CHAPTER 3.

Large-Scale Patterns of Forest Fire Occurrence in the Conterminous United States and Alaska, 2013

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INTRODUCTION

Free-burning wildland fire has been a frequent ecological phenomenon on the American landscape, and its expression has changed as new peoples and land uses have become predominant (Pyne 2010). As a pervasive disturbance agent operating at many spatial and temporal scales, wildland fire is a key abiotic factor affecting forest health both positively and negatively. In some ecosystems, wildland fires have been essential for regulating processes that maintain forest health (Lundquist and others 2011). Wildland fire, for example, is an important ecological mechanism that shapes the distributions of species, maintains the structure and function of fire-prone communities, and acts as a significant evolutionary force (Bond and Keeley 2005).

At the same time, wildland fires have created forest health problems in some ecosystems (Edmonds and others 2011). Specifically, fire outside the historic range of frequency and intensity can impose extensive ecological and socioeconomic impacts. Current fire regimes on more than half of the forested area in the conterminous United States have been moderately or significantly altered from historical regimes, potentially altering key ecosystem components such as species composition, structural stage, stand age, canopy closure, and fuel loadings (Schmidt and others 2002). Understanding existing fire regimes is essential to properly assessing the impact of fire on forest health because changes to historical fire regimes can alter forest developmental patterns, including the establishment, growth, and mortality of trees (Lundquist and others 2011).

As a result of intense suppression efforts during most of the 20th century, the forest area burned annually decreased from approximately 16 million to 20 million ha (40 to 50 million acres) in the early 1930s to about 2 million ha (5 million acres) in the 1970s (Vinton 2004). In some regions, plant communities have experienced or are undergoing rapid compositional and structural changes as a result of fire suppression (Nowacki and Abrams 2008). At the same time, fires in some regions and ecosystems have become larger, more intense, and more damaging because of the accumulation of fuels as a result of prolonged fire suppression (Pyne 2010). Such large wildland fires also can have long lasting social and economic consequences, which include the loss of human life and property, smoke-related human health impacts, and the cost of fighting the fires themselves (Gill and others 2013, Richardson and others 2012).

Fire regimes have been dramatically altered, in particular, by fire suppression (Barbour and others 1999) and by the introduction of nonnative invasive plants, which can change fuel properties and in turn both affect fire behavior and alter fire regime characteristics such as frequency, intensity, type, and seasonality (Brooks and others 2004). Additionally, changes in fire intensity and recurrence could result in decreased forest resilience and persistence (Lundquist and others 2011), and fire regimes altered by global climate change could cause large-scale shifts in vegetation spatial patterns (McKenzie and others 1996).

This chapter presents analyses of high temporal fidelity fire occurrence data, collected nationally by satellite, that map and quantify where fire occurrences have been concentrated spatially across the conterminous United States and Alaska in 2013. It also, within a geographic context, compares 2013 fire occurrences to all the recent years for which such data are available. Quantifying and monitoring such broad-scale patterns of fire occurrence across the United States can help improve the understanding of the ecological and economic impacts of fire as well as the appropriate management and prescribed use of fire. Specifically, large-scale assessments of fire occurrence can help identify areas where specific management activities may be needed, or where research into the ecological and socioeconomic impacts of fires may be required.

METHODS

Data

Annual monitoring and reporting of active wildland fire events using the Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States database (USDA Forest Service 2014) allows analysts to spatially display and summarize fire occurrences across broad geographic regions (Coulston and others 2005; Potter 2012a, 2012b, 2013a, 2013b, 2014, 2015). A fire occurrence is defined as one daily satellite detection of wildland fire in a 1-km^2 pixel, with multiple fire occurrences possible on a pixel across multiple days. The data are derived using the MODIS Rapid Response System (Justice and others 2002, 2011) to extract fire location and intensity information from the thermal infrared bands of imagery collected daily by two satellites at a resolution of 1 km^2, with the center of a pixel recorded as a fire occurrence (USDA Forest Service 2014). The Terra and Aqua satellites' MODIS sensors identify the presence of a fire at the time of image collection, with Terra observations collected in the morning and Aqua observations collected in the afternoon. The resulting fire occurrence data represent only whether a fire was active, because the MODIS data bands do not differentiate between a hot fire in a relatively small area (0.01 km^2, for example) and a cooler fire over a larger area

(1 km^2, for example). The MODIS Active Fire database does well at capturing large fires during cloud-free conditions, but may underrepresent rapidly burning, small, and low-intensity fires, as well as fires in areas with frequent cloud cover (Hawbaker and others 2008). For more information about the performance of this product, see Justice and others (2011).

Analyses

These MODIS products for 2013 were processed in ArcMap® (ESRI 2012) to determine the number of fire occurrences per 100 km^2 (10 000 ha) of forested area for each ecoregion section in the conterminous 48 States (Cleland and others 2007) and Alaska (Nowacki and Brock 1995). This forest fire occurrence density measure was calculated after screening out wildland fires on nonforested pixels using a forest cover layer derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center (RSAC) (USDA Forest Service 2008). The total numbers of forest fire occurrences were also determined separately for the conterminous States and for Alaska.

The fire occurrence density value for each ecoregion in 2013 was then compared with the mean fire density values for the first 12 full years of MODIS Active Fire data collection (2001–12). Specifically, the difference of the 2013 value and the previous 12-year mean for an ecoregion was divided by the standard deviation across the previous 12-year period, assuming normal distribution of fire density over time in the ecoregion. The result for each ecoregion was a standardized *z*-score, which is a dimensionless quantity describing whether the fire occurrence density in the ecoregion in 2013 was higher, lower, or the same relative to all the previous years for which data have been collected, accounting for the variability in the previous years. The *z*-score is the number of standard deviations between the observation and the mean of the previous observations. Approximately 68 percent of observations would be expected within one standard deviation of the mean, and 95 percent within two standard deviations. Near-normal conditions are classified as those within a single standard deviation of the mean, although such a threshold is somewhat arbitrary. Conditions between about one and two standard deviations of the mean are moderately different from mean conditions, but are not significantly different statistically. Those outside about two standard deviations would be considered statistically greater than or less than the long-term mean (at $p < 0.025$ at each tail of the distribution).

