Middle Rockies Rapid Ecoregional Assessment

DRAFT FOREST MORTALITY ASSESSMENT REPORT FOR THE MIDDLE ROCKIES ECOREGION

Prepared for:

Department of Interior
Bureau of Land Management
Rapid Ecological Assessments

Prepared by:

SAIC

With Assistance From:

THE HEINZ CENTER

Dr. Dennis Ojima
Dr. Jeff Hicke
Dr. Jesse Logan
Dr. Tania Schoennagel
Dr. Cameron Aldridge
Dr. Jim Graham
Dr. Michael Coughenour
Mr. Peter Lesica
Mr. Don Childress

August 24, 2012

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF GRAPHS

LIST OF FIGURES

NUMBER

LIST OF ACRONYMS AND ABBREVIATIONS

^{0}C	degrees Celsius
AD	Aspen Dieback
ADS	aerial detection survey
AMT	Assessment Management Team
BLM	Bureau of Land Management
ESRI	Environmental Science Research Institute
EVT	Existing Vegetation Type
ft	feet
FHTET	Forest Heath Technology Enterprise Team
FIA	Forest Inventory and Analysis
FMAR	Forest Mortality Assessment Report
FMI	Forest Mortality Index
GAP	Gap Analysis Program
GCC	Global Climate Change
GCM	Global Climate Model
GIS	Geographic Information System
GYE	Greater Yellowstone Ecosystem
km	kilometer(s)
LANDFIRE	Landscape Fire and Resource Management Planning Tools Project
m	meter(s)
MPB	mountain pine beetle
MTBS	Monitoring Trends in Burn Severity
NASA	National Aeronautics and Space Administration
NBCD	National Biomass and Carbon Dataset
PRISM	Parameter-Elevation Regressions on Independent Slopes Model
REA	Rapid Ecoregional Assessment
ReGAP	Regional Gap Analysis Program
RegCM3	Regional Climate Model, Version 3
SAD	Sudden Aspen Decline
SAIC	Science Applications International Corporation
SB	spruce beetle
USGS	U.S. Geological Survey
USDA	U.S. Department of Agriculture
WLIS	Whitebark and Limber Pine Information System
WPBR	white pine blister rust
WSBW	western spruce budworm

1.0 INTRODUCTION

An especially important component of analysis of this ecoregion is an assessment of the forestry resources within the Middle Rockies; therefore, a Forest Mortality Assessment Report (FMAR) has been performed to compliment the Middle Rockies Rapid Ecoregional Assessment (REA) conducted to assist the Bureau of Land Management (BLM) and others with planning at a landscape scale. The Middle Rockies are estimated to have more than 20 million acres of forest, with most of those acres on federal lands (Table 1-1 and Figure 1-1). Based on aerial detection surveys (ADSs) conducted by the U.S. Forest Service, the past several years have seen unprecedented tree mortality on forested lands throughout the Middle Rockies ecoregion. Recent forest mortality resulting from disease and insect infestation is receiving significant local, state, and national attention. Forest mortality is anticipated to be the focus of resource and land management agencies throughout this ecoregion over the near term and long term.

Table 1-1. Middle Rockies Forests on Federal Lands

Owner	Acres
U.S. Forest Service	24,883,920
BLM	8,146,193
National Park Service	2,655,120
Bureau of Indian Affairs	2,844,074
U.S. Fish and Wildlife	305,273
Bureau of Reclamation	291,341
Department of Defense	10,054

The overall goal of the FMAR was to generate geospatial information focusing on the extent of recent forest mortality (previous 5 years) and anticipated forest mortality (over the next 5 years). More specifically, this analysis was conducted to identify epicenters of high/sustained mortality and to identify broad spatial patterns where adjacent mortality would be likely over the next 5 years. The data and analysis methodology is described in more detail in Section 3. Both biotic and abiotic morality agents are discussed in this report; however, only biotic mortality agents were analyzed for potential future risk to forest systems in the Middle Rockies.

Predicted climate change data used in the Middle Rockies REA were utilized to identify areas vulnerable to future climate change. Data were also obtained displaying modeled current baseline above-the-ground biomass and carbon stock. When updated in the future, these data could be used to identify areas of increased or decreased carbon sequestration.

Insects and diseases causing forest mortality have different host species, climatic controls, and life histories. To provide an overall understanding, a review of forest mortality issues and analysis methods, as well as a results discussion, are included in this FMAR.

THIS PAGE INTENTIONALLY LEFT BLANK

2.0 REVIEW OF FOREST MORTALITY ISSUES IN THE MIDDLE ROCKIES

2.1 SUMMARY OF FOREST ECOSYSTEMS OF INTEREST

Forest and woodland ecological systems classified in the Northwest Regional Gap Analysis Program (ReGAP) cover almost 30 percent of the Middle Rockies ecoregion (Table 2-1) (USGS 2010). The Gap Analysis Program (GAP) Level 3 forested ecosystems occupy elevations between the alpine zone, which supports shrub communities, and the lower timberline, below which forest gives way to steppe. In this report, ecological systems are grouped into broad elevation categories (lower montane, upper montane, subalpine) and forest types based on dominant tree species (including Douglas-fir [*Pseudotsuga menziesii*], various pine species, spruce-fir, aspen [*Populus tremuloides*], and several mixed conifer systems) (Logan and Schoenagle 2010).

Table 2-1. Forested Ecological Systems in Middle Rockies Ecoregion

GAP Level 3 Classification	Elevation Range (feet)	Elevation Category	Forest Type
Rocky Mountain Foothill Limber Pine-Juniper Woodland	3,281-7,024	Lower Montane	Limber pine/Juniper
Columbia Plateau Western Juniper Woodland and Savanna	3,281-7,024	Lower Montane	Juniper
Middle Rocky Mountain Montane Douglas-fir Forest and Woodland	3,281-7,024	Lower Montane	Douglas-fir
Southern Rocky Mountain Ponderosa Pine Woodland	3,281-7,024	Lower Montane	Ponderosa pine
Northwestern Great Plains - Black Hills Ponderosa Pine Woodland and Savanna	3,281-7,024	Lower Montane	Ponderosa pine
Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	3,281-7,024	Lower Montane	Ponderosa pine
Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	3,281-7,753	Lower/Upper Montane	Mixed conifer (dry)
Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	3,281-7,753	Lower/Upper Montane	Mixed conifer (dry)
Rocky Mountain Lodgepole Pine Forest	7,025-7,753	Upper Montane	Lodgepole pine
Rocky Mountain Poor-Site Lodgepole Pine Forest	7,025-7,753	Upper Montane	Lodgepole pine
Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland	7,025-7,753	Upper Montane	Mixed conifer (mesic)
Northern Rocky Mountain Mesic Montane Mixed Conifer Forest	7,025-7,753	Upper Montane	Mixed conifer (mesic)
Rocky Mountain Aspen Forest and Woodland	3,281-8,845	Lower/Upper Montane/ Subalpine	Aspen
Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland	7,025-7,753	Upper Montane	Aspen
Northern Rocky Mountain Subalpine Woodland and Parkland	7,753-8,845	Subalpine	Spruce-Fir
Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	7,025-7,753	Subalpine	Spruce-Fir
Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland	7,025-7,753	Subalpine	Spruce-Fir
Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	7,025-7,753	Subalpine	Limber pine

2.1.1 Subalpine Forest Systems

2.1.1.1 Krumholz

Krumholz is a term used to describe the crooked, bent, and twisted growth of trees resulting from exposure to harsh, cold winds, blowing ice, and snow crystals in subalpine treeline landscapes. This may include several high-elevation conifer species; in the Middle Rockies ecoregion krumholz formations may include subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmannii*), limber pine (*Pinus flexilis*), whitebark pine (*Pinus albicaulis*), and lodgepole pine (*Pinus contorta*). Exposure to strong, freezing winds at the treeline causes tree growth to form low, densely-matted bushes. Many trees survive under these conditions in areas where they are sheltered by rock formations or snow cover.

2.1.1.2 Spruce-Fir Forest and Woodland

Ecological systems dominated by Engelmann spruce-subalpine and fir comprise a substantial part of the subalpine forests in the Rocky Mountains and occur on mountain “islands” of north-central Montana. Combined, they are the matrix forests of the subalpine zone; they often represent the forests of highest elevation in an area. Douglas-fir may persist in occurrences of this system for long periods without regeneration. Lodgepole pine is common in many occurrences, as well as in mixed conifer/aspen stands. Upper elevation examples may have more woodland physiognomy, and whitebark pine or limber pine can be a seral component. Sites occupied by spruce-fir forest are cold year-round and may include areas where cold air drains or ponds, or where snowpacks linger late into the summer, such as on north-facing slopes and high-elevation ravines. These forests are found on gentle to very steep mountain slopes, high-elevation ridgetops and upper slopes, plateau-like surfaces, basins, alluvial terraces, well-drained benches, and inactive stream terraces. Disturbances include occasional blowdown, insect outbreaks (30-50 years), mixed-severity fire, and stand-replacing fire (150-500 years). The more summer-dry climatic areas also have occasional stand-replacing, high-severity fires.

2.1.1.3 Whitebark Pine Woodland and Limber Pine Woodland

Throughout its range, whitebark pine may occur as a climax alpine species (including a krummholz form and an open woodland form with herb or dwarf-shrub-dominated openings at treeline, as a seral species, or climax co-dominant with subalpine fir). Other common tree associates at lower subalpine elevations in the Rocky Mountains are limber pine, lodgepole pine, Engelmann spruce, and, less commonly, mountain hemlock (*Tsuga mertensiana)* and alpine larch (*Larix lyallii)* (Keane 2000). These vegetation types are a product of biological interactions and physical drivers. The primary biological interactions revolve around a coevolved system of seed collection by Clarks’ nutcracker, the red squirrel, and grizzly and/or black bears. Bird dispersal accounts for both long distance and local dispersal of small caches of seed that may or may not be utilized and results in clumped distribution of trees. Squirrels collect seed and stash them in middens, which can be raided by grizzly or black bears. In the closed canopy forests that are successional to fir, spruce, and hemlock, five-needle pines require periodic fires and recolonization by bird-dispersed seed. The result is a generally uniform age structure of the population. In areas in which these stands occur adjacent to or mixed with ponderosa pine (*Pinus ponderosa*) and lodgepole pine, the dynamics of those species (in particular their response to fire) can control stand structure. Seed dispersal is both by bird and by rodent on exeric sites, which results in stands with mixed-age structures of relatively closely related individuals.

Whitebark pine is generally considered intolerant to moderately intolerant of shade. The climate in whitebark pine woodland zones is typically very cold in winter and dry in summer. Landforms in zones occupied by whitebark pine communities include ridgetops, mountain slopes, glacial trough walls and moraines, talus slopes, landslides and rockslides, and cirque headwalls and basins. Major disturbances are windthrow and snow avalanches. Although lightning damage to individual trees is common, sparse canopies and rocky terrain limit the spread of fire, which occurs infrequently in this system.

Limber pine occurs with whitebark pine on some sites in Idaho, Wyoming, and Montana, and may also be associated with other montane conifers (USDA Forest Service 1990). The ecology of the lower treeline limber pine woodland is not well understood (Means 2010). Lower elevation associations with Douglas-fir, ponderosa pine, and Rocky Mountain juniper (*Juniperus scopulorum*) have been observed (USDA Forest Service 1990) There appears to be a large difference in the maximum age of trees in upper treeline stands (1,500 years) and lower treeline stands (300 years) (Schuster et al. 1994; Means 2010). Lower treeline woodland has been historically treated as a non-desirable invader of rangeland and has been eliminated from areas where it naturally occurs, except on rocky outcrops (Means 2010). It is unclear what the baseline conditions were for this woodland; because it occurs on a constantly shifting ecotone, treating it as a static successional stage is inappropriate (Means 2010).

2.1.2 Upper Montane Forest Systems

2.1.2.1 Aspen Forest and Woodland

Aspen-dominated forests and woodlands are common and widespread in the Middle Rockies ecoregion in montane and subalpine zones. An eastern extension occurs along the Rocky Mountain foothills and in mountain “islands” in Montana (Big Snowy and Highwood Mountains) and the Black Hills of South Dakota. Distribution of aspen forest and woodland is limited by adequate soil moisture, the length of the growing season, and low temperatures. These are upland forests and woodlands dominated by aspen without a significant conifer component. Occurrences of this system originate and are maintained by stand-replacing disturbances such as avalanches, crown fire, insect outbreak and disease, windthrow, beaver activity, and logging, within the matrix of conifer forest. Aspen-mixed conifer systems occur on montane slopes and plateaus in western Wyoming, southern Idaho, and north-central Montana (in the Big Snowy Mountains). Occurrences are typically on gentle to steep slopes on any aspect, but are often found on clay-rich soils in intermontane valleys. The tree canopy is composed of a mix of deciduous and coniferous species, codominated by aspen and conifers (Douglas-fir, grand fir/white fir [*Abies grandis* var.*concolor*], subalpine fir, Engelmann spruce, lodgepole pine, limber pine, and ponderosa pine). As the occurrences age, aspen declines and conifer species become dominant. Most occurrences at present represent a late-seral stage of aspen changing to a pure conifer occurrence. Nearly 100 years of fire suppression and livestock grazing have converted much of the pure aspen occurrences to the present-day aspen-conifer forest and woodland ecological system. Climate is temperate with a relatively long growing season, typically cold winters, and deep snow.

