

Introduction

Criterion 3, Indicator 16, of the Montréal Process Criteria and Indicators for the Conservation and Sustainable Management of Temperate and Boreal Forests was designed to assess the impact of abiotic agents upon forests (Montréal Process Working Group 2007). Various abiotic agents, both natural and human-induced, can change forest structure and species composition. Where such change goes beyond a critical threshold, forest ecosystem health may be significantly altered and its ability to recover from disturbance reduced or lost, often meaning a reduction or loss of benefits associated with that forest ecosystem. Monitoring the area and percent of forests affected by abiotic agents beyond reference conditions may provide information needed in the formulation of management strategies to mitigate risk. The summary of this analysis is reported in the National Report on Sustainable Forests 2010 Report (USDA Forest Service 2011) while the purpose of this document is to provide the detailed evidence to support the reported data.

Objectives and Methods

The original National Report on Sustainable Forests 2003 (USDA Forest Service 2004) and the Montréal Process Working Group (2007) identified several abiotic agents: fire, storm, land clearance, permanent flooding, salinization, specific air pollutants (e.g., sulfates, nitrate, ozone), ultraviolet B, and soil nutrient cycling. These were addressed in three separate indicators. In the National Report on Sustainable

Forests 2010, these were reorganized and addressed as one indicator (Criterion 3, Indicator 16) and were grouped into five sub-indicators that have the greatest impact on forest health. These abiotic sub-indicators are fire, weather-related damage, pollution, land use, and climate.

Quantitative temporal analyses of these abiotic sub-indicators were completed based on spatial and tabular data between the most recent 5-year analysis period (2003–07) and the previous 5-year time period (1998–2002). To summarize specific impact on forests, all sub-indicator assessments were limited to forested areas by using a forest/nonforest mask generated by the Remote Sensing Applications Center of the Forest Service, U.S. Department of Agriculture (Blackard and others 2008).

Fire—Data for acreage burned (1960–2007) were acquired from the National Interagency Fire Center-Wildland Fire Statistics, and the data include all wildland cover types burned. Additional data for 1916 to 1959 were acquired from the Heinz Center Report (2008). These data give a reasonably accurate national acreage estimate, but the data are nonspatial and do not specifically report forested acreage. Burn severity data from the Monitoring Trends in Burn Severity (MTBS) program come from a multi-year project designed to consistently map the burn severity and perimeters of fires across all lands of the United States starting from 1984 using the remotely sensed Landsat archive (Eidenshink and others 2007). For this report, nationwide data were available from 2004 to

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2007, with older historical data available from 1984 for the western region and from 1997 for the southern region. The data show the proportion of burn severity classes within each landcover type. For this report, data were limited to the forested landcover type.

Weather-related damage—Weather-related damage is tracked through the Aerial Detection Survey (ADS) Program of the Forest Service (USDA Forest Service 2008a). Weather-related damage caused by drought, flood, ice, hail, lightning, wind (hurricane/tornado), and avalanche agents is represented only in areas that have been tasked for survey and may not represent all of the area impacted by the agent. Areas surveyed are often preselected due to known active agents, and the total area that may be damaged cannot be estimated based upon a statistically valid sample due to the preselection bias. Data were either sketched directly on maps using standard coding and reporting criteria or captured using Digital Aerial Sketch Mapping (DASM) as an aide in the airplane or on the ground. The collected data are stored in a national ADS database (USDA Forest Service 2008a). Other sources of storm damage data, such as the National Climate Data Center storm event database, do not specifically track forest damage. It may be possible to build a geospatial dataset to produce relative damage severity; however, this effort was not pursued for this report.

Pollution—The ozone (O_3) biomonitoring program of the Forest Health Monitoring (FHM) Program of the Forest Service uses ozone-

sensitive plants to monitor air quality and the potential impacts of tropospheric O_3 (smog) on forest lands. These data include both tabular regional synopses and a raster surface model using the biomonitoring site point data. The surface ozone-injured indicator plants regional summary and graph were obtained from Smith and others (2008). A Critical Acid Loading (CAL) surface raster model obtained from McNulty and others (2007), and the forest mask were applied to create a CAL grid layer for forested areas. The data were summarized and graphed.

Land use—Assessments about urban sprawl have focused on quantifying land use changes in urban and metropolitan areas. It is critical for ecologists to examine and improve understanding of land use changes beyond the urban fringe, also called exurban sprawl, because of the extensive and widespread changes that are occurring. Human development and its impacts are continually expanding into forest land. Housing density is used as a sub-indicator of that human development. Housing density raster surfaces were obtained from the Forest Service's Forest on the Edge Program (Stein and others 2005), which analyzed housing density data for 1970–2000 and projected the data for 2000–2020 (Theobald 2005). The 2000 and 2010 housing density raster surfaces were reassigned to four classes. The four housing density classes are: (1) rural and undeveloped (> 40 acres per unit), (2) exurban (1.7–40 acres per unit), (3) suburban (0.6–1.7 acres per unit), and (4) urban (< 0.6 acres per unit). All data were limited to forested areas using the forest mask.

