USDA
United States Department of Agriculture

Fire Patterns in Piñon and Juniper Land Cover Types in the Semiarid Western United States From 1984 Through 2013

David I. Board, Jeanne C. Chambers, Richard F. Miller, and Peter J. Weisberg

Forest Service
Rocky Mountain Research Station
General Technical Report RMRS-GTR-372
January 2018

Board, David I.; Chambers, Jeanne C.; Miller, Richard F.; Weisberg, Peter J. 2018. **Fire patterns in piñon and juniper land cover types in the Semiarid Western United States from 1984 through 2013**. RMRS-GTR-372. Fort Collins, CO: U.S Department of Agriculture, Forest Service, Rocky Mountain Research Station. 57 p.

Abstract

Increases in area burned and fire size have been reported across a wide range of forest and shrubland types in the Western United States in recent decades, but little is known about potential changes in fire regimes of piñon and juniper land cover types. We evaluated spatio-temporal patterns of fire in piñon and juniper land cover types from the National Gap Analysis Program using Monitoring Trends in Burn Severity (MTBS 2016) data (1984 through 2013) for Northern and Southern Intermountain and Central and Southern Rocky Mountain geographic regions. We examined differences in total area burned, fire rotation, fire size, fire number, and fire season among: (1) the four geographic regions; (2) the EPA level III ecoregions that occur within each geographic region; and (3) the piñon and juniper land cover types (woodlands, savannas, and shrublands) and other land cover types that occur within each geographic region and level III ecoregion. We found that area burned during the 30-year period, number of fires each year, and fire size followed a strong geographic pattern: Northern Intermountain > Southern Intermountain > Southern Rocky Mountain > Central Rocky Mountain. Area burned within piñon and juniper land cover types increased significantly during the 30-year period across the study area overall and for each geographic region, except the Southern Intermountain. Fire rotations were within reported historical ranges for sagebrush ecosystems and decreased over time. Also, fire number or fire size increased for the Southern Rocky Mountain and Southern Intermountain geographic regions. Across the study area, spatio-temporal patterns in fire regimes for piñon and juniper land cover types were similar to those for other land cover types. Careful monitoring of longer term trends in fire activity and the interacting effects of invasive annual grasses, bark beetles, and climate change is needed to access the dynamics of piñon and juniper land cover types and evaluate the efficacy of management treatments in piñon and juniper land cover types.

Keywords: piñon, juniper, land cover types, fire size, fire number, fire season, total area burned, fire rotation, Intermountain geographic region, Rocky Mountain geographic region

Cover—A prescribed fire burning through *Pinus monophylla* and *Juniperus osteosperma* in the Great Basin Piñon-Juniper Woodland of the Southern Intermountain geographic region. (Photo by Jeanne Chambers, RMRS.)

Authors

David I. Board, Ecologist/Data Analyst, USDA Forest Service, Rocky Mountain Research Station, Reno, Nevada.

Jeanne C. Chambers, Research Ecologist, USDA Forest Service, Rocky Mountain Research Station, Reno, Nevada.

Richard F. Miller, Professor Emeritus, Oregon Agricultural Research Center, Oregon State University, Corvallis.

Peter J. Weisberg, Department of Natural Resources and Environmental Science, University of Nevada, Reno.

Acknowledgments

We thank Matthew L. Brooks, Douglas J. Shinneman, and Michele R. Crist for helpful review comments.

All Rocky Mountain Research Station publications are published by U.S. Forest Service employees and are in the public domain and available at no cost. Even though U.S. Forest Service publications are not copyrighted, they are formatted according to U.S. Department of Agriculture standards and research findings and formatting cannot be altered in reprints. Altering content or formatting, including the cover and title page, is strictly prohibited.

Table of Contents

Introduction

Increases in burned area and fire size have been reported for much of the semi-arid Western United States in recent decades (Brooks et al. 2015; Dennison et al. 2014; Littell et al. 2009; Westerling et al. 2006), but few studies have evaluated possible changes in fire regimes in piñon and juniper land cover types. In areas where increases in fire area or size have been reported, the increases have often been attributed to changes in plant composition and structure (Miller et al. 2011, 2013). In many warmer and drier areas, invasive annual grasses are increasing the abundance and continuity of fine fuels and resulting in more frequent and larger fires (Balch et al. 2013; Brooks et al. 2004, 2015). In many cooler and moister areas piñon and juniper have infilled preexisting woodlands and expanded into shrubland communities resulting in increases in woody fuels and potentially higher fire severity (Barger et al. 2009; Biondi and Bradley 2013; Floyd et al. 2004; Miller et al. 2008a). Climate warming has exacerbated the changes in fire regimes by increasing the length of the fire season and resulting in more extreme fire weather (McKenzie et al. 2004; Westerling et al. 2006, 2014). In addition, human population growth and increased land use and development have increased fire ignitions in many areas (Short et al. 2016). Here, we evaluated the spatio-temporal patterns of fire in piñon and juniper land cover types in the semi-arid Intermountain West for 1984–2013.

Piñon and juniper land cover types span a broad range of climatic regimes, are associated with numerous distinct vegetation types (West 1983, 1984), and exhibit different fire regimes (Romme et al. 2009). In general, fire regimes are influenced by the effects of topography and regional climate on composition, structure, and productivity of vegetation, seasonal patterns of fuel moisture, and ignitions (Abatzoglou and Kolden 2013; Littell et al. 2009; Liu and Wimberly 2015, 2016; Parks et al. 2012). In areas with piñon and juniper, local fire behavior and mortality of piñon and juniper trees are influenced by understory fuel characteristics, tree density, biomass and canopy cover, and fire weather (fig. 1; Arnold et al. 1964; Brown 1982; Dwyer and Pieper 1967; Martin 1978; Romme et al. 2009; Wright et al. 1979). In areas dominated by piñon and juniper trees with minimal understory cover, fire spread and mortality of trees greater than 2 m in height are typically low, but increase with tree density, biomass, canopy cover, and extreme fire weather (Blackburn and Bruner 1975; Wright et al. 1979). In areas where native grasses dominate the understory and shrubs are sparse, fire spread is moderate and mortality of trees greater than 2 m is low where tree densities are low to moderate. However, small trees (<1.3 m) are easily killed by fire (Arnold et al. 1964; Dwyer and Pieper 1967; Jameson 1962) even under relatively mild to moderate weather conditions (Martin 1978). In areas where shrubs are dominant or codominant in the understory, fire intensities are typically moderate to high (Brown 1982) resulting in high mortality of trees (Martin 1978). Mortality of larger trees increases as a result of extreme fire weather, increasing shrub density providing ladder fuels, and increasing proportion of piñon to juniper.

Increases in tree density result in reduction of understory grasses and shrubs due to competition for resources, and high density stands are typically characterized by low understory biomass (Blackburn and Tueller 1970; Bristow et al. 2014; Bybee et al. 2016; Miller et al. 2000; Roundy et al. 2014; Tausch and West 1995; Young et al. 2015). Fires in late successional piñon and juniper vegetation with high bulk

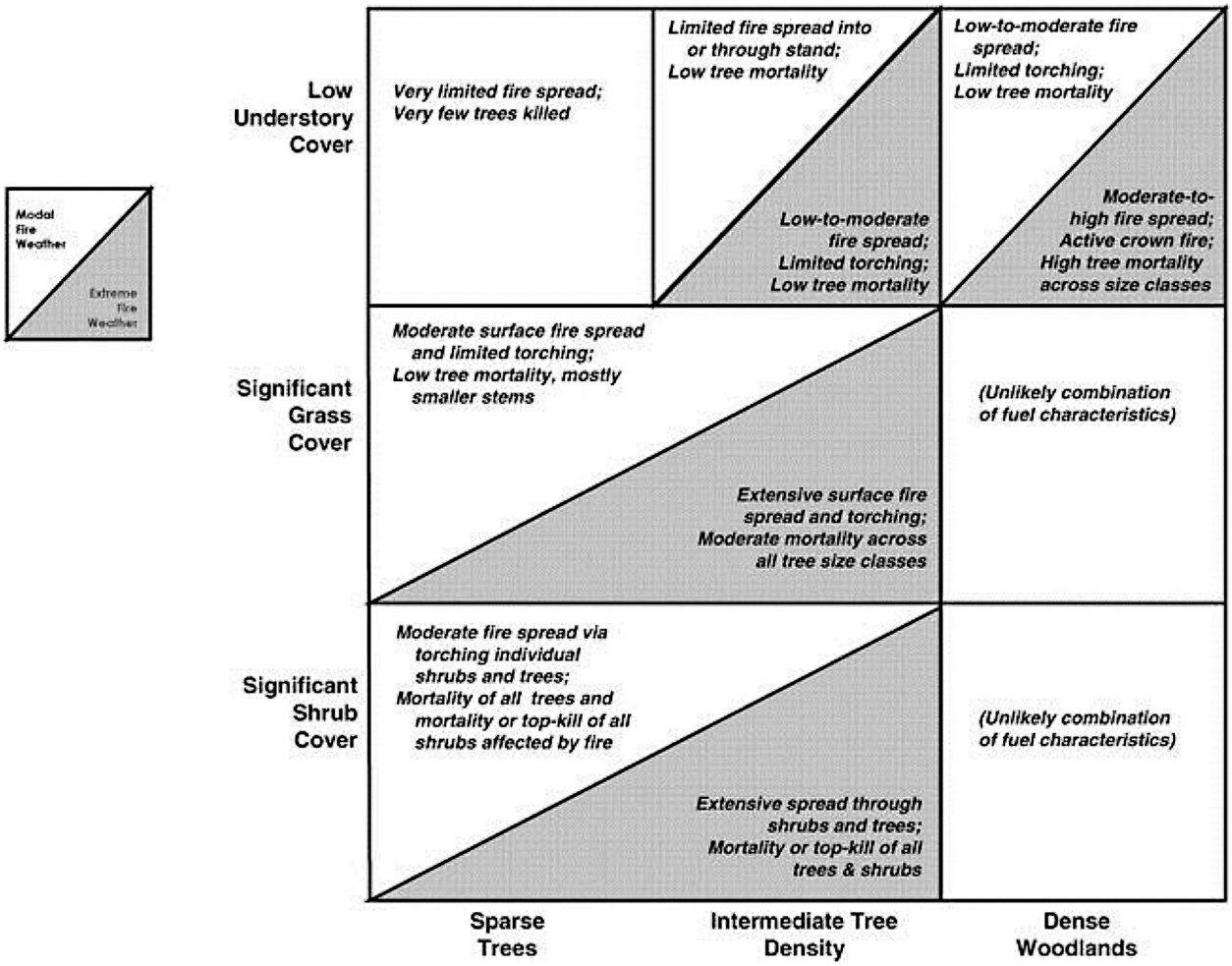

Figure 1—Probable fire behavior following a single ignition event in piñon and juniper vegetation with respect to variablity in tree density (horizontal axis) and understory fuel characterization (veritcal axis). Split cells reflect variable fire behavior, spread dynamics, and tree mortality under modal (80th percentile) in the unshaded upper left versus extreme (96th percentile) fire weather conditions in the shaded lower right. (Used with permission from Romme et al. 2009.)

density of canopy fuels tend to be high severity and stand replacing (Bates et al. 2014; Romme et al. 2009). There is little evidence of frequent, spreading, low-intensity fire in most piñon and juniper vegetation types such as occur in ponderosa pine types (Baker and Shinneman 2004). However, piñon and juniper savanna types with a high proportion of grasses are believed to have experienced low-severity fires that would have removed the small trees (Margolis 2014).

There are limited data on pre-settlement fire size or spatial distribution for the Western United States (Liu and Wimberly 2015, 2016) including for piñon and juniper vegetation types (Romme et al. 2009). Fire occurrence can be reported as fire rotation (the time required for the cumulative area burned to equal the size of the study area) (Sugihara et al. 2006). Although fire rotation does not account for the heterogeneity of fire frequency at local scales, it is useful in describing fire regimes at more regional scales. Existing data for pre-settlement piñon and juniper vegetation indicate that historical fire rotations ranged from about 400 to 600+ years for sites that included central Nevada (Bauer and Weisberg 2009), southern California

(Wangler and Minnich 1996), western Colorado (Shinneman and Baker 2009a), southern Utah (Floyd et al. 2008) and central Oregon (Waichler et al. 2001).

Fire history studies generally report that the large, stand-replacing fires that have become more frequent in recent decades, also occurred historically (Floyd et al. 2004; Miller and Heyerdahl 2008; Romme et al. 2009). Increased frequency of high-severity fires has been attributed to tree expansion and increased tree density since the late 1800s (Romme et al. 2009), although some regions show minimal net change in density or extent of piñon and juniper vegetation since the 1930s (Manier et al. 2005). Increased tree densities in expansion areas (Miller et al. 2008b; Weisberg et al. 2007) have resulted in an increase in biomass (woody fuels) with the potential to increase high-intensity crown fires (Miller and Tausch 2001).

The primary objective of this report was to investigate the fire regimes of piñon and juniper land cover types in the Northern and Southern Intermountain and Central and Southern Rocky Mountain geographic regions of the semi-arid Western United States. We evaluated differences in total area burned, fire rotations, number of fires, length of fire season, and fire size among: (1) the four geographic regions; (2) level III ecoregions (USEPA 2013) that occur within each geographic region; and (3) piñon and juniper land cover types (USGS 2011) that occurred within each geographic region and level III ecoregion. We based our analyses on piñon and juniper and other land cover types from the National Gap Analysis Program (USGS 2011) and on fire data from the Monitoring Trends in Burn Severity Program (MTBS 2016) for 1984 through 2013. We asked three questions: (1) how do fire regimes in the piñon and juniper land cover types vary geographically; (2) how have fire regimes changed in the regions with piñon and juniper land cover types in the last 30 years; and (3) are piñon and juniper land cover types more or less likely to burn than adjacent land cover types within the same region?

Study Area

The study area encompasses the distribution of two species of piñon, *Pinus edulis* Engelm. and *P. monophylla* Torr. & Frém. (fig. 2; Cole et al. 2008, 2013) and three species of juniper, *Juniperus osteosperma* (Torr.) Little, *J. occidentalis* Hook., and *J. deppeana* Steud. (fig. 3; Little 1971; Adams 2014). The study area also includes portions of the distributions of *J. scopulorum* Sarg., *J. grandis* R.P. Adams, and *J. monosperma* (Engelm.) Sarg (fig. 3). Fifteen level III ecoregions (USEPA 2013) occur within the study area. For our analyses, we aggregated these ecoregions into four geographic regions based on climate, topography, and dominant vegetation types: (1) Northern Intermountain geographic region; (2) Southern Intermountain geographic region; (3) Central Rocky Mountain geographic region; and (4) Southern Rocky Mountain geographic region (fig. 4).

The ecoregions are characterized by distinct temperature and precipitation regimes (fig. 5) and are strongly influenced by the amount of precipitation received in winter versus summer (fig. 6). The Southern Rocky Mountains geographic region is influenced by monsoonal flows, with a bimodal precipitation pattern that has peaks in both the summer (June, July, and August) and winter (December, January, and February) months (fig. 6) with some areas receiving as much as 64 percent of the annual precipitation in summer. The Central Rocky Mountain geographic region receives relatively less precipitation in summer (27%); however, some areas receive as much as 37 percent of the annual precipitation in summer.

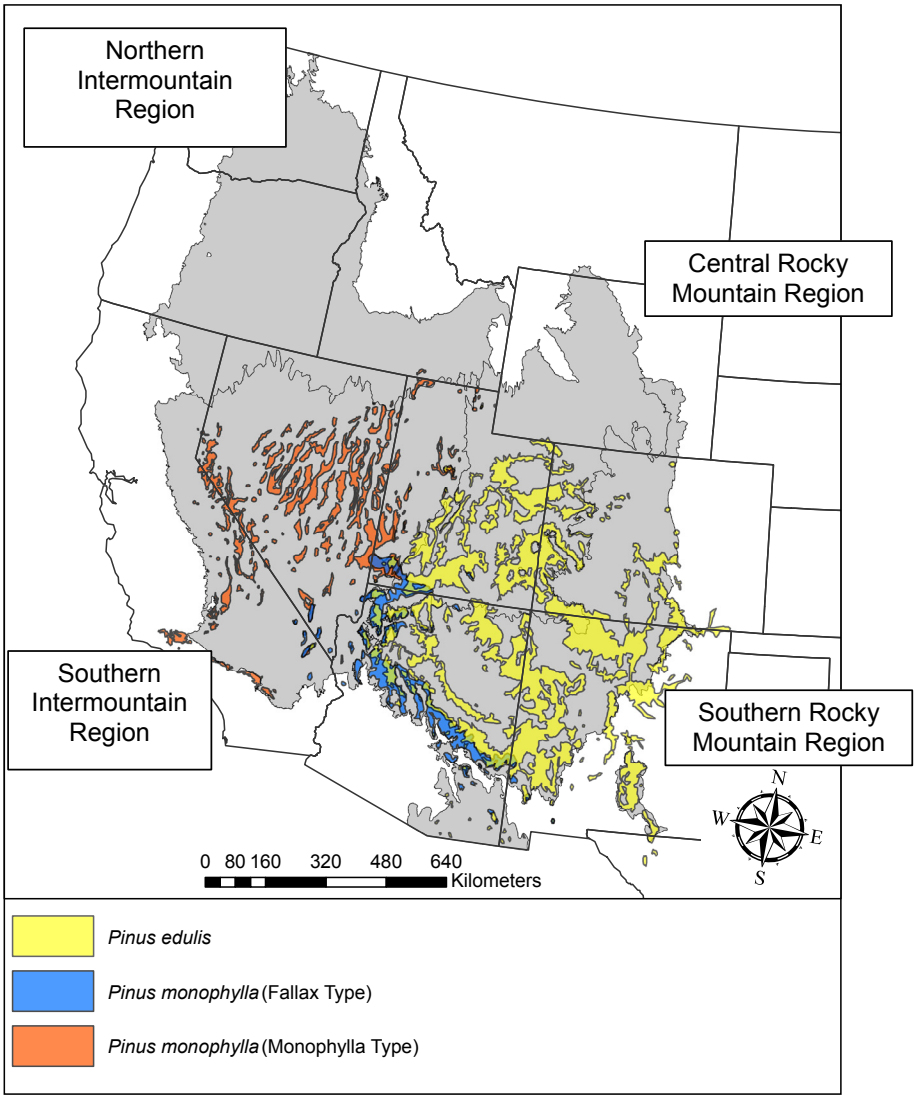

Figure 2—Distribution of the two piñon species of interest in the four geographic regions. Two varieties of *Pinus monophylla* are included (Cole et al. 2008, 2013).

In the Northern Intermountain and Southern Intermountain geographic regions most precipitation (>75%) arrives in winter and spring. Mean annual precipitation across the four geographic regions varies from as little as 46 mm in some southern areas to as much as 2,767 mm in some northern areas (30 year Normal Annual Precipitation, PRISM 2015). However, the majority of piñon and juniper land cover types receive between to 300 to 410 mm with extremes ranging between 200 and 600 mm (Stringham et al. 2015; West 1999; West et al. 1975).

The primary study species and their corresponding land cover types (table 1) vary across the four geographic regions (figs. 2, 3, 4; Adams 2014; Cole et al. 2008, 2013; Little 1971). Piñon species are restricted to a few populations of *Pinus monophylla* in northwestern Utah and southwestern Idaho in the Northern Intermountain geographic region. *Pinus monophylla* is most common in the Southern Intermountain geographic region, while *P. edulis* is most common in the Central Rocky Mountain and Southern Rocky Mountain geographic regions.

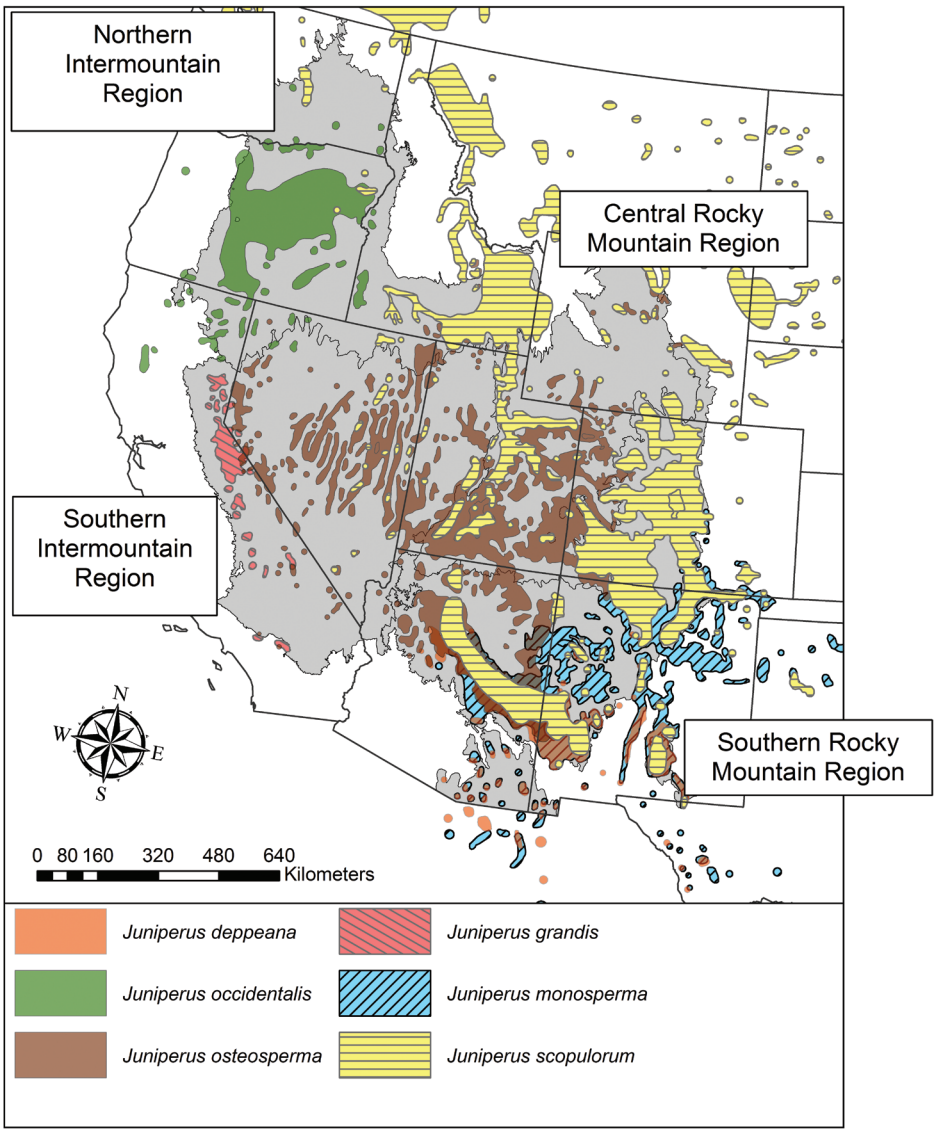

Figure 3—Distribution of the three primary juniper species (*Juniperus deppeana, J.occidentalis,* and *J. osteosprema*) and three secondary juniper species (*J. grandis*, *J. monosperma*, and *J. scopulorum*) species in the four geographic regions.

Juniperus occidentalis is the most common study species in the Northern Intermountain geographic region. *Juniperus grandis* occurs primarily in the Sierra Nevada ecoregion. *Juniperus osteosperma* occurs throughout the study areas, with the exception of the Northern Intermountain geographic region where it occurs only along the southern boundary. *Juniperus scopulorum* also occurs throughout the study area, but is more common in the two eastern Rocky Mountain geographic regions where its range extends northward along the Rockies into Canada and east into the plains. *Juniperus deppeana* occurs in the Southern Rocky Mountain geographic region, particularly in the Arizona and New Mexico Mountains and Madrean Archipelago ecoregions. *Juniperus monosperma* is found in the southeast area of the Southern Rocky Mountain geographic region and east into regions outside the study area.

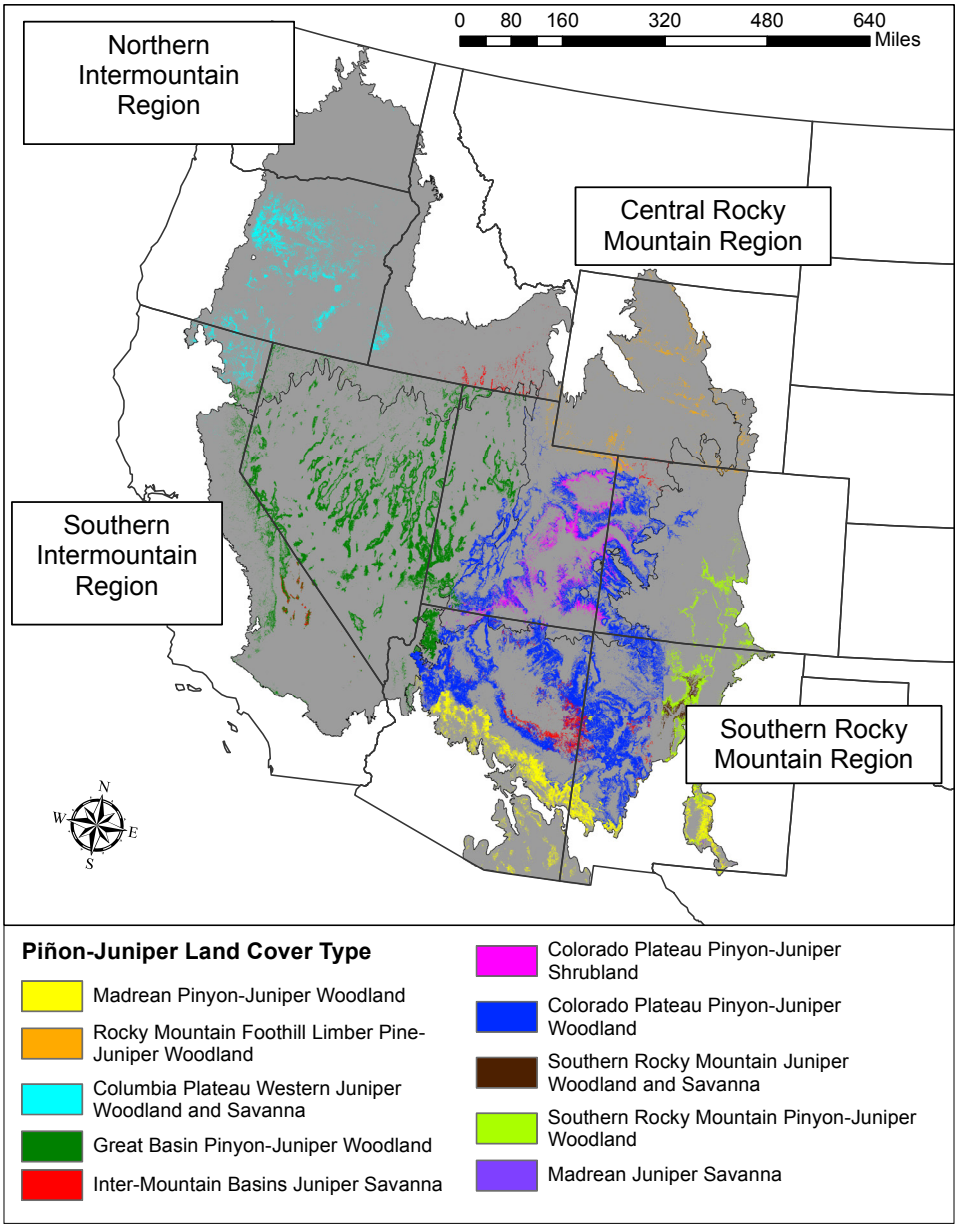

Figure 4—Distribution of the 10 piñon-juniper land cover types (USGS 2011) within the 4 geographic regions.

