CRITERION 3—

Chapter 6. Tree Mortality

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Introduction

Tree mortality is a natural process in all forest ecosystems. However, extremely high mortality also can be an indicator of forest health issues. On a regional scale, high mortality levels may indicate widespread insect or disease problems. High mortality may also occur if a large proportion of the forest in a particular region is made up of older, senescent stands.

In early (i.e., 2001–04) national reports by the Forest Health Monitoring (FHM) Program of the Forest Service, U.S. Department of Agriculture, mortality was analyzed using FHM data and phase 3 data from the Forest Inventory and Analysis (FIA) Program of the Forest Service. Those data spanned a relatively long period (for some States, up to 12 years), but the sample was not spatially intense (approximately 1 plot per 96,000 acres). In the 2008 FHM national report (Ambrose 2011), the same method was applied to FIA phase 2 data. That phase 2 dataset was more spatially intense (approximately 1 plot per 6,000 acres) but came from the relatively small number of States in the Eastern United States where repeated plot measurements had been taken. In this report, the method is applied to a larger area of the Central and Eastern United States, using data from repeated phase 2 measurements from a larger number of States.

The mission of FHM is to monitor, assess, and report on the status, changes, and long-term trends in forest ecosystem health in the United States (FHM 1994). Thus, the aim of this mortality analysis contrasts with how mortality might be approached in other reports, such as FIA State reports or State Forest Health Highlights. The approach to mortality presented here seeks to detect mortality patterns that might reflect subtle changes to fundamental ecosystem processes (due to such large-scale factors as air pollution, global climate change, or fire-regime change) that transcend individual tree species-pest/pathogen interactions. However, sometimes the proximate cause of mortality may be discernible. In such cases, the cause of mortality is reported, both because it is of interest in and of itself to many readers and because understanding such proximate causes of mortality might provide insight into whether the mortality is within the range of natural variation or reflects more fundamental changes to ecological processes.

At this point a mortality baseline is still being established for most of the United States. To discern trends in mortality rates, at least three cycles of FIA data are required. With the up to two cycles of data currently available, it is only possible to do a spatial comparison of ecoregions and identify regions of higher than average mortality (relative to growth) for further study.

Data

FIA phase 2 inventory data are collected using a rotating panel sample design (Bechtold and Patterson 2005). Field plots are divided into spatially balanced panels, with one panel being measured each year. A single cycle of measurements consists of measuring all panels. This “annualized” method of inventory was adopted, State by State, beginning in 1999. Any analysis of mortality requires data collected from at least two points in time from any given plot. Therefore, mortality analysis was possible for areas where data from repeated plot measurements using consistent sampling protocols were available (i.e., where one cycle of measurements had been completed and at least one panel of the next cycle had been measured, and where there had been no changes to the protocols affecting measurement of trees or saplings).

Because the data used here are collected using a rotating panel design and all available annualized data are used, most of the data used in this mortality analysis were also used in the analysis presented in the previous FHM national report. Using the data in this way, it would be very unusual to see any great changes in mortality patterns from one annual report to the next. Nevertheless, it is important to look at mortality patterns every year so as not to miss detecting changes in mortality patterns as soon as they may become discernible.

Table 6.1 shows the 21 States from which consistent, repeated phase 2 measurements were available, the time period spanned by the data, and the number of panels of data available. The States included in this analysis, as well as the forest cover within those States, are shown in figure 6.1.

Table 6.1—States from which repeated Forest Inventory and Analysis phase 2 measurements were available, the time period spanned by the data, and the number of panels of data available. Each panel represents approximately one-fifth of the plots in a State

Time period	States[a]	Number of Phase 2 panels
1999-2006	ME	3
1999-2007	MN, MO, WI	3[b c d]
2000-2007	IA, IN, MI, PA	3
2000-2008	VA	3[e]
2001-2007	GA, IL, KS, NE, ND, SD	2
2001-2008	AL, TN, TX[f]	3
2002-2007	AR, KY, SC	1

[a] States are listed by their standard abbreviations.
[b] In Minnesota and Wisconsin the phase 2 inventory was done at twice the standard FIA sample intensity, approximately 1 plot per 3,000 acres when the full 5 panels are measured.
[c] In Missouri the phase 2 inventory was done at twice the standard FIA sample intensity, approximately 1 plot per 3,000 acres when the full 5 panels are measured, on National Forest lands and at the standard intensity on all other lands.
[d] In Minnesota, Missouri, and Wisconsin, the field season often begins late in the calendar year, so while the earliest data are from 1999, they do not represent a separate panel but are part of the panel mostly measured in 2000.
[e] Only a small proportion of the plots measured in Virginia in 2000 used the current national standard plot design, so just slightly more than 3 full panels of remeasurement data were available for this analysis.
[f] Annualized growth and mortality data were only available for eastern Texas.

