CHAPTER 3.

Large-Scale Patterns of Forest Fire Occurrence in the Conterminous United States and Alaska, 2011

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INTRODUCTION

Free-burning fire has been a constant ecological presence on the American landscape, the expression of which has changed as new climates, peoples, and land uses have become predominant (Pyne 2010). It is an important ecological mechanism that shapes the distributions of species, maintains the structure and function of fire-prone communities, and is a significant evolutionary force (Bond and Keeley 2005). As a ubiquitous disturbance agent operating at many spatial and temporal scales, wildland fire is a key abiotic factor in forest health, and even large, intense fires that cause extensive tree mortality can play a role in maintaining healthy ecosystems (Lundquist and others 2011). In some ecosystems, wildland fires have been essential for regulating processes that maintain forest health, while fires have created forest health problems in other ecosystems (Edmonds and others 2011).

Fire outside the historic range of frequency and intensity can have extensive economic and ecological impacts. As a result of intense suppression efforts during most of the 20th century, the land area burned annually decreased from approximately 16–20 million ha (40–50 million acres) in the early 1930s to about 2 million ha (5 million acres) in the 1970s (Vinton 2004). In some regions, plant communities are undergoing rapid compositional and structural changes as a result of fire suppression (Nowacki and Abrams 2008). At the same time, fires have become larger, more intense, and more damaging because of the accumulation of fuels (Pyne 2010). Current fire regimes on more than half of the forested area in the conterminous United States have been either 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 inherent 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).

Fire suppression, and the introduction of nonnative plants in particular, has dramatically altered fire regimes (Barbour and others 1999). In addition, 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).

Quantifying and monitoring broad-scale patterns of fire occurrence across the United States can help provide a fuller understanding of the ecological and economic impacts of fire and of the appropriate management and prescribed use of fire. To be specific, large-scale assessments of fire occurrence can help identify areas where specific management activities may be useful, or where research into the ecological and socioeconomic impacts of fires may be necessary.

METHODS

Annual monitoring and reporting of active wildland fire events using the Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States ("MODIS Active Fire") database (USDA Forest Service 2012) enables analysts to spatially display and summarize fire occurrences (Coulston and others 2005; Potter 2012a, 2012b; Potter 2013a, 2013b). Fire occurrences are defined as the satellite detection of wildland fire in a 1-km^2 pixel for 1 day in a given year. The data are derived using the MODIS Rapid Response System (Justice and others 2002) 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 when the satellites' MODIS sensors identify the presence of a fire at the time of image collection (USDA Forest Service 2012). The data represent only whether a fire was active because the MODIS sensors 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 Detections database does well at capturing large fires, but it may underrepresent rapidly burning, small, and low-intensity fires as well as fires in areas with frequent cloud cover (Hawbaker and others 2008).

The number of fire occurrences per 100 km^2 (10 000 ha) of forested area was determined for each ecoregion section in the conterminous 48 States (Cleland and others 2007) and Alaska (Nowacki and Brock 1995) for 2011. 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 Forest Service Remote Sensing Applications Center (USDA Forest Service 2008). The total number of forest fire occurrences across the conterminous States and Alaska was also calculated.

The 2011 fire-occurrence density value for each ecoregion was then compared with the mean fire density values for the first 10 full years of MODIS Active Fire data collection (2001–10). To be specific, the difference of the 2011 value and the previous 10-year mean for an ecoregion was divided by the standard deviation across the previous 10-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 the degree of deficit or excess of fire-occurrence density in the ecoregion in 2011 relative to all of 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 1 standard deviation of the mean, and 95 percent expected within 2 standard deviations. Near-normal conditions are classified as those within a single standard deviation of the mean, although such a threshold is somewhat arbitrary.

In addition, a Getis-Ord hot spot analysis (Getis and Ord 1992) in ArcMap 9.2 (ESRI 2006) was employed to identify forested areas in the conterminous 48 States with higher-than-expected fire-occurrence density in 2011. The spatial units of analysis were cells of about 2500 km^2 from a hexagonal lattice of the conterminous United States, intensified from Environmental Monitoring and Assessment Program North America hexagon coordinates (White and others 1992). This cell size allows for analysis at a medium-scale resolution of approximately the same area as a typical county. 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 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 greater than 1.96 representing significant local clustering of higher fire-occurrence densities ($p < 0.025$) and values less than -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 2006).

RESULTS AND DISCUSSION

The MODIS Active Fire Detections database captured 77,892 wildland forest fire occurrences across the conterminous United States in 2011, approximately 46 percent more than in 2010 (53,309) and the third highest number since the first full year of MODIS data was collected in 2001 (fig. 3.1). It is also higher than the 48,862 mean annual forest fire occurrences during the previous 10 full years of data collection. The database captured only 343 forest fire occurrences in Alaska in 2011, the second fewest since 2001 and a small fraction of the previous 10-year annual mean of 14,736.

The increase in total number of fire occurrences across the conterminous States is consistent with the official wildland fire statistics, which show a 155-percent increase in the overall area burned nationally between 2010 (1 385 127 ha) and 2011 (3 525 365 ha) (National Interagency Coordination Center 2012).