Data and Analyses

To describe wildfire patterns in the study area, we analyzed the area burned, fire rotation, fire number, length of the fire season, frequency of fire starts through the season, and fire size from 1984 through 2013 for all land cover types combined. Area burned and fire rotation were analyzed for piñon and juniper land cover types (described below) as well as for non-piñon and juniper land cover types. Data were summarized and compared for: (1) the four geographic regions; (2) the level III ecoregions (USEPA 2013) that occur within each geographical region; and (3) the piñon and juniper land cover types that occur within each geographic region and level III ecoregion. To evaluate if the fire regime characteristics had changed in

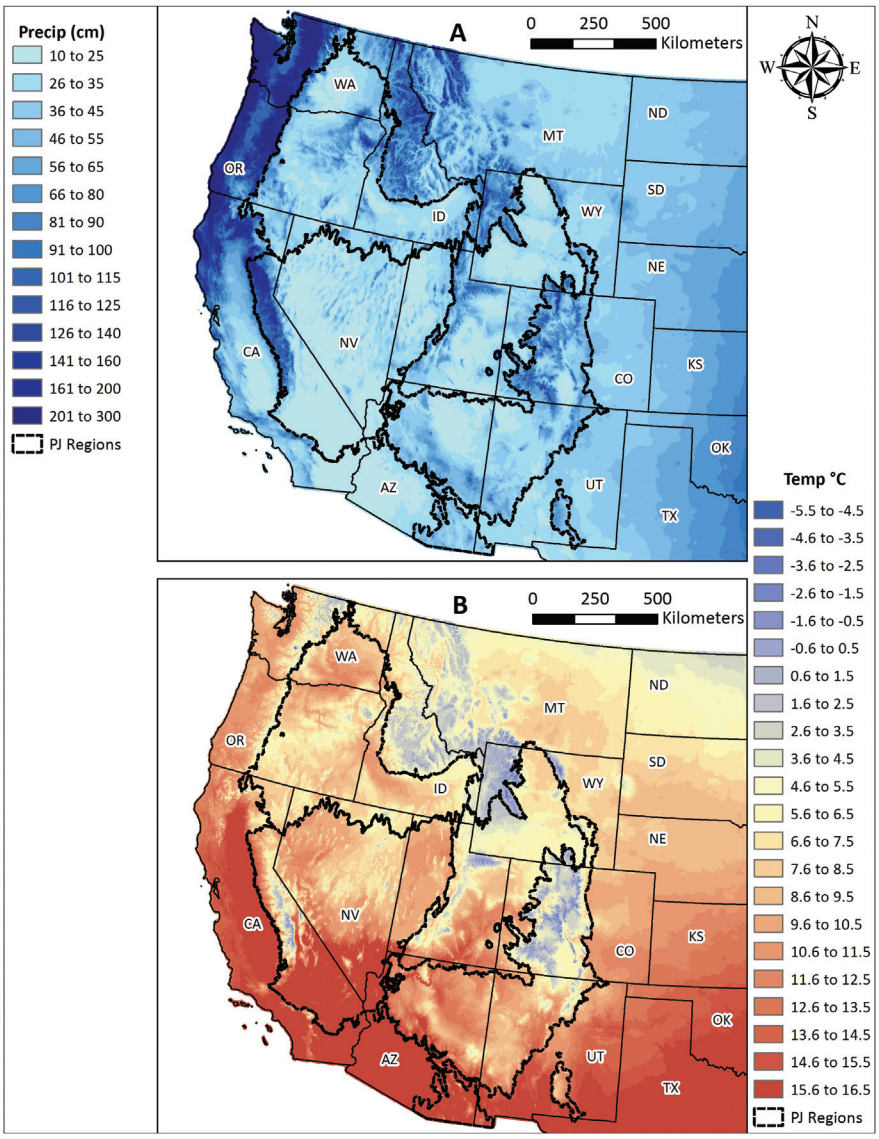

Figure 5—The 30-year normal annual values for (A) precipitation and (B) temperature (PRISM 2016) in the four geographic regions.

the last 30 years for the study area as a whole and if burn area and fire rotation had changed in piñon and juniper land cover types, the Mann-Kendall statistic was used to evaluate trends. To evaluate if piñon-juniper land cover types were burning more or less than other land cover types, fire parameters for piñon and juniper land cover types were compared to those for non-piñon and juniper land cover types. To delineate burned areas within regions or land cover types, fires were split where they crossed geographic or land cover boundaries.

Land Cover Type Data

Land cover type data were derived from the National Gap Analysis Program, Land Cover Data, Version 2 (USGS 2011). The focus was on ten land cover types where piñon and/or juniper species are common (table 1). These ten land cover types comprised six piñon and juniper woodlands, three piñon and juniper savannas, and one piñon and juniper shrubland based on the land cover type descriptions in

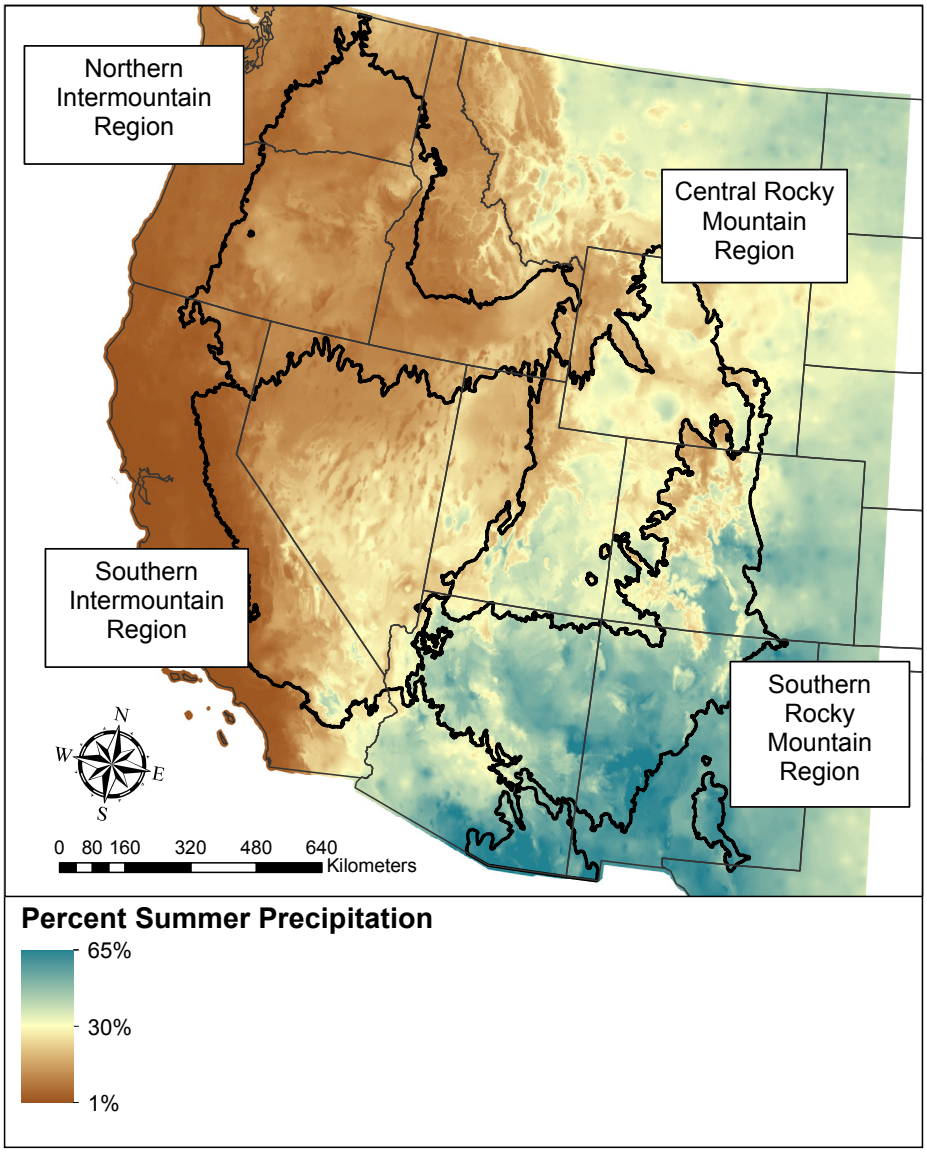

Figure 6—The percent of summer precipitation (July, August, and September) based on 30-year normal annual values for the western United States (PRISM 2016).

the Ecological System Comprehensive Report (NatureServe 2015). Shrublands were defined as areas characterized by natural or semi-natural woody vegetation with aerial stems generally less than 3 meters tall. Woodlands and savanna were characterized as having an overstory of trees, i.e., woody vegetation over 3 meters tall. Woodlands were described as typically having a shrub dominated understory while savannas were described as having a grass dominated understory. The Columbia Plateau Western Juniper Woodland and Savanna land cover type was characterized by open stands of *J. occidentalis* with an understory of open shrub-steppe; however, the land cover type includes areas where the trees intermingle or are expanding into the surrounding grassland and where conditions favor grasslands over shrublands. This land cover type was analyzed as part of the woodland land cover types. The Southern Rocky Mountain Juniper Woodland and Savanna land cover type was described as a savanna that has widely spaced trees but may have inclusions of

Table 1—Aerial extent of each land cover type followed by the percentage of the study area and percentage of piñon and juniper land cover types in parentheses. The study area was 164,874,698 ha; the area of piñon and juniper land cover types within the study area was 22,863,781 ha (13.9%); the area that was not piñon and juniper land cover types was 142,010,917 ha (86.1%).

Land cover type	Area (ha)	Dominant piñon and juniper species
Piñon-juniper woodlands		
Columbia Plateau Western Juniper Woodland and Savanna	1,499,198 (0.9%, 6.6%)	*Juniperus occidentalis*
Great Basin Piñon-Juniper Woodland	5,801,585 (3.5%, 25.4%)	*Juniperus californica* *Juniperus osteosperma* *Pinus monophylla*
Colorado Plateau Piñon-Juniper Woodland	9,683,705 (5.9%, 42.4%)	*Juniperus monosperma* *Juniperus osteosperma* *Juniperus scopulorum* *Pinus edulis*
Rocky Mountain Foothill Limber Pine-Juniper Woodland	533,096 (0.3%, 2.3%)	*Juniperus communis* *Juniperus osteosperma* *Juniperus scopulorum*
Southern Rocky Mountain Piñon-Juniper Woodland	1,123,905 (0.7%, 4.9%)	*Juniperus monosperma* *Juniperus scopulorum* *Pinus edulis*
Madrean Piñon-Juniper Woodland	2,020,409 (1.2%, 8.8%)	*Juniperus coahuilensis* *Juniperus deppeana* *Juniperus monosperma* *Juniperus pinchotii* *Pinus edulis*
All piñon-juniper woodlands	***20,661,898 ha (12.6%, 90.4%)***	
Juniper savannas		
Inter-Mountain Basins Juniper Savanna	747,200 (0.5%, 3.3%)	*Juniperus osteosperma* *Juniperus scopulorum*
Southern Rocky Mountain Juniper Woodland and Savanna	233,657 (0.1%, 1.0%)	*Juniperus monosperma* *Juniperus scopulorum*
Madrean Juniper Savanna	67,511 (0.0%, 0.3%)	*Juniperus deppeana* *Juniperus monosperma* *Juniperus pinchotii*
All juniper savanna types	***1,048,368 ha (0.6%, 4.6%)***	
Piñon-juniper shrublands		
Colorado Plateau Piñon-Juniper Shrubland	1,153,514 (0.7%, 5.0%)	*Juniperus osteosperma* *Pinus edulis*
All piñon-juniper shrubland types	***1,153,514 ha (0.7%, 5.0%)***	

denser juniper woodlands. This land cover type was analyzed as part of the savanna land cover types. All other land cover types included in the analyses were grouped into a non-piñon and juniper land cover types category.

Fire Data

Fire data were from the Monitoring Trends in Burn Severity (MTBS) program (MTBS 2016) for the years spanning 1984 through 2013, which was the last year that data were available at the beginning of the analysis. Fire perimeter polygons from MTBS were used to delineate burned areas and thus included unburned areas and low severity burn areas (fig. 7). The MTBS data included fires equal to or

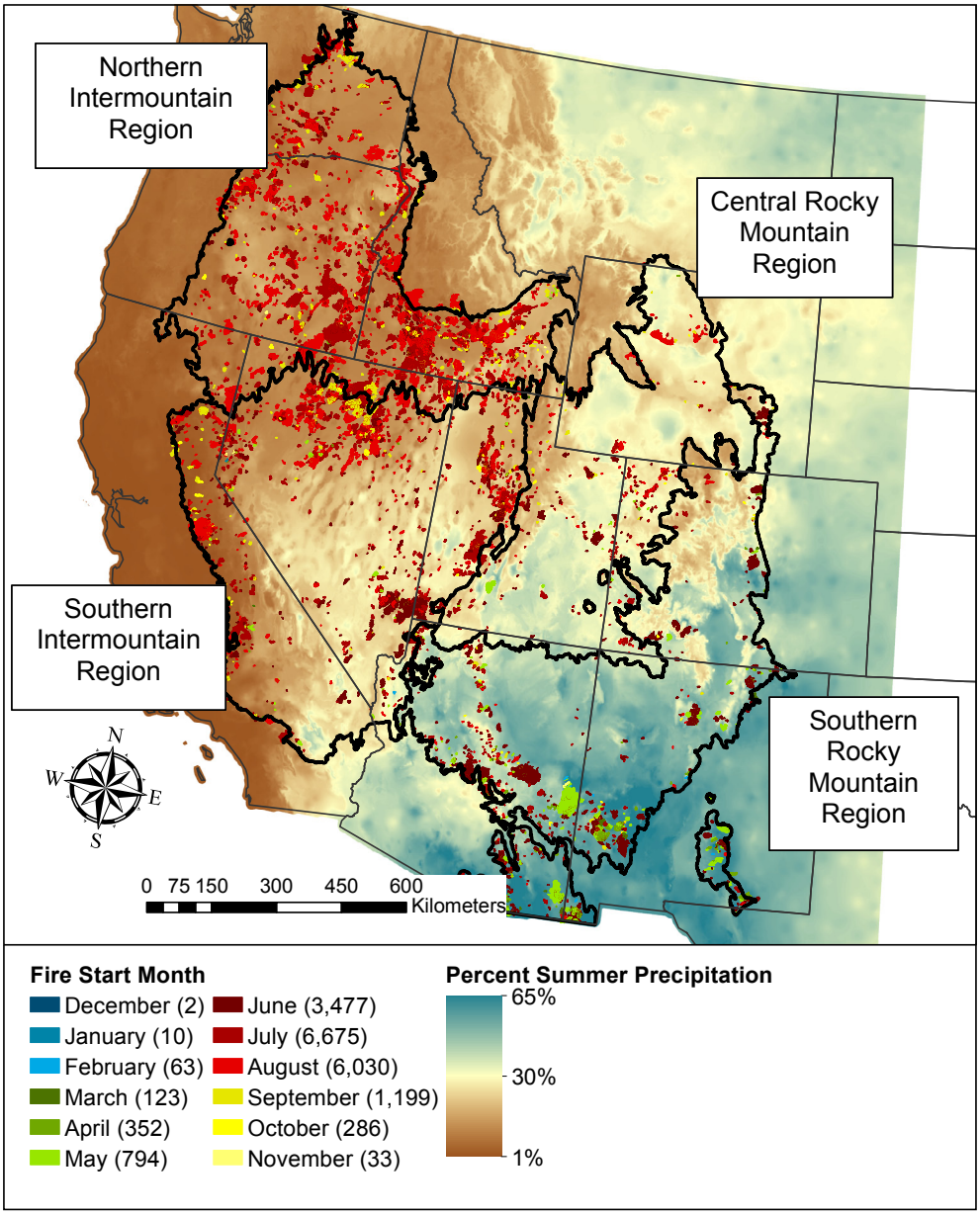

Figure 7—Fires larger than 450 ha occurring between 1984 and 2013 within the four geographic regions color coded by month of fire start. Number of fires are shown in parentheses for each month. Fires are overlaid on the percent of summer precipitation (July, August, and September) based on 30-year normal annual values for the western United States (MTBS 2016; PRISM 2016).

greater than 405 ha (1,000 ac). Fires smaller than 405 ha were not included in this study because they make up a small portion of the total area burned each year and were not always recorded accurately over the study period. Fires that were known to be prescribed fires were excluded from the data set as well as those that were not recorded with high confidence as reported in MTBS. Fires that burned across regional/land cover type boundaries were included in the calculations for both areas.

Analysis of Fire Parameters

Total area burned and area burned annually were calculated from the MTBS data. Trends in burn area were evaluated by summing the area burned annually within a geographic region and testing for a temporal trend for the period between 1983 and 2013 using a Mann-Kendall statistic (Kendall 1975; Mann 1945). Where data were sufficient, the same test was conducted for piñon and juniper land cover types. Although the Mann-Kendall statistic is non-parametric and robust to skewed data distributions and nonlinear relationships, it can perform poorly if there is a cyclic signal within the data.

Fire rotation was calculated using data for the entire 30-year time span (1984 through 2013) and the last 15 years (1999 through 2013). The last 15 years were compared to the 30-year time span to evaluate possible trends in changing fire regimes. However, 15 years is a limited time frame to extrapolate fire rotation, and estimates can be skewed by a single anomalous observation.

Fire number (number of fires >405 ha [1,000 ac]) was summarized on an annual basis, and temporal trends between 1984 and 2013 were tested using a Mann-Kendall statistic. Fire number was evaluated further to describe the fire season.

Fire season was defined as the period from the start date of the first fire of the year greater than 405 ha to the start date of the last fire of the year greater than 405 ha. Fire season was reported as the number and distribution of fire starts for each year between 1984 and 2013, including the first and last recorded fire, length of the fire season, and frequency of fire starts (shown as the number of fires per week during the fire season). To evaluate a potential change in fire season length and distribution of starts during the fire season, trends in the start date, end date, length of fire season, and the number of fires per week were tested for the period between 1984 and 2013 using the Mann-Kendall test.

Fire size was summarized using the median size of fires. Annual fire sizes (median size of all individual fires per year) were analyzed to determine if fire size was driving temporal trends in fire area. Temporal trends were tested using a Mann-Kendall statistic. To better understand the distribution of fire sizes and describe the distribution and potential change of fire size over time, the 25th, 50th (median), and 75th percentiles and maximum fire size for each year were evaluated for each geographic region (Liu and Wimberly 2015). It should be noted that the MTBS data was designed to evaluate large fires (>405 ha [1,000 ac]). This truncation of fire size limits inference about trends in small fires (i.e., the 25th percentile).

Results

Fire Patterns Across the Study Area

The four geographic regions that make up the study area extended across 165 million hectares of which 22.9 million ha (13.8%) were classified as piñon and juniper land cover types (table 1, fig. 4). Piñon and juniper woodlands accounted for 20.7 million ha (12.6%) of the area, while piñon and juniper savanna and shrubland combined accounted for 2.2 million ha (1.3%).

Fire Area

From 1984 through 2013, a total of 13.9 million ha (8.4%) burned in the study area (table 2, fig. 7). Piñon and juniper land cover types accounted for almost 1.4 million ha (10.0%) of the total area burned. The total number of hectares burned has been increasing since 1984 in both the study area overall ($\tau = 0.292$, $P = 0.0235$) and the piñon and juniper land cover types ($\tau = 0.444$, $P = 0.0006$) (table 3). The percentage of the area burned that was piñon and juniper land cover types also increased over time ($\tau = 0.366$, $P = 0.0046$).

Total hectares burned on an annual basis in the study area ranged from 76,500 ha in 1991 to 1,630,000 ha in 2012 with a median of 293,000 ha. The area of piñon and juniper land cover types that burned annually ranged from 2,900 ha in 1991 to 173,000 ha in 2012 (table 3, fig. 8).

Table 2—Area burned, percent total burn area, percent land cover type burned, and fire rotation for land cover types (USGS 2011) in the study area from 1984 through 2013 based on wildfires larger than 405 ha (1,000 ac) with high confidence in the MTBS database (MTBS 2016). Fire rotations were calculated for 1984 through 2013 and for 1999 through 2013 (shown in parentheses).

Land cover type	Area burned (ha)	Total burn area (*percent*)	Land cover type burned (*percent*)	Fire rotation (years) 1983–2013 (1999–2013)
Piñon-juniper types				
Piñon-juniper woodlands				
Columbia Plateau Western Juniper Woodland and Savanna	139,086	1.0	9.3	323 (238)
Great Basin Piñon-Juniper Woodland	597,248	4.3	10.3	291 (192)
Colorado Plateau Piñon-Juniper Woodland	305,229	2.2	3.2	952 (622)
Rocky Mountain Foothill Limber Pine-Juniper Woodland	33,794	0.2	6.3	473 (264)
Southern Rocky Mountain Piñon-Juniper Woodland	28,841	0.2	2.6	1169 (687)
Madrean Piñon-Juniper Woodland	230,361	1.7	11.4	263 (160)
All piñon-juniper woodland types	**1,334,560**	**9.6**	**6.5**	**464 (302)**
Juniper savannas				
Inter-Mountain Basins Juniper Savanna	41,429	0.3	5.5	541(314)
Southern Rocky Mountain Juniper Woodland and Savanna	1,999	0.0	0.9	3,507 (2,297)
Madrean Juniper Savanna	8,804	0.1	13.0	230 (251)
All piñon-juniper savannas types	**52,231**	**0.4**	**5.0**	**602 (362)**
Piñon-juniper shrublands				
Colorado Plateau Piñon-Juniper Shrubland	8,451	0.1	0.7	4,094 (3,279)
All piñon-juniper types	**1,395,243**	**10.0**	**6.1**	**492 (319)**
All non- piñon juniper types	**12,500,967**	**90.0**	**8.8**	**341 (251)**
All land cover types	**13,896,210**	**100.0**	**8.4**	**356 (258)**

Table 3—Variation in fire area, number, season, and size for the study area from 1984 through 2013. The year that the minimum and maximum occurred for each variable is in parentheses. Trends in fire variables were tested using Kendal tau; a positive value indicates an increase during the 30-year period and a negative value indicates a decrease. Values for area burned are the total for the study area, the total for piñon and juniper land cover types, and percent of the study area burned that was piñon and juniper land cover types. Data are for wildfires with high confidence in the MTBS database (MTBS 2016).

Variable	Minimum	Maximum	Median	Tau	*P*
Area burned					
Total for study area (ha)	76,500 (1991)	1,634,021 (2012)	293,266	0.292	0.0235
Piñon-juniper land cover types (ha)	2,898 (1991)	172,630 (2012)	28,570	0.444	0.0006
Piñon-juniper land cover types (%)	2.3 (1985)	22.8 (2004)	9.2	0.366	0.0046
Fire number					
Number	44 (1991)	321 (2006)	133	0.206	0.1121
Fire season					
Length	165 (1993)	343 (2006)	211	0.242	0.0690
Start date	Jan 7 (2006)	May 17 (2010)	Mar 18	–0.203	0.1162
End date	Sept 16 (2013)	Dec 16 (2006)	Oct 24	0.243	0.0608
Fires per week	1.64 (1991)	8.54 (2000)	4.50	0.145	0.2610
Fire size (ha)					
Median	856 (1988)	1,989 (2012)	1,217	0.287	0.0257
1st Quartile	542 (1988)	800 (1996)	800	0.260	0.0438
3rd Quartile	1,294 (1991)	5,097 (2012)	3,001	0.274	0.0337
Maximum	3,947 (1991)	229,622 (2007)	42,310	0.434	0.0007

Fire Rotation

Fire rotation for all land cover types in the study area was 356 years for 1984 through 2013 (table 2). Piñon and juniper land cover types had longer return intervals (492 years) compared to non-piñon and juniper land cover types (341 years). For all piñon and juniper land cover types, the fire rotation was less for 1999 through 2013 than for 1984 through 2013.

Fire Number

Fire number for the study area overall ranged from 44 in 1991 to 321 in 2006 with a median of 133 (table 3, fig. 8). However, the number of fires did not appear to increase over the 30-year time period ($\tau = 0.206$, $P = 0.1121$).