2.1.2.2 Lodgepole Pine Forest and Woodland

Lodgepole pine ecological systems occupy upper montane to subalpine elevations of the Rocky Mountains and mountain “islands” of north-central Montana. The lodgepole pine system occurs across a wide range of conditions in the Middle Rockies ecoregion and is equally prevalent both east and west of the Continental Divide. Lodgepole pine is an aggressively colonizing, shade-intolerant conifer that is adapted to reproduce prolifically after fire (Eyre 1980). Its tendency to grow in dense, even-aged stands, in conjunction with fire suppression policy and reduction of lodgepole pine harvest on federal lands, has produced extensive stands from 60 to 100 years of age. Pure lodgepole stands may occur on sites poorly suited to other tree species, or where stand-replacing fires have killed other trees, leaving lodgepole pine seeds stored in serotinous cones as the only surviving seed source. Other stands are mixtures including subalpine species (such as Engelmann spruce, subalpine fir, and aspen) at higher elevations, or mixed conifer species (such as ponderosa pine, Douglas-fir, and aspen) at lower elevations (Kaufmann et al. 2008). Stand-replacing fires occur at longer time intervals in subalpine lodgepole forests than in pure stands. Stand-replacing fires may occur on mixed conifer forests, but more commonly mixed-severity fires create small openings that support lodgepole pine establishment and persistence. Temperature regimes are extreme throughout this region and frequent growing season frosts occur. The majority of precipitation falls as snow; late-melting snowpacks provide the majority of growing season moisture.

2.1.2.3 Mixed Conifer-Mesic System

This ecological system occurs in western Montana. Vegetation associations are dominated by western hemlock and western red-cedar. Associated canopy species include Douglas-fir, western white pine

(*Pinus monticola*), lodgepole pine, grand fir (*Abies grandis*), western yew (*Taxus brevifolia*), and western larch (*Larix occidentalis*). Climate in the northern portion is influenced by mild, wet, Pacific maritime air masses, which result in much of the annual precipitation occurring as rain. Occurrences are generally found on all slopes and aspects, but grow best on sites with high soil moisture such as toeslopes and bottomlands. Stand-replacement fire-return intervals are typically 150-500 years, with moderate-severity fire intervals of 50-100 years. At the southern end of the ecoregion, mixed conifer forests occur predominantly in cool ravines and on north-facing slopes (where Douglas-fir and grand fir are the canopy dominants), but Engelmann spruce, blue spruce (*Picea pungens*), and/or ponderosa pine may be present. This system includes aspen-mixed conifer stands. Naturally occurring fires are of variable return intervals and are mostly light, erratic, and frequent due to the cool, moist conditions.

2.1.3 Lower Montane Forest Systems

2.1.3.1 Ponderosa Pine Woodland and Savannah

Ponderosa pine occupies the driest forestland sites on both sides of the Continental Divide and is one of the most widely distributed pine species in western North America. Ponderosa pine can be a climax species at the lower limits of coniferous forests (where it often consists of even-aged groups) or a seral species in higher elevation mesic forests where other conifers are more competitive (USDA Forest Service 1990). Fires have had the most significant effect on ponderosa woodland distribution and persistence. Ponderosa pine can maintain its position as a dominant seral species where low-intensity, high-frequency fire regimes prevail because it is better adapted to fire than competitors such as grand fir and Douglas-fir. However, widespread forest type conversion has occurred in the region due to fire suppression (which promotes the development of understories of Douglas-fir and true firs) and harvest of ponderosa pine. Thus, in contrast to Douglas-fir (with which it is co-dominant on many sites), ponderosa pine has declined in its range (Kaufmann et al. 2008).

2.1.3.2 Juniper (Rocky Mountain Foothill Limber Pine-Juniper Woodland)

Within the Middle Rockies ecoregion, Rocky Mountain juniper (*Juniperus scopulorum*) is most common as a component of the foothills or woodland coniferous zones in southeastern Idaho (USDA Forest Service 1990). In some areas, it extends into the montane zone. Juniper trees have no defense against fire and historically they survived in areas where fire could not reach them (i.e., rocky sites with little soil to support other vegetation). With post-settlement fire suppression juniper has spread into a variety of forest and woodland vegetation types, including associations with spruce-fir, whitebark pine, Douglas-fir, aspen, lodgepole pine, and limber pine. Differences in elevation, physiography, soils, and fire regime, in combination with interactions with other plant species, determine the composition of forests in which Rocky Mountain juniper occurs. Rocky Mountain juniper normally is a component of long-term seral or near-climax vegetation, but is considered less tolerant of shade than ponderosa pine, limber pine, or lodgepole pine. Juniper is found in a wide variety of sites throughout its range (including open, exposed bluffs and rock outcrops, southern exposures, and sheltered ravines and canyons) and at a wide range of elevations. It is common on northern aspects in the “badland” topography of North and South Dakota. Climates throughout its range also vary considerably; precipitation in Rocky Mountain juniper sites may include both rain and snowfall.

Rocky Mountain juniper is attacked by a variety of arachnids, beetles, moths, dipterans, and nematodes that damage foliage, roots, boles, and twigs. A few of these pests occasionally develop into epidemic populations but landscape level damage has not been reported in ADS mapping. Diseases of junipers include rusts that attack the roots, stems, and foliage. Junipers are susceptible to damage or death from fire.

2.1.3.3 Douglas Fir Forest and Woodland

Douglas-fir-dominated ecological systems occur throughout the Middle Rockies in central and southern Idaho, the Greater Yellowstone Ecosystem (GYE), the Bighorn Mountain ranges of Wyoming, into Montana on the east side of the Continental Divide, and the central “sky island” ranges of Montana.

Douglas-fir forests in the Middle Rockies occur under a comparatively drier and more continental climate regime, and at higher elevations, than in the Pacific Northwest. Elevations may range to over 7,800 feet (ft) in the Wyoming Rockies. Lower elevation stands typically occupy protected northern exposures or mesic ravines and canyons, often on steep slopes. At higher elevations, these forests occur primarily on southerly aspects or ridgetops and plateaus. Douglas-fir often occurs at the lower treeline immediately above valley grasslands or sagebrush steppe and shrublands, sometimes associated with other species like ponderosa pine, grand fir, Engelmann spruce, subalpine fir, or Western larch. Successional relationships in Douglas-fir forests are complex. Douglas-fir is less shade-tolerant than many conifers, including western hemlock, western red-cedar, grand fir, or Engelmann spruce; Douglas-fir is also less fire resistant than many associated species. At drier locations, seedlings may favor moderate shading, such as by a canopy of ponderosa pine, which helps to minimize drought stress. In some locations, much of these forests have been logged or burned post-European settlement, and present-day stands are second-growth forests dating from fire, logging, or other stand-replacing disturbances. The fire regime is of mixed severity with moderate frequency. Douglas-fir forests were probably subject to a moderate-severity fire regime in presettlement times, with fire-return intervals of 30-100 years. Many of the important tree species in these forests are fire-adapted (aspen, ponderosa pine, lodgepole pine), and fire-induced reproduction of ponderosa pine can result in its continued codominance in Douglas-fir forests.

2.1.3.4 Mixed Conifer-Dry Systems

This highly variable system of montane coniferous forests is widespread in the Middle Rockies and on mountain “islands” in central Montana. This forest system is a matrix of patches dominated or codominated by one or combinations of a number of species including Douglas-fir, white fir/grand fir, and ponderosa pine. The composition and structure of the overstory are dependent upon the temperature and moisture relationships of the site and the successional status of the occurrence. Douglas-fir and grand/white fir are most frequent in the southern portion of the range, but ponderosa pine may be present to codominant. As many as seven conifer species may be found growing in the same occurrence. This system was undoubtedly characterized by a mixed-severity fire regime, with a high degree of variability in lethality and return interval in its natural condition. Douglas-fir and ponderosa pine are typical dominants in the northern portion of the range, while other seral species including lodgepole pine, western white pine, and western larch may be present. Grand fir (a fire-sensitive, shade-tolerant species) has increased on many sites once dominated by Douglas-fir and ponderosa pine, which were formerly maintained by low-severity wildlife. Presettlement fire regimes may have been characterized by frequent, low-intensity ground fires that maintained relatively open stands of a mix of fire-resistant species. Under present conditions, the fire regime is mixed severity and more variable, with stand-replacing fire more common and the forests more homogeneous. With vigorous fire suppression, longer fire-return intervals are now the standard; multi-layered stands of Douglas-fir, ponderosa pine, and/or grand fir provide fuel ladders, making these forests more susceptible to high-intensity, stand-replacing fires. Mixed conifer dry forest systems rarely form either upper or lower timberline forests.

2.2 BIOTIC AND ABIOTIC MORTALITY AGENTS

The following sections summarize effects of various insect pests (Table 2-2), diseases, parasites, syndromes (Table 2-3), and abiotic agents (e.g., fire, drought, windthrow) that damage or kill forest vegetation types in the Middle Rockies ecoregion. ADSs and ground surveys are used to locate and map areas of new or significant forest mortality and identify the likely cause of damage. Most of the data used in this evaluation of forest mortality in the Middle Rockies ecoregion are products of ADSs and ground surveys conducted by the U.S. Department of Agriculture (USDA) Forest Service and other agencies. ADS results are reported as acres affected by identifiable mortality agents, including insects and diseases. The ADS results are snapshots in time; however, when looked at over subsequent years, they can show trends, such as peak activity and subsequent decline as host tree species are depleted or insects move on to other stands. ADS results are reported annually by the USDA Forest Service regions encompassed by the Middle Rockies ecoregion: Northern Region (R1), Rocky Mountain Region (R2) and Intermountain Region (R4). Areas in these USDA Forest Service reports that are not within the Middle Rockies ecoregion were eliminated from the geospatial analysis of forest mortality. However, in the literature review contained in this FMAR (Section 2.3), the effects of mortality/damage agents are described region-wide.

Mortality/damage agents are inferred by observers in ADSs from characteristic colors and damage patterns, as well as the sizes and species of affected trees. The number of affected trees or intensity of damage (light or heavy) is also recorded in these surveys. Ground surveys play an important role in confirming these characteristic patterns and supporting biological evaluations of nature of the damage, especially for mortality syndromes where several damage agents may be involved. ADS systems may underestimate mortality from insects such as spruce beetle (SB) (USDA Forest Service 2010) and from tree diseases such as white pine blister rust (WPBR) (*Cronartium ribicola*) and dwarf mistletoe because symptoms of these damage agents may be difficult to identify from the air (Montana DNRC and USDA Forest Service 2010). The summary of effects of mortality/damage agents in Middle Rockies forests focuses on results of 2010 surveys and, where available, cites trends from previous survey years.

2.2.1 Insects

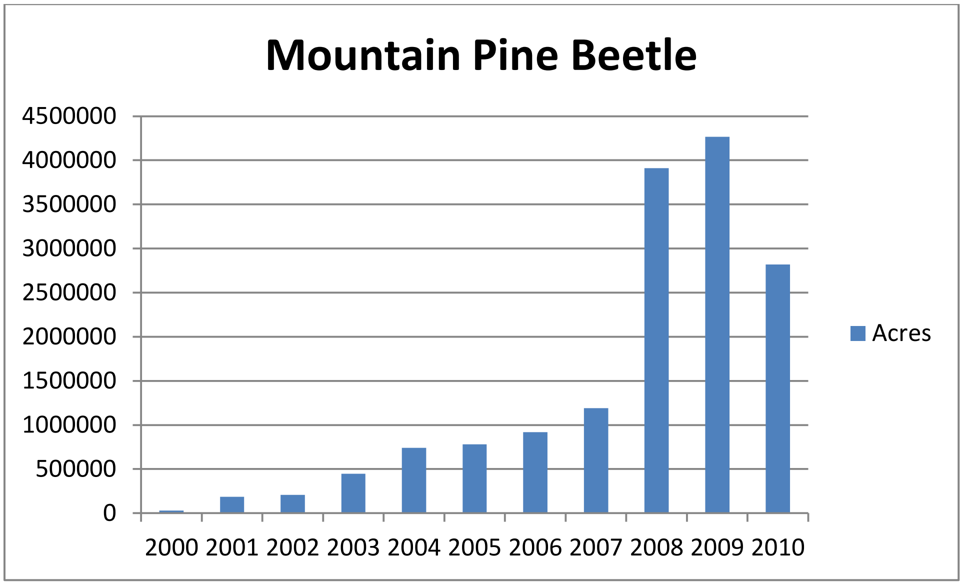
Table 2-2 lists the most important insect pests of forested portions of the Middle Rockies ecoregion during the period 2000-2010. Graphs 2-1 through 2-6 show the forested acres affected by these insect pests. The insect damage agents are further discussed in Section 2.3 to summarize recent mortality by the primary host forest systems.