In 2011, the 321A-Chihuahuan Desert Basin and Range ecoregion section in west Texas and southern New Mexico and Arizona and the 315G-Eastern Rolling Plains ecoregion section in north-central Texas were the highly forested ecoregions with the highest wildland forest fire-occurrence density (32.8 and 28.2 fires per 100 km^2 of forest, respectively) (fig. 3.2). Immediately north of the Basin and Range ecoregion, the M313A-White Mountains-San Francisco Peaks-Mogollon Rim ecoregion experienced 18.7 fire occurrences per 100 km^2 of forest.

In the Southeast, meanwhile, 232C-Atlantic Coastal Flatwoods had a high density of fire occurrences (13.6 per 100 km^2 of forest). Several neighboring ecoregions also had a relatively high fire-occurrence density, including 232G-Florida Coastal Lowlands-Atlantic (10.3 per 100 km^2), 232B-Gulf Coastal Plains and Flatwoods (9.2 per 100 km^2), 232I-Northern Atlantic Coastal Flatwoods (8.4 per 100 km^2), and 232K-Florida Coastal Plains Central Highlands (8.2 per 100 km^2).

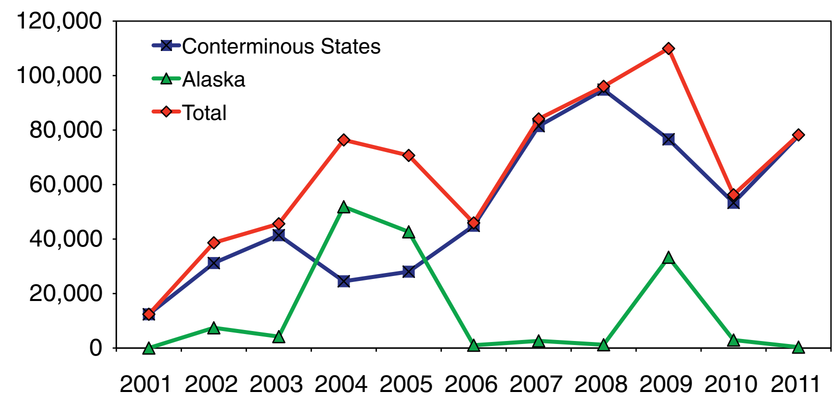


Figure 3.1—Forest fire occurrences detected by MODIS from 2001 to 2011 for the conterminous United States, for Alaska, and for the two regions combined. (Data source: USDA Forest Service, Remote Sensing Applications Center.)