Fire Season

The length of the fire season did not increase over the 30-year period for the overall study area ($\tau = 0.242$, $P = 0.0690$). However, length of fire season varied among years ranging from 165 days in 1993 to 343 days in 2006 with a median of 211 days for the study area (table 3, fig. 8). There was no temporal trend in fire season start date ($\tau = –0.203$ 0.1162) or end date ($\tau = 0.243$, $P = 0.0608$). The median start date of the fire season was March 18 with start dates ranging from as early as January 7, 2006 to as late as May 17, 2007. The median end date was October 24 with the earliest end date on September 16, 2013 and latest end date on December 16, 2006.

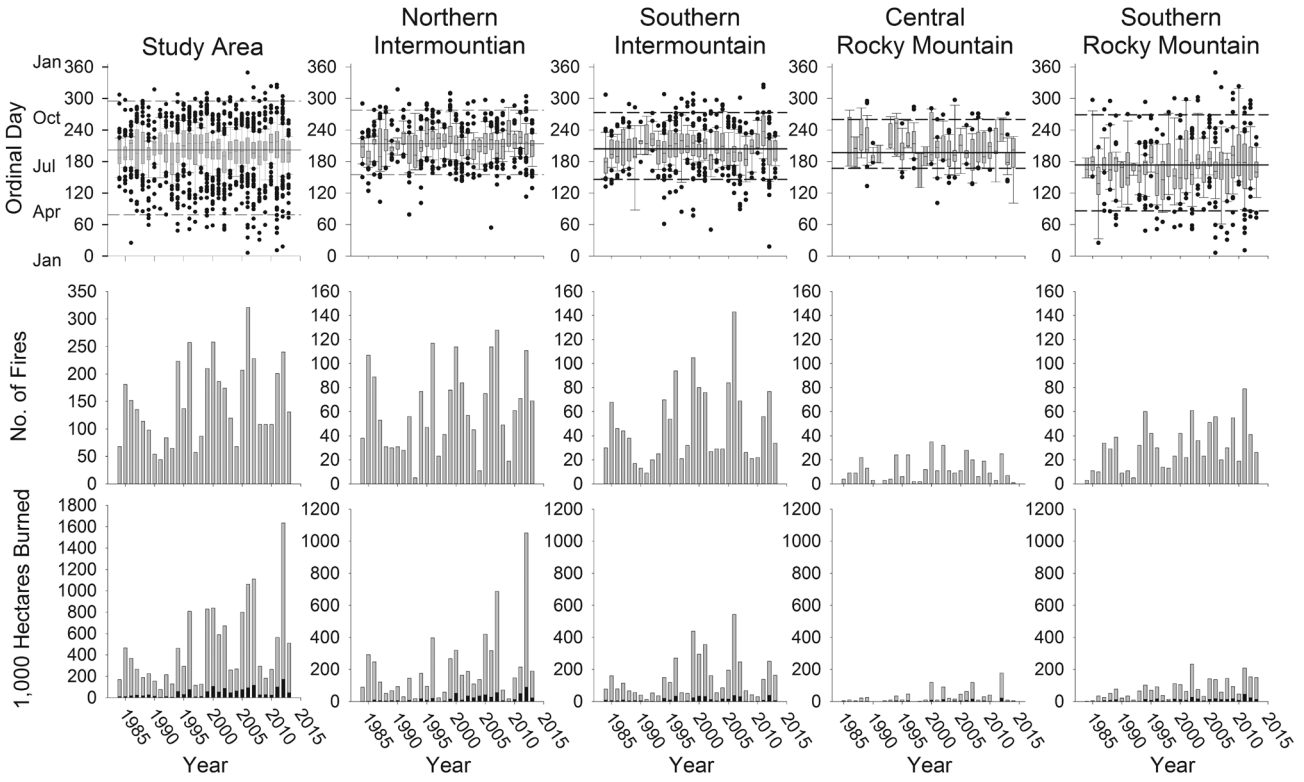

Figure 8—Characterization of the annual variation of fire within the study area overall and each geographic region. The first row of graphs shows the fire season. Each boxplot is a single year. The box shows the interquartile range with the median represented by a line within the box. The whiskers are the 10th and 90th percentile with earlier or later fires represented by dots. The dashed lines across the graphs represent the median earliest and latest fires. The solid line represents the median annual fire start. The second row of graphs illustrates the annual number of fires for the study area. The last row shows the total number of hectares burned in gray and the total number of hectares of piñon and juniper land cover types burned annually in black.

Fire Size

Median fire size for the overall study area increased between 1984 and 2013 (τ = 0.287, P = 0.0257), and ranged from a minimum of 856 ha in 1988 to a maximum of 1,989 ha in 2012 (table 3, fig. 9). First quartile fire size ranged from 542 ha in 1988 to 800 ha in 1996 and increased over the period (τ = 0.260, P = 0.0438). The third quartile fire size also increased (τ = 0.274, P = 0.0337) ranging from 1,294 ha in 1991 to 5,097 ha in 2012. The maximum fire size increased dramatically (τ = 0.434, P = 0.0007) ranging from 3,947 ha in 1991 to 229,622 ha in 2007.

Fire Patterns Within the Geographic Regions

The relative abundance of piñon and juniper land cover types differed among the four geographic regions (fig. 4). The two eastern regions had the largest percentages of piñon and juniper woodland land cover types (16.7% of the Central Rocky Mountain geographic region and 23.1% of the Southern Rocky Mountain geographic region). These two regions were also the only regions with piñon and juniper shrublands (3.6% of the Central Rocky Mountain geographic region and less than 0.1% of the Southern Rocky Mountain geographic region). Piñon and juniper savanna was most common in the Southern Rocky Mountain geographic region

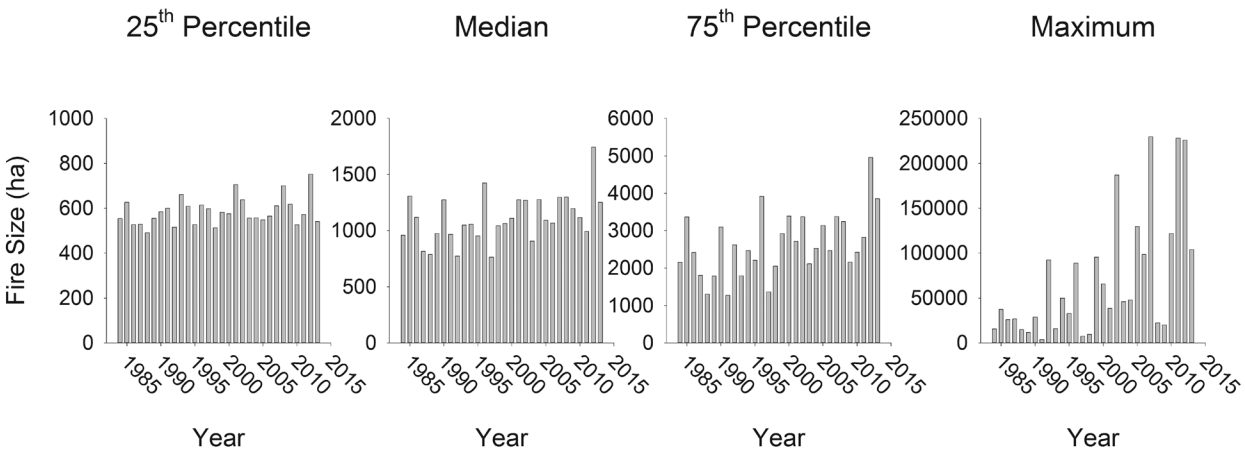

Figure 9—Fire size for the 25th, 50th, 75th quartiles and the maximum for the study area.

(1.9% of the region). However, the Columbia Plateau Woodland and Savanna land cover type (classified as a woodland type) occurred exclusively in the two western regions, contained savanna like vegetation, and was more abundant in the study area overall than any of the savanna piñon and juniper types.

The percentage of the total area that burned showed large differences among the four geographic regions. In the Northern Intermountain geographic region 15.2 percent of the area burned from 1984 through 2013; this was 6.6 times greater than the Central Rocky Mountain geographic region where only 2.3 percent of the area burned (table 4). The percentage of piñon and juniper land cover types that burned followed the general trends of the geographic regions (table 4; fig. 8). Piñon and juniper land cover types were 4.4 times more likely to burn in the Northern Intermountain than the Central Rocky Mountain geographic region (table 4). In the Northern Intermountain and Southern Rocky Mountain geographic regions, a smaller percentage of piñon and juniper land cover types burned than in the regions as a whole, while the reverse was true for the Southern Intermountain and Central Rocky Mountain geographic regions.

Table 4—The percent of piñon and juniper woodland, savanna, and shrubland cover types, non- piñon and juniper land cover types, and all land cover types that burned in the study area overall and in each geographic region from 1984 through 2013. Data are for wildfires with high confidence in the MTBS database (MTBS 2016).

Land cover	Study area	Northern Intermountain	Southern Intermountain	Central Rocky Mountain	Southern Rocky Mountain
Piñon-juniper types					
Piñon-juniper woodlands	6.5	12.5	9.9	3.7	4.5
Piñon-juniper savannas	5.0	28.2	4.9	0.1	1.7
Piñon-juniper shrublands	0.7	–	–	0.7	2.3
All piñon-juniper types	6.1	13.5	9.8	3.1	4.3
Non- piñon-juniper types	8.8	15.3	8.6	2.1	6.9
All land cover types	8.4	15.2	8.7	2.3	6.3

The number and seasonal frequency of fires also differed among geographic regions. Annual fire number varied from 1.4 fires per million ha in the Northern Intermountain geographic region to 0.32 fires per million ha in the Central Rocky Mountain geographic region (table 5, fig. 8). The longest fire season occurred in the Southern Rocky Mountain geographic region with a median length of 188 days. The length of the season was countered by this region typically having only 1.1 fires per week (scaled to the area of the Central Rocky Mountain geographic region). The Northern Intermountain geographic region had a moderate fire season length, but had the highest number of fires per week, 2.5 (scaled to the area of the Central Rocky Mountain geographic region). The Southern Rocky Mountain geographic region had a distinct fire season with a propensity for spring and early summer burns, while the Northern and Southern Intermountain geographic regions had a propensity for late summer and fall burns.

Annual median fire size was 1,343 ha in the Northern Intermountain geographic region, which was 1.5 times greater than in the Central Rocky Mountain geographic region where annual fire size was 927 ha (table 5). However, the maximum annual fire size was 7 times greater in the Northern Intermountain geographic region (30,711 ha) than in the Central Rocky Mountain geographic region (4,297 ha) (fig. 10).

Table 5—Regional comparison of the annual fire variables scaled for comparison. Area burned variables are total area burned relative to the total area of the study or ecoregion, piñon and juniper area burned relative to the area of piñon and juniper land cover types, and piñon and juniper area burned relative to the total area burned in the study area. Fire numbers are scaled to fires per million hectares; fires per week is scaled to the fires per week in area comparable to the Central Rocky Mountain region which has the smallest total area; fire season is not scaled; and fire size is not scaled. PJ area is the area of all piñon-juniper land cover types.

Variable	Study area	Northern Intermountain	Southern Intermountain	Central Rocky Mountain	Southern Rocky Mountain
Area burned annually					
Total area burned	0.18%	0.36%	0.20%	0.04%	0.15%
PJ area burned	0.12%	0.53%	0.13%	0.03%	0.10%
PJ area burned relative to total burned	9.20%	8.30%	7.50%	10.90%	13.60%
Fire number					
Fires per million ha	0.807	1.42	0.735	0.318	0.677
Fires per week scaled	0.194	2.48	1.28	0.798	1.09
Fire season	Mar 18–Oct 18 (211 days)	Jun 5–Oct 6 (125 days)	May 26–Oct 2 (135 days)	Jun 17–Sept 18 (91 days)	Mar 22–Sept 26 (188 days)
Fire size (ha)					
Median	1,214	1,343	1,255	927	1,230
1st quartile	800	667	691	618	681
3rd quartile	3,001	3,325	2,827	1,648	2,315
Maximum	42,310	30,711	18,107	4,297	10,412

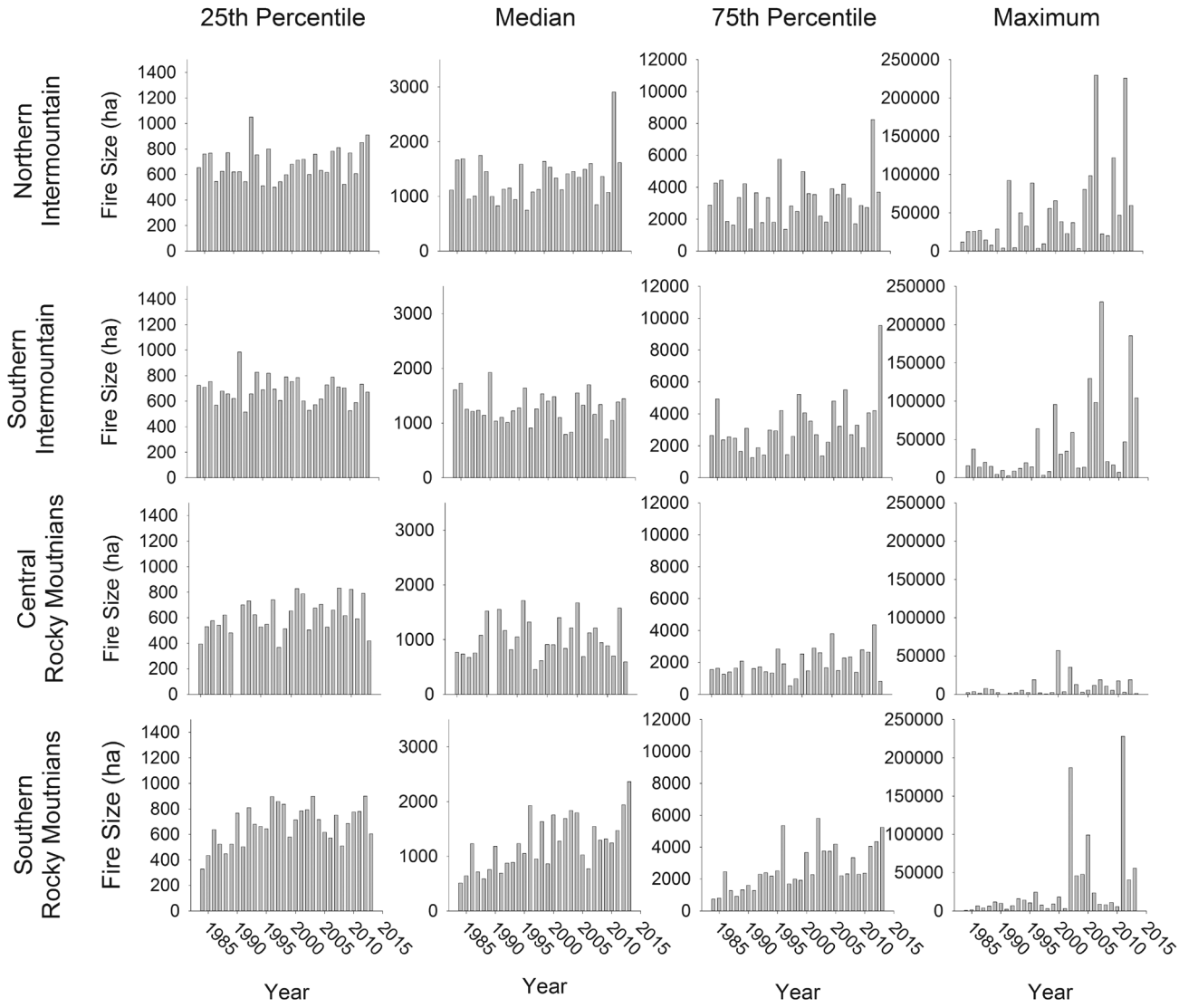

Figure 10—Fire size for the 25th, 50th, 75th quartiles and the maximum for the four geographic regions within the study area.

Fire Patterns in the Northern Intermountain Geographic Region

The Northern Intermountain geographic region encompassed 40.1 million ha, nearly a quarter of the area of interest and included five ecoregions and four major piñon-juniper land cover types (table 6, fig. 11). Piñon and juniper land cover types accounted for almost two million ha or about 5 percent of the region. The Columbia Plateau Western Juniper Woodlands and Savanna was the most common piñon and juniper land cover type in the region accounting for 3.7 percent of the total area and 74.9 percent of the piñon and juniper land cover types. Piñon and juniper land cover types were most common in the Blue Mountains ecoregion and least common in the Snake River and Columbia Plateau ecoregions.

Table 6—Aerial extent of land cover types within the Northern Intermountain geographic region ("All") and within each ecoregion followed by percentage of the land cover type in the region and the percentage in the ecoregion(s), respectively, in parentheses. Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (ha)	Eastern Cascades Slopes and Foothills (ha)	Columbia Plateau (ha)	Blue Mountains (ha)	Snake River Plain (ha)	Northern Basin and Range (ha)
Piñon-juniper						
Piñon-juniper woodland						
Columbia Plateau Western Juniper Woodland and Savanna	1,495,449 (3.7%, 74.9%)	311,748 (5.9%, 86.7%)	61,496 (0.7%, 100.0%)	816,028 (11.5%, 100.0%)	228 (0.0%, 2.7%)	305,948 (2.2%, 40.7%)
Great Basin Piñon-Juniper Woodland	378,839 (0.9%, 19.0%)	47,784 (0.9%, 13.3%)	–	–	–	331,055 (2.4%, 44.0%)
All piñon-juniper woodland types	**1,874,770 (4.7%, 93.9%)**	**359,533 (6.8%, 100.0%)**	**61,496 (0.7%, 100.0%)**	**816,028 (11.5%, 100.0%)**	**665 (0.0%, 7.9%)**	**637,048 (2.4%, 84.7%)**
Juniper savanna						
Inter-Mountain Basins Juniper Savanna	122,644 (0.3%, 6.1%)	0 (0.0%, 0.0%)	–	–	7,716 (0.1%, 92.1%)	114,928 (0.8%, 15.3%)
All piñon-juniper types	**1,997,414 (5.0%, 100.0%)**	**359,533 (6.8%, 100.0%)**	**61,496 (0.7%, 100.0%)**	**816,028 (11.5%, 100.0%)**	**8,381 (0.2%, 100.0%)**	**751,976 (5.4%, 100.0%)**
All non- piñon-juniper types	**38,113,820 (95%)**	**4,965,693 (93.2%)**	**8,251,266 (99.3%)**	**6,275,028 (88.5%)**	**5,354,030 (99.8%)**	**13,267,803 (94.6%)**
Total land area	**40,111,235 (100%)**	**5,325,721 (100.0%)**	**8,023,904 (100.0%)**	**7,091,057 (100.0%)**	**5,362,411 (100.0%)**	**14,019,798 (100.0%)**

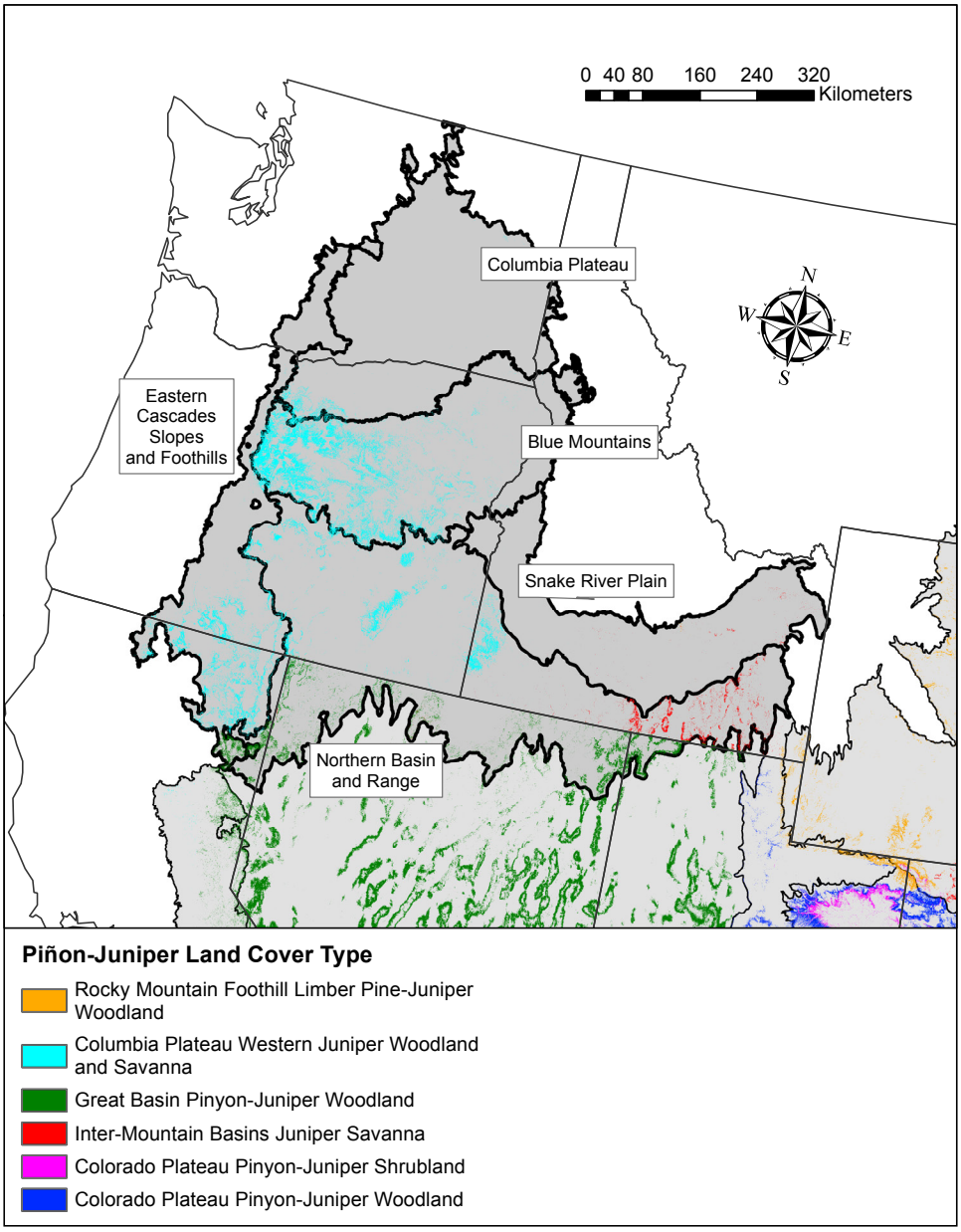

Figure 11—Distribution of the piñon and juniper land cover types across the four ecoregions within the Northern Intermountain geographic region. Piñon and juniper land cover types account for almost two million ha or about 5 percent of the region.

Fire Area

From 1984 through 2013, 6.1 million ha or 15.2 percent of the Northern Intermountain geographic region burned (table 7). There was no temporal trend in the number of hectares burned ($\tau = 0.223$, $P = 0.8350$) during the 30-year period. The number of acres burned annually ranged from 16,847 ha in 2009 to 1,050,456 ha in 2012 with a median of 146,265 ha (table 8, fig. 12).

Piñon-juniper land cover types accounted for 269,259 ha of the burned area (4.4%) (table 7). There were significant increases in the annual area burned ($\tau = 0.457$, $P = 0.0004$) and percentage of the area burned ($\tau = 0.494$, $P = 0.0001$) for the piñon-juniper vegetation land cover types from 1984 through 2013 (table 8).

Table 7—Area (ha) burned by land cover type within the Northern Intermountain geographic region ("All") and within each ecoregion. Values in parentheses are the area burned as a percentage of the total burned area (all land cover types), and as a percentage of the area burned within the specified land cover type, respectively. Burned area data are from 1984 through 2013 for wildfires with high confidence in the MTBS database (MTBS 2016). Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (ha)	Eastern Cascades Slopes and Foothills (ha)	Columbia Plateau (ha)	Blue Mountains (ha)	Snake River Plain (ha)	Northern Basin and Range (ha)
Piñon-juniper						
Piñon-juniper woodlands						
Columbia Plateau Western Juniper Woodland and Savanna	137,966 (2.3%, 9.2%)	17,442 (5.1%, 5.6%)	19,187 (2.5%, 31.2%)	77,396 (9.0%, 9.5%)	28 (0.0%, 4.2%)	23,913 (0.8%, 7.8%)
Great Basin Piñon-Juniper Woodland	96,663 (1.6%, 25.5%)	12,284, (3.6%, 25.7%)	–	–	–	84,379 (2.9%, 25.5%)
All piñon-juniper woodland types	**234,630 (3.8%, 12.5%)**	**29,726 (8.7%, 8.3%)**	**19,187 (2.5%, 31.2%)**	**77,396 (9.0%, 9.5%)**	**28 (0.0, 4.2%)**	**108,293 (3.7%, 17.0%)**
Juniper savanna						
Inter-Mountain Basins Juniper Savanna	34,629 (0.6%, 28.2%)	0 (0.0%, 0.0%)	–	–	1,641 (0.1%, 21.3%)	32,988 (1.1%, 28.7%)
All piñon-juniper types	**269,259 (4.4%, 13.5%)**	**29,726 (8.7%, 8.3%)**	**19,187 (2.5%, 31.2%)**	**77,396 (9.0%, 9.5%)**	**1,669 (0.1%, 19.9%)**	**141,281 (4.8%, 18.8%)**
All non- piñon-juniper types	**5,835,460 (95.6%, 15.3%)**	**312,451 (91.3%, 6.3%)**	**733,489 (97.5%, 8.9%)**	**778,653 (91.0%, 12.4%)**	**1,233,108 (99.9%, 23.0%)**	**2,77,759 (95.2%, 20.9%)**
All land cover types	**6,104,719 (100.0%, 15.2%)**	**342,176 (100.0%, 6.4%)**	**752,677 (100.0%, 9.4%)**	**856,049 (100.0%, 12.1%)**	**1,234,776 (100.0%, 23.0%)**	**2,919,040 (100.0%, 20.8%)**

Table 8—Annual variation in fire area, number, season, and size in the Northern Intermountain Region for 1984 through 2013. Trends in the variables were tested using Kendal's tau; a positive value indicates an increase over time and a negative value indicates a decrease. Values for area burned are the total for the study area, the total for piñon and juniper land cover types, and percent of the study area burned that was piñon and juniper land cover types. Data are for wildfires with high confidence in the MTBS database (MTBS 2016).