Table 2-2. Important Insect Pests of Middle Rockies Forest and Woodland Ecological Systems

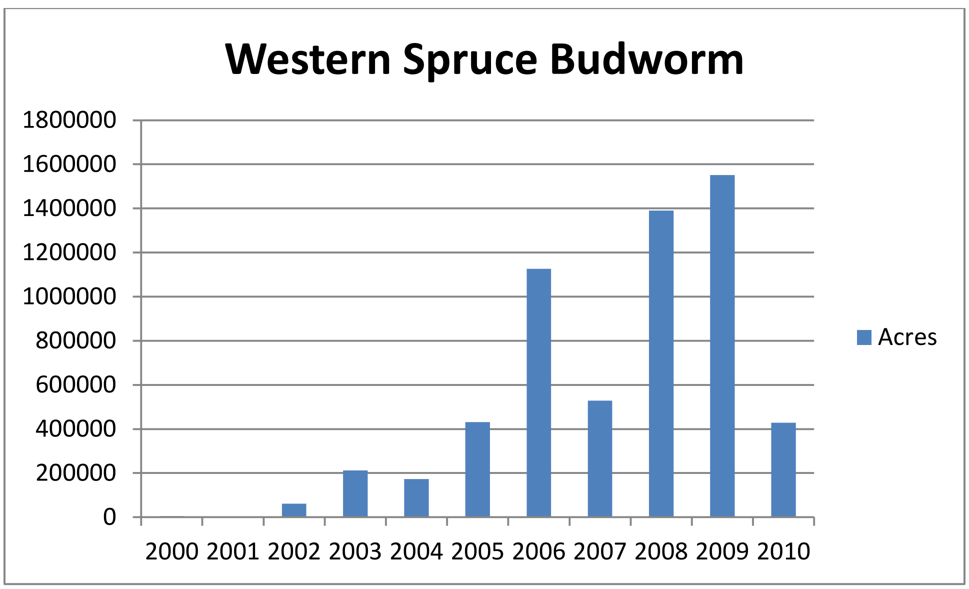
Bark Beetles and Defoliators	Scientific Name	Primary Host Trees
Mountain pine beetle (MPB)	*Dendroctonus ponderosae*	Most pine species (ponderosa, lodgepole, limber, and whitebark). During large outbreaks may attack Engelmann and blue spruce
Spruce beetle (SB)	*Dendroctonus rufipennis*	Engelmann spruce
Douglas-fir beetle	*Dendroctonus pseudotsugae*	Douglas-fir
Western balsam bark beetle	*Dryocoetes confusus*	Subalpine fir, other true firs
Pine engraver beetle	*Ips* spp	All pine species
Western spruce budworm (WSBW)	*Choristoneura occidentalis*	Douglas fir, true firs, spruce
Balsam woolly adelgid	*Adelges piceae*	Subalpine fir, grand fir

The mountain pine beetle (MPB) is currently the largest mortality agent in the Middle Rockies and is currently at outbreak levels (Graph 2-1). In 2009 alone, over 4 million acres in the Middle Rockies were infested with MPB. The western spruce budworm (WSBW) is possibly the most widely spread defoliator in the western United States (Graph 2-2). Over the last 10 years the WSBW has continuously grown in acres infested in the Middle Rockies, peaking in 2009 with over 1.5 million acres. Other major insects causing mortality include the SB, Douglas-fir beetle, western balsam bark beetle, and the pine engraver beetle. A complete summary of total forested acres affected by these important insect pests can be found in Graphs 2-1 through 2-6.

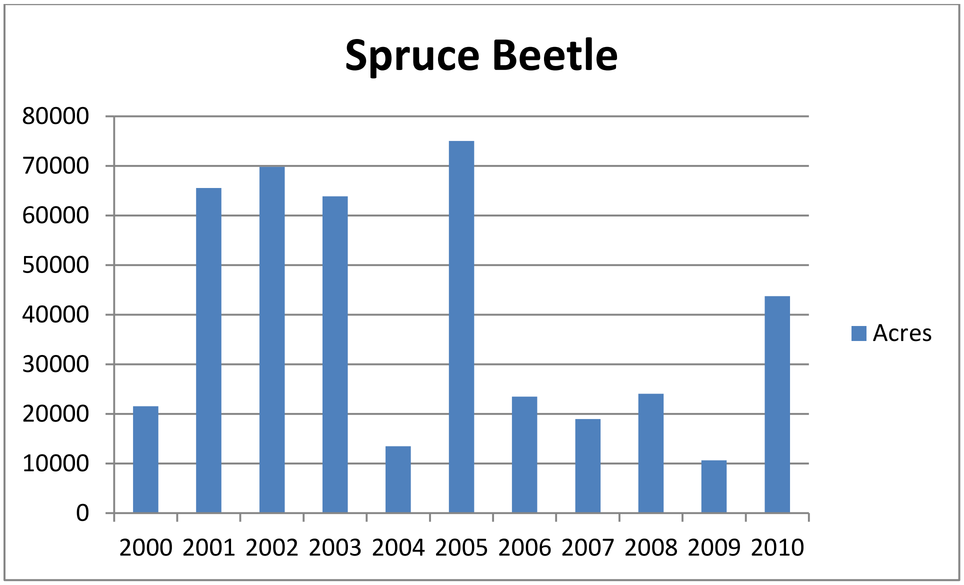
Graph 2-1. Acres Affected by Mountain Pine Beetle in the Middle Rockies Ecoregion



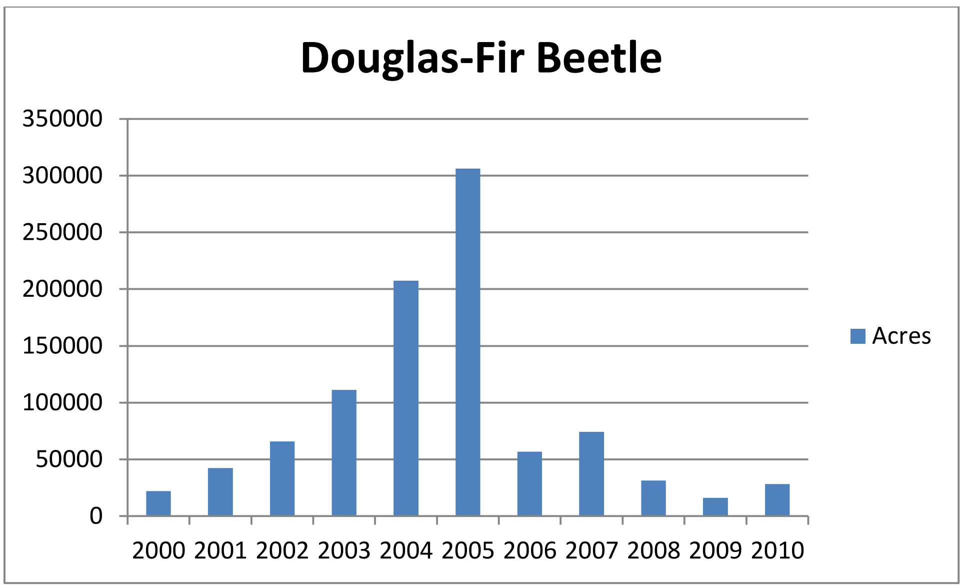
Graph 2-2. Acres Affected by Western Spruce Budworm in the Middle Rockies Ecoregion



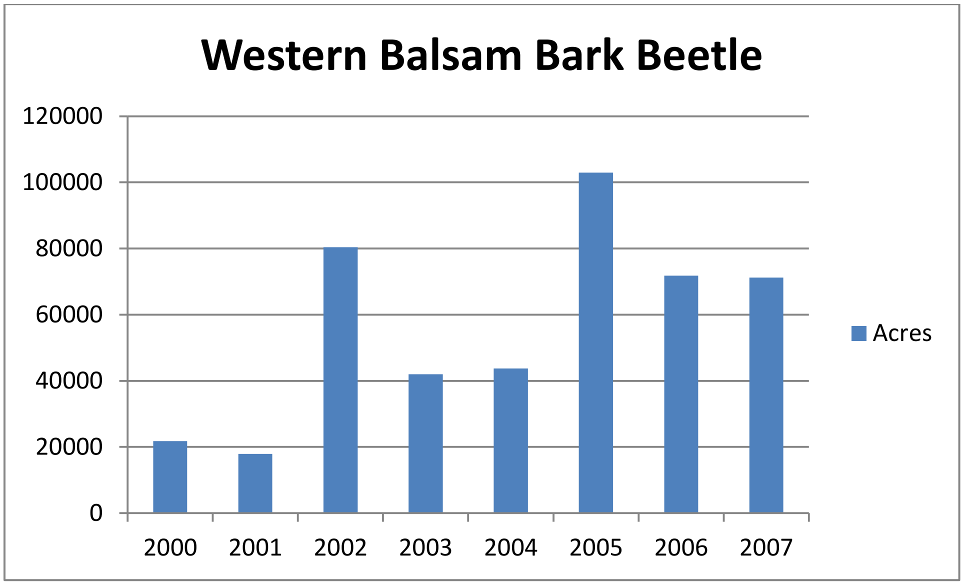
Graph 2-3. Acres Affected by Spruce Beetle in the Middle Rockies Ecoregion



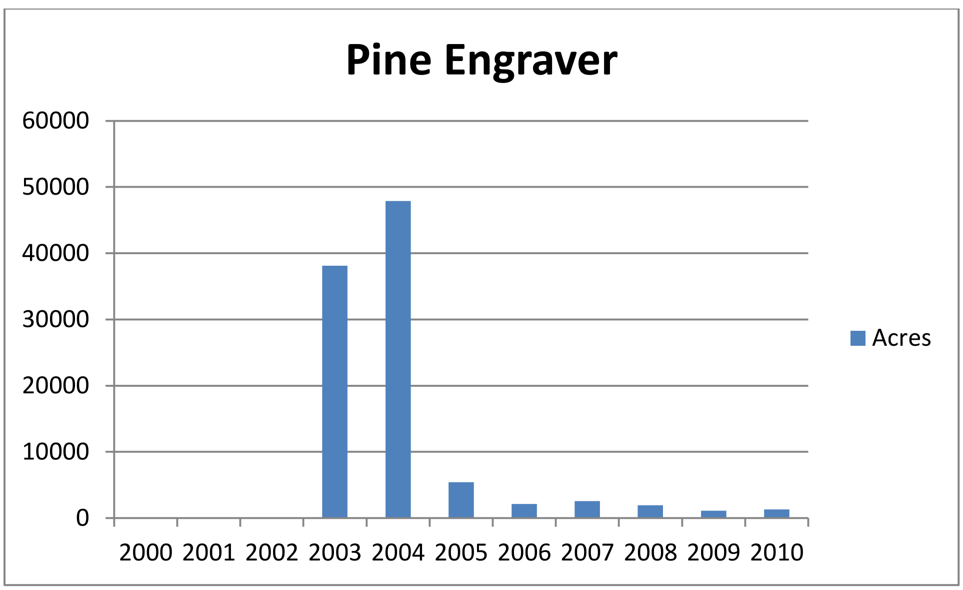
Graph 2-4. Acres Affected by Douglas-Fir Beetle in the Middle Rockies Ecoregion



Graph 2-5. Acres Affected by Western Balsam Bark Beetle in the Middle Rockies Ecoregion



Graph 2-6. Acres Affected by the Pine Engraver Beetle in the Middle Rockies Ecoregion



2.2.2 Pathogens, Mortality Syndromes, and Parasites

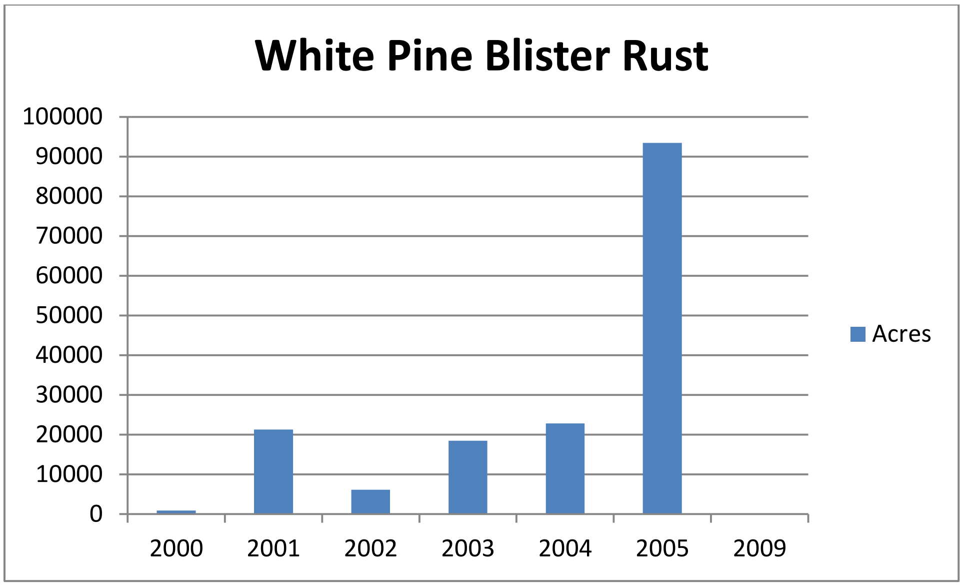
An introduced pathogen, WPBR is a significant mortality agent in the Middle Rockies ecoregion (Table 2-3). In addition, several syndromes resulting from the combined effects of stressors such as drought and/or climate change and insect and/or disease outbreaks have been identified as causing defoliation, dieback, and death of forest types. Table 2-3 lists the most important pathogens and syndrome conditions in the Middle Rockies ecoregion for the period 2000–2010. Graphs 2-7 through 2-10 indicate the forested acres affected by these mortality agents.

