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Broad-level Reconstruction of Mountain Pine Beetle Outbreaks from 1999-2015 across the Northern Region

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Figure I. Photograph showing widespread mortality in susceptible lodgepole and ponderosa pine hosts caused by mountain pine beetles within the Northern Region. Photograph by Scott Sontag.

Geospatial data summarized in this report are available to access on the U.S. Forest Service Intranet [by clicking this link](#) or can be requested externally by emailing joel.egan@usda.gov

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Executive Summary

Mountain pine beetle (*Dendroctonus ponderosae* Hopkins; MPB) is a prolific bark beetle native to forests in western North America. A severe outbreak occurred throughout pine forests within the Northern Region of the USDA Forest Service (R1) from 1999 to 2015, hereafter called the 2000s outbreak. This report summarizes a broad-level reconstruction of this outbreak event using aerial detection survey (ADS) data. The purpose of this report is to detail the severity of species impacted, spatio-temporal progression of mortality, and identify associations between drought and the 2000s outbreak period.

During the outbreak period, MPB infestations were mapped across 9,014,459 acres which, after adjusting for severity estimated across this mapped areas, represent 2,295,401 severity-weighted acres of high-impact. Lodgepole pine had the greatest impact from MPB activity with mortality mapped across 7,208,100 acres (79.96%). Mortality was also observed in other species with mortality mapped in ponderosa pine (9.60%), western white pine (0.76%), and whitebark/limber pine hosts (9.68%). Drought conditions were associated with initiation of the outbreak in the early 2000s and with the ‘boom’ year in 2008 when MPB impact was estimated to have increased 350% relative to the prior year.

Introduction

The mountain pine beetle (*Dendroctonus ponderosae* Hopkins; MPB) is a bark beetle species that occur throughout pine forest types forests in western North America. Beetle infestations have important function as disturbance agents and can provide for forest sanitation, wildlife forage, and the development of structural diversity by causing micro-scale canopy gaps at endemic levels (Lundquist and Negrón 2000). MPB outbreaks can also cause widespread damage across landscapes. Outbreak extents and damage can be especially severe across landscapes dominated by contiguous stands of susceptible lodgepole pine (*Pinus contorta*) and/or ponderosa pine (*Pinus ponderosa*) hosts. Mortality events also impact limber pine (*Pinus flexilis*), whitebark pine (*Pinus albicaulis*), and western white pine (*Pinus monticola*) hosts. Outbreak cycles can last from 10-30 years across broad-scale geographic landscapes (such as R1) and are associated with forest susceptibility conditions, climatic and weather patterns, and other factors (Cranshaw et al. 2014; Harley et al. 2019).

The 2000s MPB outbreak was one of several severe and widespread outbreaks documented in R1 from 1905-2019. Earlier outbreaks reconstructed in R1 occurred from 1917-1942 (Evenden 1945; Jenne and Egan 2019) and from 1971–1989 (Harley et al. 2019). Of these events, the 2000s outbreak event had the most extensive spatial extent of damage reconstructed. However, a broad-level reconstruction

detailing specific outbreak characteristics and host species host impacts has yet to be completed for this period. Reconstructing outbreaks is necessary to summarize across broad spatial and temporal event scales to determine if outbreak characteristics of the 2000s infestation are similar or different relative to past and future events. Furthermore, an understanding of broad-scale outbreak impacts can inform land management decisions when MPB-caused mortality conflicts with desired forest conditions.

The objectives of this assessment were to 1) reconstruct multi-year MPB outbreak characteristics from 1999-2015 across R1 with aerial detection survey data; 2) report outbreak attributes such as spatio-temporal dynamics and species impacted during the outbreak period; and 3) determine associations between outbreak occurrence and environmental drought conditions.

Methods

Aerial survey data

Broad-scale reconstruction of the 2000s outbreak was completed using aerial detection survey (ADS) data collected annually during this period (1999-2015) by USDA Forest Service, Forest Health Protection Unit and Partner agency staff (McConnell et al. 2000). Data from annual surveys provide best-available science for broad-scale forest pest monitoring, severity estimates, and temporal trend analysis. Data are collected through observational means, however, and accuracy assessments have been scarce. Johnson and Ross (2008) determined utilizing ADS data specifically for coarse-scale assessments is appropriate, but are not ideal for analyses conducted at finer spatial resolutions. ADS data collected by technicians does maintain some advantages over currently available remote sensing data. Technicians can be trained to more reliably discern low-severity damages and determine damage causal agents (Coleman et al. 2018). Quality control checks are conducted to ensure ADS data meets nationally regulated standards; however, known sources of bias (such as severity underestimations and spatial mapping extent overestimations) have been identified within collected data (Meddens et al. 2012; Backsen and Howell 2013). As such, novel, post-processing methods have been developed and validated to reduce known sources of observational bias (Egan et al. 2019; Egan et al. 2020, *manuscript in preparation*). Table I illustrates the first step in this post-processing that collapses continuous tree per acre estimates into broad, qualitative categories.

Table I. Table depicts qualitative severity classes based on the relative midpoints of percent mortality ranges that are used for collapsing aerial detection surveys (ADS) estimates.

Severity Class	Trees/Ac mortality (TPA)	% mortality midpoint	Scaling factor
Low	< 10	5	5 / 65
Moderate	10-30	20	20 / 65
High	> 30	65	65 / 65

Severity-weighted area

Calculating severity-weighted area from the collapsed classes provides an additional post-processing method to further reduce observational errors while providing a single statistic, representing spatial extent and high-severity damage, useful for analysis. In this statistic, the high severity classification is used as a baseline to scale the low and moderate classes by their relative midpoints to adjust the area mapped to represent spatially aggregated high-severity impacts. Areas within polygons are scaled by multiplying areas of damage mapped by the relationship between the mid-point of low or moderate severity classes to the high severity damage class (Table I). For example, a 100 acre polygon classified as low severity by aerial surveys would be scaled to represent 7.7 acres of aggregate, high-severity damage. This scaling allows for reasonable trend comparisons of outbreaks over a spatial or temporal extent and can be used to determine yearly damage summations and year-to-year trends.

Multi-year MPB outbreak impact summary

Multi-year, cumulative map products that depict spatio-temporal trends of outbreaks provides land managers critical information on outbreak impacts over time. To assess cumulative impacts over time, trees per acre severity estimates were iteratively summed where spatial overlap occurred to yield 1999-2015 totals. Subsequently, trees per acre continuous totals were collapsed into severity classes depicted in Table I. The resulting outputs were validated by comparing R1 vegetation and mortality classification products (e.g. Brewer et al. 2004) with these multi-year cumulative summations for outbreak areas in the Helena and Beaverhead-Deerlodge National Forests (Egan et al. 2020, *manuscript in preparation*).

Results

Area Impact Totals for MPB Outbreak from 1999-2015

ADS data were collected annually throughout the outbreak period (1999-2015) across R1 and coverage areas are provided with the annual maps in Appendix 2. Data collected from areas cumulatively surveyed for 8 years or more provide a more reliable temporal coverage for observing MPB activity trends compared to areas surveyed for less than 8 years (Figure II).

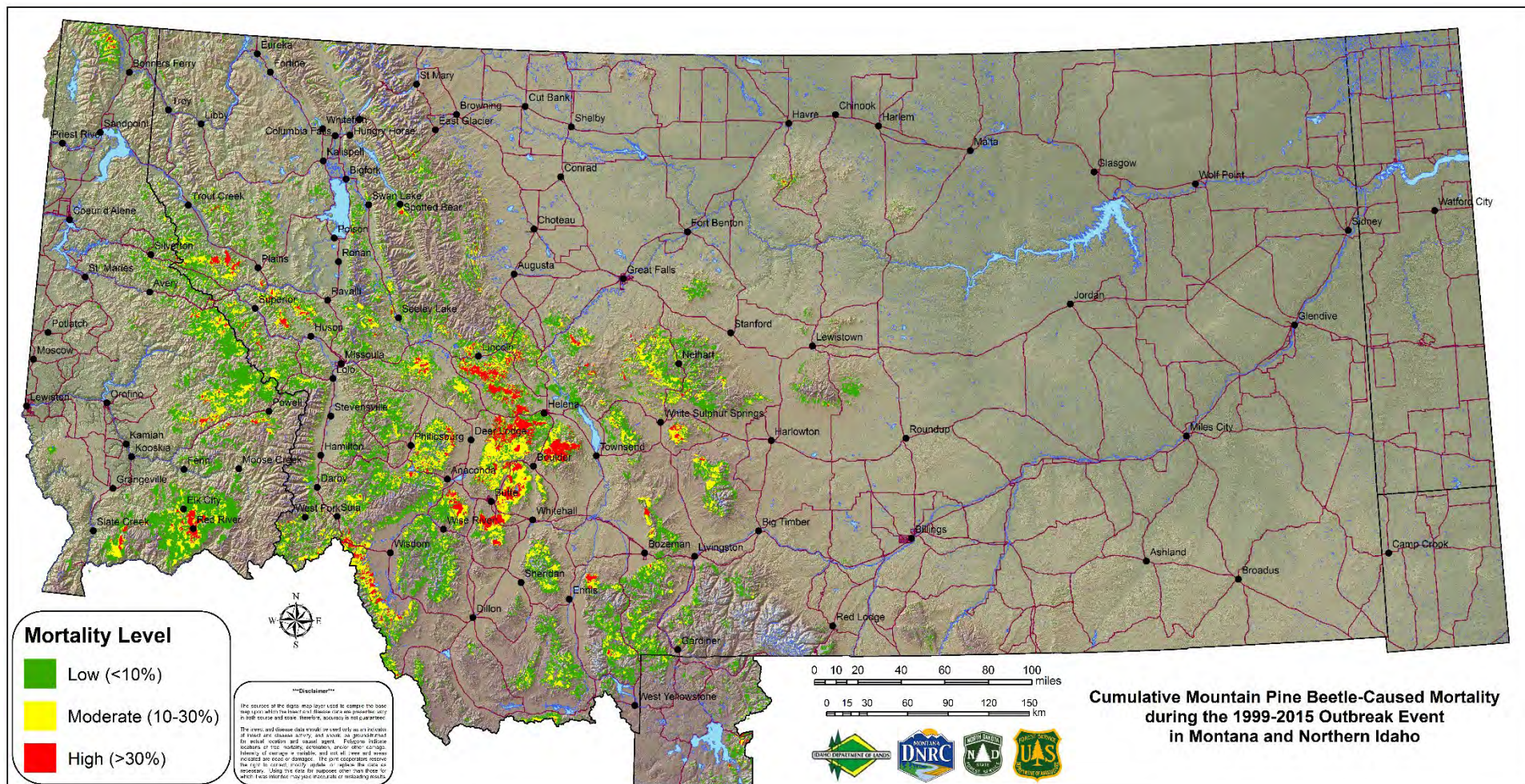


Figure III: Map depicting total cumulative MPB-caused mortality, classified by severity, during the 1999-2015 outbreak event (9 million acres).

Table II. Total area (unadjusted acres) of MPB-caused mortality during the 1999-2015 outbreak event classified by low severity, moderate severity, high severity, and total area.

	Low Severity acres	Moderate Severity acres	High Severity acres	Total Area acres
2000s Outbreak	6,323,107	2,059,540	631,812	9,014,459

The 2000s outbreak event resulted in an overall mortality footprint of over 9 million acres with 2,000,000 ac were classified as moderate severity and 631,000 ac as high severity (Table II). Severity-weighted MPB-caused mortality cumulative and individual year maps are provided in Appendices 1 and 2. The highest concentration of severe mortality was located in the Beaverhead-Deerlodge National Forest around Butte, MT and areas of the Helena National Forest south-southwest of Helena, MT (Figure III).

Temporal Progressions and Yearly Trends in MPB Outbreak from 1999-2015

The onset of the 2000s MPB outbreak began in 1999 and lasted for 17 years until ending in 2015. The initiation of the outbreak led to low mortality levels concentrated around Red River, ID and Superior, MT from 1999-2001. The footprint of the infested area during this period reached over 200,000 acres and steadily increased until surpassing 1 million acres in 2005 before decreasing again in 2006-2007 (Figure IV).

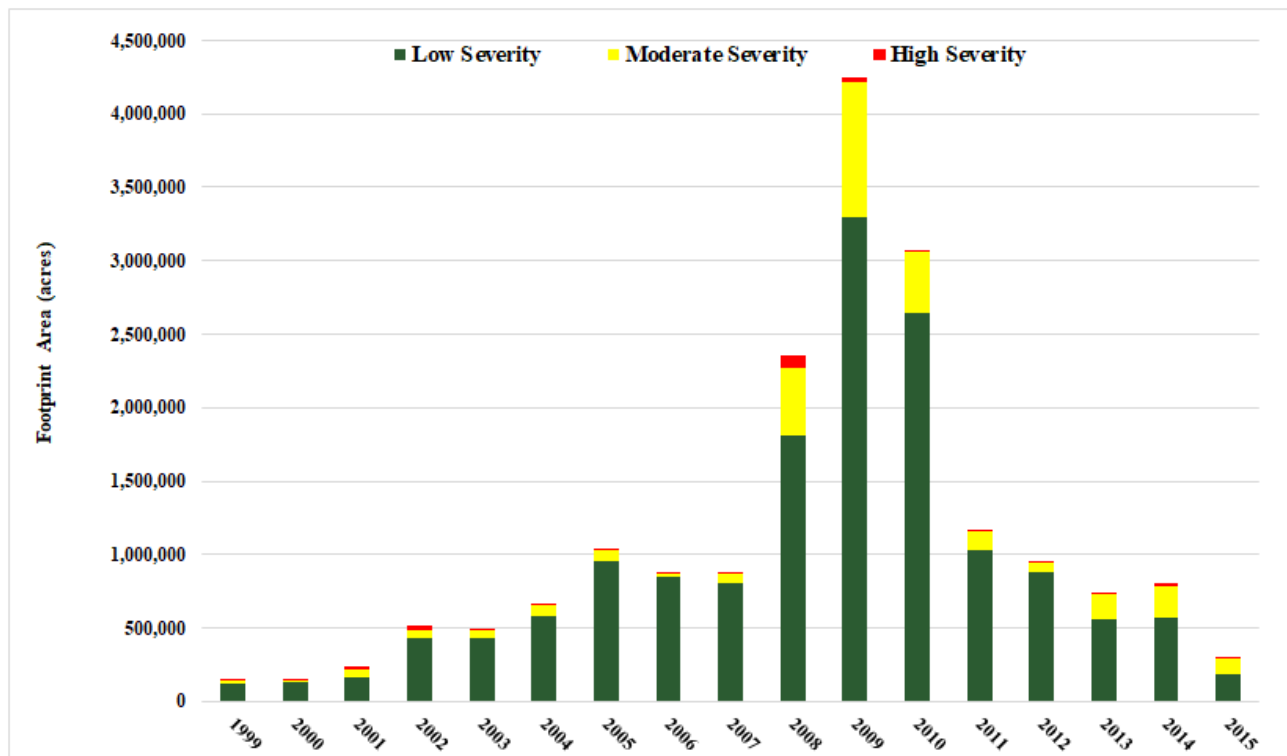


Figure IV. Histogram showing footprint area by severity of MPB-caused tree mortality mapped during the 2000s outbreak.

This outbreak experienced its greatest increase, over 350%, in footprint area during 2008 and 2009 when impacted forests reached 2.3 and 4.2 million acres respectively. Following peak infestation in 2009, change in footprint area drastically decreased until 2011 and then steadily declined until the end of the outbreak.

Annual changes in severity-weighted area were similar to those depicted with raw footprint area except from 2007 to 2008 which depicts substantially increased area relative to raw acres (Figures V).

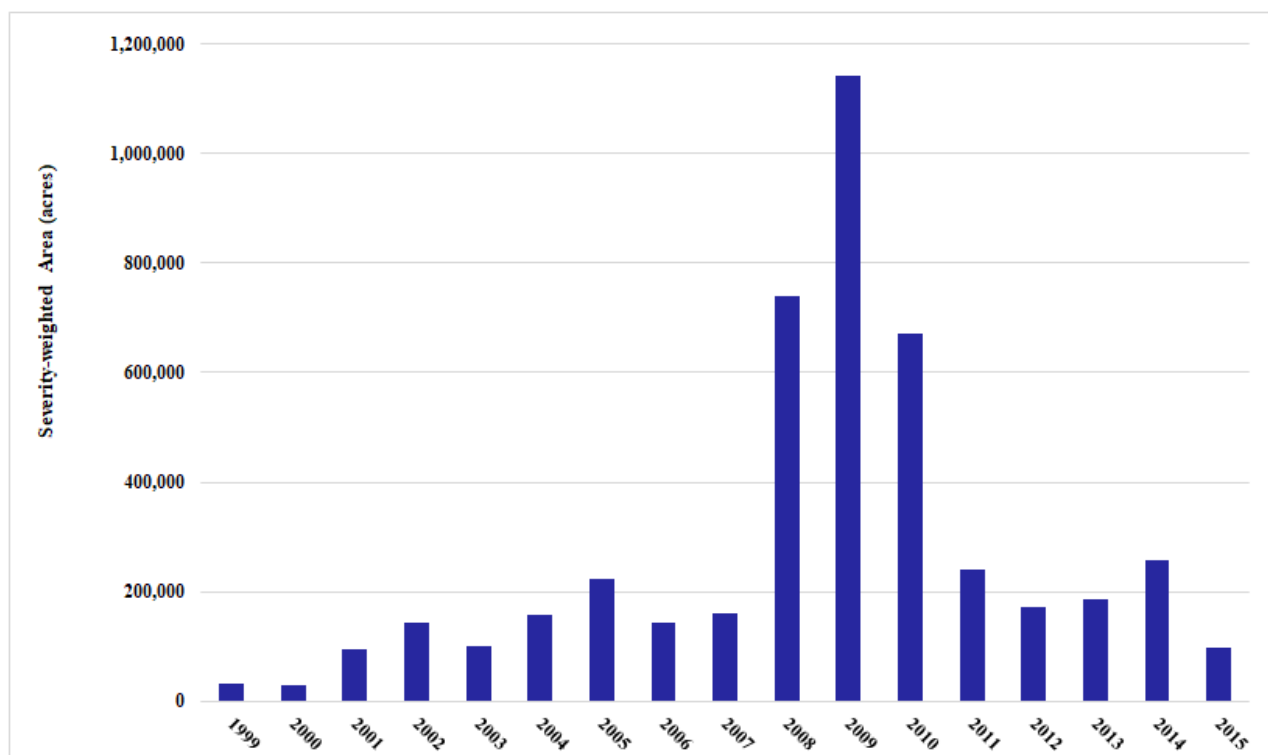


Figure V. Histogram showing severity-weighted area depictions of MPB-caused tree mortality mapped during the 2000s outbreak period.

While raw footprint and severity weighted areas trends were similar in identifying the peak year of this outbreak event, severity-weighted area is critical for trend analysis over time and any raw acre trends should be considered suspect due to exclusion of severity information estimated during data collection. Harley et al. (2019) depicted temporal differences in infestation onset and peak years between the two metrics when analyzing the 1971-1989 MPB outbreak across R1.

Figure VI illustrates the rate of change in severity-weighted area during this outbreak. The rate of change varied between positive and negative rates throughout this period with two notable increases of 225% and 363% in 2001 and 2008, respectively.