Additionally, a Getis-Ord hot spot analysis (Getis and Ord 1992) in ArcMap® 10.1 (ESRI 2012) was employed to identify forested areas in the conterminous 48 States with higher-than-expected fire occurrence density in 2013. The

spatial units of the analysis were 9,810 cells of approximately 834 km^2 from a hexagonal lattice of the conterminous United States, intensified from Environmental Monitoring and Assessment Program (EMAP) North America hexagon coordinates (White and others 1992). Fire occurrence density values for each hexagon were quantified as the number of forest fire occurrences per 100 km^2 of forested area within the hexagon.

The Getis-Ord G_i^* statistic was used to identify clusters of hexagonal cells with fire occurrence density values higher than expected by chance. This statistic allows for the decomposition of a global measure of spatial association into its contributing factors, by location, and is therefore particularly suitable for detecting outlier assemblages of similar conditions (i.e., nonstationarities) in a dataset, such as when spatial clustering is concentrated in one subregion of the data (Anselin 1992).

Briefly, G_i^* sums the differences between the mean values in a local sample, determined in this case by a moving window of each hexagon and its 18 first- and second-order neighbors (the 6 adjacent hexagons and the 12 additional hexagons contiguous to those 6), and the global mean of all the forested hexagonal cells in the conterminous 48 States. G_i^* is standardized as a z-score with a mean of 0 and a standard deviation of 1, with values >1.96 representing significant local clustering of higher fire occurrence densities ($p < 0.025$) and values <-1.96 representing significant clustering of lower fire occurrence densities ($p < 0.025$), because 95 percent of the observations under a normal distribution should be within approximately 2 standard deviations of the mean (Laffan 2006). Values between -1.96 and 1.96 have no statistically significant concentration of high or low values; a hexagon and its 18 neighbors, in other words, have a range of both high and low numbers of fire occurrences per 100 km^2 of forested area. It is worth noting that the threshold values are not exact, because the correlation of spatial data violates the assumption of independence required for statistical significance (Laffan 2006). The Getis-Ord approach does not require that the input data be normally distributed, because the local G_i^* values are computed under a randomization assumption, with G_i^* equating to a standardized z-score that asymptotically tends to a normal distribution (Anselin 1992). The z-scores are reliable, even with skewed data, as long as the distance band is large enough to include several neighbors for each feature (ESRI 2012).

RESULTS AND DISCUSSION

The MODIS Active Fire database recorded 98,682 wildland forest fire occurrences across the conterminous United States in 2013, the second largest annual number of fire occurrences since the first full year of data collection in 2001 (fig. 3.1). This number was approximately 28 percent fewer than in 2012 (138,000 forest fire occurrences, the most since the beginning of data collection), but about 68 percent more than the annual mean of 58,709 forest fire occurrences across the previous 12 full years of data collection. In contrast, the MODIS database

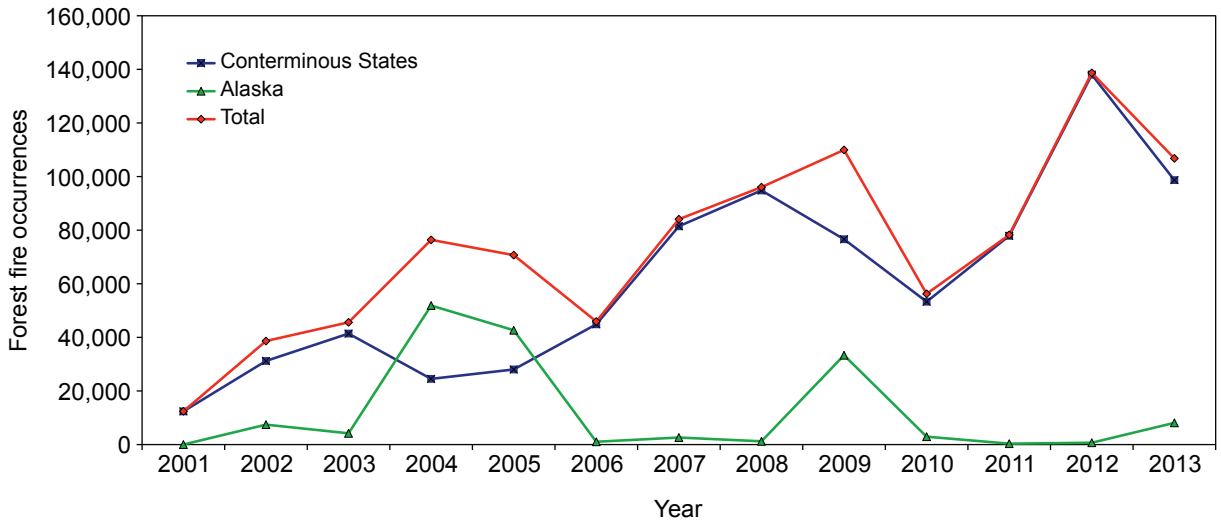

Figure 3.1—Forest fire occurrences detected by MODIS from 2001 through 2013 for the conterminous United States and Alaska and for the two regions combined. (Data source: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center, in conjunction with the NASA MODIS Rapid Response group)

captured only 8,110 forest fire occurrences in Alaska in 2013, the fourth most since 2001 and about 66 percent of the previous 12-year annual mean of 12,366.