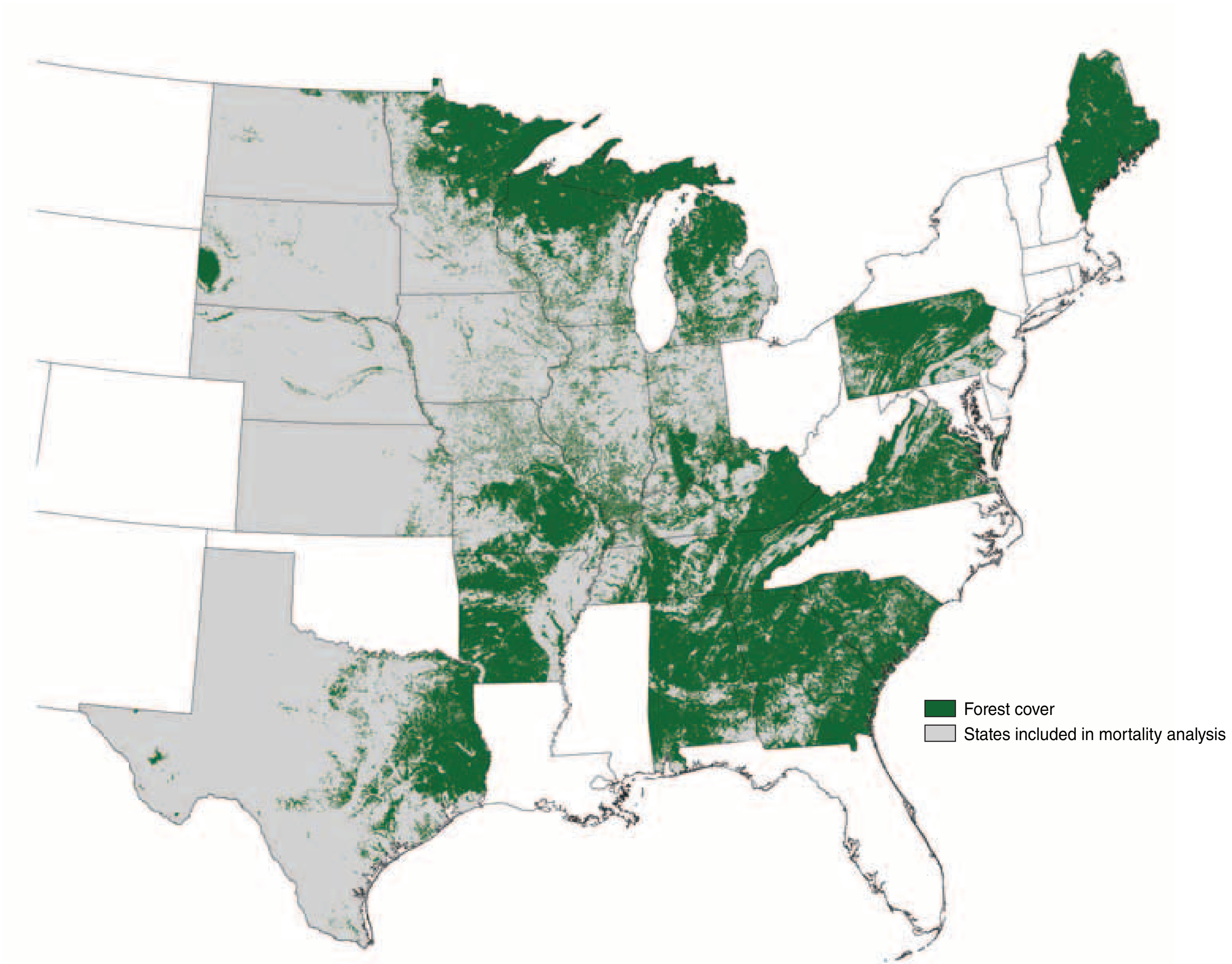

Figure 6.1—Forest cover in the States where mortality was analyzed. Forest cover was derived from Advanced Very High Resolution Radiometer satellite imagery (Zhu and Evans 1994).

Methods

FIA phase 2 tree and sapling data were used to estimate average annual tree mortality in terms of tons of biomass per acre. The biomass represented by each tree in tons was calculated by FIA and provided in the FIA Database–version 3.0 (FIA 2008). To compare mortality rates across forest types and climate zones, the ratio of annual mortality to gross growth (MRATIO) is used as a standardized mortality indicator (Coulston and others 2005a). Gross growth rate and mortality rate, in terms of tons of biomass per acre, were independently calculated for each ecoregion section (Cleland and others 2007) using a mixed modeling procedure. The mixed model is efficient for estimation using data where not all plots have been measured over identical time intervals (Gregoire and others 1995). MRATIOs were then calculated from the growth and mortality rates. For details on the method, see “Appendix A: Supplemental Methods” in the 2001 and 2003 FHM national technical reports (Coulston and others 2005b, 2005c, respectively) as well as Smith and Conkling (2004).