Climate—The moisture index difference (*MID*) raster model (Koch and others 2012) is classified according to distinct value ranges for drought and wetness categories based on the 100-year average standard deviation of *MID*. An averaged *MID* grid surface for each analysis period (1998–2002 and 2003–07) was created by averaging the annual grid surfaces. The average *MID* grid surfaces were limited to only forested areas by applying a forest mask.

Results and Products

Results are presented assessing recent trends in the five abiotic sub-indicators listed above, discussing changes in these sub-indicators since the most recent 5-year reference period (1998–2002), and describing regional variation in the results.

Reference periods are generally arbitrary, but selecting a reference period for which data can be comparably measured offers a fixed point from which to analyze. Techniques and standards for historical data may have changed over time and would confound analysis. Recent developments in mapping technologies and available base data have allowed for a higher degree of accuracy and precision in mapping the extent of many of the sub-indicators. Improvements to mapping technologies will only improve subsequent data analysis.

Fire—As the most extensive among the sub-indicators in terms of area impacted, fire is an integral part of forested ecosystems. Since the

early half of the 20th century, extensive livestock grazing followed by increasingly effective fire suppression substantially reduced the annual acreage burned until the mid-1980s, when the trend reversed (Westerling and others 2006). The area burned in 2006 was the highest recorded since 1954 (fig. 8.1), but mapping standards and technologies have changed substantially and data compilations may not be comparable. Data compiled prior to 1983 were not spatially explicit in that the data had been collated from tabular reports received from the various fire agencies and summarized by the National Interagency Coordination Center. Many of the individual fire agencies are reconstructing spatially explicit historical data and future tallies of historical data may vary.

Wildland fire summaries for the entire time period are for all landcover types, and, due to the nonspatially explicit data, forested acreage burned cannot be determined. Many nonforested ecosystems have not experienced reduced fire frequencies in the 20th century (Omi and others 2004). For this reason, the overall trends witnessed in the recorded historical fire data may not be reflective of the trends for forested areas. The compilation of spatially explicit historical data would be necessary to precisely evaluate the long-term trends for fire in forested ecosystems. In addition to being inclusive of nonforested area, the acreage reported also summarizes area over an entire fire perimeter which includes areas nonburned or minimally burned.

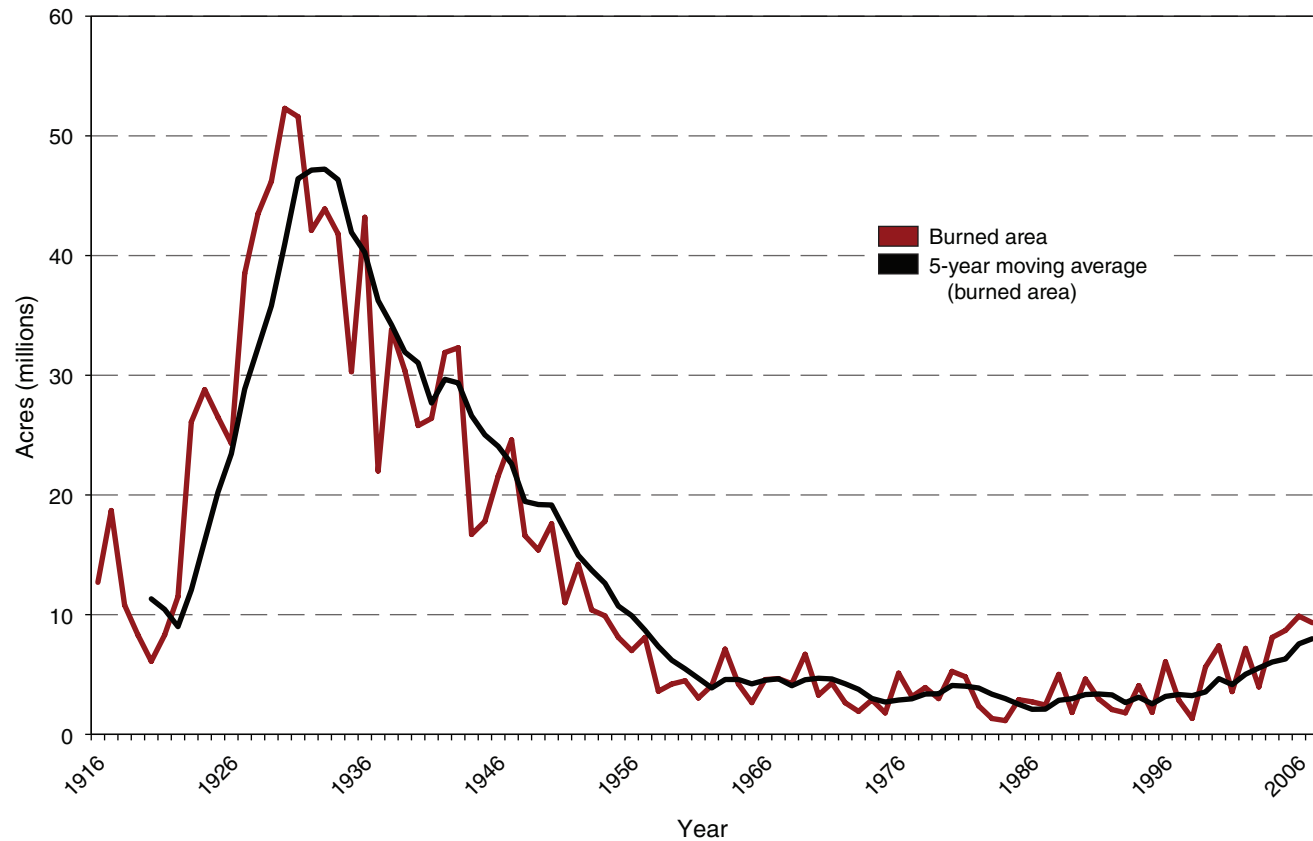


Figure 8.1—Historical acreage burned (Data source: National Interagency Fire Center, Heinz Center 2008).