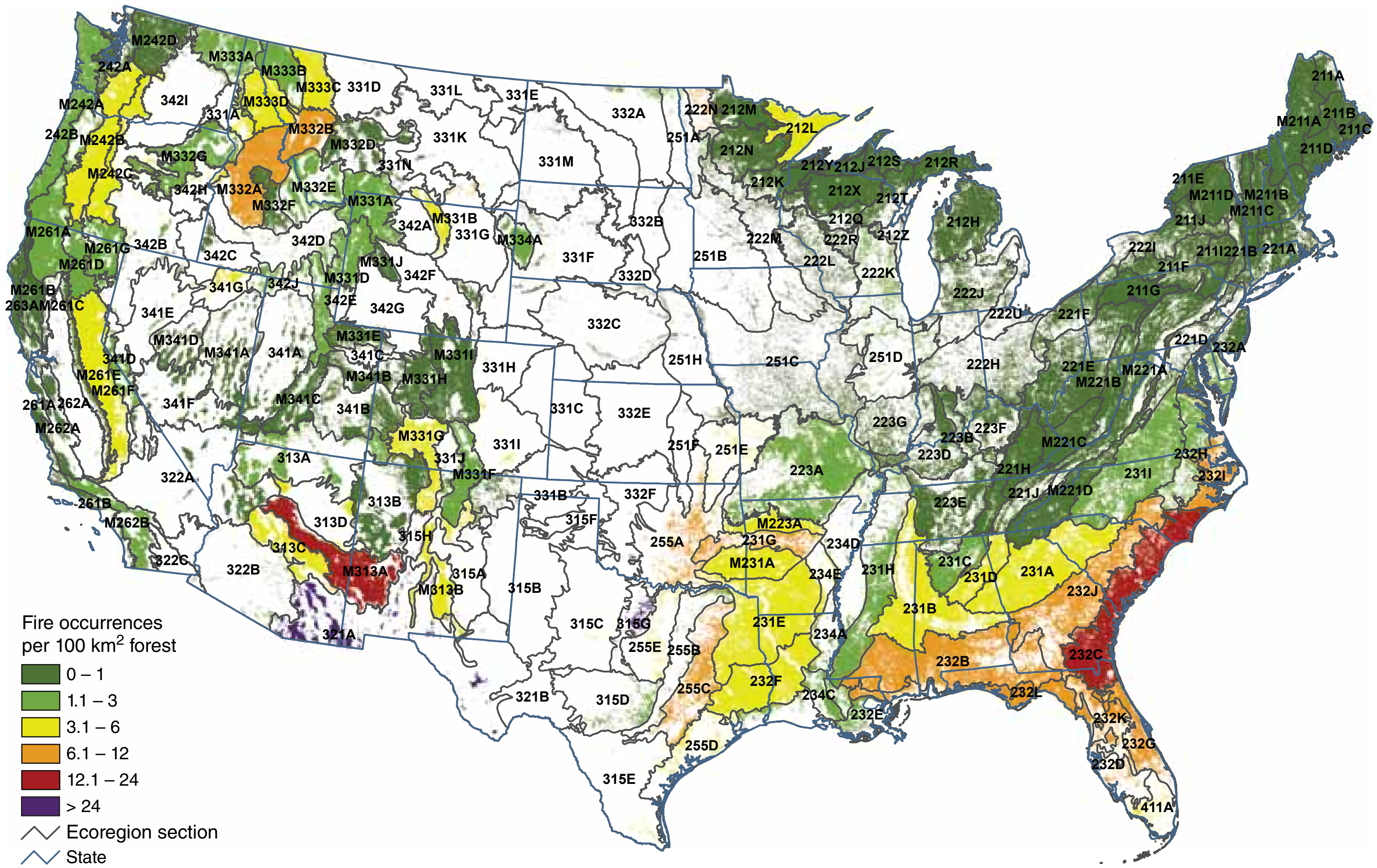


Figure 3.2—The number of forest fire occurrences, per 100 km^2 (10 000 ha) of forested area, by ecoregion section in the conterminous United States for 2011. The gray lines delineate ecoregion sections (Cleland and others 2007). Forest cover is derived from MODIS imagery by the USDA Forest Service Remote Sensing Applications Center. (Source of fire data: USDA Forest Service, Remote Sensing Applications Center.)

Ecoregions in the south-central States of Arkansas and Oklahoma also experienced relatively high fire densities, including 231G-Arkansas Valley (9.4 fire occurrences per 100 km^2) and 255A-Cross Timbers and Prairie (9.2 per 100 km^2). Nearby, the 255C-Oak Woods and Prairie ecoregion of east Texas had 6.6 fires per 100 km^2 of forest.

Fire occurrences in the West, outside of New Mexico and Arizona, were relatively few compared with the occurrences in recent years. The only two highly forested ecoregions with relatively high densities of fire occurrences were in Idaho and western Montana: M332B-Northern Rockies and Bitterroot Valley and M332A-Idaho Batholith, with 10.8 and 7.3 fires per 100 km^2 of forest, respectively. In the North, 222N-Lake Agassiz-Aspen Woodlands in northern Minnesota saw a relatively high fire-occurrence density for its region, 6.7 per 100 km^2 of forest.

In Alaska, where very few fire occurrences were detected, all ecoregions experienced fewer than 0.5 fires per 100 km^2 of forest (fig. 3.3). The M139C-Dawson Range ecoregion had the highest fire-occurrence density, with only 0.3 fires per 100 km^2 of forest.

Contrasting short-term (1-year) wildland forest fire occurrence with longer term trends is possible by comparing these results for each ecoregion section with the results for the first 10 full years of MODIS Active Fire data collection (2001–10). In general, most of the Appalachian, Central Rocky Mountain, Mid-Atlantic, Midwestern, and Northeastern regions experienced fewer than 1 fire per 100 km^2 of forest during that period, with means higher in the Northern Rocky Mountain, Pacific, Southeast, and Southwest regions (fig. 3.4A). Heavily forested areas that have experienced the most fires, on average, were located near the California coast and in central Idaho (mean annual fire-occurrence densities of 6.1 to 12.0 per 100 km^2). Ecoregions with the greatest variation in fire-occurrence densities over time were also located along the California coast and in central Idaho, with moderate variation in the M261E-Sierra Nevada of California ecoregion and in north-central Washington and western Montana (fig. 3.4B). Lesser degrees of variation occurred throughout the Rocky Mountains and in the Southeast, with the lowest degree of variation apparent in the Midwest and Northeast.

In 2011, ecoregion sections in the Midwest, Northwest, Southeast, and Southwest experienced greater fire-occurrence density than normal compared with the 10-year mean and accounting for variability over time (fig. 3.4C). Several of these ecoregions had the highest fire-occurrence densities in 2011, including 321A-Basin and Range, M313A-White Mountains-San Francisco Peaks-Mogollon Rim, 315G-Eastern Rolling Plains, and 232C-Atlantic Coastal Flatwoods. Others had moderate fire-occurrence densities in 2011 that still deviated