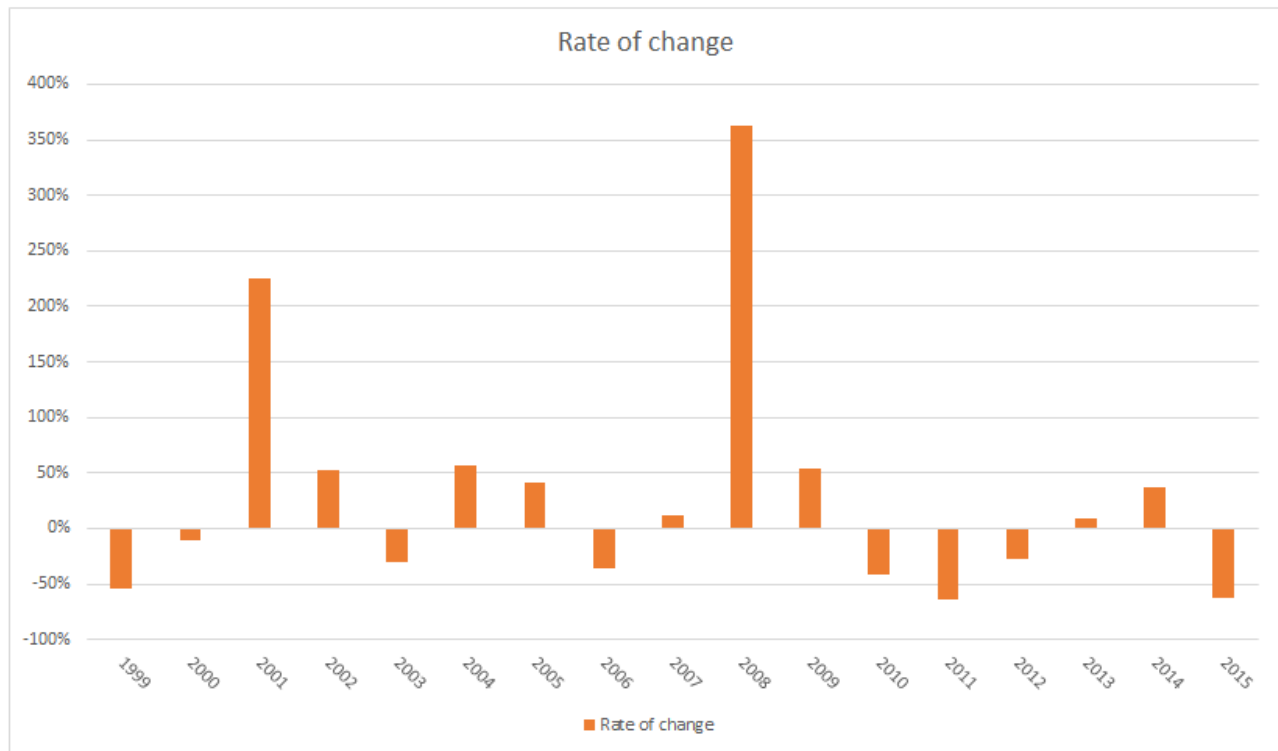


Figure VI. Histogram showing the rate of change (percent) in severity-weighted acreage in the year identified relative to the prior year.

Elevation

Region 1's location in the Northern Rocky Mountains results in a highly variable topography ranging from 1,312 ft to 14,764 ft. The 2000s outbreak footprint was primarily dispersed throughout the western, mountainous areas of the region. The highest severity of MPB-caused damage was concentrated in parts of the Beaverhead-Deerlodge and Helena National Forests located around Butte and Helena, MT. Other major concentrations of activity included areas around Superior, MT, Red River, ID, and along the Beaverhead Mountain range west of Wisdom, MT. However, these areas were considerably smaller and less severe compared to the Helena-Butte infestation area. The outbreak footprint also exhibits a distinct distribution across specific biological elevation groups (Figure VII).

Table III. Total area (ac) of the 1980s outbreak classified by elevation (ft).

	Total area (ac)	< 3000 ft	3000-6000 ft	6000-9000 ft	> 9000 ft
2000s Outbreak	9,014,459	27,753	3,973,938	4,812,071	200,697
% of total	--	0.31%	44.08%	53.38%	2.23%

Elevations ranging from 6000-9000 ft experienced the largest footprint area of 4,812,071 acres followed by the 3000-6000 ft elevation group with 3,973,938 acres impacted (Table III); together accounting for 97% of the total 9 million acre footprint. Similar elevation trends were also observed during the 1980s

outbreak (Harley et al. 2019). Elevation groups of < 3,000 ft and > 9,000 ft contained footprint areas of 27,753 and 200,697 acres, respectively.

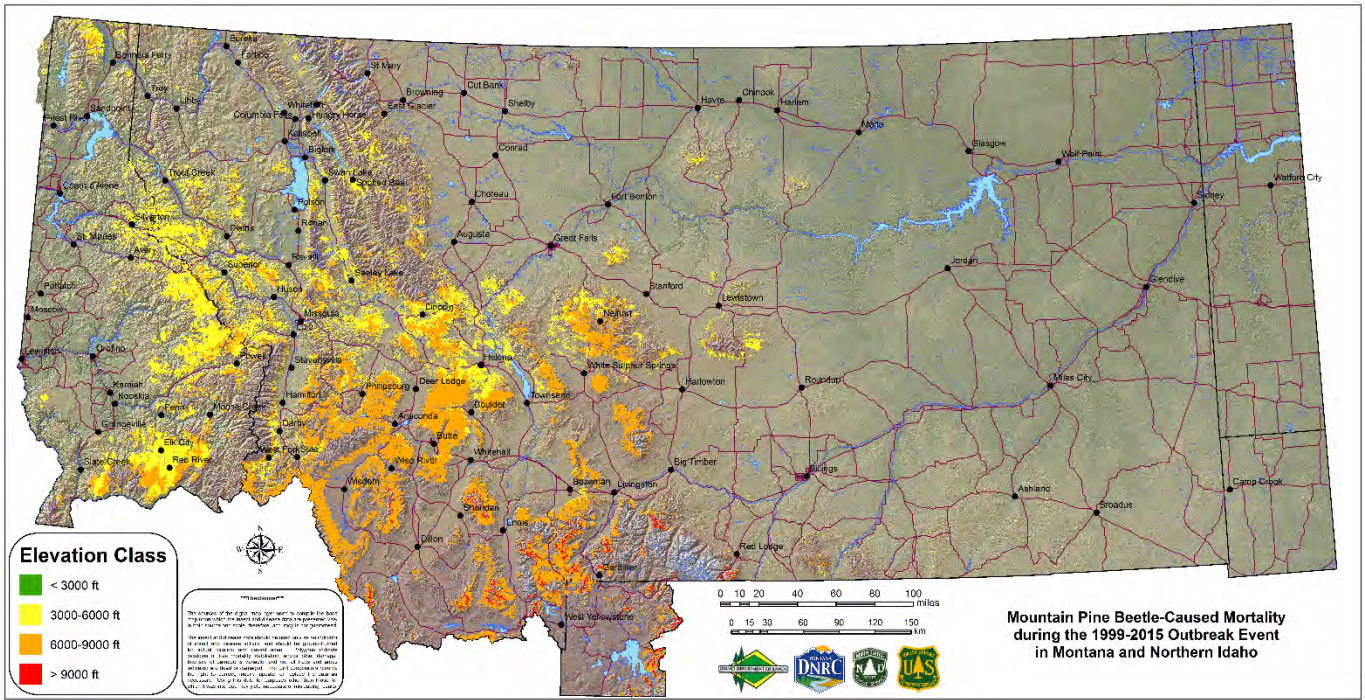


Figure VII. Map showing the total footprint area of the 2000s outbreak classified by biological elevation range (feet above sea level) groups across the Northern Region.

Species Impacted

Pinus contorta (lodgepole pine), *P. ponderosa* (ponderosa pine), *P. albicaulis* (whitebark pine), *P. flexilis* var. *reflexa* (limber pine) and *P. monticola* (western white pine) served as the primary hosts during the 2000s outbreak (Table IV, Figure VIII). Lodgepole pine had the greatest mortality compared to the other species with 7,208,100 acres impacted (79.96%). Infested areas classified as high severity were primarily concentrated in contiguous stands of lodgepole pine. Ponderosa pine mortality was estimated to cover 865,596 acres and was primarily located around the Helena infestation area. The five needle pines, limber and whitebark, had the greatest mortality in the Greater Yellowstone Ecosystem and a total of 872,396 acres were impacted. Western white pine had minimal mortality with only 68,367 acres impacted.

Table IV. Total area (acres) of the 1980s outbreak classified by species impacted.

	whitebark pine (<i>P. albicaulis</i>) & limber pine (<i>P. flexilis</i>)	ponderosa pine (<i>P. ponderosae</i>)	western white pine (<i>P. monticola</i>)	lodgepole pine (<i>P. contorta</i>)
1999-2015 Acres	872,396	865,596	68,367	7,208,100
% of total	9.68%	9.60%	0.76%	79.96%

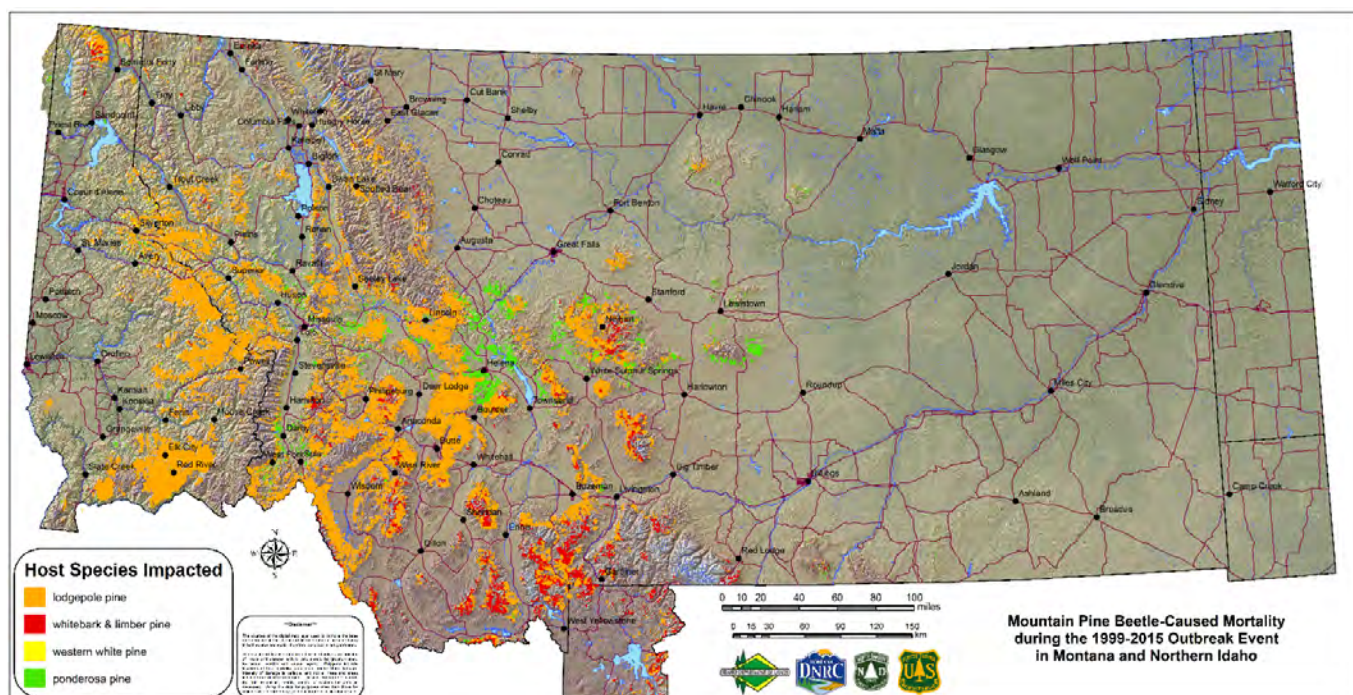


Figure VIII: Map showing total footprint area of the 2000s outbreak classified by species impacted across the Northern Region.

Environmental Drought Association

Variations in drought conditions across a large geographic area can influence overall forest health and predispose trees to infestations from bark beetles (Hart et al. 2014; Negrón et al. 2009). The Palmer Drought Severity Index (PDSI; Palmer 1965) provides a metric for assessing hydroclimatic and drought conditions and was utilized to examine potential associations with the intensity of the 2000s outbreak. PSDSI values are ranked from -6 (extremely dry) to 6 (extremely wet) and soil moisture conditions across R1 during the outbreak period were determined to be drier than normal (Figure IX).

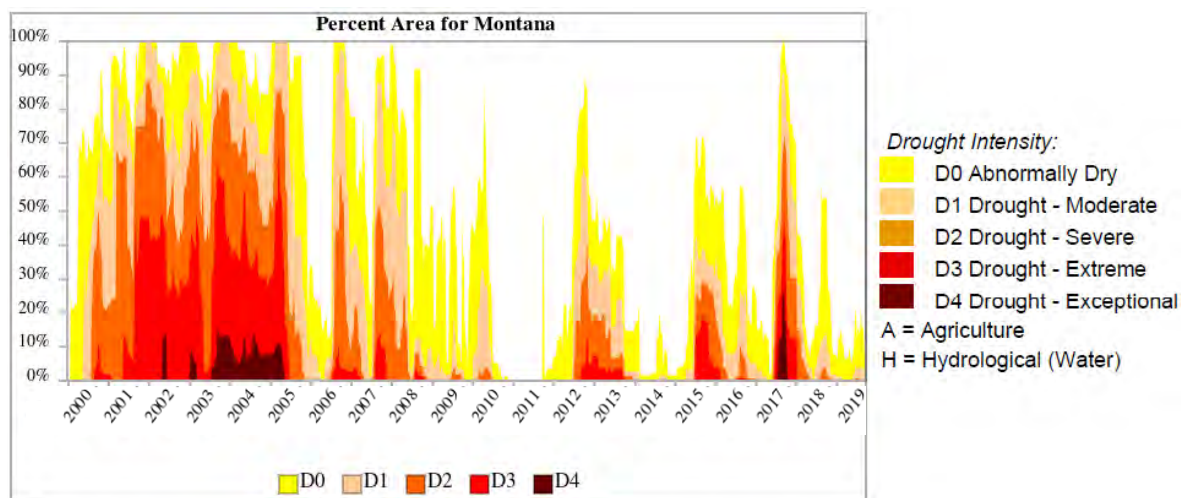


Figure IX: Graph showing drought intensity by percent of land area over the outbreak's period in Montana.

Abnormally dry conditions began to occur across most of Montana beginning around 2000 and continued to intensify until reaching extreme-exceptional conditions in 2004-2006. These adverse hydroclimatic conditions coincided with the gradual increase in MPB activity observed in the initial outbreak years (1999-2006) where infestations eventually were mapped over one million acres by 2005. Intense drought conditions returned to the region starting in 2007 when this outbreak event experienced its most significant increase in MPB-caused tree mortality with the rate of change from 2007-2008 at 350%. It's important to note that mortality observed by ADS in one year represents MPB activity from the previous year. Therefore, the severe MPB mortality observed in 2008, considered to be a 'boom' year, when epicenters expanded substantially, was associated with the severe to extreme drought conditions in 2007. By the time hydroclimatic conditions had returned to normal in 2011, MPB activity had also significantly declined and impacts remained minimal until the outbreaks ended in 2015. Additionally, high cumulative mortality areas further overlapped with areas experiencing severe to exceptional drought conditions across the region (Figure X). In 2005, when infestations reached their highest during the outbreaks initiation, most severe MPB mortality was concentrated in areas with extreme to exceptional drought conditions along the Montana-Idaho border. A similar overlap is also observed in 2007, the onset of the 'boom' year, when the most significant increase in severity-weighted acres occurred across forests experiencing severe to extreme drought conditions. These comparisons indicate spatial and temporal associations between outbreak characteristics and regional drought conditions.

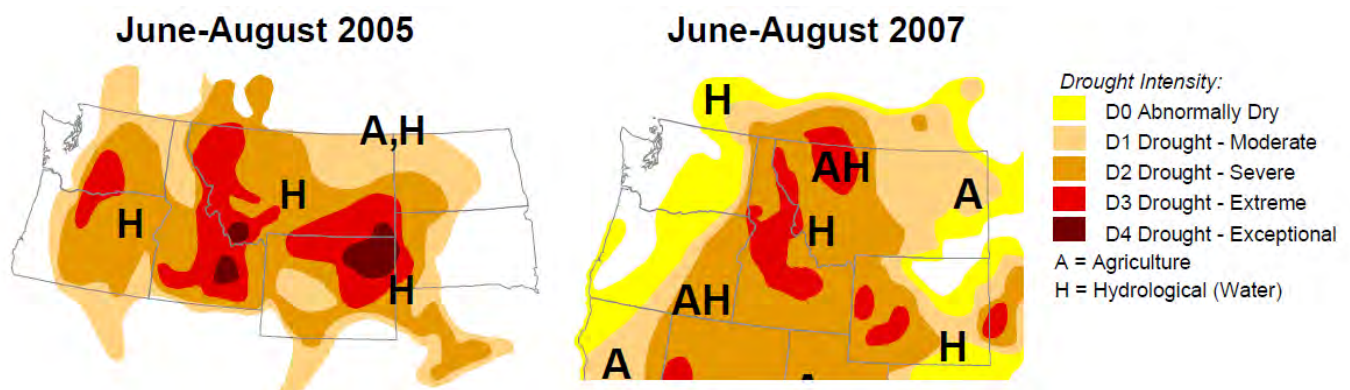


Figure X: Map showing drought intensity in 2005 and 2007 across the Northern Region and surrounding states.

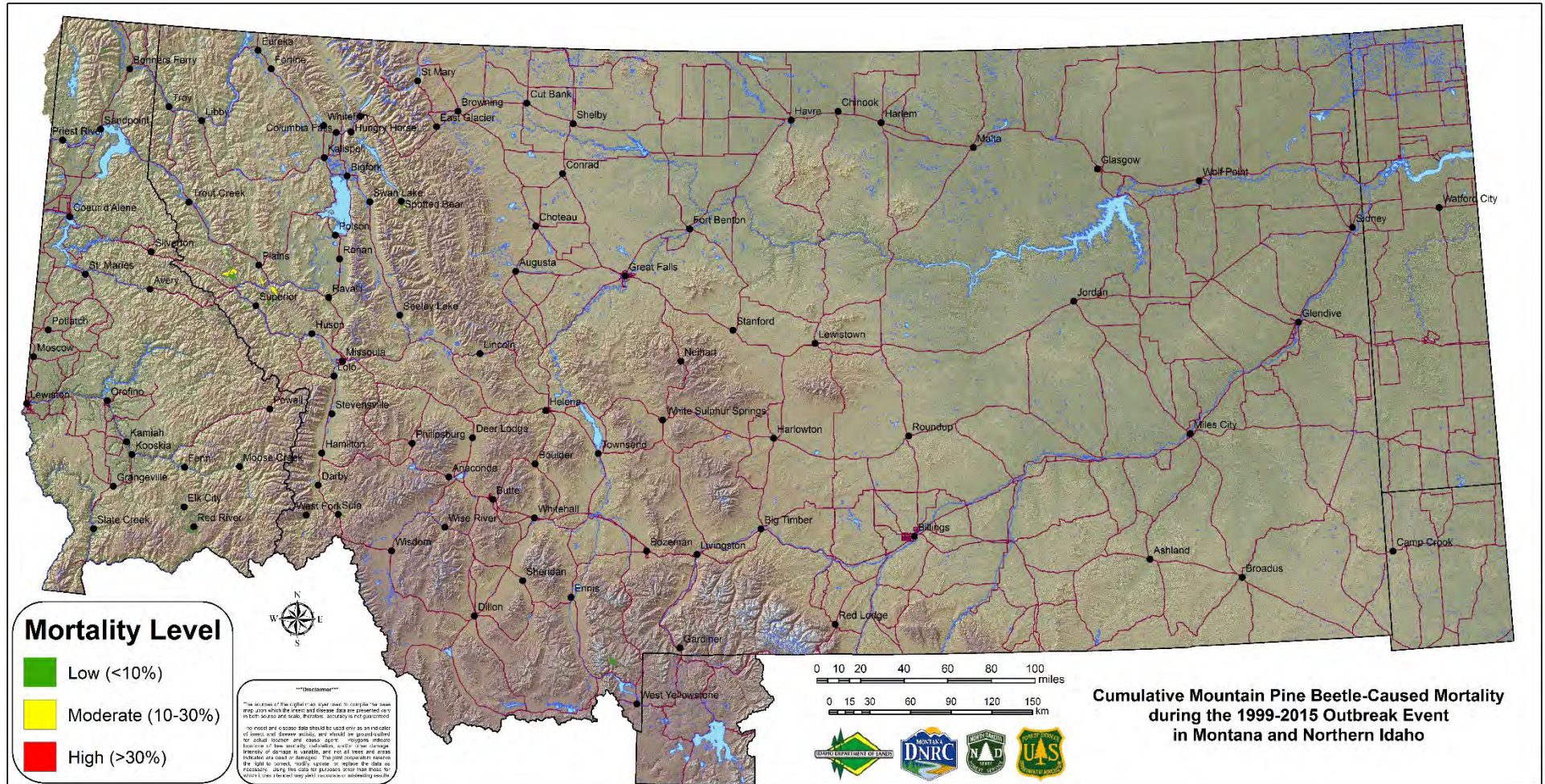
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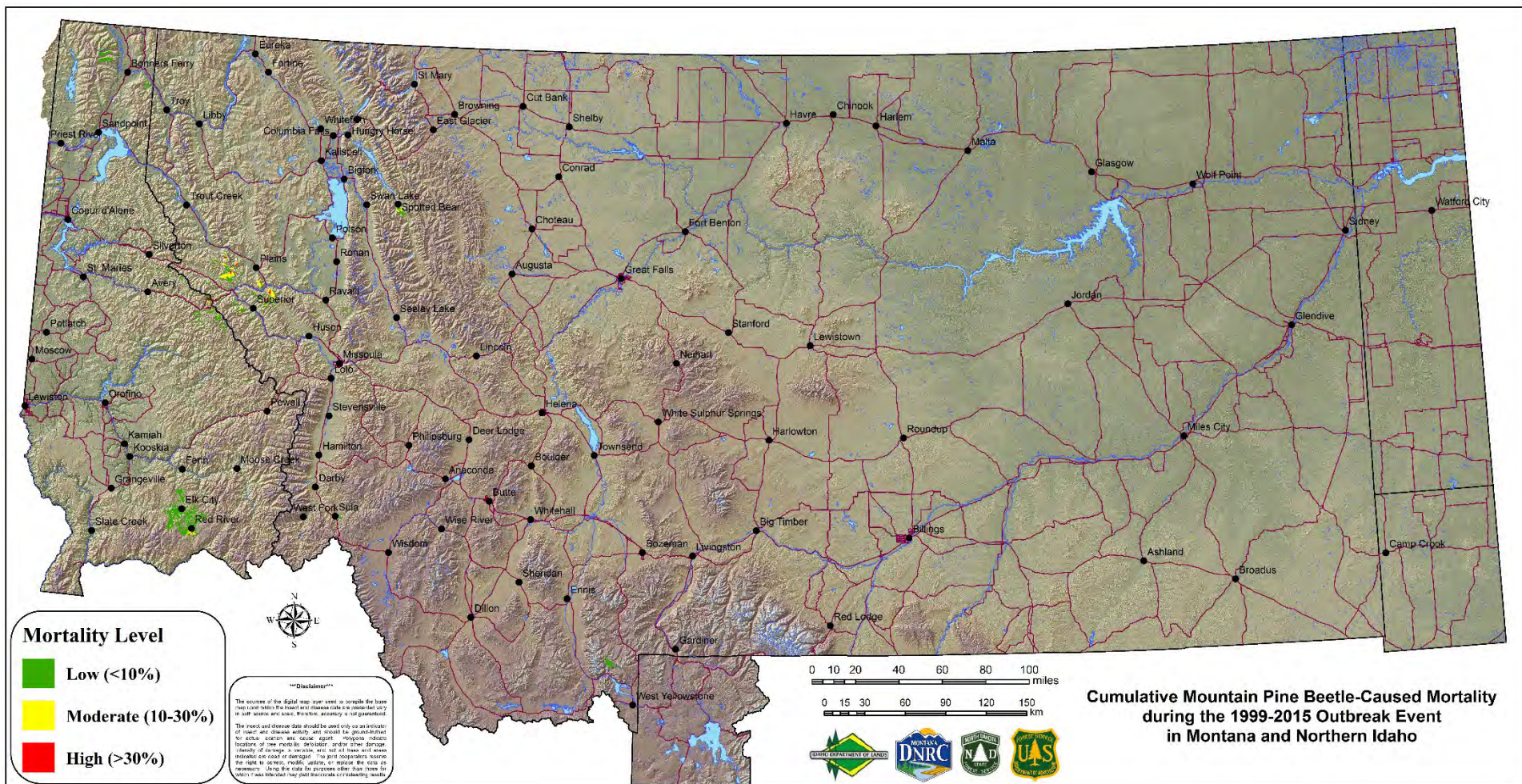
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Appendix 1: Maps showing total cumulative MPB-caused mortality area during each year of the 1999-2015 outbreak event (total 9 million acres) classified by severity of mortality estimated through aerial detection surveys.