Wildland fire data for the most recent period (2003–07) show the extent of wildland fires has increased. Forty million acres burned in the 5-year period, as compared to 25 million acres in the preceding 5-year period (table 8.1). Both of these periods are substantially less than the historic 5-year period maximum that occurred in the late 1920s, prior to the advent of effective fire suppression (fig. 8.1).

While a significant increase in the extent of wildland fires has occurred recently, concern over burn severity has prompted efforts to map the severity of large fires. The spatially explicit Monitoring Trends in Burn Severity (MTBS) data show for the most recent period (2003–07) that forested lands account for 13.1 million acres of the burned area or approximately 1.7 percent of all forested land, inclusive of Alaska and

Hawaii. Burn severity data for the Pacific and Rocky Mountain regions show the proportion of high and moderate burn severity in the forested areas has increased from 45 to 50 percent of the forested area burned for the most recent period versus the previous period (table 8.1). The increasing trend has been relatively consistent over the past 24 years, with the proportion of high and moderate burn severity on forested lands increasing from a proportion of 30 percent for the 1984–87 period to 50 percent of the burned forested area for the most recent period, with the 1993–97 period being anomalous (table 8.1). The subsequent effect of the reduced fire frequency observed in the mid-20th century manifested itself in increased fuel loadings and created recent burns of higher severity.

Data for the reference period in the southern region are incomplete, but the burn severity data indicate a different trend from the western

regions between the reference period and the most recent period, with the proportion of high and moderate severity declining from 22 percent to 15 percent between the reference period and the recent period (table 8.2).

Weather-related damage—The ADS data on damage from weather-related events show that 1.761 million acres were impacted by drought, flood, hail, lightning, wind (hurricanes and tornados), and avalanches from 2003 to 2007 (table 8.3, fig. 8.2). These 1.761 million acres represent approximately 0.3 percent of the total forested area. Damage from Hurricanes Katrina and Rita is underrepresented in this data due to limited survey. Even with this damage unaccounted for in the summary, weather-related damage has increased substantially over the previous 5-year period. This is largely the result of a greater than tenfold increase in acres affected by drought-induced mortality, the

Table 8.1—Severity of forested area burned for the Pacific and Rocky Mountain regions

Fire	1983-87 ^a	1988-1992	1993-97	1998-2002	2003-07
	<i>thousand acres</i>				
Burned area—U.S. all lands	10,535	16,482	16,635	25,105	39,950
Burn severity on forested lands—Western States					
High severity	135	322	187	946	1,717
Moderate severity	204	243	247	966	1,521
Other severity (includes unburned)	779	1,038	103	2,351	3,220
Percent of burned area in high and moderate severity	30	35	30	45	50

^a 1983 data not included.

Data source: U.S. Department of Agriculture Forest Service, Monitoring Trends in Burn Severity. <http://www.mtbs.gov/>. [Date accessed: December 4, 2009]

Table 8.2—Grand summary of fire abiotic sub-indicators

Indicator:	Forested acres impacted—reference period					Period sum	Forested acres impacted—most recent period					Period sum	Percent change
Sub-indicator	1998	1999	2000	2001	2002		2003	2004	2005	2006	2007		
Fire:	<i>thousand acres</i>												
Burned area—all lands	1,330	5,626	7,393	3,571	7,185	25,105	3,961	8,098	8,689	9,879	9,328	39,950	59%
Burn severity—forest lands—all States:							1,529 ^a	4,103	3,640	1,994	2,853	14,159	
High							402 ^a	529	944	476	770	3,122	
Moderate							386 ^a	1,296	905	487	587	3,662	
Low or other							781 ^a	2,277	1,791	1,031	1,496	7,376	
Percent high/moderate							50 ^a %	44%	51%	48%	48%	48%	
Burn severity—forest lands—Southern States:													
High	5	1	2	2	1	12	0	1	6	14	4	25	108%
Moderate	16	7	8	8	7	46	1	8	25	39	46	118	157%
Low or other	51	43	58	46	7	205	7	136	188	178	318	827	303%
Percent high/moderate	30%	15%	14%	19%	52%	22%	8%	6%	14%	23%	13%	15%	7%
Burn severity—forest lands—Western States:													
High	7	15	211	101	613	946	402	52	128	427	707	1,717	82%
Moderate	13	59	270	104	519	966	385	124	124	404	484	1,521	57%
Low or other	89	314	829	271	843	2,351	754	294	361	748	1,063	3,220	37%
Percent high/moderate	18%	19%	37%	43%	57%	45%	51%	37%	41%	53%	53%	50%	5%

^aSummarized for Western and Southern States only.Data sources: http://www.nifc.gov/fireInfo/fireInfo_statistics.html and <http://www.mtbs.gov/>. [Date accessed: December 4, 2009].

