurred. Data collected included species and individual identifications, trap number, sex, age, and weight of animals caught. Populations were estimated by mark-recapture methods using Bailey's (1952) modification of the Lincoln Index.

Two periods of trapping were conducted for each site during the summers of 1977 and 1979, and three periods were conducted during the summer of 1978. Trapping was also conducted at a few additional selected sites each year for comparisons. Plant surveys for each grid conducted during the summers of 1978 and 1979 used line-intercept and toe-point sampling methods.

Locations of individual trapping grids are shown in Fig. 1 and a map of each major grid is given in the Appendix. Brief descriptions of each trapping site are as follows.

Frijoles Mesa: Elevation, 6700 ft. Area, 6.96 hectares. Piñon-juniper woodland. Located along entrance road just east of residential area. An unburned control area. Area trapped in 1977 and 1978.

Frijolitos Mesa: Elevation, 6700 ft. Area, 8.36 hectares. Piñon-juniper woodland. Located on northern edge of Frijolitos Mesa, just south of Frijolito Ruins. An unburned control area. Trapped in 1977 and 1978.

SR 4 Grid: Elevation, 7000 ft. Area, 9.29 hectares. Piñon-juniper woodland. Located adjacent to SR 4, 1-3/4 miles west of entrance gate. The area grades from totally burnt piñon-juniper and ponderosa at the western end to unburnt piñon-juniper on the eastern side. Area trapped 1977-1979.

Burnt Mesa: Elevation, 7200 ft. Area, 8.36 hectares. Ponderosa-oak woodland. Located 1/2 mile south of SR 4 on Burnt Mesa access road. A totally burnt stand of ponderosa with oak undergrowth. Trapped 1977-1979.

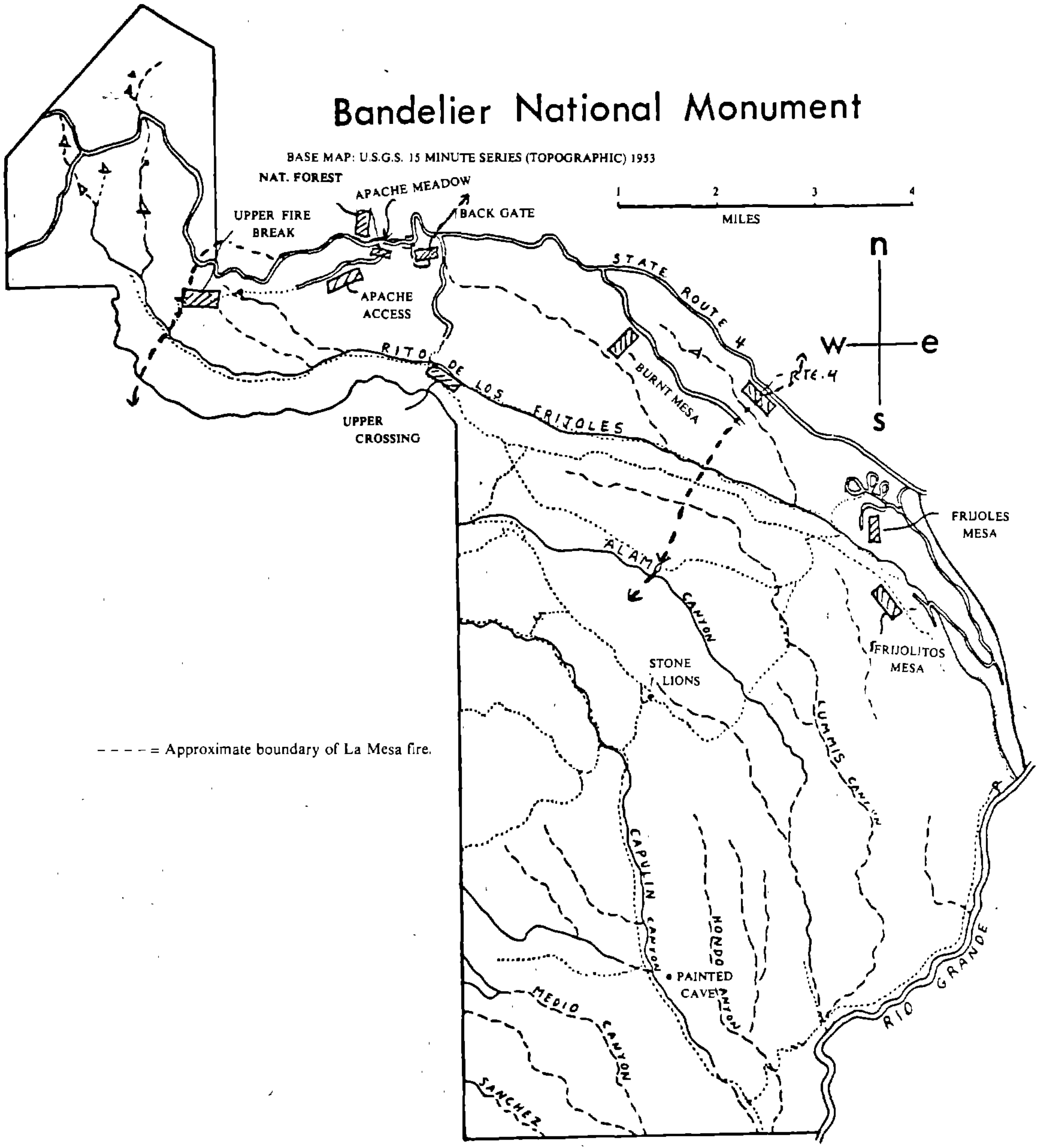

Fig. 1. Locations of small-mammal trapping grids. Dark dashed line indicates approximate boundary of La Mesa fire.

Back Gate: Elevation, 7540-7600 ft. Area, 6.96 hectares. Ponderosa-oak woodland. Located just south of back gate cabins, extending east to ponderosa campground. The eastern half of this area was totally burnt and the western half, above the fire line, was undamaged. Area trapped 1977-1979.

Apache Spring Access: Elevation, 8250 ft. Area, 6.96 hectares. Ponderosa forest. Located on the Apache Spring access road 1 mile from SR 4. A totally burnt stand of dense ponderosa with some fir and aspen. Trapped 1977-1979.

Upper Fire Break: Elevation, 8600 ft. Area, 8.36 hectares. Aspen, spruce, fir forest. Located 1/4 mile west of SR 4 on Los Alamos/Sandoval County line and bordering the upper fire break. Fire damage spotty with some portions totally burnt; others, ground fire damage only. Area trapped 1977-1979.

Upper Frijoles Crossing: Elevation, 6980 ft. Area, 5.57 hectares. Riparian habitat. Located on south side of Frijoles creek for 1/4 mile west and 3/4 mile east of Upper Crossing. Partially burnt riparian woodland, with most damage by ground fire. Area trapped 1977-1979.

National Forest Site: Elevation, 8180 ft. Area, 3.72 hectares. Fir-aspen forest. Located on north side of SR 4 at Armistead Spring turnoff (Water Canyon). A control area for fir-aspen, ponderosa woodland. Trapped 1977-1979.

Apache Meadow: Elevation, 8200 ft. Area, 2.00 hectares. Grassy meadow in fir-aspen forest. Located 1.4 mile from SR 4 on Apache Spring access road. Totally burnt by ground fire. Area trapped 1977 and 1979.

Ponderosa Campground: Elevation, 7550 ft. Area, 5.57 hectares. Ponderosa forest. Located 1/4 mile east of Ponderosa Campground adjacent to SR 4. A totally burnt area of dense young ponderosa. Trapped in 1977.

St Peters Dome Road: Elevation, 8940 ft. Area, 5.57 hectares. Aspen-spruce forest. Located on west side of St Peters Dome Road at intersection with SR 4. An undamaged control area. Trapped in 1977.

IV. RESULTS AND PRELIMINARY ANALYSIS

This study involved a total of 4300 trap nights in 1977, 5760 trap nights in 1978, and 4000 trap nights in 1979. The following section is a general discussion of expected small-mammal population changes, along with tables presenting vegetation surveys and trapping results and a specific description of mammal populations in each vegetational zone.

V. GENERAL DISCUSSION

The number of organisms that an environment can support is defined as the carrying capacity (hereafter, K) of the environment. K is controlled both by factors extrinsic to organisms such as moisture, temperature, food supply, predators, and disease; and by factors intrinsic to organisms such as life span and intra- and interspecific competition, including territoriality. K is never determined by an analysis of these factors, however. Instead, K is based on changes occurring in organism density. Thus, in practice, K is defined as the density of organisms in an area at which the net reproduction rate equals unity and the intrinsic rate of increase is zero (Pianka 1974, p. 82). If a population is increasing in size, we say that it has not reached K, whereas if it is stable, we say that it is at K. This, however, does not explain what is happening. We usually do not know what factor is limiting to organisms, and thus determining K, nor do we know how the fluctuation in population numbers for an organism compares with the numbers that an environment might support.

Deterioration of environmental conditions can depress the carrying capacity of the environment, causing a decrease in population for a species. In temperate climates, small-mammal populations usually fluctuate with the seasons, reaching their lowest point in the winter and highest point in summer. The winter low is due to a reduction in K, as here defined. The limiting factor in this reduction, however, is not known, and may vary from year to year. It could be climate or food resources, although most small mammals store food, or simply continuous predation and death from old age during a period when reproduction is not occurring.

In summer, K increases rapidly as annual plants begin rapid growth, and animal populations also increase to take advantage of the increasing food supplies and moderate climate. In areas where animal populations are severely decreased in the winter, and where summers are short, it is unlikely that animal populations are able to reach K during summer months. This means that the effects of interspecific competition on population sizes is rarely seen. Populations will be at K only when K decreases during deteriorating or severe conditions (fall and winter). Only when either a very mild winter fails to reduce animal populations, or when K is exceptionally low during the summer because of dryness will populations be at K for long periods, which results in interspecific competition, thereby reducing less successful species.

Some fluctuations in population occur due to weaning, and summer populations may periodically fluctuate slightly as older juveniles are driven from parental territories to make room for new litters.

Carnivorous mammal populations are probably more affected by winter populations of prey than by their summer population levels, and thus lower fecundity makes it impossible for them to vary their population size as much as is found in rodents.

Superimposed on the cyclic patterns of mammal populations outlined here are the effects of La Mesa fire. The replacement of climax pine communities with pioneer communities of mostly annual plants should greatly increase the food available to most small herbivorous mammals, except for those species dependent upon pines.

Thus, in environments disturbed by fire or flood, we expect K to decrease until the annual plant growth occurs. This should increase K, and with it, small-mammal populations. However, because of successional plant changes, the size of K and the type of species that appear may be different from those present before the disturbance.

Figure 2 shows the changes expected in K and in small-mammal population sizes. It also incorporates expected variations in K and in population sizes caused by climatic changes during the study period. K is lower in the summer of 1977 than in 1978 and 1979 because of poor rainfall during the spring and summer for 1977. K is low during the winter of 1978-79 but higher during other winters, reflecting differences in winter severity.

Subdominant species (species that lose in interspecific competition) should be low in numbers in 1977, when animal populations are near K and interspecific competition is occurring, but higher in 1978 and 1979, when K exceeds mammal population sizes and competition is less. Colonist species should increase in numbers in burned areas.

Specific Discussion of Results by Vegetation Zone

1. **Piñon-Juniper Woodland.** The fire burned about 80% of the piñon-juniper/oak canopy in the SR 4 grid, but left the few ponderosa relatively undamaged. Most oak resprouted from roots by the summer of 1978, but no regeneration of juniper or piñon occurred (Table I). Ground cover in the burned area was about 60% destroyed, the smaller effect caused by the scarcity of plants between tree clumps and the

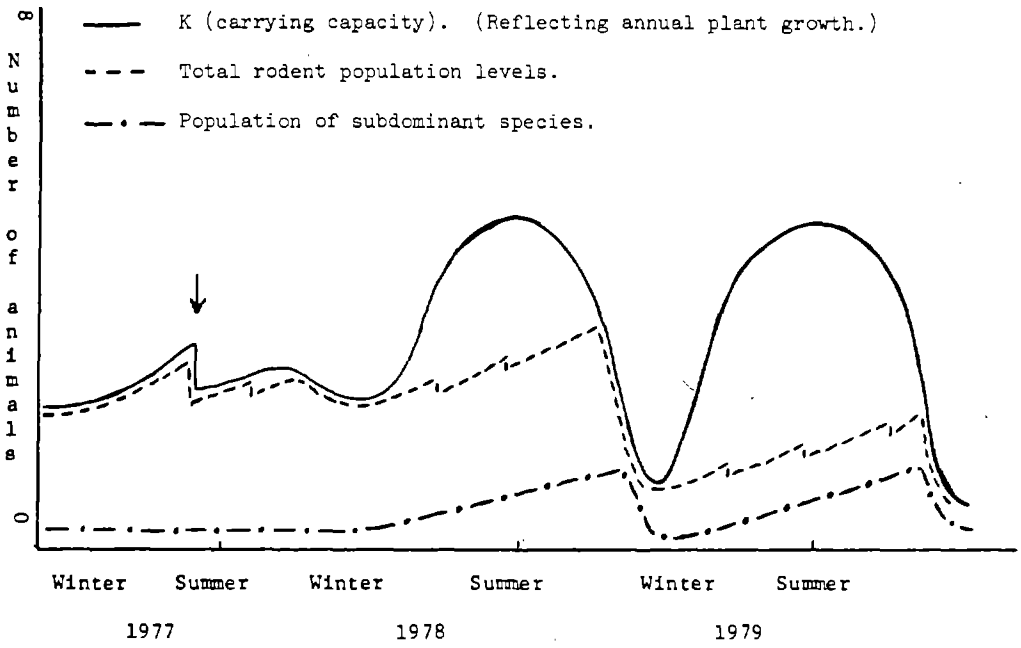

Fig. 2. Hypothetical changes in small-mammal populations and carrying capacity during this study.

TABLE I. Vegetation in Piñon-Juniper Woodland

	Frijolitos Mesa	Frijoles Mesa	Upper SR 4 Unburned		SR 4 Burned	
Canopy	1978	1978		1978-79		1978-79
Piñon pine (*Pinus edulus*)	9.1	15.1		19.7		18.6
One-seed juniper (*Juniperus monosperma*)	20.7	18.0		14.6		15.7
Wavy leaf oak (*Quercus undulata*)	---	1.0		1.8		1.5
Ponderosa pine (*Pinus ponderosa*)	3.9	8.7		5.0		3.0
Bare	65.5	57.2		58.9		61.2
Per cent canopy burned	0	0		80%		---
Ground Cover			1978	1979	1978	1979
Bare	52.6	48.6	51.8	56.4	46.8	42.6
Deadwood	5.5	6.6	0.7	---	---	---
Blue grama (*Bouteloua gracilis*)	17.6	11.9	21.2	24.1	5.2	12.7
June grass (*Koeleria cristata*)	1.5	1.6	1.0	0.2	1.7	1.2
Mutton grass (*Poa fendleriana*)	7.0	7.5	7.3	4.0	0.4	1.8
Snake weed (*Guterrhiza salothrae*)	1.8	4.1	4.3	4.8	4.6	5.9
Wavy leaf oak (*Quercus undulata*)	1.6	6.7	2.1	1.9	4.4	2.8
Squawbush (*Rhus trilobata*)	0.5	3.1	1.5	0.5	0.4	---
Spreading fleabane (*Erigeron divergens*)	0.7	1.7	---	1.0	2.4	1.6
Apache plume (*Fallugia paradoxa*)	0.6	2.1	---	---	---	---
Yellow ragweed (*Bahia dissecta*)	---	---	---	---	11.4	6.5
Lamb's quarters (*Chenpodium album*)	---	---	---	---	3.8	10.3
False tarragon (*Artemesia dracunculus*)	---	---	0.2	1.0	1.0	2.8
Golden aster (*Crysopsis foliosa*)	---	---	---	0.5	1.0	2.4
Mountain mahogany (*Cercocarpus montanus*)	1.3	0.2	1.0	---	0.8	0.6
Needle and thread grass (*Stipa comata*)	1.9	---	---	---	---	---
Miscellaneous	7.4	6.8	8.9	5.6	16.1	8.8

absence of fuel build-up (leaves and dead wood). The fire's effect on ground cover was to reduce native grasses, notably blue grama (*Bouteloua gracilis*), and to increase weedy annuals, notably ragweed (*Bahia dissecta*) and lamb's quarters (*Chenpodium album*). Effects of the reseeding program were not noticeable. The percentage of bare ground in this vegetational zone was about the same in burned and unburned areas.

The dominant species of mice in piñon-juniper woodland are the piñon mouse (*Peromyscus truei*) and the rock mouse (*Peromyscus difficilis*). The deer mouse (*Peromyscus maniculatus*) is also present in this zone but is usually found in disturbed areas or more grassy spots. These three species are interspecifically aggressive, and *P. maniculatus* loses to most other species in tests of interspecific aggression (Brown 1964, Eisenberg 1963, Matsui 1977).

Absence of a careful trapping program before the fire makes any conclusions as to the direct effects of the fire on small mammals speculative. Several authors have shown that fire severely reduced mouse populations (Tevis 1956, Tester 1965, and especially Chew, Butterworth, and Grechman 1959), whereas others have demonstrated the insulating effect of soil in protecting ground dwelling species from fire (Howard, Fenner, and Childs 1959). It seems likely that *Peromyscus* populations were reduced somewhat by the fire because most logs and dead roots where they make their homes were destroyed. Similarly, tree-dwelling species such as chipmunks and squirrels probably suffered a high mortality rate.

Population levels during the summer of 1977 were low in all areas because of dry conditions during the period preceding the fire, and remained low after the fire (Table II). However, there was a noticeable reduction in the number of *P. truei* in the burned area, presumably related to the dependence of this species on piñon and juniper. *Peromyscus maniculatus* numbers were not affected noticeably by the fire, being about the same in the SR 4 burnt and unburnt areas during 1977 (Table II). This species increased dramatically in 1978 and 1979 in burned areas. *Peromyscus truei* finally reappeared on the margins of the burnt area late in 1978 but numbers were well below normal. Squirrels remained absent in burnt piñon-juniper during 1977-78. In control areas, *P. maniculatus* apparently weathered bad conditions during 1977 better than *P. truei*; the population of the latter species was very low in all areas during 1977. As *P. truei* increased in numbers in 1978, a corresponding decrease occurred in the numbers of *P. maniculatus*, probably because of interspecific competition. *Perognathus flavus*, a minor component of the piñon-juniper woodland, appeared in small numbers in 1978.

TABLE II. Small-Mammal Densities (mammals/hectare) in Piñon-Juniper Woodland

	P. truei	*P. difficilis*	*P. maniculatus*	*P. boylii*	*E. quadrivittatus*	*Perognathus flavus*	Total
Frijoles Mesa							
July 1977	0.48	1.44	0.96	---	2.87	---	5.75
Aug. 1977	0.96	2.39	0.60	---	---	---	3.95
June 1978	5.82	2.58	0.43	0.43	2.01	0.29	11.56[a]
July 1978	6.69	2.34	0.43	0.14	3.01	0.29	12.90
Aug. 1978	4.76	2.27	0.86	---	1.87	0.29	10.04
Frijolitos Mesa							
July 1977	0.24	0.12	0.12	---	0.36	---	0.84
Aug. 1977	0.74	0.48	---	---	---	---	1.22
June 1978	2.15	3.44	0.12	---	0.72	---	6.79
July 1978	3.77	4.00	0.48	---	0.72	---	9.32
Aug. 1978	3.59	3.48	1.67	---	1.20	0.12	10.30
SR 4, Unburnt, 3.72 H							
July 1977	1.35	---	0.54	---	1.35	---	3.24
Aug. 1977	0.54	---	1.08	---	---	---	1.62
June 1978	1.08	---	4.19	---	1.21	---	6.48
July 1978	1.08	---	3.09	---	1.08	---	5.20
Aug. 1978	2.42	---	2.34	---	0.81	---	5.57
June 1979	---	---	0.81	---	---	---	0.81
July 1979	---	---	0.53	---	---	---	0.53
SR 4, Burnt, 5.57 H							
July 1977	---	---	2.08	---	---	---	2.08
Aug. 1977	---	---	1.48	---	---	---	1.48
June 1978	---	---	4.31	---	---	0.18	4.49
July 1978	0.18	---	4.49	---	---	---	4.85
Aug. 1978	0.36	---	7.34	---	---	---	7.70
June 1979	---	---	2.96	---	---	---	2.96
July 1979	---	---	1.62	---	---	---	1.62

[a] Includes one individual each of *Neotoma albigula* and *Spermophilus variegatus*

The severe winter of 1978-79 was devastating to all species at this elevation, presumably because of lack of insulation from snow. During the summer of 1979, no *P. truei* or squirrel species were present in either burned or unburned areas. These above-ground nesters suffer greatly from winter conditions. *P. maniculatus* numbers were also reduced and remained so despite a good seed crop.

2. **Ponderosa Woodland.** The effect of fire on the solid stands of ponderosa woodland was somewhat spotty. The study plots are in areas where fire destruction was total; all canopy needles were either burned or scorched and ground cover was totally burned. Normal ground cover under dense ponderosa is sparse, with a few plants showing through a ground cover of pine needles, primarily, small oaks and a few grasses (Table III). A year after the fire ground cover increased, although much of the ground was still bare, presumably because of the poor water retention in tuffaceous soils at this elevation, and because summer rains in 1977 washed seed from the slopes. Resprouted oak and reseeded grasses, notably slender wheat grass (*Agropyron trachycaulum*) and Kentucky bluegrass (*Poa pratensis*), account for most of the ground cover under burned ponderosa.

The common rodent in ponderosa is the deer mouse *P. maniculatus*. The fire seemed to have little effect on this species (Table IV). Population levels after the fire were low, but not noticeably lower than in unburned control areas. During 1978, populations of *P. maniculatus* increased in burned areas, reaching levels well above those found in the control area. A leveling of the population toward late summer probably was due to weaning of young. Squirrels were very rare in the burnt areas during 1977 but increased in 1978. The severe winter of 1978-79 had no effect on *P. maniculatus*, but populations of rock- and tree-dwelling species, the squirrels and *P. difficilis*, were reduced in 1979. *Microtus montanus* appeared for the first time in 1979. This species is a grassland form that can be expected to increase in numbers on the reseeded areas.

