

Introduction

Wildland fire represents an important ecological mechanism in many forest ecosystems. It shapes the distributions of species, maintains the structure and function of fire-prone communities, and is a significant evolutionary force (Bond and Keeley 2005). At the same time, fire outside the historic range of frequency and intensity can have extensive economic and ecological impacts. More than half the forested area in the conterminous United States is either moderately or significantly altered from historical fire regimes, potentially altering key ecosystem components such as species composition, structural stage, stand age, canopy closure, and fuel loadings (Schmidt and others 2002). Fire suppression and the introduction of nonnative plants, in particular, have dramatically altered natural fire regimes (Barbour and others 1999), while fire regimes altered by global climate change could cause large-scale shifts in vegetation spatial patterns (McKenzie and others 1996).

Methods

The Moderate Resolution Imaging Spectroradiometer (MODIS) Active Fire Detections for the United States database (USDA Forest Service 2009) allows analysts to spatially display and summarize fire occurrence on a yearly basis (Coulston and others 2005, Potter 2012). Fire occurrences are defined as the satellite detection of wildland fire in a 1-km² pixel for one day, in a given year across the United States. The data are derived using the

MODL and Rapid Response algorithm from the thermal infrared bands of imagery collected daily by two satellites at a resolution of 1 km², 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 2009). 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 km², for example) and a cooler fire over a larger area (1 km², for example). The MODIS Active Fire database does well at capturing large fires, but may underrepresent rapidly burning, small and low-intensity fires, as well as fires in areas with frequent cloud cover (Hawbaker and others 2008).

The mean number of fire occurrences per 100 km² (10 000 ha) of forested area was determined for each ecoregion section in the conterminous United States (Cleland and others 2007) and Alaska (Nowacki and Brock 1995) for each year between 2001 (the first full year of MODIS data) and 2008 (the most recent full year of available data at the time of analysis). This forest fire occurrence density measure was calculated after screening out wildland fires on nonforested pixels using a forest cover layer derived by the Remote Sensing Applications Center of the Forest Service, U.S. Department of Agriculture, from MODIS imagery (USDA Forest Service 2008). The total number of fire occurrences in each year across the conterminous States and Alaska was also calculated.

CRITERION 3—

Chapter 9. Large-Scale Patterns of Forest Fire Occurrence in the Conterminous United States and Alaska, 2001-08

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Additionally, 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 United States with greater-than-expected fire occurrence density. A hot spot analysis was conducted for the total number of fire occurrences from 2001 to 2008, all of the years for which a full 12 months of data were available. Separate hot spot analyses were then conducted for each of the last 4 years of available data, to depict recent annual trends in fire occurrences.

The spatial units of analysis were cells of approximately 2 500 km² 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). 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 km² (10 000 ha) of forested area within the hexagon. For each of the temporal units of analysis, the Getis-Ord G_i^* statistic was used to identify clusters of hexagonal cells with fire occurrence density values higher than expected by chance.

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 the six neighboring hexagons, and the global

mean of all the forested hexagonal cells in the conterminous United 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 ($p < 0.025$), since 95 percent of the observations under a normal distribution should be within approximately 2 standard deviations of the mean (Laffan 2006). Increasingly large values indicated greater spatial clustering of fire occurrence densities. Values between -1.96 and 1.96 have no statistically significant concentration of high or low values; a hexagon and its six neighbors, in other words, have a range of both high and low numbers of fire occurrences per 100 km² of forested area. 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 database captured 94,825 wildland forest fire occurrences across the conterminous United States in 2008, the most since the initial collection of MODIS data in 2000, and more than double the 8-year mean of 44,837 forest fire occurrences (fig. 9.1). Meanwhile, the database captured only 1,220 fire occurrences in Alaska, much lower than the peak fire year of 2004, when MODIS recorded 51,871 fire occurrences in Alaska. The patterns of fire occurrences in the conterminous United States and Alaska are considerably different, with the most fires occurring in the

conterminous United States in 2006, 2007, and 2008, while the peak fire years in Alaska were 2004 and 2005 (fig. 9.1). This peak in Alaska fire occurrences coincides with two relatively low-fire years in the conterminous United States, where fewer fire occurrences were recorded than in Alaska.