Table 8.3—Grand summary of nonfire abiotic subindicators

Indicator:	Forested acres impacted— reference period					Period sum	Forested acres impacted— most recent period					Period sum	Percent change		
Sub-indicator	1998	1999	2000	2001	2002	2003					2004	2005	2006	2007	
thousand acres															
Weather:	449	89	60	21	170	788	1,370	124	224	10	33	1,761	123%		
Drought	41	2	37	19	59	158	1,126	114	12	0	10	1,263	699%		
Flood	81	26	24	1	11	142	16	8	23	5	12	66	-54%		
Hail	0.024 ^a	61	0	0.016 ^a	67	128	43	0	1	0	1	45	-65%		
Lightning	0	0	0	0	0	0	0.102 ^a	0.232 ^a	0.114 ^a	0	0	0.448 ^a	NA		
Wind	326	1	0	0.259 ^a	32	360	184	1	188	5	9	387	8%		
Avalanche	0	0	0	0.142 ^a	0	0.142 ^a	0	0	0	0.197 ^a	0.024 ^a	0.221 ^a	55%		
Pollution:															
Percent plant injury	41%	17%	21%	13%	10%		8%	7%	7%	7%	7%	NA			
Southern ^b						10.2						1.6			
Northeast ^b						7.0						3.4			
Central ^b						5.0						1.0			
Rocky ^b						0.0						0.0			
Pacific ^b						1.5						1.8			
Land use ^c :															
Urban/Sub	764					821									
Exurban	16,635					17,660									
Moisture deficit:															
Extreme						400						138			
Severe						2,098						1,809			

NA = not available.

Data sources: Aerial Detection Survey Program; Ozone Biomonitoring Program; Stein and others 2005; Koch and others 2012.

^a Acreage < 500 acres are in decimal.

^b Summarized for 1997-2001 and 2002-2006 period.

^c 2000 actual data, data projected to 2010 and pro-rated to 2005.