TABLE III. Vegetation in Ponderosa Woodland

	Burnt Mesa Burned		Back Gate Burned		Back Gate Unburned	
Canopy	1978		1978		1978	
Noncanopy	64.2		29.8		31.2	
Ponderosa (*Pinus ponderosa*)	33.4		56.1		63.6	
Gambel oak (*Quercus gambelii*)	2.4		5.0		5.0	
Rocky Mt. Juniper (*Juniperus scropulorum*)			0.1		0.2	
Per cent canopy burned	100		100		100	
Ground cover	1978	1979	1978	1979	1978	1979
Bare	69.9	49.8	81.5	67.0	88.6	89.2
Slender Wheat Grass (*Agropyron trachycaulum*)	9.3	13.5	10.8	10.6	---	---
Gambel oak (*Quercus gambelii*)	5.1	2.7	2.1	1.6	4.2	4.6
Spreading Fleabane (*Ergeron divergens*)	3.1	1.9	---	---	---	---
Kentucky bluegrass (*Poa pratensis*)	1.2	3.7	3.0	14.4	4.0	2.8
Little bluestem (*Andropogon scoparius*)	1.0	0.9	---	1.6	---	---
Yellow ragweed (*Bahia dissecta*)	0.8	1.1	---	---	---	---
June grass (*Koeleria cristata*)	0.6	3.0	---	1.1	---	---
New Mexican Thistle (*Cirsium neomexicanum*)	0.7	---	---	---	---	---
New Mexican Locust (*Robina neomexicana*)	0.6	---	---	---	---	---
Blue grama (*Bouteloua gracilis*)	---	3.0	---	---	---	---
Miscellaneous	7.7	20.4	2.6	3.7	3.2	3.4

TABLE IV. Small-Mammal Densities (mammals/hectare) in Ponderosa Woodland

	P. maniculatus	*P. difficilis*	*P. truei*	*M. montanus*	*E. quadrivittatus*	*Spermophilus lateralis*	Total
Burnt Mesa							
July 1977	0.72	0.72	---	---	0.30	---	1.86[a]
Aug. 1977	1.20	0.64	---	---	0.36	---	2.20
June 1978	2.49	0.24	---	---	0.12	---	2.85
July 1978	4.13	0.54	---	---	0.48	---	5.15
Aug. 1978	6.94	1.20	---	---	0.48	---	8.62
June 1979	2.78	---	---	---	---	---	2.78
July 1979	7.66	---	---	0.11	---	---	7.77
Back Gate, Unburnt, 2.32 H							
July 1977	1.73	---	---	---	1.54	0.38	3.65
Aug. 1977	0.38	---	---	---	2.69	---	3.07
June 1978	0.36	---	---	---	1.43	0.72	2.51
July 1978	0.36	0.36	0.36	---	1.43	---	2.51
Aug. 1978	1.0	---	0.36	---	1.43	---	2.87
June 1979	0.86	---	---	---	---	---	0.86
Aug. 1979	1.29	---	---	0.43	---	---	1.72
Back Gate, Burnt, 4.64 H							
July 1977	1.68	---	---	---	---	1.68	3.36
Aug. 1977	1.34	---	---	---	---	1.34	2.68
June 1978	3.06	---	---	---	0.48	0.96	4.50
July 1978	5.10	---	---	---	0.72	---	5.82
Aug. 1978	3.68	---	---	---	1.44	---	5.12
June 1979	3.45	---	---	8.22	---	---	3.67
Aug. 1979	4.07	---	---	0.22	0.22	0.43	4.94

[a] Includes one *Neotoma albigula*

3. Upper Ponderosa Woodland. At higher elevations, where ponderosa grades into Douglas fir and aspen, the fire was not nearly as destructive as at lower elevations within pure stands of ponderosa. Only about 60% of the canopy was destroyed; the destruction was most severe on oak and aspen, with less damage to ponderosa and fir. Ground cover was almost completely destroyed in burned areas, partly because of a heavy accumulation of fuel. During 1977, very little regrowth of ground cover occurred. By 1978, reseeding increased the ground cover (mostly grasses) in burnt areas over that in control areas (Table V). Oak and aspen also showed a great deal of regrowth from root stocks. Little change in vegetation occurred in burnt areas between 1978 and 1979.

The number of *P. maniculatus*, the dominant rodent in this plant association, showed little reduction as a result of the fire (Table VI). In 1978, densities of *P. maniculatus* in burned areas were two to three times higher than in the control area. *Microtus longicaudus* also began to appear in small numbers on burned areas. Squirrel populations remained low on burned areas but reappeared in areas where canopy was not completely burned. In 1979, *M. longicaudus* and *Eutamias* populations continued to increase, but numbers of *P. maniculatus* decreased, perhaps because of competition with the more dominant *Microtus*. *Sorex vagrans* was also recorded in this zone, although numbers of this species are not comparable to those of other species because the traps used are not designed to trap shrews.

TABLE V. Vegetation in Upper Ponderosa Woodland Zone

	Apache Spring Burnt		Upper Fire Break Burnt		Apache Spring Control
Canopy	1978		1978		1978
Noncanopy	20.3		24.7		22.5
Ponderosa (*Pinus ponderosa*)	51.6		42.9		55.4
Douglas fir (*Pseudotsuga taxifolia*)	12.2		12.0		8.5
Gambel oak (*Quercus gambelii*)	7.7		12.4		10.3
Aspen (*Populus tremuloides*)	8.2		8.0		3.3
Ground cover	1978	1979	1978	1979	1978
Bare	34.1	27.4	43.6	45.0	80.5
Slender wheat grass (*Agropyron trachycaulum*)	44.3	46.3	12.7	15.7	---
Slender fescue (*Festuca ovina*)	2.5	8.4	1.6	---	---
Aspen (*Populus tremuloides*)	2.1	2.2	6.9	2.2	---
Wild strawberry (*Fragaria ovalis*)	1.6	---	1.3	1.6	1.4
Red brome (*Bromus rubens*)	3.0	0.8	1.0	1.9	---
Gambel oak (*Quercus gambelii*)	1.4	2.7	6.2	3.8	---
Oat grass (*Danthonea darryii*)	1.2	1.6	2.2	---	---
Sedge (*Carex sp.*)	0.8	+	2.3	---	2.1
Kentucky bluegrass (*Poa pratensis*)	1.9	---	1.9	3.1	---
Orchard grass (*Dactylis glomeratus*)	0.5	0.5	---	---	---
June grass (*Koeleria cristata*)	---	2.7	---	---	1.3
Mutton grass (*Poa fendleriana*)	---	---	4.2	8.3	---
Kinikinik (*Arctostaphylis urvi-ursi*)	---	+	1.6	2.2	3.0
Pussytoes (*Antennaria parvifodra*)	---	1.3	---	3.0	---
Yarrow (*Achillea zanulosa*)	---	---	1.5	3.0	---
Miscellaneous	6.6	6.1	13.0	10.2	11.7

4. Riparian Woodland. Because the vegetation was wet and the canyon bottoms are sheltered from winds, very little of the canopy in this area burned. Approximately 80% of the ground cover was damaged. A few spots near the stream, too wet to sustain fire damage, were used as controls for vegetational surveys. In general, except for an increase in some grass species, the fire caused little change in vegetation (Table VII).

Rodent populations increased after the fire and continued to increase during the summer of 1978 (Table VIII). Toward the end of 1978, populations of *P. maniculatus* decreased, probably because of weaning of the young. *Peromyscus boylii* also increased in numbers. In 1979, *M. montanus* appeared along the grassy stream banks and *P. maniculatus* numbers were high, but *P. boylii* was not present, nor were chipmunks. These later changes may be due to the severe winter of 1978-79.

5. Other Trapping Localities. During 1977 and 1979, some trapping was done on the meadow along the Apache Spring access road. In 1977, *M. montanus* was found here, but it was not found in 1979, presumably because of the preceding severe winter. This species probably is present in small numbers in all grassy areas at the proper elevation within Bandelier, surviving on old burns and along stream banks in grassy areas.

TABLE VI. Small-Mammal Densities (mammals/hectare) in Upper Ponderosa Woodland

	P. maniculatus	*M. longicaudus*	*E. quadrivitattus or minimus*	*Sorex vagrans*	*Spermophilus lateralis*	Total
Apache Spring Access						
Aug. 1977	3.82	---	---	---	0.18	4.00
June 1978	5.41	---	---	---	---	5.41
July 1978	11.22	0.14	---	---	---	11.36
Aug. 1978	16.46	---	---	---	---	16.46
June 1979	3.58	0.72	0.54	---	---	4.93
July 1979	5.14	1.80	0.54	0.18	---	7.66
Upper Fire Break						
June 1977	5.60	---	---	---	---	---
June 1978	4.38	0.24	0.48	---	---	5.10
July 1978	10.64	---	0.48	---	---	11.12
Aug. 1978	10.38	---	0.48	---	---	10.86
June 1979	7.86	0.48	2.39	---	---	10.97
July 1979	5.18	0.60	3.58	0.24	---	9.60
National Forest						
Aug. 1977	3.87	---	1.08	---	0.27	5.76
June 1978	2.87	---	1.20	---	0.27	4.34
July 1978	3.87	---	1.20	---	---	5.07
Aug. 1978	5.34	---	1.60	---	---	6.94

During 1977, trapping was also conducted at higher elevations, along St Peters Dome Road. Results for both areas are presented in Table IX comparisons.

VI. SUMMARY OF THE EFFECTS OF LA MESA FIRE ON SMALL-MAMMAL POPULATIONS

A. Direct Effects

Because there was no trapping program before the fire, these conclusions are speculative. Several authors have shown that fire severely reduces mouse populations (Tevis 1956, Tester 1965, and especially Chew, Butterworth, and Grechman 1959), but others have demonstrated the insulating effect of soil in protecting ground-dwelling species from fire (Howard, Fenner, and Childs 1959). It seems likely that *Peromyscus* populations were reduced somewhat by the fire since most logs and dead roots where they make their homes were destroyed. Similarly, tree-dwelling species such as chipmunks and squirrels suffered high mortality rates from the fire and were noticeably absent in burned areas despite the presence of much undamaged food (pinecones). Burrowing forms, such as golden-mantled ground squirrel were less affected by the fire, as were species using rocky outcrops devoid of vegetation, such as ground squirrels and *P. difficilis*.

TABLE VII. Vegetation in Riparian Woodland

Canopy	1978
Noncanopy	11.3
Ponderosa pine (*Pinus ponderosa*)	13.3
Douglas fir (*Pseudotsuga taxifolia*)	47.5
Gambel oak (*Quercus gambelii*)	24.3
Box elder (*Acer negundo*)	4.6

Ground cover	Overall 1979	Burned 1978	Unburned 1978
Bare	38.6	41.6	30
Kentucky bluegrass (*Poa pratensis*)	7.1	10.0	23.3
Meadow rue (*tharlictrum fendleri*)	6.1	7.2	4.2
Gambel oak (*Quercus gambelii*)	4.1	6.3	9.2
Slender wheat grass (*Agropyron trachycaulum*)	10.2	8.1	1.7
Sedge (*Carex sp.*)	---	2.2	---
Poison ivy (*Rhus radicans*)	3.0	0.9	1.7
Violet (*Viola adunca*)	2.3	1.2	1.3
Big golden pea (*Thermopsis pinetorum*)	--	---	3.3
Brome grass (*Bromus japonicus*)	3.3	1.0	---
Wild strawberry (*Fragaria ovalis*)	2.5	---	---
Chickweed (*Stellaria media*)	2.8	---	---
Sheep fescue (*Festuca ovina*)	6.6	---	---
Miscellaneous	13.4	21.5	25.2

TABLE VIII. Small Mammal Densities (mammals/hectare) in Riparian Woodland

	P. maniculatus	*P. boylii*	*M. montanus*	*E. quadrivitattus*	Total
Upper Crossing					
July 1977	2.29	0.12	---	0.42	2.95[a]
Aug. 1977	4.62	---	---	---	4.74[b]
June 1978	12.12	0.36	---	0.18	12.66
July 1978	13.68	0.81	---	---	14.49
Aug. 1978	8.53	0.90	---	0.72	10.15
June 1979	6.46	---	0.36+	---	6.80
Aug. 1979	8.48	---	2.15	---	10.63

[a] Includes on *Reithrodontomys megalotis*.

[b] Includes one *Sorex vagrans*.

TABLE IX. Small-Mammal Densities (mammals/hectare) at Other Trapping Localities

	P. maniculatus	*M. montanus*	*Spermophilus lateralis*	*E. minimus*	*Tamiasciurus hudsonicus*	Total
Apache Meadow						
July 1977	5.50	2.00	0.50	2.00	---	10.00
June 1979	4.00	---	---	---	---	4.00
St Peters Dome Road						
July 1979	2.33	---	1.08	2.96	0.36	6.73

B. Long-Term Effects

All species of small mammals mentioned in this report are so-called r species; that is, they exhibit high rates of reproduction and population increases to take advantage of fluctuating environments. These species normally undergo annual population cycles with a reduction in numbers during the winter followed by an increase each summer. Enough unburned areas were left within the fire's perimeter to serve as repopulation centers for all species involved. Therefore, although there may be some initial effects on small-mammal populations because of fire mortality, long-term population changes are the result of habitat changes, the availability of suitable food sources, and cover.

C. Decreases

Where piñon-juniper woodland burned, the piñon mouse (*P. truei*) disappeared, demonstrating the relationship of this species with these trees. Similarly, at higher elevations, red squirrels remain absent in areas where ponderosa or Douglas fir were killed.

D. Increases

After the fire, *P. maniculatus* populations increased in all burned areas. This species is known as a colonizer species that favors disturbed habitats and areas where competition with other more aggressive species of *Peromyscus* is low (Ahlgren 1966, Beck and Vogel 1972, Lawrence 1966, and Tester 1965). The increase was most noticeable in piñon-juniper woodland, where other species of *Peromyscus* were present before the fire. *Peromyscus truei* and *P. difficilis*, more dependent on piñon and juniper for food than *P. maniculatus*, failed to reestablish themselves in the area after the fire. In ponderosa and fir woodlands, *P. maniculatus* is normally the dominant species of small rodent. After the fire, populations of this species were the same or larger than before. In some cases, *P. maniculatus* populations decreased during the summer. This may be due to the establishment of territories after invasion into burned areas and some resultant diminution of population density. Voles (*M. montanus* and *M. longicaudus*) are also considered colonizing species that favor grassland habitats. The low numbers of these species present before the fire (Apache meadow and on old burns) made colonization of the burned area a slow process, but by 1979, *Microtus* were present in all grassy areas, doing especially well in the upper ponderosa woodland, where denseness of grass limited movement of other rodent species.

Chipmunks (*Eutamius quadrivittatus* and *E. minimus*) also seemed to do well in burned areas, perhaps switching food sources from evergreens to the abundant annual seed crop.

Ahlgren (1966) commented on the failure of controlled burns to affect rodent populations and the subsequent problem of reforestation because rodents eat pine seedlings. However, these populations seem to have been less reduced in winter than were the Bandelier populations. The severe winter of 1978-79 reduced rodent populations by 60 to 90%; a normal winter should reduce rodent populations by at least 50%. At least two or three successive mild winters would be required before rodent populations would reach 'explosive' levels where normal summer vegetational growth would be severely threatened.

VII. CONCLUSIONS

The immediate effect of La Mesa fire on small-mammal populations was to reduce populations of nonburrowing species within the fire area, particularly arboreal forms such as red squirrel. Most burrowing rodents survived the fire. Changes in vegetation after the fire, for example, greater development of grasses and annual plants and the death of many evergreens, caused changes in small-mammal populations within the burn area. Populations of species heavily dependent upon evergreens decreased (red squirrel in ponderosa and fir and *P. truei* in piñon-juniper). Species increasing in population were *P. maniculatus*, which increased in all burned areas. Populations of *M. montanus* and *M. longicaudus*, the latter species at higher elevations, also increased in grassy areas. Finally, chipmunks (*E. quadrivitattus* and *E. minimus*) showed increases in ponderosa and fir zones.

Because of seasonal changes, all rodent populations undergo periodic population decreases; therefore, little change in carnivore populations can be expected. Also, these seasonal decreases should keep rodent populations from overeating food supplies or affecting reseeding or reforestation efforts.

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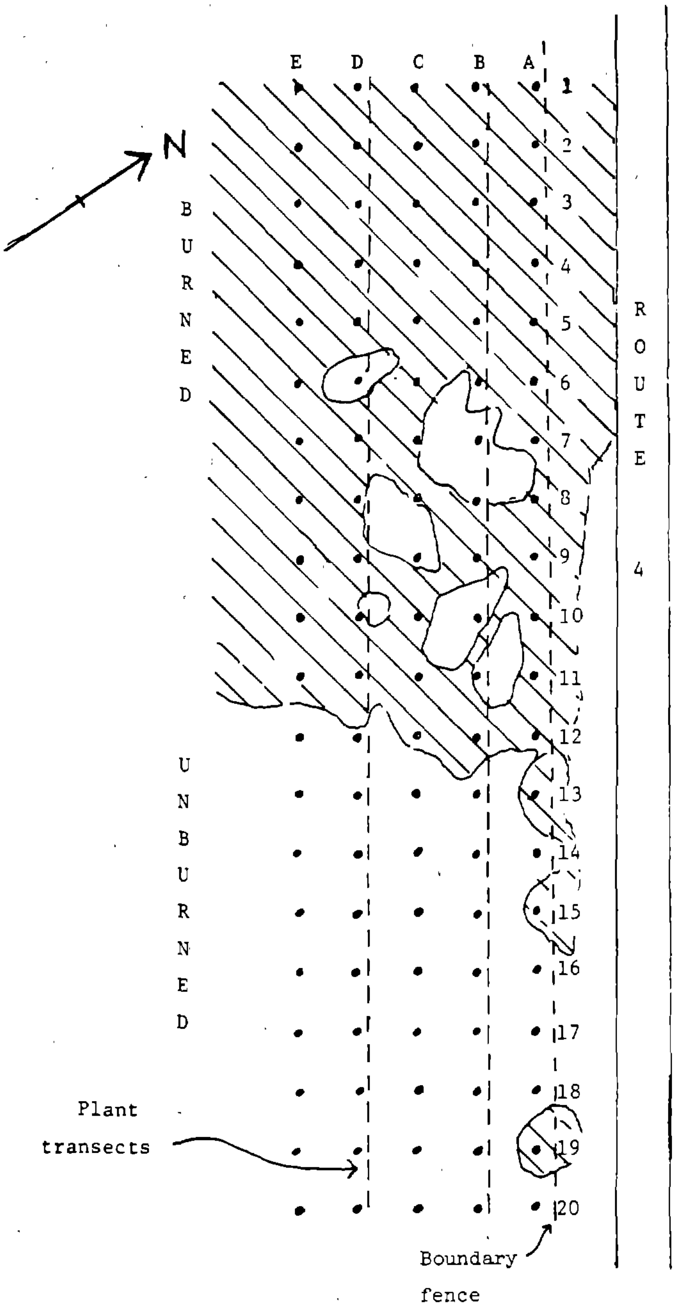
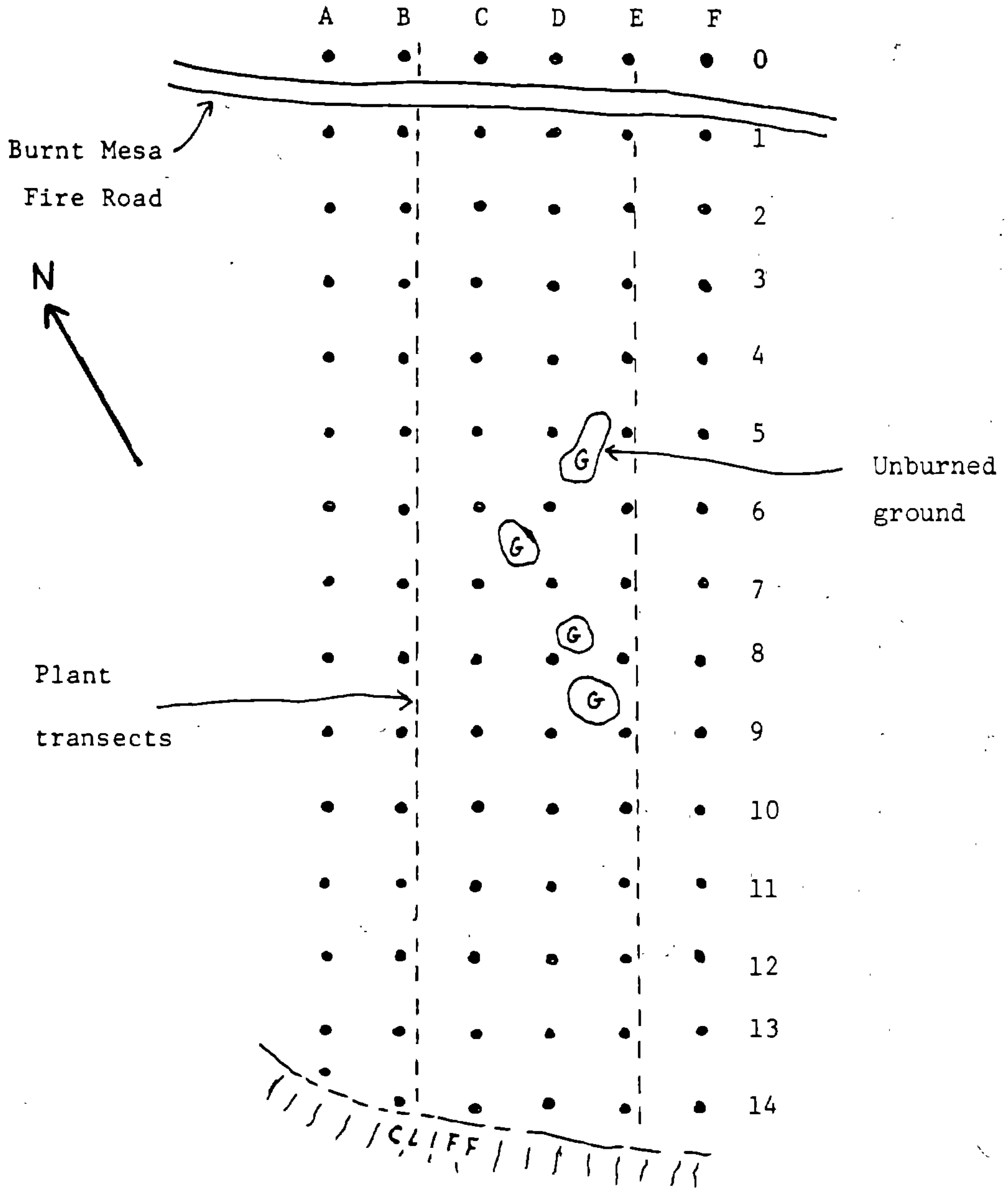
APPENDIX