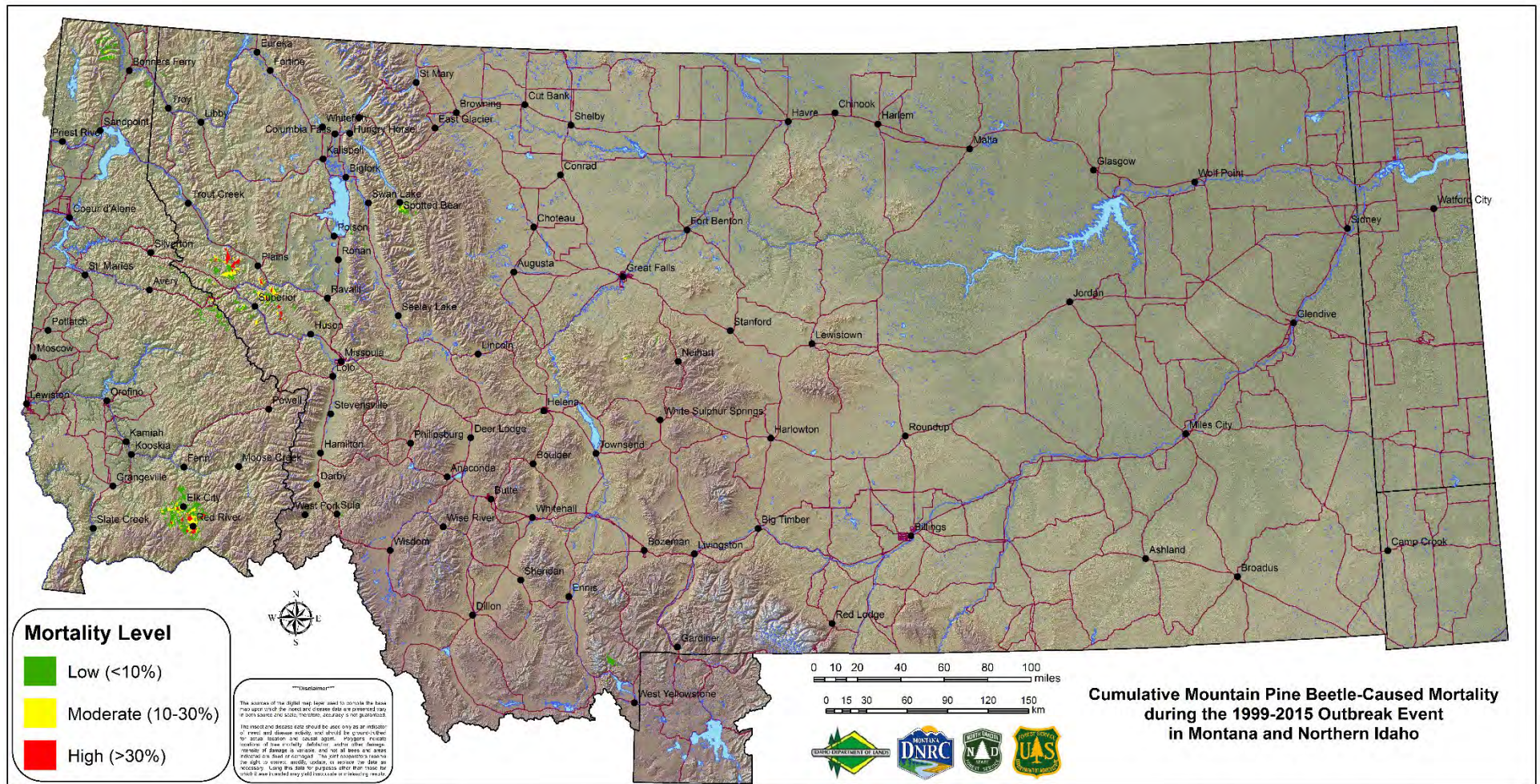
Map I: 1999 Mountain pine beetle-caused mortality estimated by ADS



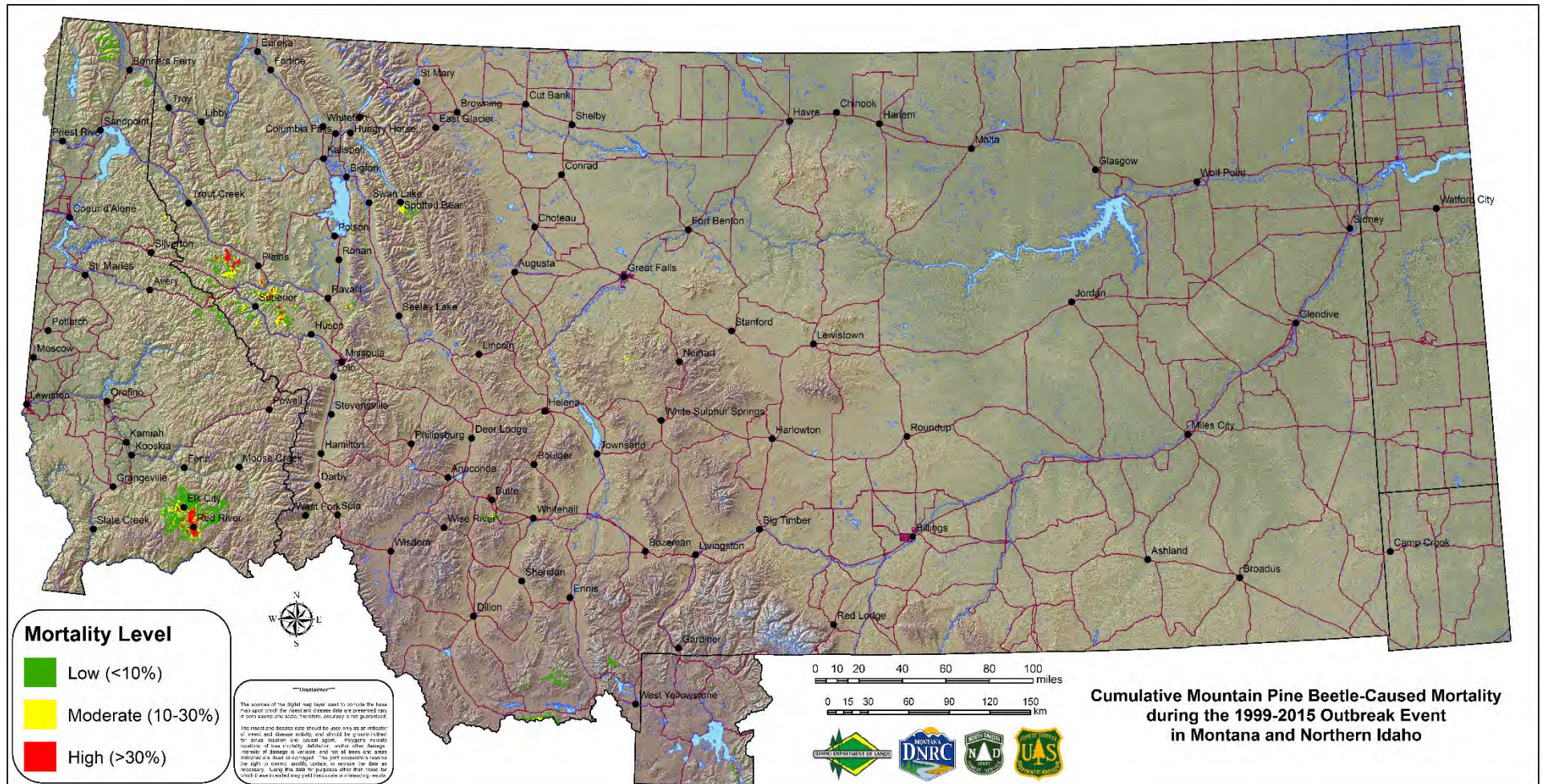
Map II: 1999-2000 Cumulative mountain pine beetle-caused mortality estimated by ADS



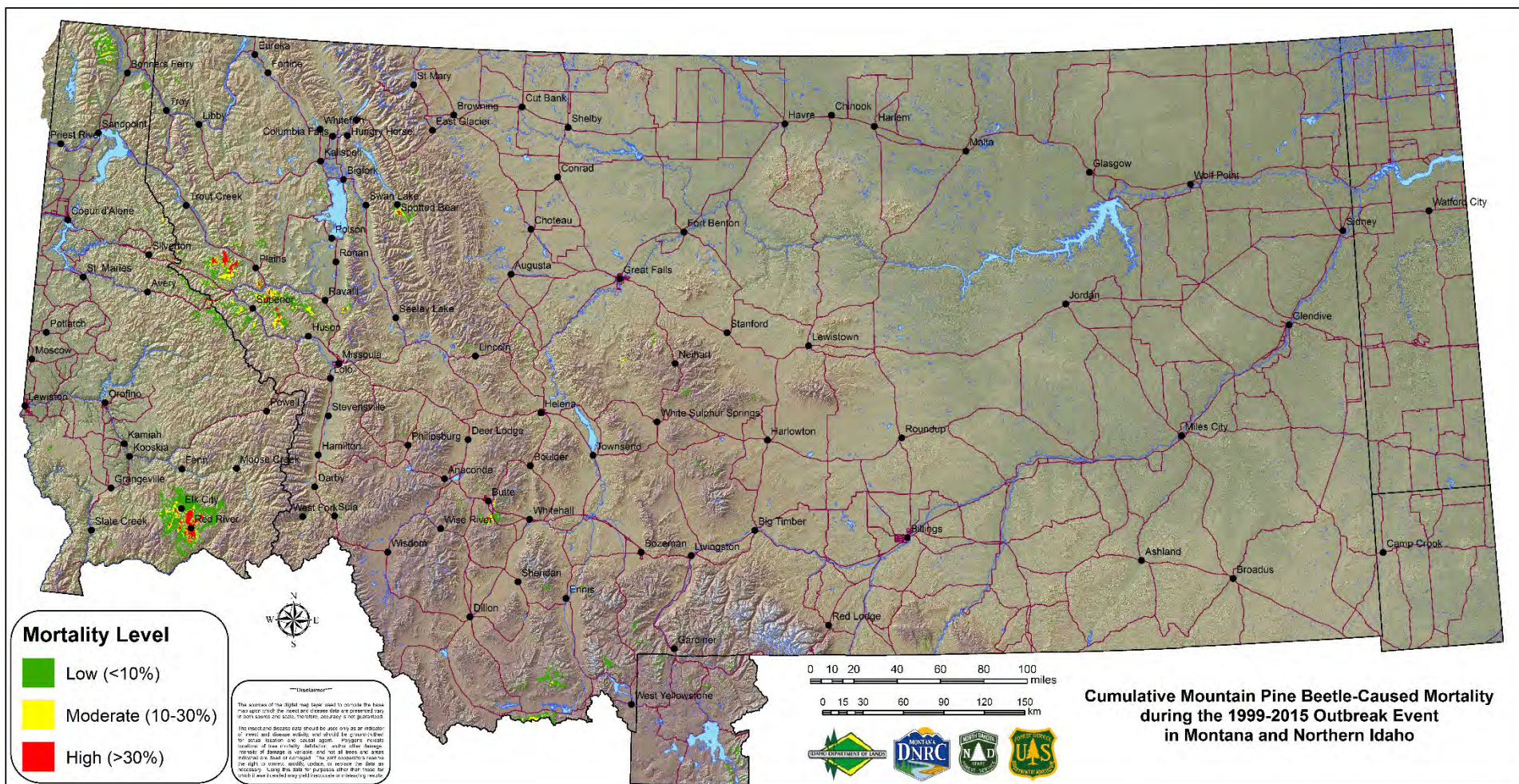
Map III: 1999-2001 Cumulative mountain pine beetle-caused mortality estimated by ADS



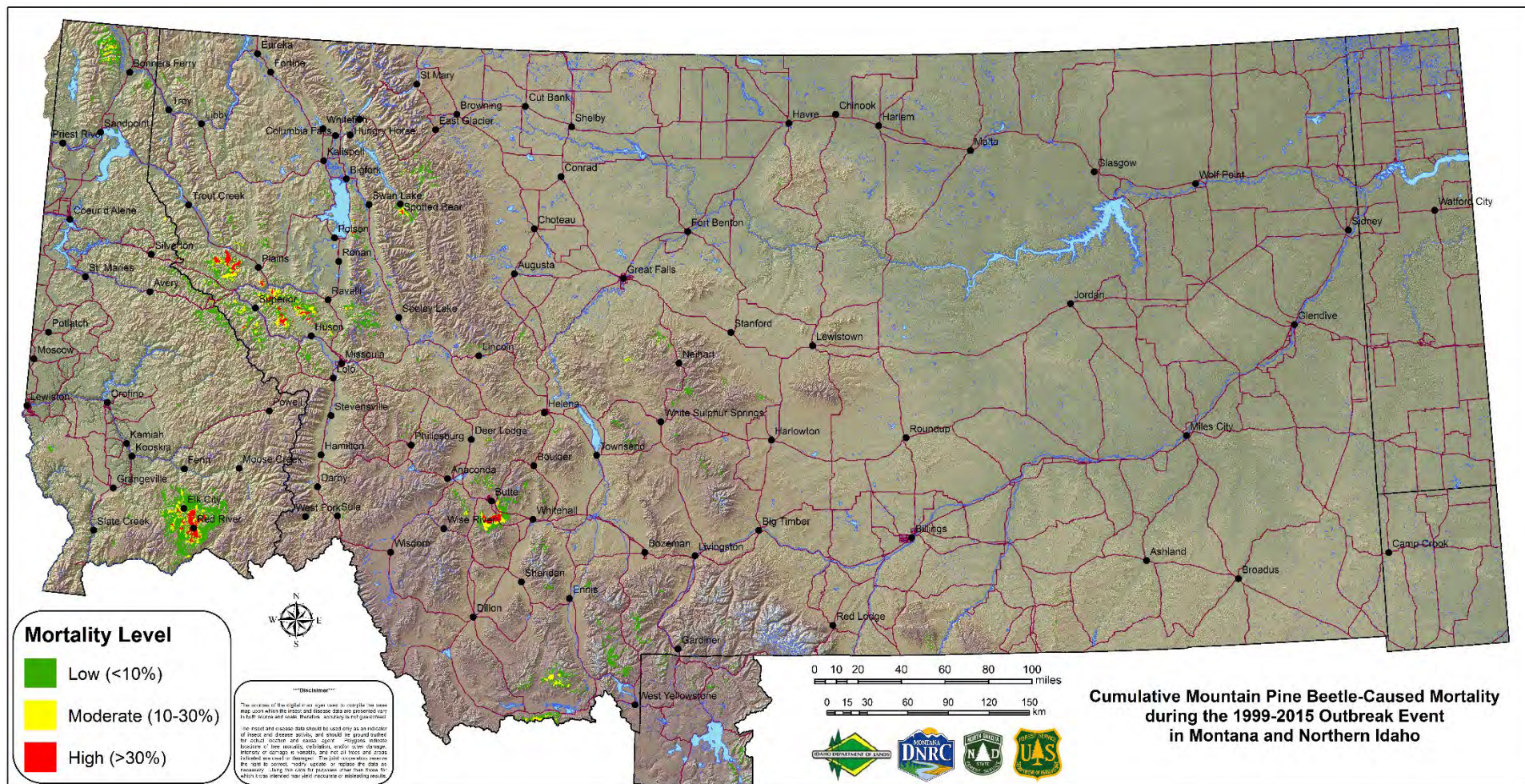
Map IV: 1999-2002 Cumulative mountain pine beetle-caused mortality estimated by ADS