Variable	Minimum	Maximum	Median	Tau	*P*
Area burned					
Total (ha)	16,847 (2009)	1,050,456 (2012)	146,265	0.223	0.8350
Piñon-juniper (ha)	626 (1997)	89,654 (2012)	10,587	0.457	0.0004
Piñon-juniper (%)	1.0 (1985)	25.6 (2004)	8.3	0.494	0.0001
Fire number					
Number	5 (1993)	128 (2007)	57	0.145	0.2609
Fire season					
Length (days)	72 (2004)	218 (2006)	125	0.074	0.5677
Start date	Feb 24 (2006)	Jul 9 (1991)	Jun 5	-0.134	0.3004
End date	Aug 13 (2004)	Nov 14 (1990)	Oct 6	0.019	0.8863
Fires per week	0.322 (1993)	7.14 (2007)	3.16	0.145	0.2610
Fire size (ha)					
Median	749 (1997)	2,906 (2012)	1,343	0.126	0.3265
1st Quartile	500 (1997)	1,050 (1993)	667	0.131	0.3092
3rd Quartile	1,363 (1997)	8,238 (2012)	3,325	0.053	0.6816
Maximum	3,307 (2004)	229,622 (2007)	30,711	0.310	0.0160

The area of piñon-juniper land cover types that burned annually ranged from 626 ha in 1997 to 89,654 ha in 2012, while the percentage of the total burned area that was within piñon and juniper land cover types varied annually from 1.0 percent in 1985 to 25.6 percent in 2004 (table 8, fig. 12, fig. A.1).

Total area burned varied among the five ecoregions with the Snake River Plain and Northern Basin and Range having the largest burned areas, as well as the largest percentages of the total ecoregion area burned (23.0% and 20.8%, respectively) (table 7, fig. 12, fig. A.1). The Northern Basin and Range had the largest area of piñon and juniper land cover types burned and the percentage of the area burned in these land cover types (18.8%) paralleled that for the ecoregion overall (20.8%). The burned areas of piñon and juniper land cover types in the other ecoregions ranged from 1,669 ha on the Snake River Plain to 77,396 ha in the Blue Mountains, and the percentage of the area burned within piñon and juniper land cover types ranged from a low of 8.3 percent in the Eastern Cascades Slopes and Foothills to a high of 31.2 percent in the Columbia Plateau.

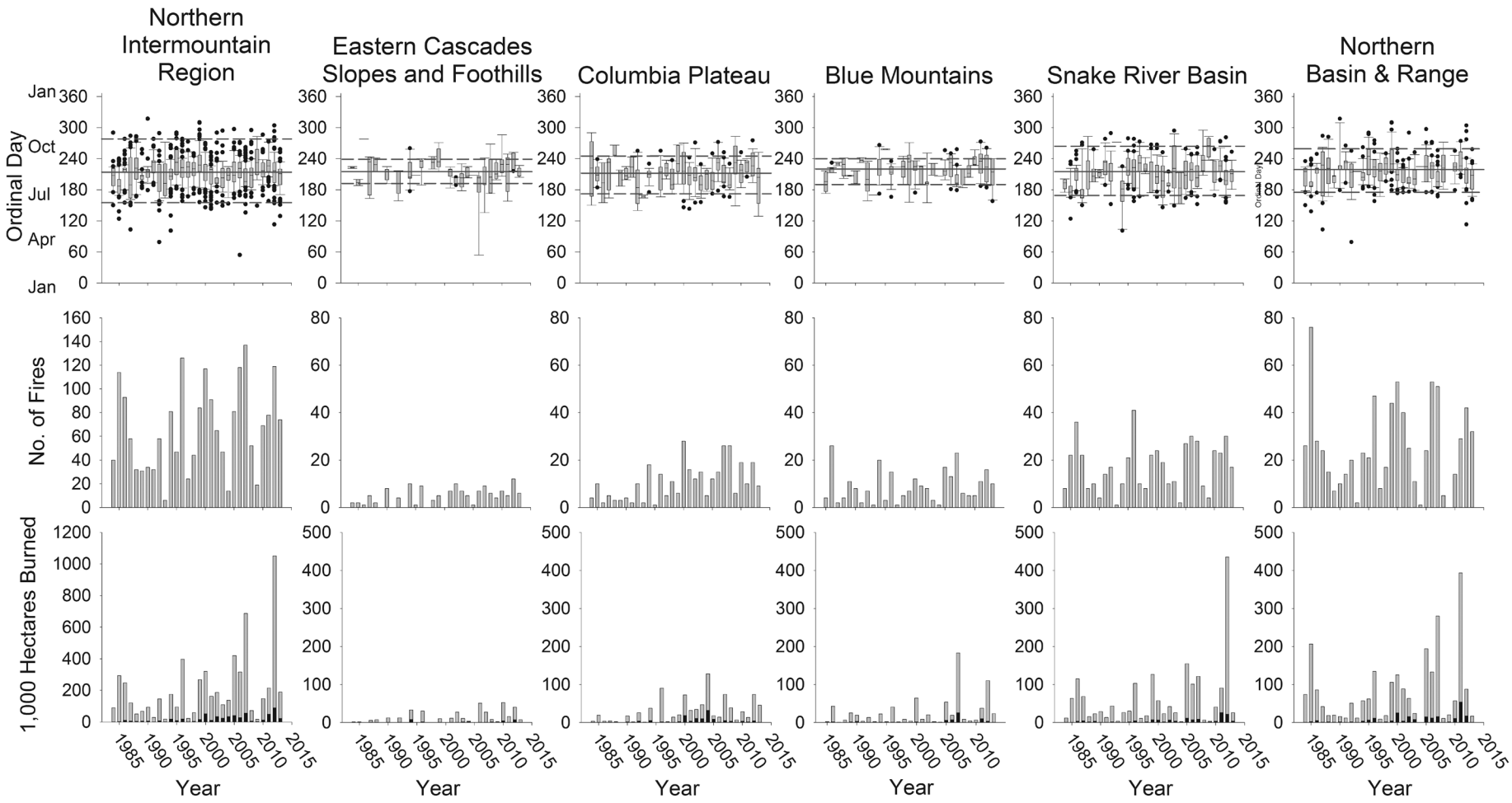

Figure 12—Start day, number of fires, and total area burned in the five ecoregions within the Northern Intermountain geographic region. The first row shows the fire season based on the ordinal day of ignition with each boxplot representing a single year. The box shows the interquartile range with the median represented by a line within the box. The whiskers are the 10th and 90th percentile with earlier or later fires represented by dots. The dashed lines across the graphs represent the median earliest and latest fires for the area of focus. The solid line represents the median of the annual median fire start for the area of focus. The second row represents the annual number of fires in the study area. The last row shows the total number of hectares burned in gray and the total number of hectares of piñon and juniper land cover types burned annually in black.

Fire Rotation

Mean fire rotation across piñon and juniper land cover types was 223 years in the Northern Intermountain geographic region (table 9). The longest rotation was 536 years for the Columbia Plateau Western Juniper Woodland and Savanna land cover type in the Eastern Cascades Slopes and Foothills ecoregion, while the shortest rotation was 96 years for the Columbia Plateau Western Juniper Woodland and Savanna in the Columbia Plateau ecoregion.

Fire Number

The number of fires in the Northern Intermountain geographic region varied 26-fold during the 30-year period, ranging from as few as 5 in 1993 to as many as 128 in 2007 with a median of 57 (table 8, fig. 12). The number of fires did not increase over the time period ($\tau = 0.145$, $P = 0.2609$).

Fire Season

The median fire season was 125 days, ranging from 72 days in 2004 to 218 days in 2006 (table 8, fig. 12). Length of fire season did not show a trend between 1984 through 2013 ($\tau = 0.074$, $P = 0.5677$). The median start date for the season was June 5 and median end date for the season was October 6. Neither start nor end date showed a temporal change ($\tau = -0.134$, $P = 0.3004$ and $\tau = 0.019$, $P = 0.8863$, respectively).

Fire Size

Median fire size varied from 749 ha in 1997 to 2,906 ha in 2012 and did not increase over time ($\tau = 0.126$, $P = 0.3265$; table 8, fig. 12). However, the size of large fires occurring in the maximum percentile did increase during the 30-year period ($\tau = 0.310$, $P = 0.0160$).

Table 9—Fire rotation in years for piñon-juniper land cover types within the Northern Intermountain geographic region ("All") and within each ecoregion from 1983 through 2013 and from 1999 through 2013 in parentheses. Data are for wildfires with high confidence in the MTBS database (MTBS 2016). Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (yrs)	Eastern Cascades slopes and foothills (yrs)	Columbia Plateau (yrs)	Blue Mountains (yrs)	Snake River Plain (yrs)	Northern Basin and Range (yrs)
Piñon-juniper types						
Piñon-juniper woodland types						
Columbia Plateau Western Juniper Woodland and Savanna	325 (240)	536 (365)	96 (61)	316 (372)	–	384 (224)
Great Basin Piñon-Juniper Woodland	118 (68)	117 (75)	–	–	–	118 (67)
All piñon-juniper woodland types	**240 (159)**	**363 (241)**	**96 (61)**	**316 (272)**	**–**	**176 (101)**
Juniper savanna types						
Inter-Mountain Basins Juniper Savanna	106 (59)	–	–	–	141 (83)	105 (58)
All piñon-juniper types	**223 (144)**	**363 (241)**	**96 (61)**	**316 (272)**	**151 (89)**	**160 (91)**

Fire Patterns in the Southern Intermountain Geographic Region

The Southern Intermountain geographic region occupied 48.9 million ha or about 30 percent of the study area and included three ecoregions with six piñon-juniper land cover types (table 10, fig. 13). Colorado Plateau Piñon-Juniper Shrubland and Madrean Piñon-Juniper Woodlands occupied less than 200 ha total and are included in the total for all piñon-juniper woodland types, but are not presented separately in table 10. Piñon and juniper land cover types accounted for 5.4 million ha or about 11.0 percent of the region. The majority of the piñon-juniper land cover in the region was Great Basin Piñon-Juniper Woodland (94.0%). The Central Basin and Range was the largest ecoregion in this geographic region with 30.9 million ha and had the largest amount of piñon and juniper land cover (4.8 million ha).

Table 10—Aerial extent of land cover types within the Southern Intermountain geographic region ("All") and within each ecoregion followed by percent of the land cover type in the geographic region and ecoregion(s), respectively, in parentheses. Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (ha)	Sierra Nevada (ha)	Central Basin and Range (ha)	Mojave Basin and Range (ha)
Piñon-juniper types				
Piñon-juniper woodland types				
Columbia Plateau Western Juniper Woodland and Savanna	3,749 (0.0%, 0.1%)	3,747 (0.1%, 1.2%)	2 (0.0%, 0.0%)	–
Great Basin Piñon-Juniper Woodland	5,070,199 (10.4%, 94.0%)	298,524 (5.6%, 94.0%)	4,494,962 (14.6%, 94.5%)	276,713 (2.2%, 82.6%)
Colorado Plateau Piñon-Juniper Woodland	257,519 (0.5%, 4.8%)	–	244,957 (0.8%, 5.1%)	12,562 (0.1%, 3.8%)
All piñon-juniper woodland types	**5,331,640 (10.9%, 98.8%)**	**302,271 (5.7%, 96.6%)**	**4,739,922 (15.3%, 99.6%)**	**289,448 (2.3%, 86.4%)**
Juniper savanna types				
Inter-Mountain Basins Juniper Savanna	**64,300 (0.1%, 1.2%)**	**–**	**18,852 (0.1%, 0.4%)**	**45,448 (0.4%, 13.6%)**
All piñon-juniper types	**5,395,953 (11.0%, 100.0%)**	**302,271 (5.7%, 100.0%)**	**4,758,773 (15.4%, 100.0%)**	**334,909 (2.6%, 100.0%)**
All non- piñon juniper types	**43,561,803 (89.0%)**	**5,007,558 (94.3%)**	**26,120,247 (84.6%)**	**12,433,998 (97.4%)**
Total land area	**48,957,756 (100.0%)**	**5,309,829 (100.0%)**	**30,879,020 (100.0%)**	**12,768,907 (100.0%)**

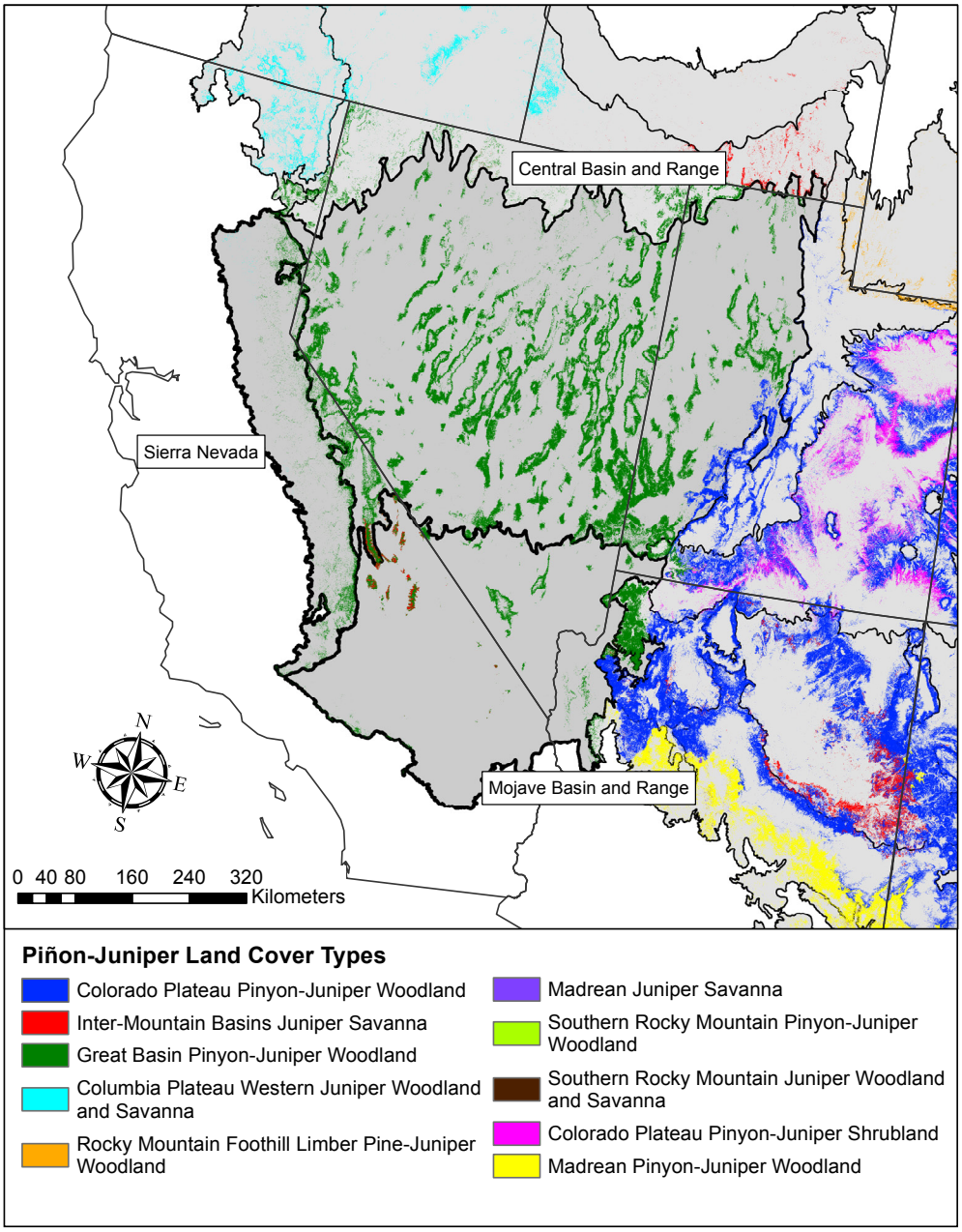

Figure 13—Distribution of the piñon-juniper land cover types across the three ecoregions within the Southern Intermountain geographic region. Piñon and juniper land cover types account for 5.4 million ha or nearly 11.0 percent of the region.

Fire Area

From 1984 through 2013, 4.26 million ha (8.7%) burned in the Southern Intermountain geographic region (table 11). There was no trend in total hectares burned ($\tau = 0.154$, $P = 0.232$) during the 30-year period (table 12, fig. 14). The number of hectares burned in the study area ranged from 13,143 ha in 1991 to 542,905 ha in 2006 with a median of 99,632 ha.

Piñon and juniper vegetation land cover types accounted for 528,738 ha (12.4%) of the total burned area (table 11). Great Basin Piñon-Juniper Woodlands accounted for the largest amount of the piñon and juniper land cover types burned (84.6%).

Table 11—Area (ha) burned by land cover type within the Southern Intermountain geographic region ("All") and within each ecoregion. Values in parentheses are the area burned as a percentage of the total burned area (all land cover types), and as a percentage of the area burned within the specified land cover type, respectively. Burned area data are from 1984 through 2013 for wildfires with high confidence in the MTBS database (MTBS 2016). Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (ha)	Sierra Nevada (ha)	Central Basin and Range (ha)	Mojave Basin and Range (ha)
Piñon-juniper types				
Piñon-juniper woodland types				
Columbia Plateau Western Juniper Woodland and Savanna	1,120 (0.0%, 29.9%)	1,119 (0.2%, 29.9%)	1 (0.0%, 40.5%)	–
Great Basin Piñon-Juniper Woodland	447,417 (10.5%, 8.8%)	58,258 (8.1%, 19.5)	354,717 (12.0%, 71.7%)	34,443 (5.8%, 12.4%)
Colorado Plateau Piñon-Juniper Woodland	77,064 (1.8%, 30.0%)	–	76,886 (2.6%, 31.4%)	178 (0.0%, 1.4%)
All piñon-juniper woodland types	**525,601 (12.3%, 9.9%)**	**59,377 (8.3%, 19.6%)**	**431,603 (14.6%, 9.1%)**	**34,621 (5.9%, 12.0%)**
Juniper savanna types				
Inter-Mountain Basins Juniper Savanna	3,137 (0.1%, 4.9%)	–	2,068 (0.1%, 11.0%)	1,069 (0.2%, 2.4%)
All piñon-juniper types	**528,738 (12.4%, 9.8%)**	**59,377 (8.3%, 19.6%)**	**433,671 (14.7%, 9.1%)**	**35,690 (6.4%, 10.7%)**
All non- piñon juniper types	**3,734,617 (87.6%, 8.6%)**	**656,091 (91.7%, 13.1%)**	**2,523,409 (85.3%, 9.7%)**	**55,117 (94.0%, 2.1%)**
All land cover types	**4,263,036 (100.0%, 8.7%)**	**715,468 (100.0%, 2.3%)**	**2,957,080 (100.0%, 9.6%)**	**590,807 (100.0%, 4.6%)**

Table 12—Annual variation in fire area, number, season, and size in the Southern Intermountain Region for 1984 through 2013. Trends in the variables were tested using Kendal's tau; a positive value indicates an increase over time and a negative value indicates a decrease. Values for area burned are the total for the study area, the total for piñon and juniper land cover types, and percent of the study area burned that was piñon and juniper land cover types. Data are for wildfires with high confidence in the MTBS database (MTBS 2016).

Variable	Minimum	Maximum	Median	Tau	*P*
Area burned					
Total (ha)	13,143 (1991)	542,905 (2006)	99,632	0.154	0.2320
Piñon-juniper (ha)	144 (1991)	38,987 (2012)	7,206	0.136	0.2925
Piñon-juniper (%)	1.1 (1991)	20.2 (2004)	7.5	–0.030	0.8166
Fire number					
Number	9 (1991)	143 (2006)	36	0.127	0.3265
Fire season					
Length	73 (1991)	256 (2012)	135	0.254	0.0579
Start Data	Jan 19 (2012)	Jul 16 (2010)	May 26	0.280	0.0362
End Date	Aug 23 (2013)	Nov 23 (2011)	Oct 2	0.302	0.0243
Fires per week	0.609 (1989)	7.10 (2006)	2.00	0.126	0.2925
Fire size (ha)					
Median	705 (2010)	1,921 (1990)	1,255	–0.076	0.5560
1st Quartile	514 (1992)	985 (1991)	691	–0.094	0.4645
3rd Quartile	1,252 (1991)	9,536 (2013)	2,827	0.251	0.0518
Maximum	2,567 (1991)	229,622 (2007)	18,107	0.306	0.0177

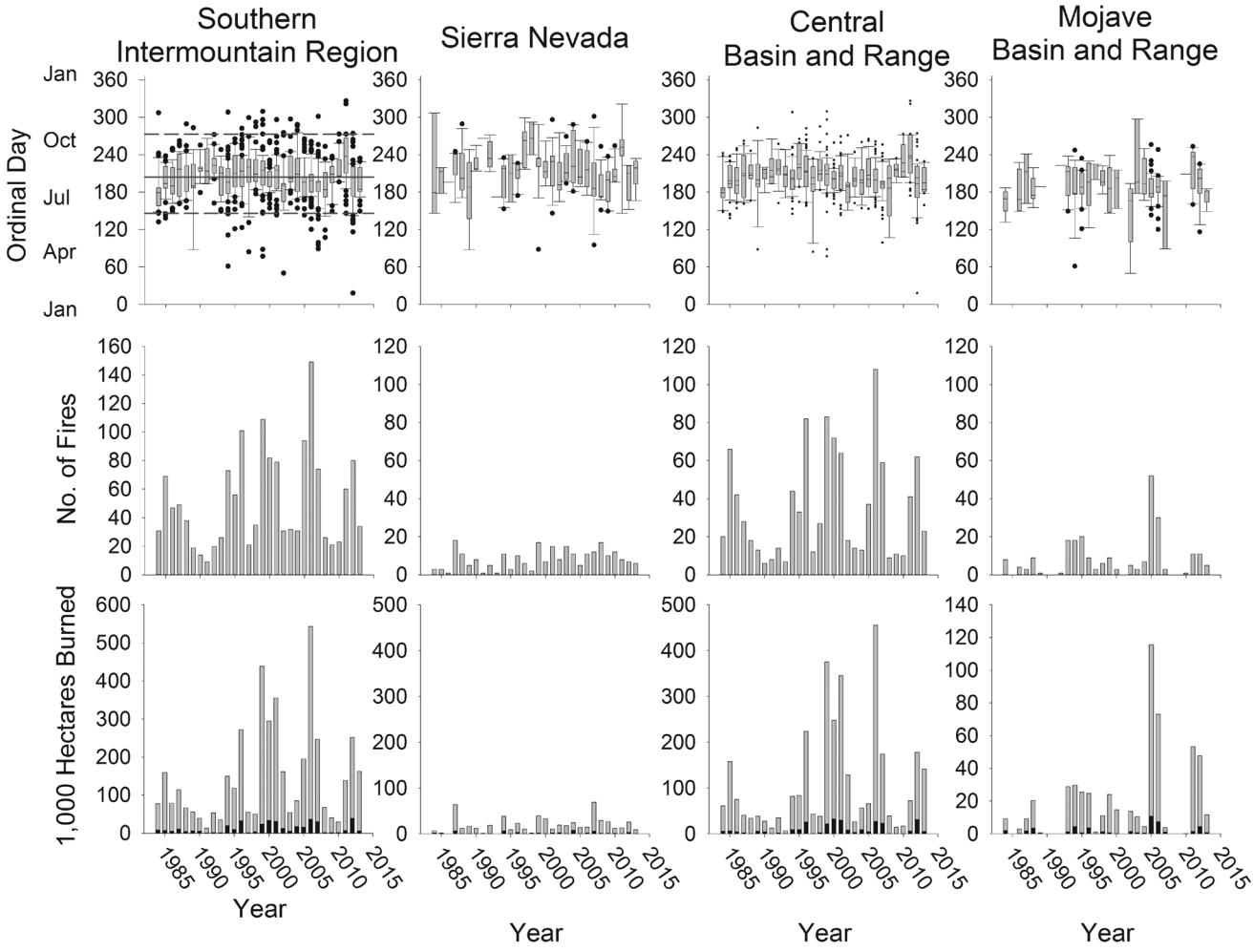

Figure 14—Start day, number of fires, and total area burned in the five ecoregions within the Southern Intermountain Region. The first row shows the fire season based on the ordinal day of ignition with each boxplot representing a single year. The box shows the interquartile range with the median represented by a line within the box. The whiskers are the 10th and 90th percentile with earlier or later fires represented by dots. The dashed lines across the graphs represent the median earliest and latest fires. The solid line represents the median of the annual median fire start. The second row represents the annual number of fires in the study area. The last row shows the total number of hectares burned in gray and the total number of hectares of piñon and juniper land cover types burned annually in black.

The piñon and juniper land cover types showed no trend in total hectares ($\tau = 0.136$, $P = 0.2925$) or percentage of piñon and juniper land cover ($\tau = -0.030$, $P = 0.8166$) burned during the 30-year period (table 12). The area of piñon and juniper land cover types burned ranged from 144 ha in 1991 to 39,987 ha in 2012, while the percentage of piñon and juniper land cover types burned varied from 1.1 percent in 1991 to 20.2 percent in 2004 (table 12, fig. 14).

The three ecoregions were very different in the amount of area burned (table 11, fig. 14, fig. A.2). The Central Basin and Range was the largest ecoregion and had similar percentages burn in the ecoregion overall (9.6%) and the piñon and juniper land cover types (9.1%). In contrast, the Sierra Nevada and Mojave Basin and Range ecoregions had relatively low percentage area burn overall (2.3% and 4.6%, respectively), but high percentage area burn in piñon and juniper land cover types (19.6% and 10.7%, respectively).

Fire Rotation

Fire rotation in piñon and juniper land cover types in the Southern Intermountain geographic region averaged 306 years (table 13). The longest rotation was 1,275 years for the Inter-mountain Basins Juniper Savanna in the Mojave Basin and Range, while the shortest rotation was 42 years for the Great Basin Piñon-Juniper Woodland in the Central Basin and Range ecoregion.