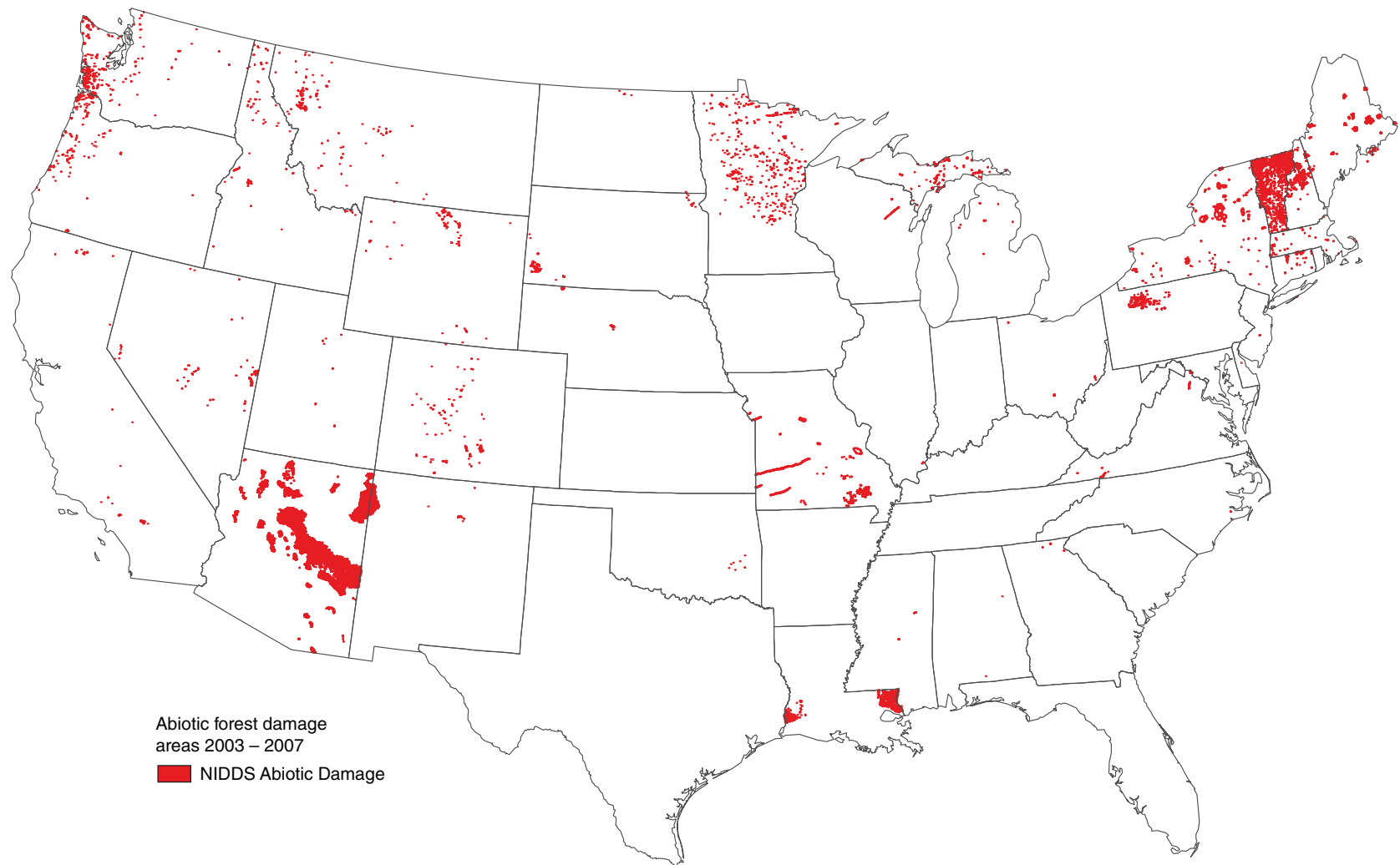


Figure 8.2—Weather-related forest damage areas, 2003–07 (Data source: U.S. Department of Agriculture Forest Service 2008a).

largest increase in acreage impacted by weather (fig. 8.3). Though the observed differences are compelling, conclusive evidence for a trend cannot be made, due to the selection bias in the sampling. A better monitoring of weather-related damage impacts may be achieved by developing a program modeled after the MTBS program, which can utilize the vast archive of Landsat imagery.

Pollution—Surface ozone (O_3) is an important air pollutant that affects vegetation (U.S. Environmental Protection Agency 1996). Ozone is routinely monitored throughout the world, and data were mostly recorded as hourly or half-hourly averages. Over the last 30 years, hourly averaged data have been summarized in different ways for the purpose of assessing vegetation effects. The development of exposure indices to characterize plant exposure and to quantify the relationship between O_3 exposure and ensuing plant response has been, and remains, a challenge (Musselman and others 2006). The FHM program utilizes ozone-sensitive plants (bio-indicators) to assess O_3 impact upon forest ecosystems (Smith and others 2008). There is not yet any evidence linking FHM ozone bio-indicator response data to specific tree health problems or regional declines. Nevertheless, the mapped data demonstrate that plant damaging concentrations of ozone air pollution are widespread in parts of the Nation. Continued monitoring and analysis will be important when determining probable or significant ozone damage (Smith and others 2008). Ozone damage is far greater in the northeastern States; however

the 5-year trend indicates a decline in damage, while the west coast States have experienced an increase in ozone damage (fig. 8.4).

Concern regarding the impacts of continued nitrogen and sulfur deposition on ecosystem health has prompted the development of critical acid load (CAL) assessments for forest soils. A CAL is a quantitative estimate of exposure to one or more pollutants at or above which harmful acidification-related effects on sensitive elements of the environment occur. A pollutant load in excess of a CAL is termed exceedance. Simple mass balance equations were used to estimate forest soil critical acid loads for the conterminous United States (McNulty and others 2007). These spatial data were acquired and masked by the forest mask and summarized. From 1994 to 2000, 74.2 million acres or 17 percent of the soils on forest land exceeded their CAL threshold by more than 101 equivalents per acre per year. These areas include much of New England and West Virginia with very few areas of exceedance predicted in the Western United States.

Land use—In 2000, there were 28.4 million forested acres in urban and suburban (< 1.67 acres per unit) residential housing density in the conterminous United States, but there were slightly more than seven times that (205.6 million acres) in exurban housing density (1.67–40 acres per unit). According to Theobald (2005), the development footprint had grown from 10.1 percent in 1980 to 13.3 percent in 2000 of total national land area, roughly at a rate of 1.6 percent per year. This rate outpaced the population growth rate (1.18 percent per

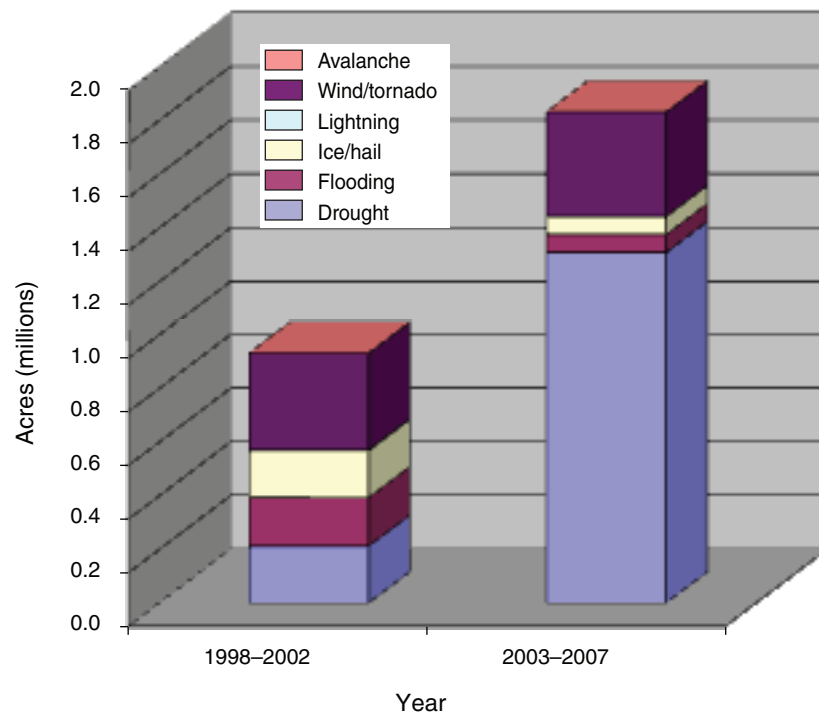


Figure 8.3—Weather-related damage—reference period comparison to current period (Data source: U.S. Department of Agriculture Forest Service 2008a).