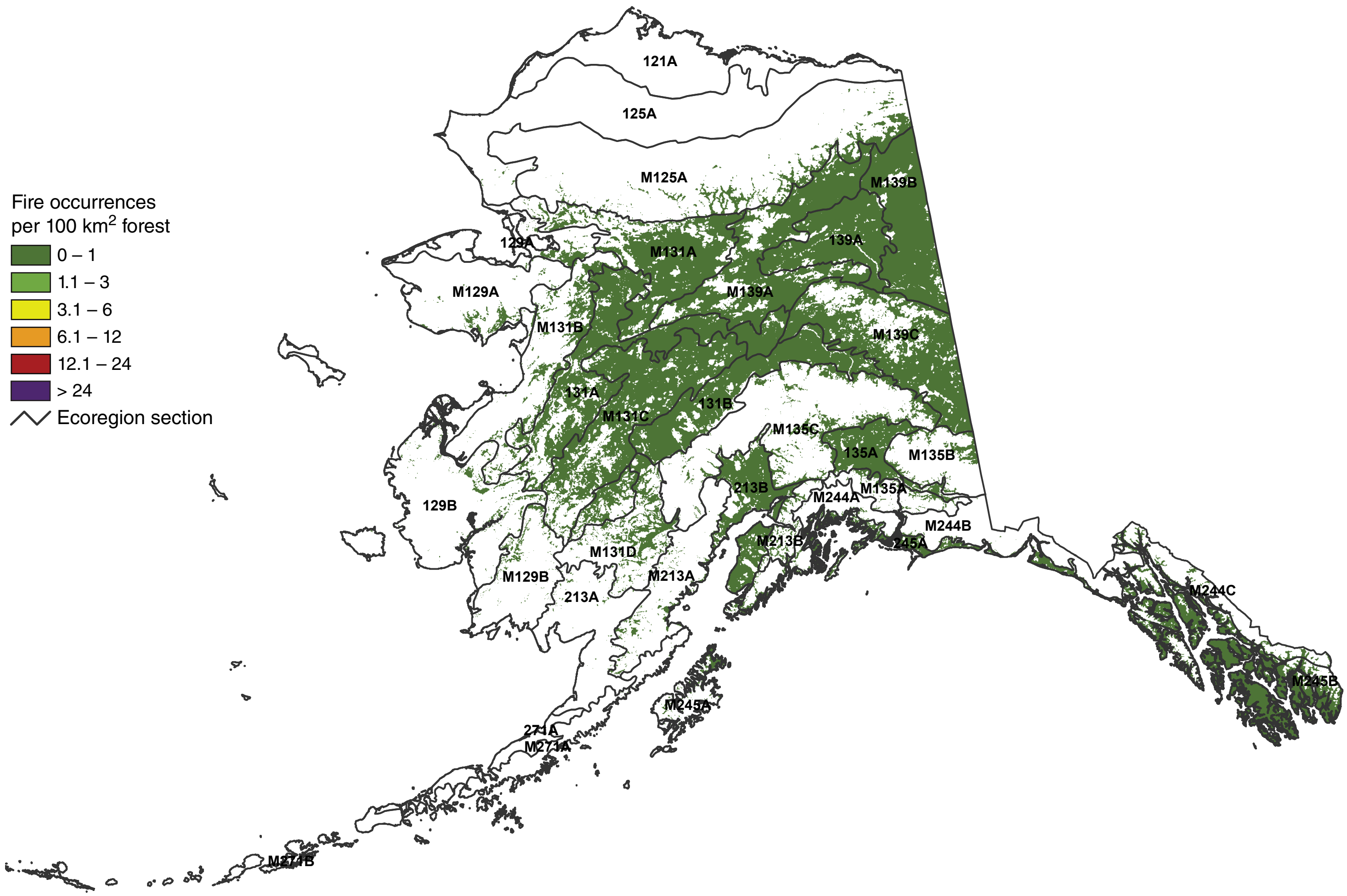
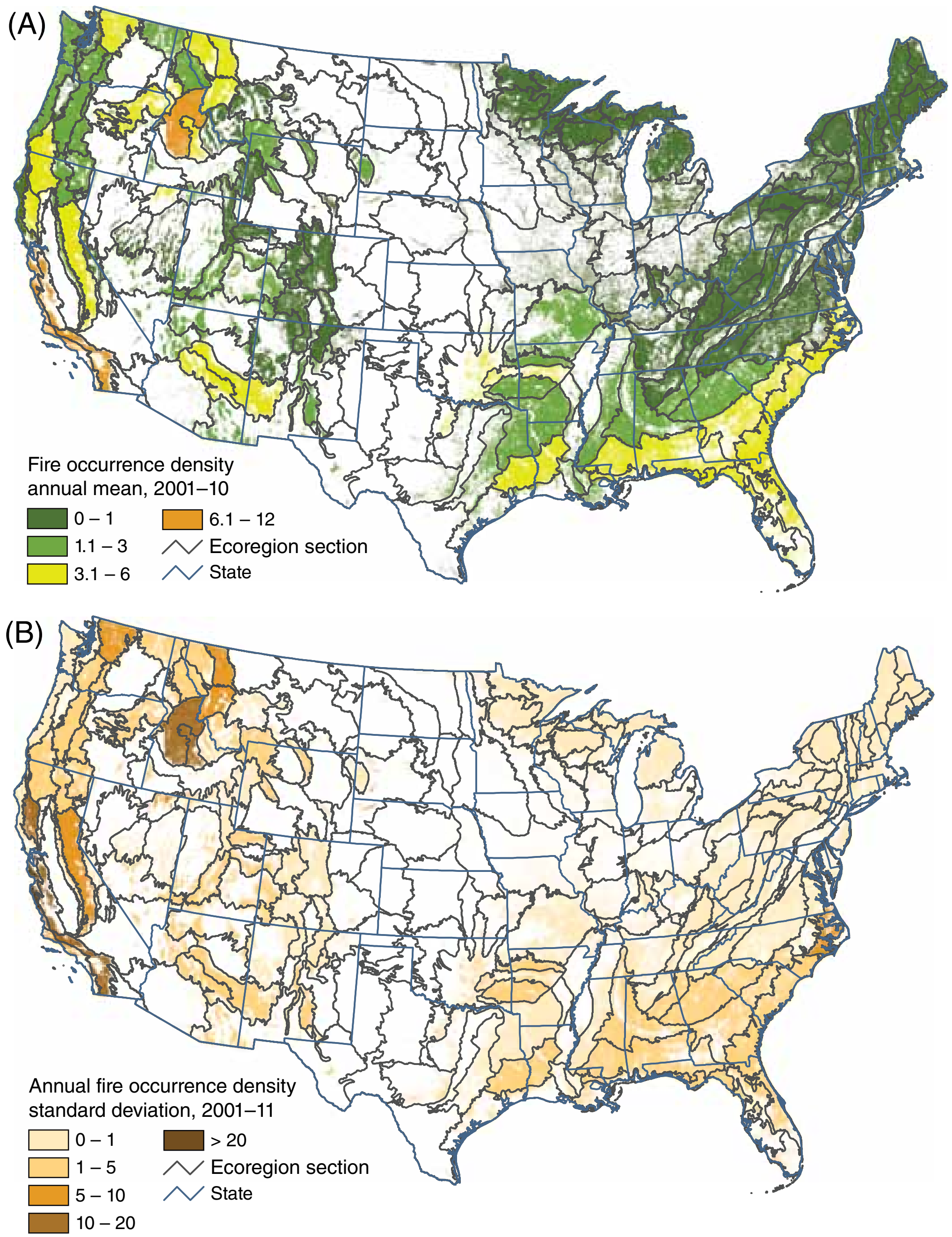