Over the 8-year period during which MODIS fire occurrence data have been recorded, ecoregion section 261A-Central California Coast has experienced the most fires per year, 12.78 fires per 100 km² of forested area (fig.9.2A). Other ecoregion sections with high mean fire occurrence densities are M332F-Challis Volcanics

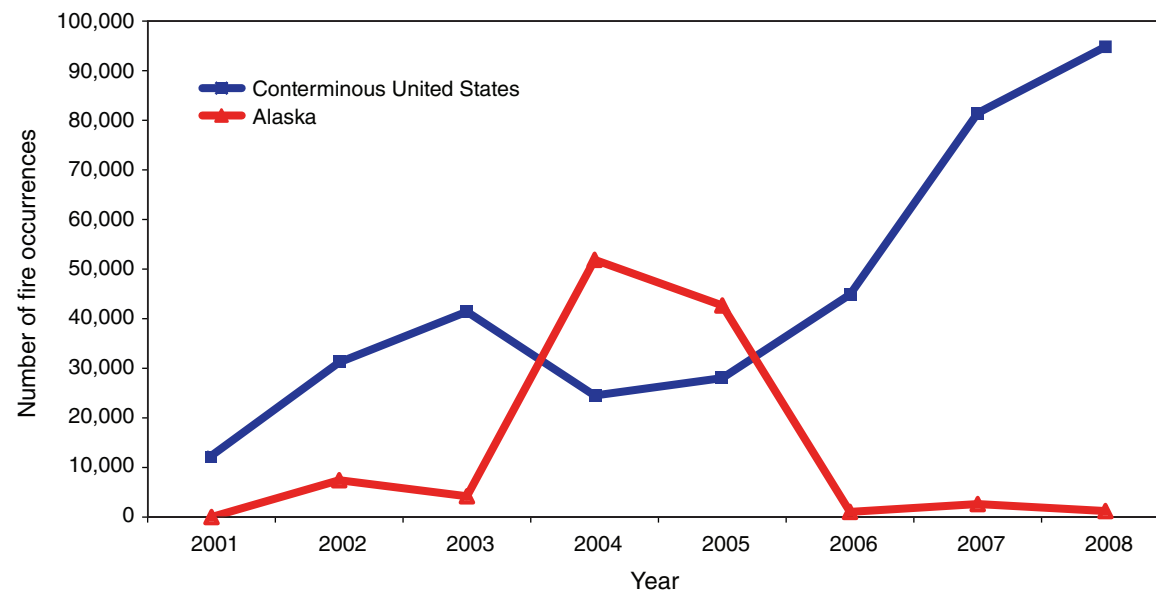


Figure 9.1—Forest fire occurrences detected by MODIS from 2001 to 2008, for the conterminous United States and Alaska (Data source: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center.)