year) by 25 percent. Based on model forecasts (fig. 8.5), urban and suburban housing densities will expand to 1.3 percent by 2020, whereas exurban development will expand to 28.7 percent of the forested area.

Climate change—The effects of climate change confound the impacts of other indicators such as fire, insect mortality, and storm damage. Most biotic disturbance factors have been impacted in complex ways by potential climate change. Tree growth and productivity will also change

with increasing temperatures and increased atmospheric carbon concentrations. Lower snowpacks and longer growing seasons may result in increasing growth and productivity in subalpine forests. However, forest productivity may decrease in lower elevation forests owing to water limitations. The highest and coldest alpine (tundra) zones will likely contract significantly with increased temperatures in the Western United States. The boreal and temperate forest zones (primarily conifer dominated) will likely shift up in elevation helping to squeeze the high-elevation zones into smaller domains. The frost-sensitive vegetation of the subtropical zone, including oaks and other woody and ephemeral species, will also likely expand northward and to higher elevations. The expansion of southern species could result in a contraction of the Great Basin shrublands (USDA Forest Service 2008b).

Significant inferences can be made based upon climate data projections, but the direct impacts may not be fully understood. Warming contributes to increasing mortality rates by increasing water deficits and thus drought stress on trees, with possible direct and indirect contributions to tree mortality (van Mantgem and others 2009). Drought-caused tree mortality is immediately noticeable; however changes in productivity and regeneration success of species within their historic range would not be discernable at the 5-year reference period. While drought-induced mortality is monitored and reported under the weather sub-indicator, the drought condition is reported here to account for these additional impacts on productivity and regeneration success.

Moisture index difference (*MID*) data (Koch and others 2012) were analyzed as a way to quantify drought conditions for the reference and most recent periods (1998–2002 and 2003–07, respectively) using averages of the annual *MID* surfaces. For the reference period, a total of 2,497,881 acres of forest land was in extreme and severe moisture deficit (fig. 8.6). For the most recent period, 1,947,604 acres of forest land were in extreme and severe moisture deficit (fig. 8.7). The area summarized does not appear to match the area reported under the weather sub-indicator for drought-induced mortality. The monitoring of drought conditions does not always relate to the degree of forest health impact.

Summary

The Montréal Process defines a set of conditions or processes for which forest management may be assessed. A criterion is characterized by a set of related indicators which are monitored to periodically assess change (Montréal Process, 2007). Criterion 3 is the maintenance of forest ecosystem health and vitality of which indicator 3b (16) is the area and percent of forest affected by abiotic agents (e.g., fire, storm, land clearance) beyond reference conditions. Many of these agents have been monitored anecdotally and projections of climate change indicate that if warming continues as anticipated over the next 30 years: the number and severity of large wildfires are likely to increase, the range and frequency of large insect outbreaks are likely to increase, and hurricanes and ice storms are likely to increase. Storm damage can reduce forest productivity

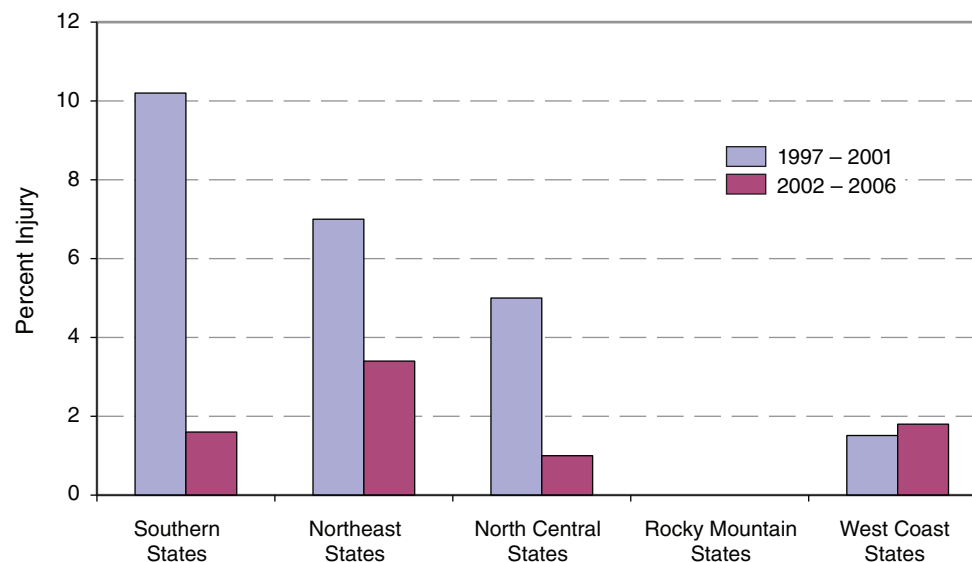


Figure 8.4—Regional comparison of 5-year reference period for ozone plant injury by region (Data source: Smith and others 2008).