Fire Number

The annual number of fires varied by 16-fold, ranging from 9 to 143 with a median of 36 (table 12, fig. 14). However, there did not appear to be an increase in the number of fires over time ($\tau = 0.127$, $P = 0.3265$).

Fire Season

Length of the fire season did not show a significant increase during the time period ($\tau = 0.254$, $P = 0.0579$) (table 12, fig. 14). The fire season ranged from 73 days in 1991 to 256 days in 2012 with a median of 135 days. The median start date for the season was May 26 and the median end date for the season was October 2. By the end of the study period, the start date was significantly earlier ($\tau = 0.280$, $P = 0.0362$) and the end date was significantly later ($\tau = 0.302$, $P = 0.0243$).

Fire Size

The median fire size ranged from 705 ha in 2010 to 1,921 ha in 1990 and did not show a significant trend (table 12, fig. 14, fig. A.2). Maximum fire size increased during the 30-year period ($\tau = 0.306$, $P = 0.0177$), ranging from 2,567 ha in 1991 to 229,622 ha in 2007.

Table 13—Fire rotation in years for piñon-juniper land cover types in the Southern Intermountain geographic region ("All") and within each ecoregion from 1983 through 2013 and from 1999 through 2013 in parentheses. Data are for wildfires with high confidence in the MTBS database (MTBS 2016). Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (yrs)	Sierra Nevada (yrs)	Central Basin and Range (yrs)	Mojave Basin and Range (yrs)
Piñon-juniper types				
Piñon-juniper woodland types				
Columbia Plateau Western Juniper Woodland and Savanna	100 (54)	100 (54)	–	–
Great Basin Piñon-Juniper Woodland	340 (236)	154 (122)	42 (29)	241 (149)
Colorado Plateau Piñon-Juniper Woodland	100 (83)	–	96 (79)	–
All piñon-juniper woodland types	**304 (216)**	**153 (120)**	**329 (234)**	**251 (155)**
Juniper savanna types				
Inter-Mountain Basins Juniper Savanna	615 (353)	–	274 (156)	1275 (736)
All piñon-juniper types	**306 (217)**	**153 (120)**	**329 (234)**	**282 (174)**

Fire Patterns in the Central Rocky Mountain Geographic Region

The Central Rocky Mountain geographic region spanned 31.5 million ha, about 20 percent of the study area, and included three ecoregions and six piñon and juniper land cover types. (The Southern Rocky Mountain Piñon-Juniper Woodland land cover type only occupied 401 ha and was not presented separately; table 14, fig. 15). Piñon and juniper land cover types occupied 5.3 million ha or 16.7 percent of the region. Colorado Plateau Piñon-Juniper Woodland was the most common piñon and juniper land cover type, occupying 11.3 percent of the region and 87.3 percent of the piñon-juniper types. The piñon and juniper shrubland land cover type was found almost exclusively in the Colorado Plateaus ecoregion of the Central Rocky Mountain geographic region (table 14, fig. 15). The largest amount of piñon and juniper land cover types was in the Colorado Plateaus ecoregion (31.3%) with lesser amounts in the Wasatch and Uinta Mountains and Wyoming Basin ecoregions (12.2% and 3.2%, respectively).

Fire Area

From 1984 through 2013, 725,795 ha or 2.3 percent of Central Rocky Mountain geographic region burned (table 15). There was no detectable increase in annual area burned ($\tau = 0.254$, $P = 0.0579$) (table 16). The area burned annually ranged from 890 ha in 2009 to 178,065 ha in 2012 with a median of 12,574 ha. Most of the area that burned was in the Colorado Plateau Piñon-Juniper Woodlands (101,090 ha) (fig. 16, fig. A.3).

Table 14—Aerial extent of land cover types within the Central Rocky Mountain geographic region ("All") and within each ecoregion followed by the percent of the land cover type in the geographic region and ecoregion(s), respectively, in parentheses. Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (ha)	Wasatch and Uinta Mountains (ha)	Wyoming Basin (ha)	Colorado Plateaus (ha)
Piñon-juniper types				
Piñon-juniper woodland types				
Great Basin Piñon-Juniper Woodland	62,290 (0.2%, 4.3%)	24,154 (0.5%, 2.9%)	–	38,136 (0.3%, 0.9%)
Colorado Plateau Piñon-Juniper Woodland	3,554,286 (11.3%, 87.3%)	488,222 (10.7%, 59.5%)	4,767 (0.0%, 1.1%)	3,061,298 (22.4%, 71.6%)
Rocky Mountain Foothill Limber Pine-Juniper Woodland	454,495 (1.4%, 7.8%)	43,660 (1.0%, 5.3%)	382,565 (2.9%, 91.1%)	28,270 (0.2%, 0.7%)
All piñon-juniper woodland types	**4,071,472 (12.9%, 99.4%)**	**556,036 (12.2%, 67.8%)**	**387,331 (2.9%, 92.2%)**	**3,128,105 (22.9%, 73.2%)**
Juniper savanna types				
Inter-Mountain Basins Juniper Savanna	35,105 (0.1%, 0.3%)	1,453 (0.0%, 0.2%)	26,041 (0.2%, 6.2%)	7,610 (0.1%, 0.2%)
Piñon-juniper shrubland types				
Colorado Plateau Piñon-Juniper Shrubland	1,146,319 (3.6%, 21.8%)	1,837 (0.0%, 0.2%)	6,525 (0.0%, 1.6%)	1,137,956 (8.3%, 26.6%)
All piñon-juniper types	**5,252,895 (16.7%, 100.0%)**	**559,326 (12.2%, 100.0%)**	**419,898 (3.2%, 100.0%)**	**4,273,672 (31.3%, 100.0%)**
All non- piñon-juniper types	**26,241,488 (83.3%)**	**4,009,993 (87.8%)**	**12,847,618 (96.8%)**	**9,383,877 (68.7%)**
Total land area	**31,494,984 (100.0%)**	**4,569,319 (100.0%)**	**13,267,516 (100.0%)**	**13,657,548 (100.0%)**

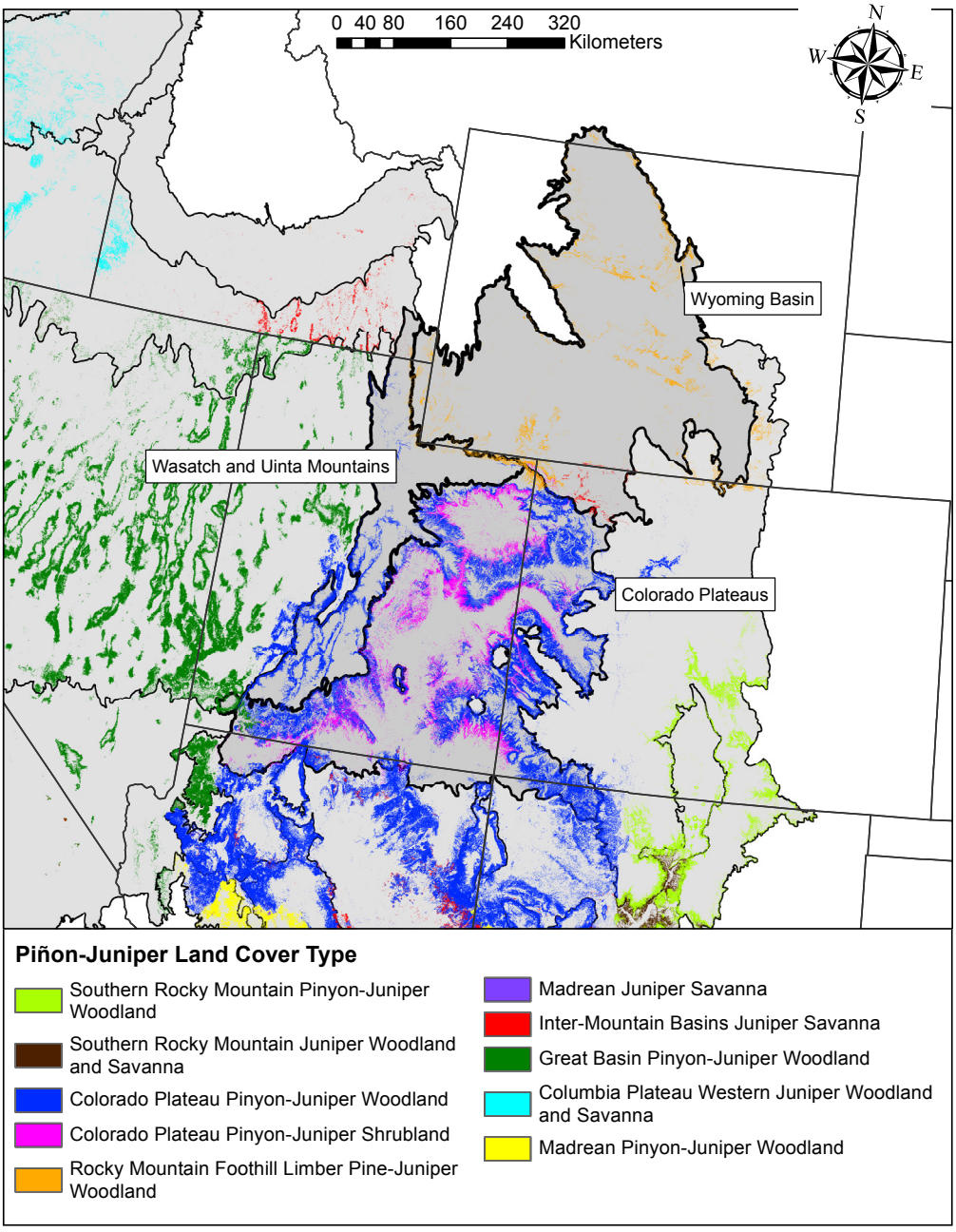

Figure 15—Distribution of the piñon-juniper land cover types across the three ecoregions within the Central Rocky Mountain geographic region. Piñon and juniper land cover types occupy 5.3 million ha or 16.7 percent of the region.

Table 15—Area (ha) burned by land cover type within the Central Rocky Mountain geographic region ("All") and within each ecoregion. Values in parentheses are the area burned as a percentage of the total burned area (all land cover types), and as a percentage of the area burned within the specified land cover type, respectively. Burned area data are from 1984 through 2013 for wildfires with high confidence in the MTBS database (MTBS 2016). Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (ha)	Wasatch and Uinta Mountains (ha)	Wyoming Basin (ha)	Colorado Plateaus (ha)
Piñon-juniper types				
Piñon-juniper woodland types				
Great Basin Piñon-Juniper Woodland	10,772 (1.5%, 17.3%)	6,425 (3.0%, 26.6%)	–	4,347 (2.1%, 11.4%)
Colorado Plateau Piñon-Juniper Woodland	112,695 (15.5%, 3.2%)	28,057 (13.0%, 5.7%)	622 (0.3%, 13.1%)	84,015 (28.8%, 2.7%)
Rocky Mountain Foothill Limber Pine-Juniper Woodland	28,727 (4.0%, 6.3%)	2,290 (1.1%, 5.2%)	21,975 (10.0%, 5.7%)	4,461 (1.5%, 15.8%)
All piñon-juniper woodland types	**152,215 (21.0%, 3.7%)**	**36,773 (17.1%, 6.6%)**	**22,597 (10.3%, 5.8%)**	**92,845 (31.8%, 3.0%)**
Juniper savanna types				
Inter-Mountain Basins Juniper Savanna	23 (0.0%, 0.1%)	5 (0.0%, 0.3%)	18 (0.0%, 0.1%)	0 (0.0%, 0.0%)
Piñon-juniper shrubland types				
Colorado Plateau Piñon-Juniper Shrubland	8,289 (1.1%, 0.7%)	23 (0.0%, 1.2%)	21 (0.0%, 0.3%)	8,245 (2.8%, 0.7%)
All piñon-juniper types	**160,527 (22.1%, 3.1%)**	**36,800 (17.1%, 6.6%)**	**22,636 (10.3%, 5.4%)**	**101,090 (34.6%, 2.4%)**
All non- piñon-juniper types	**565,268 (77.9%, 6.0%)**	**178,204 (82.9%, 4.4%)**	**196,235 (89.7%, 1.5%)**	**190,830 (65.4%, 2.0%)**
All land cover types	**725,795 (100.0%, 2.3%)**	**215,004 (100.0, 4.7%)**	**218,871 (100.0%, 1.6%)**	**291,920 (100.0%, 2.1%)**

Table 16—Annual variation in fire area, number, season, and size in the Central Rocky Mountain geographic region for 1984 through 2013. Trends in the variables were tested using Kendal's tau; a positive value indicates an increase over time and a negative value indicates a decrease. Values for area burned are the total for the study area, the total for piñon and juniper land cover types, and percentage of the study area burned that was piñon and juniper land cover types. Data are for wildfires with high confidence in the MTBS database (MTBS 2016).

Variable	Minimum	Maximum	Median	Tau	*P*
Area burned					
Total (ha)	890 (2011)	178,065 (2012)	12,574	0.254	0.0579
Piñon juniper (ha)	30 (1998)	20,091 (2012)	1,419	0.280	0.0362
Piñon-juniper (%)	0.1 (2010)	27.8 (2004)	10.9	0.302	0.0243
Fire number					
Number	2 (1997)	35 (2000)	10	0.108	0.4275
Fire season					
Length	34 (1990)	162 (1988)	91	0.159	0.2359
Start date	Apr 12 (2013)	Aug 7 (2011)	Jun 17	–0.236	0.0785
End date	Jul 15 (1997)	Oct 25 (2003)	Sept 18	–0.059	0.6635
Fires per week	0.217 (1997)	2.46 (1989)	0.798	0.037	0.7821
Fire size (ha)					
Median	451 (1998)	1,714 (1996)	927	0.032	0.8126
1st Quartile	367 (1998)	833 (2008)	618	0.228	0.0893
3rd Quartile	535 (1998)	4,357 (2012)	1,648	0.249	0.0633
Maximum	535 (1998)	57,112 (2000)	4,297	0.233	0.0821

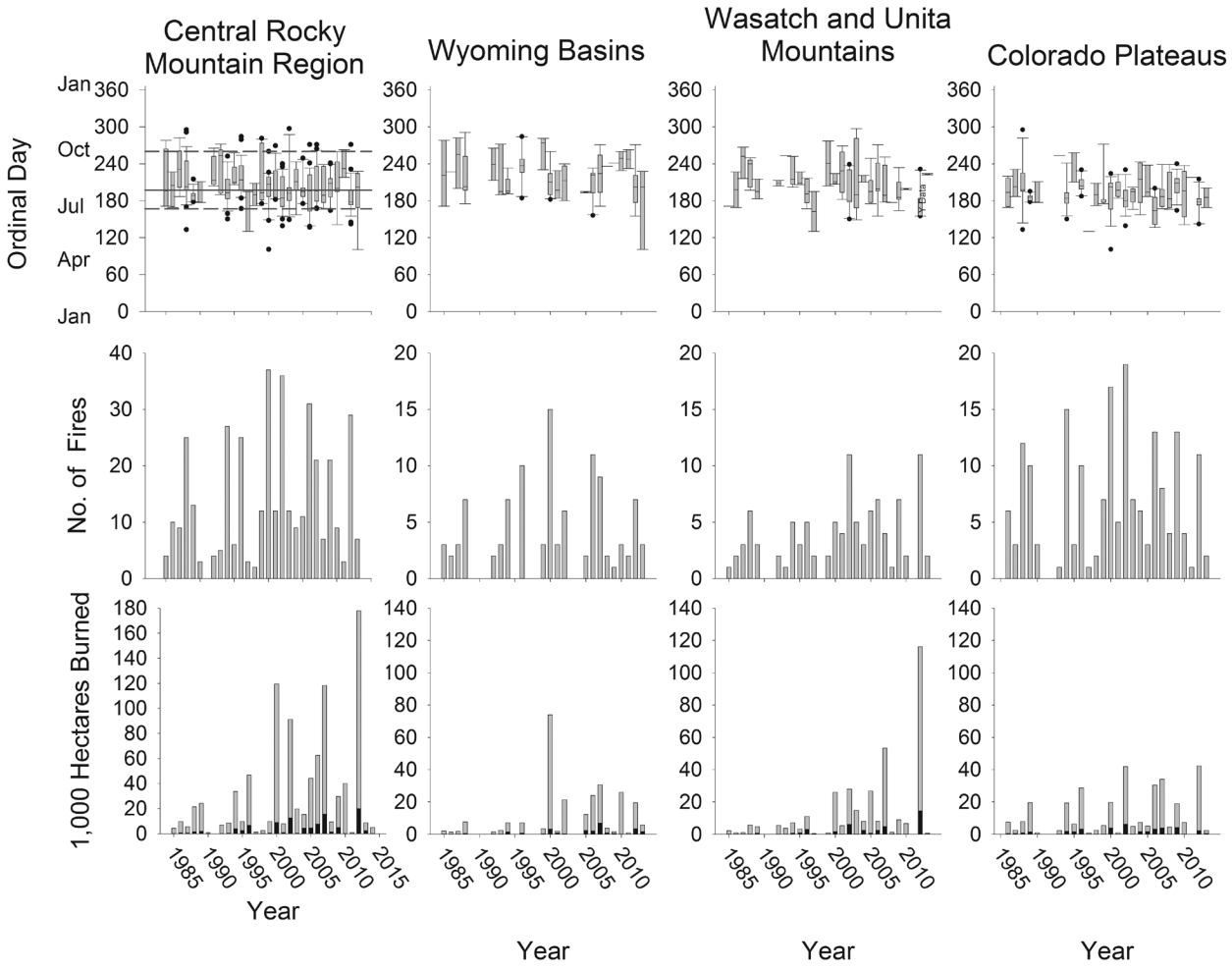

Figure 16—Start day, number of fires, and total area burned in the five ecoregions within the Central Rocky Mountain geographic region. The first row shows the fire season based on the ordinal day of ignition with each boxplot representing a single year. The box shows the interquartile range with the median represented by a line within the box. The whiskers are the 10th and 90th percentile with earlier or later fires represented by dots. The dashed lines across the graphs represent the median earliest and latest fires. The solid line represents the median of the annual median fire start. The second row represents the annual number of fires in the study area. The last row shows the total number of hectares burned in gray and the total number of hectares of piñon and juniper land cover types burned annually in black.

The area burned in piñon and juniper land cover types increased significantly over the 30-year period ($\tau = 0.280$, $P = 0.0362$) ranging from as little as 30 ha in 1998 to 20,091 ha in 2012 (table 16, fig. 16). The percentage of burned area that was piñon and juniper land cover also increased significantly ($\tau = 0.302$, $P = 0.0243$), ranging from 0.1 percent in 2010 to 27.8 percent in 2004.

The number of hectares burned was highly similar among the three ecoregions ranging from 215,004 ha in the Wasatch and Uinta Mountains to 291,920 ha in the Colorado Plateaus (table 15). However, the percentage of the total area that burned in piñon and juniper land cover types varied widely among ecoregions. The Colorado Plateaus had the largest percentage of piñon and juniper land cover types burn in the region (34.6%) followed by the Wasatch and Uinta Mountains (17.1%) and Wyoming Basin (10.3%).

Fire Rotation

Piñon and juniper land cover types had a fire rotation of 982 years in the Central Rocky Mountain geographic region (table 17). The longest rotation was 4,140 years for the Colorado Plateau Piñon-Juniper Shrubland in the Colorado Plateaus, while the shortest rotation was 113 years for the Great Basin Piñon-Juniper Woodland in the Wasatch and Uinta Mountains.

Fire Number

The median number of fires per year for the region was 10 (table 16), and the number of fires per year varied from 2 in 1997 to 35 in 2000 (table 16, fig. 16). The number of fires did not increase over time ($\tau = 0.108$, $P = 0.4275$).

Fire Season

The median fire season was 91 days and ranged from 34 days in 1990 to 162 days in 1988. The length of the fire season did not change over time ($\tau = 0.159$, $P = 0.2359$) (table 16, fig. 16). The median start date for the fire season was June 17 and the earliest start to the fire season was April 12, 2013. The median end date for the fire season was September 18 and the latest end to the season was October 25, 2003. There was no significant change in the start date ($\tau = –0.236$, $P = 0.0785$) or end date ($\tau = –0.059$, $P = 0.6635$) of the fire season.

Fire Size

The median size of fires was 927 ha and varied annually from 451 ha in 1998 to 1,714 ha in 1996 (table 16, fig. 16). There was no significant change in fire size over time for any quantile.

Table 17—Fire rotation in years for piñon-juniper land cover types in the Central Rocky Mountain geographic region ("All") and within each ecoregion from 1984 through 2013 and from 1999 through 2013 in parentheses. Data are for wildfires with high confidence in the MTBS database (MTBS 2016). Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (yrs)	Wasatch and Uinta Mountains (yrs)	Wyoming Basin (yrs)	Colorado Plateaus (yrs)
Piñon-juniper types				
Piñon-juniper woodland types				
Great Basin Piñon-Juniper Woodland	173 (91)	113 (61)	–	263 (132)
Colorado Plateau Piñon-Juniper Woodland	946 (560)	522 (308)	230 (143)	1,093 (647)
Rocky Mountain Foothill Limber Pine-Juniper Woodland	475 (267)	572 (413)	522 (287)	190 (106)
All piñon-juniper woodland types	**802 (466)**	**454 (267)**	**514 (284)**	**1011 (592)**
Juniper savanna types				
Inter-Mountain Basins Juniper Savanna	–	–	–	–
Piñon-juniper shrubland types				
Colorado Plateau Piñon-Juniper Shrubland	4,149 (3,344)	–	–	4,140 (3,348)
All piñon-juniper types	**982 (578)**	**456 (268)**	**556 (307)**	**1268 (760)**

Fire Patterns in the Southern Rocky Mountain Geographic Region

The Southern Rocky Mountain geographic region occupied 44.3 million ha and included four ecoregions and nine piñon and juniper land cover types (table 18, fig. 17). This geographic region had the largest cover of piñon and juniper land cover types of any region accounting for 10.2 million ha or 23.1 percent of the region. Although piñon and juniper woodlands were the dominant piñon and juniper land cover types, occupying 21.2 percent of the region and 91.8 percent of the types, juniper savanna was more abundant in the Southern Rocky Mountain geographic region than any other region, occupying 1.9 percent of the region and 8.1 percent of the piñon and juniper types. Each ecoregion had a unique composition of piñon and juniper land cover types. The most common piñon and juniper land cover type was the Colorado Plateau Piñon and Juniper Woodland, which accounted for 57.5 percent of the piñon and juniper land cover types. The Arizona/New Mexico

Table 18—Aerial extent of land cover types within the Southern Rocky Mountain geographic region ("All") and within each ecoregion followed by percent of the land cover type in the geographic region and ecoregion(s), respectively, in parentheses. Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (ha)	Southern Rockies (ha)	Arizona/New Mexico Plateaus (ha)	Arizona/New Mexico Mountains (ha)	Madrean Archipelago (ha)
Piñon-juniper types					
Piñon-juniper woodland types					
Great Basin Piñon-Juniper Woodland	290,256 (0.7%, 2.8%)	-	274,309 (1.9%, 6.2%)	15,948 (0.1%, 0.4%)	-
Colorado Plateau Piñon-Juniper Woodland	5,871,900 (13.3%, 57.5%)	334,526 (2.3%, 29.3%)	3,249,895 (22.1%, 73.2%)	2,287,480 (20.6%, 52.7%)	-
Rocky Mountain Foothill Limber Pine-Juniper Woodland	78,119 (0.2%, 0.8%)	78,199 (0.5%, 6.9%)	-	-	-
Southern Rocky Mountain Piñon-Juniper Woodland	1,123,505 (2.5%, 11.0%)	700,874 (4.8%, 61.5%)	225,997 (1.5%, 5.1%)	196,453 (1.8%, 4.5%)	181 (0.0%, 0.1%)
Madrean Piñon-Juniper Woodland	2,020,237 (4.6%, 19.8%)	1,009 (0.0%, 0.1%)	34,387 (0.2%, 0.8%)	1,707,134 (15.4%, 39.3%)	277,706 (7.0%, 94.8%)
All Piñon-juniper woodland types	**9,384,017 (21.2%, 91.8%)**	**1,114,528 (7.6%, 97.8%)**	**3,784,587 (25.8%, 85.2%)**	**4,207,015 (37.9%, 96.9%)**	**277,887 (7.0%, 94.9%)**
Juniper savanna types					
Inter-Mountain Basins Juniper Savanna	525,152 (1.2%, 5.1%)	2,385 (0.0%, 0.2%)	481,492 (3.3%, 10.8%)	41,275 (0.4%, 1.0%)	-
Southern Rocky Mountain Juniper Woodland and Savanna	233,657 (0.5%, 2.3%)	22,995 (0.2%, 2.0%)	166,777 (1.1%, 3.8%)	43,885 (0.4%, 1.0%)	-
Madrean Juniper Savanna	67,511 (0.2%, 0.7%)	31 (0.0%, 0.0%)	2,353 (0.0%, 0.1%)	50,073 (0.5%, 1.2%)	15,054 (0.4%, 5.1%)
All juniper savanna types	**826,320 (1.9%, 8.1%)**	**25,411 (0.2%, 2.2%)**	**650,622 (4.4%, 14.6%)**	**135,233 (1.2%, 3.1%)**	**15,054 (0.4%, 5.1%)**
Piñon-juniper shrubland types					
Colorado Plateau Piñon-Juniper Shrubland	7,182 (0.0%, 0.1%)	116 (0.0%, 0.0%)	7,035 (0.0%, 0.2%)	30 (0.0%, 0.0%)	-
All piñon-juniper types	**10,217,518 (23.1%, 100.0%)**	**1,140,055 (7.8%, 100.0%)**	**4,442,244 (30.2%, 100.0%)**	**4,342,278 (39.2%, 55.6%)**	**292,941 (7.4%, 100.0%)**
All non- piñon-juniper types	**34,093,805 (76.9%)**	**13,429,662 (92.2%)**	**10,243,706 (69.8%)**	**6,748,498 (608%)**	3,671,939 (92.6%)
Total land area	**44,311,324 (100.0%)**	**14,569,718 (100.0%)**	**14,685,950 (100.0%)**	**11,090,776 (100.0%)**	**3,964,880 (100.0%)**