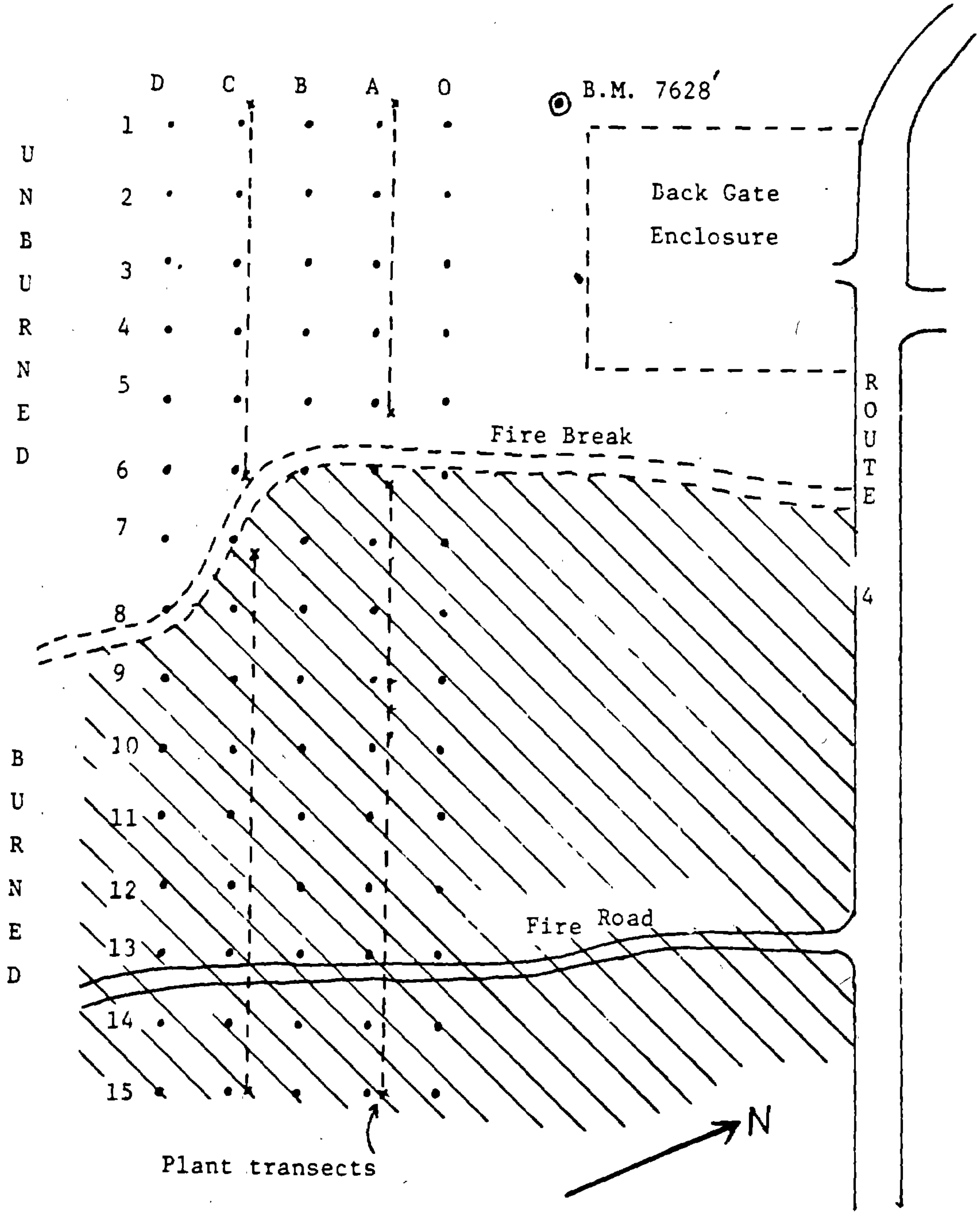
MAJOR SMALL-MAMMAL TRAPPING GRIDS



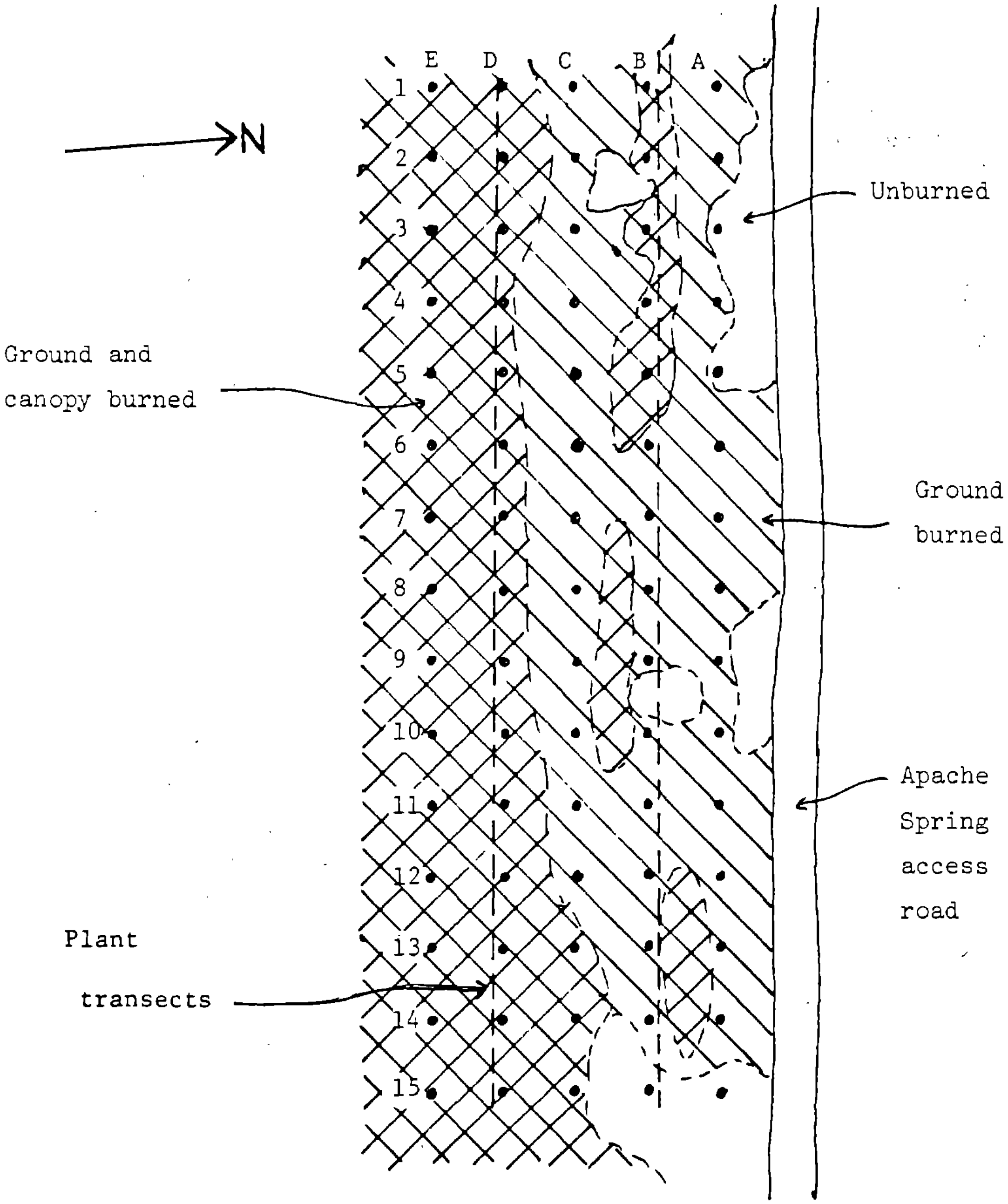
SR 4 Small-Mammal Trapping Grid



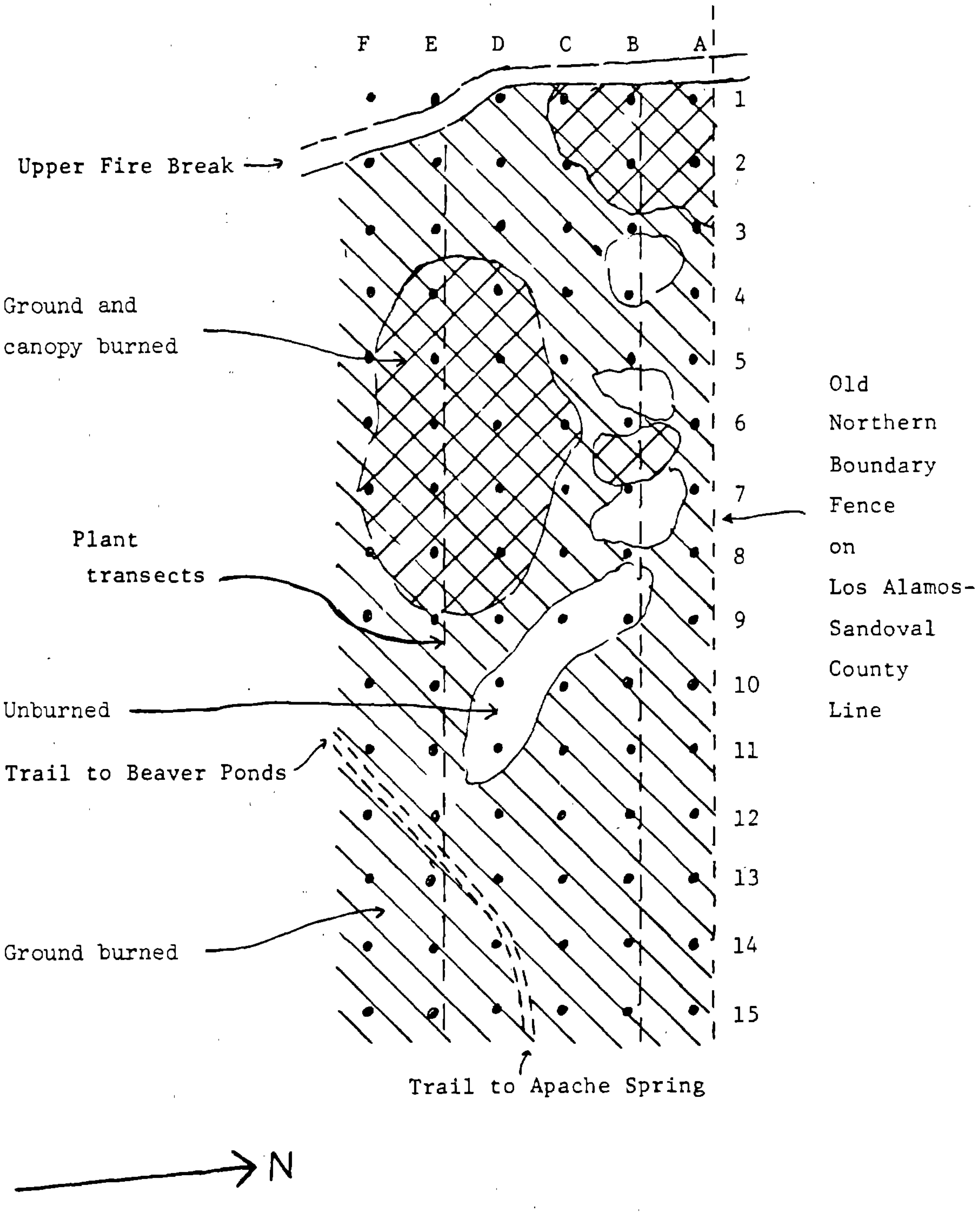
Burnt Mesa Small-Mammal Trapping Grid



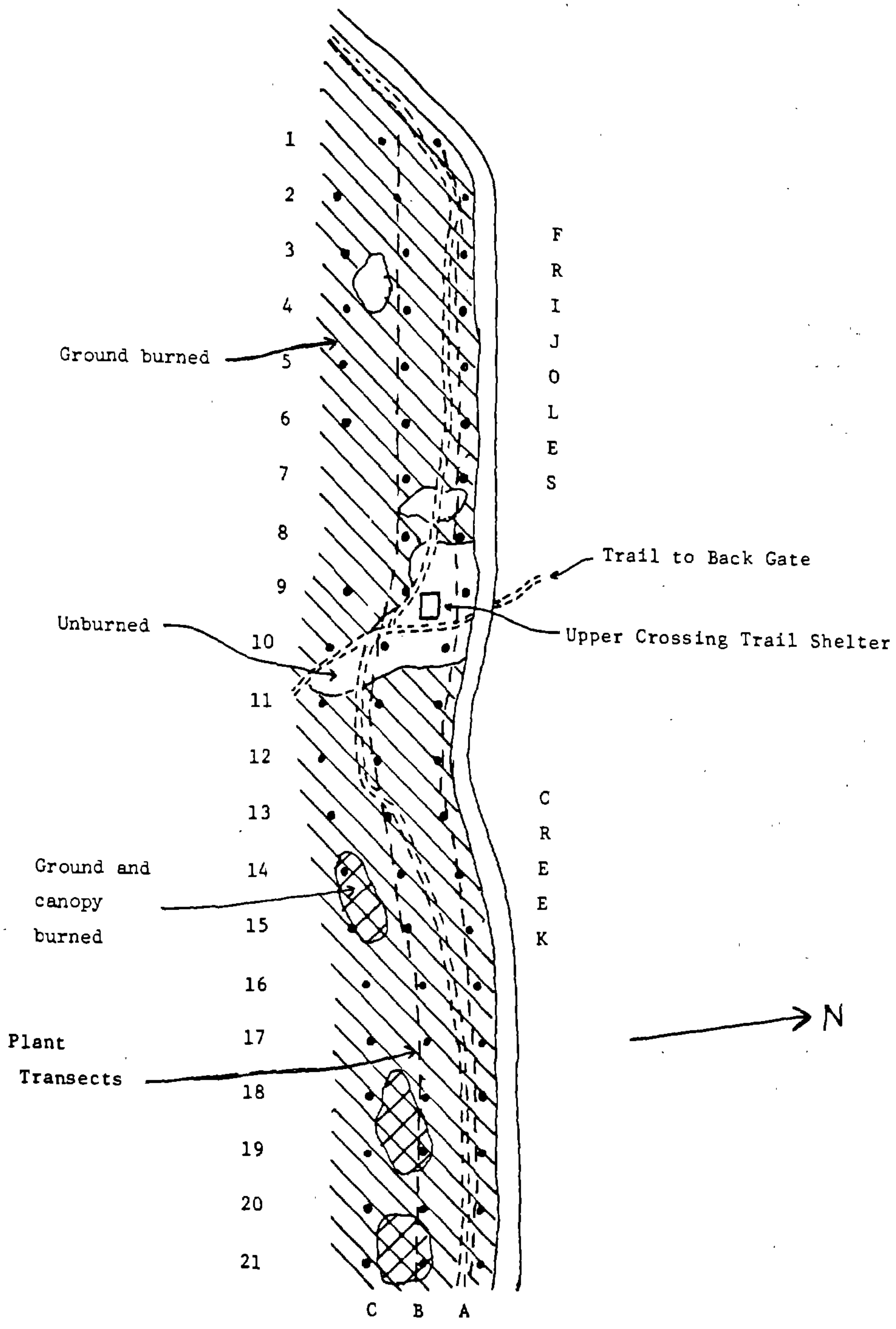
Back Gate Small-Mammal Trapping Grid



Apache Spring Access Small-Mammal Trapping Grid



Upper Fire Break Small-Mammal Trapping Grid



Upper Crossing Small-Mammal Trapping Grid

THE EFFECTS OF CLEARING FIRE-KILLED TREES ON WILDLIFE

Susan Moeur* and Daniel A. Guthrie*

I. INTRODUCTION

Rapid recovery of the forest after a fire should be an important objective of forest management. Following a severe fire in the Jemez Mountains in north central New Mexico, two management approaches were instituted on adjacent burn sites. The purpose of this study is to compare the effects of these two management policies on the flora and fauna of both areas.

History

After La Mesa fire, burnt forest areas were heavily seeded from the air with a variety of grasses. On the Bandelier National Monument property, this was the only action taken. However, on the Los Alamos National Laboratory site, all dead trees were cut down and removed during the summers of 1978 and 1979.

Two consequences resulted from removal of the dead trees: physical disturbance to the site caused by the removal process and depletion of habitat provided by the trees. After the trees were felled on Laboratory property, the public was invited to remove the wood for use as firewood. Consequently, a large number of pickup trucks drove over much of the area. The resulting soil disturbance, combined with that caused by the fire, should render this soil less favorable for plant growth, relative to the Bandelier site.

Removal of dead trees also resulted in the removal of an important habitat. Standing dead trees provide vertical stratification that is especially significant to bird populations. Cody and Walter (1976) directly correlated high densities of breeding bird populations with vertical niche expansion. In addition, Cody (1968) found that various species of birds in grassland communities are able to coexist by virtue of differences in habitat preferences, feeding behaviors, and feeding heights. Also, after a fire, dead trees become infested with woodboring insects, which attract several avian species (Bock and Lynch 1970). Finally, many species of birds depend on dead trees for nest sites (Miller and Miller 1980; Scott, Whelan, and Svoboda 1980).

For this study, two areas, one on Laboratory property and one on Bandelier property, were selected for examination (Fig. 1). The indexes used in comparing the two sites are compositions of vegetation, relative insect populations, bird populations, and small-mammal populations. These were chosen because they represent primary productivity, primary consumption, and secondary consumption. They also represent a variety of habitat preferences and requirements.

II. MATERIALS AND METHODS

The study was conducted from June to August 1979. The study sites were adjacent but separated by a road. The adjacent locations provided important controls: elevation (approximately 7200 ft) and

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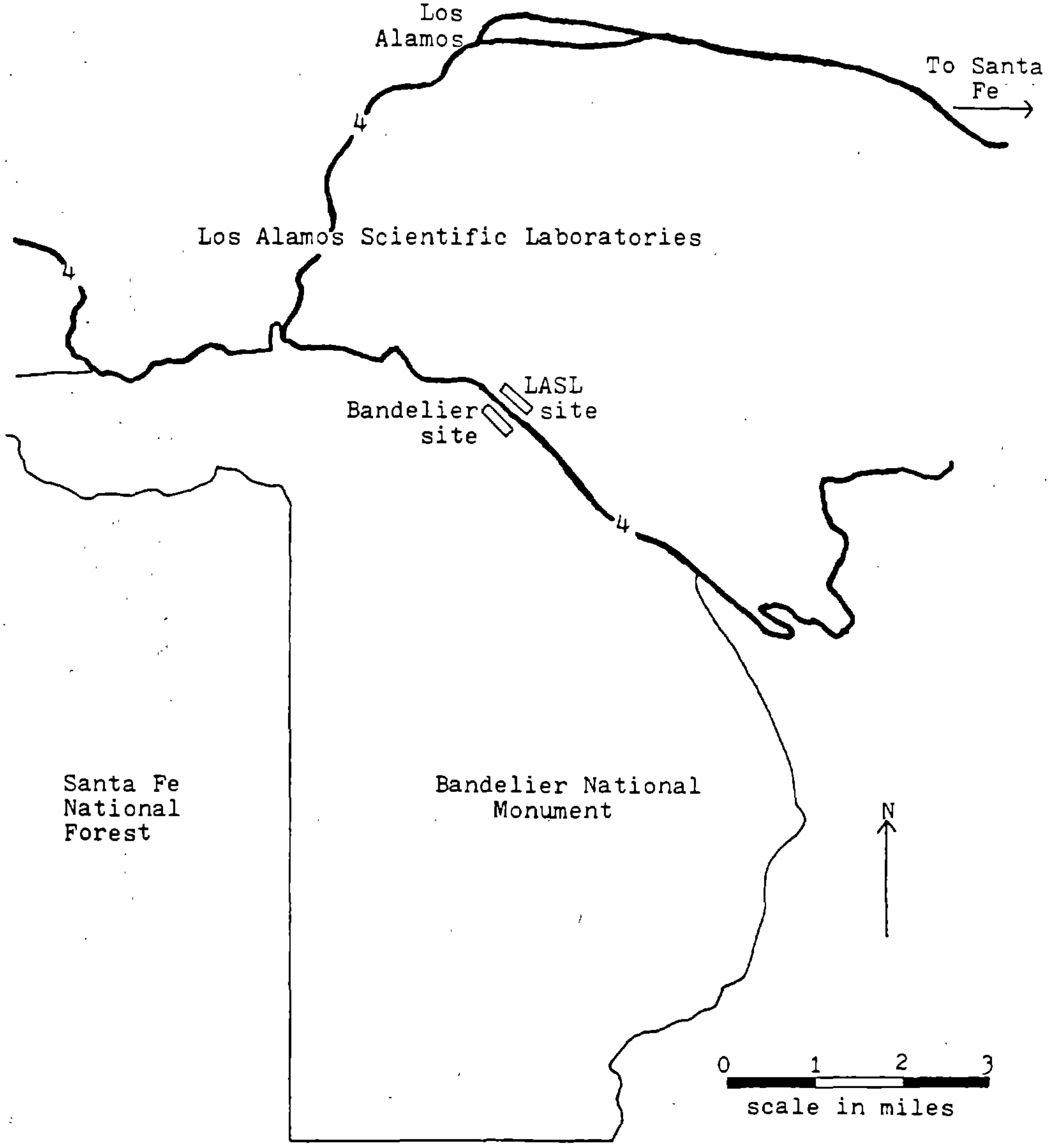


Fig. 1. Map of study site.

topography are nearly identical, as are light, temperature, and precipitation. The Laboratory site was not totally devoid of trees. At the west end of the site, a patch of about 10 trees survived the fire and were left standing.

Each site was mapped and gridded. The grids contained six parallel lines, 100 ft apart, each 2400 ft long, and markers were placed 100 ft apart on these lines. (Figs. 2 and 3).

No studies of the area were made before the fire. Therefore, to assess the forest similarity of both sites before the fire, trees on the Bandelier side and stumps on the Laboratory side were counted and basal diameters measured. Counting was done along random transects. The assessment showed no differences in tree density or size between the two sites before the fire (Figs. 4 and 5).

Vegetational analysis was done by a toe-point line transect method. The first, second, third, and fifth lines of the grids were surveyed, and the plant cover every third step was recorded. This information was converted to per cent coverage.

Insects were collected by sweep netting to determine comparative populations. No effort was made to determine total insect populations. Forty random 100-ft transects were swept during four days on each

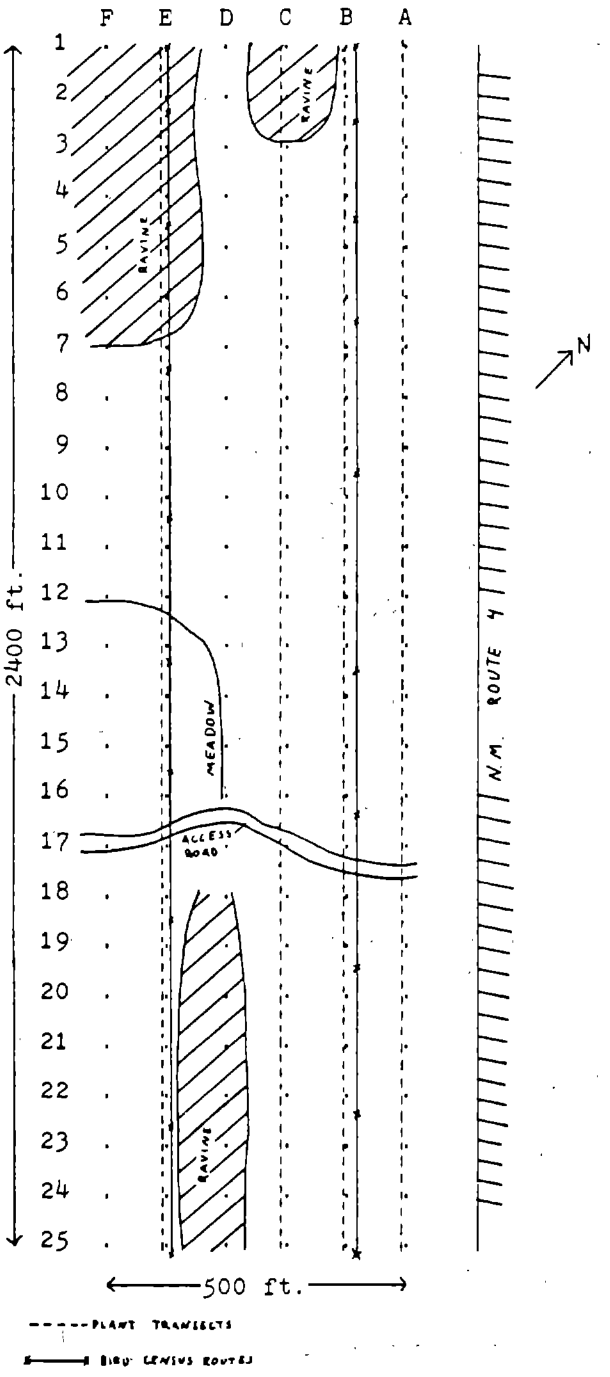


Fig. 2. Bandelier site.