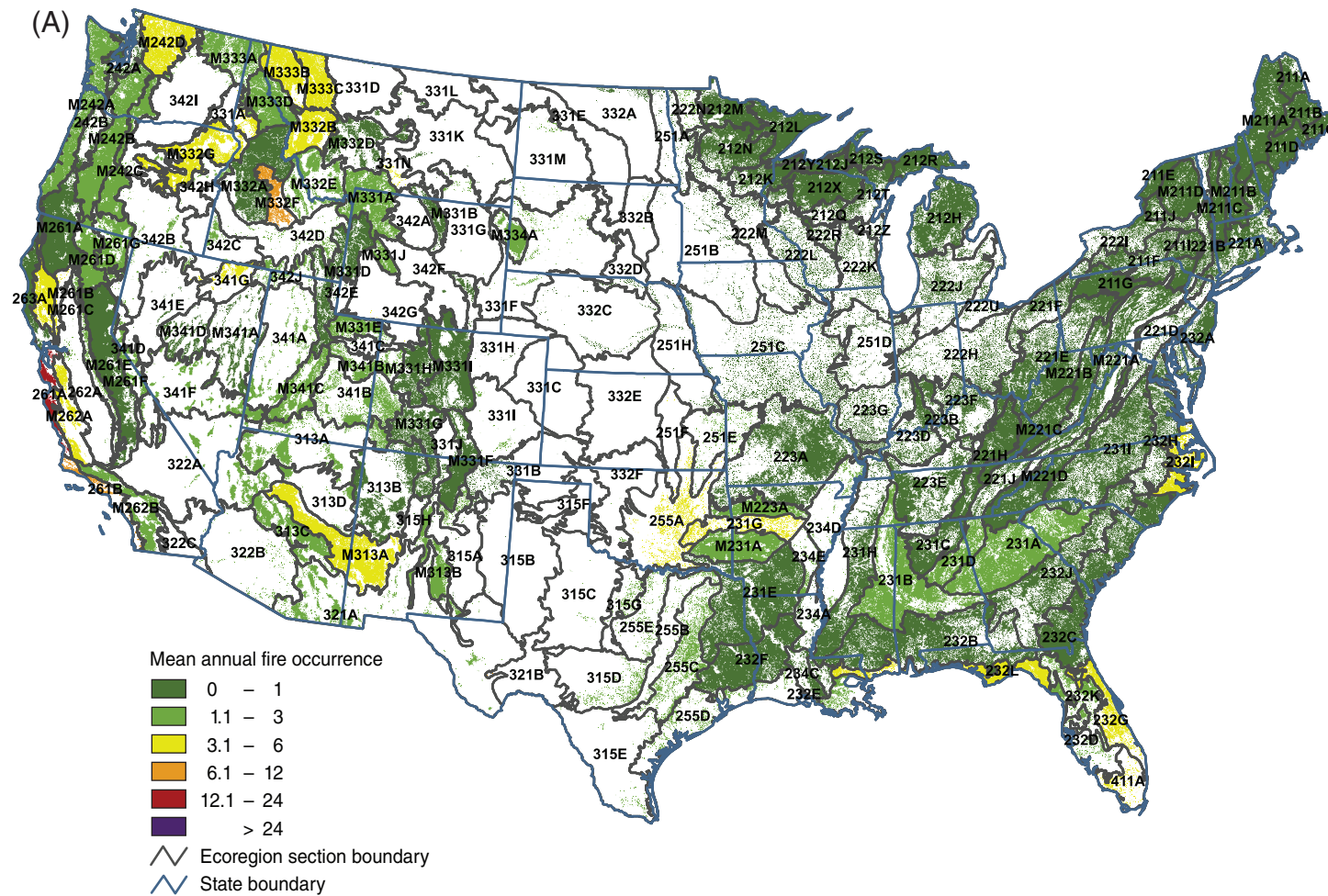
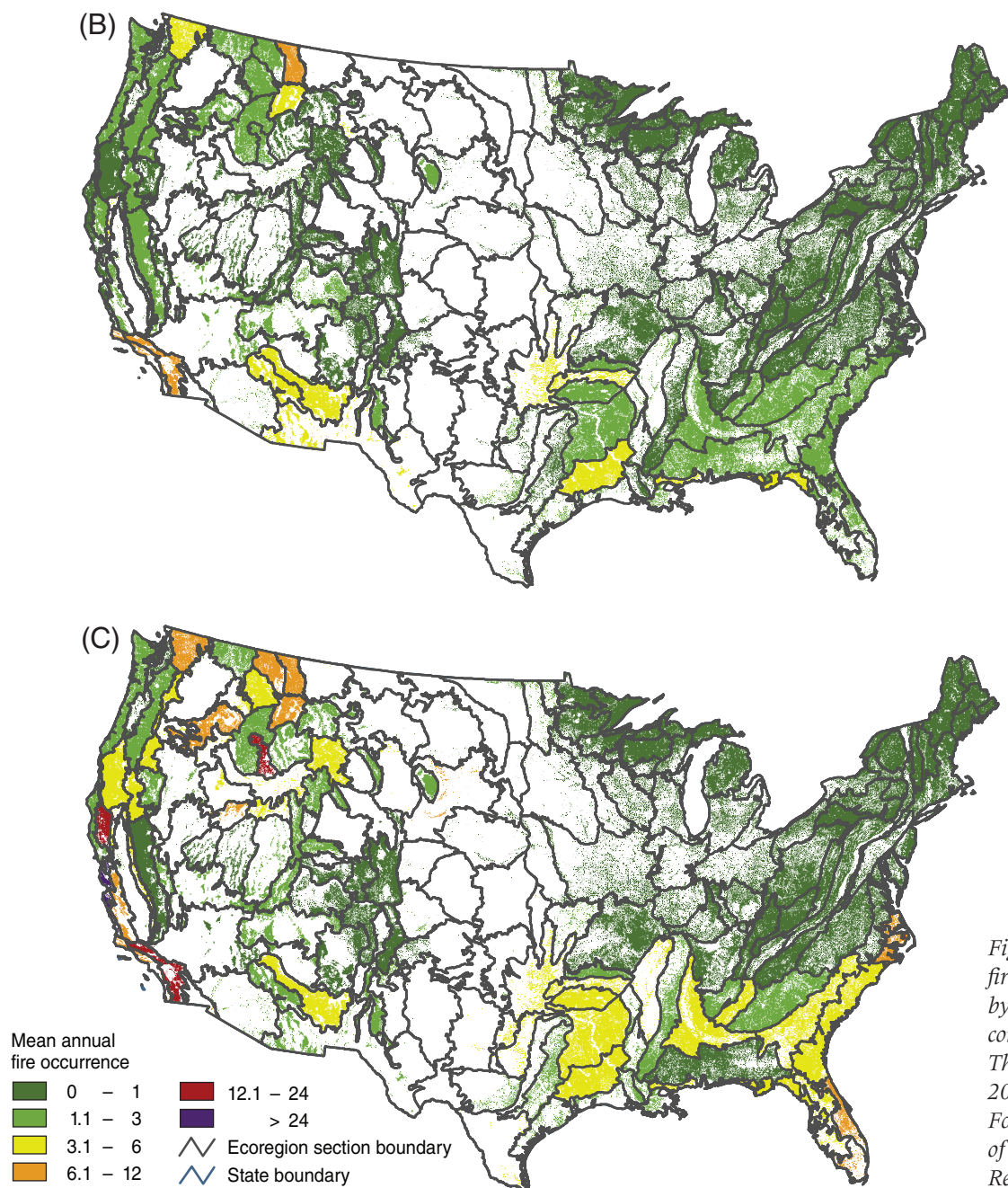