The MRATIO can be large if an over-mature forest is senescing and losing a cohort of older trees. If forests are not naturally senescing, a high MRATIO (> 0.6) may indicate high mortality due to some acute cause (insects or pathogens) or due to generally deteriorating forest health conditions. An MRATIO value greater than 1 indicates that mortality exceeds growth and live standing biomass is actually decreasing.

In addition, the ratio of average dead tree diameter to average surviving live tree diameter (DDLD ratio) was calculated for each plot where mortality occurred. Low DDLD ratios (much less than 1) usually indicate competition-induced mortality typical of young, vigorous stands, while high ratios (much greater than 1) indicate mortality associated with senescence or some external factors such as insects or disease (Smith and Conkling 2004). (Intermediate DDLD ratios can be hard to interpret because a variety of stand conditions can produce such DDLD values.) The DDLD ratio is most useful for analyzing mortality in regions that also have high MRATIOs. High DDLD values in regions with very low MRATIOs may indicate small areas experiencing high mortality of large trees or locations where the death of a single large tree (such as a remnant pine in a young hardwood stand) has produced a deceptively high DDLD.

To further analyze tree mortality, the number of stems and the total biomass of trees that died also were calculated by species within each ecoregion. Identifying the tree species experiencing high mortality in an ecoregion is a first step in identifying what forest health issue may be affecting the forests. Although determining particular causal agents associated with all the observed mortality is beyond the scope of this report, often there are well-known insects and pathogens that are “likely suspects” once the affected tree species are identified.

Also, a biomass weighted mean mortality age was calculated by ecoregion and species. For each species experiencing mortality in an ecoregion the mean stand age was calculated, weighted by the dead biomass on the plot. This value gives a rough indicator of the average age of trees that died. However, the age of individual trees may differ significantly from the age assigned to a stand by FIA field crews, especially in mixed species stands. When the age of trees that die is relatively low compared with the age at which trees of a particular species usually become senescent, it suggests that some pest, pathogen, or other forest health problem may be affecting the forest.

Results and Discussion

The MRATIO values are shown in figure 6.2. Table 6.2 shows the tree species experiencing the greatest mortality in ecoregions having MRATIOs of 0.6 or greater.

The highest MRATIOs occurred in ecoregion sections 332C-Nebraska Sand Hills (MRATIO = 1.21), 332A-Northeastern Glaciated Plains (MRATIO = 1.18), and 332E-South Central Great Plains (MRATIO = 1.11). Another area of extremely high mortality relative to growth occurred in section 251C-Central Dissected Till Plains (MRATIO = 0.91). Other areas having relatively high MRATIOS were sections 255A-Cross Timbers and Prairies (MRATIO = 0.79), M334A-Black Hills (MRATIO = 0.66), and 251H-Nebraska Rolling Hills (MRATIO = 0.60).

The results of the analysis of the relative sizes of trees that died to those that lived, the DDLD ratio, are shown in figure 6.3. The DDLD ratio is a plot-level indicator and is so represented in the figure. However, given the density of FIA phase 2 plots, overlap of markers representing plot values on a national scale map sometimes can give a misleading impression, so close-up views of the Lake States, the Northeast, and the Southeast are also provided.

In the three ecoregion sections exhibiting highest mortality relative to growth (332A-Northeastern Glaciated Plains, 332C-Nebraska Sand Hills, and 332E-South Central Great Plains), the predominant vegetation is grassland, and there were very few forested plots measured. Most of the forest in these sections is riparian forest, and, indeed, the species experiencing greatest mortality (table 6.2) are commonly found in riparian areas. DDLD values vary widely within each of these sections. There are a small number of plots with high DDLDs, and these plots represent most of the biomass that died in these sections. However, on many of these plots the overall level of mortality is fairly low, as would be the case when remnant larger trees die, leaving young, vigorous stands behind. Tree growth is generally slow in these ecoregion sections because of naturally dry conditions. Where the number of sample plots is small and tree growth is slow, care must be taken in interpreting mortality relative to growth over short time intervals.