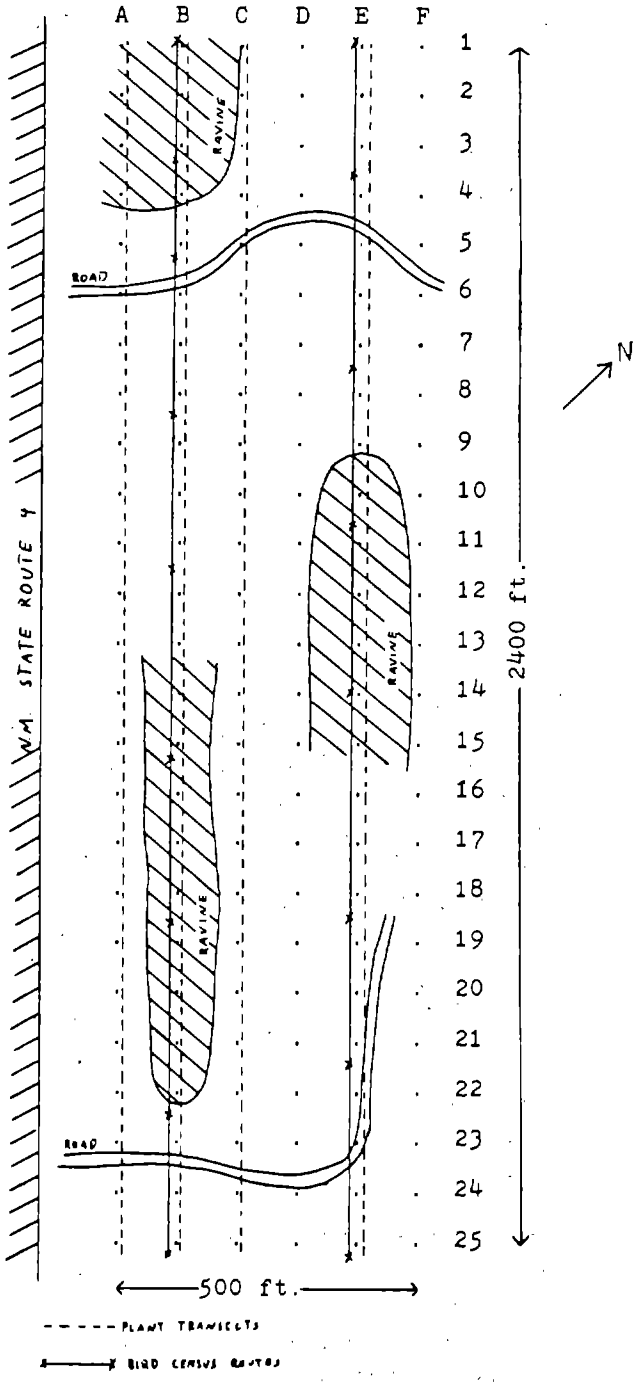


Fig. 3. Laboratory site.

site. Every effort was made to keep the sweeping technique uniform. Insects were chloroformed, separated from plant debris, and stored in formalin for later classification according to family.

The bird census was completed by a variation of the spot-mapping method. On eight occasions at each site, the second and fifth lines of the grids were walked and the location of every bird sighted or heard was recorded on a map of the grid area. Censuses were taken between 8 and 11 a.m. A compilation of the eight censuses yields an estimation of the total avian populations; birds recorded three or more times ir

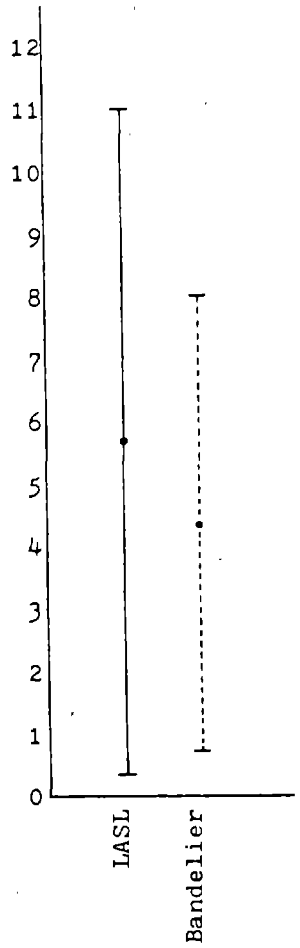


Fig. 4. Trees and stumps per transect.

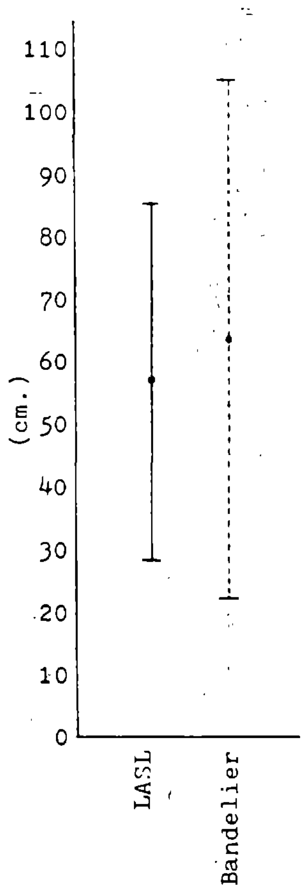


Fig. 5. Basal tree diameters.

the same general location are considered stationary residents of the area, those recorded fewer than three times are considered nonstationary visitors (Audubon Field Notes 1970). This is the method recommended for nongame bird inventories by the Bureau of Land Management (1969). Maps of resident birds and their territories were made from the censuses and, from these, population density estimates were determined.

Small-mammal populations were determined by a mark capture and release method. Traps were set at the flagged intersections of the grids for three consecutive evenings (6 x 25 = 150 traps per grid). Populations were determined by a modification of the Lincoln index (Bailey 1952).

III. RESULTS

Table I shows the percentage of ground cover on the two sites. There is a slightly greater percentage of ground cover on the Bandelier site, but the difference is not significant.

The total numbers of insects collected per day are shown in Fig. 6. The total insect populations were significantly different on only one of the four sampling dates. No differences were found in the number of families of insects represented nor in the proportions of herbivorous insects between the two sites.

The means and ranges of birds recorded per day are given in Table II. Figures 7 and 8 show composite maps of resident birds and their observed territories, along with densities for resident species. Small-mammal densities are given in Table III.

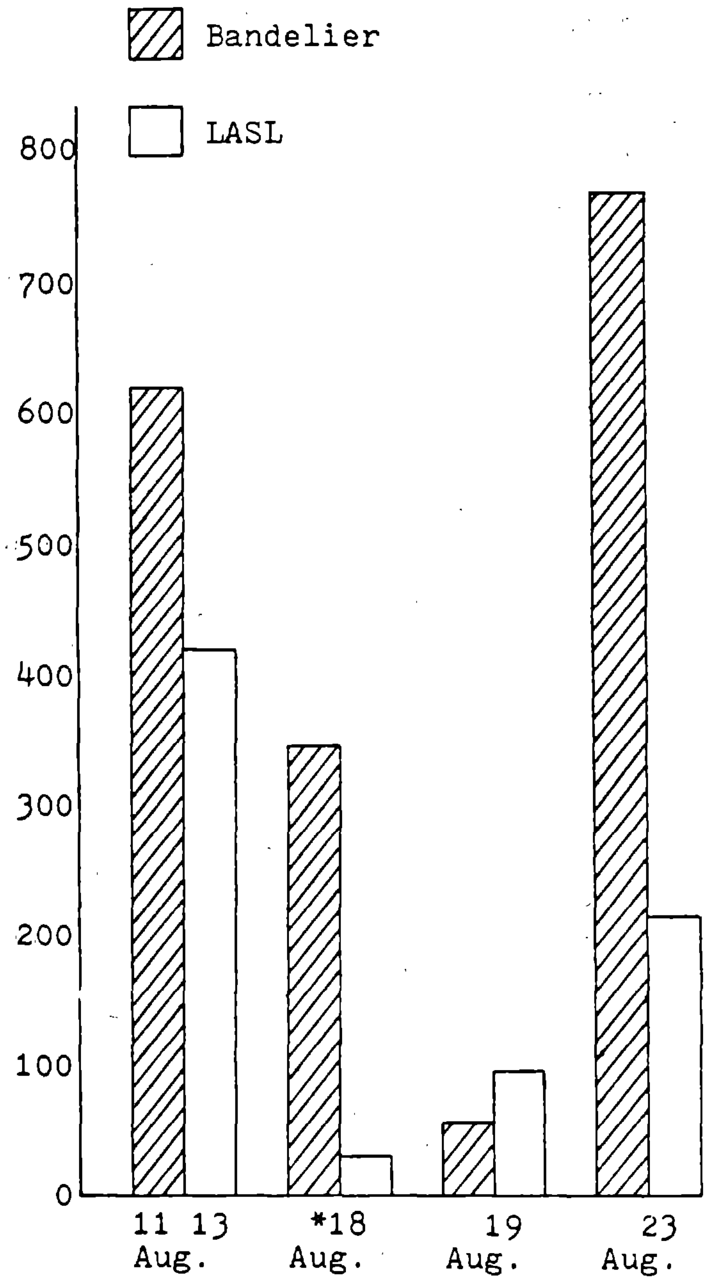
TABLE I. Ground Cover

Species	Bandelier (%)	Laboratory (%)
Bare Ground	47.1	58.5
Dead wood (slash piles)		3.3
Slender Wheat Grass (*Agropyron trachycaulum*)	13.6	16.6
Blue Grama (*Bouteloua gracilis*)	4.5	1.2
Sage (*Artemisia frigide*)	4.3	1.6
Ratty Fescue (*Festuca ovina*)	4.2	2.1
Oak (*Quercus dumosa*)	4.1	0.1
Gambel Oak (*Quercus gambelii*)		3.4
Blue Lupine (*Lupinus argenteus*)	2.7	0.7
Hairy Wheat Grass (*Sitanion hystrix*)	2.1	0.4
Lamb's Quarters (*Chenpodium alba*)	2.0	0.1
Hairy Golden Aster (*Chrysopsis foliosa*)	1.8	0.6
Ragweed (*Chenpodium graniolens*)	1.5	
Snakeweed (*Gutierrezia sarothrae*)	1.0	0.5
Short Feather Grass (*Muhlenbergia montanus*)	1.0	0.4
Sheep's Fescue (*Poa pratensis*)	0.9	0.4
Wormwood (*Artemisia dranculoides*)	0.9	
Tall Fleabane (*Erigeron* sp.)	0.8	
Scarlet Gilia (*Gilia* sp.)	0.7	0.2
June Grass (*Koeleria cristata*)	0.7	0.4
Mullein (*Verbascum thapsus*)	0.6	0.2
New Mexican Thistle (*Cirsium neomexicana*)	0.4	0.1
Deer Vetch (*Lotus wrightii*)	0.4	0.4
Scarlet Penstemon (*Penstemon* sp.)	0.4	0.2
Little Blue Stem (*Andropogon scoparius*)	0.4	0.7
New Mexican Locust (*Robinia neomexicana*)	0.4	0.8
Spreading Fleabane (*Erigeron divergens*)	0.3	0.1
Red Brome (*Bromus japonicus*)	0.3	1.4
Rat-tail Grass (*Muhlenbergia wrightii*)	0.3	0.6
White Fiddleneck (*Cryptantha jamesii*)	0.2	
Gaura coccinea	0.1	
White Sweet Clover (*Petalostamen candidus*)	0.1	
Salsify (*Tragopogon* sp.)	0.1	
Wild Rose (*Rosa* sp.)	0.1	0.1
Yellow Wall Flower (*Erysimum* sp.)	0.1	
Liatrus puntada	0.1	
Showy Fleabane (*Erigeron* sp.)	0.1	
Beggar's Ticks (*Lapula* sp.)	0.1	
Spike Grass (*Andropogon gerardi*)	0.1	
Wild Geranium (*Geranium* sp.)	0.1	0.1
Indian Paintbrush (*Castilleja* sp.)	0.1	
Heterotheca lirsutima	0.1	
Ragweed (*Ambrosia psilotachya*)		1.8
Canadian Fleabane (*Erigeron canadensis*)		0.4
Cut-leaf Ragweed (*Bahia dissecta*)		0.3
Silver Sage (*Artemisia ludoviciana*)		0.3
Skunk Cabbage (*Polemonium* sp.)		0.3
Mentzelia (*Mentzelia* sp.)		0.2
White Yarrow (*Achillea lanulosa*)		0.1
Purple Aster (*Erigeron* sp.)		0.1
Milkweed (*Asclepius* sp.)		0.1
Miscellaneous	1.2	1.2

IV. DISCUSSION

The diversity of vegetation does not differ significantly on the two sites. Of 39 plant species found on the Bandelier site and 35 on the Laboratory site, 25 are common to both. These 25 species constitute about 90% of the total vegetation on the Bandelier site and 80% of that on the Laboratory site.

Total vegetational coverage on the two sites does differ, with the Bandelier site having slightly more cover. Two factors probably contribute to this difference: the continuing soil compaction and disturbance caused by vehicles driving over the Laboratory site, and the protection provided by standing trees on the



*18 August significant at .95

Fig. 6. Total insects per day.

Bandelier site. Approximately 10% of the Bandelier site was shaded by the dead trees left standing, which aids soil moisture retention and also may provide some protection against hard winds, rain, and hail.

Because of more abundant plant growth, and because they are low on the food chain, insects would be expected to occur in higher numbers and greater diversity on the Bandelier site than on the Laboratory site (Erickson 1979, Yoder 1976). However, the results do not support this. A possible reason is increased predation by birds on insects on the Bandelier site. Also, the differences in plant cover are not great and may not be reflected in insect populations.

TABLE II. Birds Observed	Bandelier				Laboratory			
	Mean	range	No.	No./ha.	Mean	range	No.	No./ha.
Resident Birds								
Broad-tailed hummingbird (*Selasphorus platycercus*)	3.6	2-5	4	.36	4.8	3-8	21	.54
Hairy woodpecker (*Dendrocopus villosus*)	7.1	4-12	13	1.17	---	---	---	---
Western wood pewee (*Contopus sordidulus*)	1.8	0-3	3	.27	0.7	0-2	1	.09
Western bluebird (*Sialia mexicana*)	5.5	2-11	6	.54	4.3	0-7	6	.54
Mountain bluebird (*Sialia currucoides*)	0.4	0-2	---	---	1.3	0-6	3	.27
Green-tailed towhee (*Chlorura chlorura*)	1.5	1-3	1	.09	1.7	1-4	4	.36
Rufous-sided towhee (*Pipilo erthrophthalmus*)	0.4	0-1	1	.09	0.8	0-1	1	.09
Chipping sparrow (*Spizella passerina*)	4.9	3-7	6	.54	0.8	0-2	---	---
TOTALS			34	3.05		21	1.88	
Visiting Birds								
Red-tailed hawk (*Buteo jamaicencis*)	---	---			0.1	0-1		
Goshawk (*Accipiter gentilus*)	0.1	0-1			---	---		
Sparrow hawk (*Falco sparverius*)	0.1	0-1			---	---		
White-throated swift (*Aeronautes saxatalis*)	0.2	0-1			0.3	0-2		
Rufous hummingbird (*Selasphorus rufus*)	---	---			0.3	0-2		
Northern flicker (*Colaptes auritus*)	0.3	0-2			---	---		
Say's phoebe (*Sayornis saya*)	0.8	0-2			---	---		
Ash-throated flycatcher (*Myiarchus cinerascens*)	0.4	0-3			0.3	0-1		
Dusky flycatcher (*Empidonax oberholseri*)	0.1	0-1			---	---		
Violet-green swallow (*Tachycineta thalassina*)	0.9	0-3			1.3	0-5		
Raven (*Corvus corax*)	1.0	0-7			---	---		
Steller's jay (*Cyanocitta stelleri*)	1.6	0-4			---	---		
Clark's nutcracker (*Nucifraga columbina*)	---	---			0.3	0-2		
White-breasted nuthatch (*Sitta carolinensis*)	0.2	0-1			0.2	0-1		
Rock wren (*Salpinctes obsoletus*)	---	---			0.7	0-3		
Robin (*Turdus migratorius*)	0.9	0-2			0.3	0-2		
Solitary vireo (*Vireo solitarius*)	0.6	0-4			---	---		
Grace's warbler (*Dendroica graciae*)	0.1	0-1			---	---		
Brown-headed cowbird (*Molothrus ater*)	0.1	0-1			---	---		
Western tanager (*Piranga ludoviciana*)	0.2	0-1			---	---		
Black-headed grosbeak (*Pheucticus melanocephalus*)	0.3	0-2			---	---		
Lesser goldfinch (*Spinus psaltria*)	0.5	0-2			0.5	0-2		
Song sparrow (*Melospiza melodia*)	0.1	0-1			---	---		
TOTALS	33.7	21-43			19.7	12-31		

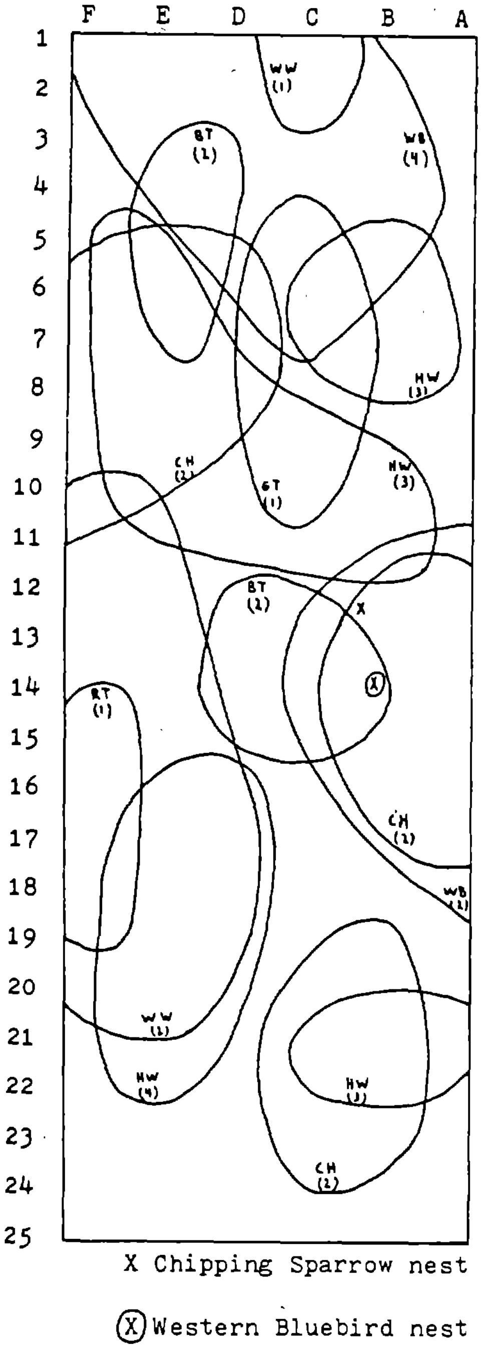


Fig. 7. Resident avian territories at Bandelier.
BT - Broad-tailed hummingbird.
CH - Chipping sparrow.
GT - Green-tailed towhee.
HW - Hairy woodpecker.
RT - Rufous-sided towheee.
WB - Western bluedird.
WW - Western wood pewee.

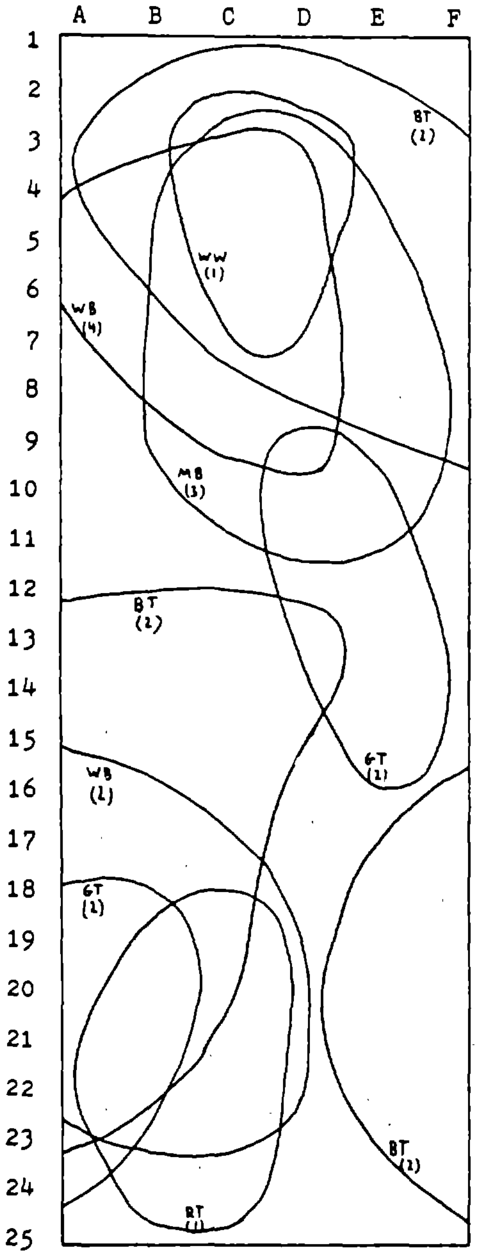


Fig. 8 Resident avian territories, Laboratory.
BT - Broad-tailed hummingbird.
GT - Green-tailed towhee.
MB - Mountain bluebird.
RT - Rufous-sided towhee.
WB - Western bluebird.
WW - Western wood pewee.

TABLE III. Small-Mammal Populations

	Mammals/Hectare	
	Bandelier	Laboratory
Peromyscus maniculatus	7.4	8.0
Eutamias quadrivitattus	0.4	0.4
Microtus montanus	0.5	0.3

The major factors affecting avian populations are food availability (Stenger 1958, Cody and Cody 1972) and habitat structure (Cody and Walter 1976, Cody 1968). With the exceptions of two visitors to the sites, all birds recorded are either insect eaters or subsist on insects and vegetation. Neither food source is lacking or appears to be limiting to the populations. Instead, the differences in both resident and visiting bird populations between the two sites is clearly a matter of habitat choice and selection. The standing trees provide not only feeding stratification, but breeding sites as well. Comparison of the two sites shows greater use of the Bandelier site by seed-eating and insectivorous species. Many tree-nesting species observed on the Laboratory site were observed to cross the road to the Bandelier site after feeding. Tree-nesting species on the Laboratory site used the few trees left standing, and many insectivorous species were observed to perch in these trees between feeding forays.

Mammal populations did not differ between the two study sites. Guthrie (1980) suggests that there is more than enough food for small herbivorous mammals in the area and that mammal populations are determined more by the severity of winter conditions than by the amount of food available during summer months.