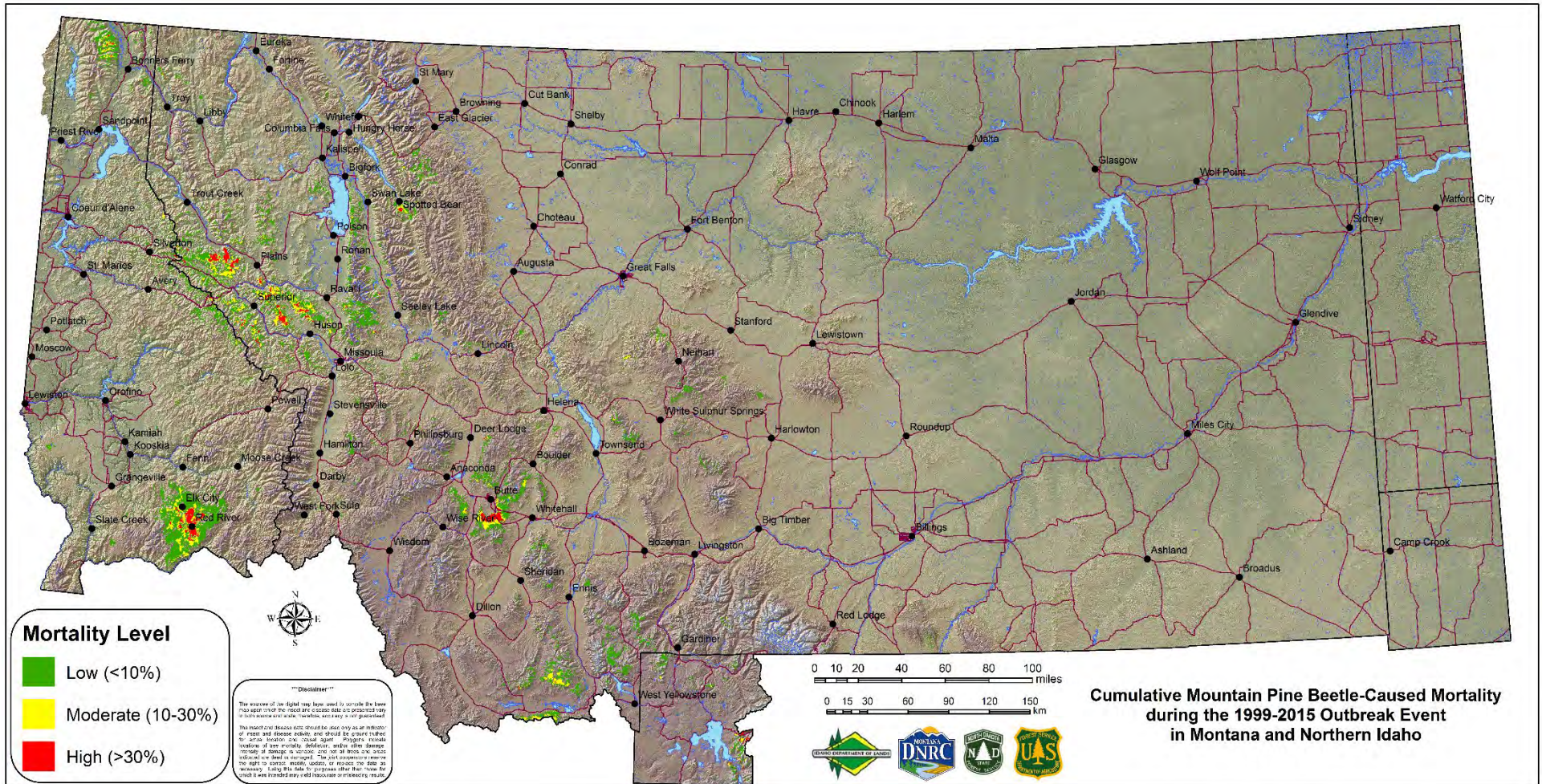
Map V: 1999-2003 Cumulative mountain pine beetle-caused mortality estimated with ADS



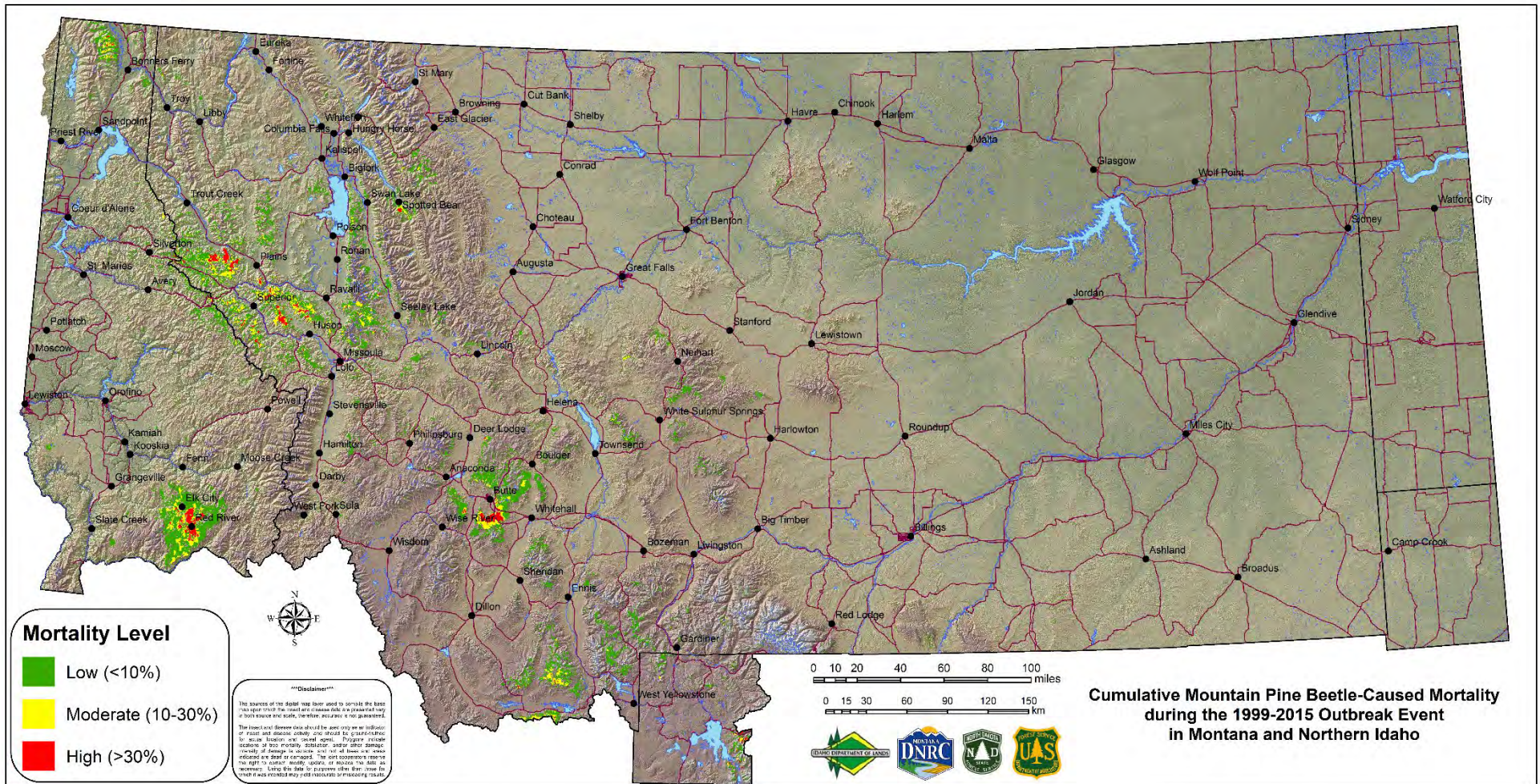
Map VI: 1999-2004 Cumulative mountain pine beetle-caused mortality estimated with ADS



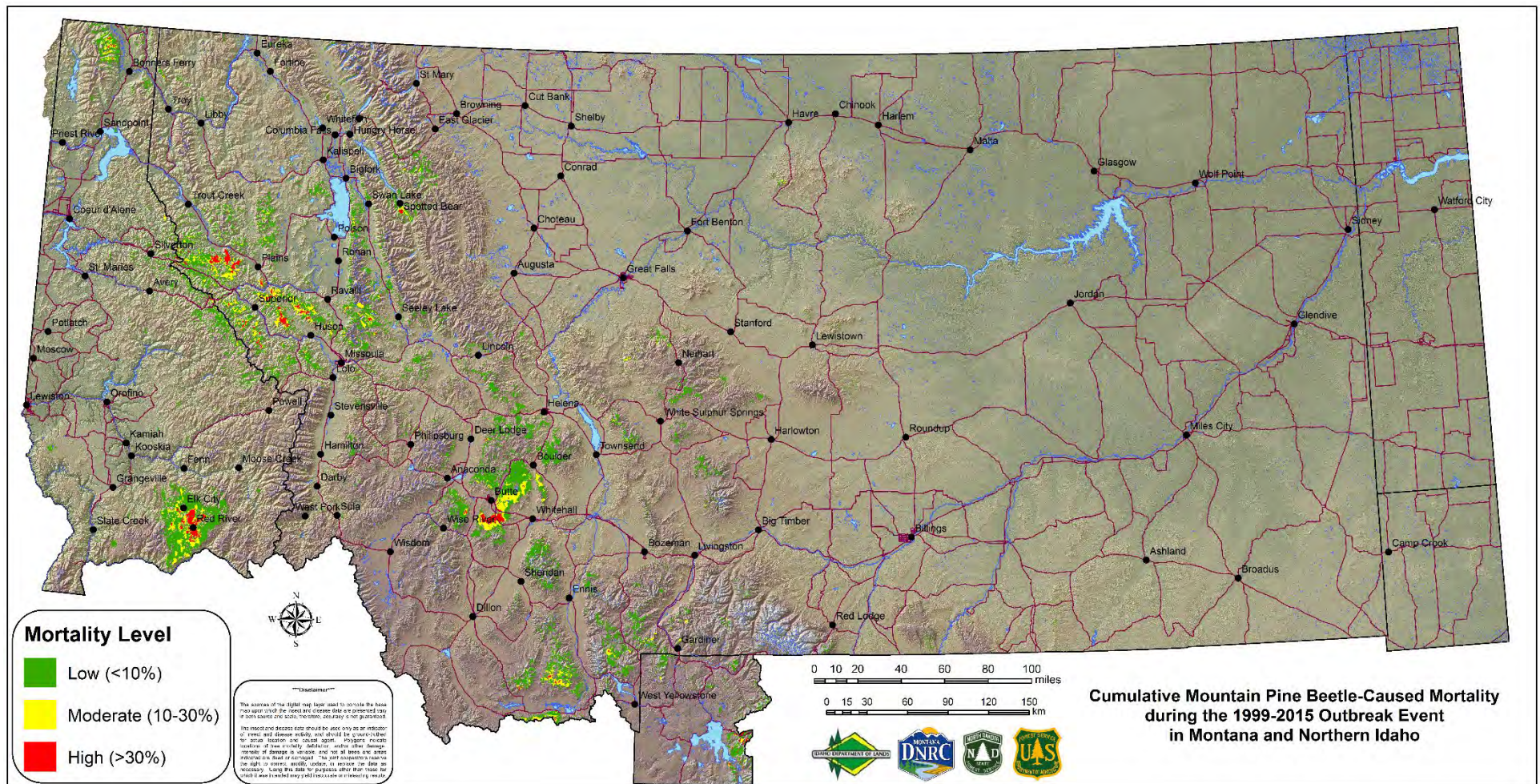
Map VII: 1999-2005 Cumulative mountain pine beetle-caused mortality estimated with ADS



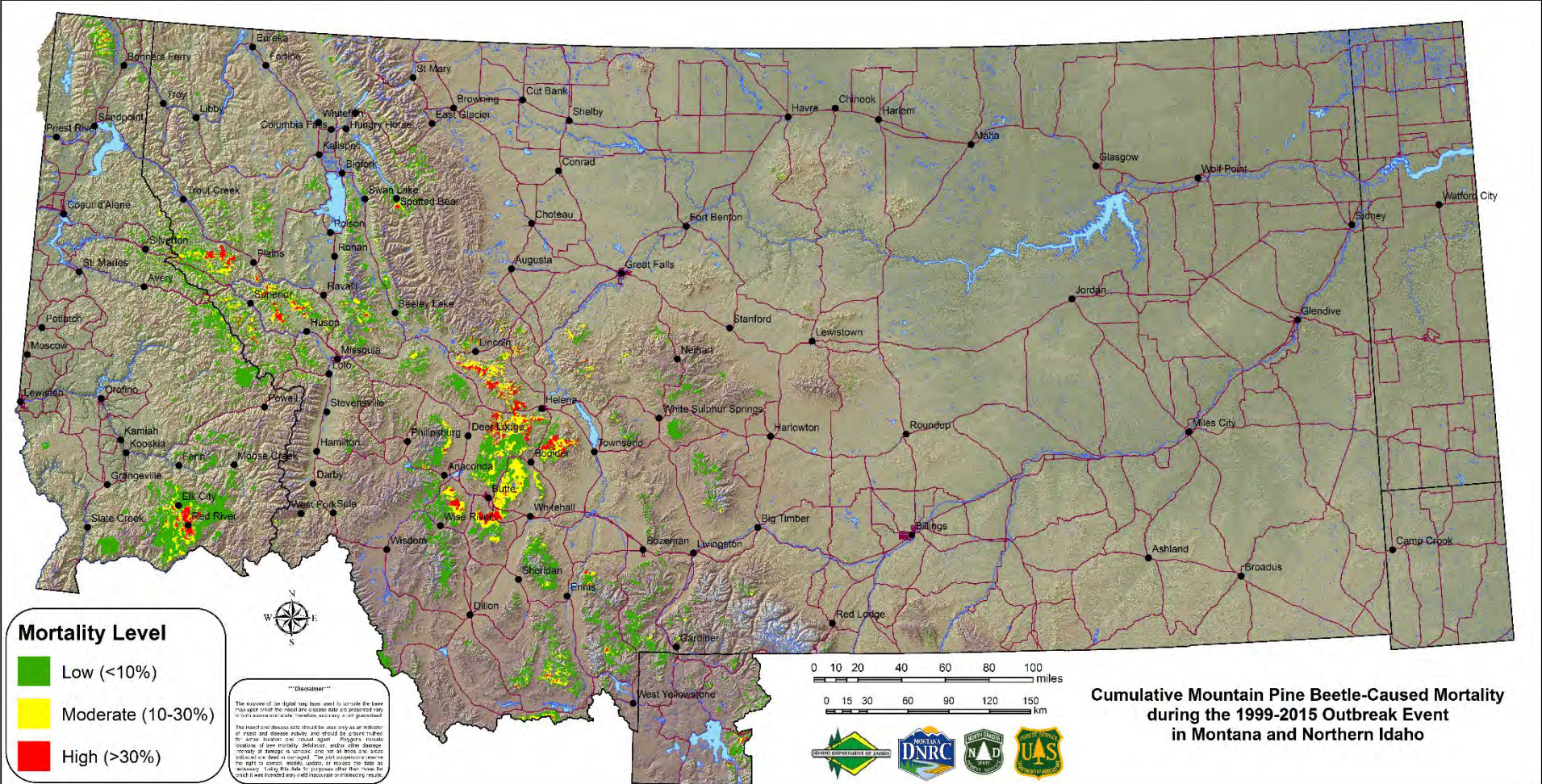
Map VIII: 1999-2006 Cumulative mountain pine beetle-caused mortality estimated with ADS



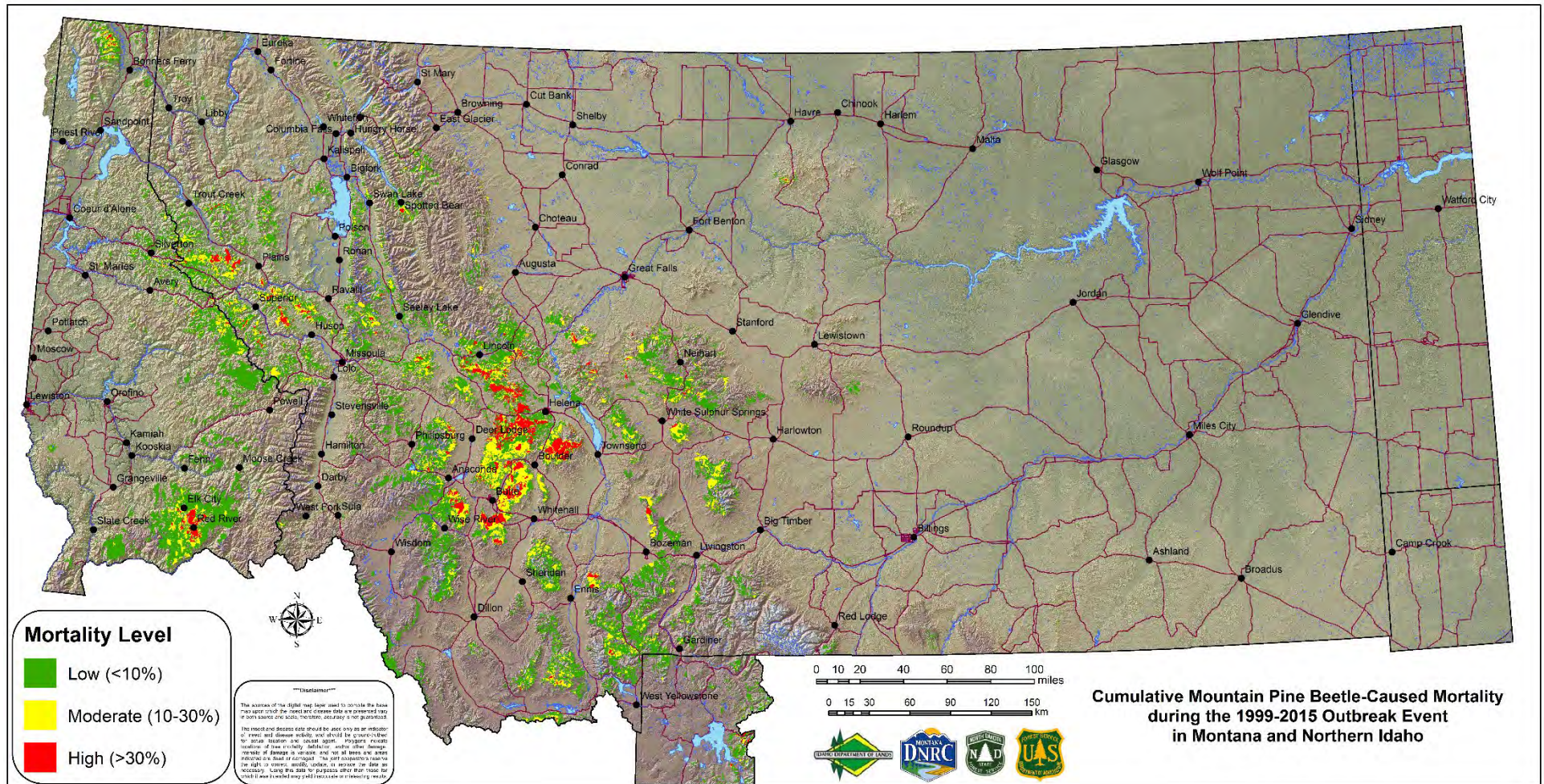
Map IX: 1999-2007 Cumulative mountain pine beetle-caused mortality estimated with ADS



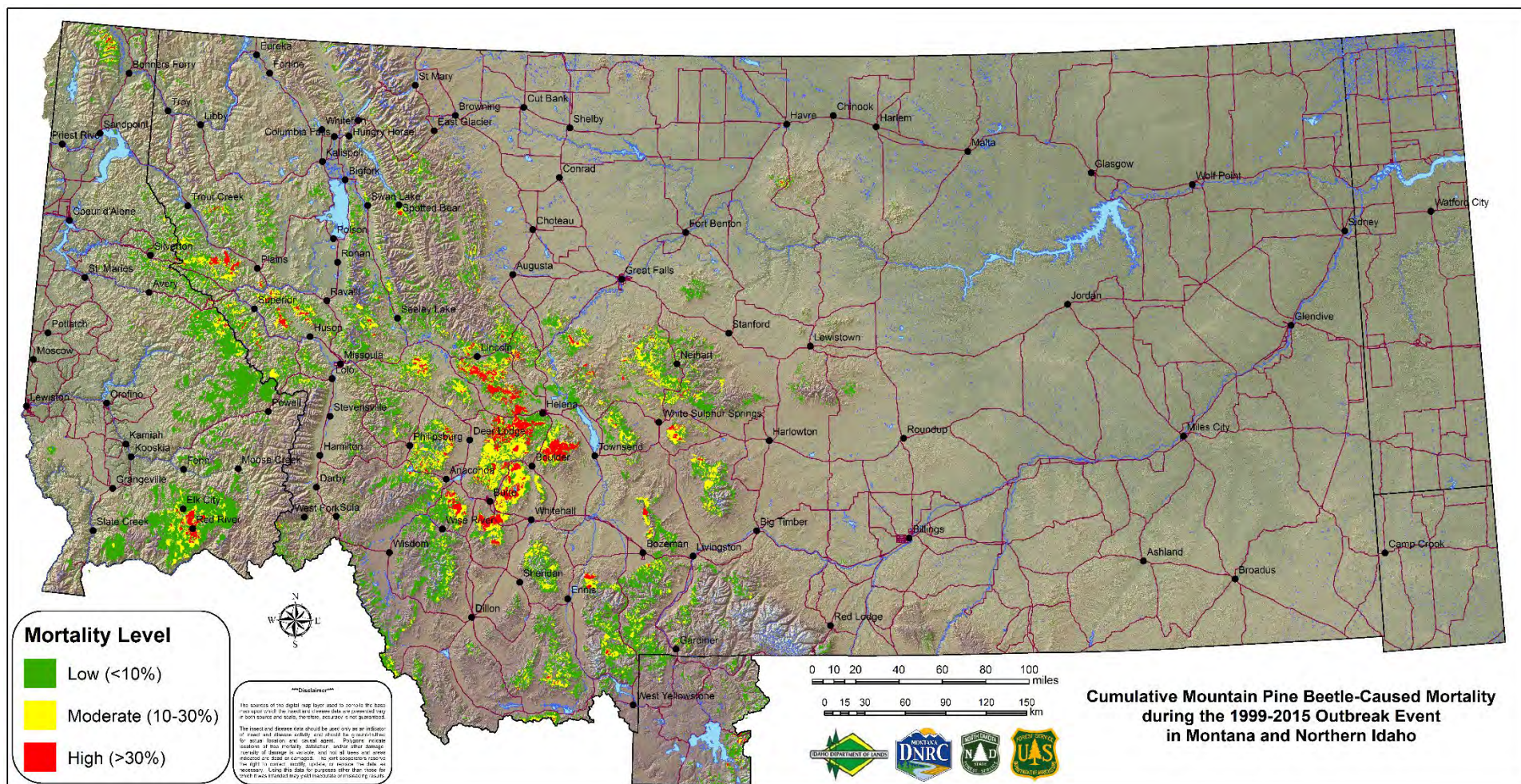
Map X: 1999-2008 Cumulative mountain pine beetle-caused mortality estimated with ADS