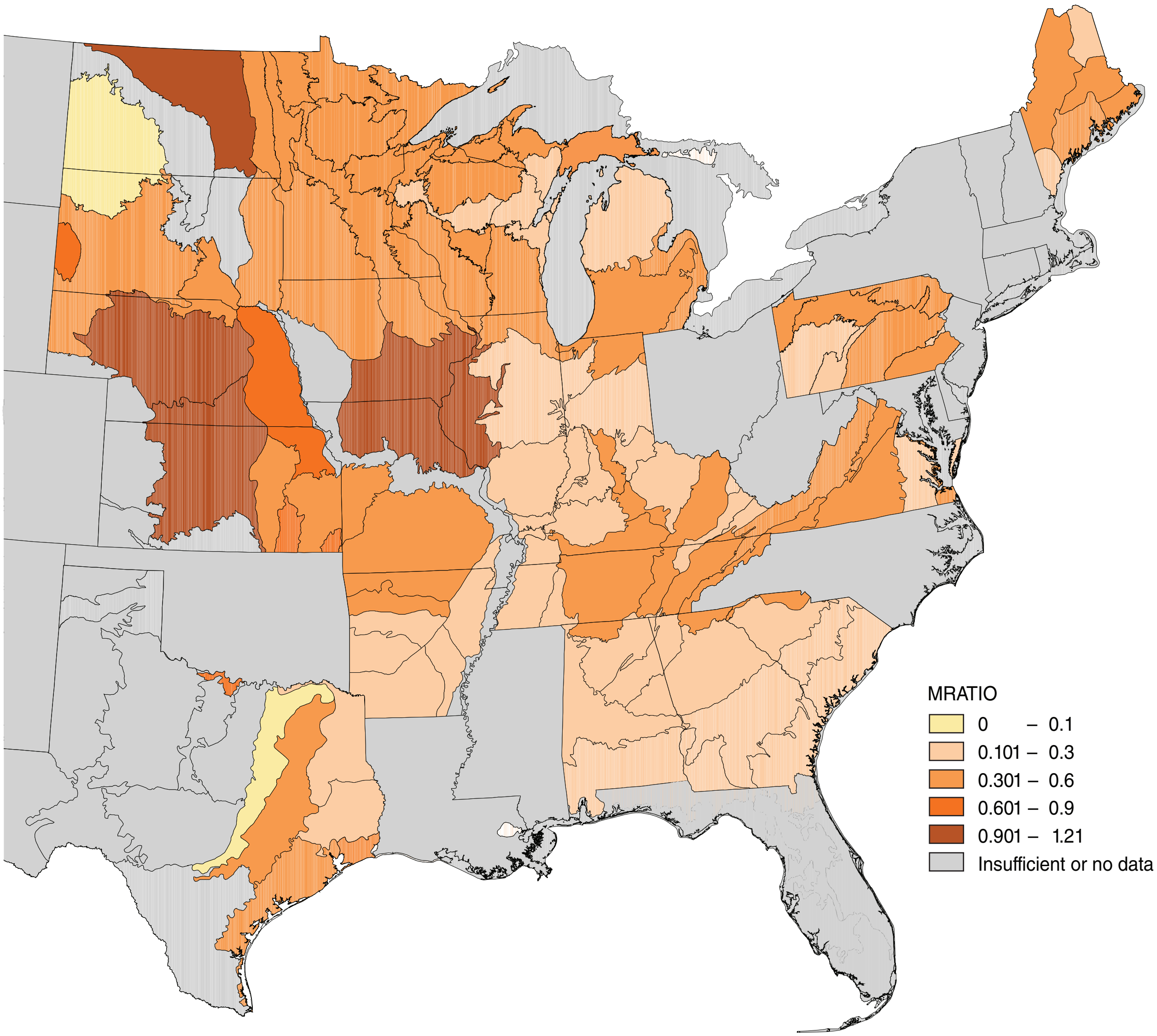

Figure 6.2—Tree mortality expressed as the ratio of annual mortality of woody biomass to gross annual growth in woody biomass (MRATIO) by ecoregion section (Cleland and others 2007). (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

Table 6.2—Tree species responsible for at least 10 percent of the mortality (in terms of biomass) for ecoregions where the MRATIO was 0.60 or greater, including the mean age of the dead trees of these species and the species-level percent mortality within the ecoregion

Ecoregion section	MRATIO	Tree species	Percent of total mortality biomass	Mean age of dead trees[a]	Percent mortality of each species	
					(biomass)	*(stems)*
332C-Nebraska Sand Hills	1.21	Eastern cottonwood *(Populus deltoides)*	67.09	54	55.45	35.46
		Green ash *(Fraxinus pennsylvanica)*	10.46	62	19.67	17.06
		Eastern redcedar *(Juniperus virginiana)*	10.14	64	8.17	25.00
332A-Northeastern Glaciated Plains	1.18	Quaking aspen *(Populus tremuloides)*	33.82	53	16.44	13.05
		Bur oak *(Quercus macrocarpa)*	26.29	101	10.01	4.13
		Green ash *(F. pennsylvanica)*	20.59	95	14.30	16.76
		Balsam poplar *(Populus balsamifera)*	14.44	45	52.73	67.47
332E-South Central Great Plains	1.11	Hackberry *(Celtis occidentalis)*	34.72	60	29.33	1.91
		Box elder *(Acer negundo)*	16.94	30	41.73	16.33
		Eastern cottonwood *(P. deltoides)*	10.68	62	7.37	17.65
251C-Central Dissected Till Plains	0.91	American elm *(Ulmus americana)*	14.52	51	19.46	21.67
		Black oak *(Quercus velutina)*	12.09	66	20.70	25.47
255A-Cross Timbers and Prairies	0.79	Blackjack oak *(Quercus marilandica)*	29.34	75	24.41	4.90
		Hackberry *(C. occidentalis)*	18.11	49	10.66	10.08
		Black oak *(Q. velutina)*	11.89	7	73.76	40.00
M334A-Black Hills	0.66	Ponderosa pine *(Pinus ponderosa)*	80.65	95	4.39	10.08
		Quaking aspen *(P. tremuloides)*	11.45	64	37.76	32.35
251H-Nebraska Rolling Hills	0.60	Slippery elm *(Ulmus rubra)*	23.35	48	46.34	45.60
		American elm *(U. americana)*	14.78	43	10.66	16.71
		Eastern cottonwood *(P. deltoides)*	13.61	45	3.53	7.23
		Box elder *(A. negundo)*	10.11	54	22.94	33.39