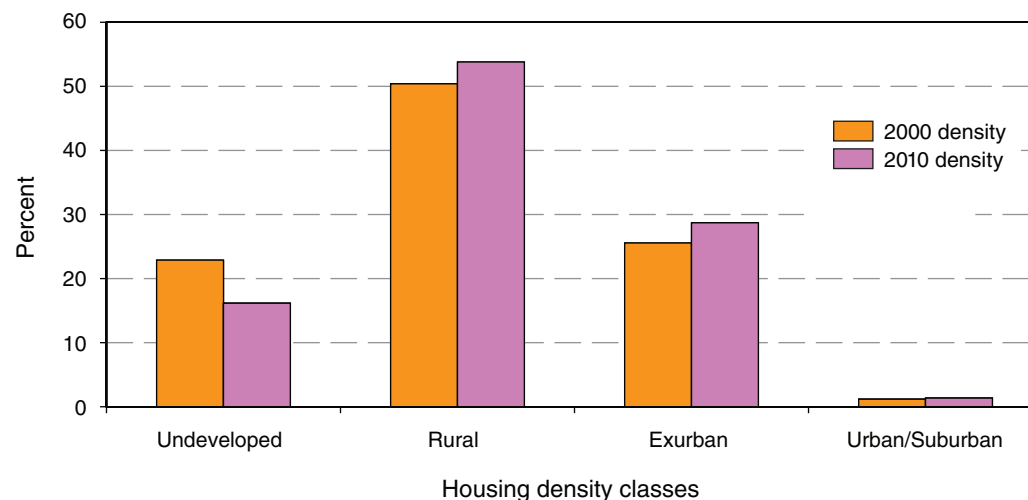


Figure 8.5—Comparison of projected housing density (Data source: Theobald 2005).