Figure 9.2—The mean annual number of forest fire occurrences, per 100 km² (10 000 ha) of forested area, by ecoregion section (Cleland and others 2007) within the conterminous United States, for (A) 2001–08, (B) 2003–05 and (C) 2006–08. The gray lines delineate ecoregion sections (Cleland and others 2007). 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.) (continued on next page)



in central Idaho, with 6.14 fires per year per 100 km² of forest; 261B-Southern California Coast, with 6.02; and M261B-Northern California Coast Ranges with 5.98 fires. Ecoregion sections with moderate fire occurrence densities are generally located in the northern Rocky Mountains, the Southeast, and the Southwest.

An ecoregion-level comparison of fire occurrence densities during 2003–05 and 2006–08 reveals a large increase in the number of fires in several ecoregion sections (fig. 9.2B and fig. 9.2C). From 2003 to 2005, 16 sections had more than three fire occurrences per year per 100 km² of forest, while 3 sections had more than six fires per year for that amount of forest, compared to 52 and 20 sections, respectively, for 2006–08. The Central California Coast averaged a remarkable 33.18 fire occurrences each year per 100 km² of forest from 2006 to 2008.

In Alaska, the highest fire occurrence densities over the 8 years of MODIS data collection were recorded in the four ecoregion sections of the 139-Upper Yukon Taiga Province, particularly 139A-Yukon Flats and M139A-Ray Mountains (fig. 9.3A). In contrast to the pattern in the

Figure 9.2 (continued)—The mean annual number of forest fire occurrences, per 100 km² (10 000 ha) of forested area, by ecoregion section (Cleland and others 2007) within the conterminous United States, for (B) 2003–05 and (C) 2006–08. 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.)