[a] Ages are estimated from the stand age as determined by the Forest Inventory and Analysis field crew. It is possible, especially in mixed-species stands, that the age of individual trees that died differed significantly from the stand age.

(A)

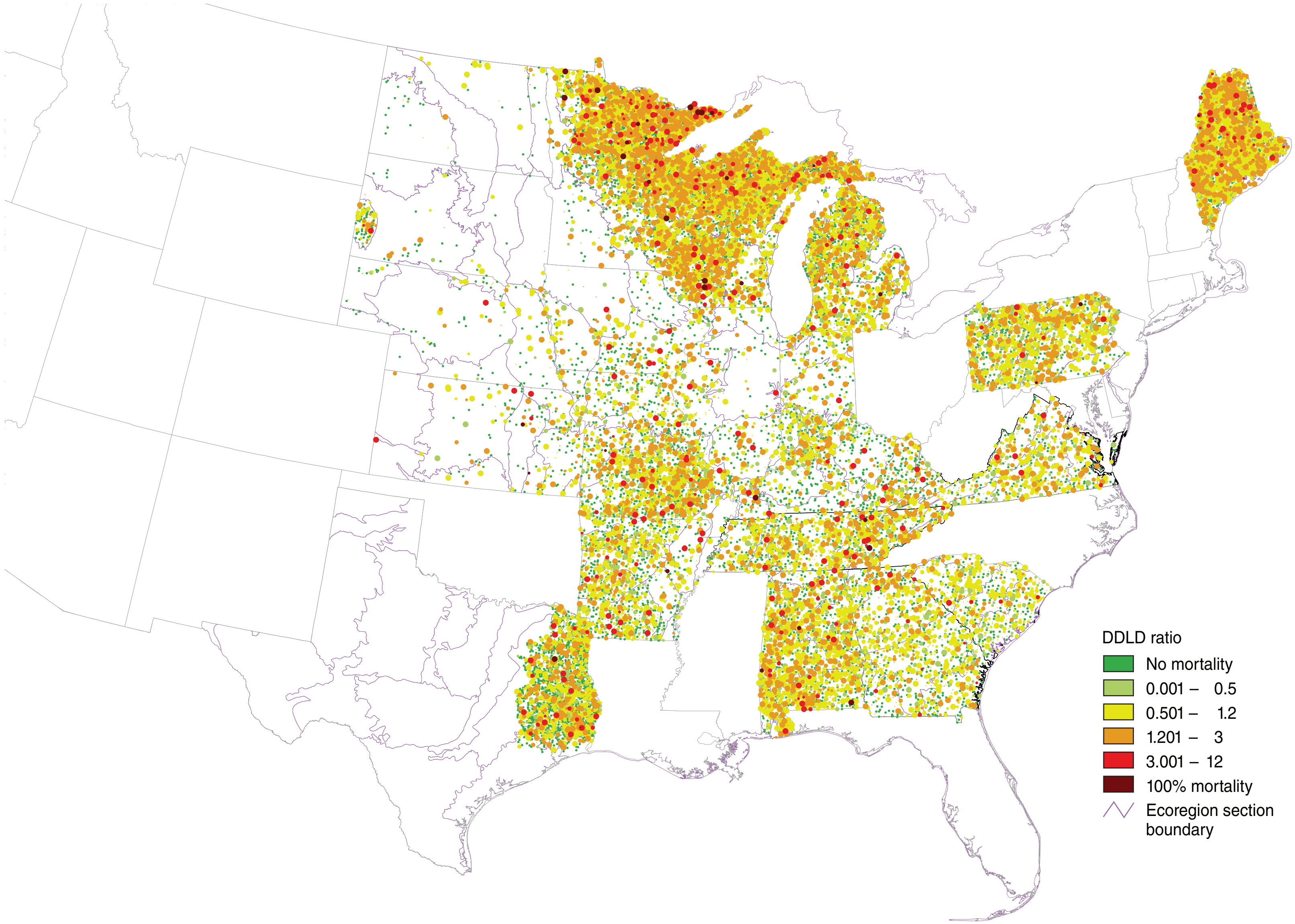

Figure 6.3—The ratio of average dead tree diameter to average surviving tree diameter (DDLD) on each plot at the time of its last measurement: (A) Eastern United States, (B) Upper Midwest, (C) Northeast, (D)Southeast. DDLD is indicated by dot color; dot sizes are scaled relative to the biomass that died on each plot. Plot locations are approximate. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program) (continued on next page)