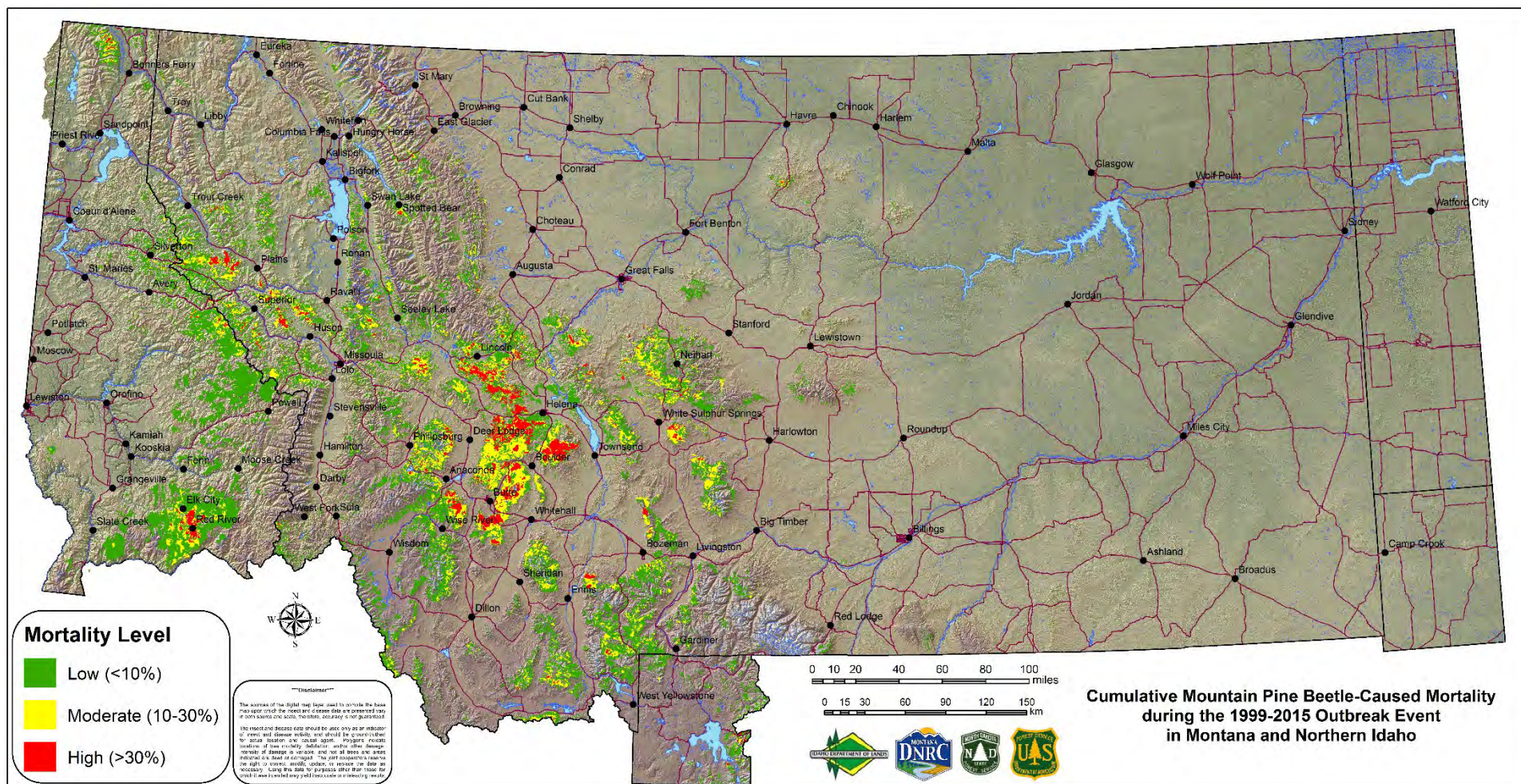
Map XI: 1999-2009 Cumulative mountain pine beetle-caused mortality estimated with ADS



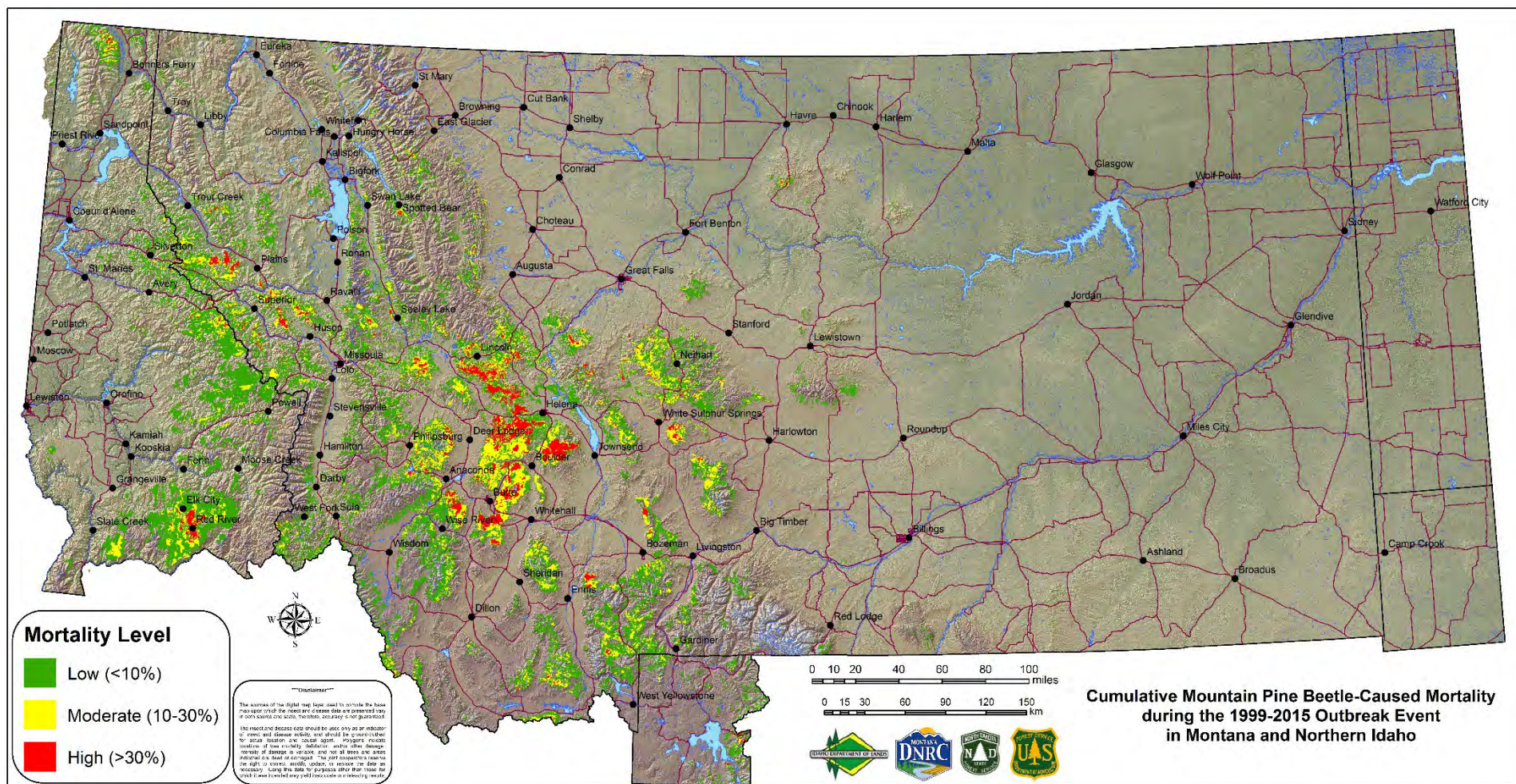
Map XII: 1999-2010 Cumulative mountain pine beetle-caused mortality estimated with ADS



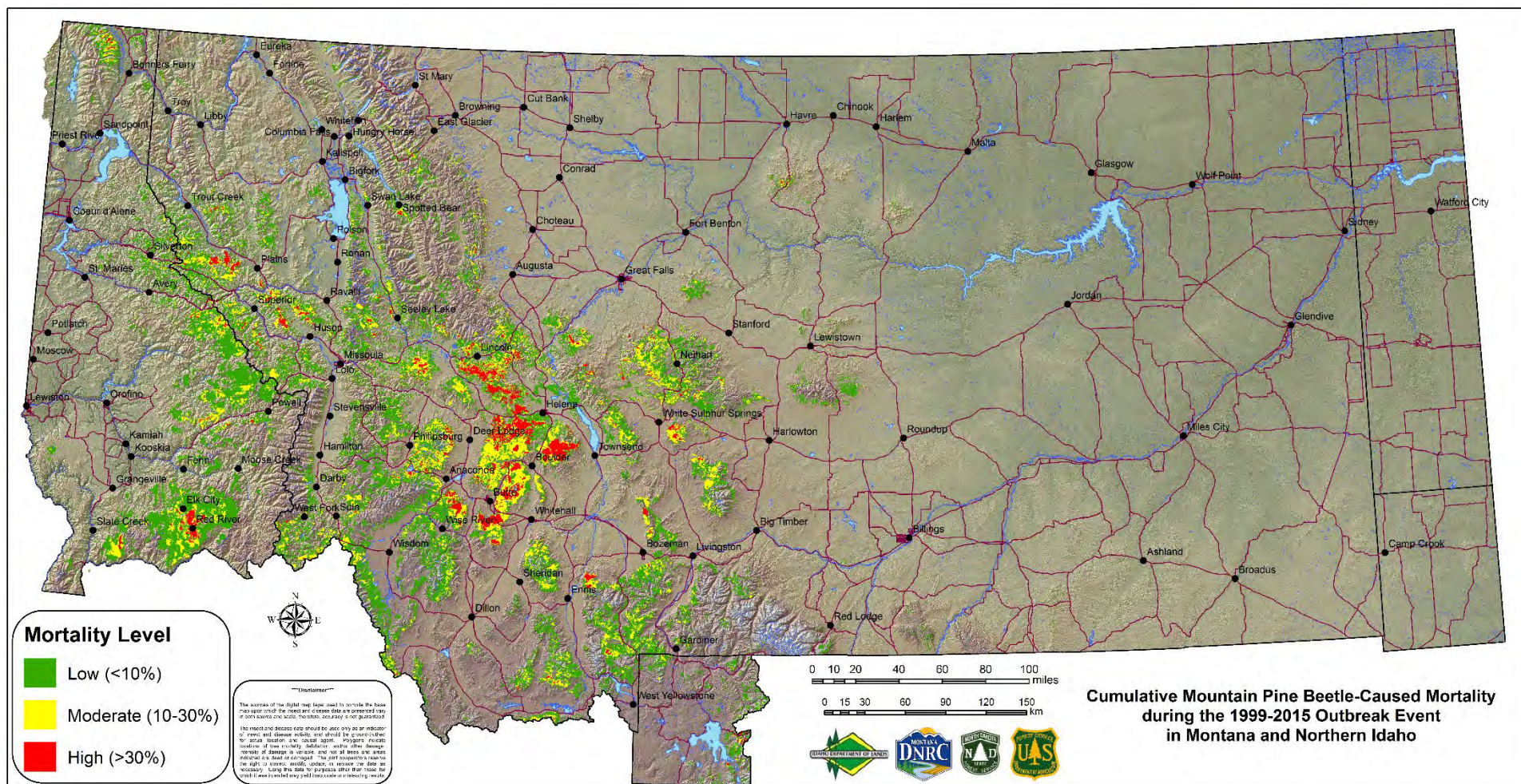
Map XIII: 1999-2011 Cumulative mountain pine beetle-caused mortality estimated with ADS



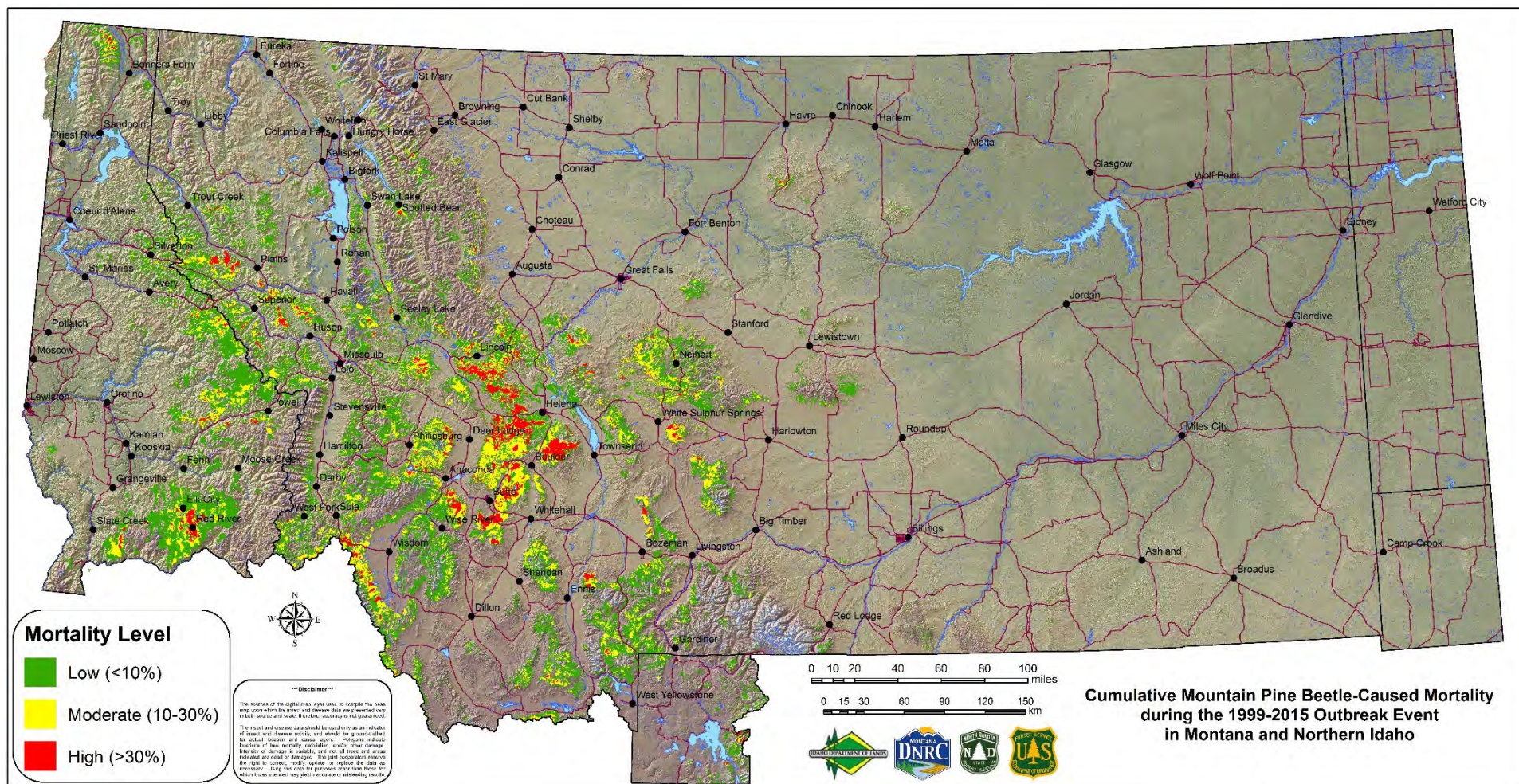
Map XIV: 1999-2012 Cumulative mountain pine beetle-caused mortality estimated with ADS



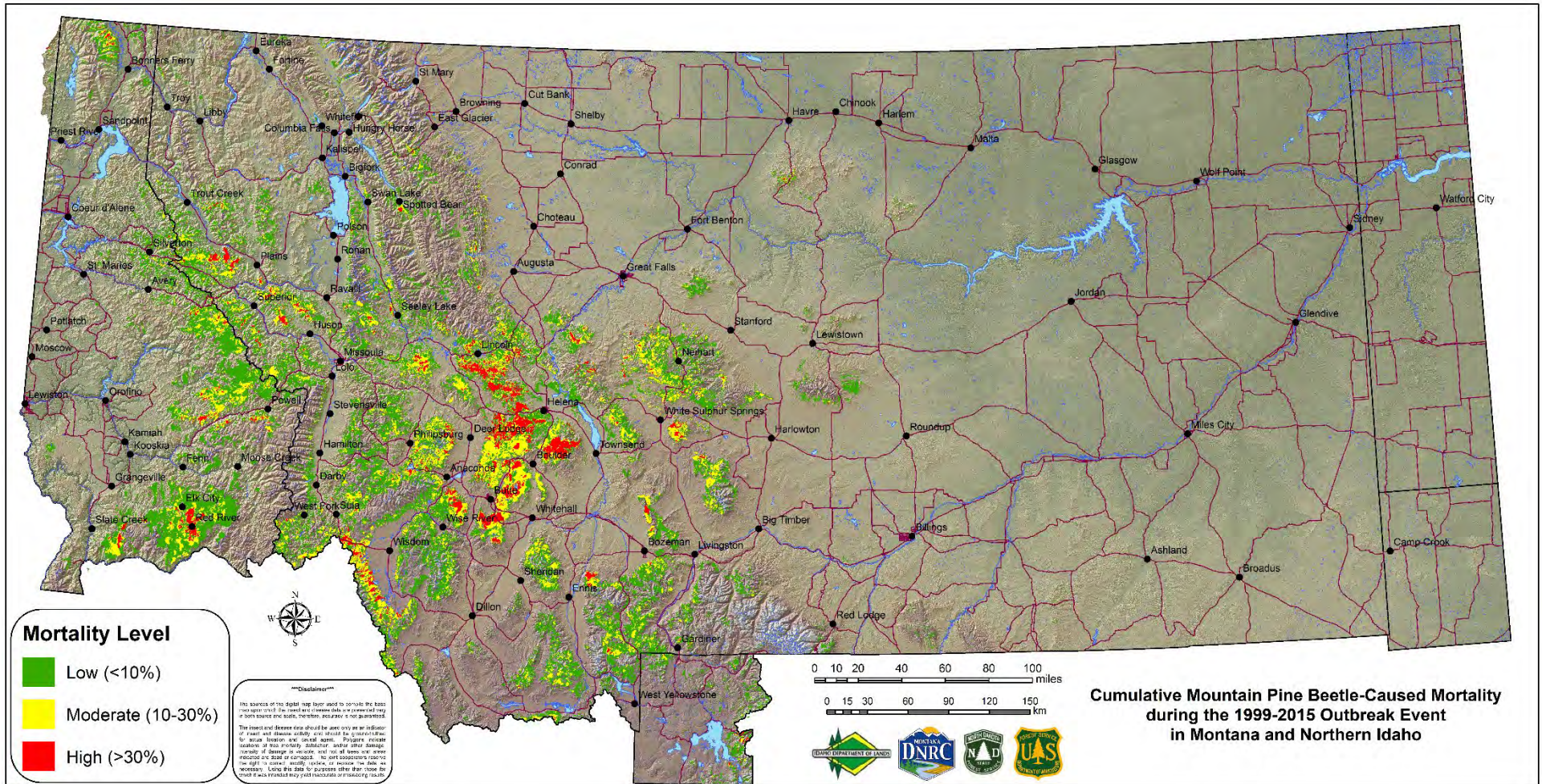
Map XV: 1999-2013 Cumulative mountain pine beetle-caused mortality estimated with ADS



Map XVI: 1999-2014 Cumulative mountain pine beetle-caused mortality estimated with ADS