Figure 3.3—The number of forest fire occurrences, per 100 km² (10 000 ha) of forested area, by ecoregion section in Alaska for 2011. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Forest cover is derived from MODIS imagery by the USDA Forest Service Remote Sensing Applications Center. (Source of fire data: USDA Forest Service, Remote Sensing Applications Center.)



considerably from the previous 10-year mean, including 212L-Northern Superior Uplands of Minnesota; M331G-South-Central Highlands of Colorado and New Mexico; 231E-Mid-Coastal Plains-Western of east Texas, northern Louisiana, and southern Arkansas; and M231A-Ouachita Mountains and 231G-Arkansas Valley of Oklahoma and Arkansas.

Perhaps more interesting is the fact that some ecoregions had relatively low fire-occurrence densities in 2011 that were still considerably higher than the longer term mean. These ecoregions include 231H-Coastal Plains-Loess of Mississippi, Tennessee, and Kentucky; 231C-Southern Cumberland Plateau of northern Alabama; 251D-Central Till Plains and Grand Prairies of Illinois and Indiana; and M341D-Western Great Basin and Mountains of central Nevada (fig. 3.4C). Conversely, some ecoregions with high relative fire-occurrence densities in 2011 did not deviate much from the longer term mean when considering temporal variability,

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 to 2010, by ecoregion section within the conterminous United States. (C) Degree of 2011 fire occurrence density excess or deficiency by ecoregion relative to 2001–10 and accounting for variation over that time. 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: USDA Forest Service, Remote Sensing Applications Center.) (continued to next page)