(B)

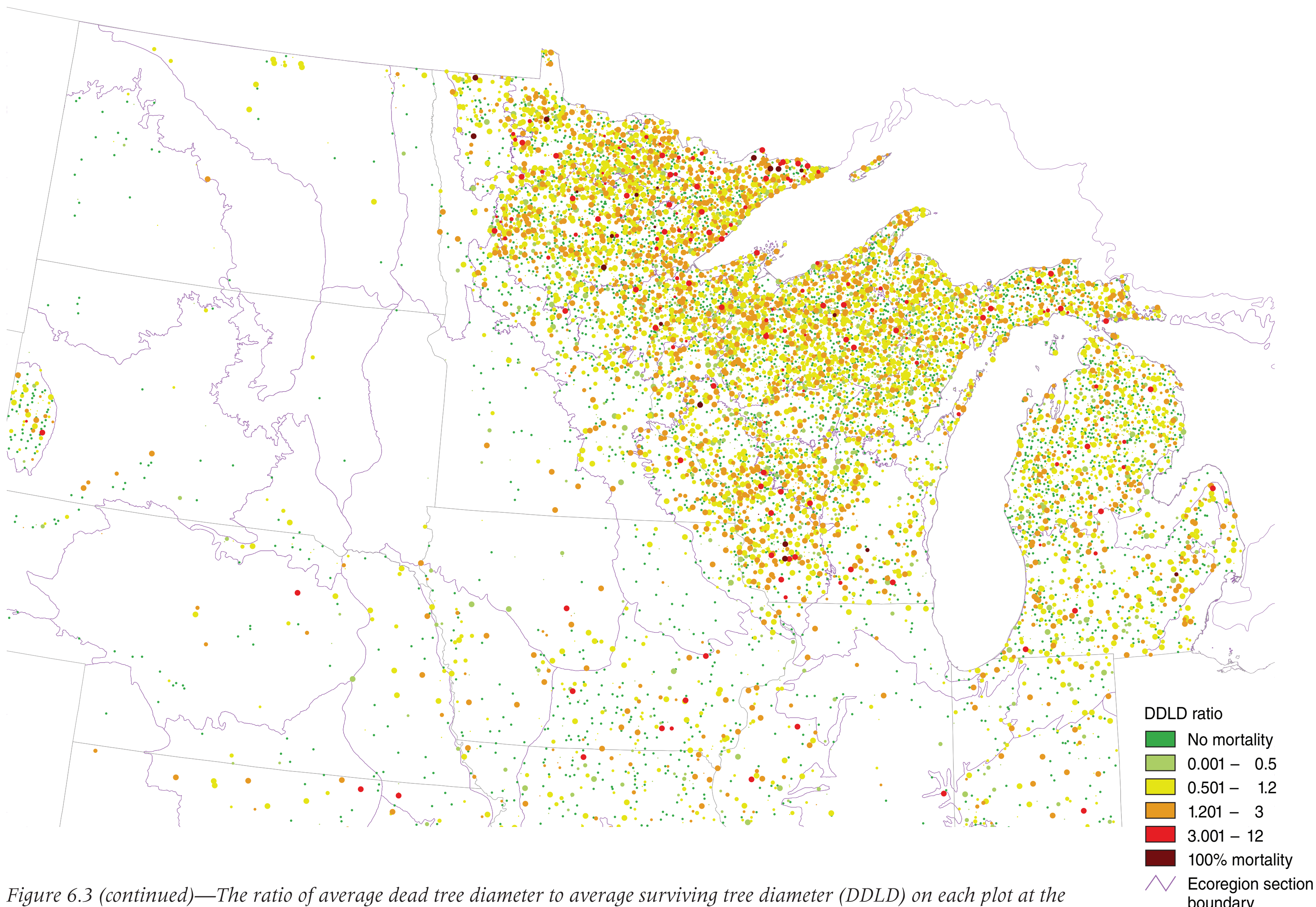

Figure 6.3 (continued)—The ratio of average dead tree diameter to average surviving tree diameter (DDLD) on each plot at the time of its last measurement: (B) Upper Midwest. DDLD is indicated by dot color; dot sizes are scaled relative to the biomass that died on each plot. Plot locations are approximate. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program) (continued on next page)

(C)