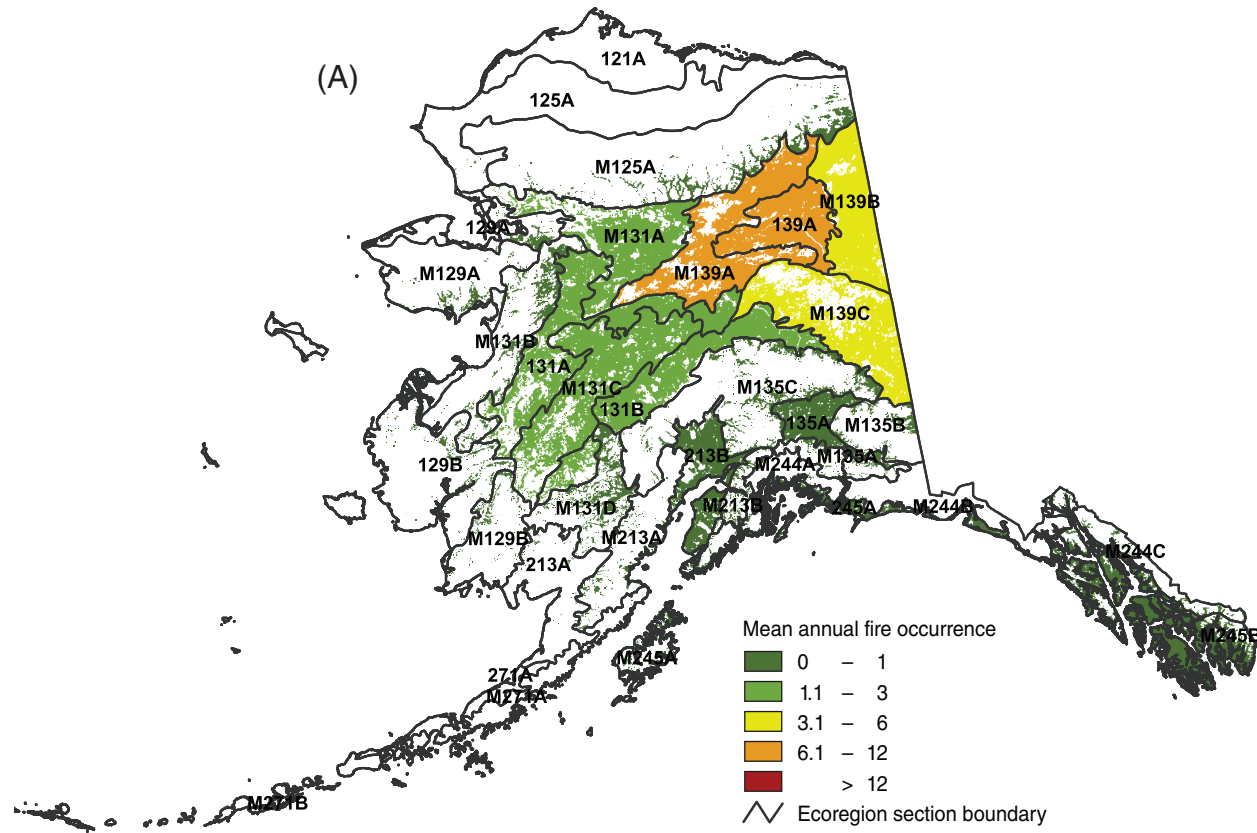


Figure 9.3—The mean annual number of forest fire occurrences, per 100 km² (10 000 ha) of forested area, by ecoregion section (Nowacki and Brock 1995) within Alaska, for (A) 2001–08, (B) 2003–05, and (C) 2006–08. The gray lines delineate ecoregion sections. Forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Source of fire data: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center.) (continued on next page)