V. CONCLUSIONS

Slight differences in vegetation and insect populations were found between the Bandelier and Laboratory sites, but these differences were not significant. No difference was found in mammal populations between the two sites. Bird populations differed, with greater populations of both resident and visiting species on the Bandelier site. This difference is thought to be due to the presence of nesting sites and perches provided by dead trees rather than to differences in food supply. The few trees left standing on the Laboratory site were used by birds and lessen the differences observed between the two sites.

The effects of the two strategies of forest management thus have their greatest effect on bird populations. Effects of the Laboratory approach on vegetation are minor, but could be minimized even more by restricting vehicular travel in the process of wood removal (requiring cut wood to be carried to existing roads rather than allowing vehicles to drive to the cutting site). The effects on birds could be greatly reduced by leaving a certain percentage of dead trees standing, particularly large trees that were partially dead before the fire and that were used by hole-nesting species.

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LA MESA FIRE EFFECTS ON AVIFAUNA

Changes in Avian Populations and Biomass

Roland H. Wauer* and Terrell Johnson**

I. INTRODUCTION

Before La Mesa fire, Wauer had begun an avian population study within Bandelier National Monument. Seven dual transects had been established on seven vegetative units. Three of these were burned between June 19 and June 23, 1977.

This report compares the avifauna present within the three units before and immediately after the fire and during the breeding seasons for 2 additional years.

II. STUDY AREA

Bandelier National Monument comprises a series of mesas separated by steep-walled canyons cut into the ancient volcanics of the Pajarito Plateau. The various mesas provide a series of steps between the semidesert Rio Grande lowlands and the boreal zones of the Jemez Mountains highlands.

Each elongated mesa is itself a series of benches that produce different vegetative communities with respect to elevations. The most accessible of these mesas is north of Frijoles Canyon and adjacent to State Road 4. The three study units were selected on successive benches of this northernmost mesa of the Monument.

Burnt Mesa unit is situated between 7200 and 7600 ft elevation (2200 to 2320 m). Vegetation is typical of ponderosa pine forest communities of the American Southwest. Ponderosa pine (*Pinus ponderosa*) is dominant, but piñon pine (*P. edulis*), Rocky Mountain juniper (*Juniperus scropulorus*), and Gambel oak (*Quercus gambelii*) are common throughout.

Escobas Mesa unit is situated between 7400 and 7800 ft elevation (2250 to 2380 m). Dominant vegetation consists of ponderosa pine, Rocky Mountain juniper, Gambel oak, Douglas fir (*Pseudotsuga menziesii*) and, in the moist, protected places, quaking aspen (*Populus tremuloides*) occurs in less abundance.

Apache Spring unit is situated between 8200 and 8800 ft elevation (2500 to 2680 m). The dominant vegetation in this area includes ponderosa pine, Gambel oak, Douglas fir, and quaking aspen. White fir (*Abies concolor*), Rocky Mountain juniper, and New Mexico locust (*Robina neomexicana*) are fairly common as well.

III. METHODS

Field activities began with a reconnaissance of the various mesas within the more accessible northern portion of Bandelier National Monument to select study areas within each vegetative community.

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Transect lines were then measured on the three units following procedures suggested by Emlen (1971). The 1-mile (1.61-km) transect lines were divided into fifty-two 31-m intervals (by flagging and rebar) and four 31-m intervals (124 m) on each side of the lines. Thus, each transect of fifty-two by eight 31-m squares yielded a total of 40 hectares (100 acres).

Birds were counted from May 15 to July 12, 1977, April 26 to July 23, 1978, and May 7 to July 2, 1979, when nesting was well under way, by walking the 1-mile transect lines at about 1/2 mi/h. Wauer initiated the study and took every census in 1977; Johnson took half in 1978, and all those in 1979. All detected avian species (by two- or three-letter abbreviations) and their activities relating to breeding and feeding behavior were recorded on field sampling forms. Counts were made between 6:00 and 9:30 a.m. All the data were transferred to permanent summary sheets to illustrate the number of individuals detected within each set of intervals paralleling the transect lines. Data were interpreted according to Emlen (1977), except that all songs, calls, and sightings were used and interpolated. Coefficients of detectability were computed for quiet species, such as scrub jay (during the nesting season) and western bluebird. Population estimates for more vocal species, such as mourning dove and solitary vireo, were derived directly from songs, calls, and sightings, without coefficients.

Species known definitely not to breed in the habitats of the study area (for example, white-throated swift, common raven) or during the survey period (Clark's nutcracker), and those flying over but not observed using the habitat (turkey vulture, red-tailed hawk, piñon jay) were excluded from consideration. All other species were tabulated as potential breeding species. All species were later divided into 10 feeding and 4 nesting guilds. Feeding guilds used are a variation of those developed by Salt (1957) and require placing all species into specific categories of primary consumers (grainivores/nectarivores) or secondary consumers (insectivores/carnivores). The omnivores category was not used because of the necessity to place all species in principal categories according to which types of food formed the largest part of the diets during the breeding season so that all species could be categorized more readily. Feeding and nesting guilds were determined by direct observation and known behavioral patterns.

Population data were derived from the maximum numbers of specific individuals recorded on each study unit and were converted to population densities, individuals per 100 acres. Relative abundance indexes were derived by calculating the factors of individuals of a species relative to the total number of individuals per acre. Species deversity (H') was computed as $H' = \Sigma P_i \log_e Pi$ (Shannon and Weaver 1963). Evenness (J'), a measure of relative abundance, was calculated as $J' = H'/H'_{max}$ (Tramer 1969). This value "represents the ratio of observed diversity to the maximum diversity possible for the same number of species."

Biomass figures were derived from mean weights and numbers of individuals per 100 acres. Standing crop biomass (SCB) was calculated by multiplying the weight of each species by the number of individuals. Weights for each species were obtained from the literature (Bock and Lynch 1970, Salt 1957, Wauer and Dennis 1980). Consuming biomass (CB) was calculated by raising the mean weight of each species to the 0.633 power and then multiplying that figure by the number of individuals per species (Karr 1968).

IV. RESULTS

A total of 55 bird species were recorded and tabulated as breeding within the three study areas during the course of the project (Table I). Totals of 44 species were detected on Burnt Mesa, 47 on Escobas Mesa, and 43 at Apache Spring.

TABLE I. Breeding Bird Densities Before and After La Mesa Fire

			Individuals per 100 acres											
			Burnt Mesa				Escobas Mesa				Apache Spring			
	Feeding	Nesting	1977		1978	1979	1977		1978	1979	1977		1978	1979
Species	Guilds	Guilds	Pre-	Post-			Pre-	Post-			Pre-	Post-		
Cooper's hawk (*Accipiter cooperii*)	GP	FN	2				2		2	2		2		
Band-tailed pigeon (*Columba fasciata*)	GS	FN					4		4					
Mourning dove (*Zenaida macroura*)	GS	FN	12	10	14	8	8	6	4	4	2	2	4	4
Great horned owl (*Bubo virginianus*)	GP	CD						2						
Northern pygmy owl (*Glaucidium gnoma*)	GP	CD	2	2	2				2			2		
Common nighthawk (*Chordeiles minor*)	GI	GN	4			4	4	4	4					
Broad-tailed hummingbird (*Selasphorus platycercus*)	FN	FN	10	10	22	18	8	8	10	8	4	6	10	8
Common flicker (*Colaptes auratus*)	GI	CD	8	18	8	6	8	10	28	8	4	16	12	20
Yellow-bellied sapsucker (*Sphyrapicus varius*)	TDI	CD											4	
Williamson's sapsucker (*S. thyroideus*)	TDI	CD							12		24	12	30	8
Hairy woodpecker (*Dendrocopus villosus*)	TDI	CD	14	12	36	36	6	24	24	28	5	10	20	25
Downy woodpecker (*D. pubescens*)	TDI	CD									4		8	
Northern three-toed woodpecker (*Picoides tridactylus*)	TDI	CD		4	6	6	2	4	4	16		2	12	10
Ash-throated flycatcher (*Myiarchus cinerascens*)	API	CD	20		8	4			4	4				
Hammond's flycatcher (*Empidonax hammondii*)	API	FN	32	34	20	12	36	28	72	35	40	12	20	52
Western flycatcher (*E. difficilis*)	API	CD		12	4	4	14	18	8	8	12	30	16	12
Western pewee (*Contopus sordidulus*)	API	FN	12	24	16	18	16		16	20	4	2	10	8
Olive-sided flycatcher (*Nuttallornis borealis*)	API	FN							4	2			2	
Violet-green swallow (*Tachycineta thalassina*)	ASI	CD	50	80	24	44	18	40	36	12	8	22	16	14
Steller's jay (*Cyanocitta stelleri*)	FS	FN	20	14	22	17	14	20	28	12	10	16	28	12
Mountain chickadee (*Parus gambeli*)	TSI	FN	20	8	6	4	24	20	12	4	53	64	28	22
White-breasted nuthatch (*Sitta carolensis*)	TSI	CD	12	12	20	8	12	18	12	4	8	14	12	8
Red breasted nuthatch (*S. canadensis*)	TSI	CD										4	4	4

Abbreviations: FS = foliage-seed; GS = ground-seed; FN = foliage-nectar; ASI = air-soaring-insect; API = air-perching-insect; FI = foliage-insect; TSI = timber-searching-insect; TDI = timber-drilling-insect; GI = ground-insect; and FN = foliage or branch nesting; CD = cavity or depression nesting; GN = ground nesting; P = parasitic.

TABLE I. (cont)

			Individuals per 100 acres											
			Burnt Mesa				Escobas Mesa				Apache Spring			
	Feeding	Nesting	1977		1978	1979	1977		1978	1979	1977		1978	1979
Species	Guilds	Guilds	Pre-	Post-			Pre-	Post-			Pre-	Post-		
Pygmy nuthatch (*S. pygmaea*)	TSI	CD	100	46	46	12	70	56	46	20	52	42	36	8
Brown creeper (*Certhia familiaris*)	TSI	CD					2	2			12	16	12	4
House wren (*Troglodytes aedon*)	FI	CD		4	12	8			22	25			16	28
Canyon wren (*Catherpes mexicanus*)	GI	GN			4									
Rock wren (*Salpinctes obsoletus*)	GI	GN				4								
American robin (*Turdus migratorius*)	GI	FN	4	4	10		10	6	4	16	16	8	20	16
Hermit thrush (*Hylocichla guttatus*)	GI	FN	24	52	12	4	44	44	28	12	36	52	38	22
Western bluebird (*Sialia mexicana*)	FI	CD	12	8	32	12	10	8	20	16		4	4	10
Mountain bluebird (*S. currucoides*)	FI	CD			4				4					
Townsend's solitaire (*Myadestes townsendi*)	FI	CD	4	26	12	4	12	24	8	8	4	4	16	8
Blue-grey gnatcatcher (*Polioptila caerulea*)	FI	FN			4									
Golden-crowned kinglet (*Regulus satrapa*)	FI	FN					4						4	
Ruby-crowned kinglet (*R. calendula*)	FI	FN								4	32	12	14	16
Solitary vireo (*Vireo solitarius*)	FI	FN	11	10	8	14	18	18	12	23	8	4	4	6
Warbling vireo (*V. gilvus*)	FI	FN				2	2		8	10	34	52	38	22
Orange-crowned warbler (*Vermivora celata*)	FI	FN								4	10	20	4	6
Virginia's warbler (*V. virginiae*)	FI	GN	29	12	16	10	14	4	4		8	16		4
Yellow-rumped warbler (*Dendroica coronata*)	FI	FN	8	16	8	8	20	10	48	20	40	32	36	32
Grace's warbler (*D. graciae*)	FI	FN	26	6	10	12	20	12	14	20	4	6	12	13
Brown-headed cowbird (*Molothrus ater*)	GSP	P	4	4	4	4			4	8		4	4	4
Western tanager (*Piranga ludoviciana*)	FI	FN	24	16	12	28	12	10	24	12	10	16	16	16
Black-headed grosbeak (*Pheucticus melanocephalus*)	FI	FN	4		12	8	20	2	24	8	8	8	12	10
Evening Grosbeak (*Hesperiphona vespertina*)	FS	FN			4				10	8	10	6	30	16
Cassin's finch (*Carpodacus cassinii*)	FS	FN			4				4					
House finch (*C. mexicanus*)	FS	FN			12									

TABLE I. (cont)

			Individuals per 100 acres											
			Burnt Mesa				Escobas Mesa				Apache Spring			
	Feeding	Nesting	1977		1978	1979	1977		1978	1979	1977		1978	1979
Species	Guilds	Guilds	Pre-	Post-			Pre-	Post-			Pre-	Post-		
Pine siskin (*Spinus pinus*)	FS	FN	4		8		14	8	8		14	8	12	14
Lesser Goldfinch (*S. psaltria*)	FS	FN	6		8	4	2							
Red crossbill (*Loxia curvirostra*)	FS	FN	20	6	16		8	22	18		8	28	6	16
Rufous-sided towhee (*Pipilo erythrophthalmus*)	GS	FN	12	2	16	4		2				2		
Lark sparrow (*Chondestes grammacus*)	GS	GN		2										
Gray-headed junco (*Junco caniceps*)	GS	GN	16	16	8	8	16	26	32	18	10	48	40	30
Chipping sparrow (*Spizella passerina*)	GI	FN	20	10	32	20	4	8	12	8	8	8	8	10
Total number of individuals (Population)			546	480	522	355	478	464	636	411	502	612	618	518
Total number of species (Richness)			32	30	39	32	34	30	39	34	32	38	39	36
Total number of transect censuses			5	3	9	5	5	5	9	5	2	4	10	5

A. Burnt Mesa

Thirty-two avian species were detected on Burnt Mesa on five censuses before the fire, and 30 species were detected on three censuses immediately afterward, a decrease of only 6%. Six of the 32 prefire species were missing immediately after the fire (Cooper's hawk, common nighthawk, ash-throated flycatcher, black-headed grosbeak, pine siskin, and lesser goldfinch), and four new postfire species were recorded (northern three-toed woodpecker, western flycatcher, house wren, and lark sparrow).

In 1978, 39 bird species were recorded on nine censuses, a 22% increase from the prefire total. Species recorded for the first time in 1978 included canyon wren, mountain bluebird, blue-gray gnatcatcher, evening grosbeak, and Cassin's and house finches. No species that was detected during both 1977 periods was absent in 1978. Common nighthawk and lark sparrow were recorded only before and after the fire in 1977, respectively, but were absent in 1978.

In 1979, the number of birds recorded on five Burnt Mesa censuses returned to 32. Two new species—rock wren and warbling vireo—were added, but 12 species that had been detected in either 1977 or 1978 were missing; Cooper's hawk, northern pygmy owl, canyon wren, American robin, mountain bluebird, blue-gray gnatcatcher, evening grosbeak, Cassin's and house finches, pine siskin, red cross-bill, and lark sparrow.

Total numbers of individual birds recorded on Burnt Mesa were 546/100 acres before the fire, and 480/100 acres immediately afterward, a 12% decline; 522/100 acres in 1978, 4% below prefire conditions; and 355/100 acres in 1979, a 35% decrease in density from the prefire population. This decline occurred in spite of the apparent recovery in the number of species.

Ten species (23%) of the Burnt Mesa avifauna exhibited a significant (50% mean) decline in numbers during 1978 and 1979 below the prefire population, but 17 species (39%) showed a significant increase:

broad-tailed hummingbird; hairy and northern three-toed woodpeckers; western flycatcher; house, canyon, and rock wrens; western and mountain bluebirds; Townsend's solitaire; blue-gray gnatcatcher; warbling vireo; black headed and evening grosbeaks; Cassin's and house finches; and lark sparrow. Seventeen species (39%) showed less than either a 50% increase or decrease in population.

Table I includes feeding and nesting guilds for all species encountered. Thirteen (30%) of the 44 species are primary consumers; 7 are foliage-seed feeders, 5 are ground-seed feeders, and 1 is a foliage nectar feeder. Thirty-one (70%) of the 44 species are secondary consumers. Twelve of these are foliage-insect feeders, seven are ground-insect feeders, four are air-perching-insect feeders, three are timber-searching-insect feeders, two species occur in each of the timber-drilling-insect and ground-predator guilds, and one species is an air-soaring-insect feeder.

Twenty-four (54.5%) of the 44 species nest on the foliage or on branches of trees and shrubs. Thirteen species (30%) nest in cavities and/or depressions of vegetation or cliffs. Six species (14%) nest on the ground, and one (2%) is parasitic.

B. Escobas Mesa

Forty-seven avian species were recorded during the four count periods. Thirty-four species were detected on Escobas Mesa on 5 censuses before the fire, and 30 species were detected on 5 censuses immediately afterward, a 12% decrease (Table I). Six of the 34 prefire species were not detected immediately after the fire; Cooper's hawk, band-tailed pigeon, western pewee, golden-crowned kinglet, warbling vireo, and lesser goldfinch. Two of the 30 postfire (1977) species—great horned owl and rufous-sided towhee—were recorded only after the fire.

In 1978, 39 species were detected on 9 censuses, representing a 15% increase over the prefire total. Eight species were recorded for the first time; northern pygmy owl, Williamson's sapsucker, ash-throated and olive-sided flycatchers, house wren, brown-headed cowbird, evening grosbeak, and Cassin's finch. The brown creeper was the only species recorded on both pre- and postfire counts in 1977 that was absent in 1978. Four species—great horned owl, golden-crowned kinglet, lesser goldfinch, and rufous-sided towhee—were absent in 1978, after being present during at least one of the two 1977 count periods.

In 1979, the number of birds recorded on 5 Escobas Mesa censuses returned to 34, the same as the prefire total. New 1979 species included the mountain bluebird, ruby-crowned kinglet, and orange-crowned warbler. Eight species found on the prefire censuses were absent in 1979; band-tailed pigeon, common nighthawk, brown creeper, golden-crowned kinglet, Virginia's warbler, pine siskin, lesser goldfinch, and red crossbill.

Total numbers of individual birds recorded on Escobas Mesa were 478/100 acres before the fire, and 464/100 acres immediately afterward (a decrease of only 3%), a 37% increase to 636/100 acres in 1978, and a 35% decline in 1979 to 411/100 acres, 14% below the prefire population. The number of species recorded in 1979 (34) was the same as that detected before the fire.

Ten species (21%) of the Escobas Mesa avifauna exhibited a significant mean decline (50%) in numbers during 1978 and 1979, below the prefire population; band-tailed pigeon, mourning dove, mountain chickadee, pygmy nuthatch, brown creeper, hermit thrush, golden-crowned kinglet, Virginia's warbler, pine siskin, and lesser goldfinch.

Nineteen species (40%) showed a significant increase; northern pygmy owl, common flicker, Williamson's sapsucker, hairy and northern three-toed woodpeckers, ash-throated and olive-sided flycatchers, house wren, western and mountain bluebirds, ruby-crowned kinglet, warbling vereo, orange-crowned and yellow-rumped warblers, brown-headed cowbird, evening grosbeak, Cassin's finch, gray-headed junco, and chipping sparrow. Eighteen species (38%) showed less than a 50% increase or decrease in population.

Twelve (26%) of the 47 Escobas Mesa species were primary consumers; 6 were foliage-seed feeders, 5 were ground-seed feeders, and 1 was a foliage-nectar feeder. Thirty-five (74%) of the 47 species were secondary consumers. Of these, 14 were foliage-insect feeders, 5 each were ground-insect and air-perching-insect feeders, 4 were timber-searching-insect feeders, timber-drilling-insect and ground-predator feeders each had 3, and 1 was an air-soaring-insect feeder.

Of the 47 species, 27 (57%) nest on foliage or on branches of trees and shrubs, 16 (34%) nest in crevices and/or depressions on vegetation of cliffs, 3 (6%) nest on the ground, and 1 (2%) was parasitic.

C. Apache Spring

Forty-three bird species were detected during the four count periods on the Apache Spring unit. Thirty-two species were recorded on the study area on 2 censuses before the fire, and 38 species were detected on 4 censuses immediately afterward, an increase of 19%. Only one species—downy woodpecker—was absent, but seven new species were added; Cooper's hawk, northern pygmy owl, northern three-toed woodpecker, red-breasted nuthatch, western bluebird, brown-headed cowbird, and rufous-sided towhee.

In 1978, 39 species were recorded on 10 censuses, a 22% increase over the prefire total. Species recorded at Apache Spring for the first time included yellow-bellied sapsucker, olive-sided flycatcher, house wren, and golden-crowned kinglet. Only one species—Virginia's warbler—was recorded on both pre- and postfire censuses in 1977, but was absent in 1978.

In 1979, the avifauna recorded on five censuses declined to 36 species. No species were added to the study area total, and only downy woodpecker, present before the fire, was absent.

Total numbers of individual birds recorded on the Apache Spring unit were 502/100 acres before the fire and 612/100 acres immediately afterward (an increase of 22%), 618/100 acres in 1978, and 518/100 acres in 1979, an increase of only 3% above the prefire population.

Of the 43 species, 9 (21%) were primary consumers; 4 were foliage-seed feeders, 4 were ground-seed feeders, and 1 was a foliage-nectar feeder. Thirty-four (79%) of the 43 species were secondary consumers. Thirteen were foliage-insect feeders, five species occurred in each of the timber-searching-insect and timber-drilling-insect guilds, ground-insect and air-perching-insect feeders each contributed four species, two were ground predators, and one was an air-soaring-insect feeder.

V. DISCUSSION

Analysis of the data obtained from the three study areas over the four periods (pre- and postfire 1977, 1978, and 1979) reveals that differences exist with respect to numbers of species, population sizes, and biomass values.

A. Number of Species

The number of avian species, or richness, provides the simplest and most convenient measure of organic diversity. Bird densities before and after La Mesa Fire, as well as both feeding and nesting guilds for each species, are illustrated in Table I. Species richness is more clearly summarized for the four count periods in Table II.

The largest number of prefire avian species was recorded on Escobas Mesa. Postfire censuses revealed a 12% decline on Escobas Mesa, compared with a 6% decline on Burnt Mesa and a 19% increase on the Apache Spring unit. This variation occurred because Escobas Mesa experienced the most severe burn. The Apache Spring habitat was least severely burned—only the understory burned on most of the study area.

Species richness increased in 1978 by 30% on both Escobas and Burnt Mesas, but only 3% at Apache Spring. The 1979 richness declined for all three units; 8% at Apache Spring, 13% on Escobas Mesa, and 18% on Burnt Mesa. Compared with prefire values, both Burnt and Escobas Mesas richness returned to prefire conditions, but Apache Spring remained 12.5% above the prefire richness.

TABLE II. Population Summaries for Species Richness, Density, Diversity, and Evenness

	Species Richness				Population Density				Species Diversity				Species Evenness			
	1977		1978	1979	1977		1978	1979	1977		1978	1979	1977		1978	1979
Location	Pre-	Post-			Pre-	Post-			Pre-	Post-			Pre-	Post		
Apache Spring	32	38	39	36	506	612	618	518	3.115	3.218	3.399	3.380	0.899	0.885	0.928	0.943
Escobas Mesa	34	30	39	34	478	464	636	411	3.139	3.073	3.303	3.311	0.890	0.904	0.902	0.939
Burnt Mesa	32	30	39	32	546	480	522	355	3.082	2.990	3.434	3.152	0.899	0.879	0.937	0.909
Average	33	33	39	34	510	519	592	428	3.112	3.094	3.379	3.281	0.893	0.889	0.922	0.930
Total					1530	1556	1776	1284								

B. Population Size

Species density provides a more sensitive comparison of an area's ability to sustain an avifauna (Table II). Although Escobas Mesa supported the largest number of species before the fire, it had the lowest species density. Burnt Mesa supported the highest avian density before the fire. Immediately after the fire, density values for all three areas changed, two dramatically; Burnt and Escobas Mesas declined by 12% and 3%, respectively, and Apache Spring density increased 17%.