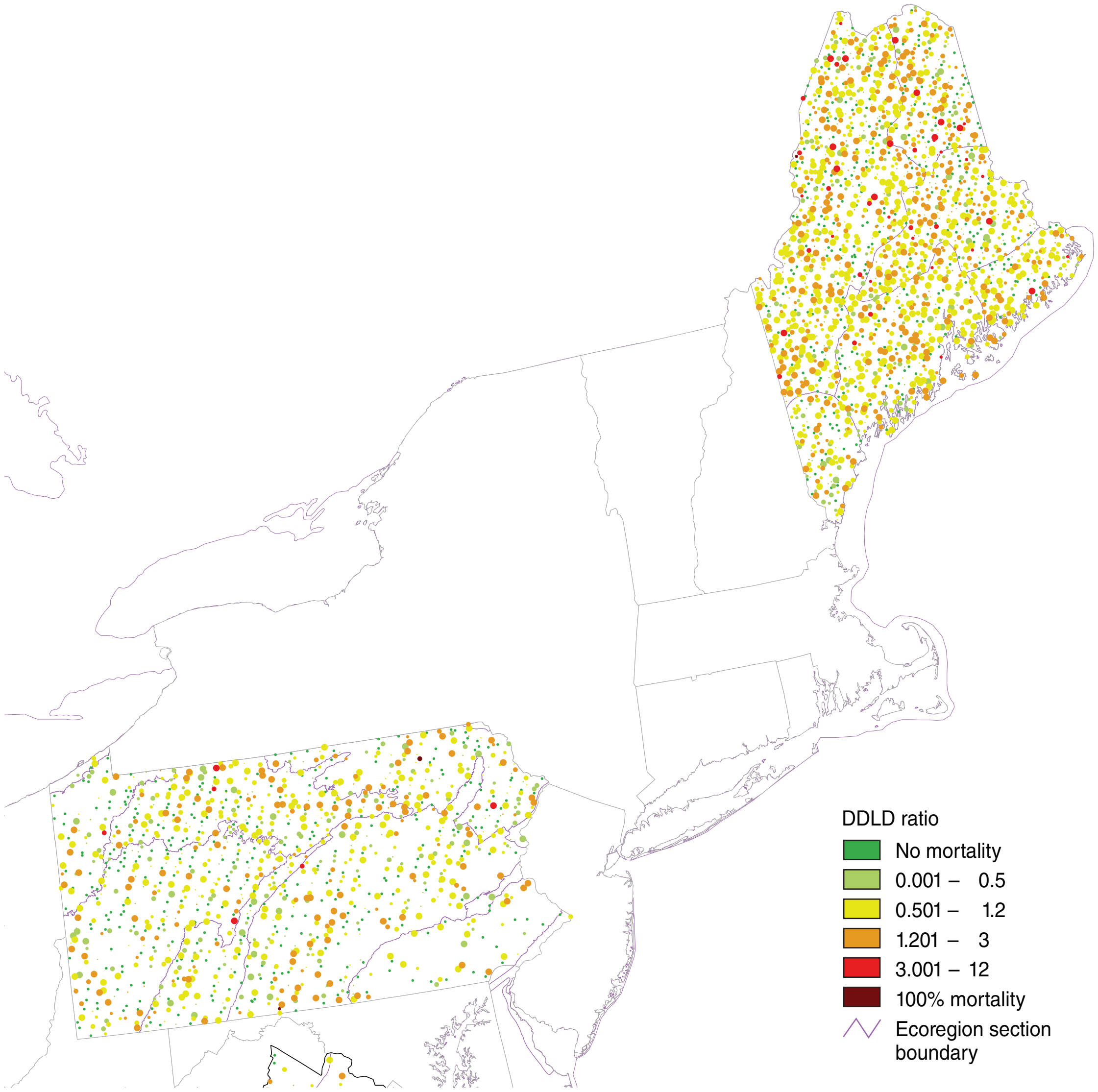

Figure 6.3 (continued)—The ratio of average dead tree diameter to average surviving tree diameter (DDLD) on each plot at the time of its last measurement: (C) Northeast. DDLD is indicated by dot color; dot sizes are scaled relative to the biomass that died on each plot. Plot locations are approximate. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program) *(continued on next page)*