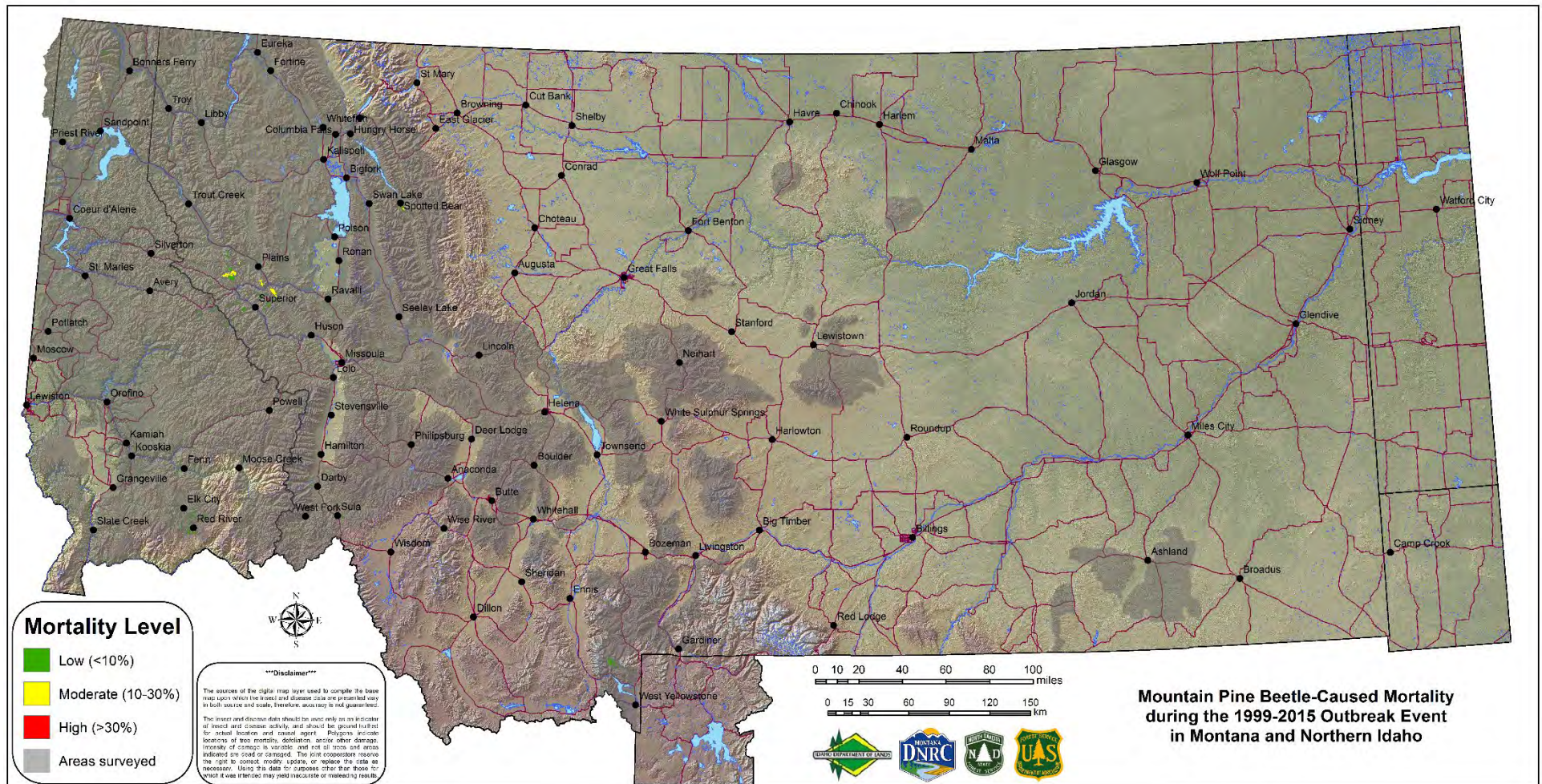


Map XVII: 1999-2015 Cumulative mountain pine beetle-caused mortality estimated with ADS

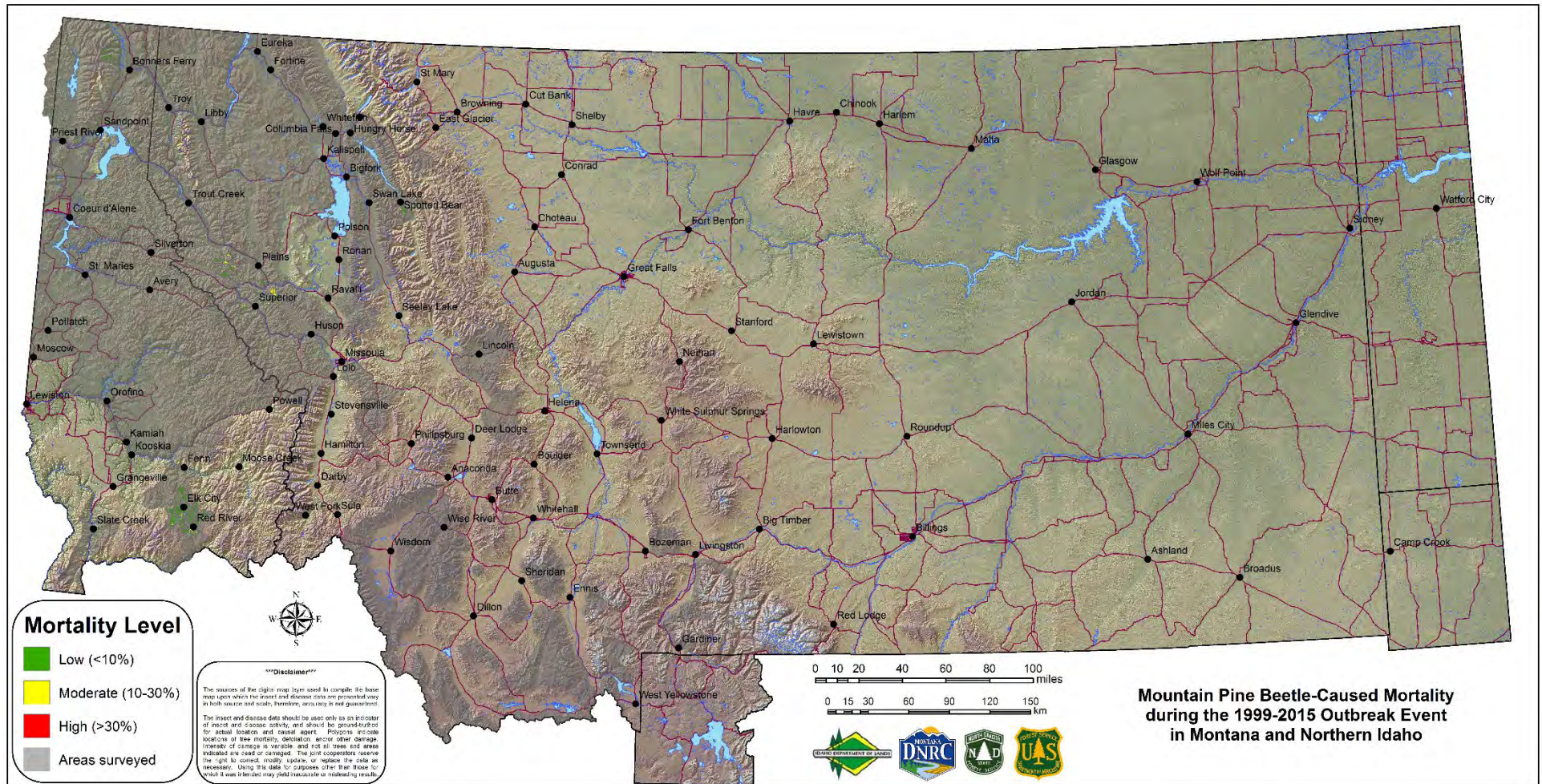


Appendix 2: Maps showing annual MPB-caused mortality area during each year of the 1999-2015 outbreak event (9 million acres) classified by severity of mortality estimated through aerial detection surveys (survey coverage shown in gray).

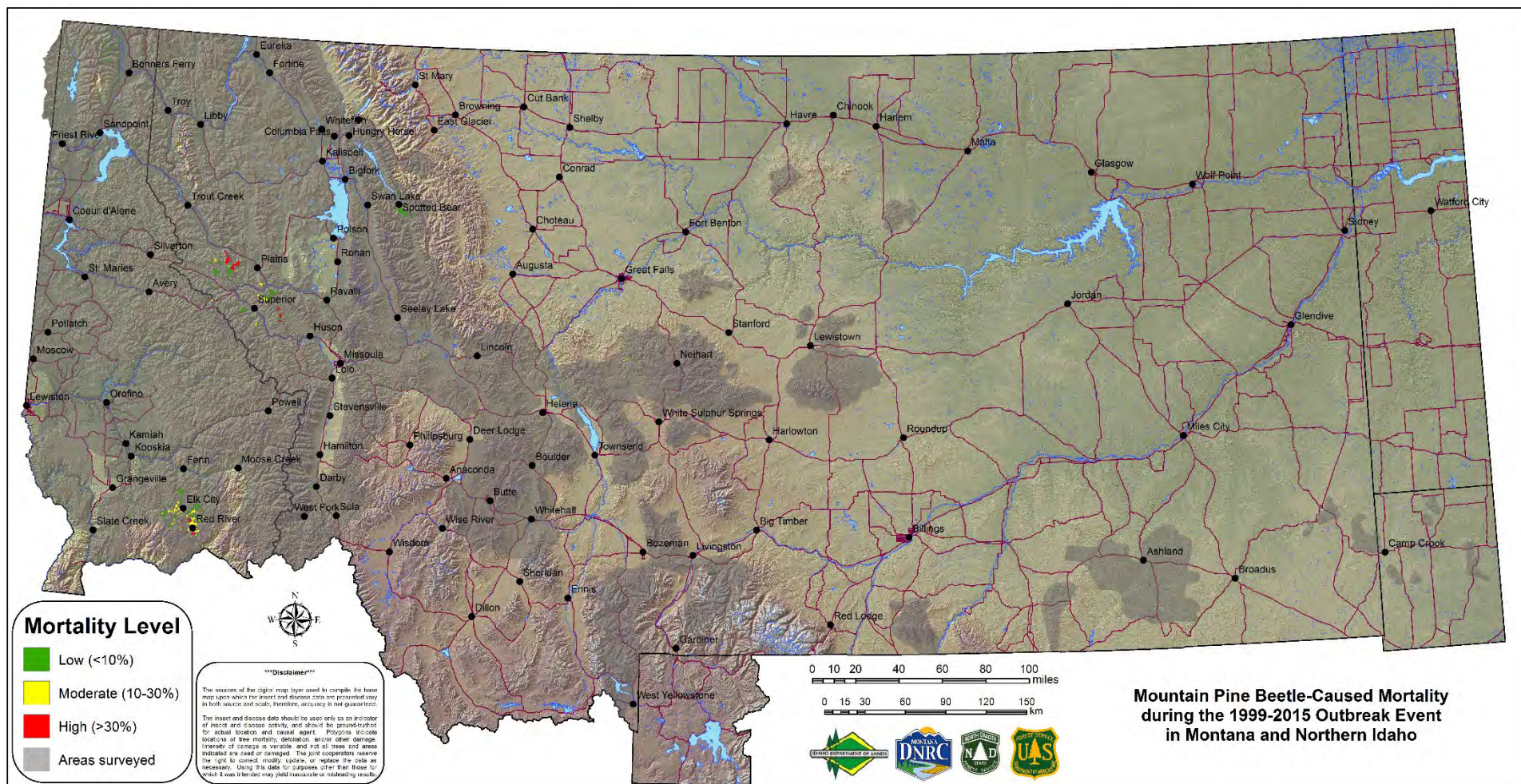
Map I: 1999 Annual mountain pine beetle-caused mortality estimated by ADS



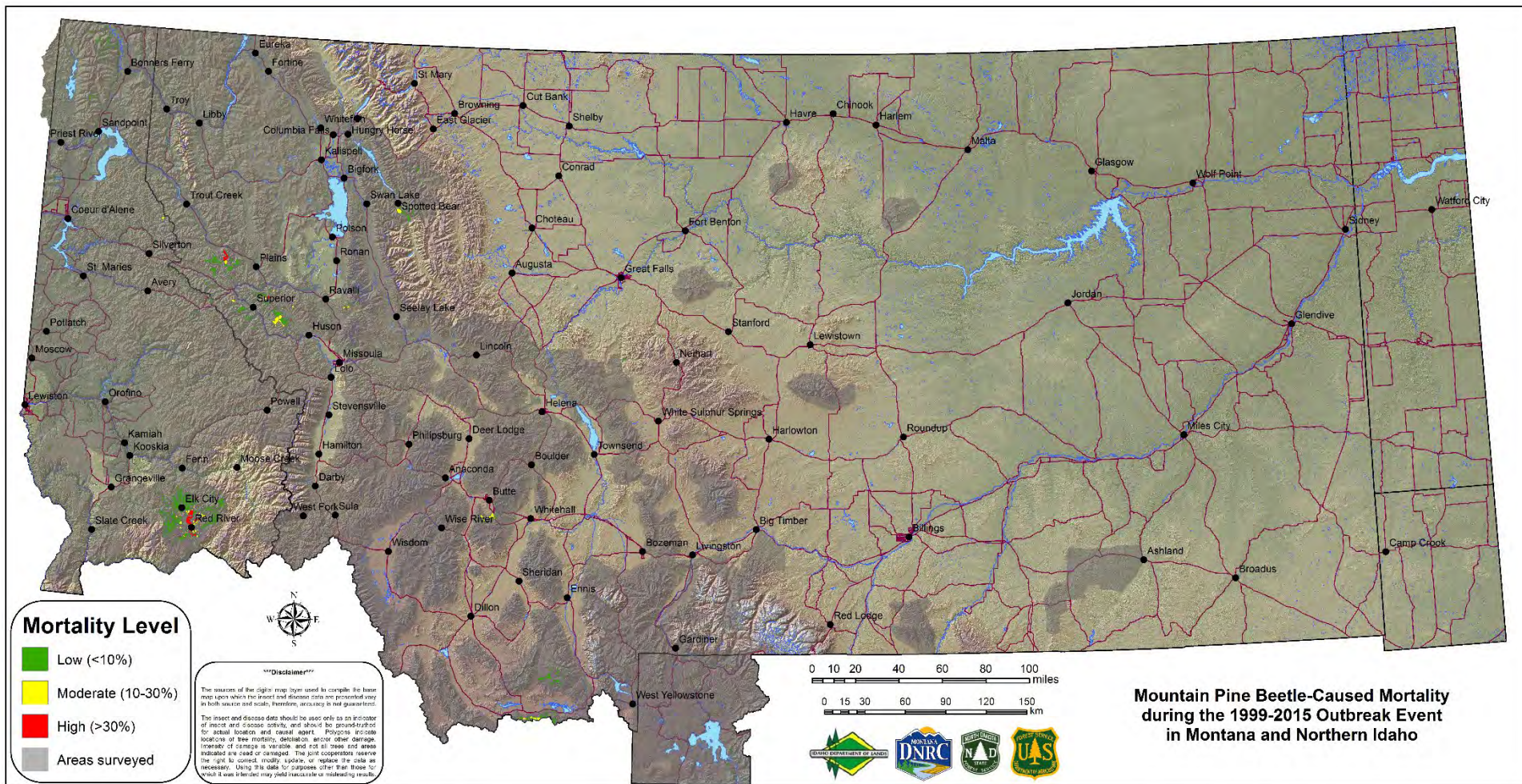
Map II: 2000 Annual mountain pine beetle-caused mortality estimated by ADS



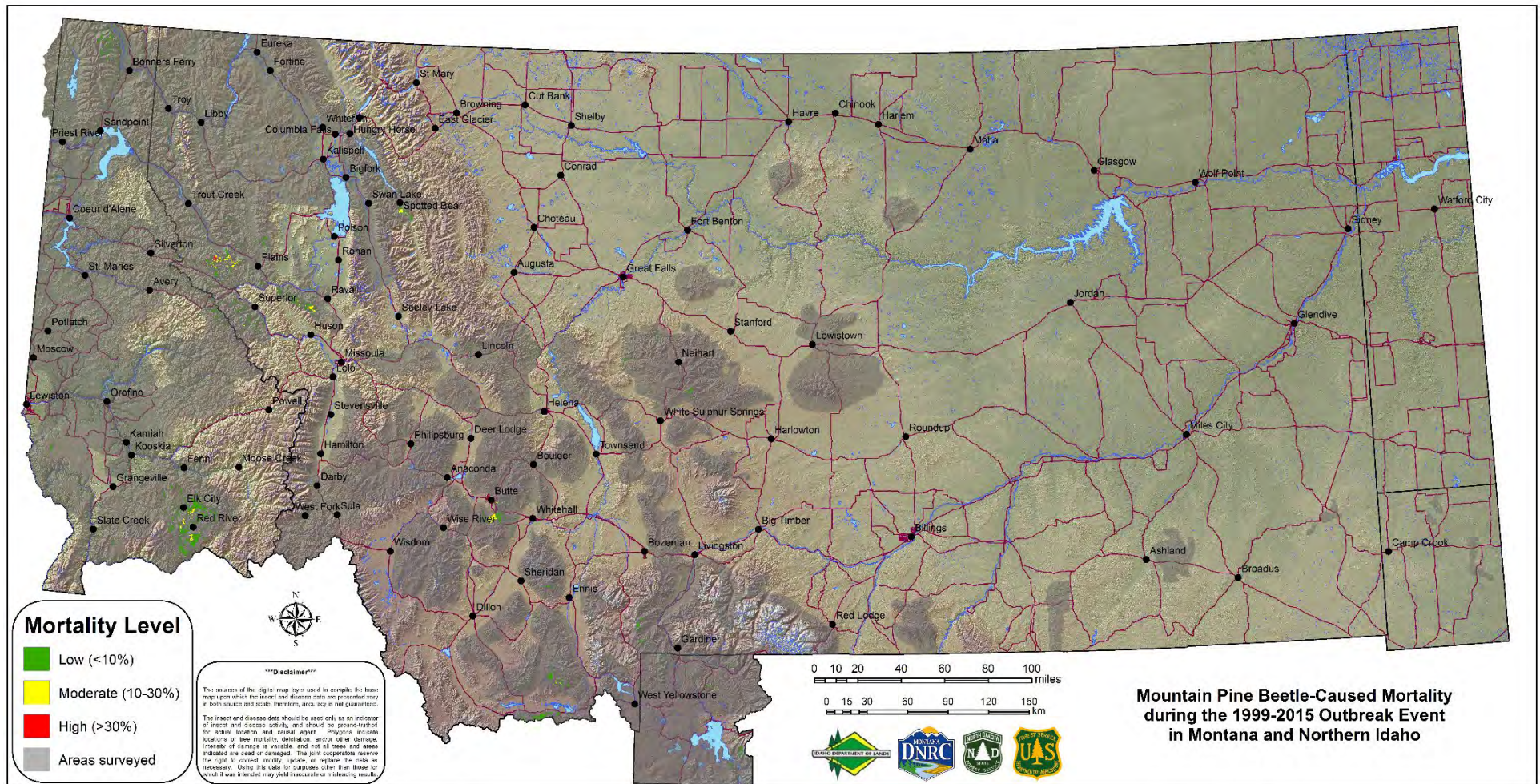
Map III: 2001 Annual mountain pine beetle-caused mortality estimated by ADS