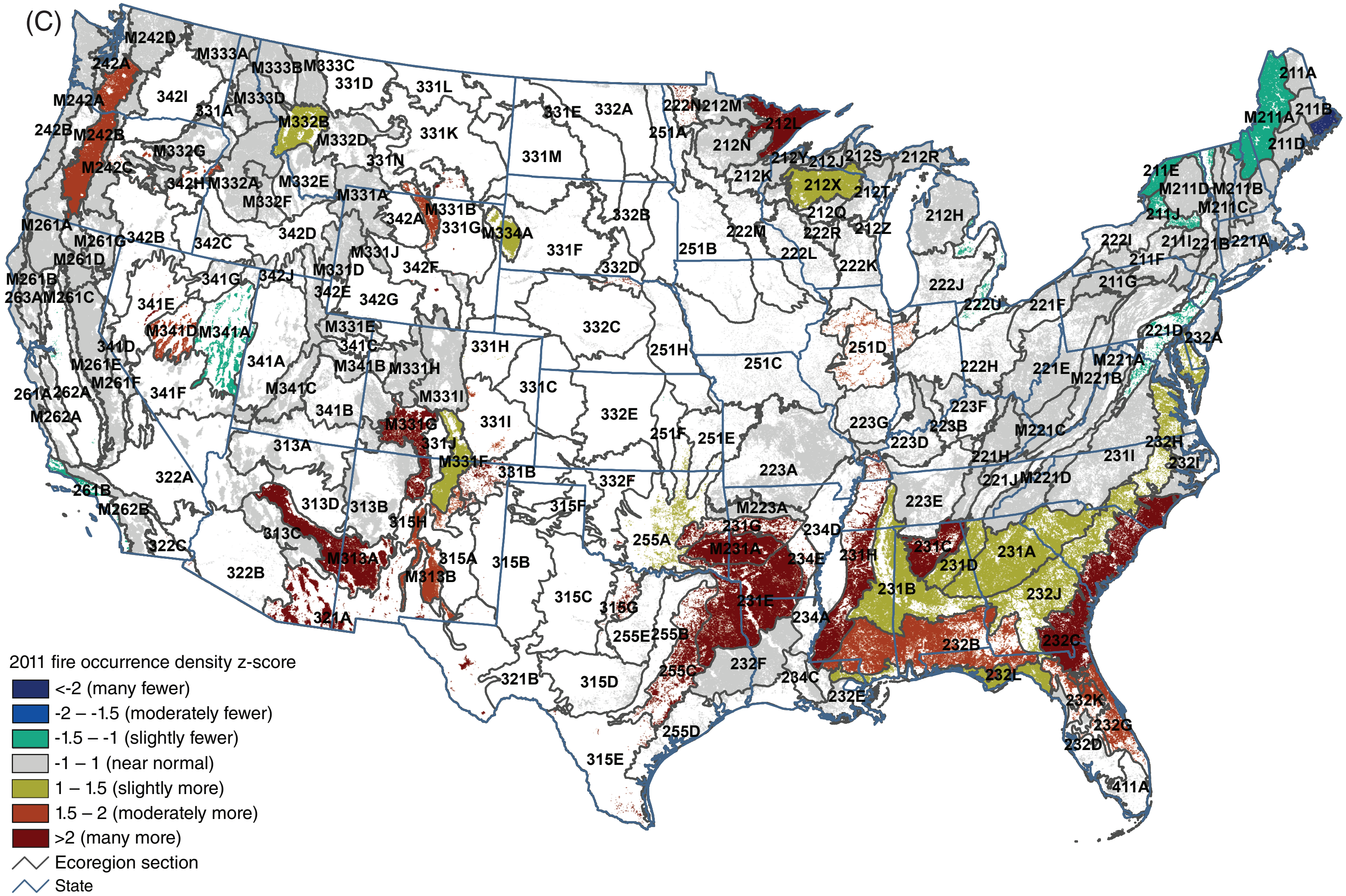


Figure 3.4 (continued)—(A) Mean number and (B) standard deviation of forest fire occurrences, per 100 km^2 (10 000 ha) of forested area from 2001 to 2010, by ecoregion section within the conterminous United States. (C) Degree of 2011 fire occurrence density excess or deficiency by ecoregion relative to 2001–10 and accounting for variation over that time. The gray lines delineate ecoregion sections (Cleland and others 2007). Forest cover is derived from MODIS imagery by the USDA Forest Service Remote Sensing Applications Center. (Source of fire data: USDA Forest Service, Remote Sensing Applications Center.)

including M332A-Idaho Batholith and several neighboring ecoregions, M261E-Sierra Nevada of California, and 232I-Northern Atlantic Coastal Flatwoods of eastern North Carolina.

A handful of ecoregions in the West and in the Northeast, meanwhile, had lower fire-occurrence densities in 2011 compared with the longer term mean. Most had relatively low long-term means and standard deviations, including 211C-Fundy Coastal and Interior and M211A-White Mountains of Maine, 211E-St. Lawrence and Champlain Valley and 211J-Tug Hill Plateau-Mohawk Valley of northern New York, and M341A-East Great Basin and Mountains of eastern Nevada (fig. 3.4C). One ecoregion, 261B-Southern California Coast, had a lower fire-occurrence density in 2011 compared with a relatively high long-term mean.

In Alaska, meanwhile, the highest mean annual fire-occurrence density between 2001 and 2010 occurred in the east-central and central parts of the State (fig. 3.5A), in the 139A-Yukon Flats and M139A-Ray Mountains ecoregions, with moderate mean fire-occurrence density in neighboring areas. Many of those same areas experienced the greatest degree in variability during the 10-year period (fig. 3.5B). In 2011, only two ecoregions were outside the range of near-normal fire-occurrence density compared with the mean of the previous 10 years and accounting for variability. The M135B-Wrangell Mountains ecoregion, an area in southeast Alaska, had a greater-than-normal fire-occurrence density, and 139A-Yukon Flats, in east-central Alaska, had a lower-than-normal fire-occurrence density (fig. 3.5C).

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 into where, at a finer scale, fire occurrences are concentrated. In 2011, the most intense geographical hot spots of fire density within the conterminous States existed in the Southwestern and Southeastern States, with less intense hot spots existing in the Northwest (fig. 3.6). In the Southwest, intense geographic hot spots occurred in the 321A-Chihuahuan Desert Basin and Range section of southwestern New Mexico and southeastern Arizona and in the M313A-White Mountains-San Francisco Peaks-Mogollon Rim section of western New Mexico and eastern Arizona.

Less intense geographic hot spots of fire-occurrence density in the region were detected in 315G-Eastern Rolling Plains of north-central Texas; 315D-Edwards Plateau, 255B-Blackland Prairie, and 255C-Oak Woods and Prairie of east Texas; 321A-Chihuahuan Desert Basin and Range of west Texas; 255A-Cross Timbers and Valley, 231G-Arkansas Valley, and M231A-Ouchita Mountains of eastern Oklahoma; and M331G-South-Central Highlands, M313B-Sacramento-Monzano Mountains, and M331F-Southern Parks and Rocky Mountain Range of north-central New Mexico (fig. 3.6).