All three units experienced an increase in 1978; 9% for Burnt Mesa, 37% for Escobas Mesa, and a modest 1% for Apache Spring. These data suggest that the least burned area—Apache Spring—received an early influx of birds immediately after the fire in 1977, probably individuals deserting their breeding territories on Escobas Mesa and to a lesser extent Burnt Mesa, and perhaps during the second (1978) season as well.

The 1979 density values approached prefire conditions, although Burnt and Escobas Mesas dropped below prefire conditions by 35% and 14%, respectively. Only Apache Spring's species density remained above the prefire condition (by 2%).

Total density values for the combined three units increased by 2% immediately after the fire in 1977, increased an additional 14% in 1978, and then declined 28%, or 16% below the prefire density, in 1979.

Because the maximum detected number of specific individuals figures strongly into population estimates, estimates from a set of fewer censuses might be lower than those from a larger set. In 1978, 9 or 10 censuses were made on each unit; 5 each in 1979; and 2 to 5 in pre- and postfire 1977. A set of 9 censuses also contains 36 subsets of 2 censuses, 84 of 3 censuses, and 126 of 4 and of 5 censuses. Although these are not random, they may be used to approximate the average maximum number of individuals that would be detected in the given number of censuses, compared with the number detected in nine censuses. Using the data gathered for a vocal species (solitary vireo) and a quiet one (western bluebird) on all three units in 1978, and averaging the results, yields average maximum counts (and thus population estimates) of 60% of the value for two censuses, 70% for three censuses, 79% for four censuses, and 85% for five censuses. Thus, the 1979 population estimates might be expected to be 15% lower than those for 1978, with all other factors equal; and where only two censuses were made, population estimates might be 40% lower than those that would have been made from a base of nine censuses.

Also, estimates based on few censuses will generally be more accurate for a vocal species than for a quiet species. For example, for solitary vireo on five censuses, the estimate will average 92% of that for nine censuses, while it will average only 78% for western bluebird. Because these are statistical averages, not every case applies, but this suggests the confidence that should be placed in the population estimates, as a function of the number of censuses. Only one pair of solitary vireos was detected at Apache Spring in 1978, and those data suggest a 58% chance of detecting the pair in only two censuses, 71% in three, 83% in four, and 92% in five. If, on a typical census, 1/5 of the species were of such low density that they might be missed, then about one species (2%) on the average, might be missed on five censuses, when compared with the number detected on nine censuses. The number missed would increase to about 8% (four species) if only two censuses were taken.

Thus, populations estimated from two or three censuses—1977 prefire Apache Spring and postfire Burnt Mesa—are probably significantly underestimated, and those deduced from four or five censuses—all others but those of 1978—are probably slightly underestimated because of the limited number of censuses. However, species diversity and evenness, and feeding and nesting guild breakdowns will not be as sensitive to the numbers of censuses as are population estimates, since they are based on fractions of populations and of biomass.

The general concept of species diversity suggests that more stable communities will have higher diversity indexes, which will reflect longer food chains, more cases of symbiosis, and greater possibilities for negative feedback control, all of which act to reduce oscillations and, hence, cause increased stability (Margalef 1958). Diversity indexes (H′) computed from the results of this study were derived from the number of species and the mean abundances of the species within each community (Tables III-V) and are summarized in Table II.

Species diversity values before the fire were highest on Escobas Mesa (3.139), followed by Apache Spring (3.115) and Burnt Mesa (3.082). The Escobas Mesa species diversity value decreased 2% immediately after the fire in 1977, but increased 7% in 1978, and an additional 0.2% in 1979, to 5% higher than the prefire conditions. The Burnt Mesa species diversity value also decreased (3%) immediately after the fire, but increased 15% in 1978, and declined 8% in 1979, to 2% above the prefire conditions. Apache Spring species diversity, on the other hand, increased immediately after the fire by 3%, increased an additional 6% in 1978, declined 0.6% in 1979, and remained 8.5% above the prefire value.

These avian species diversity values for ponderosa and coniferous forest environments complement data presented by other authors. Tramer (1969), for example, reported bird species diversity values of 1.79 to 1.93 for marshes and grasslands, 3.14 for shrublands, 3.53 for coniferous forest, and 5.23 for tropical forests. Similarily, Karr (1968) measured avifaunal diversity indexes within successional stages of strip-mined lands in Illinois to be 1.54 for bare ground, 2.74 for early shrub successional areas, 3.27 in late shrub stages, and 3.31 in bottomland forest areas. In addition, Haldeman et al. (1973) reported a bird species diversity value of 2.83 for a ponderosa pine forest community in the San Francisco Mountains of Arizona.

Community diversity depends on the number of species and the evenness with which individuals are apportioned (Pielou 1975). Therefore, a community with a few evenly spaced species can have the same diversity index as one with many unevenly spaced species. Evenness values are required for a full analysis of community equitability.

Tramer (1969) states that birds generally are "equilibrium" species, whose requirements and characteristics are relatively stable from one generation to the next. Avian species "partition the breeding space in a characteristic way, and a series of samples from the same or from different localities will yield similar distributions of species abundance." The relative abundance of the avifauna is best measured by evenness (J′). Tramer's examples vary from 0.718 for marshes to 0.921 for tropical woodlands; evenness components from coniferous and upland deciduous forests are 0.880 and 0.879, respectively. Prefire evenness values for the three study areas were 0.899, 0.890, and 0.899 for Burnt Mesa, Escobas Mesa, and Apache Spring, respectively (Table II).

Burnt Mesa evenness and species diversity values followed the same pattern, a decrease immediately after the fire, a major increase in 1978, and a leveling off in 1979. Escobas Mesa evenness values, on the other hand, increased immediately after the fire, declined slightly in 1978, and reached an exceptionally high 1979 value of 0.939. Apache Spring evenness values declined immediately after the fire, increased 5% in 1978, and reached a high of 0.943 in 1979. Evenness values for all three units were higher in 1979 than they were before the fire, 1% for Burnt Mesa, 5.5% for Escobas Mesa, and 5% for Apache Spring.

TABLE III. Comparative Abundance and Diversity of Avifauna on Burnt Mesa

	Number/100 Acres				Relative Abundance				Species Diversity			
	1977		1978	1979	1977		1978	1979	1977		1978	1979
	Pre-	Post-			Pre-	Post-			Pre-	Post-		
Cooper's hawk	2	---	---	---	0.004	---	---	---	0.022	---	---	--
Mourning dove	12	10	14	8	0.022	0.021	0.027	0.022	0.084	0.081	0.098	0.084
N. pygmy owl	2	2	2	---	0.004	0.004	0.004	---	0.022	0.022	0.022	---
Common nighthawk	4	---	---	4	0.007	---	---	0.011	0.035	---	---	0.050
Broad-tailed hummingbird	10	10	22	18	0.018	0.021	0.042	0.051	0.072	0.081	0.133	0.152
Common flicker	8	18	8	6	0.015	0.038	0.015	0.017	0.063	0.124	0.063	0.069
Hairy woodpecker	14	12	36	36	0.026	0.025	0.069	0.101	0.095	0.092	0.184	0.232
N. three-toed woodpecker	---	4	6	6	---	0.008	0.011	0.017	---	0.039	0.050	0.069
Ash-throated flycatcher	20	---	8	4	0.037	---	0.015	0.011	0.122	---	0.063	0.050
Hammond's flycatcher	32	34	20	12	0.059	0.071	0.038	0.034	0.167	0.188	0.124	0.115
Western flycatcher	---	12	4	4	---	0.025	0.008	0.011	---	0.092	0.039	0.050
Western pewee	12	24	16	18	0.022	0.050	0.031	0.051	0.084	0.150	0.108	0.152
Violet-green swallow	50	80	24	44	0.092	0.167	0.046	0.124	0.220	0.299	0.142	0.259
Steller's jay	20	14	22	17	0.037	0.029	0.042	0.048	0.122	0.103	0.133	0.146
Mountain chickadee	20	8	6	4	0.037	0.017	0.011	0.011	0.122	0.069	0.050	0.050
White-breasted nuthatch	12	12	20	8	0.022	0.025	0.038	0.022	0.084	0.092	0.124	0.084
Pygmy nuthatch	100	46	46	12	0.183	0.096	0.088	0.034	0.311	0.225	0.214	0.115
House wren	---	4	12	8	---	0.008	0.023	0.022	---	0.039	0.087	0.084
Canyon wren	---	---	4	---	---	---	0.008	---	---	---	0.039	---
Rock wren	---	---	---	4	---	---	---	0.011	---	---	---	0.050
American robin	4	4	10	---	0.007	0.008	0.019	---	0.035	0.039	0.075	---
Hermit thrush	24	52	12	4	0.044	0.108	0.023	0.011	0.137	0.240	0.087	0.050
Western bluebird	12	8	32	12	0.022	0.017	0.061	0.034	0.084	0.069	0.171	0.115
Mountain bluebird	---	---	4	---	---	---	0.008	---	---	---	0.039	---
Townsend's solitaire	4	26	12	4	0.007	0.054	0.023	0.011	0.035	0.158	0.087	0.039
Blue-gray gnatcatcher	---	---	4	---	---	--	0.008	---	---	---	0.039	---
Solitary vireo	11	10	8	14	0.020	0.021	0.015	0.039	0.078	0.081	0.063	0.127
Warbling vireo	---	---	---	2	---	---	---	0.006	---	---	---	0.031
Virginia's warbler	29	12	16	10	0.053	0.025	0.031	0.028	0.156	0.092	0.108	0.100
Yellow-rumped warbler	8	16	8	8	0.015	0.033	0.015	0.022	0.063	0.113	0.063	0.084
Grace's warbler	26	6	10	12	0.048	0.013	0.019	0.034	0.146	0.056	0.075	0.115
Brown-headed cowbird	4	4	4	4	0.007	0.008	0.008	0.011	0.035	0.039	0.039	0.050
Western tanager	24	16	12	28	0.044	0.033	0.023	0.079	0.137	0.113	0.087	0.201
Black-headed grosbeak	4	---	12	8	0.007	---	0.023	0.022	0.035	---	0.087	0.084
Evening grosbeak	---	---	4	---	---	---	0.008	---	---	---	0.039	---
Cassin's finch	---	---	4	---	---	---	0.008	---	---	---	0.039	---
House finch	---	---	12	---	---	---	0.023	---	---	--	0.087	--
Pine siskin	4	---	8	---	0.007	---	0.015	---	0.035	---	0.063	--
Lesser goldfinch	6	---	8	4	0.011	---	0.015	0.011	0.050	---	0.063	0.050
Red crossbill	20	6	16	---	0.037	0.013	0.031	---	0.122	0.056	0.108	---
Rufous-sided towhee	12	2	16	4	0.022	0.004	0.031	0.011	0.084	0.022	0.108	0.050
Lark sparrow	---	2	---	---	---	0.004	---	---	---	0.022	---	---
Gray-headed junco	16	16	8	8	0.029	0.033	0.015	0.022	0.103	0.113	0.063	0.084
Chipping sparrow	20	10	32	20	0.037	0.021	0.061	0.051	0.122	0.081	0.171	0.161
Totals	546	480	522	355								
H' values									3.082	2.990	3.434	3.152
J' values									0.889	0.879	0.937	0.909

TABLE IV. Comparative Abundance and Diversity of Avifauna on Escobas Mesa

	Number/100 Acres				Relative Abundance				Species Diversity			
	1977		1978	1979	1977		1978	1979	1977		1978	1979
	Pre-	Post-			Pre-	Post-			Pre-	Post-		
Cooper's hawk	2	---	2	2	0.004	---	0.003	0.005	0.022	---	0.017	0.026
Band-tailed pigeon	4	---	4	---	0.008	---	0.006	---	0.039	---	0.031	---
Mourning dove	8	6	4	4	0.017	0.013	0.006	0.010	0.069	0.056	0.031	0.046
Great horned owl	---	2	---	---	---	0.004	---	---	---	0.022	---	---
N. pygmy owl	---	---	2	---	---	---	0.003	---	---	---	0.017	---
Common nighthawk	4	4	4	---	0.008	0.009	0.006	---	0.039	0.042	0.031	---
Broad-tailed hummingbird	8	8	10	8	0.017	0.017	0.016	0.019	0.069	0.069	0.066	0.075
Common flicker	8	10	28	8	0.017	0.022	0.044	0.019	0.069	0.084	0.137	0.075
Williamson's sapsucker	---	---	12	---	---	---	0.019	---	---	---	0.075	---
Hairy woodpecker	6	24	24	28	0.008	0.052	0.038	0.068	0.039	0.154	0.124	0.183
N. three-toed woodpecker	2	4	4	16	0.002	0.009	0.006	0.039	0.012	0.042	0.031	0.127
Ash-throated flycatcher	---	---	4	4	---	---	0.006	0.010	---	---	0.031	0.046
Hammond's flycatcher	36	28	72	35	0.075	0.060	0.113	0.085	0.194	0.169	0.246	0.210
Western flycatcher	14	18	8	8	0.029	0.039	0.013	0.019	0.103	0.127	0.056	0.075
Western pewee	16	---	16	20	0.033	---	0.025	0.049	0.113	---	0.092	0.148
Olive-sided flycatcher	---	---	4	2	---	---	0.006	0.005	---	---	0.031	0.026
Violet-green swallow	18	40	36	12	0.038	0.086	0.057	0.029	0.124	0.211	0.163	0.103
Steller's jay	14	20	28	12	0.029	0.043	0.044	0.029	0.103	0.135	0.137	0.103
Mountain chickadee	24	20	12	4	0.050	0.043	0.019	0.010	0.150	0.135	0.075	0.046
White-breasted nuthatch	12	18	12	4	0.025	0.039	0.019	0.010	0.092	0.127	0.075	0.046
Pygmy nuthatch	70	56	46	20	0.146	0.121	0.072	0.049	0.281	0.256	0.189	0.148
Brown creeper	2	2	---	---	0.004	0.004	---	---	0.022	0.022	---	---
House wren	---	---	22	25	---	---	0.035	0.061	---	---	0.117	0.171
American robin	10	6	4	16	0.021	0.013	0.006	0.039	0.081	0.056	0.031	0.127
Hermit thrush	44	44	28	12	0.092	0.095	0.044	0.029	0.220	0.224	0.137	0.103
Western bluebird	10	8	20	16	0.021	0.017	0.031	0.039	0.081	0.069	0.108	0.127
Mountain bluebird	---	---	---	4	---	---	---	0.010	---	---	---	0.046
Townsend's solitaire	12	24	8	8	0.025	0.052	0.013	0.019	0.092	0.154	0.056	0.075
Golden-crowned kinglet	4	---	---	---	0.008	---	---	---	0.039	---	---	---
Ruby-crowned kinglet	---	---	---	4	---	---	---	0.010	---	---	---	0.046
Solitary vireo	18	18	12	23	0.038	0.039	0.019	0.056	0.124	0.127	0.075	0.161
Warbling vireo	2	---	18	10	0.004	---	0.013	0.024	0.022	---	0.056	0.090
Orange-crowned warbler	---	---	---	4	---	---	---	0.010	---	---	---	0.046
Virginia's warbler	14	4	4	---	0.029	0.009	0.006	---	0.103	0.042	0.031	---
Yellow-rumped warbler	20	10	48	20	0.042	0.022	0.075	0.049	0.133	0.084	0.194	0.148
Grace's warbler	20	12	14	20	0.042	0.026	0.022	0.049	0.133	0.095	0.084	0.148
Brown-headed cowbird	---	---	4	8	---	---	0.006	0.019	---	---	0.031	0.075
Western tanager	12	10	24	12	0.025	0.022	0.038	0.029	0.092	0.084	0.124	0.103
Black-headed grosbeak	20	2	24	8	0.042	0.004	0.038	0.019	0.133	0.022	0.124	0.075
Evening grosbeak	---	---	10	8	---	---	0.016	0.019	---	---	0.066	0.075
Cassin's finch	---	---	4	---	---	---	0.006	---	---	---	0.031	---
Pine siskin	14	8	8	---	0.029	0.017	0.013	---	0.103	0.069	0.056	---
Lesser goldfinch	2	---	---	---	0.004	---	---	---	0.022	---	---	---
Red crossbill	8	22	18	---	0.017	0.047	0.028	---	0.069	0.144	0.100	---
Rufous-sided towhee	---	2	---	---	---	0.014	---	---	---	0.022	---	---
Gray-headed junco	16	26	32	18	0.033	0.056	0.050	0.044	0.113	0.161	0.152	0.137
Chipping sparrow	4	8	12	8	0.008	0.017	0.019	0.019	0.039	0.069	0.075	0.075
Totals	478	464	636	411								
H′ values									3.139	3.073	3.303	3.311
J′ values									0.890	0.904	0.902	0.939

TABLE V. Comparative Abundance and Diversity of Avifauna at Apache Spring

	Number/100 Acres				Relative Abundance				Species Diversity			
	1977		1978	1979	1977		1978	1979	1977		1978	1979
	Pre-	Post-			Pre-	Post-			Pre-	Post-		
Cooper's hawk	---	2	---	---	---	0.003	---	---	---	0.017	---	---
Mourning dove	2	2	4	4	0.004	0.003	0.006	0.008	0.022	0.017	0.031	0.039
N. pygmy owl	---	2	---	---	---	0.003	---	---	---	0.017	---	---
Broad-tailed hummingbird	4	6	10	8	0.008	0.010	0.016	0.015	0.039	0.046	0.066	0.063
Common flicker	4	16	12	20	0.008	0.026	0.019	0.039	0.039	0.095	0.075	0.127
Yellow-bellied sapsucker	---	---	4	---	---	---	0.006	---	---	---	0.031	---
Williamson's sapsucker	24	12	30	8	0.048	0.020	0.049	0.015	0.146	0.078	0.148	0.063
Hairy woodpecker	5	10	20	25	0.010	0.016	0.032	0.048	0.046	0.066	0.110	0.148
Downy woodpecker	4	---	8	---	0.008	---	0.013	---	0.039	---	0.056	---
N. three-toed woodpecker	---	2	12	10	---	0.003	0.019	0.019	---	0.017	0.075	0.075
Hammond's flycatcher	40	12	20	52	0.080	0.020	0.032	0.100	0.202	0.078	0.110	0.230
Western flycatcher	12	30	16	12	0.024	0.049	0.026	0.023	0.090	0.148	0.095	0.087
Western pewee	14	2	10	8	0.008	0.003	0.016	0.015	0.039	0.017	0.066	0.063
Olive-sided flycatcher	---	---	2	---	---	---	0.003	---	---	---	0.017	---
Violet-green swallow	8	22	16	14	0.016	0.036	0.026	0.027	0.066	0.120	0.095	0.098
Steller's jay	10	16	28	12	0.020	0.026	0.045	0.023	0.078	0.095	0.140	0.087
Mountain chickadee	53	64	28	22	0.106	0.105	0.045	0.042	0.238	0.237	0.140	0.133
White-breasted nuthatch	8	14	12	8	0.016	0.023	0.019	0.015	0.066	0.087	0.075	0.063
Red-breasted nuthatch	---	4	4	4	---	0.007	0.006	0.008	---	0.035	0.031	0.039
Pygmy nuthatch	52	42	36	8	0.104	0.069	0.058	0.015	0.235	0.184	0.165	0.063
Brown creeper	12	16	12	4	0.024	0.026	0.019	0.008	0.090	0.095	0.075	0.039
House wren	---	---	16	28	---	---	0.026	0.054	---	---	0.095	0.158
American robin	16	8	20	16	0.032	0.013	0.032	0.031	0.110	0.056	0.110	0.108
Hermit thrush	36	52	38	22	0.072	0.085	0.061	0.042	0.189	0.210	0.171	0.133
Western bluebird	---	4	4	10	---	0.007	0.006	0.019	---	0.035	0.031	0.075
Mountain bluebird	---	---	---	4	---	---	---	0.010	---	---	---	0.046
Townsend's solitaire	4	4	16	8	0.008	0.007	0.026	0.015	0.039	0.035	0.095	0.063
Golden-crowned kinglet	---	---	4	---	---	---	0.006	---	---	---	0.031	---
Ruby-crowned kinglet	32	12	14	16	0.064	0.020	0.023	0.031	0.176	0.078	0.087	0.108
Solitary vireo	8	4	4	6	0.016	0.007	0.006	0.012	0.066	0.035	0.031	0.053
Warbling vireo	34	52	38	22	0.068	0.085	0.061	0.042	0.183	0.210	0.172	0.133
Orange-crowned warbler	10	20	4	4	0.020	0.033	0.006	0.012	0.078	0.113	0.031	0.053
Virginia's warbler	8	16	---	4	0.016	0.026	---	0.008	0.066	0.095	---	0.039
Yellow-rumped warbler	40	32	36	32	0.080	0.052	0.058	0.062	0.202	0.154	0.165	0.172
Grace's warbler	4	6	12	13	0.008	0.010	0.019	0.025	0.039	0.046	0.075	0.092
Brown-headed cowbird	---	4	4	4	---	0.007	0.006	0.008	---	0.035	0.031	0.039
Western tanager	10	16	16	16	0.020	0.026	0.026	0.031	0.078	0.095	0.095	0.108
Black-headed grosbeak	8	8	12	10	0.016	0.013	0.019	0.019	0.066	0.056	0.075	0.075
Evening grosbeak	10	6	30	16	0.020	0.010	0.049	0.031	0.078	0.046	0.148	0.108
Pine siskin	14	8	12	14	0.028	0.013	0.019	0.027	0.100	0.056	0.075	0.098
Red crossbill	8	28	6	16	0.016	0.046	0.010	0.031	0.066	0.142	0.046	0.108
Rufous-sided towhee	---	2	---	---	---	0.003	---	---	---	0.017	---	---
Gray-headed junco	10	48	40	30	0.020	0.078	0.065	0.058	0.078	0.199	0.178	0.165
Chipping sparrow	8	8	8	10	0.016	0.013	0.013	0.019	0.066	0.056	0.056	0.075
Totals	502	612	618	518								
H′ values									3.115	3.218	3.399	3.380
J′ values									0.899	0.885	0.928	0.943

C. Biomass Comparisons

Salt (1957) pointed out that avifaunal composition data expressed as numbers of individuals do not always clearly depict an ecological condition; that is, they incorrectly imply that "three horned owls and one hummingbird are equal to four sparrows." Ecologically more meaningful expressions of density data can be obtained by converting them to SCB and CB values. SCB is the total weight of avifauna present at the time of the census. CB, on the other hand, is related more closely to community metabolism because it is indicative of the rate of food consumption or energy intake by the avifauna and it represents the amount of stored community energy present as birds.