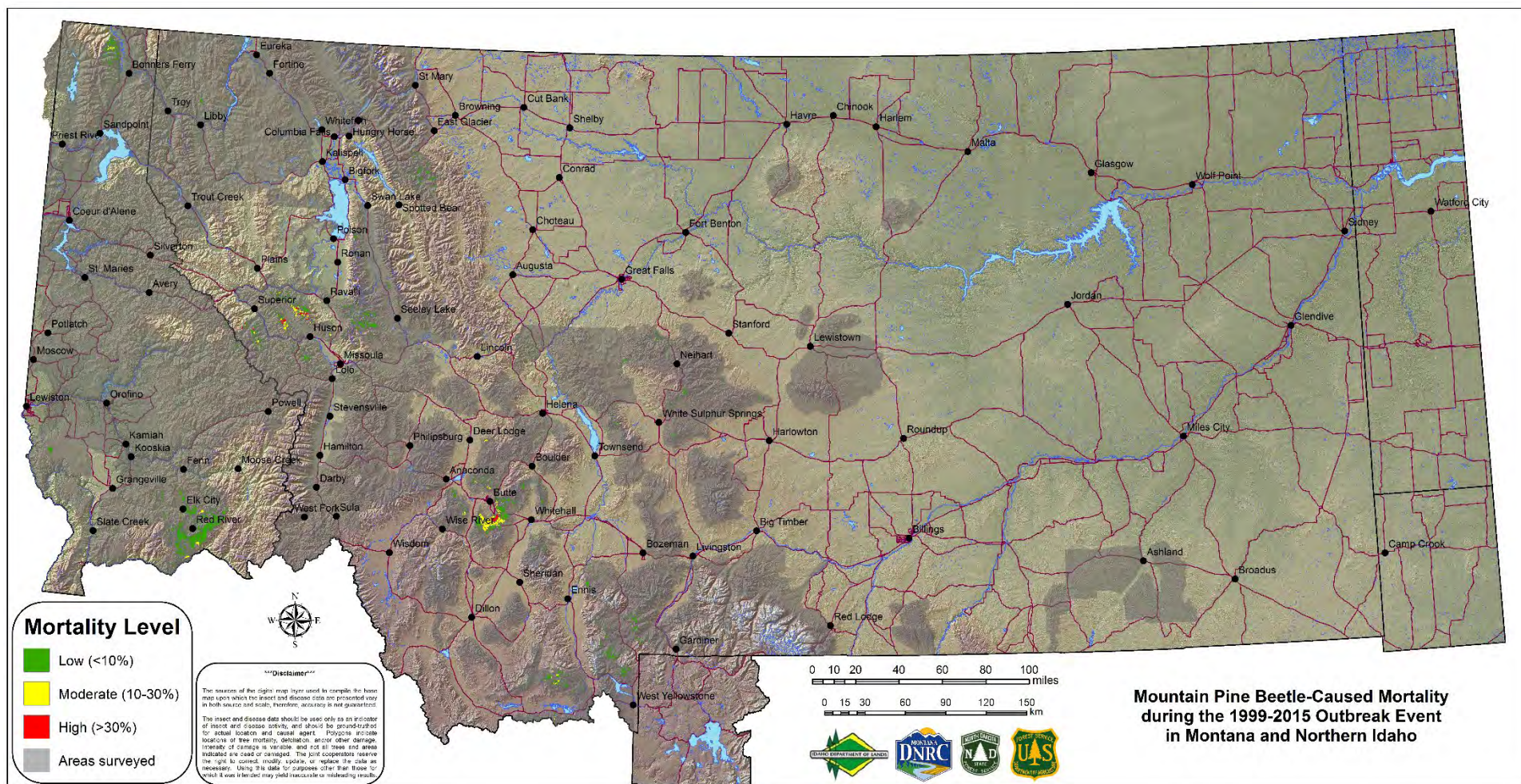
Map IV: 2002 Annual mountain pine beetle-caused mortality estimated by ADS



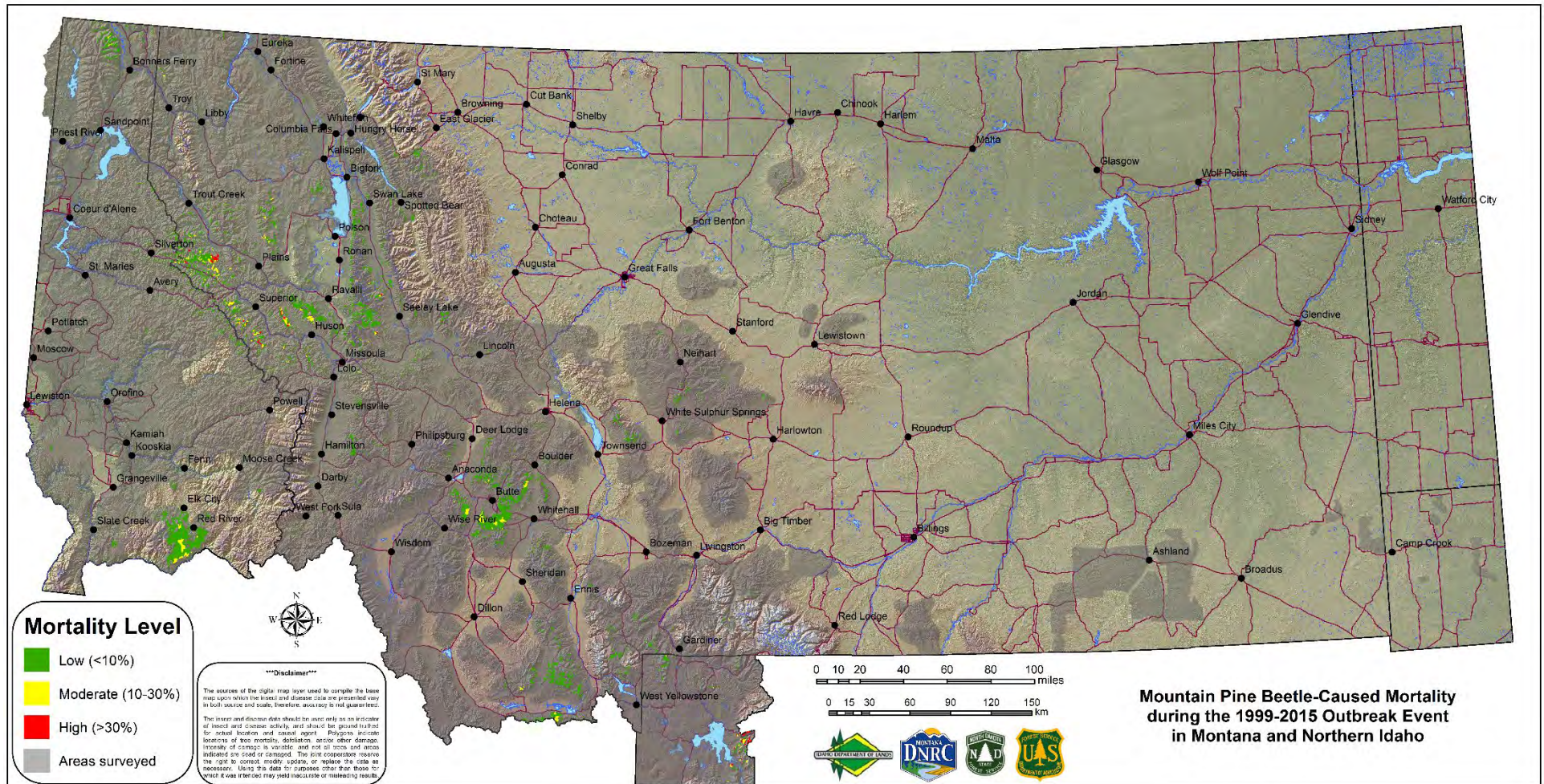
Map V: 2003 Annual mountain pine beetle-caused mortality estimated by ADS



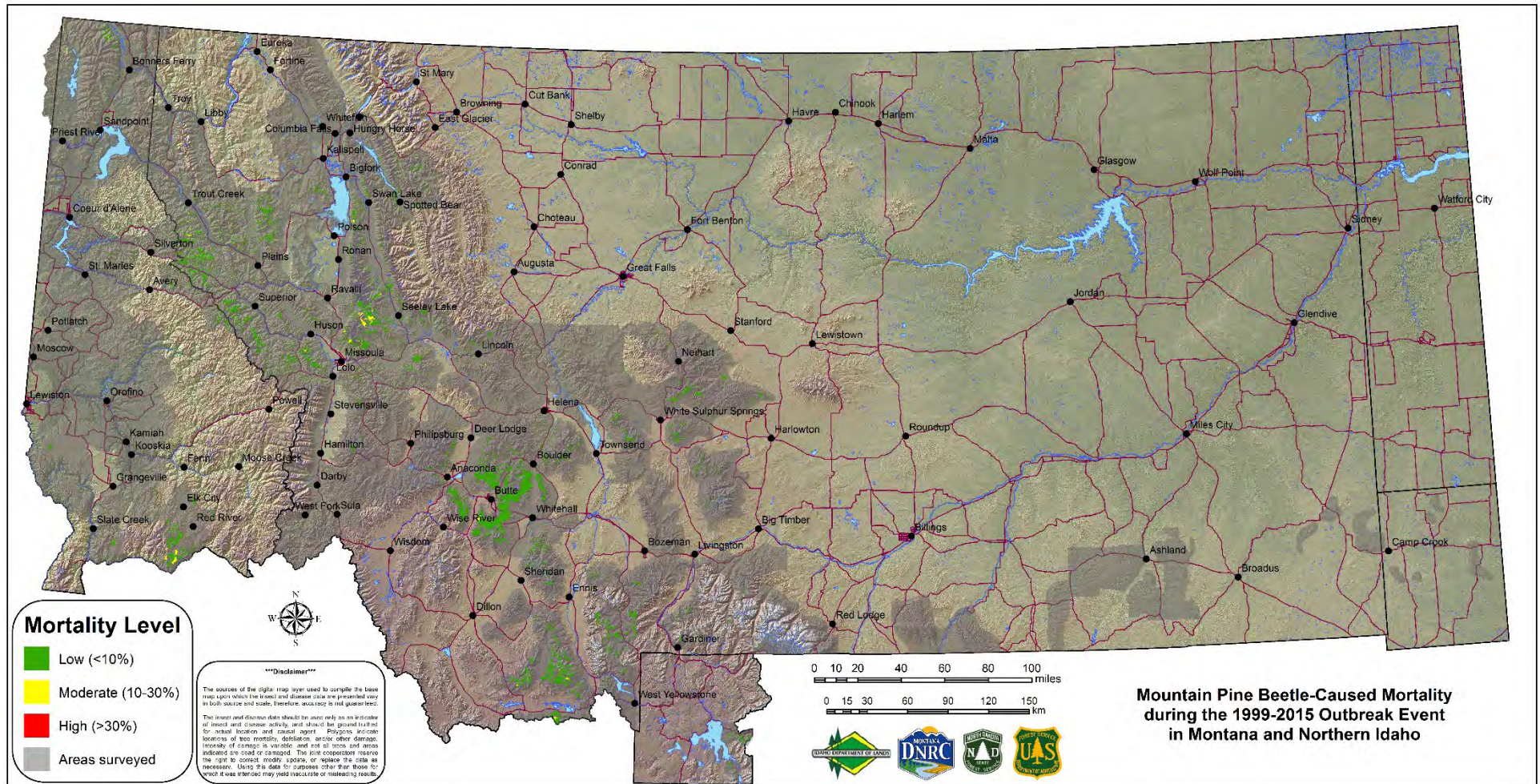
Map VI: 2004 Annual mountain pine beetle-caused mortality estimated by ADS



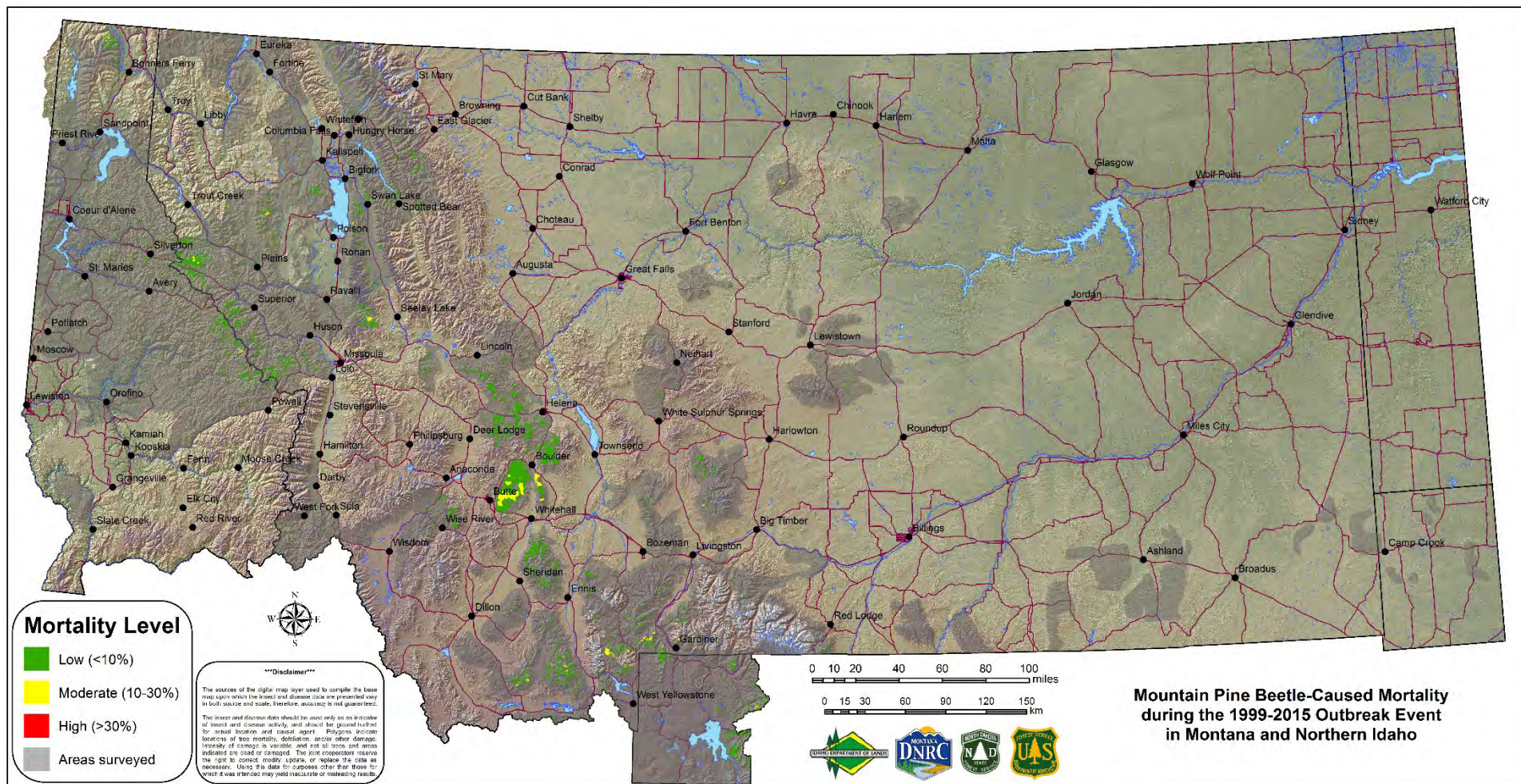
Map VII: 2005 Annual mountain pine beetle-caused mortality estimated by ADS



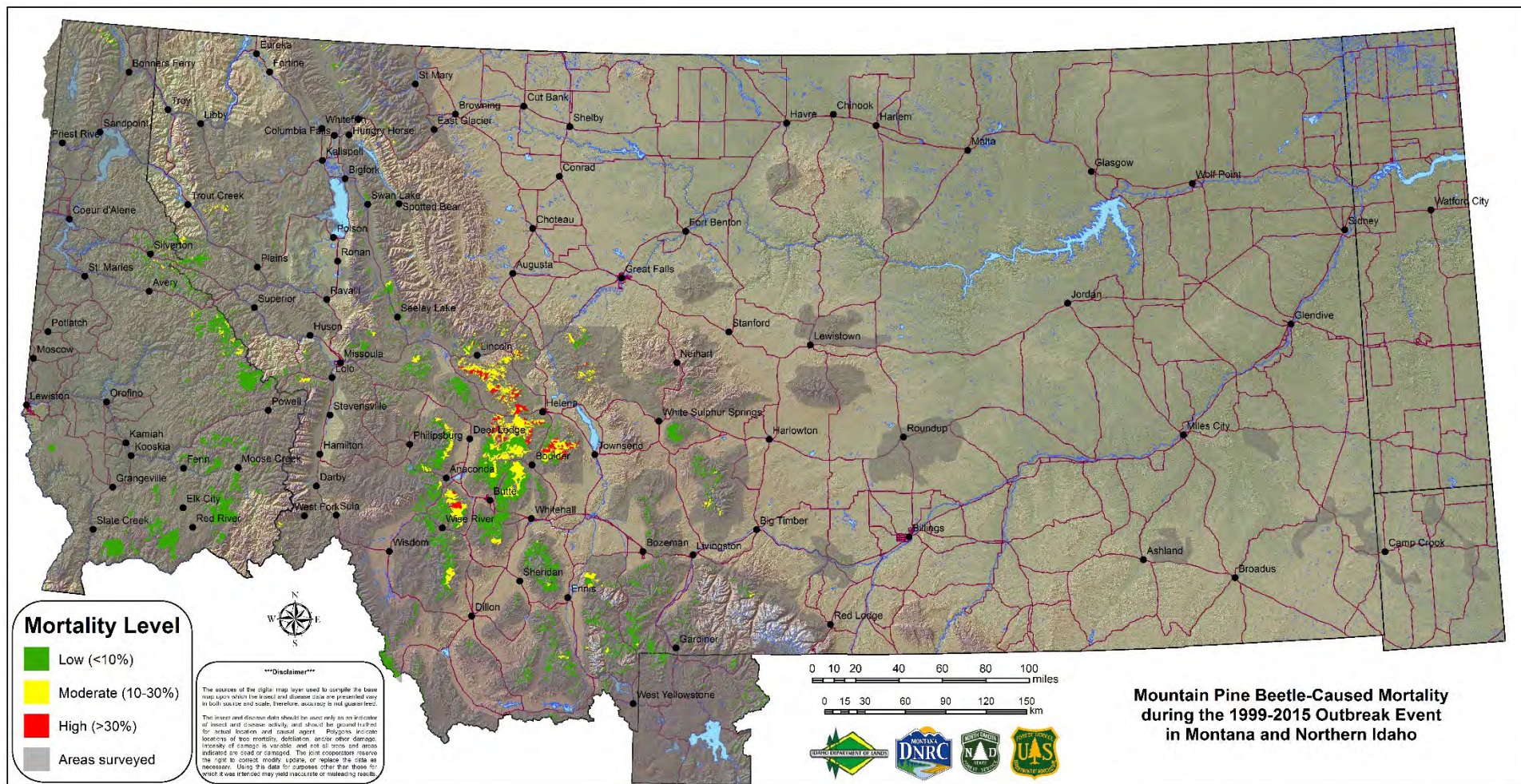
Map VIII: 2006 Annual mountain pine beetle-caused mortality estimated by ADS



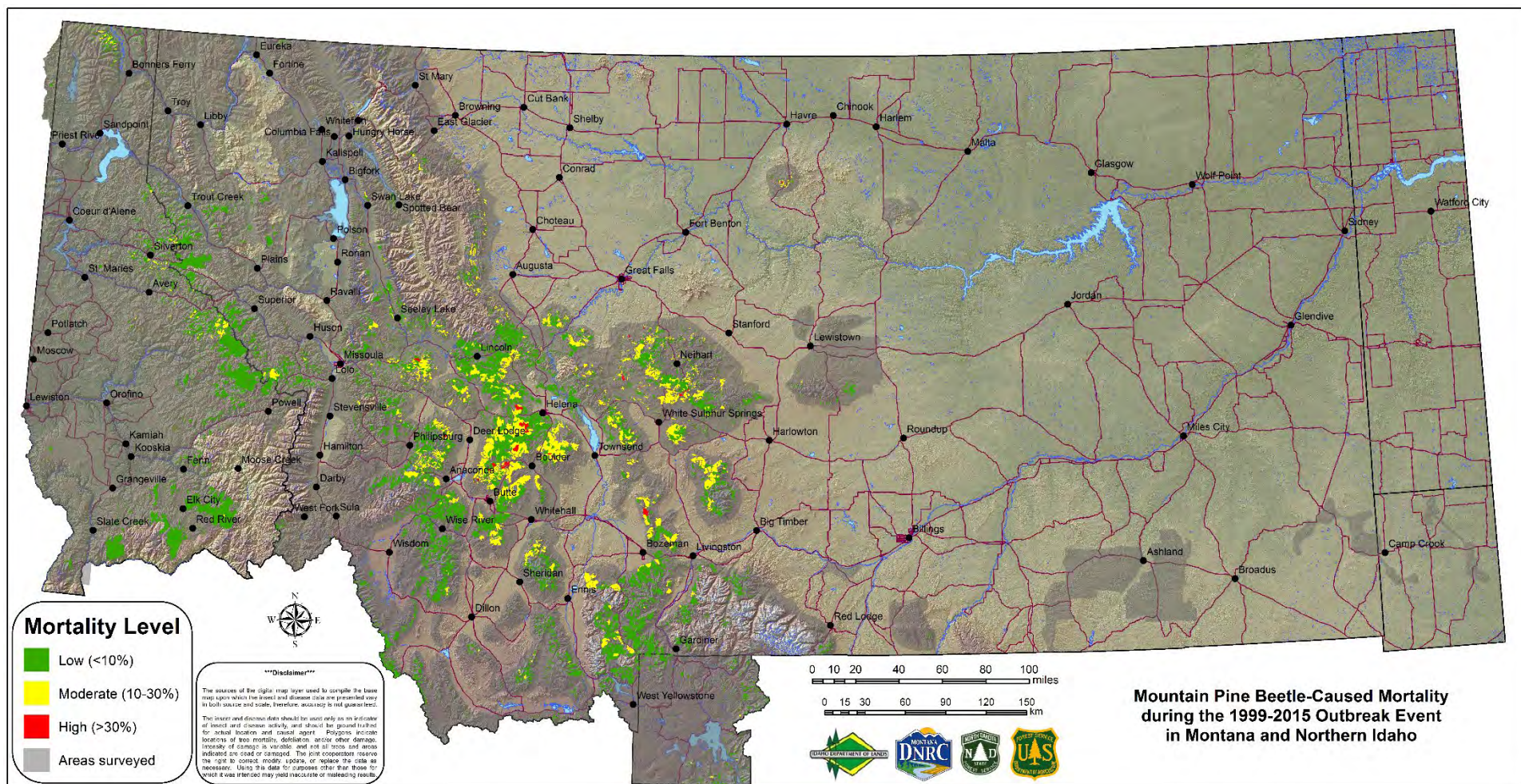
Map IX: 2007 Annual mountain pine beetle-caused mortality estimated by ADS