In the Southeast, a 2011 high-intensity hot spot of fire-occurrence density occurred

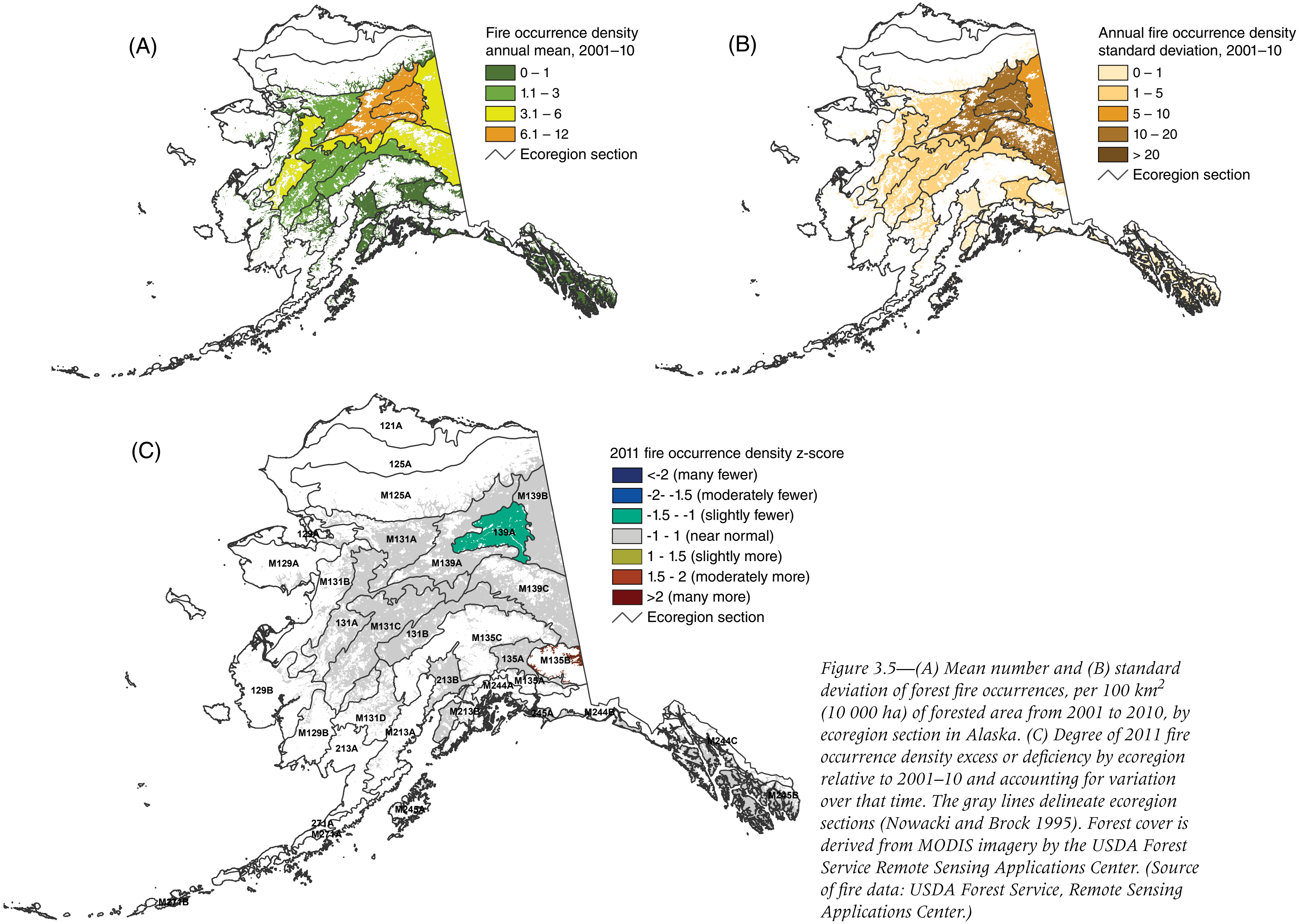


Figure 3.5—(A) Mean number and (B) standard deviation of forest fire occurrences, per 100 km² (10 000 ha) of forested area from 2001 to 2010, by ecoregion section in Alaska. (C) Degree of 2011 fire occurrence density excess or deficiency by ecoregion relative to 2001–10 and accounting for variation over that time. The gray lines delineate ecoregion sections (Nowacki and Brock 1995). Forest cover is derived from MODIS imagery by the USDA Forest Service Remote Sensing Applications Center. (Source of fire data: USDA Forest Service, Remote Sensing Applications Center.)