The decrease in the total number of fire occurrences across the conterminous United States is generally consistent with the official wildland fire statistics. In 2013, 47,579 wildfires were reported nationally, compared to 67,774 the previous year. The area burned nationally in 2013 (1 748 058 ha) was 59 percent of the 10-year average, with 20 fires exceeding 16 187 ha (31 fewer than in 2012) (National Interagency Coordination Center 2014). The total area burned nationally represented a 54-percent decrease from 2012 (3 774 195 ha) (National Interagency Coordination Center 2013). It is important to underscore that estimates of burned area and calculations of MODIS-detected fire occurrences are two different metrics for quantifying fire activity within a given year. Most importantly, the MODIS data contain both spatial and temporal components, since persistent fire will be detected repeatedly over several days on a given 1-km^2 pixel. In other words, a location can be counted as having a fire occurrence multiple times, once for each day a fire is detected at the location. Analyses of the MODIS-detected fire occurrences, therefore, measure the total number of daily 1-km^2 pixels with fire during a year, as

opposed to quantifying only the area on which fire occurred at some point during the course of the year.

In 2013, the highest forest fire occurrence densities occurred in Idaho, California, Oregon, and Colorado (fig. 3.2), after summer drought conditions allowed fire fuels to become extremely dry, particularly in northern California and southwestern Oregon (National Interagency Coordination Center 2014). The forested ecoregion with the highest wildland forest fire occurrence density in 2013 (32.8 fire occurrences per 100 km^2 of forest) was section M332F–Challis Volcanics (fig. 3.2) in central Idaho. The adjacent M332A–Idaho Batholith, meanwhile, experienced 18 fires per 100 km^2 of forest. These ecoregion sections are located in the Eastern Great Basin Geographic Area, where official wildland fire statistics recorded nearly 311 000 ha burned in 2013 (National Interagency Coordination Center 2014), including the Pony Complex, Elk Complex, and Beaver Creek fires (60 453, 53 118, and 45 118 ha, respectively). Meanwhile, M261E–Sierra Nevada, in central California, saw nearly 30.8 fire occurrences per 100 km^2 of forest. This area included the Nation's largest fire in 2013, the 104 131-ha Rim fire, which also was the third largest wildfire in recorded California history, costing an estimated $127.35 million (National Interagency Coordination Center 2014). In northwestern California and southwestern Oregon, M261A–Klamath Mountains experienced a fire occurrence density of 16.2 fires per 100 km^2 of forest.

Additionally, two ecoregions that contain relatively small amounts of forest (and therefore do not stand out as easily on fig. 3.2) also had high fire occurrence densities in 2013: 331I–Arkansas Tablelands in southeast Colorado (17.8 fires per 100 km^2 of forest) and 342I–Columbia Basin in central Washington (16.2 fires per 100 km^2 of forest).

Elsewhere in the West, several ecoregions had moderate fire occurrence densities, including M331G–South-Central Highlands (south-central Colorado and north-central New Mexico); 322A–Mojave Desert (southeastern California, southern Nevada, and northwestern Arizona); M333C–Northern Rockies (northwestern Montana); and M262B–Southern California Mountain and Valley.

Ecoregions of the Southeastern United States generally experienced moderate fire occurrence densities in 2013 (fig. 3.2). Southeastern ecoregions with relatively high fire densities included 232B–Gulf Coast Plains and Flatwoods (Louisiana, Mississippi, Alabama, Georgia, and Florida, 10.7 fire occurrences); 232G–Florida Coastal Lowlands-Atlantic (eastern Florida, 7.3 occurrences); 232J–Southern Atlantic Coastal Plains and Flatwoods (Georgia, South Carolina, and North Carolina, 9.7 fire occurrences); 232F–Coastal Plains and Flatwoods-Western Gulf (Louisiana and east Texas, 8.4 fire occurrences); and 232D–Florida Coastal Lowlands-Gulf (southwest Florida, 6.8 fire occurrences). Fire occurrence densities, meanwhile, were almost universally low in the Northeastern, Mid-Atlantic, and Midwestern States.