It should be noted the ADS does attempt to map WPBR; however, it is difficult to identify and map the rust fungus from ADS methods, resulting in underestimations of the amount of WPBR presence in the Middle Rockies.

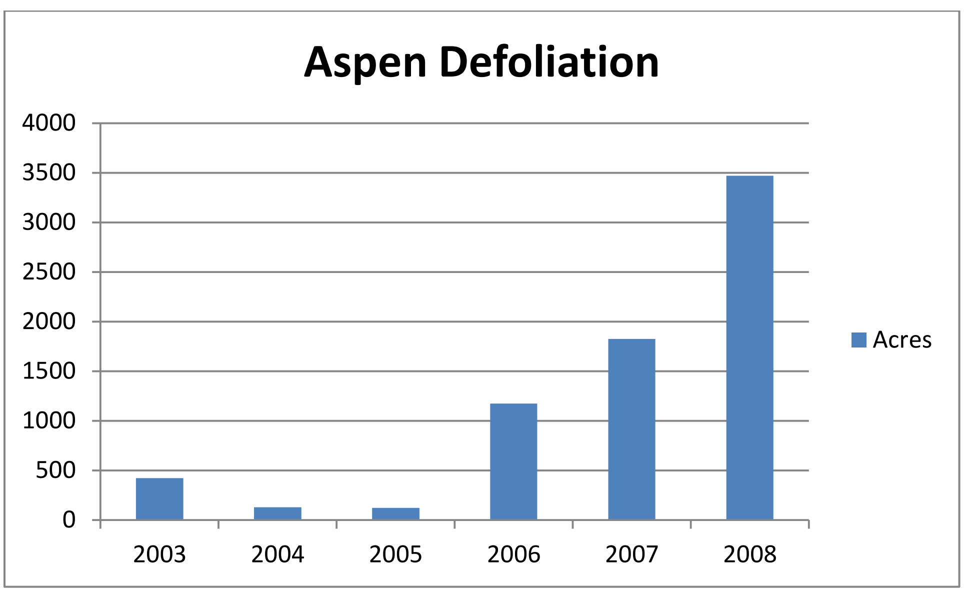
Table 2-3. Important Pathogens, Mortality Syndromes, and Parasites of Middle Rockies Forest and Woodland Ecological Systems

Pathogen, Mortality Syndrome, or Parasite	Scientific Name/Cause	Primary Host Trees
WPBR	*Cronartium ribicola*	Five-needle pine (limber pine, whitebark pine)
Aspen dieback/defoliation Sudden aspen decline (SAD)	Site-related factors, drought, elevated temperatures, secondary insect and disease attacks	Aspen
Subalpine fir mortality	Combined effects of western balsam bark beetle, and root disease fungi (*Armillaria* sp and *Heterobasidion annosum*	Subalpine fir
Five-needle pine decline	Combined effects of mountain pine beetle and white pine blister rust	Five-needle pine (limber pine, whitebark pine)

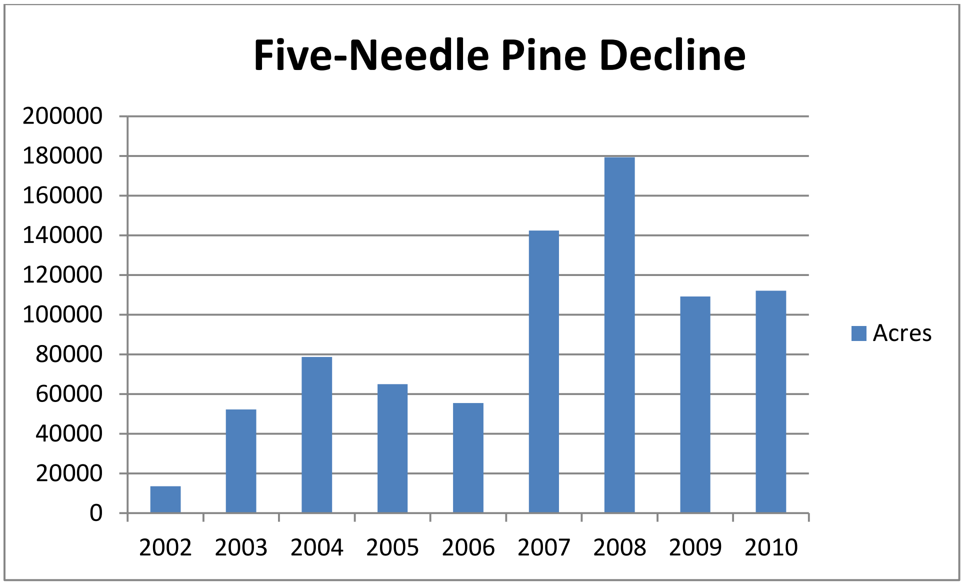
Graph 2-7. Acres Affected by White Pine Blister Rust in the Middle Rockies Ecoregion



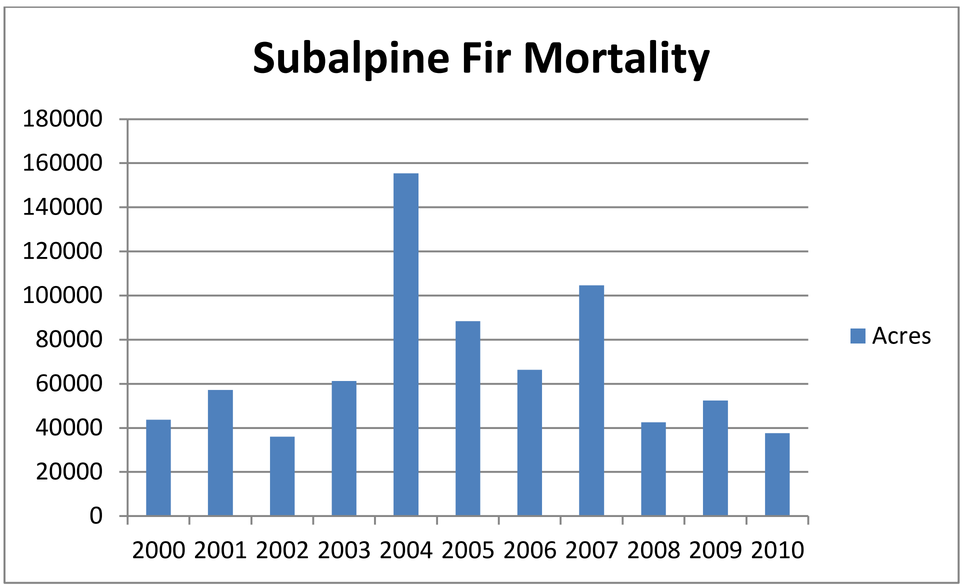
Graph 2-8. Acres Affected by Aspen Defoliation in the Middle Rockies Ecoregion



Graph 2-9. Acres Affected by Five-Needle Pine Decline in the Middle Rockies Ecoregion



Graph 2-10. Acres Affected by Subalpine Fir Mortality in the Middle Rockies Ecoregion



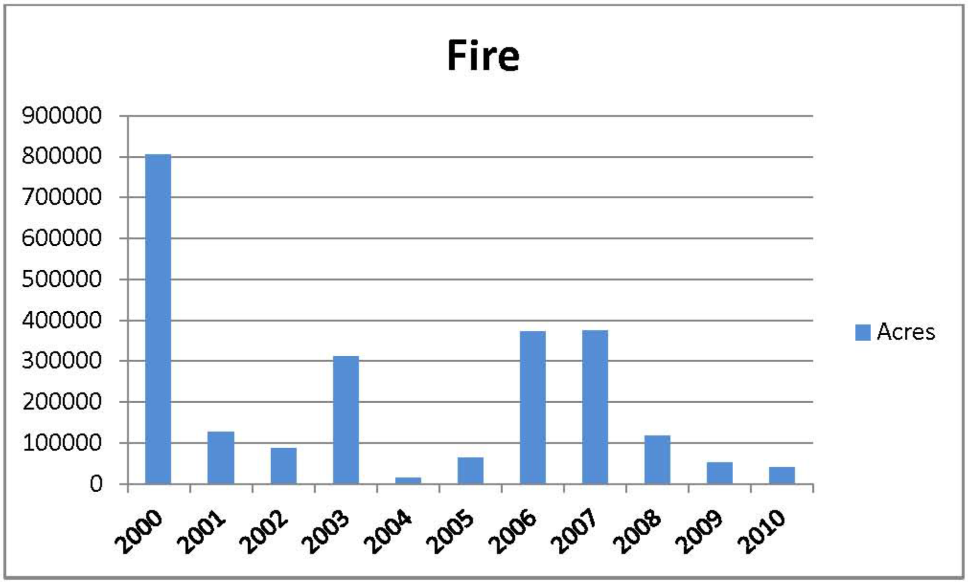
2.2.3 Abiotic Mortality Agents

In addition to biotic mortality agents, fire has been the most significant abiotic mortality agent in the Middle Rockies ecoregion since 2000; the remaining abiotic mortality agents have not been identified as causing significant damage relative to fire (i.e., less than approximately 5,000 acres in a given survey year).

The presettlement fire regimes of the Middle Rockies cover the entire range of fire types – from frequent, low-intensity surface fires to high-intensity crown fire and everything in between. Under present conditions, stand-replacing fires are more common and the forests are more homogeneous. Due to current fire management practices, fire suppression and longer fire-return intervals are now common. This results in multi-layered stands of Douglas-fir, ponderosa pine, and/or grand fir; this provides fuel ladders, making these forests more susceptible to high-intensity, stand-replacing fires. In some areas of the Middle Rockies fire suppression and altered fire regimes have resulted in decreased stand diversity and increased fuel loads. Mortality due to bark beetles is also increasing fuel loads, creating conditions for severe, large-scale, catastrophic fires.

Graph 2-11 shows the forested acres affected by fire in the Middle Rockies ecoregion for the period 2000 – 2010 from the Monitoring Trends in Burn Severity (MTBS) data. The MTBS maps the perimeters of fire across the United States. Figure 2-1 shows the MTBS fire perimeters from 2000-2010. As discussed in earlier, none of the abiotic mortality agents were carried into the analysis of future risk of mortality for forests in the ecoregion.

Graph 2-11. Acres Affected by Fire in the Middle Rockies Ecoregion



2.3 LITERATURE REVIEW/SUMMARY OF RECENT TREE MORTALITY EXTENT DUE TO DAMAGE AGENTS

The following sections describe the most important mortality and damage agents affecting the forest types in the Middle Rockies. The Middle Rockies Assessment Management Team (AMT) recommended that the following mortality agents be included in the analysis, based on magnitude of recent mortality in this ecocregion: MPB, SB, Douglas-fir beetle, WSBW, subalpine fir mortality and WPBR. Pine engraver beetles had an outbreak in the ecoregion from 2003-2004, but since then affected acres have been relatively low (Graph 2-5). The most comprehensive ecoregion-wide information on the extent of forest mortality is available in annual ADSs and ground surveys within reporting areas in the three USDA Forest Service Regions in the ecoregion (the Northern Region – R1, Rocky Mountain Region – R2, and Intermountain Region – R4). These data are summarized annually in forest condition reports available online at USDA Forest Service websites for the three administrative regions. Forest condition reports are available for ADSs conducted annually from 2001 to the present, but may include ground survey data as well. ADS results are reported as acres affected by identifiable mortality agents, including insects and diseases. These results are further broken out by county and ownership. The extent of forest mortality is not reported by forest type in these summaries, with the exception that MPB damage to host tree species (lodgepole pine, ponderosa pine, high-elevation five-needle pine) is reported. Some of the other insect and disease mortality agents are host-specific and the extent of their impacts on forest types must be inferred from knowledge of host species.