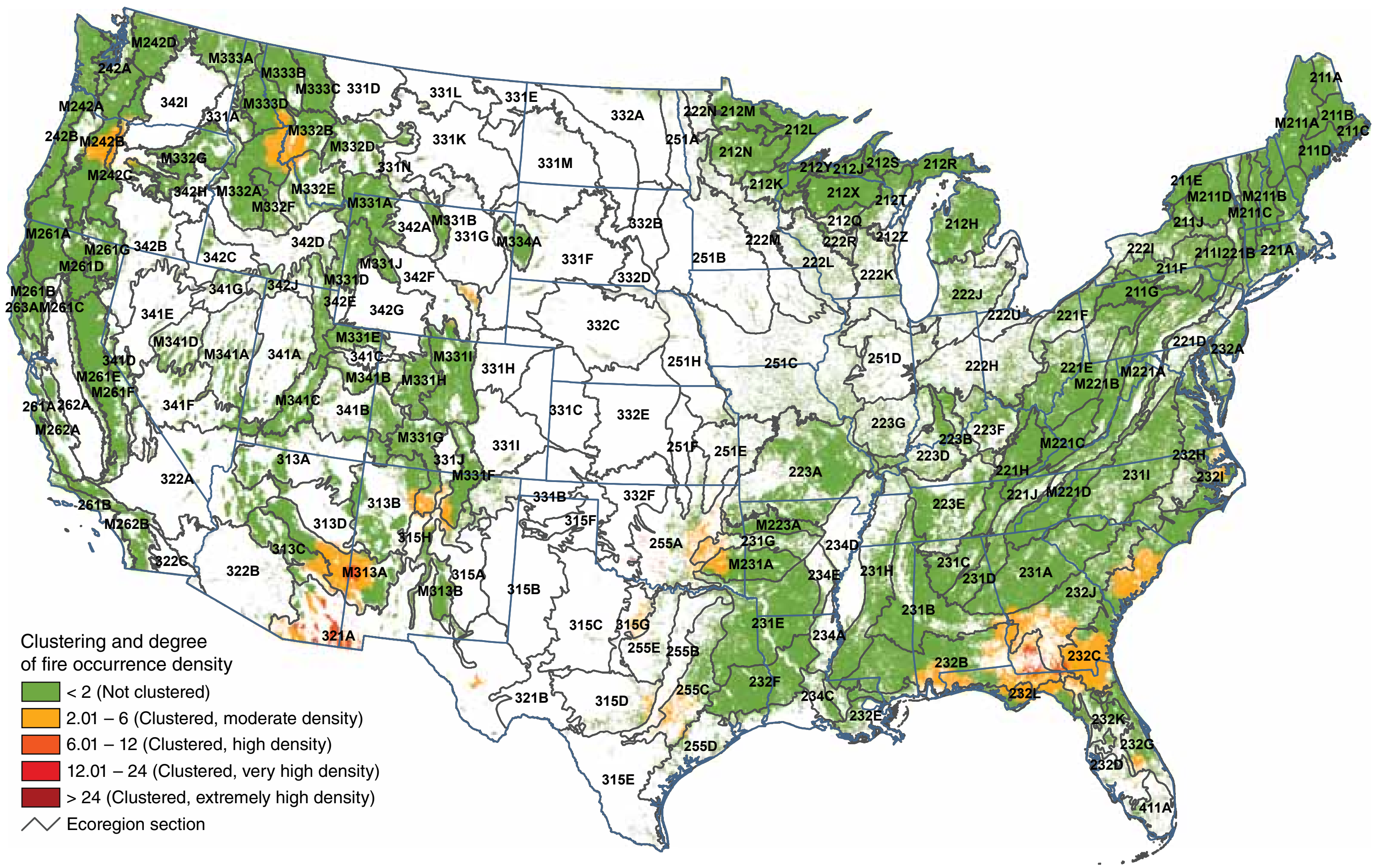


Figure 3.6—Hot spots of fire occurrence across the conterminous United States for 2011. Values are Getis-Ord G_i* *scores, with values > 2 representing significant clustering of high fire occurrence densities. (No areas of significant clustering of low fire occurrence densities, <-2, were detected.) The gray lines delineate ecoregion sections (Cleland and others 2007). Background forest cover is derived from MODIS imagery by the USDA Forest Service Remote Sensing Applications Center. (Source of fire data: USDA Forest Service, Remote Sensing Applications Center.)*

in 232B-Gulf Coastal Plains and Flatwoods, 232J-Southern Atlantic Coastal Plains and Flatwoods, 232L-Gulf Coastal Lowlands, and 232C-Atlantic Coastal Flatwoods of southeastern Alabama, southern Georgia, and north-central Florida. Less intense geographic hot spots were detected in the Southeast, in 232B-Gulf Coastal Plains and Flatwoods of southern Alabama and western Florida, 232C-Atlantic Coastal Flatwoods of South Carolina, 232I-Northern Atlantic Coastal Flatwoods of eastern North Carolina, and 232G-Florida Coastal Lowlands-Atlantic and 232D-Florida Coastal Lowlands-Gulf of southern Florida.

A handful of other low-intensity geographic hot spots of fire occurrence were detected in the Northwest and the Interior West:

- M242B-Western Cascades and M242C-Eastern Cascades of north-central Oregon.
- M332A-Idaho Batholith, M333D-Bitterroot Mountains, M332B-Northern Rockies and Bitterroot Valley, and M323E-Beaverhead Mountains of eastern Idaho and western Montana.
- M331I-Northern Parks and Ranges of southeastern Wyoming.

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 with previous years but are not intended to quantify the severity of a given fire season. While ecological impact and forest health relating to fire and other abiotic disturbances are scale-dependent properties that in turn depend on management objectives (Lundquist and others 2011), information about the concentration of fire occurrences may be useful for identifying areas for management activities and for conducting followup investigations related to the ecological and socioeconomic impacts of fires that may be outside the range of historic frequency.

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