Biomass comparisons derived from the density values for the three study units are illustrated in Table VI. The prefire SCB values for Burnt and Escobas Mesas were quite similar, 15,385 and 14,916 g/100 acres, but the Apache Spring prefire SCB (11,794 g/100 acres) was 22% less than the mean SCB value for Burnt and Escobas Mesas. Changes in SCB values during the ensuing 2 years varied, and Table VI includes percentages of increases and decreases from the prefire values.

Salt (1957) pointed out that efficiency is proportional to size, and that (p. 391) "the efficiency of an avifauna is indicated by the proportion of its biomass made up of large birds." This relationship results from larger birds being more efficient because of their ability to store food for longer periods. Analysis by size classes of bird densities on the three study units (Table VII) shows that heavy species (those of weight classes greater than 100.1 g) made up only 6% of the prefire population, but increased to 8% immediately after the fire in 1977, increased to 9% in 1978, and declined to 7% in 1979. Middle-weight birds (those of weight classes from 30.1 to 100 g) composed 13% of the prefire population, 15% immediately afterward, 22% in 1978, and 21% in 1979. Small species (those of weights up to 30 g) made up most of the population; 81% of the prefire total, 77% immediately after the fire, 69% in 1978, and 72% in 1979. These data reveal that the small species, such as the ash-throated and Hammond's flycatchers, violet-green swallow, mountain chickadee, white-breasted and pygmy nuthatches, solitary vireo, Virginia's and Grace's warblers, lesser goldfinch, and chipping sparrow, were most critically affected by the fire; that large species received minimal benefit; and that the middle-sized species, such as all six woodpeckers, Townsend's solitaire, and evening grosbeak, benefitted most.

Habitat selection operates most strongly for birds during the breeding season because that is when habitat requirements, particularly those relating to feeding and nesting, are most essential. Analysis of the avian density and biomass data by foraging diversity (Table VIII) provides additional insight into avian community structures and suggests possible mechanisms to explain differences recorded in bird populations on the three study areas during the course of the study.

Foraging diversity ratios of the 10 feeding guilds, calculated by SCB values, are illustrated in Fig. 1 and further broken down in Table IX, which also illustrates the percentages of the various SCB values within the specific study units relative to each study period. Primary consumers made up 29% and secondary consumers made up 71% of the combined SCB.

TABLE VI. Biomass Comparisons (g/100 acres)

	Standing Crop Biomass				Consuming Biomass			
	1977		1978	1979	1977		1978	1979
Location	Pre-	Post-			Pre-	Post-		
Apache Spring	11 794	17 201	19 967	16 667	3 374	4 499	5 022	4 126
	0	(+46%)	(+69%)	(+41%)	0	(+33%)	(+49%)	(+22%)
Escobas Mesa	14 916	17 876	23 182	14 052	3 655	3 864	5 459	3 437
	0	(+20%)	(+55%)	(-6%)	0	(+6%)	(+49%)	(-6%)
Burnt Mesa	15 385	14 096	17 305	11 444	4 007	3 654	4 327	2 880
	0	(-8%)	(+12%)	(-26%)	0	(-9%)	(+8%)	(-28%)

TABLE VII. Avifaunal Diversities by Weight Class

		Burnt Mesa				Escobas Mesa				Apache Spring			
	Number/	1977		1978	1979	1977		1978	1979	1977		1978	1979
Weight Class (g)	Species	Pre-	Post-			Pre-	Post-			Pre-	Post-		
0.0-15.0	21	317/ 58%	262/ 55%	236/ 45%	176/ 50%	268/ 56%	214/ 46%	316/ 50%	198/ 48%	355/ 67%	352/ 58%	296/ 48%	277/ 53%
15.1-30.0	13	119/ 22%	114/ 24%	124/ 24%	82/ 23%	112/ 23%	124/ 27%	136/ 21%	93/ 23%	76/ 15%	138/ 23%	122/ 20%	92/ 18%
30.1-65.0	11	48/ 9%	40/ 8%	64/ 12%	24/ 7%	44/ 9%	54/ 12%	84/ 13%	34/ 8%	54/ 11%	64/ 10%	104/ 17%	62/ 12%
65.1-100.0	3	18/ 3%	20/ 4%	52/ 10%	42/ 12%	18/ 4%	34/ 7%	32/ 5%	60/ 15%	21/ 4%	20/ 3%	52/ 8%	51/ 10%
100.1-350.0	4	42/ 8%	44/ 9%	46/ 9%	31/ 9%	30/ 6%	36/ 8%	62/ 10%	24/ 6%	16/ 3%	36/ 6%	44/ 7%	36/ 7%
350.1-800	2	2/ 0.4%	0 0	0 0	0 0	6/ 1%	0 0	6/ 1%	2/ 0.5%	0 0	2/ 0.3%	0 0	0 0
800.1+	1	0 0	0 0	0 0	0 0	0 0	2/ 0.4%	0 0	0 0	0 0	0 0	0 0	0 0
Total	55	546	480	522	355	478	464	636	411	502	612	618	518

Foliage-seed feeders accounted for 17% of the combined SCB totals for the three units before the fire, 16% immediately afterward, 22% in 1978, and 16% in 1979. SCB totals increased 12% immediately after the fire, increased dramatically (by 68%) in 1978, but declined 50% in 1979, to 6% below the prefire biomass. On Burnt Mesa, this feeding guild declined 43% immediately after the fire, increased 116% in 1978, and declined 50% in 1979, to 38.5% below the prefire biomass. On Escobas Mesa, foliage-seed feeders increased 55% immediately after the fire, an additional 47% in 1978, and declined 60% in 1979, to 10% below the prefire biomass. And on Apache Spring unit, the guild increased 49% immediately after the fire, an additional 62% in 1978, and declined 41.5% in 1979, to 41% above the prefire biomass.

Seven species of birds composed the foliage-seed guild (Table VIII). Only one of these—Steller's jay—was present on every unit in every time period. The other six species varied considerably in abundance. Only in 1978 were all seven species present on at least one of the three study areas. Also the presence of red crossbills during the study is of interest. This species is known for its sporadic occurrence, but it was present throughout the study. It occurred in moderate to large numbers on all three units before the fire (average was 462 g/100 acres), and postfire data show a decrease on Burnt Mesa and increases (average of 719 g/100 acre) on Escobas Mesa and the Apache Spring unit, a 64% SCB increase.

Ground-seed feeders accounted for 14.5% of the combined prefire SCB totals for Burnt and Escobas Mesas and Apache Spring, 10% of the combined totals immediately after the fire, 12% in 1978, and 10% in 1979. SCB totals declined 20% immediately after the fire, but increased 50% in 1978, and declined 45% in 1979, to 34% below the prefire biomass. On Burnt Mesa, ground-seed feeders declined 23% immediately after the fire, increased 44% in 1978, and declined 45% in 1979, to 40% below the prefire biomass. The Escobas Mesa SCB declined 53% immediately after the fire, increased 107% in 1978, and declined 60% in 1979, to 61% below the prefire biomass. At Apache Spring, the SCB increased 206% immediately after the fire, an additional 2.5% in 1978, and declined 13.5% in 1979, to 171.5% above the prefire biomass.

The most abundant representative of this guild was the gray-headed junco. Although junco SCB values were considerably below those of some of the larger birds, the species provided 853 g/100 acres SCB on the three study areas before the fire, 1827 g/100 acres immediately afterward (an increase of 114%), 1625 g/100 acres in 1978 (an 11% decline), and 1137 g/100 acres in 1979 (an additional decline of 30%); leaving a 33% higher SCB value than before the fire. The significant increase immediately after the fire was likely due to the greater availability of ground seeds and insects and, to some degree, observer visibility.

TABLE VIII. Foraging Diversity and Biomass Values (g/100 acres)

		Prefire 1977 Biomass						Postfire 1977 Biomass					
		Standing Crop			Consuming			Standing Crop			Consuming		
Guild	Mean wt/ bird (g)	B	E	A	B	E	A	B	E	A	B	E	A
Primary Consumers													
Foliage-Seed (FS)													
Steller's jay	106.5	2 130	1 491	1 065	384	269	192	1 491	2 130	1 704	269	384	307
Evening grosbeak	64.2	0	0	642	0	0	139	0	0	385	0	0	84
Cassin's finch	27.6	0	0	0	0	0	0	0	0	0	0	0	0
House finch	19.3	0	0	0	0	0	0	0	0	0	0	0	0
Pine siskin	12.1	48	169	169	19	68	68	0	97	97	0	39	39
Lesser goldfinch	8.7	52	17	0	24	8	0	0	0	0	0	0	0
Red crossbill	38.5	770	308	308	202	81	81	231	847	1 078	60	222	282
		3 000	1 985	2 184	629	426	480	1 722	3 074	3 264	329	645	712
Ground-Seed (GS)													
Band-tailed pigeon	406.0	0	1 624	0	0	179	0	0	0	0	0	0	0
Mourning Dove	137.5	1 650	1 100	275	271	181	45	1 375	825	275	226	135	45
Brown-headed cowbird	34.8	139	0	0	38	0	0	139	0	139	38	0	38
Rufous-sided towhee	39.0	468	0	0	122	0	0	78	78	78	20	20	20
Lark sparrow	30.5	0	0	0	0	0	0	61	0	0	17	0	0
Gray-headed junco	20.3	325	325	203	108	108	67	325	528	974	108	175	323
		2 582	3 049	478	539	468	112	1 978	1 431	1 466	409	330	426
Foliage-Nectar (FN)													
Broad-tailed hummingbird	4.0	40	32	16	24	19	10	40	32	24	24	19	14
		40	32	16	24	19	10	40	32	24	24	19	14
Total Primary Consumers		5 622	5 066	2 678	1 192	913	602	3 740	4 537	4 754	762	994	1 152
Secondary Consumers													
Air-Soaring-Insect (ASI)													
Violet-green swallow	10.6	530	191	85	223	80	36	848	424	233	357	178	98
		530	191	85	223	80	36	848	424	233	357	178	98

		1978 Biomass						1979 Biomass					
		Standing Crop			Consuming			Standing Crop			Consuming		
Guild	Mean wt/ bird (g)	B	E	A	B	E	A	B	E	A	B	E	A
Primary Consumers													
Foliage-Seed (FS)													
Steller's jay	106.5	2 343	2 982	2 982	422	538	538	1 810	1 278	1 278	326	260	230

TABLE VIII. (cont)

		1978 Biomass						1979 Biomass					
	Mean wt/	Standing Crop			Consuming			Standing Crop			Consuming		
Guild	bird (g)	B	E	A	B	E	A	B	E	A	B	E	A
Evening grosbeak	64.2	257	642	1 926	56	139	245	0	514	1 027	0	111	131
Cassin's finch	27.6	110	110	0	33	33	0	0	0	0	0	0	0
House finch	19.3	232	0	0	78	0	0	0	0	0	0	0	0
Pine siskin	12.1	97	97	145	39	39	58	0	0	169	0	0	68
Lesser goldfinch	8.7	70	0	0	31	0	0	35	0	0	16	0	0
Red crossbill	38.5	616	693	231	161	181	60	0	0	616	0	0	161
		3 725	4 524	5 284	820	930	901	1 845	1 792	3 090	342	341	590
Ground-Seed (GS)													
Band-tailed pigeon	406.0	0	1 624	0	0	179	0	0	0	0	0	0	0
Mourning Dove	137.5	1 925	550	550	316	90	90	1 100	550	550	181	90	90
Brown-headed cowbird	34.8	139	139	139	38	38	38	139	278	139	38	76	38
Rufous-sided towhee	39.0	624	0	0	163	0	0	156	0	0	41	0	0
Lark sparrow	30.5	0	0	0	0	0	0	0	0	0	0	0	0
Gray-headed junco	20.3	162	650	813	54	215	269	162	365	609	54	121	202
		2 850	2 963	1 502	571	522	397	1 557	1 193	1 298	314	287	330

		Prefire 1977 Biomass						Postfire 1977 Biomass					
	Mean wt/	Standing Crop			Consuming			Standing Crop			Consuming		
Guild	bird (g)	B	E	A	B	E	A	B	E	A	B	E	A
Foliage-Nectar (FN)													
Broad-tailed hummingbird	4.0	88	40	40	53	24	24	72	32	32	43	19	19
		88	40	40	53	24	24	72	32	32	43	19	19
Total Primary Consumers		6 663	7 527	6 826	1 444	1 476	1 322	3 474	3 017	4 420	699	647	939
Secondary Consumers													
Air-Soaring-Insect (ASI)													
Violet-green swallow	10.6	254	382	170	107	160	71	466	127	148	196	53	62
		254	382	170	107	160	71	466	127	148	196	53	62
Air-Perch.-Insect (API)													
Ash-throated flycatcher	27.6	552	0	0	163	0	0	0	0	0	0	0	0
Hammond's flycatcher	12.1	387	436	484	155	174	194	411	339	145	165	136	58
Western flycatcher	12.5	0	175	150	0	69	59	150	225	375	59	89	148
Western pewee	14.0	168	224	56	64	85	21	336	0	28	128	0	11
Olive-sided flycatcher	31.5	0	0	0	0	0	0	0	0	0	0	0	0
		1 107	835	690	382	328	274	897	564	548	352	225	217

TABLE VIII. (cont)

Guild	Mean wt/ bird (g)	Prefire 1977 Biomass						Postfire 1977 Biomass					
		Standing Crop			Consuming			Standing Crop			Consuming		
		B	E	A	B	E	A	B	E	A	B	E	A
Foliage-Insect (FI)													
House wren	10.0	0	0	0	0	0	0	400	0	0	17	0	0
Western bluebird	24.6	295	246	0	91	76	0	197	197	98	61	61	30
Mountain bluebird	26.6	0	0	0	0	0	0	0	0	0	0	0	0
Townsend's solitaire	32.0	128	384	128	36	108	36	832	768	128	233	215	36
Blue-gray gnatcatcher	5.0	0	0	0	0	0	0	0	0	0	0	0	0
Golden-crowned kinglet	5.1	0	20	0	0	11	0	0	0	0	0	0	0
Ruby-crowned kinglet	6.1	0	0	195	0	0	101	0	0	73	0	0	38
Solitary vireo	15.3	168	275	122	62	101	45	153	275	61	56	101	22
Warbling vireo	11.3	0	23	384	0	9	158	0	0	588	0	0	292
Orange-crowned warbler	9.6	0	0	96	0	0	42	0	0	192	0	0	84
Virginia's warbler	8.4	244	118	67	112	54	31	101	34	134	46	15	62
Yellow-rumped warbler	13.1	105	262	524	41	102	204	210	131	419	82	51	163
Grace's warbler	7.5	195	150	30	93	72	14	45	90	45	21	43	21
Western tanager	29.0	696	348	290	202	101	84	464	290	464	135	84	135
Black-headed grosbeak	46.0	184	920	368	45	226	90	0	92	368	0	23	90
		2 015	2 746	2 204	682	860	805	2 042	1 877	2 570	651	593	973
Timber-Searching-Insect (TSI)													
Mountain chickadee	11.5	230	276	610	94	113	249	91	230	736	38	94	300
White-breasted nuthatch	18.0	216	216	144	75	75	50	216	324	252	75	112	87
Red-breasted nuthatch	10.1	0	0	0	0	0	0	0	0	40	0	0	17
Pygmy nuthatch	10.0	1 000	700	520	430	301	223	460	560	420	198	241	180
Brown creeper	7.7	0	15	92	0	7	44	0	15	123	0	7	58
		1 446	1 207	1 366	599	496	566	767	1 129	1 571	311	454	642

TABLE VIII. (cont)

		1978 Biomass						1979 Biomass					
	Mean wt/	Standing Crop			Consuming			Standing Crop			Consuming		
Guild	bird (g)	B	E	A	B	E	A	B	E	A	B	E	A
Secondary Consumers (cont)													
Air-Perch.-Insect (API)													
Ash-throated flycatcher	27.6	221	110	0	65	33	0	110	110	0	33	33	0
Hammond's flycatcher	12.1	242	871	242	97	349	97	145	424	629	58	170	252
Western flycatcher	12.5	50	100	200	20	40	79	50	100	150	20	40	59
Western pewee	14.0	224	224	140	85	85	53	252	280	112	96	106	43
Olive-sided flycatcher	31.5	0	126	63	0	36	18	0	63	0	0	18	0
		737	1 431	645	267	543	247	557	977	891	207	367	354
Foliage-Insect (FI)													
House wren	10.0	120	220	160	52	94	69	80	250	280	34	107	120
Western bluebird	24.6	787	492	98	243	152	30	295	394	246	91	122	76
Mountain bluebird	26.6	106	0	0	32	0	0	0	106	0	0	32	0
Townsend's solitaire	32.0	384	256	512	108	72	143	128	256	256	36	72	72
Blue-gray gnatcatcher	5.0	20	0	0	11	0	0	0	0	0	0	0	0
Golden-crowned kinglet	5.1	0	0	20	0	0	11	0	0	0	0	0	0
Ruby-crowned kinglet	6.1	0	0	85	0	0	44	0	24	98	0	13	50
Solitary vireo	15.3	122	184	61	45	67	22	214	352	92	79	129	34
Warbling vireo	11.3	0	90	429	0	37	214	23	113	249	9	46	124
Orange-crowned warbler	9.6	0	0	38	0	0	17	0	38	58	0	17	25
Virginia's warbler	8.4	134	34	0	62	15	0	84	0	34	38	0	15
Yellow-rumped warbler	13.1	105	629	472	41	245	183	105	262	419	41	102	163
Grace's warbler	7.5	75	105	90	36	50	43	90	150	98	43	72	47
Western tanager	29.0	348	696	464	101	202	135	812	348	464	236	101	135
Black-headed grosbeak	46.0	552	1 104	552	135	271	135	368	368	460	90	90	1 130
		2 753	3 810	2 981	866	1 205	1 046	2 199	2 661	2 754	697	903	974
Timber-Searching-Insect (TSI)													
Mountain chickadee	11.5	69	138	322	28	56	131	46	46	253	19	19	103
White-breasted nuthatch	18.0	360	216	216	125	75	75	144	72	144	50	25	50
Red-breasted nuthatch	10.1	0	0	40	0	0	17	0	0	40	0	0	17
Pygmy nuthatch	10.0	1 000	700	520	430	301	223	460	560	420	198	241	180
Brown creeper	7.7	0	15	92	0	7	44	0	15	123	0	7	58
		1 446	1 207	1 366	599	496	566	767	1 129	1 571	311	454	642

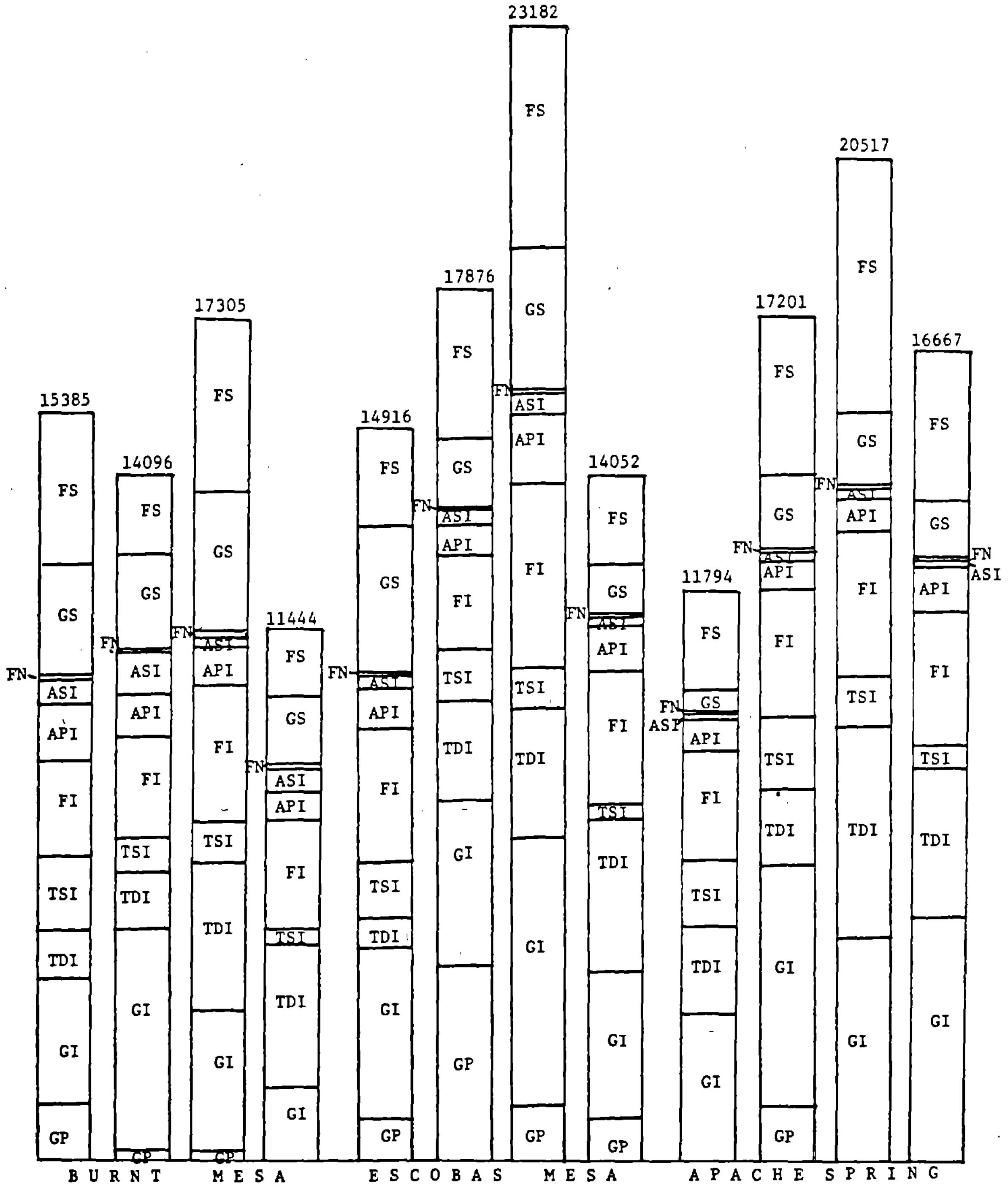

Fig. 1. Foraging diversity ratios (g/100 acres).