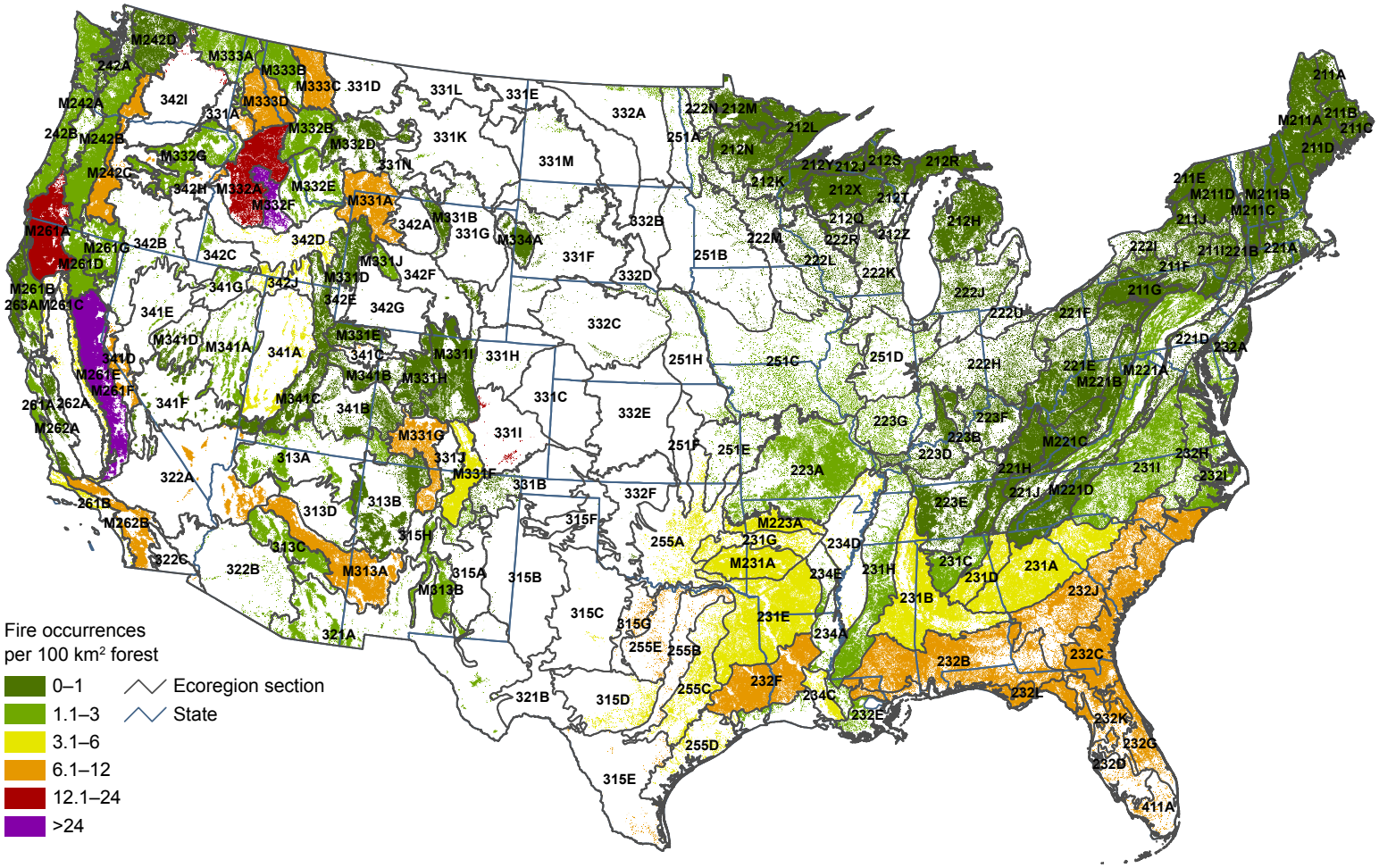

Figure 3.2—The number of forest fire occurrences per 100 km^2 (10 000 ha) of forested area, by ecoregion section within the conterminous 48 States, for 2013. The gray lines delineate ecoregion sections (Cleland and others 2007). Forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Source of fire data: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center, in conjunction with the NASA MODIS Rapid Response group)

Meanwhile, Alaska experienced an increase in fire occurrences during its second warmest summer on record, which was coupled with significant dryness that resulted in a later-than-normal fire season (National Interagency Coordination Center 2014). Three Alaskan ecoregions had moderate fire occurrence densities (fig. 3.3). The M139C–Dawson Range ecoregion had the highest fire occurrence density, with 5.4 fire occurrences detected per 100 km^2 of forest, followed by 131B–Kuskokwim Colluvial Plain (3.7 fire occurrences per 100 km^2 of forest) and M131D–Nushagak-Lime Hills (3.3 fire occurrences per 100 km^2 of forest). The Lime Hills fire burned 81 668 ha during the course of 3 months from the end of May to the end of August (National Interagency Coordination Center 2014).

Comparison to Longer Term Trends

Contrasting short-term (1-year) wildland forest fire occurrence with longer term trends is possible by comparing these results for each ecoregion section to the first 12 full years of MODIS Active Fire data collection (2001–12). In general, most ecoregions within the Northeastern, Midwestern, Middle Atlantic, and Appalachian regions experienced <1 fire per 100 km^2 of forest during that period, with means higher in the northern Rocky Mountain, California, Southeastern, and Southwestern regions (fig. 3.4A). The forested ecoregion that experienced the most fires on average was M332A–Idaho Batholith in central Idaho (mean annual fire occurrence density of 13.6). Other ecoregions with mean fire occurrence densities of 6.1 to 12.0 were located near the southern California coast, in central Arizona and New Mexico, and in north-central Texas. Ecoregions with the greatest variation in fire occurrence densities from 2001 to 2012 were also located in central Idaho, along the California coast, and in southeastern Oregon, with moderate variation in northeastern California, north-central Washington, western Montana, western Utah, central and southeastern Arizona and southwestern New Mexico, and eastern North Carolina (fig. 3.4B). Less variation occurred throughout the Southeast, central California, noncoastal Oregon and Washington, the Rocky Mountain States, and northern Minnesota. The least variation was apparent throughout most of the Midwest and Northeast.

In 2013, ecoregions scattered across the conterminous United States experienced greater fire occurrence densities than normal, compared to the previous 12-year mean and accounting for variability over time, as determined by the calculation of standardized fire occurrence *z*-scores (fig. 3.4C). These included ecoregions in central and northwestern California, northern and central Idaho, northwestern Wyoming, southern Colorado and north-central New Mexico, and north-central Minnesota. This was also the case for much of the Southeast and New England. The New England ecoregions had high *z*-scores despite a relatively low density of fire occurrences in 2013 because these were slightly higher than normal in areas that typically have very little variation over time in fire occurrence density. Several of the western ecoregions also had very high fire occurrence