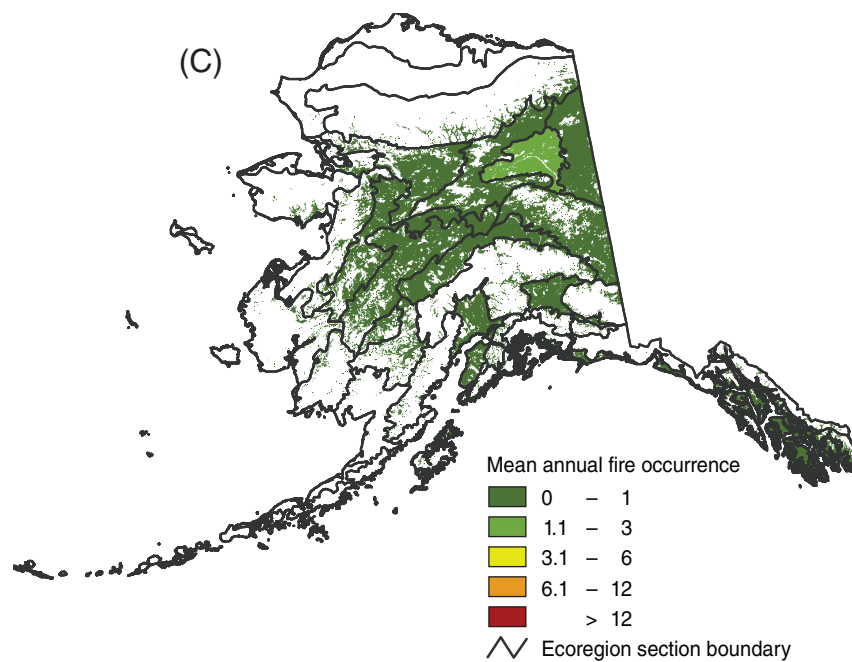
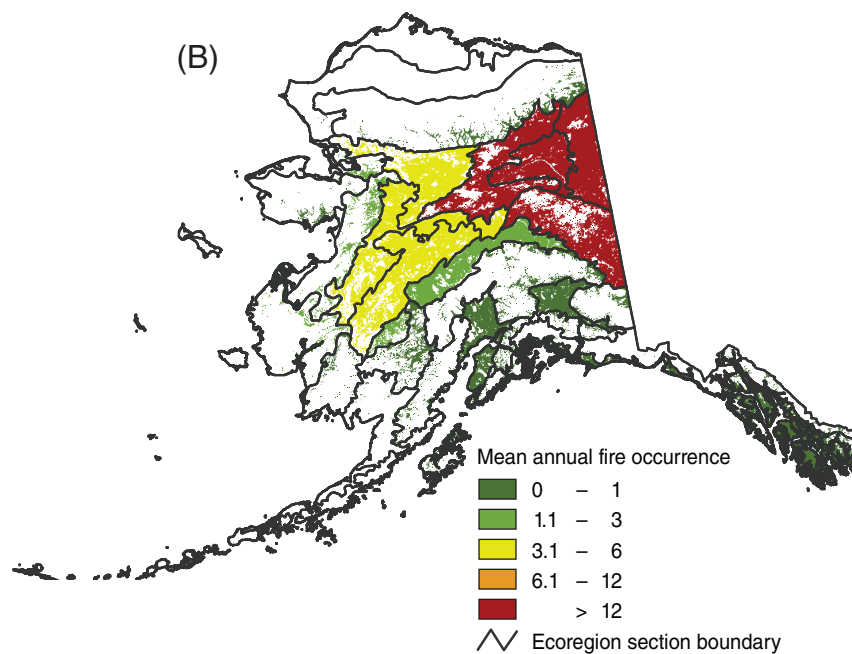


Figure 9.3 (continued)—The mean annual number of forest fire occurrences, per 100 km² (10 000 ha) of forested area, by ecoregion section (Nowacki and Brock 1995) within Alaska, for (B) 2003–05, and (C) 2006–08. The gray lines delineate ecoregion sections. Forest cover is derived from MODIS imagery by the U.S. Forest Service Remote Sensing Applications Center. (Source of fire data: U.S. Department of Agriculture Forest Service, Remote Sensing Applications Center.)

conterminous United States, the fire occurrence densities were much greater in the period of 2003–05 (fig. 9.3B) than in 2006–08 (fig. 9.3C). During the earlier period, seven ecoregions averaged more than six fire occurrences per year per 100 km² of forest, with four ecoregions averaging more than 12 fires. During the later period, only one ecoregion (139A-Yukon Flats) averaged more than one fire occurrence per 100 km² of forest.