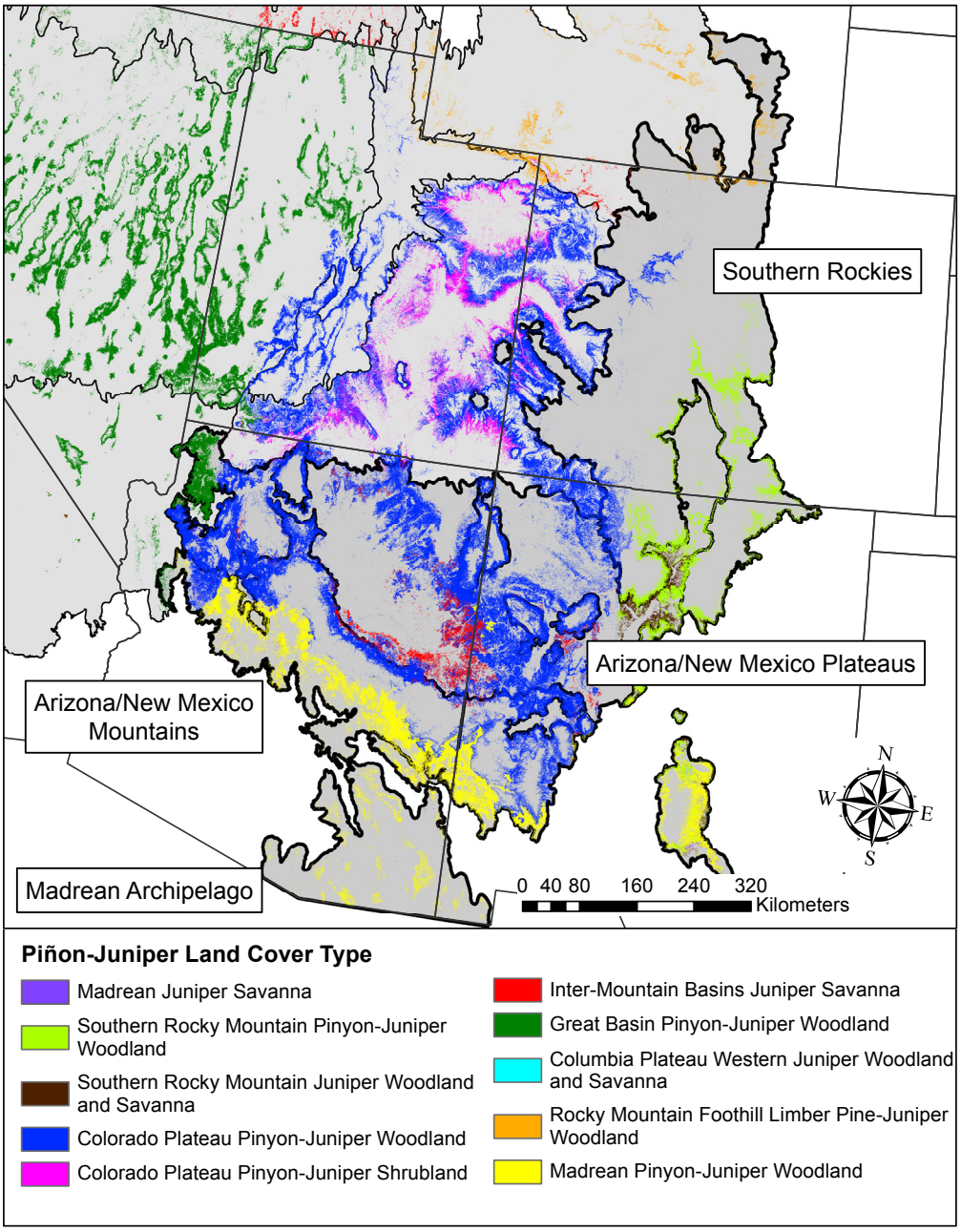

Figure 17—Distribution of the piñon-juniper land cover types across the four ecoregions within the Southern Rocky Mountain region. This geographic region has the largest cover of piñon and juniper land cover types of any region, accounting for 10.2 million ha or 23.1 percent of the region.

Plateaus and Arizona/New Mexico Mountains ecoregions had the largest amount of piñon and juniper land cover types with 4.4 million ha (30.2%) and 4.3 million ha (39.2%), respectively.

Fire Area

The Southern Rocky Mountain geographic region had 2.8 million ha or 6.3 percent of the total area burn between 1984 and 2013 (table 19). There was a significant increase in the annual area burned from 1984 through 2013 ($\tau = 0.5035$, $P < 0.0001$) (table 20). The median annual area burned was 67,786 ha and ranged from 2,530 ha in 1984 to 231,888 ha in 2002 (table 20, fig. 18).

Table 19— Area (ha) burned by land cover type within the Southern Rocky Mountain geographic region ("All") and within each ecoregic Values in parentheses are the area burned as a percentage of the total burned area (all land cover types), and as a percentage of the area burned within the specified land cover type, respectively. Burned area data are from 1984 through 2013 for wildfires with high confidence in the MTBS database (MTBS 2016). Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (ha)	Southern Rockies (ha)	Arizona/New Mexico Plateaus (ha)	Arizona/New Mexico Mountains (ha)	Madrean Archipelago (ha)
Piñon-juniper					
Piñon-juniper woodland types					
Great Basin Piñon-Juniper Woodland	42,396 (1.5%, 14.6%)	–	41,558 (34.3%, 15.2%)	838 (0.1%, 5.3%)	–
Colorado Plateau Piñon-Juniper Woodland	115,470 (4.1%, 2.0%)	3,138 (0.5%, 0.9%)	13,928 (11.5%, 0.4%)	98,404 (6.3%, 4.3%)	–
Rocky Mountain Foothill Limber Pine-Juniper Woodland	5,067 (0.2%, 6.5%)	5,067 (0.9%, 6.5%)	–	–	–
Southern Rocky Mountain Piñon-Juniper Woodland	28,820 (1.0%, 2.6%)	22,235 (3.8%, 3.2%)	59 (0.0%, 0.0%)	6,493 (0.4%, 3.3%)	33 (0.0%, 18.2%)
Madrean Piñon-Juniper Woodland	230,361 8.2%, 11.4%)	28 (0.0%, 2.8%)	20 (0.0%, 0.1%)	151,146 (9.7%, 8.9%)	79,167 (14.8%, 28.5%)
All piñon-juniper woodland types	**422,114 (15.1%, 4.5%)**	**30,468 (5.1%, 2.7%)**	**55,565 (45.8%, 1.5%)**	**256,882 (16.5%, 6.1%)**	**79,200 (14.8%, 28.5%)**
Juniper savanna types					
Inter-Mountain Basins Juniper Savanna	3,640 (0.1%, 0.7%)	0 (0.0%, 0.0%)	2,815 (2.3%, 0.6%)	826 (0.1%, 2.0%)	–
Southern Rocky Mountain Juniper Woodland and Savanna	1,999 (0.1%, 0.9%)	359 (0.1%, 1.6%)	101 (0.1%, 0.1%)	1,539 (0.1%, 3.5%)	–
Madrean Juniper Savanna	8,804 (0.3%, 13.0%)	2 (0.0%, 7.5%)	0 (0.0%, 0.0%)	6,542 (0.4%, 13.1%)	2,259 (0.4%, 15.0%)
All juniper savanna types	**14,443 (0.5%, 1.7%)**	**361 (0.1%, 1.4%)**	**2,916 (2.4%, 0.4%)**	**8,907 (0.6%, 6.6%)**	**861 (0.2%, 5.7%)**
Piñon-juniper shrubland types	**162 (0.0%, 2.3%)**	**6 (0.0%, 5.4%)**	**156 (0.1%, 2.2%)**	**0 (0.0%, 0.0%)**	–
Colorado Plateau Piñon-Juniper Shrubland	162 (0.0%, 2.3%)	6 (0.0%, 5.4%)	156 (0.1%, 2.2%)	0 (0.0%, 0.0%)	–
All piñon-juniper types	**436,719 (15.6%, 4.3%)**	**30,835 (5.2%, 2.7%)**	**58,637 (48.3%, 1.3%)**	**265,788 (17.1%, 6.1%)**	**81,459 (15.2%, 27.8%)**
All non- piñon-juniper types	**2,365,621 (84.4%, 6.9%)**	**561,378 (94.8%, 4.2%)**	**62,677 (51.7%, 0.6%)**	**1,288,078 (82.9%, 19.1%)**	**453,487 (84.8%)**
All land cover types	**2,802,340 (100.0%, 6.3%)**	**592,213 (100.0%, 4.1%)**	**121,314 100.0%, 0.8%)**	**1,553,867 (100.0%, 14.0%)**	**534,946 (100.0%, 13.5%)**

Table 20—Annual variation in fire area, number, season, and size in the Southern Rocky Mountain geographic region for 1984 through 2013. Trends in the variables were tested using Kendal's tau; a positive value indicates an increase over time and a negative value indicates a decrease. Values for area burned are the total for the study area, the total for piñon and juniper land cover types, and percent of the study area burned that was piñon and juniper land cover types. Data are for wildfires with high confidence in the MTBS database (MTBS 2016).

Variable	Minimum	Maximum	Median	Tau	*P*
Area burned					
Total (ha)	2,530 (1984)	231,888 (2002)	67,786	0.5035	<0.0001
Piñon-juniper (ha)	46 (1992)	44,663 (2011)	10,405	0.5310	<0.0001
Piñon-juniper (%)	0.5 (1992)	30.7 (1998)	13.6	0.2184	0.0901
Fire number					
Number	3 (1984)	79 (2011)	30	0.3210	0.0131
Fire season					
Length	23 (1992)	343 (2006)	188	0.2748	0.0336
Start date	Jan 7 (2006)	Jun 3 (1992)	Mar 22	–0.1686	0.1925
End date	Jun 26 (1992)	Dec 15 (2006)	Sept 26	0.5191	0.0742
Fires per week	0.385 (1986)	2.223 (2002)	1.13	0.2184	0.0901
Fire size (ha)					
Median	509 (1984)	2,363 (2013)	1,230	0.5172	<0.0001
1st Quartile	328 (1984)	898 (2012)	681	0.2920	0.0235
3rd Quartile	744 (1984)	5,804 (2002)	2,315	0.5402	<0.0001
Maximum	744 (1984)	228,106 (2011)	10,412	0.4299	0.0008

Piñon and juniper land cover types accounted for 436,719 ha or 15.6 percent of the area burned (table 19). The median area of piñon and juniper land cover types burned annually was 10,405 ha and varied from only 46 ha in 1992 to 44,663 ha in 2011 (table 20, fig. 18). The area of piñon and juniper types that burned increased over time ($\tau = 0.5310$, $P < 0.0001$), but the percentage of the area burned that was piñon and juniper types did not change ($\tau = 0.2184$, $P = 0.0901$). Madrean Piñon-Juniper Woodlands were the most commonly burned type with 230,361 ha.

The total area burned in each ecoregion was very different in the Southern Rocky Mountain geographic region (table 19, fig. 18, fig. A.4). The Arizona/New Mexico Mountains had the largest area burned (1.5 million ha) and greatest percentage of the ecoregion burned (14.0%). This contrasted sharply with the Arizona/New Mexico Plateaus, where only 121,000 ha (0.8%) burned. The Madrean Archipelago ecoregion had the highest proportion of piñon and juniper land cover burn (27.8%).

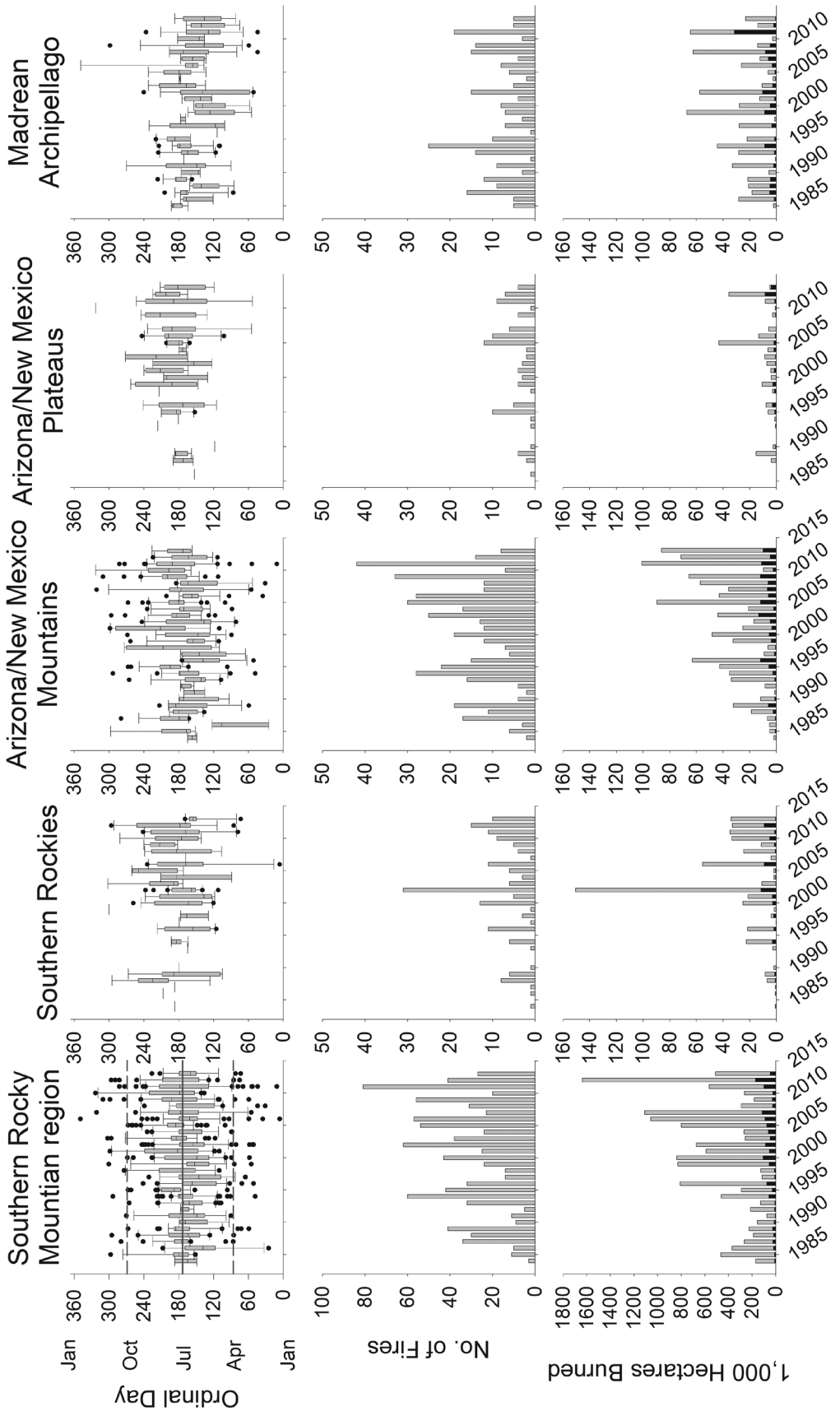

Figure 18—Start day, number of fires, and total area burned in the four ecoregions within the Southern Rocky Mountain geographic region. The first row shows the fire season based on the ordinal day of ignition with each boxplot representing a single year. The box shows the interquartile range with the median represented by a line within the box. The whiskers are the 10th and 90th percentile with earlier or later fires represented by dots. The dashed lines across the graphs represent the median earliest and latest fires. The solid line represents the median of the annual median fire start. The second row represents the annual number of fires in the study area. The last row shows the total number of hectares burned in gray and the total number of hectares of piñon and juniper land cover types burned annually in black.

Fire Rotation

Fire rotation was highly variable in the Southern Rocky Mountain geographic region (table 21). Rotations ranged from 105 years for Madrean Piñon-Juniper Woodland in the Madrean Archipelago to 7,000 years for the Colorado Plateau Piñon Juniper Woodland in the Arizona/Mew Mexico Plateaus. Fire rotation for all piñon and juniper land cover types in the region was 702 years.

Fire Number

The median number of fires for the region was 30, and varied from 3 fires in 1984 to 79 fires in 2011 (table 20, fig. 18). The number of fires increased significantly over the 30-year period ($\tau = 0.3210$, $P = 0.0131$).

Table 21—Fire rotation in years for piñon-juniper land cover types in the Southern Rocky Mountain geographic region ("All") and within each ecoregion from 1984 through 2013 and from 1999 through 2013 in parentheses. Data are for wildfires with high confidence in the MTBS database (MTBS 2016). Dashes reflect areas where piñon-juniper land cover type did not occur.

Land cover type	All (yrs)	Southern Rockies (yrs)	Arizona/New Mexico Plateaus (yrs)	Arizona/New Mexico Mountains (yrs)	Madrean Archipelago (yrs)
Piñon-juniper types					
Piñon-juniper woodland types					
Great Basin Piñon-Juniper Woodland	205 (117)	–	198 (112)	571 (395)	–
Colorado Plateau Piñon-Juniper Woodland	1526 (958)	3198 (1372)	7000 (5863)	697 (423)	–
Rocky Mountain Foothill Limber Pine-Juniper Woodland	463 (251)	463 (251)			
Southern Rocky Mountain Piñon-Juniper Woodland	1170 (687)	946 (544)	–	908 (573)	–
Madrean Piñon-Juniper Woodland	263 (160)	–	–	–	–
All piñon-juniper woodland types	**667 (404)**	**1097 (630)**	**2043 (1260)**	**491 (286)**	**105 (74)**
Juniper savanna types					
Inter-Mountain Basins Juniper Savanna	4328 (3917)	–	–	1500 (769)	–
Southern Rocky Mountain Juniper Woodland and Savanna	3507 (2297)	1922 (1134)	–	856 (573)	–
Madrean Juniper Savanna	230 (162)	–	–	230 (139)	200 (278)
All juniper savanna types	**1716 (1269)**	**2110 (1251)**	–	**456 (275)**	**200 (278)**
Piñon-juniper shrubland types	–	–	–	–	–
Colorado Plateau Piñon-Juniper Shrubland	–	–	–	–	–
All piñon-juniper types	**702 (428)**	**1109 (637)**	**2273 (1434)**	**490 (286)**	**108 (77)**

Fire Season

The Southern Rocky Mountain geographic region was the only region in which the length of the fire season increased significantly ($\tau = 0.2748$, $P = 0.0336$; table 20). The median length of the fire season was 188 days and ranged from 23 days in 1992 to 343 in 2006 (table 20, fig. 18). The fire season typically started on March 22 and ran until September 26. The earliest start date was January 7, 2006, and the latest end date was December 15, 2006, (which was a fire season length of almost the entire year).

Fire Size

The median fire size was 1,230 ha and ranged from 509 ha in 1984 to 2,363 ha in 2013. The Southern Rocky Mountain geographic region was the only region in which fire size increased across all fire sizes for the 30-year period (table 20, fig. 18).

Discussion

Regional Patterns

Fire characteristics across the study area and piñon and juniper land cover types differed among the geographic regions. Area burned during the 30-year period and on an annual basis, number of fires each year, and median or larger fire size all followed a strong geographic pattern: Northern Intermountain > Southern Intermountain > Southern Rocky Mountain > Central Rocky Mountain. These differences in fire patterns can be attributed to the influence of climate, vegetation composition and structure, and patterns of invasion by exotic grasses on fire regimes.

In the Southern Intermountain and especially the Northern Intermountain geographic regions, most precipitation arrives as winter snow and rain, while in the Central Rocky Mountain and especially the Southern Rocky Mountain geographic regions, as much as 30 to 60 percent of the annual precipitation arrives during the summer months of July, August, and September (fig. 6). Although topography strongly influences temperatures across the study area, there is a north-south gradient of increasing ambient temperature that is becoming more pronounced with climate warming (Kunkel et al. 2013 b,c) (fig. 5). These differences in summer precipitation and temperature correspond with differences in both fire season and length in the geographic regions (table 5, fig. 7).

The Southern Rocky Mountain geographic region has the longest fire season (188 days), but most fires occur in relatively warm and dry portions of the region and burn early in the season (May and June) before the onset of the summer monsoons. In contrast, the Northern Intermountain geographic region has an intermediate fire season length (125 days), but most fires burn in July and August when surface fuel moisture is low and there can be abundant lightning with little to no precipitation and high summer temperatures. The Southern Intermountain geographic region also has an intermediate fire season (135 days) but summer precipitation is higher in the southern portion of the region. The Central Rocky Mountain geographic region has the shortest fire season (91 days) and is generally cool with an intermediate to high amount of summer precipitation.

The differences in climate among the geographic regions influence plant functional type dominance (Lauenroth et al. 2014; Sala et al. 1997) and fire characteristics (Brown et al. 1982; Romme et al. 2009). The amount of precipitation received during the period when temperature, and thus potential evapotranspiration are low, influences the amount of water stored in deep soil layers, which in turn affects the balance between woody and herbaceous species (Lauenroth et al. 2014; Sala et al. 1997). Areas that receive more winter and spring precipitation typically have more deep soil water storage and greater relative abundance of woody species, such as sagebrush, which are more effective at using deep soil water. In contrast, areas that receive predominantly summer precipitation typically have higher relative abundance of grasses. These differences in relative proportion of shrubs and grasses influence fire characteristics in the different regions (Brown 1982; Romme et al. 2009). In areas where grasses dominate, as in large areas of the Central and Southern Rocky Mountain geographic regions, fire spread is usually moderate. In areas where shrubs are dominant or codominant, such as in the Northern and Southern Intermountain geographic regions, fire intensities are typically moderate to high, and extreme fire weather can result in extensive spread. These differences in plant functional groups also influence fire characteristics in piñon and juniper vegetation (fig. 1; Romme et al. 2009). However, as tree densities increase and surface fuels become limited, fires tend to be high severity and stand replacing and occur during periods of extreme fire weather when fire can spread through these types of fuels (Bates et al. 2014; Blackburn and Bruner 1975; McCulloch 1969; Schroeder 1966; Romme et al. 2009).

Ecosystem resistance to many invasive annual *Bromus* species, such as *Bromus tectorum* (cheatgrass), and the tendency for invasive annual grass/fire cycles to develop is also influenced by climate (Brooks et al. 2016, Chambers et al. 2016). In general, resistance to invasive annual grasses increases as summer precipitation and/or amount of precipitation increase due to higher perennial grass dominance and increased competition for resources (Bradford and Lauenroth 2006; Bradley 2009; Chambers et al. 2016). Resistance to many invasive annual grasses, such as *B. tectorum*, also increases as soil temperature decreases along elevation gradients (Chambers et al. 2007, 2014a, 2016).

Annual grass/fire cycles are currently most problematic in piñon and juniper land cover types on warmer and drier soils in the western regions. They are also likely contributing to the large fire areas in the Northern Intermountain geographic region and northern portion of the Southern Intermountain geographic region, which receive little summer precipitation (fig. 7; Balch et al. 2013; Brooks et al. 2015; Downs et al. 2016). Cheatgrass and other invasive annuals now dominate at least 6 percent (650,000 km2) of the central Great Basin (Balch et al. 2013). Invasive annual grasses increase the amount and continuity of fine fuels resulting in shorter fire return intervals and larger, more contiguous fires (Brooks et al. 2004, 2016; Pyke et al. 2016). In the central Great Basin, cheatgrass dominated lands have burned almost four times more frequently than any other vegetation type and are disproportionately represented in the largest fires (Balch et al. 2013).

In the Central and Southern Rocky Mountain geographic regions invasive annual grasses are a rapidly emerging problem (Baker 2011; Brooks et al. 2015; Mealor et al. 2012). In these regions as elsewhere, resistance to invasive annual grasses is reduced by anthropogenic disturbances that remove perennial native grass cover, especially where total precipitation and productivity are low (Bradford and

Lauenroth 2006; Chambers et al. 2014a; Knight et al. 2014; Lauenroth et al. 2014). Invasive annual grasses are increasing with wildfire in both the Wyoming Basin (Knight et al. 2014) and eastern portion of the Colorado Plateau (Floyd et al. 2004; Shinneman and Baker 2009b).

Changes in Fire Regimes in Piñon and Juniper Land Cover Types

Various studies have found increasing trends in total area burned, fire size, or fire severity across the western United States (Dennison et al. 2014; Dillon et al. 2011; Miller and Safford 2012; Miller et al. 2012). We found that the total area of piñon and juniper land cover types that burned increased significantly from 1984 through 2013 for the study area overall and for each geographic region, except the Southern Intermountain Mountain region. We found the same result for the percentage of the study area and each geographic region comprised of piñon and juniper land cover types that burned. Also, fire number increased for the Southern Rocky Mountain geographic region and fire size increased for both the Southern Rocky Mountain and Southern Intermountain geographic regions. These results are consistent with Dennison et al. (2014) who found that increases in fire size for the western United States were most significant for southern and mountainous ecoregions, and that the Arizona-New Mexico Mountains ecoregion exhibited significant positive trends in number of fires.

Fire rotations for 1984 through 2013 varied greatly among regions for piñon and juniper land cover types and were generally less in the Northern Intermountain geographic region (223 yrs) and Southern Intermountain geographic region (306 yrs) than in the Central Rocky Mountain (982 yrs) and Southern Rocky Mountain geographic region (702 yrs). Fire rotations decreased by about 35 percent in piñon and juniper land cover types overall when 1999 through 2013 was compared to the 30-year period. This decrease was generally reflective of all types except Madrean Juniper Savanna, which showed little change.