TABLE IX. Foraging Diversity in Standing Crop Biomass Values

		Burnt Mesa				Escobas Mesa				Apache Spring			
		1977		1978	1979	1977		1978	1979	1977		1978	1979
Feeding Guilds	Spp.	Pre-	Post-			Pre-	Post-			Pre-	Post-		
Foliage-Seed (FS)	7	3 000/ 19%	1 722/ 12%	3 725/ 21.5%	1 845/ 16%	1 985/ 13%	3 074/ 17%	4 524/ 19.5%	1 792/ 13%	2 184/ 18.5%	3 264/ 19%	5 284/ 26%	3 090/ 18.5%
Ground-seed (GS)	6	2 582/ 17%	1 978/ 14%	2 850/ 16%	1 557/ 14%	3 049/ 20%	1 431/ 8%	2 963/ 13%	1 193/ 8%	478/ 4%	1 466/ 8.5%	1 502/ 7%	1 298/ 0.8%
Foliage-nectar (FN)	1	40/ 0.3%	40/ 0.3%	88/ 0.5%	72/ 0.6%	32/ 0.2%	32/ 0.2%	40/ 0.2%	32/ 0.2%	16/ 0.1%	24/ 0.1%	40/ 0.2%	32/ 0.2%
Air-soaring-insect (ASI)	1	530/ 3%	848/ 6%	254/ 1%	466/ 4%	191/ 1%	424/ 2%	382/ 2%	127/ 0.9%	85/ 0.7%	233/ 1%	170/ 0.8%	148/ 0.8%
Air-perching insect (API)	5	1 107/ 7%	897/ 6%	737/ 4%	557/ 5%	835/ 5.5%	564/ 3%	1 431/ 6%	977/ 7%	690/ 6%	548/ 3%	645/ 3%	891/ 5%
Foliage-insect (FI)	15	2 015/ 13%	2 042/ 14%	2 753/ 16%	2 199/ 19%	2 746/ 18%	1 877/ 10.5%	3 810/ 16%	2 661/ 19%	2 204/ 19%	2 570/ 15%	2 981/ 14.5%	2 754/ 16%
Timber-searching-insect (TSI)	5	1 446/ 9%	767/ 5%	889/ 5%	310/ 3%	1 207/ 8%	1 129/ 6%	814/ 3.5%	318/ 2%	1 366/ 11.5%	1 571/ 9%	1 030/ 5%	548/ 3%
Timber-drilling-insect (TDI)	5	977/ 6%	1 130/ 8%	2 951/ 17%	2 951/ 26%	565/ 4%	1 967/ 11%	2 625/ 11%	3 122/ 22%	1 763/ 15%	1 502/ 9%	4 294/ 21%	2 913/ 17%
Ground-insect (GI)	7	2 574/ 17%	4 415/ 31%	2 801/ 16%	1 487/ 13%	3 449/ 23%	3 436/ 19%	5 479/ 24%	2 973/ 21%	3 008/ 25.5%	4 909/ 28.5%	4 571/ 22%	4 993/ 30%
Ground-predator (GP)	3	1 114/ 7%	257/ 2%	257/ 1%	0 ---	857/ 6%	3 942/ 22%	1 114/ 55%	857/ 6%	0 ---	1 114/ 6%	0/ ---	0/ ---
Total	55	15 385	14 096	17 305	11 444	14 916	17 876	23 182	14 052	11 794	17 201	20 517	16 667

The foliage-nectar guild was represented by only one species, the broad-tailed hummingbird, which was present in small numbers on all three units throughout the course of the study. It accounted for only 0.2% of the combined prefire SCB, 0.1% immediately after the fire, 0.3% in 1978, and 0.3% in 1979. SCB totals increased by 9% immediately after the fire, increased again (75%) in 1978, and declined 19% in 1979, to 54.5% above the prefire biomass.

The violet-green swallow was the only representative of the air-soaring-insect guild. Prefire population accounted for only 2% of the combined SCB totals, 3% immediately afterwards, 1% in 1978, and 2% in 1979. SCB totals increased immediately after the fire by 88% but declined 46% in 1978, and an additional 8% in 1979, to 8% below the prefire biomass. The significant increase of this aerial feeder on all three units immediately after the burn is likely due to the increased openness of the habitats and presence of flying insects that occur after forest fires.

Five air-perching-insect feeders were recorded during the study. The guild accounted for 6% of the combined SCB totals for the three units in the prefire period, 4% immediately after the fire, 5% in 1978, and 6% in 1979. Unlike the air-soaring-insect feeder, this guild experienced a decline (24%) in biomass immediately after the fire, probably because of the reduction of habitat variability. There were three exceptions; Hammond's flycatcher and western pewee on Burnt Mesa and western flycatcher on the Apache Spring unit. SCB totals increased 40% in 1978 and declined 14% in 1979, to 8% below the prefire biomass. Burnt Mesa SCB declined 19% immediately after the fire, another 18% in 1978, and an additional 26.5% in 1979, to only one-half the prefire biomass. On Escobas Mesa, air-perching-insect feeders declined 32.5% immediately after the fire, increased 121% in 1978, and then declined 32% in 1979, to 15% above the prefire biomass. On Apache Spring, the guild declined 20.5% immediately after the fire, increased 18% in 1978, and an additional 38% in 1979, to 29% above the prefire biomass.

Foliage-insect feeders accounted for 16.5% of the combined SCB totals for the three units before the fire, 13% immediately afterward, 16% in 1978, and 18% in 1979. SCB totals dropped 7% immediately after the fire, but increased 47% in 1978, and declined 20% in 1979, to 9% above the prefire biomass. On Burnt Mesa, the SCB increased 1% immediately after the fire, increased an additional 35% in 1978, and then declined 20% in 1979, to 9% above the prefire biomass. On Escobas Mesa, SCB declined 32% immediately after the fire, but increased 103% in 1978, and declined 30% in 1979, to only 3% below the prefire SCB value. Apache Spring's SCB increased 17% immediately after the fire, an additional 16% in 1978, and declined 8% in 1979, to 25% above the prefire biomass.

The foliage-insect guild contained the largest number of representatives (15) of any guild in the study. Six species were recorded in every time period: Townsend's solitaire; solitary vireo; Virginia's, yellow-rumped, and Grace's warblers; and western tanager. An additional four species—house wren, western bluebird, warbling vireo, and black-headed grosbeak—were recorded in 50% or more of the time periods. The pattern of abundance varied considerably. Moderate increases occurred immediately after the fire on both Burnt Mesa and Apache Spring, but a significant decline occurred on Escobas Mesa. Increases were extensive in 1978 on all three units, and particularly for Escobas Mesa, where significant increases (50% or more) were recorded for house wren, western bluebird, warbling vireo, yellow-rumped warbler, western tanager, and black-headed grosbeak. All three units experienced population declines in 1979.

Five species of birds were recorded in the timber-searching-insect guild. SCB totals accounted for 9.5% of the combined totals for the three units before the fire, 7% immediately afterward, 4% in 1978, and 3% in 1979. SCB totals declined each year after the fire; 14% immediately afterward in 1977, 21% in 1978, and an additional 57% in 1979, to 71% below the prefire biomass. On Burnt Mesa, the SCB dropped 47% immediately after the fire, increased 16% in 1978, and declined 65% in 1979, to 79% below the prefire biomass. Escobas Mesa's SCB declined 6% immediately after the fire, an additional 28% in 1978, and 61% more in 1979, to 74% below the prefire biomass. Apache Spring's SCB increased 15% immediately after the fire, declined 34% in 1978, and an additional 47% in 1979, to 60% below the prefire biomass.

The one parasitic species, brown-headed cowbird (present during 9 of the 12 count periods), accounted for 0.3% of the combined SCB totals for the three study areas before the fire, 0.6% immediately afterward, 0.7% in 1978, and 1% in 1979. SCB totals increased by 100% immediately after the fire, an additional 86% in 1978, and 33% more in 1979, to 300% above the prefire biomass. The increase of this species on Escobas Mesa and at Apache Spring after the fire was probably due to the increased openness of the forest to permit more ready access to nests, as well as greater availability of food.

In summary, the four nesting guilds exhibited varying degrees of change by 1979 over prefire biomass. In order of degrees, they include

parasitic	+ 300%
cavity-depression nesters	+ 50%
ground nesters	− 10%
foliage nesters	− 22%

This feeding guild suffered the greatest population decline of any of the 10. Four of the five species showed some population increase immediately after the fire. Populations dropped sharply in 1978 and 1979. The exception was a 23% increase above the prefire value for the white-breasted nuthatch.

The timber-drilling-insect guild, on the other hand, exhibited the highest population increase. This guild, represented by five species, accounted for 8% of the combined SCB totals for the three units in the prefire period, 9% immediately afterward in 1977, 16% in 1978, and 21% in 1979. SCB totals showed significant increase immediately after the fire (39%), an additional 115% in 1978, and a minor decline of 9% in 1979, to 172% above the prefire biomass. On burnt Mesa, the SCB increased 16% immediately after the fire, a jump of 161% in 1978, and no change in 1979; resulting in a 202% increase above the prefire biomass. The Escobas Mesa SCB increased dramatically (248%) immediately after the fire, 33% in 1978, and 19% more in 1979, to 453% higher than the prefire biomass. At Apache Spring, the SCB declined 15% immediately after the fire, but increased 186% in 1978, and declined 32% in 1979, to 65% above the prefire biomass. Only in 1978 were all five species found to breed on one or more of the study areas (Table VII).

Similar increases in woodpecker populations have been detected in burned forests by other authors (Blackford 1955, Yeager 1955, Bock and Lynch 1970, Kilgore 1971, Taylor 1980). Studies described by these authors have, however, provided either no prefire comparisons or their study units were considerably smaller.

The most abundant species in this guild was the hairy woodpecker; it was present on every unit in every time period. On Burnt Mesa, the SCB values were 977 g/100 acres before the fire, 838 g/100 acres immediately afterward (a 14% decline), and 2513 g/100 acres in 1978 and 1979 (a 200% increase above prefire biomass values). On Escobas Mesa, hairy woodpecker SCB values were 419 g/100 acres before the fire, 1675 g/100 acres immediately afterward and in 1978 (an increase of 300%), and 1954 g/100 acres in 1979, an additional increase of 17% or 364% above the prefire biomass. On the Apache Spring unit, hairy woodpecker SCB values were 349 g/100 acres before the fire, 689 g/100 acres immediately afterward (a 97% increase), 1396 g/100 acres in 1978 (an additional 103% increase), and 1745 g/100 acres in 1979 (an additional 25% increase), to 400% above the prefire biomass.

The northern three-toed woodpecker is of particular interest because it was previously considered to be a rare bird in northern New Mexico forests (Hubbard 1970). At Bandelier National Monument, only one bird was detected on a small burned plot (1 acre 1976 burn) on Escobas Mesa before La Mesa Fire. However, immediately after the fire, the species was recorded on all three study areas; for example, 292 g/100 acres on both Burnt and Escobas Mesas, SCB increased to 438 g/100 acres in 1978 (50% increases), and 1168 g/100 acres in 1979 (167% increases) in 1979, to 300% over the postfire 1977 biomass. At Apache Spring, SCB values increased to 876 g/100 acres in 1978 (500% increase) and 730 g/100 acres in 1979 (400% above the postfire 1977 biomass).

The question of recruitment is an interesting one because the northern three-toed woodpecker must have traveled to La Mesa fire location from considerable distances if the prefire populations in similar habitats is a criterion. Hairy woodpecker recruitment is not so difficult to explain because that species was present in some numbers throughout the region before the fire.

The ground-insect guild is represented by seven species, of which three were recorded on every unit in every time period: common flicker, hermit thrush, and chipping sparrow. This guild accounted for 21% of the combined SCB totals for the three units in the prefire period, 26% immediately after the fire, 21% in 1978, and 22% in 1979. SCB totals increased dramatically immediately after the fire by 41%, increased only 0.7% in 1978, and declined 26% in 1979, to 5% above the prefire biomass. Burnt Mesa SCB values increased 71.5% immediately after the fire, declined 36.5% in 1978, and an additional 47% in 1979, to 42% below the prefire biomass. On Escobas Mesa, SCB declined only slightly immediately after the fire, increased 59% in 1978, and declined 46% in 1979, to 14% below the prefire biomass. SCB values for Apache Spring increased 63% immediately after the fire, dropped 7% in 1978, and increased 9% in 1979, to 66% above the prefire biomass.

The significant increase in avian populations in this guild is attributed to the sudden increase of terrestrial invertebrates that occur immediately after a fire. The greatest avifaunal increase occurred at Apache Spring, which received only minor burns over the study area. Next was Burnt Mesa, which received only moderate burns. The last was Escobas Mesa, which received the most severe burn over much of the study area.

The ground-predator guild contained only three species, all of which occurred sporadically during the course of the study. The guild accounted for 5% of the combined SCB totals for the three units during the prefire period, 11% immediately afterward, 2% in 1978, and 2% in 1979. SCB totals increased by 169.5% immediately after the fire, declined 74% in 1978, and an additional 37% in 1979, to 56.5% below the prefire biomass. At least one pair of Cooper's hawks was present on Escobas Mesa before the fire and in each year after the fire. A pair of northern pygmy owls was present on Burnt Mesa before and immediately after the fire and in 1978, but was not detected in 1979. The great horned owl was recorded only in 1977 after the fire on Escobas Mesa.

In summary, 4 of the 10 feeding guilds exhibited increases by 1979 over prefire biomass. In order of degrees, they include

timber-driller-insect feeders	+ 172%
foliage-nectar feeder	+ 54.5%
foliage-insect feeders	+ 9%
ground-insect feeders	+ 5%

Six of the ten feeding guilds exhibited decreases by 1979 over prefire biomass. In order of degrees, they include

foliage-seed feeders	− 6%
air-soaring-insect feeder	− 8%
ground-seed feeders	− 34%
air-perching-insect feeders	− 50%
ground predators	− 56.5%
timber-searching-insect feeders	− 71%

Nesting diversity ratios of the four nesting guilds, calculated by SCB values, are illustrated in Fig. 2 and further broken down in Table X, which also illustrates the percentages of the various SCB values

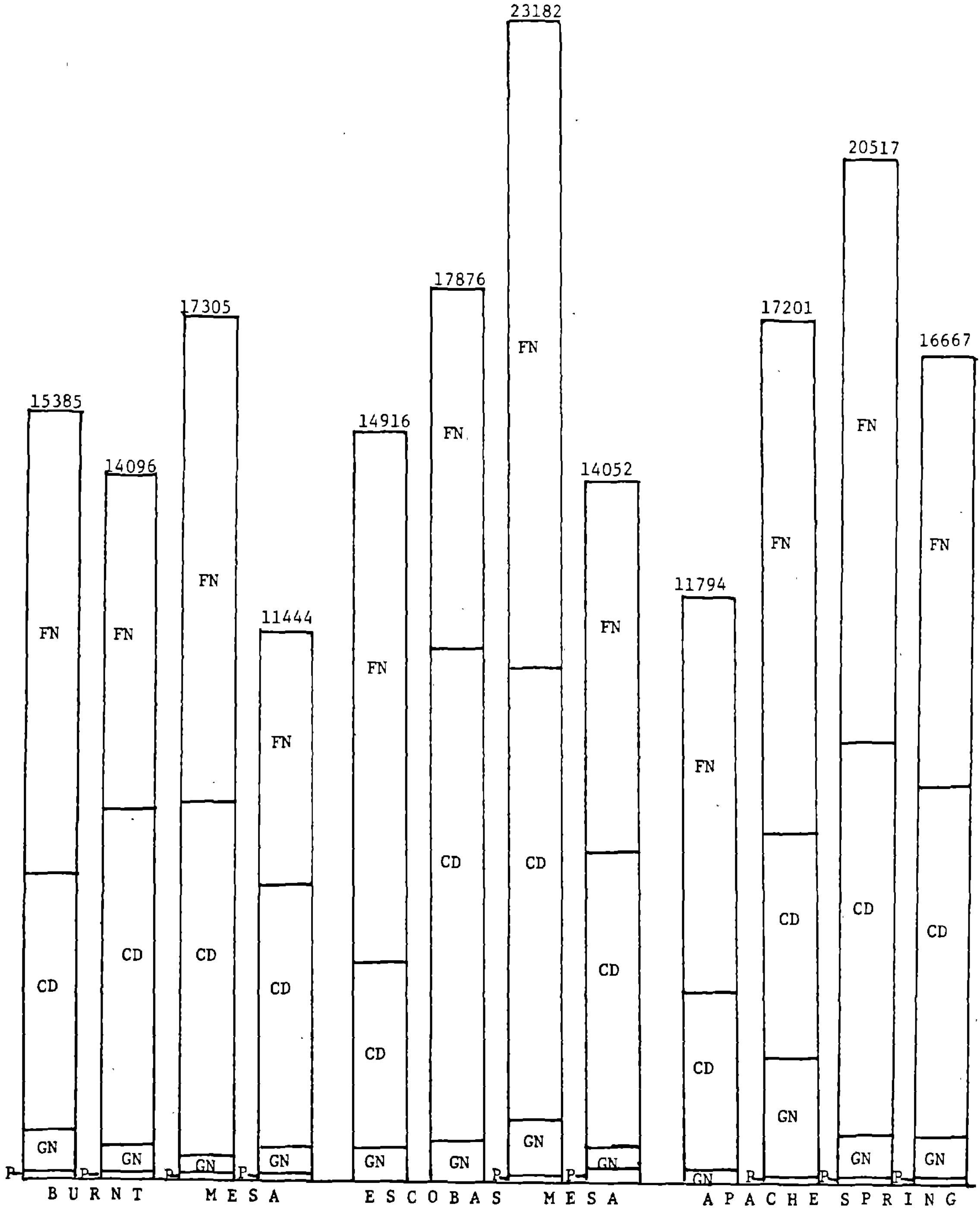

Fig. 2. Nesting diversity ratios (g/100 acres).

TABLE X. Nesting Diversity Standing Crop Biomass Values

		Burnt Mesa				Escobas Mesa				Apache Spring			
		1977		1978	1979	1977		1978	1979	1977		1978	1979
Nesting Guilds	Spp.	Pre-	Post-			Pre-	Post-			Pre-	Post-		
Foliage nesters (FN)	29	9 358/	6 730/	9 696/	5 574/	10 617/	7 238/	12 977/	7 512/	8 062/	10 206/	11 683/	8 697/
		61%	48%	56%	49%	71%	40%	56%	53%	68%	59%	57%	52%
Cavity-Depression Nesters (CDN)	19	5 115/	6 740/	7 110/	5 214/	3 652/	9 872/	9 178/	5 897/	3 462/	5 748/	7 882/	7 188/
		33%	48%	41%	46%	24%	55%	40%	42%	29%	33%	38%	43%
Ground nesters (GN)	6	773/	487/	360/	517/	647/	766/	888/	365/	270/	1 108/	813/	643/
		5%	3%	2%	5%	4%	4%	4%	3%	2%	6%	4%	4%
Parasitic (P)	1	139/	139	139/	139	0/	0/	139/	278/	0/	139/	139/	139/
		1%	1%	0.8%	1%	---	---	0.6%	2%	---	0.8%	0.8%	0.8%
Total	55	15 385	14 096	17 305	11 444	14 916	17 876	23 182	14 052	11 794	17 201	20 517	16 667

within the specific time periods. Foliage nesters composed 53% of the 55 detected species, 35% were cavity-depression nesters, 11% were ground nesters, and 2% were parasitic.

Foliage nesters accounted for 67% of the combined SCB totals for the three study units before the fire, 49% immediately afterward, 56% in 1978, and 52% in 1979. SCB totals declined 14% immediately after the fire, increased 42% in 1978, and decreased 36.5% in 1979, to 22% below the prefire biomass. Dominant foliage nesters (present in at least 10 of the 12 time periods) included mourning dove; broad-tailed hummingbird; Hammond's flycatcher; western pewee; Steller's jay; mountain chickadee; American robin; hermit thrush; solitary vireo; Virginia's, yellow-rumped, and Grace's warblers; western tanager; black-headed grosbeak; red crossbill; and chipping sparrow.

Cavity depression nesters accounted for 29% of the combined SCB totals for the three study units before the fire, 45% immediately afterward, 40% in 1978, and 43% in 1979. SCB totals increased 83% immediately after the fire, an additional 8% in 1978, and declined 24% in 1979, to 50% above the prefire biomass. Dominant cavity-depression nesters included common flicker, hairy and northern three-toed woodpeckers, western flycatcher, violet-green swallow, white-breasted and pygmy nuthatches, western bluebird, and Townsend's solitaire.

Ground nesters accounted for 4% of the combined SCB totals for the three study areas before the fire, 5% immediately afterward, 3% in 1978, and 4% in 1979. SCB totals increased 40% immediately after the fire, declined 13% in 1978, and an additional 26% in 1979, to 10% below the prefire biomass. Dominant ground nesters included only Virginia's warbler and gray-headed junco.

D. Weather

Some of the changes in the avifauna from year to year might be due to factors other than the response of the ecosystem to fire. The most obvious is weather. Comparing the weather between April 21 and June 21 in 1977, 1978, and 1979, average temperatures recorded at Los Alamos were 15.0°C (59°F), 13.3°C (56°F), and 12.4°C (54°F). Precipitation was 57 mm (2.3 in.), 61 mm (2.4 in.), and 130 mm (5.1 in.). Precipitation in 1979 was twice that of the 2 previous years. Thus, 1977 was warmer than 1978, and 1979 was cooler and much wetter. Such differences could affect both vegetation and insect fauna. Although it is not possible to sort out the quantitative effects of weather, some qualitative effects may appear in species marginal to a study unit. For example, the occurrence of warbling vireos on Burnt Mesa and ruby-crowned kinglets and orange-crowned warblers on Escobas Mesa in 1979, where they had not been recorded before, although they were present on the higher transects, is probably due to the cool, wet weather that year. Weather unusual enough to produce such shifts could also have resulted in different population densities, and might be partly responsible for the lower values on all transects in 1979.

VI. SUMMARY AND CONCLUSIONS

La Mesa fire affected the avifauna in a number of ways. In general, populations and biomass values declined immediately after the fire on Burnt and Escobas Mesas but exhibited increases on the higher, less severely burned Apache Spring unit. All three units displayed small to extensive increases in 1978, but exhibited minor to moderate declines, with a few exceptions, in 1979. In comparing 1979 data with prefire values, considerable variations are evident.

Species richness returned to the same values on Burnt and Escobas Mesas as before the fire, but remained 12.5% higher at Apache Spring. Species density values declined 16% on the average; on Burnt and Escobas Mesas, they declined 35% and 14%, respectively, but at Apache Spring, they increased by 2%. Species diversity increased on all three units: 2% on Burnt Mesa, 5% on Escobas Mesa, and 8.5% at Apache Spring. Evenness values increased on all three units as well: 1%, 5.5%, and 5% on Burnt and Escobas Mesas and Apache Spring, respectively.

Biomass analysis reveals that middle-sized species (those of weight classes from 30.1 to 100 g) increased more than larger species and considerably more than smaller species. Four of the 10 feeding guilds exhibited population increases between the prefire period and 1979, and 6 guilds exhibited declines. Timber-drilling-insect and foliage-nectar feeders received the greatest benefit, and timber-searching-insect, ground-predator, and air-perching-insect feeders were most critically affected. Two of the four nesting guilds (parasitic and cavity-depression nesters) exhibited positive responses, and two (ground and foliage nesters) exhibited negative responses.

Combined analysis of the avifauna before and after the fire suggests that middle-sized species that use the timber-drilling-insect guild (woodpeckers) and are either parastic in nature or use cavities and depressions for nesting receive the greatest benefit from fire. Large species that use foliage-insect and ground-insect feeding guilds receive some benefit. All other combinations are casually or severely affected by fire.

Evidence accumulated from this study suggests that Bandelier's avifauna, particularly species diversity, which in itself is a foremost objective for a natural environment such as Bandelier, is increased by fire when the habitat receives light to moderate fire. Of the three categories of fire, severe fire has the most drastic effect on avifauna and the longest period of time is required to adjust. Severe burns also subject the environment to greater probabilities for other adverse effects such as erosion, overgrazing, and infestations. These in turn will affect the avifauna in a secondary way and extend the period of adjustment.

ACKNOWLEDGMENTS

We greatly appreciate the assistance of John Lissoway and Bob LaFrance with transect installations.

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