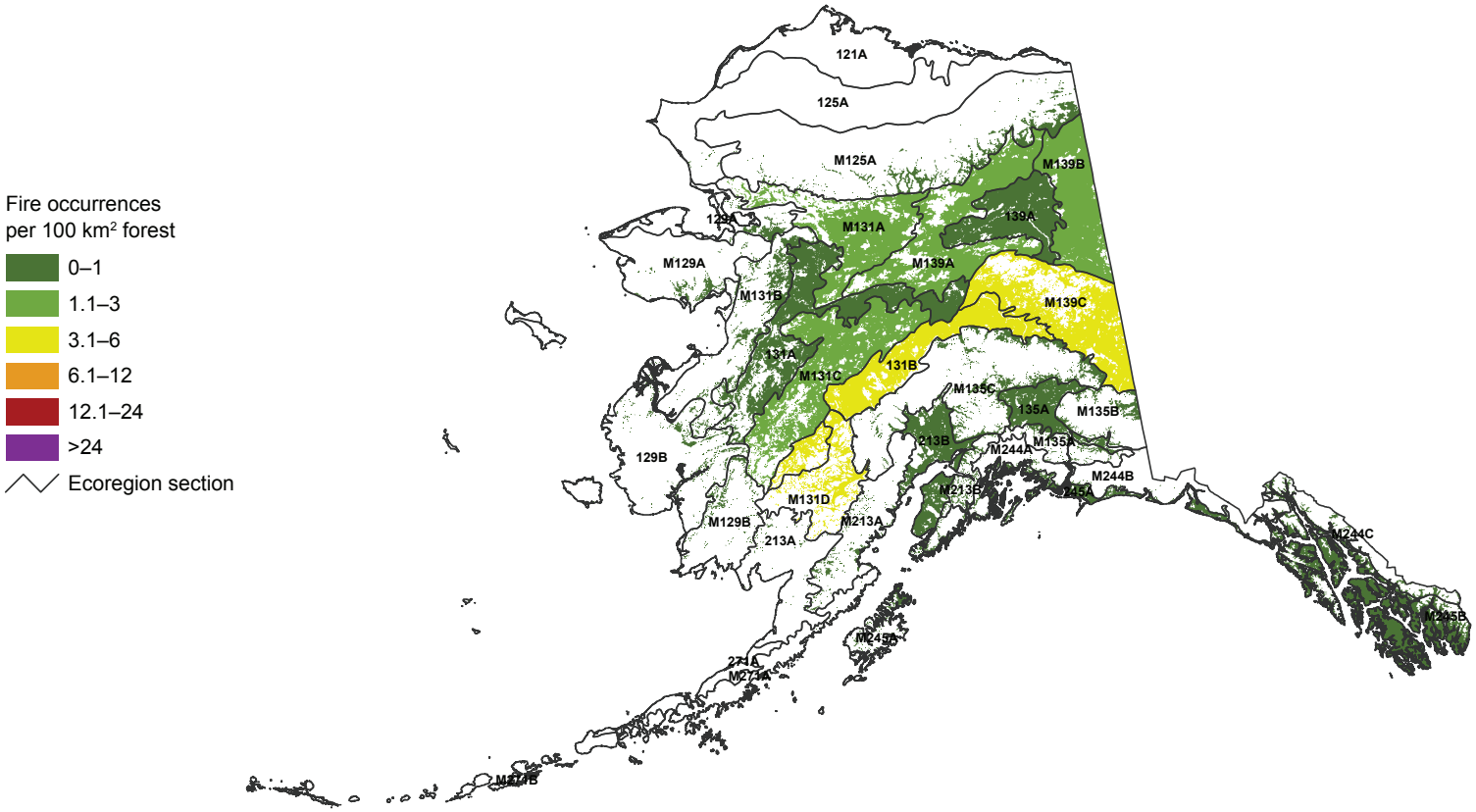

Figure 3.3—The number of forest fire occurrences per 100 km^2 (10 000 ha) of forested area, by ecoregion section within Alaska, for 2013. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Source of fire data: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center, in conjunction with the NASA MODIS Rapid Response group)