Our fire rotations for the Northern and Southern Intermountain geographic regions fell within ranges of historical fire rotations derived from historical General Land Office Survey (GLO) notes for Inter-Mountain Basins Big Sagebrush Shrubland and Steppe (based on Regional GAP Analysis Project data; Re-GAP) in Oregon (173–345), Idaho (131–262), and Nevada (251–502) (Bukowski and Baker 2013). For the Central Rocky Mountain geographic region, our fire rotations were somewhat longer than reported from GLO data for Inter-Mountain Basins Montane Sagebrush Steppe in Wyoming (535–930 years; Bukowski and Baker 2013) and for specific areas such as the Uncompahgre Plateau (400–600+) (Shinneman and Baker 2009a) and Mesa Verde (400+) (Floyd et al. 2004, 2008). Little data on fire rotations appear to be available for the Southern Rocky Mountain geographic regions, but our values were greater than those reported for *P. edulis*, *J. osteosperma*, and *J. scopulorum* woodland-ponderosa pine (*Pinus ponderosa* P. & C. Lawson) forest ecotones in Arizona (Tusayan–340 years) and in New Mexico (Canjilon–290 years) (Huffman et al. 2008). However, a comparison of tree-ring and charcoal-based fire histories covering the past 7,000 years showed an unprecedented lack of fire in the Arizona/New Mexico Mountains ecoregion during the most recent century that was attributed to livestock grazing and fire suppression (Allen et al. 2008; Savage and Swetnam 1990). Limited fire rotation data from other studies make comparisons difficult, and estimates of the fire rotations for the two Rocky Mountain geographic

regions were likely affected by a small number of fires and a relatively short time frame for comparison.

Several interacting factors are likely contributing to greater total area burned and reduced fire rotations for piñon and juniper land cover types over the 30-year period. Elevated levels of carbon dioxide have been shown to result in increased biomass of both woody species and invasive annual grasses during favorable periods for growth (Nowak et al. 2004; Polley et al. 2011) and thus higher fuel loads over large areas (Allen et al. 2015). Also, fire frequency is increasing due to human-caused fires that start in proximity to human settlements and road corridors (Narayanaraj and Wimberly, 2011, 2012; Syphard et al. 2007). However, invasive annual grasses and climate change are likely major contributors to changing fire regimes in semi-arid piñon and juniper land cover types.

Invasive annual grasses are likely influencing the increase in total and percentage area burned of piñon and juniper land cover types over time in the Northern Intermountain and Central Rocky Mountain geographic regions. In warmer and drier areas with piñon and juniper vegetation, cheatgrass is often a component of the understory that can increase significantly following wildfire (Condon et al. 2011), prescribed fire, or other management treatments if perennial native grasses and forbs have been depleted (Chambers et al. 2014b; Roundy et al. 2014; Urza et al. 2017).

In the Central Great Basin (Snake River Plain and Northern Basin and Range) fires that burn across multiple vegetation types are significantly more likely to have started in cheatgrass dominated vegetation (Balch et al. 2013). In the Colorado Plateaus, it has been suggested that shorter fire rotations caused by interactions with cheatgrass and other fire prone invasives are leading to a net decline of piñon and juniper land cover compared to their historical extent (Arendt and Baker 2013). For example, in southwestern Colorado in Mesa Verde National Park, a greater proportion of the piñon-juniper woodland burned in the decade between 1995 and 2005 than had burned throughout the previous 200 years (Floyd et al. 2004). Those stands that had sparse understories prior to burning are now dominated largely by cheatgrass and other annual invaders (Floyd et al. 2004).

Increases in large wildfire activity including higher large-wildfire frequency, total burned area, longer wildfire durations, and longer wildfire seasons have been associated with increased spring and summer temperatures and earlier spring snowmelt due to climate change (Dennison et al. 2014; Westerling et al. 2006, 2014). Projected changes in precipitation due to climate change can have very different implications than changes in temperature in terms of the characteristics and spatial location of wildfire regime responses. Fuel availability effects are most important in arid, sparsely vegetated ecosystems, while flammability effects are most important in moist, densely vegetated ecosystems (Abatzoglou and Kolden 2013; Littell et al. 2009; Westerling et al. 2014). In general cooler, moister areas with forested vegetation types have greater biomass, and wildfires tend to occur in dry years. Warmer and drier areas with grassland and shrubland vegetation types often have less biomass and wildfires tend to occur after one or more years with above-normal precipitation (Crimmins and Comrie 2004; Littell et al. 2009; Westerling et al. 2014). In these warmer and drier areas, long-term drought (>4 months) is not necessarily a prerequisite for extensive area burned, and seasonal climate can override the effect of antecedent climate (Abatzoglou and Kolden 2013). Piñon and juniper vegetation occurs over a range of precipitation and temperature regimes, is associated with a

wide variety of vegetation types, and differs in amount of biomass both spatially and temporally.

There is general agreement that elevated temperatures and historical and current droughts have contributed to the recent increase in fire activity in the Southwest United States (Dennison et al. 2014; Westerling et al. 2014). We found that in the Southern Rocky Mountain geographic region the fire season was longer, while in the Southern Intermountain geographic region the fire season started earlier and ended later over the 30-year study period. The two southern regions also had increases in fire size, especially the Southern Rocky Mountain geographic region. The U.S. National Climate Assessment indicates that annual temperature in the Southwest United States has increased over the past 115 years with recent 10-year averages surpassing any previous decadal value in the southern portion of the area (Kunkel et al. 2013a). The frost-free season length has increased by about 2 weeks relative to the 1960s and 1970s and by a month relative to the early 1900s.

Since 2000, several fires in forested landscapes of the Southern Rocky Mountain geographic region exceeded the burned area of any other wildfire in at least the past 100 years (e.g., most notably, the 189,651 ha [468,640 acre] Rodeo-Chediski Fire in central Arizona in 2002, the 217,741 ha [538,049 acre] Wallow Fire in east-central Arizona and west-central New Mexico in 2011, and the 63,000 ha [156,593 acre] Las Conchas Fire in New Mexico in 2011; Westerling et al. 2014).

In addition, large areas of piñon and juniper land cover types have experienced extensive tree mortality due to a combination of direct drought-induced physiological stress and mortality and effects of the piñon *Ips* bark beetle (*Ips confusus*) (Allen and Breshears 1998; Breshears et al. 2005). Williams et al. (2010) estimate that nearly 20 percent of forested areas in the region experienced high levels of tree mortality between 1984 and 2010 due to drought, fire, and bark beetles. Although both temperature and the frost-free length have increased in the more northern regions in this analysis (Kunkel et al. 2013b,c), the change may not yet be reflected in the fire season or other factors may currently have a greater influence on fire seasons in the more northern regions.

Differences Between Piñon and Juniper and Other Land Cover Types

The percentage of the study area that burned in piñon and juniper land cover types versus non-piñon and juniper land cover types differed among geographic regions. The relative influence of fire in piñon and juniper land cover types within the different regions was a function of the total area of the piñon and juniper land cover types, the area of piñon and juniper land cover types vs non-piñon and juniper land cover types that burned, and the rate of burning.

In the Northern Intermountain geographic region, the percentage of the area that burned within piñon and juniper land cover types was slightly less than the percentage of the area that burned within non-piñon and juniper land cover types (13.5 vs 15.3%). Piñon and juniper land cover types were only 5 percent of total land cover and 4.4 percent of total area, but a relatively high percentage of piñon and juniper land cover burned annually. In contrast, the percentage of the area that burned within piñon and juniper land cover types in the Southern Intermountain geographic region was slightly more than the percentage of the area that burned within non-piñon and juniper land cover types (9.8 vs 8.6%). Piñon and juniper land cover totaled 11 percent of total land cover and 12.4 percent of total area. A moderate

to high percentage of piñon and juniper land cover burned annually. In both Intermountain geographic regions, similar factors appear to influence fire regimes in piñon and juniper and non-piñon and juniper land cover types. Invasive annual grasses (Downs et al. 2016) and higher burn probabilities (Short et al. 2016) have a relatively greater influence on fire regimes in the northern part of the Intermountain geographic region, and longer fire seasons have a stronger influence in the southern part.

In the Central Rocky Mountain geographic region, the percentage of the area that burned within piñon and juniper land cover types was more than the percentage of the area that burned within non-piñon and juniper land cover types (3.1 vs 2.3%). Piñon and juniper land cover types made up 16.7 percent of total land cover and 22.1 percent of the total area burned, but a low percentage of piñon and juniper land cover burn annually. In the Southern Rocky Mountain geographic region the percentage of the area that burned within piñon and juniper land cover types was less than the percentage of the area that burned within non-piñon and juniper land cover types (4.3 vs 6.9%). Piñon and juniper land cover types were the greatest area of all the regions (23.1%). However, low to intermediate percentages of the piñon and juniper land cover types burned annually and only 15.6 percent of the total area that burned was piñon and juniper land cover. The higher percentage of burned area in piñon and juniper than non-piñon and juniper land cover types in the Central Rocky Mountain geographic region may be related to the increasing influence of climate warming, drought (Westerling et al. 2014), and invasive annual grasses (Arendt and Baker 2013; Floyd et al. 2004). A reverse trend in the Southern Rocky Mountain geographic region may be explained by the very large fires that burned in forested areas during the 30-year study period (Westerling et al. 2014).

Conclusions

Increases in the total area burned and decreases in fire rotations occurred in all four geographic regions for piñon and juniper land cover types during the 30-year period. Fire rotations for piñon and juniper land cover types were generally within historical ranges for the dominant shrubland or piñon and juniper land cover types within a region. Also, the percentage of the study area that burned in piñon and juniper land cover types was higher than in non-piñon and juniper land cover types in both the Southern Intermountain and Central Rocky Mountain geographic regions. These increases in fire coupled with other global change factors appear to be increasing the vulnerability of many piñon and juniper ecosystems.

In the Northern and Southern Intermountain geographic regions greater burn areas are linked to changes in climate and increases in invasive annual grasses that result in greater burn probabilities (Balch et al. 2013; Downs et al. 2016; Short et al. 2016). In the Colorado Plateau ecoregion, however, invasive annual grasses and associated increases in fire are counter-balancing the effects of tree expansion and resulting in net losses of piñon and juniper land cover types (Arendt and Baker 2013). In the Southern Rocky Mountain geographic region, longer fire seasons coupled with hotter droughts and increases in bark beetles are resulting in significant tree mortality (Allen et al. 2015; Breshears et al. 2005). Similar trends have been observed in the Southern Intermountain geographic region (Greenwood and Weisberg 2008; Flake 2016).

The magnitude of the effects of increased fire activity versus other global change factors varied across the four geographic regions. Careful monitoring of longer-term trends in fire activity and the interacting effects of invasive annual grasses, bark beetles, and climate change is needed to better understand the dynamics of piñon and juniper land cover types and to develop predictive modeling capacity. Understanding the longer-term ecosystem trends and primary drivers for the different regions can help inform the desirability of management treatments to remove piñon and juniper.

References

Abatzoglou, J.T.; Kolden, C.A. 2013. Relationships between climate and macroscale area burned in the western United States. International Journal of Wildland Fire. 22(7): 1003–1020.

Adams, R.P. 2014. Junipers of the world: The genus Juniperus. Bloomington, IN: Trafford Publishing. 415 p.

Allen, C.D.; Anderson, R.S.; Jass, R.B.; [et al.]. 2008. Paired charcoal and tree-ring records of high frequency Holocene fire from two New Mexico bog sites. International Journal of Wildland Fire. 17(1): 115–130.

Allen, C.D.; Breshears, D.D. 1998. Drought-induced shift of a forest-woodland ecotone: Rapid landscape response to climate variation. Proceedings of the National Academy of Sciences USA. 95(25): 14839–14842.

Allen, C.D.; Breshears, D.D.; McDowell, N.G. 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. Ecosphere. 6(8): 129. http://dx.doi.org/10.1890/ ES15-00203.1

Arendt, P.A.; Baker, W.L. 2013. Northern Colorado Plateau piñon-juniper woodland decline over the past century. Ecosphere. 4(8): 1–30

Arnold, J.F.; Jameson, D.A.; Reid, E.H. 1964. The pinyon-juniper type of Arizona: Effects of grazing, fire, and tree control. Product Research Report No. 84. Washington, DC: Department of Agriculture, Forest Service. 28 p.

Baker, W.H. 2011. Pre–Euro-American and recent fire in sagebrush ecosystems. In: Knick, S.T.; Connelly, J.W., eds. Greater sage-grouse—Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology. 38. Berkeley, CA: University of California Press: 185–201.

Baker, W.L.; Shinneman, D.J. 2004. Fire and restoration of piñon-juniper woodlands in the Western United States: A review. Forest Ecology and Management. 189: 1–21.

Balch, Jennifer K.; Bradley, Bethany A.; D'Antonio, Carla M.; [et al.]. 2013. Introduced annual grass increases regional fire activity across the arid western USA (1980–2009). Global Change Biology. 19(1): 173–183.

Barger, N.N.; Adams, H.D.; Woodhouse, C.; [et al.]. 2009. Influence of livestock grazing and climate on pinyon pine (*Pinus edulis*) dynamics. Rangeland Ecology and Management. 62(6): 531–539.

Bates, J.D.; Sharp, R.; Davies, K.W. 2014. Sagebrush steppe recovery after fire varies by development phase of *Juniperus occidentalis* woodland. International Journal of Wildland Fire. 23: 117–130.

Bauer, John M.; Weisberg, Peter J. 2009. Fire history of a central Nevada piñon-juniper woodland. Canadian Journal of Forest Research. 39(8): 1589–1599.

Biondi, F.; Bradley, M. 2013. Long-term survivorship of single-needle pinyon (*Pinus monophylla*) in mixed-conifer ecosystems of the Great Basin, USA. Ecosphere. 4(10): 120. http://dx.doi.org/10.1890/ES13-00149.1

Blackburn, W.H.; Bruner, A.D. 1975. Use of fire in manipulation of the pinyon-juniper ecosystem. In: Gifford, Gerald; Busby, Frank E., eds. Proceedings, the pinyon-juniper ecosystem: A symposium; 1975 May; Logan, UT: Utah State University; College of Natural Resources. Utah Agricultural Experiment Station: 91–96.

Blackburn, W.H.; Tueller P.T. 1970. Pinyon and juniper invasion in black sagebrush communities in east-central Nevada. Ecology. 51(5): 841–848.

Bradford, J.B.; Lauenroth, W.K. 2006. Controls over invasion of *Bromus tectorum*: The importance of climate, soil, disturbance and seed availability. Journal of Vegetation Science. 17: 693–704.

Bradley, B.A. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. Global Change Biology. 15: 196–208.

Breshears, D.D.; Cobb, N.S.; Rich, P.M.; [et al.]. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences of the United States of America 102(42): 15144–15148.

Bristow, N.A.; Weisberg, P.J.; Tausch, R.J. 2014. A 40-year record of tree establishment following chaining and prescribed fire treatments in singleleaf pinyon (*Pinus monophylla*) and Utah juniper (*Juniperus osteosperma*) woodlands. Rangeland Ecology and Management. 67(4): 389–396.

Brooks, M.L.; Brown, C.S.; Chambers, J.C.; [et al.]. 2016. Exotic annual *Bromus* invasions: Comparisons among species and ecoregions in the western United States [Chapter 2]. In: Germino, M.J., Chambers, J.C., Brown, C.S., eds. Exotic brome-grasses in arid and semiarid ecosystems of the western U.S. New York, NY: Springer: 11–60.

Brooks, M.L.; D'Antonio, C.M.; Richardson, D.M.; [et al.]. 2004. Effects of invasive alien plants on fire regimes. BioScience. 54(7): 677–688.

Brooks, M.L.; Matchett, J.R.; Shinneman, D.J.; [et al.]. 2015. Fire patterns in the range of greater sage-grouse, 1984–2013—Implications for conservation and management. Open-File Report 2015-1167, U.S. Geological Survey. 66 p. http://dx.doi.org/10.3133/ofr20151167. [Accessed June 13, 2016].

Brown, J.K. 1982. Fuel and fire behavior prediction in big sagebrush. Res. Pap. INT-290. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 10 p.

Bukowski, B.E.; Baker, W.L. 2013. Historical fire regimes, reconstructed from land-survey data, led to complexity and fluctuation in sagebrush landscapes. Ecological Applications. 23: 546–564.

Bybee, J.; Roundy, B.A.; Young, K.R; [et al.]. 2016. Vegetation response to piñon and juniper tree shredding. Rangeland Ecology and Management. 69(3): 224–234.

Chambers, J.C.; Bradley, B.A.; Brown, C.A.; [et al.]. 2014a. Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in the cold desert shrublands of western North America. Ecosystems. 17: 360–375.

Chambers, J.C.; Germino, M.J.; Belnap, J.; [et al.]. 2016. Plant community resistance to invasion by Bromus species—The role of community attributes, *Bromus* interactions with plant communities and *Bromus* traits [Chapter 10]. In: Germino, M.J., Chambers, J.C., Brown, C.S., eds. Exotic brome-grasses in arid and semiarid ecosystems of the western U.S. New York, NY: Springer: 275–306.

Chambers, J.C.; Miller, R.F.; Board, D.I.; [et al.]. 2014b. Resilience and resistance of sagebrush ecosystems: Implications for state and transition models and management treatments. Rangeland Ecology and Management. 67: 440–454.

Chambers, J.C.; Roundy, B.A.; Blank, R.R.; [et al.]. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum*? Ecological Monographs. 77: 117–145.

Cole, K.L.; Fisher, J.; Arundel, S.T.; [et al.]. 2008. Geographical and climatic limits of needle types of one- and two-needled pinyon pines. Journal of Biogeography. 35(2): 257–269.

Cole, K.L.; Fisher, J.F.; Ironside, K.; [et al.]. 2013. The biogeographic histories of *Pinus edulis* and *Pinus monophylla* over the last 50,000 years. Quaternary International. 310: 96–110.

Condon, L.; Weisberg, P.L.; Chambers, J.C. 2011. Abiotic and biotic influences on *Bromus tectorum* invasion and *Artemisia tridentata* recovery after fire. International Journal of Wildland Fire. 20: 1–8.

Crimmins, M.A.; Comrie, A.C. 2004. Interactions between antecedent climate and wildfire variability across southeastern Arizona. International Journal of Wildland Fire. 13(4): 455–466.

Dennison, P.E.; Brewer, S.C.; Arnold, J.D.; [et al.]. 2014. Large wildfire trends in the western United States, 1984–2011. Geophysical Research Letters. 41: 2928–2933.

Dillon, G.K.; Holden, Z.A.; Morgan, P.; [et al.]. 2011. Both topography and climate affected forest and woodland burn severity in two regions of the western US, 1984 to 2006. Ecosphere. 2(12): Article130. http://onlinelibrary.wiley.com/doi/10.1890/ES11-00271.1/epdf [Accessed January 16, 2017].

Downs, J.L.; Larson, K.B.; Cullinan, V.I. 2016. Mapping cheatgrass across the range of the Greater sage-grouse. Prepared for the U.S. Fish and Wildlife Service under Contract DE-AC05-76RL01830 U.S. Department of Energy. Richland, WA: Pacific Northwest National Laboratory. 28 p.

Dwyer, D.D.; Pieper, R.D. 1967. Fire effects on blue grama-pinyon rangeland in New Mexico. Journal of Range Management. 20: 359–362.

Flake, S.W. 2016. Stand dynamics during drought: Responses of adult trees, tree regeneration and understory vegetation to multiyear drought in pinyon-juniper woodlands. Thesis. Reno: University of Nevada. 127 p.

Floyd, M.L.; Hanna, D.D.; Romme, W.H. 2004. Historical and recent fire regimes in piñon-juniper woodlands on Mesa Verde, Colorado, USA. Forest Ecology and Management. 198: 269–289.

Floyd, M.L.; Romme, W.H.; Hanna, D.D.; [et al.]. 2008. Fire history of piñon-juniper woodlands on Navajo Point, Glen Canyon National Recreation Area. Natural Areas Journal. 28(1): 26–36.

Greenwood, D.L.; Weisberg, P.J. 2008. Density-dependent tree mortality in pinyon-juniper woodlands. Forest Ecology and Management. 255(7): 2129–2137.

Huffman, D.W.; Fulé, P.Z.; Pearson, K.M.; [et al.]. 2008. Fire history of pinyon-juniper woodlands at upper ecotones with ponderosa pine forests in Arizona and New Mexico. Canadian Journal of Forest Research. 38: 2097–2108.

Jameson, D.A. 1962. Effects of burning on a galleta-black grama range invaded by juniper. Ecology. 43(4): 760–763.

Kendall, M. 1975. Rank correlation methods. 4th ed. Oxford: Oxford University Press. 272 p.

Knight, D.H.; Jones, G.P.; Reiners, W.A.; [et al.]. 2014. Mountains and plains: The ecology of Wyoming landscapes. 2nd ed. New Haven, CT: Yale University Press. 404 p.

Kunkel, K.E.; Stevens, L.E.; Stevens, S.E.; [et al.]. 2013a. Regional climate trends and scenarios for the U.S. National Climate Assessment. Part 4. Climate of the U.S. Great Plains. NOAA Tech. Rep. NESDIS 142-4. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 82 p. https://scenarios.globalchange.gov/report/regional-climate-trends-and-scenarios-us-national-climate-assessment-part-4-climate-us-great [Accessed June 15, 2017].

Kunkel, K.E.; Stevens, L.E.; Stevens, S.E.; [et al.]. 2013b. Regional climate trends and scenarios for the U.S. National Climate Assessment. Part 5. Climate of the Southwest U.S. NOAA Tech. Rep. NESDIS 142-5. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 79 p. https://scenarios.globalchange.gov/report/regional-climate-trends-and-scenarios-us-national-climate-assessment-part-5-climate-southwest [Accessed June 15, 2017].

Kunkel, K.E.; Stevens, L.E.; Stevens, S.E.; [et al.]. 2013c. Regional climate trends and scenarios for the U.S. National Climate Assessment. Part 6. Climate of the Northwest U.S. NOAA Tech. Rep. NESDIS 142-6. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration. 83 p. https://www.nesdis.noaa.gov/sites/default/files/asset/document/NOAA_NESDIS_Tech_Report_142-6-Climate_of_the_Northwest_U.S.pdf [Accessed June 15, 2017].

Lauenroth, W.K.; Schlaepfer, D.R.; Bradford, J.B. 2014. Interactions between climate and habitat loss effects on biodiversity: A systematic review and meta-analysis. Ecosystems. 17: 1469–1479.

Littell, J.S.; McKenzie, D.; Peterson, D.L.; [et al.]. 2009. Climate and wildfire area burned in the western U.S. ecoprovinces, 1916–2003. Ecological Applications. 19(4): 1003–1021.

Little, E.L., Jr. 1971. Atlas of United States trees, conifers and important hardwoods—Volume 1: Conifers and important hardwoods. Miscel. Publ. 1146. Washington, DC: U.S. Department of Agriculture, Forest Service. 400 p.

Liu, Z.; Wimberly, M.C. 2015. Climatic and landscape influences on fire regimes from 1984 to 2010 in the western United States. PLoS One, 10(10): e0140839. doi:10.1371/journal.pone.0140839.

Liu, Z.; Wimberly, M.C. 2016. Direct and indirect effects of climate change on projected future fire regimes in the western United States. Science of the Total Environment. 542(A): 65–75.

Manier, D.J.; Hobbs, N.T.; Theobold, D.M.; [et al.]. 2005. Canopy dynamics and human caused disturbance on a semi-arid landscape in the Rocky Mountains, USA. Landscape Ecology. 20(1): 1–17.

Mann, H.B. 1945. Nonparametric tests against trend. Econometrica. 13(3): 245–259.

Margolis, E.Q. 2014. Fire regime shift linked to increased forest density in a piñon-juniper savanna landscape. International Journal of Wildland Fire. 23(2): 234–245.

Martin, R.E. 1978. Fire manipulation and effects in western juniper (*Juniperus occidentalis* Hook.). In: Proceedings of the western juniper ecology and management workshop. Gen. Tech. Rep. PNW-GTR-74. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station: 121–136.

McCulloch, C.Y. 1969. Some effects of wildfire on deer habitat in pinyon-juniper woodland. Journal of Wildland Management. 33: 778–784.

McKenzie, D.; Gedalof, Z.; Peterson, D.L.; Mote, P. 2004. Climatic change, wildfire, and conservation. Conservation Biology. 18(4): 890–902.

Mealor, B.A.; Cox, S.; Booth, D.T. 2012. Post fire downy brome (*Bromus tectorum*) invasion at high elevation in Wyoming. Invasive Plant Science and Management. 5: 427–435.

Miller, J.; Safford, H.; Crimmins, M.; [et al.]. 2008a. Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. Ecosystems. 12: 16–32.

Miller, J.; Skinner, C.; Safford, H.; [et al.]. 2012. Trends and causes of severity, size, and number of fires in northwestern California, USA. Ecological Applications. 22: 184–203.

Miller, R.F.; Heyerdahl, E.K. 2008. Fine-scale variation of historical fire regimes in sagebrush-steppe and juniper woodland: an example from California, USA. International Journal of Wildland Fire. 17:245–254.

Miller, R.F.; Tausch, R.J. 2001. The role of fire in juniper and pinyon woodlands: A descriptive analysis. In: Galley, K.E.M.; Wilson, T.P., eds. Proceedings of the invasive species workshop: The role of fire in the control and spread of invasive species—Fire Conference 2000: The first National Congress on fire ecology, prevention, and management; 2000 November 27–December 1; San Diego, CA. Miscel. Publ. 11. Tallahassee, FL: Tall Timbers Research Station: 15–30.

Miller, R.F.; Chambers, J.C.; Pyke, D.A.; [et al.]. 2013. A review of fire effects on vegetation and soils in the Great Basin Region: Response and ecological site characteristics. Gen. Tech. Rep. RMRS-GTR-308. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.126 p.

Miller, R.F.; Knick, S.T.; Pyke, D.A.; [et al.]. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. In: Knick S.T.; Connelly, J.W., eds. Greater sage-grouse—Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology. 38. Berkeley, CA: University of California Press: 145–185.

Miller, R.F.; Svejcar, T.J.; Rose, J.A. 2000. Impacts of western juniper on plant community composition and structure. Journal of Range Management. 53: 574–585.

Miller, R.F.; Tausch, R.J.; McArthur, E.D.; [et al.]. 2008b. Age structure and expansion of piñon-juniper woodlands: A regional perspective in the Intermountain West. Res. Pap. RMRS-RP-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p.