To put forest mortality into a larger regional perspective, some cumulative results for the period 1996-2010 and results of the 2010 ADS effort in USDA Forest Service Regions 1, 2 and 4 are summarized by state in Table 2-4. Since affected acreage detected in ADSs varies from year to year, the 2010 values listed in Table 2-4 capture a portion of the effects of the major insect mortality agents during outbreaks that have been going on for more than a decade in the region. The summary in Table 2-4 is based on summary reports available online, including:

1. Idaho Forest Insect and Disease Conditions Report. 2004. Idaho Department of Lands and USDA Forest Service Northern & Intermountain Region.
2. 2010 Aerial Detection Survey Summary for Wyoming. Tables. USDA Forest Service Region 2.
3. Montana Forest Insect and Disease Conditions and Program Highlights-2010. Compiled by Montana DNRC and USDA Forest Service R1.
4. Forest Health Conditions 2009-2010. Rocky Mountain Region (R2). Compiled by USDA Forest Service R2.
5. Idaho Forest Health Highlights 2010. Idaho Department of Lands and USDA Forest Service.

Table 2-4. Forest Condition Survey Results (Acres) for Mortality/Damage Agents by USDA Forest Service Region

State	MPB			ESB	DFB	WBBB/ SAF	WSBW	AD		
	Lodgepole Pine	Ponderosa Pine	Five-Needle Pine					Low	Moderate	High
2004 ADSs										
Idaho	483,180[1]	12,679[1]	65,572[1]	1,176[1]	111,657[1]	139,873	51,161[1]			
2010 ADSs										
Wyoming	478,000[2]	53,000[2]	195,000[2]	79,000[2]	7,400[2]	67,000[4]	4,400[4]	70[4]	7,600[4]	1,300[4]
Montana	1,672,487[3]	296,795[3]	190,302[3]	5,827[3]	16,052[3]	23,899[3]	325,549[3]			
Idaho	1,900,00 (all hosts)[6]		221,000[6]				840,000[6]	14,700[6]		
South Dakota	0[5]	44,000[5]	0[5]	0[5]				0[5]	160[5]	0[5]
1996-2010 ADSs (Cumulative)										
Wyoming	2,080,000[2]	151,000[2]	1,351,000[2]	454,000[2]	426,000[2]					
South Dakota	0[4]	369,000[4]	0[4]	100[4]						

MPB = mountain pine beetle, ESB = spruce beetle, DFB = Douglas-fir beetle, WBBB = western balsam bark beetle, WSBW – western spruce budworm, SAF = subalpine fir mortality, AD = aspen decline.

1. Source: Idaho Department of Lands and USDA Forest Service Northern & Intermountain Region
2. Source: ADS Summary for Wyoming Tables. USDA Forest Service Rocky Mountain Region (R2)
3. Source: Montana DNRC and USDA Forest Service Northern Region (R1)
4. Acres affected in R2 only. Source: USDA Forest Service Rocky Mountain Region (R2) (Harris et al. 2011)
5. Source: USDA Forest Service Rocky Mountain Region (R2) (Harris et al. 2011)
6. 2010 Data. Source: Idaho Forest Health Highlights 2010

2.3.1 Five-Needle Pine Systems

Whitebark pine and limber pine are the dominant trees in Middle Rockies five-needle pine ecological systems. These systems include high-elevation woodlands dominated by whitebark pine and lower-elevation limber pine woodlands. The primary damage/mortality agents of five-needle pines are **MPB, WPBR,** wildfire, competing vegetation (which may be the result of fire suppression), and global climate change (GCC) (Schwandt 2006).

All North American five-needle pines are susceptible to WPBR, an Asian fungus that was introduced to this continent in the early 1900s (Tomback and Achuff 2010; USDA Forest Service 2010), although some trees have a level of resistance (Kearns and Jacobi 2007; Geils et al. 2010; King et al. 2010; Larson and Kipfmueller 2010). The fungus cannot spread from pine to pine, instead requiring an intermediate host such as currants and gooseberries in the genus *Ribes* (Geils et al. 2010). Studies of the complex lifecycle of WPBR have found that optimal (moist) weather conditions may increase the incidence of pine infection (Koteen 2002; Burns et al. 2008). WPBR affects trees of all ages and sizes by killing branches or crowns (Geils et al. 2010). Its virulence depends on tree structure (branch height, single versus multiple stems), stand structure (open versus closed), and micrometeorological conditions. When WPBR weakens or kills cone-bearing branches, reproductive potential of the tree is impacted. Infected trees may become susceptible to other damage agents such as bark beetles (Tomback and Achuff 2010, Kearns and Jacobi 2007).

There has not been a comprehensive survey of the incidence of WPBR within the range of whitebark pine, but individual surveys are providing evidence that the rust is now present throughout the range in the Middle Rockies (Schwandt 2006). WPBR has been found in a limber pine stand in South Dakota (Lundquist et al. 1992), and was monitored in whitebark and limber pine stands in Wyoming (Bighorn, Medicine Bow, Shoshone National Forests) (Kendall et al. 1996; Smith and Hoffman 1998; Taylor and Schwandt 1998). Most areas had low incidences of the disease, but a few locations had moderate to high levels of infection. Surveys of whitebark pine stands by USDA Forest Health Protection in Idaho and Montana found WPBR infection levels from 0 percent to 81 percent in sampled stands, and 40 percent of stands had infection levels greater than 20 percent. WPBR and MPB are currently being monitored in the GYE (Jean et al. 2011), where WPBR was widespread and highly variable in intensity and severity (baseline estimate in transects established from 2004 to 2007 was 20 percent of stands infected). WPBR has been present in whitebark pine ecosystems for many years, but recent outbreaks of MPB have caused widespread mortality in many whitebark pine stands already impacted by WPBR. Figure 2-2 represents the WPBR occurrence in the Middle Rockies ecoregion.

Limber pine communities have received less monitoring and management attention than whitebark pine communities. Condition of limber pine stands, including damage agents such as WPBR, was sampled in stands extending from southern Alberta, Canada, to eastern Idaho and northern Wyoming in the late 1990s (Kendall et al. 1996). Limber pine mortality and incidence of rust was low to moderate, with a few areas of heavy infection in southwest Montana, northwest Wyoming, and adjoining areas of Idaho. WPBR incidence in limber pine stands in the Bighorn Mountains was generally low, but high infection rates and significant mortality were found at some sites.

Because WPBR is still expanding its range in the western United States and has not completely invaded all stands within its current range (Burns et al. 2008; Geils et al. 2010), and because other mortality agents such as MPB, changing fire regime, and GCC also affect the same stands, it has proven very difficult to separate how the various factors interact. Regionwide, the ADS database provides acreages of five-needle pines affected by MPB, WPBR, and combined effects of mortality agents called five-needle pine decline. Research in the Bighorn National Forest found MPB-infested trees had higher incidences of WPBR cankers compared with noninfested trees, indicating a positive correlation between MPB attack and canker severity and location. Overall, the prognosis for five-needle pine species is for large reductions in the extent of their ranges and stand densities (Tomback and Achuff 2010), with conversion to other forest types. These effects will occur across a vast landscape and will result in biological ecosystem-level impacts (McKinney and Tomback 2007; Tomback and Resler 2007; Resler and Tomback 2008).

Native bark beetles such as MPB exist at endemic levels in Rocky Mountain conifer forests, causing a relatively low level of mortality that mostly affects older or stressed individuals (Samman and Logan 2000). Outbreaks occur when environmental conditions such as warmer temperatures promote large beetle populations and large numbers of susceptible host trees are available. MPB is a native species that has unique eruption outbreak characteristics and historically was largely confined to lower elevation lodgepole and ponderosa forests, except during abnormal climatic events (Logan et al. 2010; Raffa et al. 2008). MPB also attacks larger trees, generally those of reproductive age, and must attack in mass in order to overcome the tree’s defenses, so developmental synchronization (fostered by thermal regimes) and adult communications that coordinate a mass attack are critical to its success (Raffa et al. 2008). MPB is endemic in lodgepole-ponderosa pine forests; periodically, temperature-driven eruptive outbreaks occur in these forests and in upper treeline five-needle pine forests and woodlands (the most recent having started in the 1980s). The historic pattern appears to be changing to more protracted outbreaks, increasing frequency, and movement into higher elevation whitebark pine woodlands. The elevational or orographic-driven historical frequency of MPB outbreaks on whitebark pine has been explained through the use of models that incorporate temperature controls on MPB larval survivorship, timing of emergence, synchronization of maturation, MPB adult population size, and the distribution of living host trees (Powell and Logan 2005; Powell and Bentz 2009; Bentz et al. 2010; Logan and Powell 2009).

Forest condition surveys have provided data on the extent of MPB activity on five-needle pine vegetation types in Wyoming, Montana, Idaho, and South Dakota during 2010 (Table 2-4). Wyoming, Montana, and Idaho have lost vast areas occupied by five-needle pine forest types due to WPBR and MPB during the ongoing outbreak of MPB (1996-present). Cumulative data for Wyoming show 1.3 million acres within the range of these species have been affected.

GCC effects and natural fire regimes are thought to have complex interactions with biotic mortality/damage agents. GCC is predicted to drive the upper treeline to higher elevations, although there may be local thermal refugia due to cold air drainage and aspect. Increased winter temperatures, longer growing seasons, and increased drought during the growing season may be playing major roles in MPB outbreaks. Fuel loads and fire return intervals and severity may also be affected by GCC. GCC appears to exacerbate the effects of wildland fire and MPB outbreaks. GCC, particularly increased temperature, is likely to have a profound effect on the MPB life cycle by reducing generation time and increasing overwinter survival. Changes in precipitation and temperature are predicted to lead to more frequent drought stress on lodgepole-ponderosa pine forests; this will lead to greater vulnerability to MPB, which will in turn alter fuel loads and the fire regime, and, consequently, the age structure of woodlands and forests. The effects of GCC on hydrology vary depending on the spatial scale analyzed. Upper treeline is generally defined by the presence of whitebark pine; while increased temperatures due to GCC will tend to force its distribution to higher elevations and northward (Warwell et al. 2007), the interactions between MPB, WPBR, and Clarks' nutcracker will likely drive the elevation of upper treeline downward (Tomback and Resler 2007; Resler and Tomback 2008). Figure 2-3 represents the MBP infestation in the Middle Rockies from the ADSs from 2000-2010.

2.3.2 Lodgepole Pine Systems

MPB and fire are the primary mortality agents of lodgepole pine in the Middle Rockies in recent years (Kaufmann et al. 2008). Dwarf mistletoe and windthrow affect lodgepole forests but result in more localized effects than MPB outbreaks and fire. MPB is a native insect that occurs in endemic populations capable of producing small-scale forest mortality in lodgepole pine systems. Historically, MPB were generally controlled by weather. At low levels MPB attacks can be overcome by tree defenses such as sap production, but trees that are stressed by drought or other insects and pathogens are more vulnerable. Under endemic conditions, individual trees are killed, resulting in patchy mortality throughout the stand (Samman and Logan 2000). During outbreaks 80 percent or more of trees in even-aged pine stands can be killed over a 5 to 7-year period. Population outbreaks in lodgepole pine are often stand-replacing events, as fire usually follows the outbreak within 15 years (Samman and Logan 2000). Fire generally tends to result in regeneration of lodgepole pine; however, if fire is suppressed following MPB outbreaks, other species such as spruce and fir may become dominant.

The current MPB epidemic is unprecedented in its extent and severity, and appears to be the result of multiple factors including the availability of vast stands of host trees of the appropriate age, size, and density to support large numbers of MPB, and warmer temperatures over the last decade sufficient to increase MBP reproduction and overwintering survival (Kaufmann et al. 2008). Extensive, dense lodgepole pine stands in particular have supported the current MPB epidemic. All of the lodgepole forest types in the Rocky Mountains (pure stands, subalpine stands, and lower elevation stands) are susceptible to attack by MPB, but the mixture of species may influence the way forests are affected by MPB and fire (Jenkins et al. 2008; Kaufmann et al. 2008). Limited information is available to predict likely fire behavior during and following a MPB epidemic under varying climate conditions, but it is possible that fuel structure would evolve differently in pure beetle-killed lodgepole stands than in mixed stands with live trees of other species (Kaufmann et al. 2008). At the stand scale, surface fire intensity and likelihood of passive crown fire may differ, affecting regeneration of understory vegetation and, ultimately, the dominant canopy species. Fire behavior in pure lodgepole stands at the landscape or regional scale will likely be more difficult to predict, as there are no examples of systems with such heavy fuel loads over such extensive areas (Kaufmann et al. 2008).