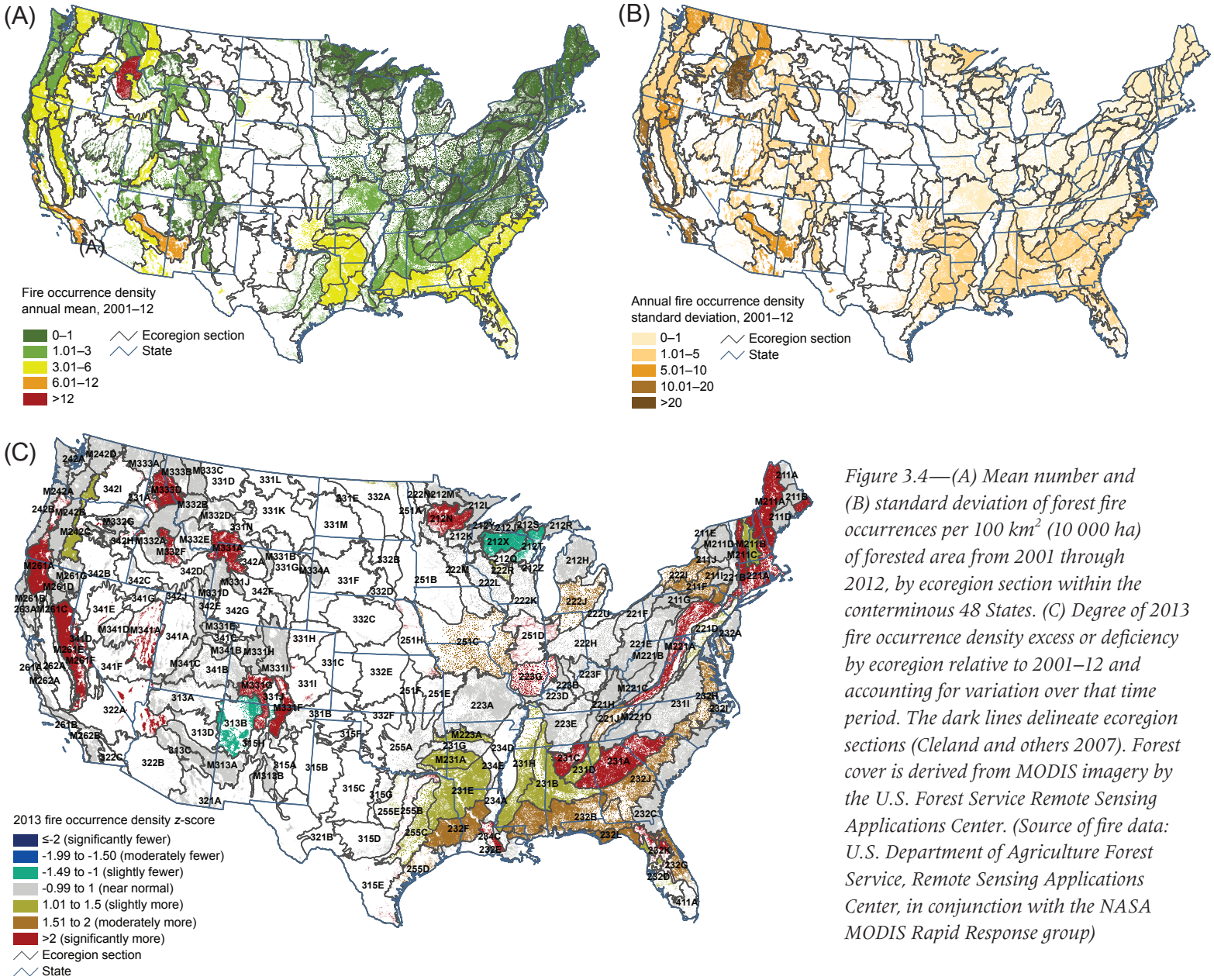

Figure 3.4—(A) Mean number and (B) standard deviation of forest fire occurrences per 100 km^2 (10 000 ha) of forested area from 2001 through 2012, by ecoregion section within the conterminous 48 States. (C) Degree of 2013 fire occurrence density excess or deficiency by ecoregion relative to 2001–12 and accounting for variation over that time period. The dark lines delineate ecoregion sections (Cleland and others 2007). Forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Source of fire data: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center, in conjunction with the NASA MODIS Rapid Response group)

densities in 2013 (fig, 3.2), including M261E–Sierra Nevada in California, M261A–Klamath Mountains in northwestern California and southwestern Oregon, M332F–Challis Volcanics in central Idaho, and 331I–Arkansas Tablelands in southeastern Colorado. Others had moderate fire occurrence densities in 2013 (fig. 3.2) that still deviated from the previous 12-year mean (fig. 3.4C), including M242C–Eastern Cascades (in central Washington and Oregon), M333D–Bitterroot Mountains (in northern Idaho), M331A–Yellowstone Highlands (in Wyoming), 322A–Mojave Desert (in southern Nevada and northwestern Arizona), and M331G–South-Central Highlands and M331F–Southern Parks and Rocky Mountain Range (in southern Colorado and northern New Mexico). In the Southeastern United States, these included 231A–Southern Appalachian Piedmont, 232K–Florida Coastal Plains Central Highlands, and 234C–Atchafalaya and Red River Alluvial Plains.

Only three ecoregions in the conterminous United States had a lower fire occurrence density in 2013 compared to the longer term: 313B–Navaho Canyonlands (in northwestern New Mexico), 212X–Northern Highlands (in northern Wisconsin), and 212T–Northern Green Bay Lobe (in northeastern Wisconsin and the Upper Peninsula of Michigan) (fig. 3.4C). This is the case because these are all regions with relatively low annual mean fire occurrence densities (<1 fire per 100 km^2 of forest per year) and low levels of variability in those mean densities, where a slightly smaller-than-usual number of fire occurrences in 2013 was coupled with low variability over time.

Of additional interest are the several ecoregions across the Midwestern, Northeastern, and Mid-Atlantic States that had 2013 fire occurrence densities that were low but still had relatively high *z*-scores (fig. 3.4C). Among these are 212N–Northern Minnesota Drift and Lake Plains (in northern Minnesota); M221A–Northern Ridge and Valley (in Tennessee, Virginia, West Virginia, Maryland, and Pennsylvania); 221A–Lower New England (stretching from Pennsylvania to Maine); and M211A–White Mountains (in Maine, New Hampshire, and Vermont).

In Alaska, meanwhile, the highest mean annual fire occurrence density between 2001 and 2012 occurred in the east-central and central parts of the State (fig. 3.5A) in the 139A–Yukon Flats ecoregion, with moderate mean fire occurrence density in neighboring areas. As expected, many of those same areas experienced the greatest degree of variability over the 12-year period (fig. 3.5B). In 2013, three ecoregions were outside the range of near-normal fire occurrence density, compared to the mean of the previous 12 years and accounting for variability. All are located in south-central Alaska: M213A–Northern Aleutian Range, M131D–Nushagak-Lime Hills, and M135C–Alaska Range (fig. 3.5C).