Monitoring Trends in Burn Severity [MTBS]. 2016. National burned area boundaries dataset. http://www.mtbs.gov/nationalregional/burnedarea.html. [Accessed April 23, 2017].

Narayanaraj, G.; Wimberly, M.C. 2011. Influences of forest roads on the spatial pattern of wildfire boundaries. International Journal of Wildland Fire. 20(6): 792–803.

Narayanaraj, G.; Wimberly, M.C. 2012. Influences of forest roads on the spatial patterns of human-and lightning-caused wildfire ignitions. Applied Geography. 32(2): 878–888.

Natureserve. 2015. NatureServe Explorer: An online encyclopedia of life. Version 7.0. NatureServe, Arlington, VA. U.S.A. http://explorer.natureserve.org. [Accessed: 07/15/15].

Nowak, R.S.; Ellsworth, D.S.; Smith, S.D. 2004. Functional responses of plants to elevated atmospheric CO_2—Do photosynthetic and productivity data from FACE experiments support early predictions? New Phytologist. 162: 253–280.

Parks, S.A.; Parisien, M.; Miller, C. 2012. Spatial bottom-up controls on fire likelihood vary across western North America. Ecosphere. 3(1): 1–20.

Polley, H.W.; Morgan, J.A.; Fay, P.A. 2011. Application of a conceptual framework to interpret variability in rangeland responses to atmospheric CO_2 enrichment. Journal of Agricultural Science. 149: 1–14.

PRISM Climate Group [PRISM]. 2016. 30-Year Normals. http://www.prism.oregonstate.edu/. [Accessed January 16, 2017].

Pyke, D.A.; Chambers, J.C.; Beck, J.L.; [et al.]. 2016. Land uses, fire and invasion: Exotic annual *Bromus* and human dimensions [Chapter 11]. In: Germino, M.J.; Chambers, J.C.; Brown, C.S., eds. Exotic brome-grasses in arid and semiarid ecosystems of the Western US: Causes, consequences and management implications. New York, NY: Springer: 307–337.

Romme, W.H.; Allen, C.D.; Bailey, J.D.; [et al.]. 2009. Historical and modern disturbance regimes, stand structures, and landscape dynamics in piñon-juniper vegetation of the western United States. Rangeland Ecology and Management. 62: 203–222.

Roundy, B.A.; Young, K.; Cline, N.; [et al.] 2014. Piñon-juniper reduction increases soil water availability of the resource growth pool. Rangeland Ecology and Management. 67: 495–505.

Sala, O.E.; Lauenroth,W.K.; Gollucio, R.A. 1997. Plant functional types in temperate semi-arid regions. In: Smith, T.M.; Shugart, H.H.; Woodward, F.I., eds. Plant functional types. Cambridge, UK: Cambridge University Press: 217–233.

Savage, M.; Swetnam, T.W. 1990. Early 19th-century fire decline following sheep pasturing in a Navajo ponderosa pine forest. Ecology. 71: 2374–2378.

Schroeder, W.L. 1966. Guidelines for control burning in pinyon-juniper woodlands on the Hualapi Reservation. Memo. Washington, DC: U.S. Department of the Interior, Bureau of Indian Affairs.

Shinneman, D.J.; Baker, W.L. 2009a. Historical fire and multidecadal drought as context for piñon-juniper woodland restoration in Western Colorado. Ecological Applications. 19(5): 1231–1245.

Shinneman, D.J.; Baker, W.L. 2009b. Environmental and climatic variables as potential drivers of post-fire cover of cheatgrass (*Bromus tectorum*) in seeded and unseeded semiarid ecosystems. International Journal of Wildland Fire. 18: 191–202.

Short, K.C.; Finney, M.A.; Scott, J.H.; [et al.]. 2016. Spatial dataset of probabilistic wildfire risk components for the conterminous United States. Fort Collins, CO: Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2016-0034.

Stringham, T.K.; Novak-Echenique, P.; Blackburn, P.W.; [et al.]. 2015. Final Report for USDA Ecological Site Description State-and-Transition Models. Major Land Resource Area 28A and 28B Nevada. Nevada Agricultural Experiment Station Research Report. 1:1524. Reno, NV: University of Nevada Reno, Nevada Agricultural Experiment Station.

Sugihara, N.G.; Van Wagtendonk, J.W.; Fites-Kaufman, J. 2006. Fire as an Ecological Process. In: Sugihara, N., ed. Fire in California ecosystems. Berkley, CA: University of California Press: 58–74.

Syphard, A.D.; Radeloff, V.C.; Keeley, J.E.; [et al.]. 2007. Human influence on California fire regimes. Ecological Applications. 17(5): 1388–1402.

Tausch, R.J.; West, N.E. 1995. Plant species composition patterns with differences in tree dominance on a southwestern Utah pinyon-juniper site. In: Shaw, D.W.; Aldon, E.F.; LoSapio, C., comps. Desired future conditions for pinyon-juniper ecosystems. Gen. Tech. Rep. RM-GTR-258. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 16–23.

Urza, A.K.; Weisberg, P.J.; Chambers, J.C.; [et al.]. 2017 Post-fire vegetation response at the woodland-shrubland interface is mediated by ecological memory of pre-fire community. Ecosphere. Volume 8(6) Article e01851.

U.S. Environmental Protection Agency [USEPA]. 2013. Level III ecoregions of the continental United States: Corvalis, OR: U.S Environmental Protection Agency, National Health and Environmental Research Laboratory. Map scale 1:750,000. https://www.epa.gov/eco-research/level-iii-and-iv-ecoregions-continental-united-states. [Accessed January 16, 2017].

U.S. Geological Survey [USGS]. 2011. National Gap Analysis Program (GAP)-Core Science Analytics and Synthesis. National Land Cover, Version 2. Washington, DC: U.S. Department of the Interior, U.S. Geological Survey. https://gapanalysis.usgs.gov/data/. [Accessed January 16, 2017].

Waichler, W.S.; Miller, R.F.; Doescher, P.S. 2001. Community characteristics of old-growth western juniper woodlands. Journal of Range Management. 54:518–527.

Wangler, M.J.; Minnich, R.A. 1996. Fire and succession in piñon-juniper woodlands of the San Bernardino Mountains, California. Madrono. 43(4): 493–514.

Weisberg, P.J.; Lingua, E.; Pillai, R.B. 2007. Spatial patterns of pinyon-juniper expansion in central Nevada. Rangeland Ecology and Management. 60(2): 115–124.

West, N.E. 1983. Great Basin-Colorado Plateau sagebrush semi-desert. In: West, N.E., ed. Temperate deserts and semi-deserts. Amsterdam: Elsevier Publishing Company: 331–350.

West, N.E. 1984. Successional patterns and productivity potentials of pinyon-juniper ecosystems. In: Kozlowski, T.T., ed. Developing strategies for range management. Boulder, CO: National Resource Council/National Academy of Science. Westview Press: 1301–1332.

West, N.E. 1999. Juniper-piñon savannas and woodlands of western North America. In: Anderson, R.C.; Fralish, J.S.; Baskin, J.M., eds. Savannas, barrens and rock outcrop plant communities of North America. London: Cambridge University Press: 288–308.

West, N.E., Rea, K.H., Tausch, R.J. 1975. Basic synecological relationships in juniper-pinyon woodlands. In: The pinyon-juniper ecosystem: A symposium. Logan, UT: Utah State University College of Natural Resources and Utah Agricultural Experiment Station: 41–53.

Westerling, A.; Brown, T.; Schoennagel, T.; [et al.]. 2014. Briefing: Climate and wildfire in western U.S. forests. In: Sample, V.A.; Bixler, R.P., eds. Forest conservation and management in the Anthropocene: Conference proceedings. Proceedings. RMRS-P-71. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 81–102.

Westerling, A.L.; Hidalgo, H.G.; Cayan, D.R.; [et al.]. 2006. Warming and earlier spring increase western US forest wildfire activity. Science. 313(5789): 940–943.

Williams, A.P.; Allen, C.D.; Millar, C.I.; [et. al]. 2010. Forest responses to increasing aridity and warmth in the southwestern United States. Proceedings of the National Academy of Sciences USA. 107(50): 21289–21294.

Wright, H.A.; Neunshwander, L.F.; Britton, C.M. 1979. The role and use of fire in sagebrush and pinyon-juniper communities. Gen. Tech. Rep.INT-GTR-58. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Young, K.R.; Roundy, B.A.; Bunting, S.C.; [et al.]. 2015. Utah juniper and two needle piñon reduction alters fuel loads. International Journal of Wildland Fire. 24(2): 236–248.

Appendix A—Summaries of Each Piñon and Juniper (PJ) Land Cover Type Burned Annually for Each Geographic Region and its Ecoregions.

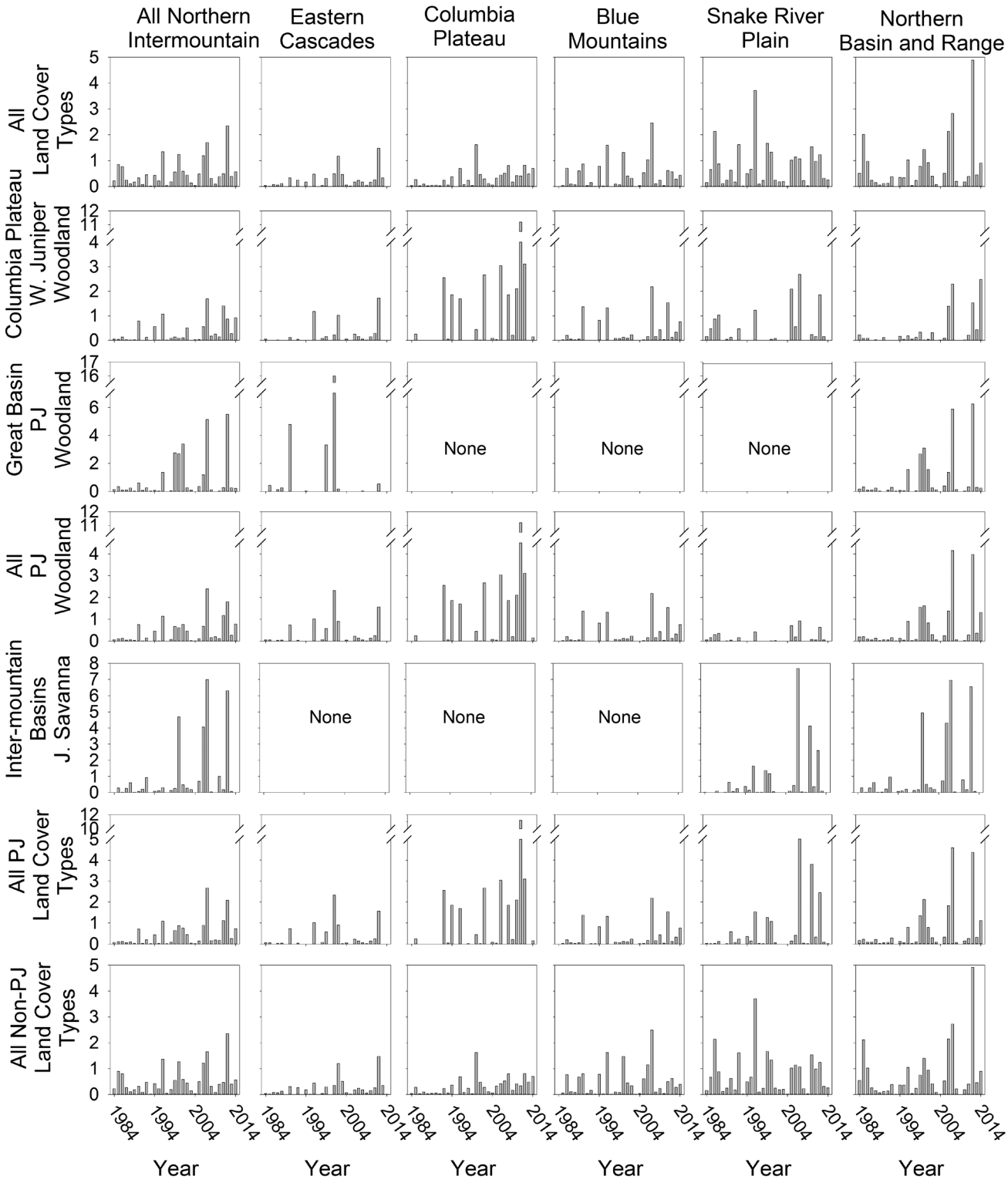

Figure A.1— Percent area of each piñon and juniper (PJ) land cover type burned annually on a 100,000 hectare basis for the Northern geographic region overall and the ecoregions within the geographic region.

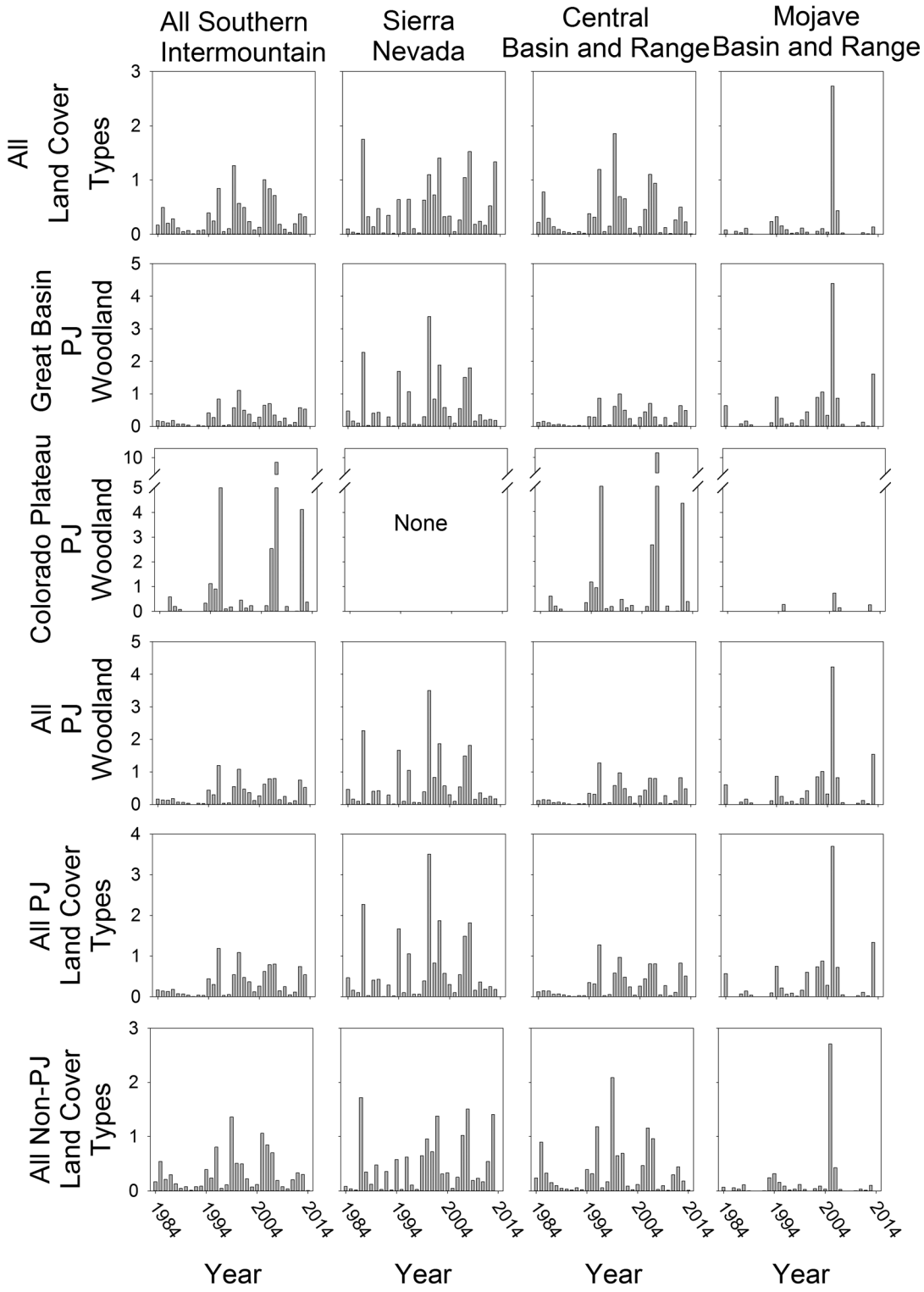

Figure A.2—Percent area of each piñon and juniper (PJ) land cover type burned annually on a 100,000 hectare basis for the Southern Intermountain geographic region overall and for the ecoregions within the geographic region.

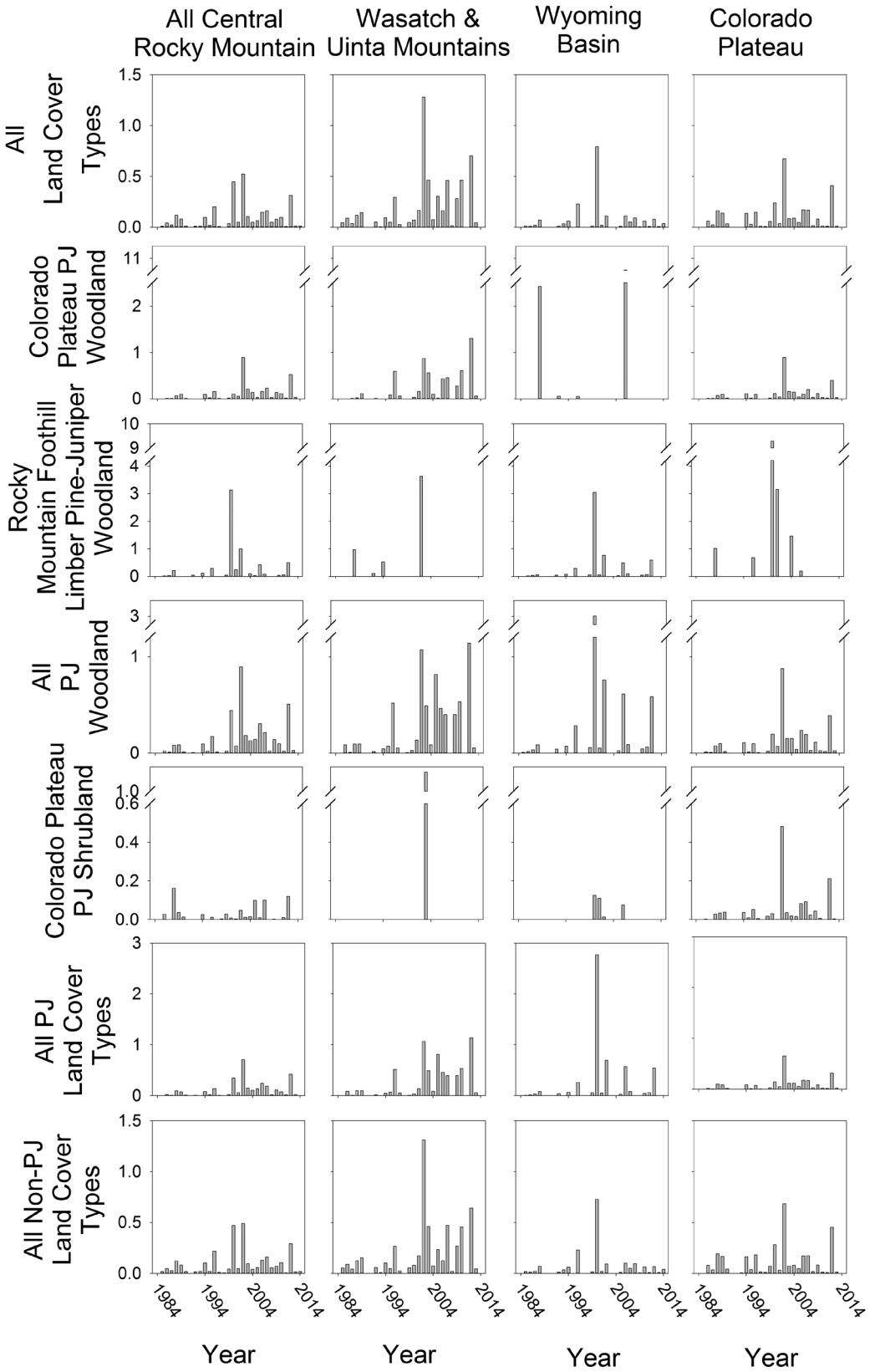

Figure A.3—Percent area of each piñon and juniper (PJ) land cover type burned annually on a 100,000 hectare basis for the Central Rocky Mountain geographic region overall and the ecoregions within the geographic region.

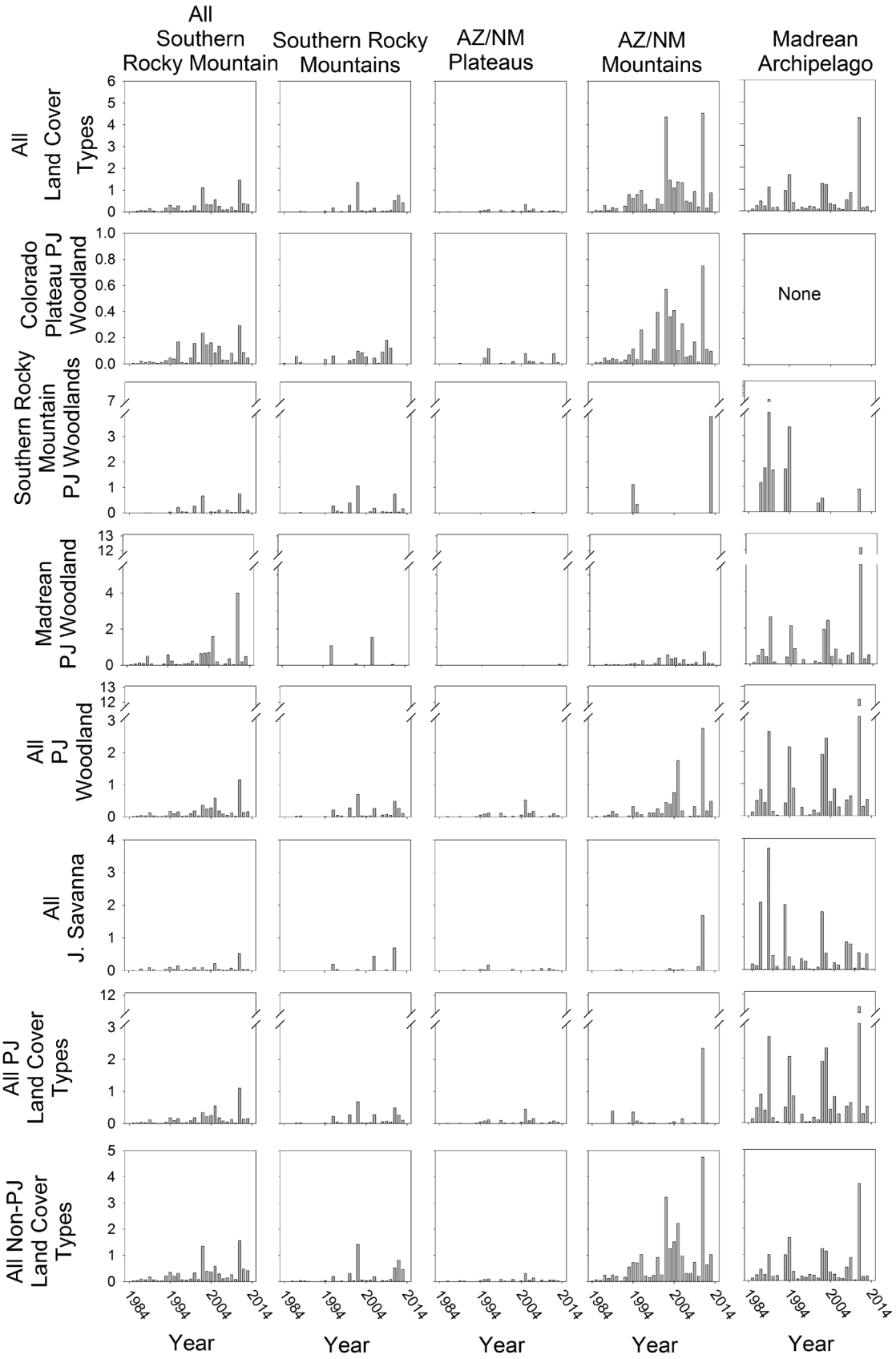

Figure A.4—Percent area of each piñon and juniper (PJ) land cover type burned annually on a 100,000 hectare basis for the Southern Rocky Mountain geographic region overall and the ecoregions within the geographic region.

Federal Recycling Program  Printed on Recycled Paper

In accordance with Federal civil rights law and U.S. Department of Agriculture (USDA) civil rights regulations and policies, the USDA, its Agencies, offices, and employees, and institutions participating in or administering USDA programs are prohibited from discriminating based on race, color, national origin, religion, sex, gender identity (including gender expression), sexual orientation, disability, age, marital status, family/parental status, income derived from a public assistance program, political beliefs, or reprisal or retaliation for prior civil rights activity, in any program or activity conducted or funded by USDA (not all bases apply to all programs). Remedies and complaint filing deadlines vary by program or incident.

Persons with disabilities who require alternative means of communication for program information (e.g., Braille, large print, audiotape, American Sign Language, etc.) should contact the responsible Agency or USDA's TARGET Center at (202) 720-2600 (voice and TTY) or contact USDA through the Federal Relay Service at (800) 877-8339. Additionally, program information may be made available in languages other than English.

To file a program discrimination complaint, complete the USDA Program Discrimination Complaint Form, AD-3027, found online at http://www.ascr.usda.gov/complaint_filing_cust.html and at any USDA office or write a letter addressed to USDA and provide in the letter all of the information requested in the form. To request a copy of the complaint form, call (866) 632-9992. Submit your completed form or letter to USDA by: (1) mail: U.S. Department of Agriculture, Office of the Assistant Secretary for Civil Rights, 1400 Independence Avenue, SW, Washington, D.C. 20250-9410; (2) fax: (202) 690-7442; or (3) email: program.intake@usda.gov.

To learn more about RMRS publications or search our online titles:

www.fs.fed.us/rm/publications

www.treesearch.fs.fed.us