Forest condition reports provide summaries of ADS results, reported as surveyed acres affected by specific, identifiable mortality agents, including insects and diseases. Host trees are reported by ADSs for MPB-identified mortality. ADS results indicate that MPB has killed approximately 5 million acres of Montana forests (R1) (all vegetation types) during the period 2000-2010. The tally includes 1.6 million acres of the 4.9 million acres of lodgepole pine forests in Montana (Montana DNRC and USDA Forest

Service 2010). Much of the MPB infestation in Wyoming depicted in Table 2-4 involves lodgepole pine forests. MPB caused mortality on 1.9 million acres in Idaho in 2010, most of which was in lodgepole pine forests.

2.3.3 Ponderosa Pine Systems

MPB is the primary mortality agent of ponderosa pine vegetation types in the Middle Rockies, although the western pine beetle and *Ips* beetle also cause mortality (Samman and Logan 2000). Similar to lodgepole pine, endemic levels of bark beetle populations kill scattered, individual ponderosa pine and small groups, creating small patches of mortality. At outbreak, population levels half of the stand may be killed. Endemic beetle populations and low-level outbreak populations historically provided the fuel necessary for the periodic low-intensity fires that perpetuate uneven-aged ponderosa pine stands. If fire is subsequently suppressed, stand densities increase and age-class diversity decreases, resulting in increased likelihood of beetle population outbreaks. Following large-scale outbreaks, fuel loads increase to the extent that entire ponderosa pine-dominated stands are killed by severe fire events and replaced by shrub and grass communities. In mixed-species stands fire suppression may lead to loss of ponderosa pine and conversion to a fir or spruce forest type.

Forest condition reports provide summaries of ADS results, reported as surveyed acres affected by specific, identifiable mortality agents, including insects and diseases. Host trees are reported by ADSs for MPB-identified mortality. Survey results indicate that MPB has killed approximately 5 million acres of Montana forests (R1) (all vegetation types) during the period 2000-2010. The tally includes 297,000 acres of ponderosa pine forests identified in Montana in 2010 (Montana DNRC and USDA Forest Service 2010) and 53,000 acres in Wyoming (cumulative acres for Wyoming from 1996 to 2010 are 151,000) (Table 2-4). MPB infestations in Idaho (based on 2004 ADS results) primarily affect lodgepole pine forests; affected ponderosa pine woodland appears to involve much smaller acreages (Table 2-4).

2.3.4 Douglas-Fir Systems

Douglas-fir ecological systems are widespread in the ecoregion on a range of sites and elevations, and frequently involve associations of Douglas-fir with several other codominant tree species. For this reason, several insect damage agents may affect these systems, often acting in concert. **Douglas-fir** beetle and **WSBW** have had significant outbreaks in Douglas-fir associations in the past decade. WSBW is a widespread defoliator in the Middle Rockies; in Montana and Idaho is it the most significant defoliator. Larvae of this moth mine needles or newly swelling buds of host trees, which include Douglas-fir, subalpine fir, and Engelmann spruce. Defoliation occurs in tree crowns and outer branches. Defoliation events can affect entire stands, mostly severely damaging understory trees. Repeated defoliation events can decrease tree growth, cause mortality, or increase susceptibility of trees to other damage agents such as bark beetles.

Compared to previous forest condition reports, affected acres declined in northwestern and central Montana in 2010; most defoliation was in the southwestern portion of the state (Montana DNRC and Forest Service 2010). Overall in Montana, over 325,500 acres were mapped as defoliated by WSBW, which represents a marked decline from the 2,554,205 acres mapped in 2009 surveys (Montana DNRC 2009, 2010). The decline may be attributed to increased moisture and a cool spring, or limited ADSs in some areas. Recurring defoliation from WSBW can kill understory trees, and where drought and overstocking are prevalent, mature trees can also succumb after recurring years of defoliation. A few areas with multiple years of defoliation are beginning to result in tree mortality in association with Douglas-fir beetle (Montana DNRC 2010). In Wyoming, WSBW affected a relatively small acreage in Fremont and Park Counties in the Wind River and Absaroka Mountains. Smaller areas of defoliation were detected in the Bighorn National Forest in 2010. Idaho’s 2010 ADS reported 840,000 acres of WSBW defoliation scattered throughout the state, including the Salmon-Challis National Forest in the Middle Rockies ecoregion (Table 2-4). WSBW outbreaks in southern Idaho are causing mortality of Douglas-fir in association with Douglas-fir beetle (Idaho Department of Lands 2010). Figure 2-4 represents the WSBW infestation in the Middle Rockies from the ADSs from 2000-2010.

Douglas-fir beetle has been an important disturbance agent in the Rocky Mountain Region (USDA Forest Service R2) and a portion of the Intermountain Region (R4) in western Wyoming over the past 15 years (Harris et al. 2011). Increases appear to have followed where trees have been damaged by fire or heavy defoliation from WSBW or Douglas-fir tussock moth. ADSs have detected Douglas-fir beetle mortality on 632,000 acres within the Rocky Mountain Region (USDA Forest Service R2) and 100,000 acres within the Intermountain Region (R4). However, observed Douglas-fir beetle infestations in western Montana (R1) were scattered (Montana DNRC and USDA Forest Service 2010) and declined following the outbreak of the mid-2000s. ADSs conducted in Montana in 2010 reported only 16,052 affected acres (Table 2-4) (Montana DNRC and USDA Forest Service 2010). The cumulative Douglas-fir beetle acreage in Wyoming (all Forest Service regions) from 1996-2010 was 426,000 acres. In contrast, only 7,400 acres were affected in 2010 (Figure 2-5). Declining numbers of affected acres detected by ADS suggest that some areas have been depleted of suitable hosts; for example, Douglas-fir beetle-caused mortality in the Bighorn National Forest in Wyoming peaked in 2005 and has declined since 2007 (Harris et al. 2011). However, increases have been detected in Yellowstone and Grand Teton National Parks from 91 acres in 2009 to 1,400 acres in 2010, so the declining trend may not be uniform throughout these states. Figure 2-5 represents the Douglas-fir beetle infestation in the Middle Rockies from the ADS from 2000-2010.

2.3.5 Spruce-Fir Systems (Subalpine Fir Mortality, Spruce Fir Beetle, Western Balsam Bark Beetle)

High-elevation subalpine fir is susceptible to the **subalpine fir mortality syndrome**, which is related to attacks by a group of organisms including **western balsam bark beetle** (*Dryocoetes confusus*) and two groups of **root decay fungi** (*Armillaria* sp. and *Heterobasidion annosum*). Western balsam bark beetles attack trees weakened by root disease, drought, wind breakage, and other damage factors (USDA Forest Service 2010). Unlike mortality and damage associated with MPB and SB outbreaks, tree mortality resulting from the western balsam bark beetle is not uniformly distributed across the landscape (although cumulative mortality over the years may affect large areas). All national forests in the Rocky Mountain Region (R2), including Bighorn National Forest, experienced moderate to significant mortality in subalpine fir, with increases from 2009 to 2010. Most of the subalpine fir mortality mapped in Wyoming was in the Bridger-Teton National Forest. This outbreak has persisted in the area since 2004. Observed mortality was scattered across western Montana (R1) at fairly low levels. (Montana DNRC and USDA Forest Service 2010). Mortality of subalpine fir in Idaho, attributed to **balsam wooly adelgid**, western balsam bark beetle, and possible root disease, was detected on over 15,000 acres (Table 2-4); however, western balsam bark beetle and balsam wooly adelgid occurrences are currently most prevalent in the panhandle region outside of the Middle Rockies ecoregion (Idaho Department of Lands 2004).

Figure 2-6 represents the subalpine fir mortality infestation in the Middle Rockies from the ADSs from 2000-2010.

The **spruce beetle (SB**) is the most important natural mortality agent of mature spruce (USDA Forest Service 2010), and major outbreaks have developed in spruce forests from Alaska to Arizona. Outbreaks cause tree mortality and can alter stand structure and composition by reducing tree growth and stand density of surviving trees. Spruce regeneration requires some low level of disturbance to its preferred moist, shaded sites. SB-associated mortality at endemic population levels may facilitate spruce regeneration (Samman and Logan 2000). However, increases in downed woody debris due to windthrow or logging slash may allow beetle populations to increase rapidly, as these trees are the SB's preferred site. Where this occurs, spruce stands may be significantly affected, either regenerating as spruce or converting to another dominant species. Younger spruce trees and non-host trees (such as firs) may subsequently provide shade for spruce regeneration. In other cases, many stands once dominated by Engelmann spruce became subalpine fir stands following SB outbreaks (USDA Forest Service 2010). If a severe fire occurs following SB outbreak, spruce regeneration in the stand would follow regeneration of a pioneer species such as lodgepole pine or Douglas-fir at low elevations, and aspen or subalpine fir at higher elevations (Samman and Logan 2000).

SB outbreaks have occurred in the Rocky Mountains since the late 1990s, with a number of infestations in varying stages of development. SB may be running out of suitable host trees in many areas of northwestern Wyoming, but the outbreaks remain active in this area (Harris et al. 2011). The aerial "signature" of SB-infested spruce is not as striking or long-lasting as that of pine beetles in pines (USDA Forest Service 2010). Therefore, aerial detection of SB is difficult. Recent spruce mortality was detected in 2010 ADSs primarily in the Absaroka Range and the adjacent Bridger-Teton National Forest. Since 1996, cumulative affected areas total 454,000 acres in Wyoming (Table 2-4). During recent years, SB levels have remained relatively low across Montana (Table 2-4) (Montana DNRC and USDA Forest Service 2010). SB data from 2004 surveys in Idaho indicate endemic-level occurrences (Table 2-4), and more recent forest health summaries (Idaho Department of Lands 2009, 2010) do not indicate any severe outbreaks.

Figure 2-7 represents the SB infestation in the Middle Rockies based on the ADSs from 2000-2010.

Balsam wooly adelgid is an introduced hemipteran (true bug) in North America that has become an important pest of true firs in eastern states and provinces. It causes top kill and may attack the main stem and large branches. In the west, this insect has caused extensive mortality in true firs in the Cascade Mountains of Washington and Oregon (USDA Forest Service 2005); however, much of the damage has become chronic but subtle, and is often not visible from the air. Balsam wooly adelgid is present in northern Idaho, has been recently confirmed in Montana, and may occur elsewhere in the region (Livingston et al. 2000; Hagle et al. 2003; Montana DNRC 2010). An initial survey detected balsam wooly adelgid in Ravalli, Mineral, Sanders, and Lincoln Counties in Montana (Montana DNRC 2010). Balsam wooly adelgid has not been reported by the USDA Forest Service in annual forest condition reports in the Middle Rockies region. Balsam wooly adelgid is thought to be limited by climate, and may not be able to spread significantly through high-elevation spruce-fir forests in this region.

2.3.6 Aspen Systems

Largescale aspen decline has been documented from western Canada (Hogg et al. 2008) through southern Colorado and Arizona (Figure 2-8) (Bartos and Campbell 1998; Worrall et al. 2008; Fairweather et al. 2008). Aspen dieback was particularly rapid in southwestern Colorado beginning in 2004 and increasing through 2008 (Worrall et al. 2008; Worrall et al. 2010). Affected aspen forests show widespread, severe, rapid branch dieback, crown thinning, and root mortality, leading to mortality of clones. The phenomenon has been termed "sudden aspen decline" (SAD) and is characterized by rapid onset of mortality in which dying stands have little to no regeneration or recruitment. Recent research indicates that SAD is caused by several interacting factors, including site-related factors (low elevations, south and south-west aspects, open stands), higher temperatures, and drought stress (Hogg et al. 2008; Rehfeldt et al. 2009; Worrall et al. 2008; Fairweather et al. 2008; St. Clair et al. 2010; Worrall et al. 2010). The region experienced a significant drought from 1999-2004 immediately prior to the current episode of aspen dieback (Guyon and Hoffman 2011). Contributing factors that kill stressed trees include *Cytospora* canker, bark beetles, poplar borer, and bronze poplar borer. In many affected stands there was no significant regeneration response to overstory loss from SAD. The impacts of SAD have been consistent with projected effects of GCC; in southwestern Colorado SAD occurred mostly in areas projected to become climatically unsuitable for aspen in the early 21st century (Worrall et al. 2010).