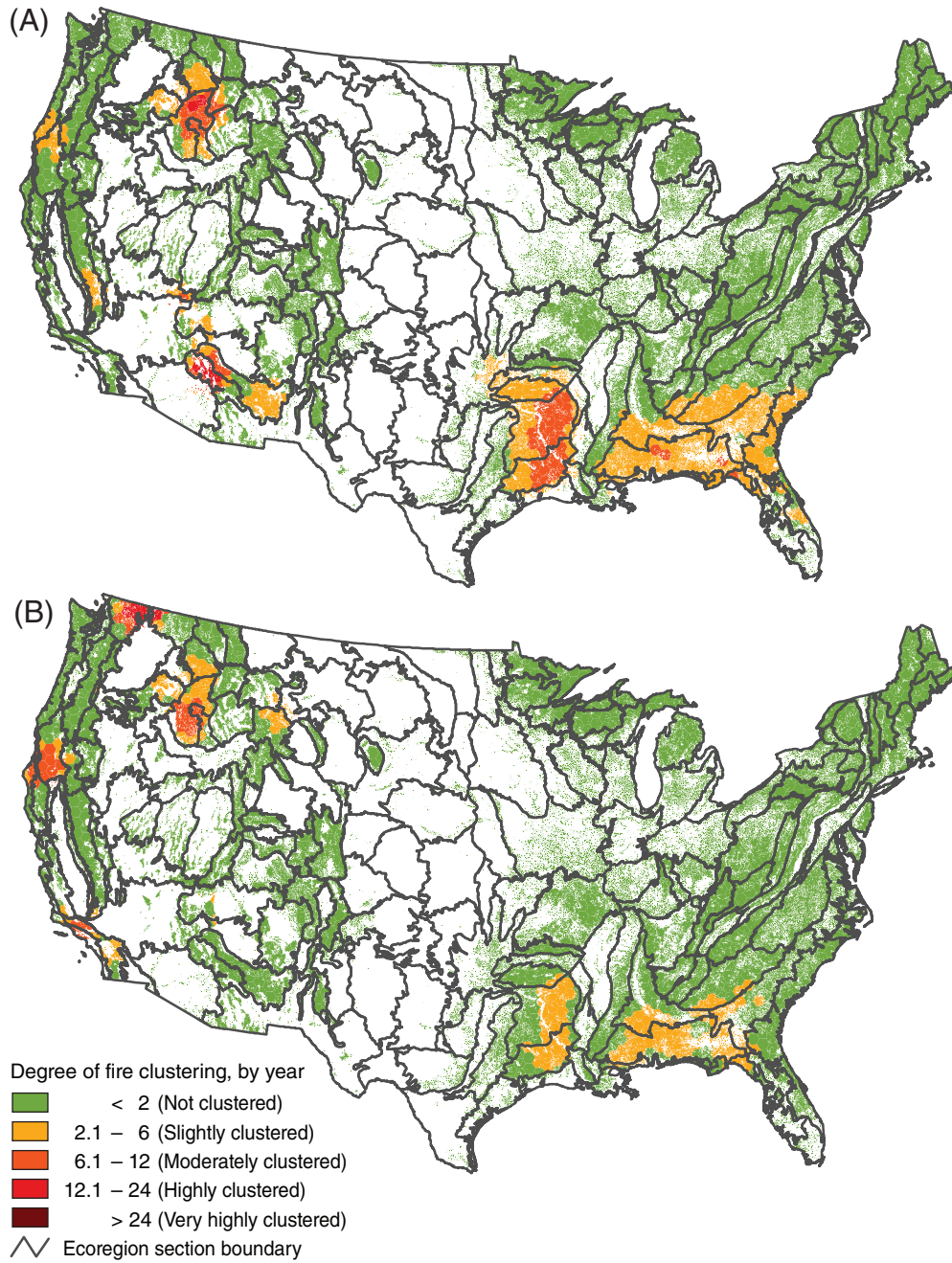
While summarizing fire occurrence data at the ecoregion scale allows for the summary of fire density over time in a relatively large geographic area, a geographical hot spot analysis can offer insights into where fire occurrences are concentrated at a finer scale during a given length of time.