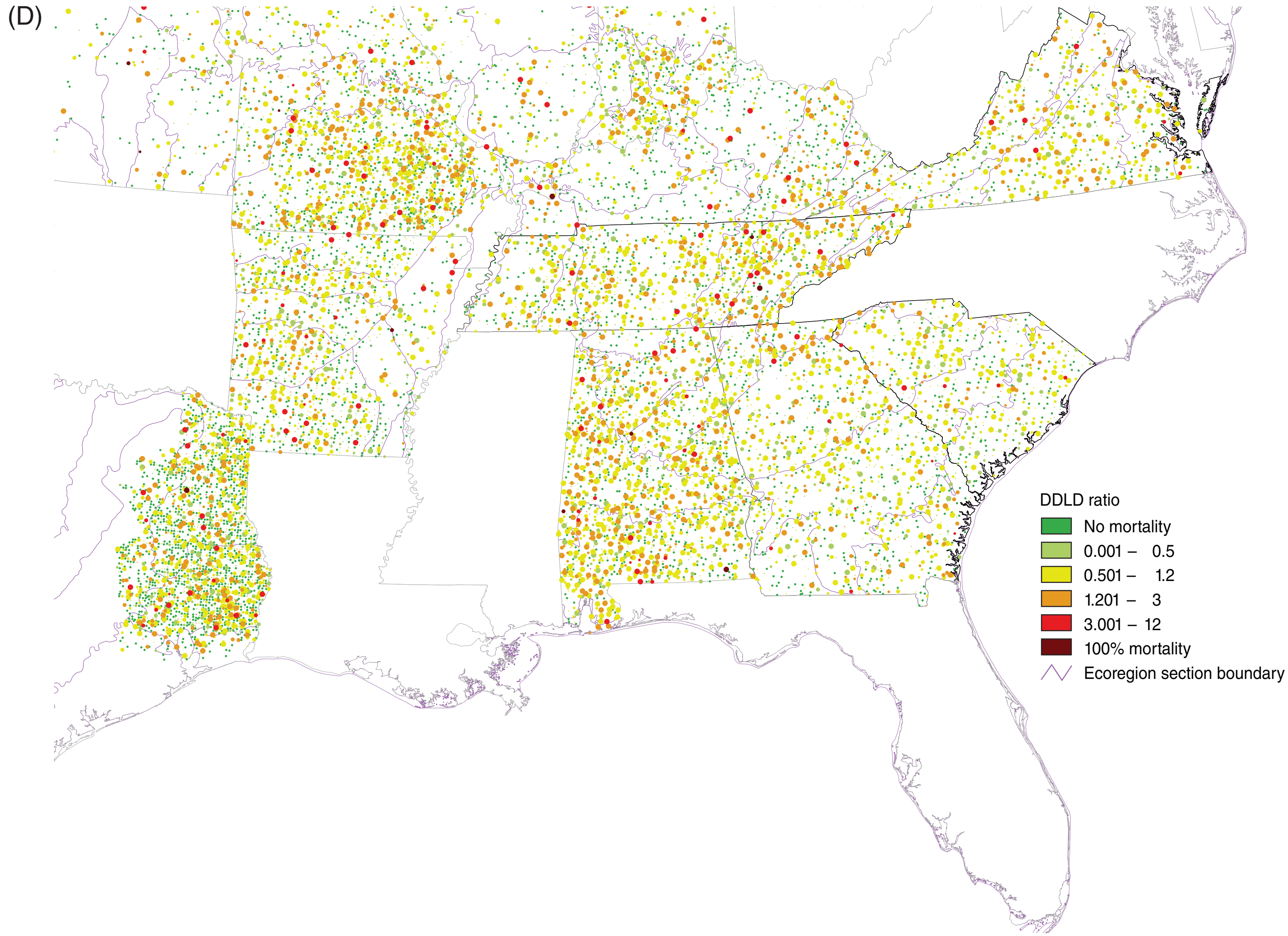

Figure 6.3 (continued)—The ratio of average dead tree diameter to average surviving tree diameter (DDLD) on each plot at the time of its last measurement: (D) Southeast. DDLD is indicated by dot color; dot sizes are scaled relative to the biomass that died on each plot. Plot locations are approximate. (Data source: U.S. Department of Agriculture Forest Service, Forest Inventory and Analysis Program)

In ecoregion section 332C-Nebraska Sand Hills, where the MRATIO was highest, by far the largest amount of biomass that died was eastern cottonwood (table 6.2); more cottonwood biomass died than had survived at the end of the analysis period. In contrast, the largest number of trees that died in the section was eastern redcedar, but the biomass associated with the dead redcedars was less than one-sixth of the biomass of the cottonwood that died. Thus, much larger (and probably older) cottonwoods were dying than redcedar.

In ecoregion section 332A-Northeastern Glaciated Plains, three species experienced the highest total mortality in terms of biomass and together represent over 80 percent of the mortality in the ecoregion: bur oak, green ash, and quaking aspen. About 13 percent of the trees of these species, representing about 13 percent of their biomass, died over the analysis period. A fourth species, balsam poplar, represented only 14.4 percent of the mortality in the ecoregion, but that mortality was more than half of the balsam poplar growing in the ecoregion, both in terms of biomass and number of trees. In ecoregion section 332E-South Central Great Plains, the three species experiencing the greatest mortality were hackberry, boxelder, and eastern cottonwood.

In ecoregion section 251C-Central Dissected Till Plains, the largest amount of biomass that died was American elm. About 20 percent of the elms (in terms of both number of stems and biomass) died over the measurement cycle. Black oak made up a slightly smaller proportion of the mortality in the ecoregion, but had a slightly higher mortality rate (about 21 percent of biomass and 25 percent of stems).

The mortality patterns shown in these analyses do not immediately suggest large-scale forest health issues. Mortality is rather low in most of the areas for which data are available. The areas of highest mortality occur in the mostly riparian forests of several plains ecoregions. Further study of the health of these forests may be warranted.

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