Surveys in the Intermountain Region (USDA Forest Service R4) have reported different patterns of aspen mortality, such as the prevalent damage agents and susceptibility of different stem sizes (Guyon and Hoffman 2011). Some stands experiencing dieback were still capable of regenerating, although recruitment may be below the threshold suggested for successful aspen recruitment (O'Brien et al. 2010). Steed and Kearns (2010) reported that rapid stand decline (SAD) noted in Colorado was not prevalent in Montana and northern Idaho surveys undertaken in the Northern Region (USDA Forest Service R4). Patterns of mortality detected in ground survey plots indicated that mortality had occurred over many years. Nonetheless, aspen is declining in many areas of Montana and southern Idaho (Idaho Department of Lands 2010), likely caused by a combination of factors including increased conifer encroachment due to fire suppression, diseases and insects, and heavy ungulate grazing on regeneration. Drought may be an important factor in future mortality (Steed and Kearns 2010).

Aspen health is also a major concern in the Rocky Mountain Region (USDA Forest Service R2), which includes northern Wyoming, the Bighorn Mountains, and the Black Hills. In 2010, some Colorado areas with severe aspen decline detected in the previous two years via ADSs appeared to have significantly lower levels of decline because 1) there was aspen regeneration in the understory of many affected stands and 2) dead trees have fallen in some stands without regeneration, making SAD-related damage less apparent from the air (Harris et al. 2011). ADSs were conducted in 2009-2010 in other parts of Colorado, Wyoming, and South Dakota to evaluate the extent and severity of SAD (Harris et al. 2011). Although a few declining aspen stands were mapped during ADSs, ground survey data indicated most aspen stands in South Dakota and northern and western Wyoming were healthy. Ground plots in declining stands of central and northern Colorado and southern Wyoming showed some conditions consistent with SAD.

THIS PAGE INTENTIONALLY LEFT BLANK

3.0 ANALYSIS METHODS

3.1 DATASETS USED IN THIS ASSESSMENT

3.1.1 Gap Analysis Program Landcover Description

Satellite imagery (30-meter [m] grid) from the national GAP data was used to map the forest types used in the FMAR. This dataset combines the work of several different projects to create a seamless dataset for the contiguous United States. Except for a portion of the Black Hills National Forest in South Dakota, these data consisted of the Pacific Northwest ReGAP Projects. The small portion in South Dakota is made up of the original national GAP data. The data layer was merged then clipped to the Middle Rockies ecoregion, at which point the forest and woodlands were extracted for use in the FMAR analysis. For some forest types, such as the whitebark pine, the national GAP classification did not have a classification. In cases like this, Landscape Fire and Resource Management Planning Tools Project (LANDFIRE) data were supplemented.

3.1.2 LANDFIRE Description

LANDFIRE provides an existing vegetation layer. The LANDFIRE Existing Vegetation Type (EVT) layer represents the current vegetation present at a given site using nationally consistent ecological systems classification. Similar to the GAP data, LANDFIRE is based on a 30-m grid derived from satellite imagery. The EVT also uses elevation, field data, and decision tree models in the mapping process. LANDFIRE uses the same classification system as Natureserve's ecological systems for an easy cross-walk to GAP.

3.1.3 Aerial Detection Survey Maps

Insect infestation was analyzed using ADSs from the USDA Forest Service. ADSs report data on insect, disease, and other types of disturbances to forested ecosystems. Survey data on the health of affected forest areas are collected across private, state, and federal lands, assigned standardized forest damage codes, and recorded and maintained by the Forest Heath Technology Enterprise Team (FHTET), Fort Collins, Colorado. To identify insect and disease activity, the observer looks for characteristic signatures to distinguish the tree species and the type of damage that has occurred. Characteristics that observers use to determine the host tree species include the shape of the tree's crown, slope position, elevation, and aspect. Variation in the color of the tree's foliage indicates the presence and type of insect or disease activity. For example, bark beetle activity causes tree mortality which results in foliage color fading from green to a species-specific yellow, red, or straw color. In contrast, defoliators remove some of the foliage, resulting in discoloration such as a gray, red, or yellow tinge. During the survey, all of the observed damages are recorded in a digital format, which is compiled for use in the production of maps and summary statistics. When unknown signatures are observed, ground checks are conducted to verify the host and damage causing agent (Johnson 2012).

3.1.4 Whitebark and Limber Pine Information System

The ADS has a classification for WPBR, but after reviewing the data, and after discussion with BLM foresters, this dataset appears to be greatly underestimating the presence of WPBR. For WPBR, Science Applications International Corporation (SAIC) plotted data from the Whitebark and Limber Pine Information System (WLIS). WLIS is a database of summary data of plots established for whitebark and limber pines in the United States and Canada assembled from researchers, surveyors, and literature sources. In addition, data from Forest Inventory and Analysis (FIA) plots with whitebark or limber pine are included. Since the WLIS data are point data, they could not be used to predict actual areas of infestation on a patch of host forest types. These data were not used in the identification of epicenters for the last 5 years, but were used in the future mortality analysis. Figure 2-2 displays data from WLIS with WPBR data from ADS that were converted to a point data layer to represent current presence of WPBR.

3.1.5 National Biomass and Carbon

Ecoregion-wide carbon sequestration data were limited and identified as a data gap early in the FMAR identification process. There is a National Biomass and Carbon Dataset (NBCD) from Woods Hole Research Center. The data were created by the National Aeronautics and Space Administration's (NASA's) Terrestrial Ecology Program supported by LANDFIRE. Datasets from the NBCD include 30-m above-the-ground biomass and carbon stock for the United States. For forest biomass and carbon sequestration mapping data from the NBCD was used for mapping and carbon sequestration discussion.

3.1.6 Climate

The current climate model used for this assessment is the U.S. Geological Survey (USGS) Regional Climate Model, Version 3 (RegCM3) 15 x 15 kilometer (km) downscaled data that was bias-corrected using the USDA's Parameter-Elevation Regressions on Independent Slopes Model (PRISM) 15 x 15 km data. PRISM is an analytical tool that uses point data, a digital elevation model, and other spatial datasets to generate gridded estimates of monthly, yearly, and event-based climatic parameters, such as precipitation, temperature, snowfall, degree days, and dew point. PRISM uses historical data from weather stations and follows a coordinated set of rules, decisions, and calculations that are typically used by climatologists to create a climate map. Using a weighted linear regression for each station, PRISM interpolates the data across the landscape using the grid square size set in the analysis. The weight is the sum of the weights specified for distance, elevation, cluster, vertical layer, topographic facet, coastal proximity, and effective terrain (Daly and Johnson 2008). Elevation thresholds for the lapse rate function can be set in PRISM to compensate for the winter temperature inversions that are common in mountainous terrain in the western United States due to down-slope cold air drainage with valleys and canyons (e.g., Wyoming's Bighorn Valley) being colder than mid-slope areas (Daly and Johnson 2008; Daly et al. 2008, 2009). PRISM's spatial resolution is approximately 3 x 4 km, but current climate data were based on models for the period of 1980 to 1999. Data for the period between 2000 and 2010 were not available. The current RegCM3 data were stored as decadal climate data (i.e., 1980 to 1989 and 1990 to 1999). Therefore, these data were merged and averaged across all three global climate models (GCMs) to create an output raster for the current period of 1980 to 1999.

Future climate data were based on the models for the period of 2050 to 2069. Because the RegCM3 models were based on decadal periods, a date range encompassing this date was used in the analysis. The future RegCM3 data were stored as decadal climate data (i.e., 2050 to 2059 and 2060 to 2069). Therefore, these data were merged and averaged across all three GCMs to create an output raster for the future period of 2050 to 2069.

3.2 ANALYTICAL METHODS

3.2.1 Digital Aerial Detection Survey Maps and Insect Damage Information from 2000 Onward

The U.S. Forest Service ADS polygon data for the 2000 – 2010 period were used for all but WPBR to map insect infestations and diseases. As discussed previously, WLIS was used for mapping and analysis of WPBR. For this portion of the analysis, the data were mapped for 10 years to capture past outbreaks (like the Douglas-fir beetle) that have run their course; the purpose of this was to provide a good baseline for choosing insects and disease to run the mortality assessment against.

The ADS vector data from 2000 to 2010 were clipped to the Middle Rockies ecoregion and used to map the damage agents for the last 10 years. The damage agents were queried by the appropriate code from the ADS damage code appendix. From these data, acreage was calculated for each damage agent and reviewed internally and by BLM foresters from Montana and Wyoming. From these data, the major damage and mortality agents were identified in the FMAR analysis. After review and discussion with BLM foresters, a determination was made to analyze the MPB, SB, WSBW, subalpine fir mortality, Douglas-fir beetle, and WPBR.

The major insects used in the FMAR analysis to identify epicenters for the last 5 years were merged together and converted to raster format for spatial analysis.

For WPBR, the ADS polygon data were converted to points and merged with the WLIS data to ensure comprehensive coverage across the ecoregion.

3.2.2 Forest Mortality Index by Insect/Disease Mortality Agent

The overall goal of the FMAR was to generate geospatial information focusing on the extent of recent forest mortality (previous 5 years) and anticipated forest mortality (over the next 5 years). To achieve this goal, a forest mortality index (FMI) by insect/disease mortality agent was created. An FMI for each insect or damage agent was created because, in most cases, they attack different host tree species. For each FMI analysis, except for that of WPBR, the 2005-2010 ADS data were used.

For each damage agent, a composite index was created by analyzing the ADS data for the past 5 years collectively. The assumption is that the longer the infestation has been in one location, the higher the mortality. This can then be used to identify those epicenters of high mortality and adjacent areas to determine the potential for future mortality.

More precisely, for each damage agent for each year from 2005-2010, the appropriate insect or disease ADS code was queried from the dataset. The vector polygon layer was then converted to a raster dataset. Each layer was combined to create a final FMI representing the number of years the damage agent had been on the host forest. For example, presence of MPB in an area 5 out of 5 years reflects very high mortality in the host forest types. Previous work at the University of Colorado has shown that this method is effective in mapping patterns of forest mortality by MPB in Colorado (Schoenagle 2010).

The potential host tree species were mapped using GAP data or a combination of GAP and LANDFIRE. For example, GAP and LANDFIRE were mapped for five-needle pine forests. This output was used to analyze the overall distribution of insect and disease compared to the host tree species.

3.2.3 Identify Epicenters of High/Sustained Mortality to Identify Broad Spatial Patterns Where Adjacent Mortality Would be Likely over the Next 5 Years

It is assumed that areas adjacent to high recent mortality will be at higher risk of future mortality over the next 5 years. To identify these areas, a simple crosswalk was created (Table 3-1) to map areas adjacent to current high mortality. The crosswalk also included those areas not currently infested to show areas of low future risk over the next 5 years. This allowed for a more comprehensive approach to the future mortality risk for all primary forest host types across the Middle Rockies ecoregion.

A combination of the WLIS point data and ADS converted data was used for WPBR, and a proximity analysis was used to identify areas of likely future mortality. The assumption for this analysis was that if a host forest is in close proximity to a current occurrence of WPBR, that forest is at higher risk for future mortality.

Table 3-1. Crosswalk from Current Forest Mortality Index to Potential Risk of Mortality

Number of Years of Mortality Agent Detection	Current Forest Mortality Index	Future Risk of Mortality (Next 5 Years)
0	Non-Infested	Low
1-2	Low to Low-Moderate	Moderate
3-4	Moderate to Moderate-High	High
≥5	High	Very High

3.2.3.1 Mountain Pine Beetle Outputs

The MPB FMI shows widespread infestation across the Middle Rockies ecoregion over the last 5 years (Figure 3-1).). Areas in the Big Belt and Elkhorn Mountains near Helena indicate a very high potential for forest mortality. The MPB infestation is not limited to these areas, and multiple years of infestation are common throughout host forest types (Table 3-2). Generally speaking, the number of MPB-infested acres has increased over the last 5 years.

Areas identified for future MPB-caused mortality over the next 5 years are also widespread (Figure 3-2). Areas in the Big Belt and Elkhorn Mountains show a very high potential for future mortality. The Lemhi Mountain range in the Salmon and Challis National Forests (in the western potions of the Middle Rockies) also shows the likelihood of future mortality. Other areas likely to see high future mortality due the MPB are in the Teton Mountain and Wind River Ranges.