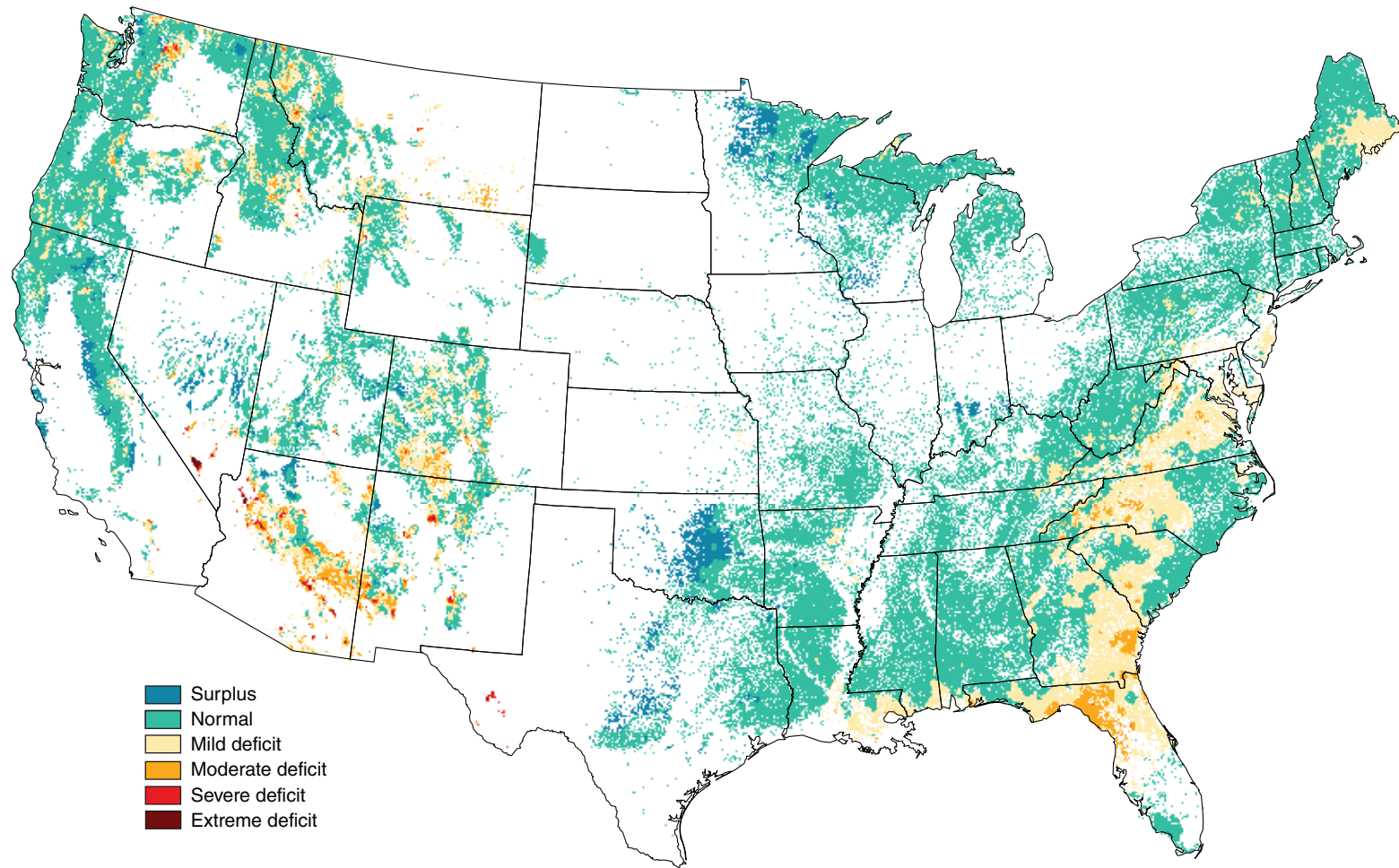


Figure 8.6—Mean moisture index deficit for the reference period, 1998–2002 (Data source: derived from Koch and others 2012).

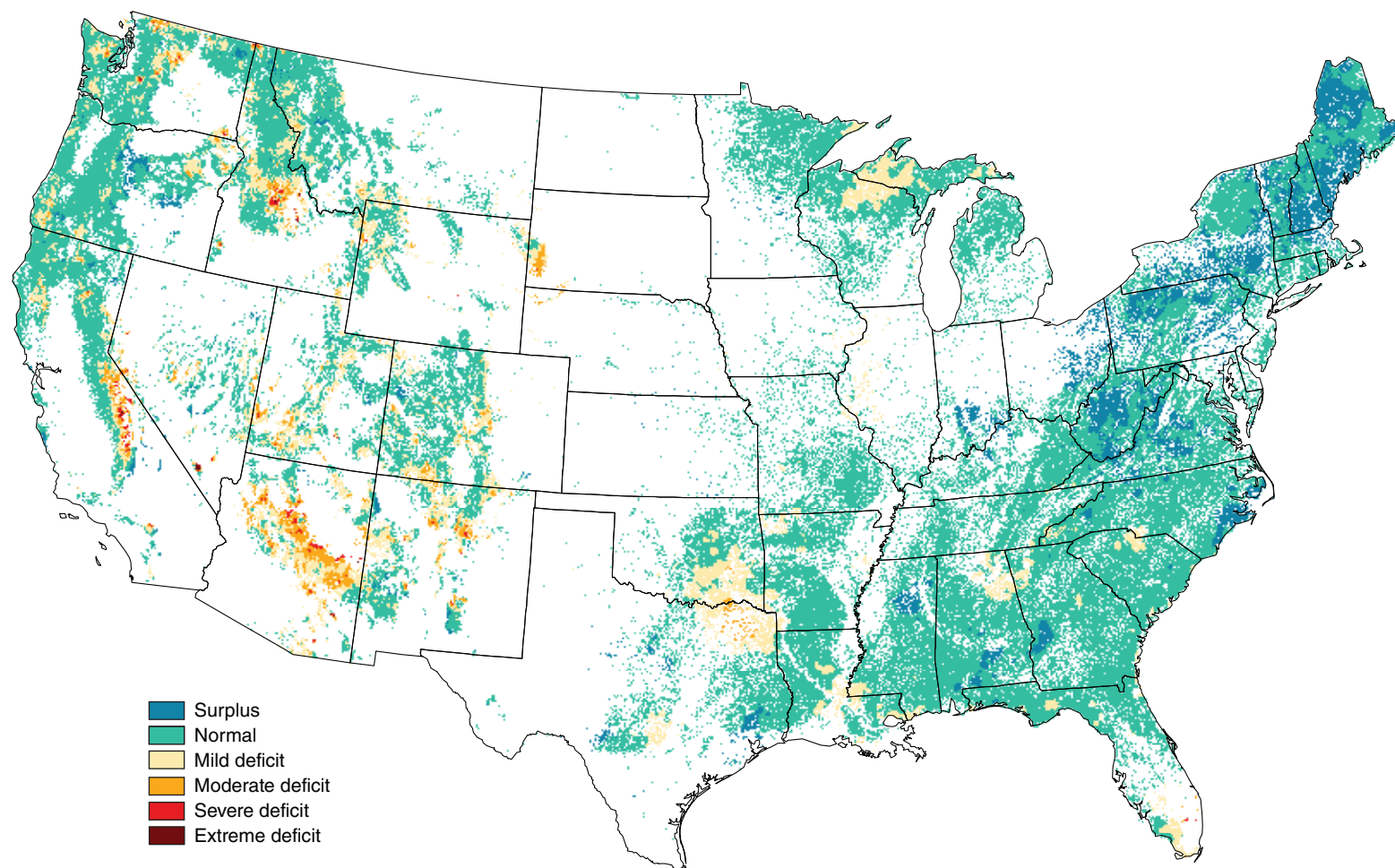


Figure 8.7—Mean moisture index deficit for the most recent period, 2003–07 (Data source: derived from Koch and others 2012).

and carbon storage (USDA Forest Service 2008b). The intent of this paper was to establish a baseline reference condition from which to monitor these changing conditions, to evaluate the trend, and determine a course for action.

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