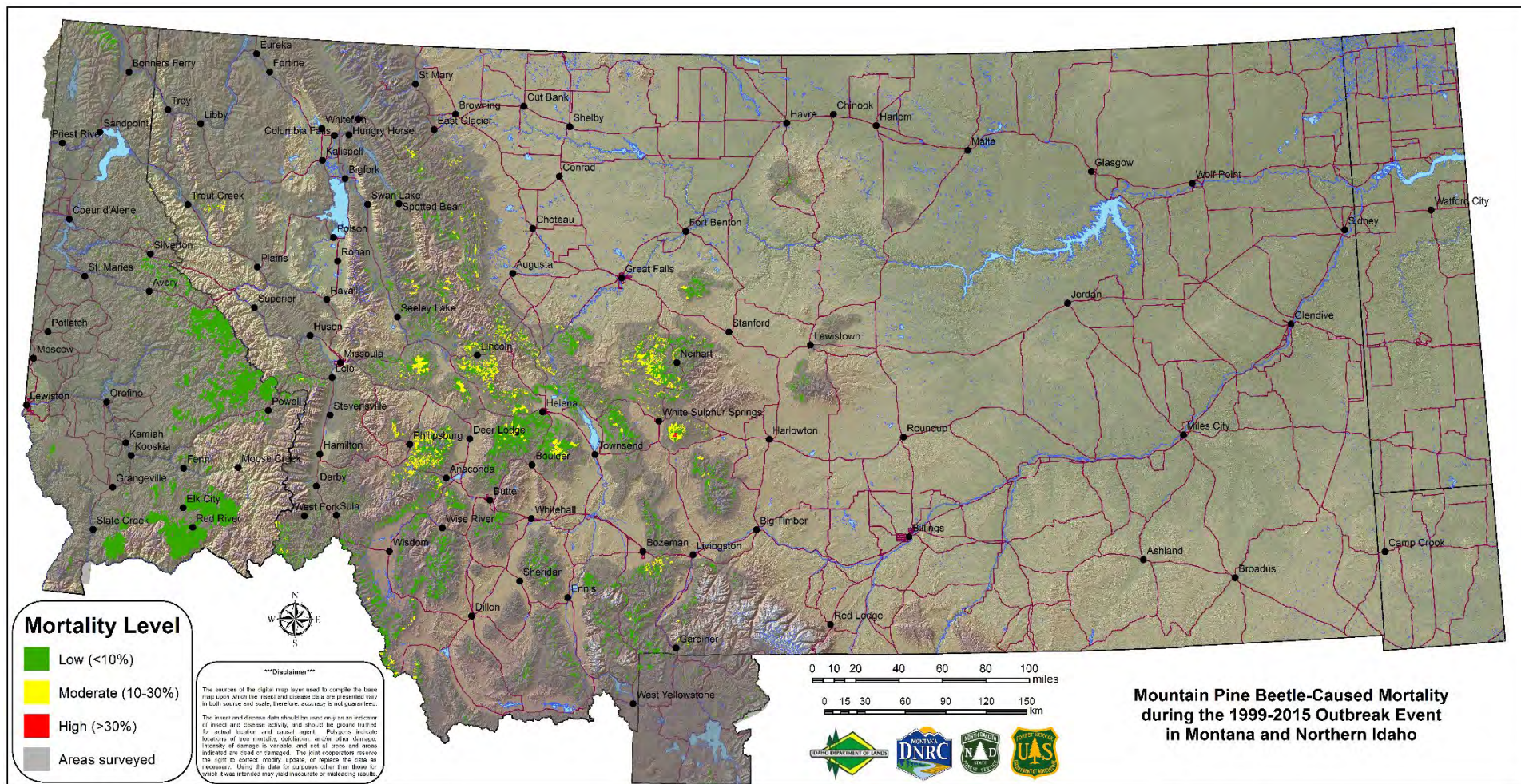
Map X: 2008 Annual mountain pine beetle-caused mortality estimated by ADS



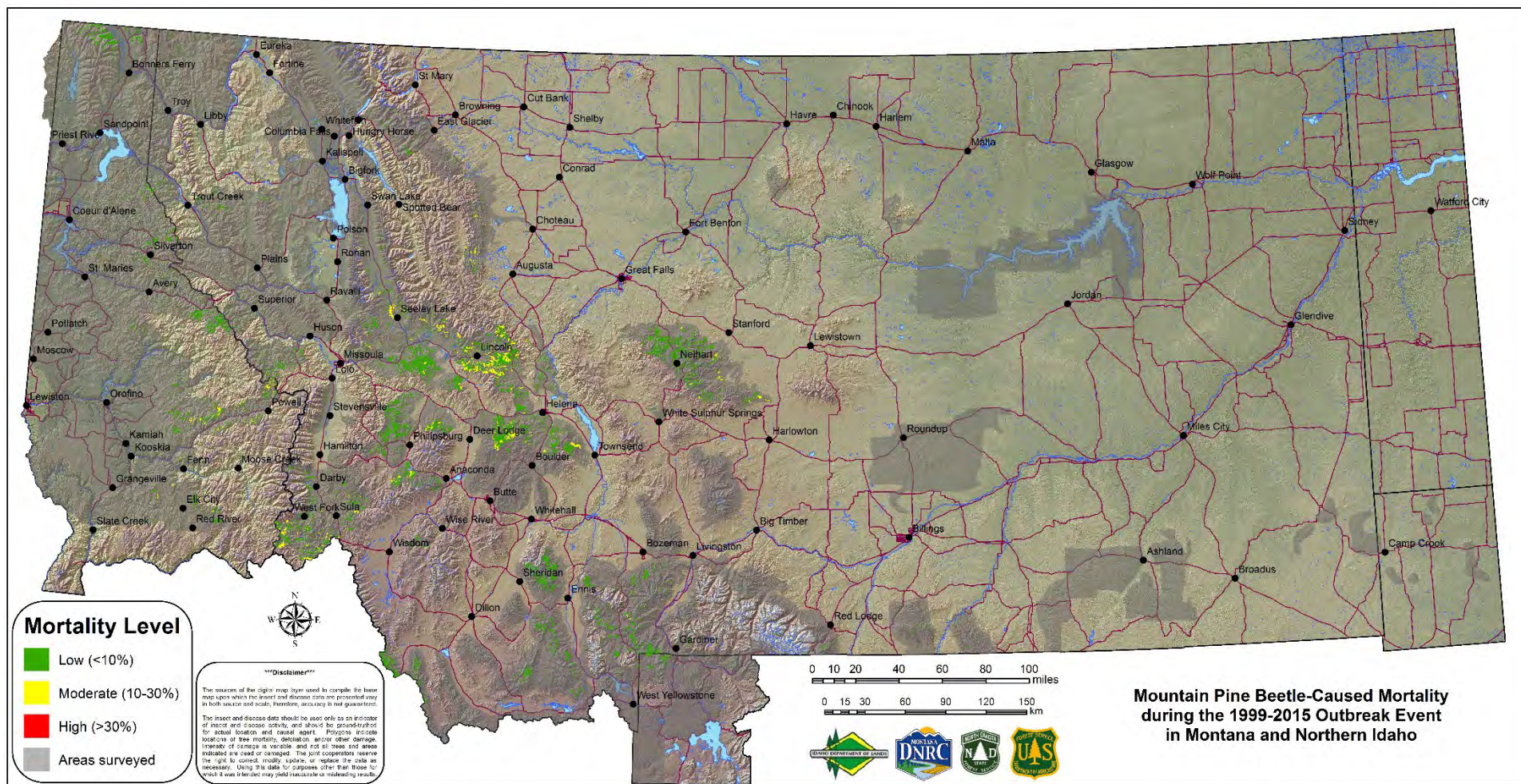
Map XI: 2009 Annual mountain pine beetle-caused mortality estimated by ADS



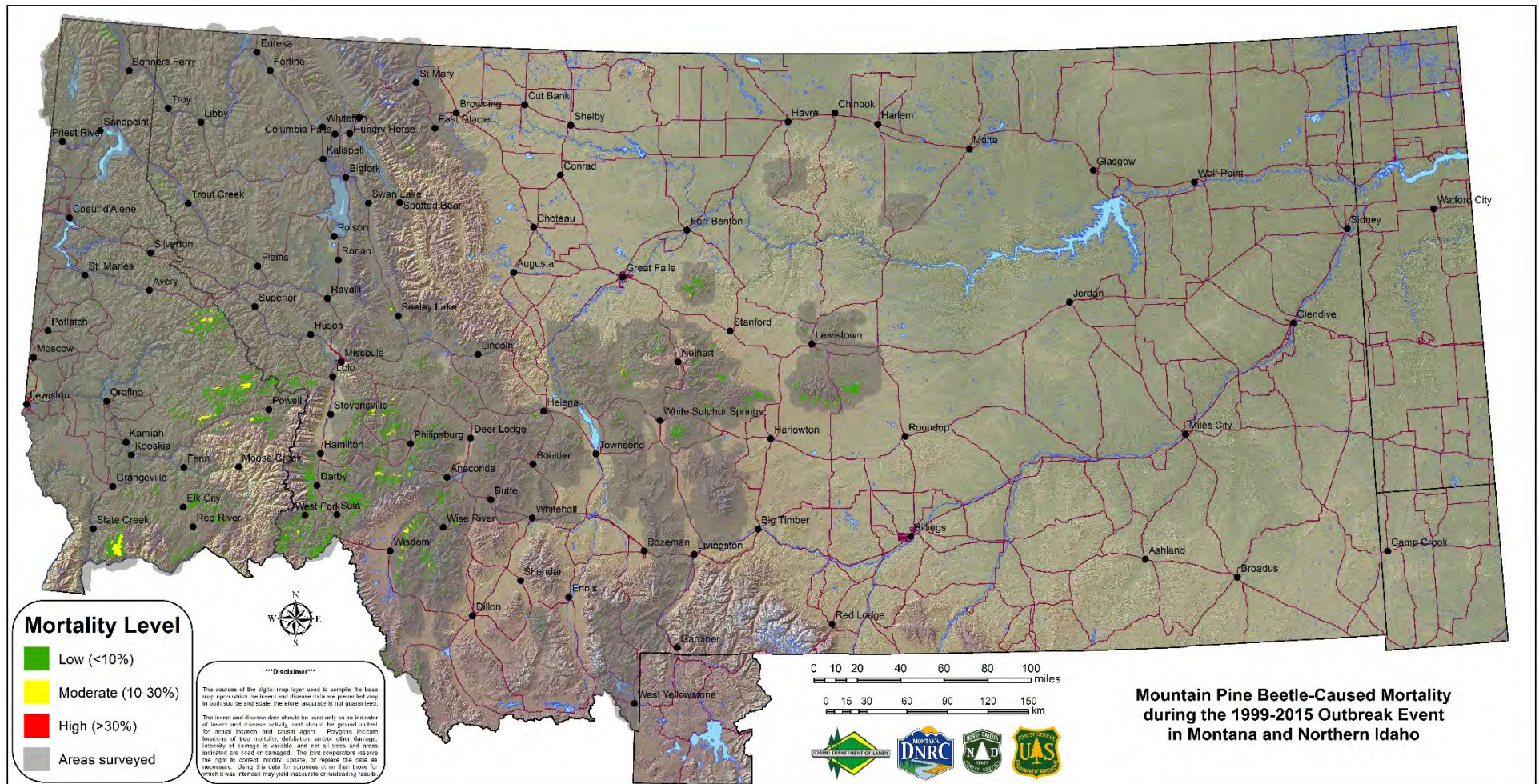
Map XII: 2010 Annual mountain pine beetle-caused mortality estimated by ADS



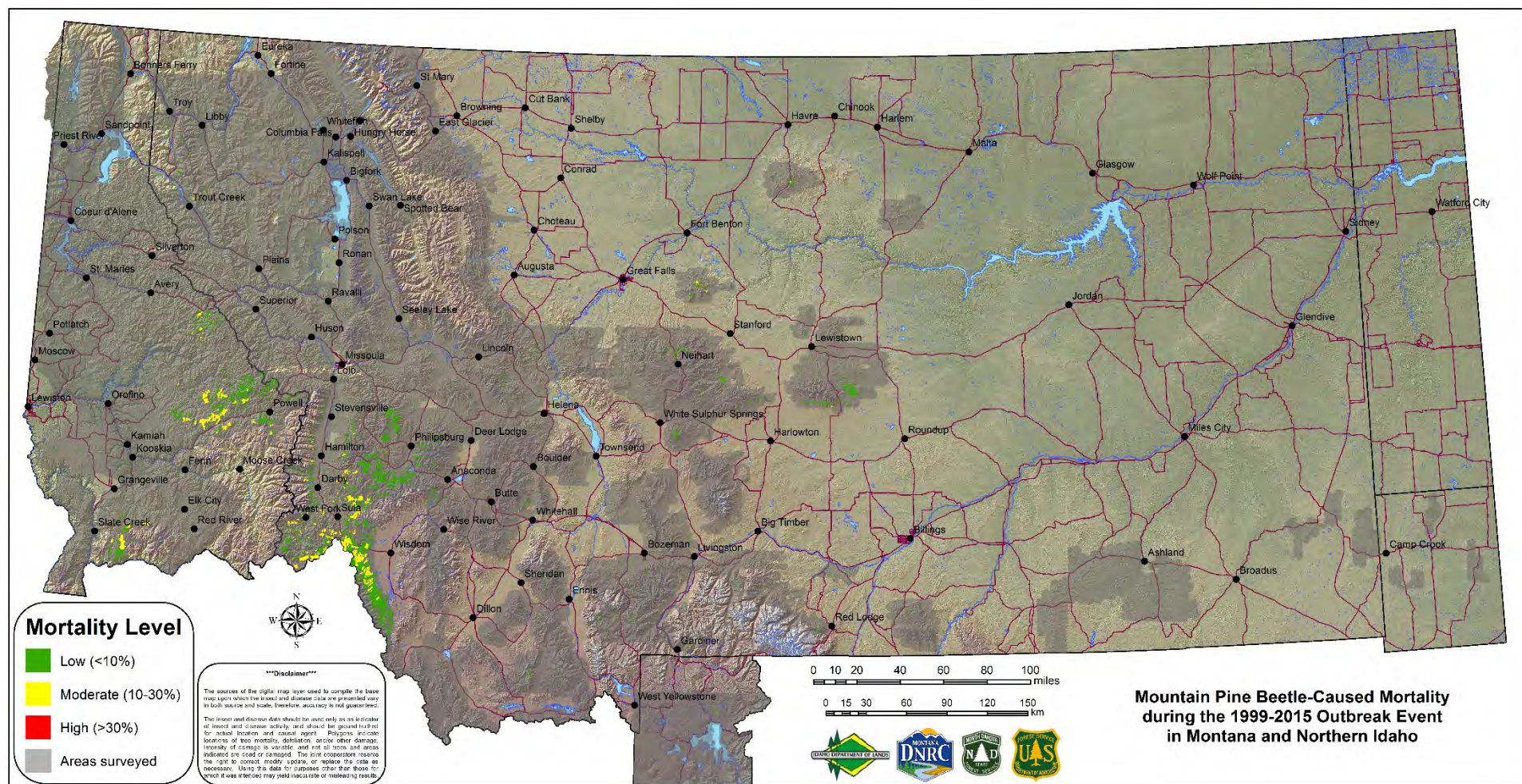
Map XIII: 2011 Annual mountain pine beetle-caused mortality estimated by ADS



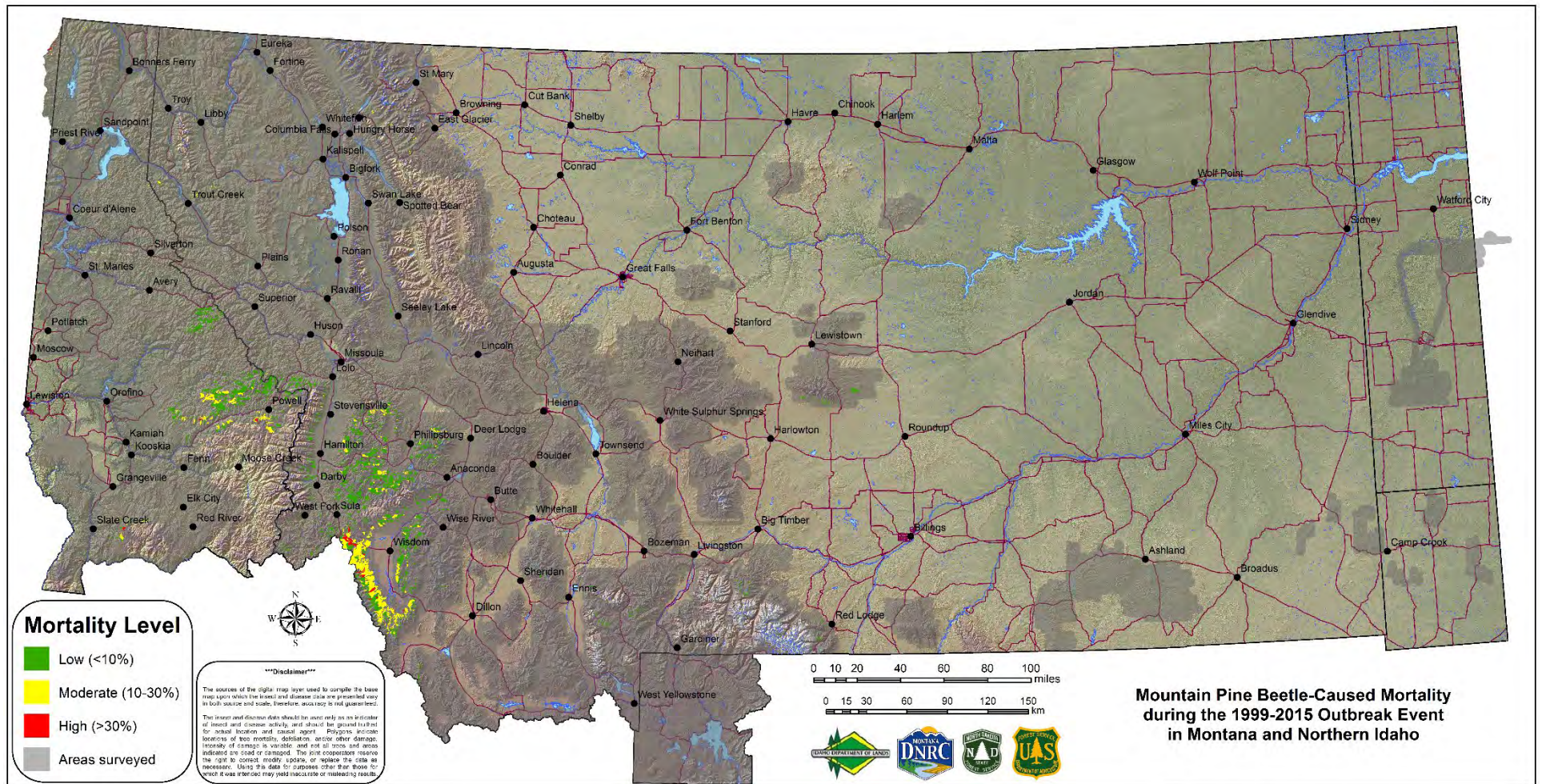
Map XIV: 2012 Annual mountain pine beetle-caused mortality estimated by ADS



Map XV: 2013 Annual mountain pine beetle-caused mortality estimated by ADS



Map XVI: 2014 Annual mountain pine beetle-caused mortality estimated by ADS



Map XVII: 2015 Annual mountain pine beetle-caused mortality estimated by ADS