Geographical Hot Spots of Fire Occurrence Density

While summarizing fire occurrence data at the ecoregion scale allows for the quantification of fire occurrence density across the country, a geographical hot spot analysis can offer insights

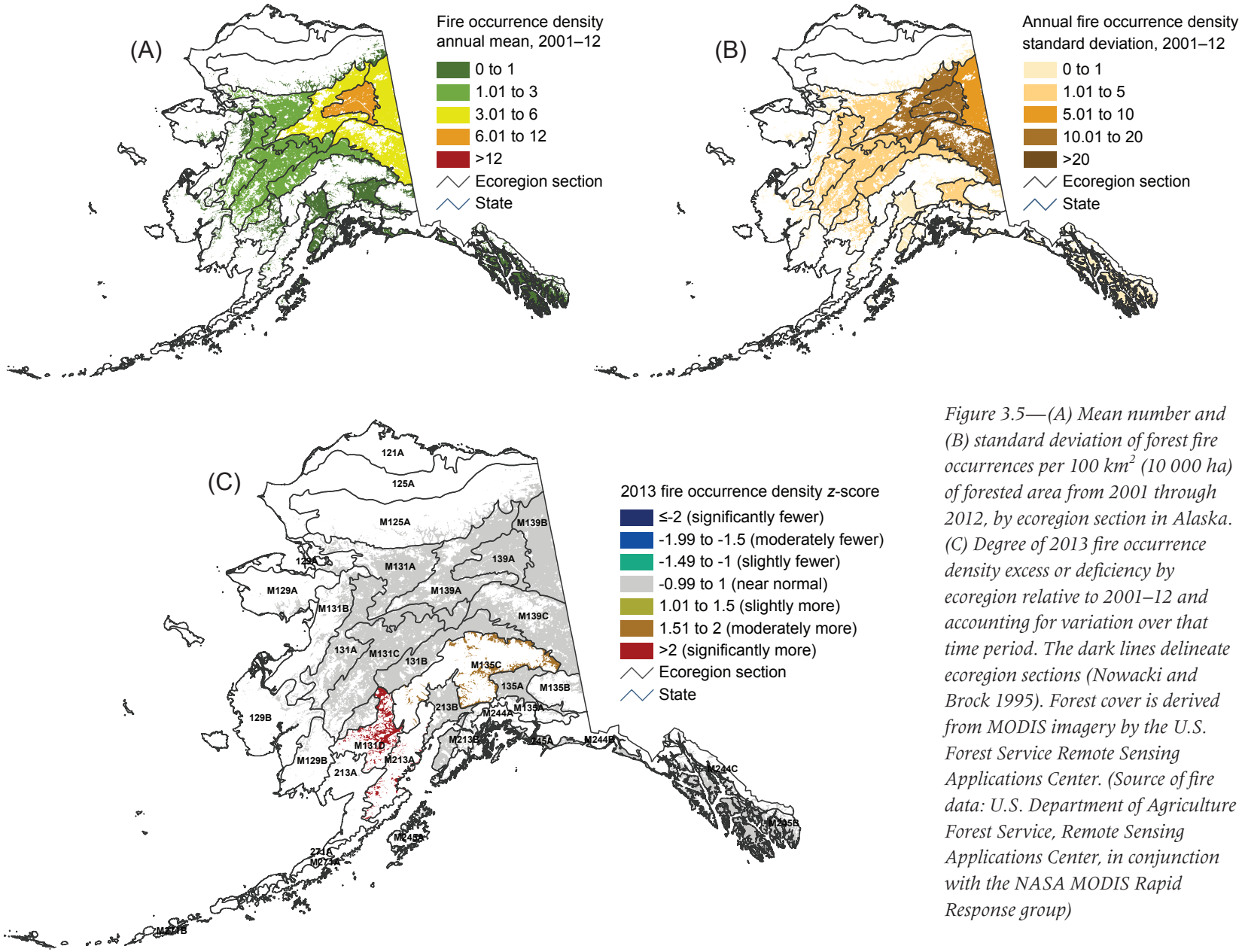

Figure 3.5—(A) Mean number and (B) standard deviation of forest fire occurrences per 100 km^2 (10 000 ha) of forested area from 2001 through 2012, by ecoregion section in Alaska. (C) Degree of 2013 fire occurrence density excess or deficiency by ecoregion relative to 2001–12 and accounting for variation over that time period. The dark lines delineate ecoregion sections (Nowacki and Brock 1995). Forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Source of fire data: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center, in conjunction with the NASA MODIS Rapid Response group)

into where, statistically, fire occurrences are more concentrated than expected by chance. In 2013, the two geographical hot spots with the highest fire occurrence density were located in California and Idaho (fig. 3.6). The larger of these was centered in M261E–Sierra Nevada, the location of the 2-month Rim fire in and around Yosemite National Park. The second high-density hot spot was located in M332A–Idaho Batholith, M332F–Challis Volcanics, and 342D–Snake River Basalts and Basins.

Three other hot spots of high fire occurrence density were located in south-central Washington (M242C–Eastern Cascades); south-central New Mexico (321A–Chihuahua Desert Basin and Range, M313B–Sacramento-Monzano Mountains, and M313A–White Mountains-San Francisco Peaks-Mogollon Rim); and south-central Georgia (232B–Gulf Coastal Plains and Flatwoods, 232J–Southern Atlantic Coastal Plains and Flatwoods, and 232L–Gulf Coastal Lowlands).