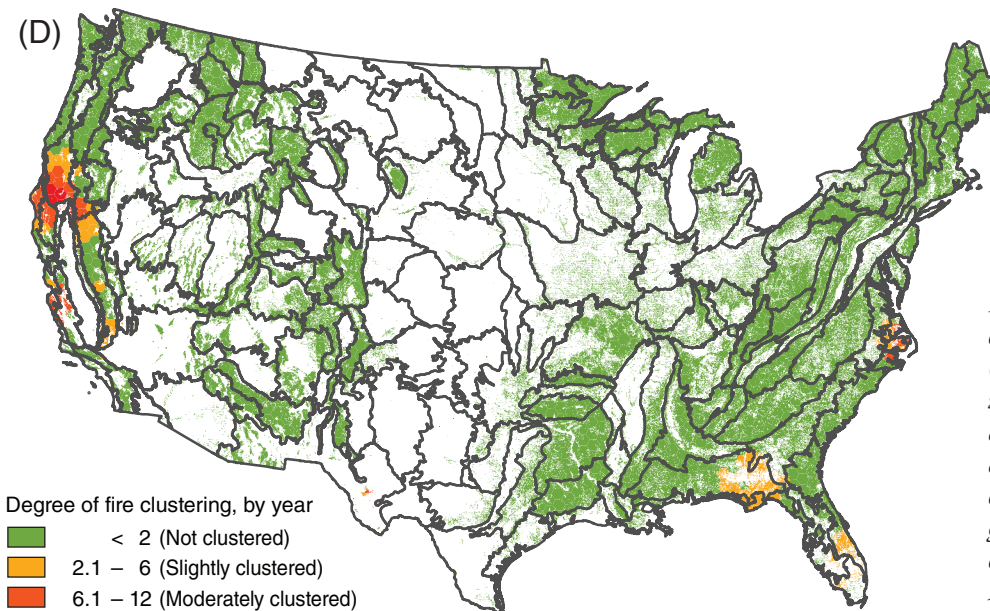
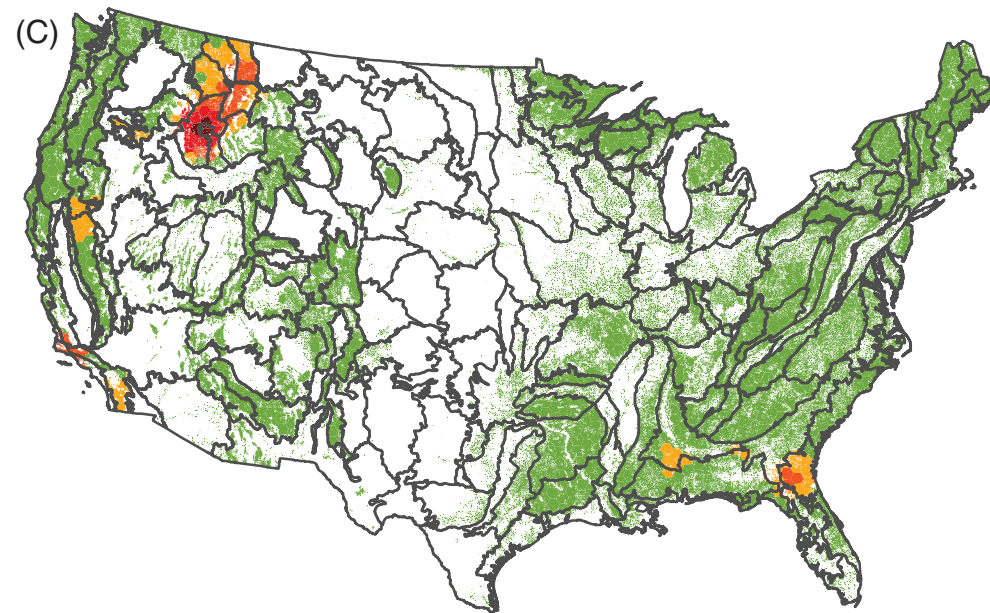
Across the 8-year period during which MODIS fire detection data were collected, geographical hot spots of fire occurrence density were limited almost entirely to the Pacific Coast, the Rocky Mountains, and the Southeastern Coastal Plain (fig. 9.4). Four of the highest-density hot spots were located in California, while another three were spread across the northern Rocky Mountains, in M333A-Okanogan Highlands in

Washington, M332A-Idaho Batholith, and M332F-Challis Volcanics in Idaho, and M331I-Northern Parks and Ranges in Wyoming. New high-density hot spots were detected in 2008 on the central coast of California, in coastal North Carolina, and in west Texas (fig. 9.5D), compared to hot spots from the 3 previous years (fig. 9.5A–C). Lower-density hot spots during that year were located in the central and southern Sierra Nevada of California; in south Florida; and in the Gulf Coastal Plains of northwest Florida, southwestern Georgia, and southeastern Alabama.

The results of these hot spot analyses are intended to offer insights into where fire occurrences have been concentrated both over time and during specific years. They are not intended to quantify the severity of a given fire season. When considered across multiple years, information about the concentration of fire occurrences may be useful for the identification of areas for management activities and for follow-up investigations related to the ecological, economic, and sociological impact of fires that may be outside the range of historic frequency.

Figure 9.5—Hot spots of high fire occurrence across the conterminous United States for (A) 2005, (B) 2006, (C) 2007, and (D) 2008. Values are Getis-Ord G_i^* scores, with values greater than 2 representing strong and significant clustering of high fire occurrence densities. (No areas of significant clustering of low fire occurrence densities, less than -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.) (continued on next page)





Degree of fire clustering, by year

■	< 2 (Not clustered)
■	2.1 – 6 (Slightly clustered)
■	6.1 – 12 (Moderately clustered)
■	12.1 – 24 (Highly clustered)
■	> 24 (Very highly clustered)
—	Ecoregion section boundary

Figure 9.5 (continued)—Hot spots of high fire occurrence across the conterminous United States for (C) 2007, and (D) 2008. Values are Getis-Ord G_i^* scores, with values greater than 2 representing strong and significant clustering of high fire occurrence densities. (No areas of significant clustering of low fire occurrence densities, less than -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.)

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