Several hot spots of moderate fire density were scattered across the Western United States (fig. 3.6), including in:

- Northwestern California (M261A–Klamath Mountains, 263A–Northern California Coast, and M261B–Northern California Coast Ranges)
- Southwestern Oregon (M242A–Oregon and Washington Coast Ranges, M261A–Klamath Mountains, and M242B–Western Cascades)
- Southern California (M262B–Southern California Mountain and Valley and 261B–Southern California Coast)
- Central Washington (M242D–Northern Cascades)
- Southern Nevada (322A–Mojave Desert)
- Northwestern Montana (M333C–Northern Rockies)
- Northern Utah and southern Idaho (342J–Eastern Basin and Range and M331D–Overthrust Mountains)
- Southwestern Colorado (M331G–South-Central Highlands)
- Central Colorado (M331I–Northern Parks and Ranges and 331I–Arkansas Tablelands)

The Getis-Ord hot spot analysis also detected a handful of areas with moderate concentrations of forest fire occurrence density in the Southeast:

- West-central Louisiana (232F–Coastal Plains and Flatwoods-Western Gulf)
- South-central Alabama and northwestern Florida (232B–Gulf Coastal Plains and Flatwoods)
- Central Florida (232G–Florida Coastal Lowlands-Atlantic, 232D–Florida Coastal Lowlands-Gulf, 232K–Florida Coastal Plains Central Highlands, and 411A–Everglades)

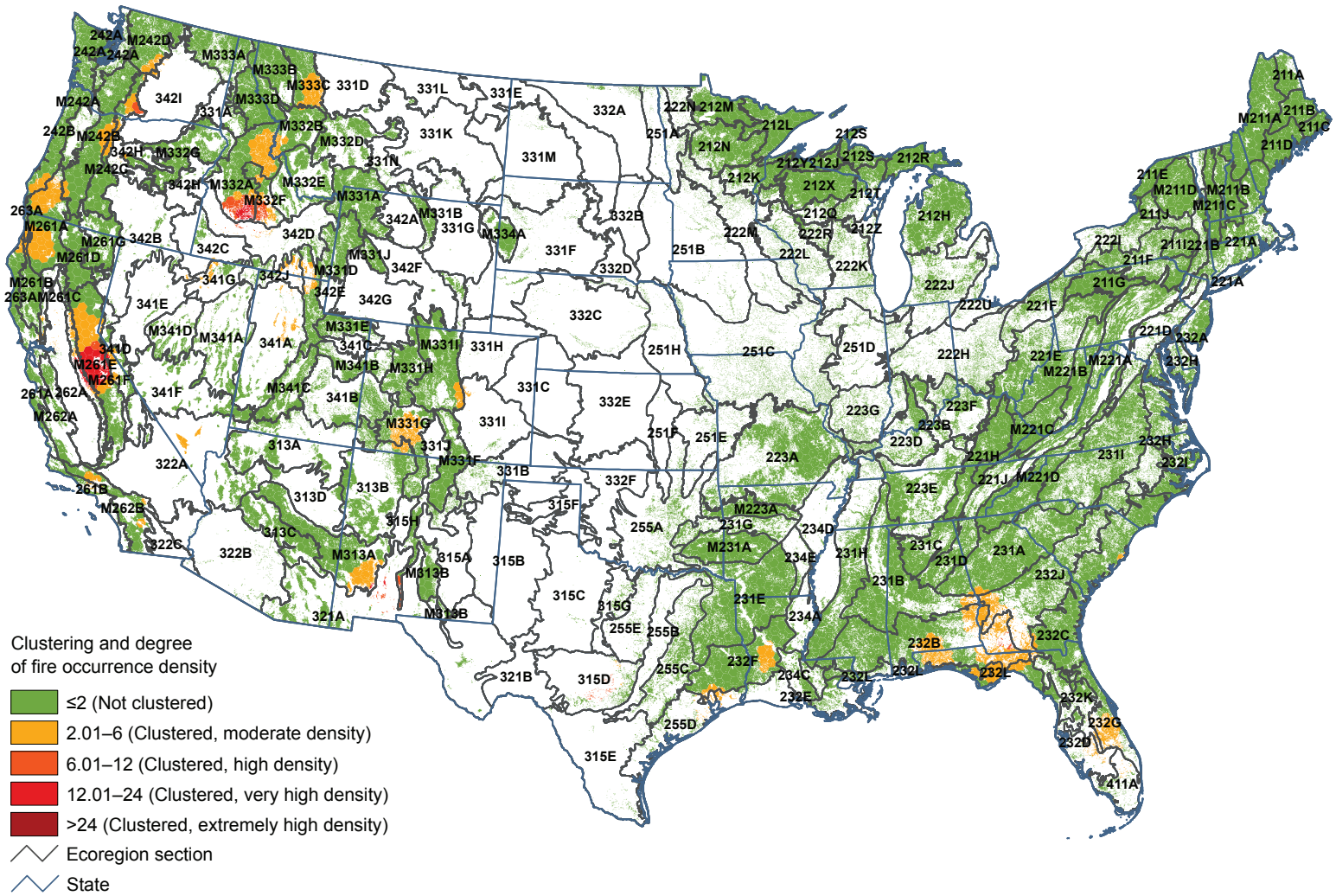

Figure 3.6—Hot spots of fire occurrence across the conterminous United States for 2013. Values are Getis-Ord G_i scores, with values >2 representing significant clustering of high fire occurrence densities. (No areas of significant clustering of low fire occurrence densities, <-2, were detected). The gray lines delineate ecoregion sections (Cleland and others 2007). Background forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Source of fire data: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center, in conjunction with the NASA MODIS Rapid Response group)*

CONCLUSION

The results of these geographic analyses are intended to offer insights into where fire occurrences have been concentrated spatially in a given year and compared to previous years, but are not intended to quantify the severity of a given fire season. Given the limits of MODIS active fire detection using 1-km^2 resolution data, these products also may underrepresent the number of fire occurrences in some ecosystems where small and low-intensity fires are common. These products can also have commission errors. However, these high temporal fidelity products currently offer the best means for daily monitoring wildfire impacts. Ecological and forest health impacts relating to fire and other abiotic disturbances are scale-dependent properties, which in turn are affected by management objectives (Lundquist and others 2011). Information about the concentration of fire occurrences may help pinpoint areas of concern for aiding management activities and for investigations into the ecological and socioeconomic impacts of wildland forest fire potentially outside the range of historic frequency.

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