Table 3-2. Mountain Pine Beetle Host Forest Types

Mortality Agent	GAP Level 3 Systems
Mountain Pine Beetle	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
	Northern Rocky Mountain Foothill Conifer Wooded Steppe
	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest
	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
	Northern Rocky Mountain Subalpine Woodland and Parkland
	Northwestern Great Plains - Black Hills Ponderosa Pine Woodland and Savanna
	Rocky Mountain Foothill Limber Pine-Juniper Woodland
	Rocky Mountain Lodgepole Pine Forest
	Rocky Mountain Poor-Site Lodgepole Pine Forest
	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland
	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland

3.2.3.2 Douglas-Fir Beetle Outputs

The Douglas-fir beetle FMI indicates areas of isolated mortality over the last 5 years. Comparatively speaking, the Douglas-fir beetle is not as widespread as the MPB. There are areas in which Douglas-fir beetle infestations have occurred for multiple years, such as the Bitterroot Mountains south of Missoula, eastern portions of the Bighorn Mountains, and the Absaroka Mountain range in northeast Wyoming. Based on the ADS data, the Douglas-fir beetle seemed to peak in 2005. In most areas, the FMI scores show low mortality for the last 5 years (Figure 3-3). Table 3-1 lists the primary hosts and GAP Level 3 systems the analysis was performed on.

The potential for future mortality was mainly low to moderate and was also isolated in these same areas. (Figure 3-4).

Table 3-3. Douglas-Fir Beetle Primary Host Forest Types

Mortality Agent	GAP Level 3 Systems
Douglas Fir Beetle	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland
	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland
	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
	Northern Rocky Mountain Foothill Conifer Wooded Steppe
	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest
	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland
	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland

3.2.3.3 Spruce Beetle Outputs

The SB infestation is also much smaller in scale compared to the MPB. Since 2005, the ADS amount of acres has maintained steady. The SB FMI indicates relatively small, isolated areas of high FMI in areas such as the Absaroka and Washakie Wilderness located east and southeast of Yellowstone National Park (Figure 3-5). These areas also represent the potential for higher risk of future mortality (Figure 3-6). Current and future mortality is relatively low across the ecoregion. Table 3-4 lists the primary host forest types used in the SB FMI analysis.

Table 3-4. Spruce Beetle Primary Host Forest Types

Mortality Agent	GAP Level 3 Systems
Spruce Beetle	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland
	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland

3.2.3.4 Subalpine Fir Mortality Outputs

Over the last 5 years, the subalpine fir mortality infestation had the lowest amount of impacted acres; therefore, areas of potentially high FMI are isolated in smaller areas (Figure 3-7). Those areas of potentially high subalpine fir mortality are primarily in the Bighorn National Forest in the southwest portion of the ecoregion. Table 3-5 lists the primary host forest types for the subalpine fir mortality.

Areas at risk of future mortality also include areas in the Bighorn Mountains. Other areas with future mortality potential are small and more isolated in areas of the Absaroka Mountains (Figure 3-8).

Table 3-5. Subalpine Fir Mortality Primary Host Forest Types

Mortality Agent	GAP Level 3 Systems
Subalpine Fir Decline	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna
	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland
	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland

3.2.3.5 White Pine Blister Rust Outputs

As previously mentioned, the ADS has a classification for WPBR but seems to underestimate the presence of WPBR. For WPBR, SAIC plotted data from the WLIS. These point data were then merged with the ADSs that were converted to a point data layer to represent current presence of WPBR. Therefore, an FMI was not performed. However, Figure 2-2 displays a widespread occurrence of WPBR on host forest types (Table 3-6) in the Middle Rockies ecoregion.

Table 3-6. White Pine Blister Rust Primary Host Forest Types

Mortality Agent	GAP Level 3 Systems
White Pine Blister Rust	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest
	Northern Rocky Mountain Subalpine Woodland and Parkland
	Rocky Mountain Foothill Limber Pine-Juniper Woodland
	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland

A proximity analysis from current WPBR occurrence was completed to identify areas of potential future mortality. Because this analysis did not have areas of previous mortality to classify the data into very high, high, moderate or low potential for future mortality, the proximity analysis was classified and scored. This information came from the Middle Rockies REA five-needle pine Rolling Review Team, comprised of BLM foresters and subject matter experts in the ecoregion (Table 3-7).

Table 3-7. White Pine Blister Rust Future Risk of Mortality Classification

Mortality Agent	Proximity	Future Risk of Mortality
White Pine Blister Rust Proximity (m)	Present	Very High
	0 – 300 m	High
	300 – 3,000 m	Moderate
	>3,000 m	Low

Though current occurrences of WPBR are widespread throughout the ecoregion, highest potential risk of mortality within the next 5 years is isolated to those areas close in proximity to current clusters of occurrences (Figure 3-9). Though WPBR is responsible for a high percent of whitebark pine mortality in the Middle Rockies, it usually takes the infected tree a long time to die. Thus the majority of the ecoregion is classified as having a moderate risk of mortality over the next 5 years.

3.2.3.6 Western Spruce Budworm Outputs

Since 2005, the WSBW has been a major mortality agent in the Middle Rockies. In 2009, almost 1.6 million acres of forests were impacted by the WSBW, with most damage occurring in the central and north-central portion of the ecoregion (Figure 3-10). Current areas with the highest forest mortality are located within the Big Belt Mountain Range and the Crazy Mountains north of Bozeman. Other areas of high mortality are more isolated, with much of the ecoregion displaying moderate mortality. However, much of these same areas are at a higher risk of future mortality in the next 5 years. Figure 3-11 displays a widespread risk of WSBW mortality.

Table 3-8. Western Spruce Budworm Primary Host Forest Types

Mortality Agent	GAP Level 3 Systems
Western Spruce Budworm	Inter-Mountain Basins Aspen-Mixed Conifer Forest and Woodland
	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland
	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest
	Northern Rocky Mountain Foothill Conifer Wooded Steppe
	Northern Rocky Mountain Mesic Montane Mixed Conifer Forest
	Northern Rocky Mountain Subalpine Woodland and Parkland
	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland
	Rocky Mountain Subalpine Mesic Spruce-Fir Forest and Woodland
	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland
	Southern Rocky Mountain Mesic Montane Mixed Conifer Forest and Woodland

3.2.4 Using Current and Predicted Future Climate Change to Assess the Vulnerability of Major Tree Species over the Next 50 Years

The analysis of climate change was conducted using delta outputs, which were created using inherent geographic information system (GIS) processes related to spatial analysis. After the data were aggregated into the appropriate time periods, the current climate data were subtracted from the future climate data on a cell-by-cell basis. This provided the data for the comparison of current climate patterns to future modeled climate patterns and resulted in the delta (change) output figures. The climate change data was not modified in this way because of the potential loss of pertinent regional information in the comparison phase. This enabled climatologists to observe patterns affecting the ecoregion rather than simply looking at the smaller ecoregional scale.

The RegCM3 data format was based on 15-km Environmental Sciences Research Institute (ESRI) grids and was created for broad (regional) analysis. Although this provided a better overall approach for the ecoregional model than the GCMs, the accuracy of this model across areas of great topographical variation presented problems in the overall analysis.

As presented on Figure 3-12, the RegCM3 data indicate that most of the ecoregion could experience a mean annual temperature increase of between 1.9 to 2.4 degrees Celsius (^{0}C). From March to April, there are three critical effects (as presented on Figure 3-13). First, the data show that actual mean temperature for the colder mountain ranges in central and western Wyoming and those along the southwestern border of Montana could increase from below 0 to 0^{0}C, likely resulting in more frequent freeze/thaw cycles. Second, the data show that the higher elevations could experience increases of 3 to 5^{0}C, while the highest peaks in the Bighorn Range could experience up to a 6.7^{0}C increase. Third, while the general increase for the entire ecoregion could be between 1.1 to 3^{0}C during this seasonal period, the areas where the increases are at the higher end of the interval would be adjacent to the highest peaks. The model shows an interesting pattern of cooling temperature on the eastern slopes of the Wind River Range and the Bighorn Range.

During May and June, the data show that most of the ecoregion could be 0.6 to 3.3^{o}C warmer (Figure 3-14), with the colder mountain ranges in central and western Wyoming and those along the southwestern border of Montana potentially increasing from 0 to above 0^{o}C. This increase, while not as great as that of some other seasons, is important because it occurs during the warm, wet season. With warmer temperatures plant growth could start earlier in the year and evapotranspiration rates would increase. These increased evapotranspiration rates would especially affect the Black Hills because it is primarily a warm precipitation-dependent area.

The future climate patterns for July and August are presented on Figure 3-15. This is a season of convective storms and temperatures in the mountains are predicted to increase from 3.1 to 5^{o}C at middle elevations and from 5.1 to 8.7^{o}C at higher elevations. If this happens, these increases would significantly increase evapotranspiration rates and reduce the water content of dead vegetation and litter. Both conditions could likely increase water stress in plants and provide more flammable materials for wildfires.

The RegCM3 data for September to October (Figure 3-16) indicate that most of the ecoregion could be 1.1 to 3^{o}C warmer, with potential increases up to 7.2^{o}C in the higher areas such the Teton Range, the Wyoming Range, the Wind River Range, and especially in the Bighorn Range. For the November to February timeframe, the data show increases similar to those for the September to October period, with potential increases of up to 6.2^{o}C in the higher mountain ranges (Figure 3-17).

3.2.5 Using Available Models for Carbon Sequestration, Assess Potential Trends in Carbon Sequestration Resulting from Changes in Vulnerability of Major Tree Species

Carbon sequestration data were identified as a data gap early in the FMAR data identification process. However, the NBCD data were downloaded for the entire contiguous United States and clipped to the Middle Rockies ecoregion (Figure 3-18), as previously mentioned. These NBCD data for the year 2000 are a baseline for quantifying carbon stock in U.S. forests. As this information is updated, the datasets can be used to assess carbon flux between forests and the atmosphere for the Middle Rockies. However, using the current baseline data to assess potential trends is difficult. Much of the carbon stored in forests and soils is released into the atmosphere when forests are cleared or burned. Carbon is also released as dead plant material decomposes, but this release occurs at a very slow rate. Therefore, future predictions based on the current baseline biomass and carbon data may be unreliable.

THIS PAGE INTENTIONALLY LEFT BLANK

4.0 RESULTS AND DISCUSSION

4.1 FOREST MORTALITY-SYNTHESIS OF DATA COVERING PAST 5 YEARS

One of the main objectives of the FMAR was to identify epicenters of recent high/sustained mortality in the Middle Rockies. An FMI by insect/disease mortality agent was created to identify these areas. For each damage agent, a composite index was created by analyzing the ADS data for the past 5 years collectively. As stated previously, the assumption is that the longer the infestation has been in one location, the higher the mortality. This can then be used to identify those epicenters of high mortality and adjacent areas to determine the potential for future mortality.

When looking at forest mortality covering the past 5 years, certain mortality agents such as the MPB and WSBW have flourished and expanded throughout the Middle Rockies ecoregion. However, it appears other mortality agent outbreaks, such as that of the Douglas-fir beetle, may be declining. The SB and the subalpine fir mortality infestations are smaller and more isolated than other damage agents, but over the last 5 years have maintained similar acreages of infestation. In addition, WPBR appears to still be a major threat to whitebark pine forests.

The MPB by far has caused the most widespread mortality in the Middle Rockies. Large portions of the ecoregion showed moderate-high to high mortality. The Black Hills displays isolated areas of high mortality from MPB over the last 5 years. However, the Black Hills mortality from MPB may appear more isolated due to the large areas of infestation in the rest of the ecoregion. In addition, when looking at MPB infestation over the last 10 years, it becomes apparent the impacts of the MPB are widespread throughout the Black Hills area. The WSBW has been the second highest cause of mortality in the ecoregion. However, compared to the MPB, WSBW-caused mortality was much lower and found mainly in the central and north-central forests in the ecoregion. Though the damage agents were analyzed individually, many of the same areas in the ecoregion showed high levels of mortality for several damage agents. Forests in the northwest portions of the ecoregion, such as those within the Big Belt and Elkhorn Mountains, had high mortality due to MPB and WSBW and have a high occurrence of WPBR.

The Douglas-fir beetle and SB are never as widespread as MPB, but the analysis does indicate several areas where the two damage agents overlap. Areas infested by the Douglas-fir beetle and SB were isolated, but in many cases both damage agents occurred in the same areas. The Douglas-fir beetle and SB have caused high mortality in the Bitterroot and Absaroka Mountains. Subalpine fir mortality and Douglas-fir beetle had isolated epicenters in the Bighorn Mountains in the southwest portion of the ecoregion.

4.2 EXPECTED FOREST MORTALITY OVER THE NEXT 5 YEARS

The other main objective of the FMAR was to identify areas of anticipated mortality over the next 5 years. More specifically, the goal was to identify areas adjacent to existing mortality where future mortality has a greater chance of occurring. To achieve this, a simple crosswalk was completed (Table 3-1) to map areas adjacent to current high mortality. In order to map areas of low future risk over the next 5 years, the crosswalk also included those areas not currently infested.

As expected, future MPB-caused mortality over the next 5 years will be widespread. Areas in the Belt and Elkhorn Mountains near Helena show a very high potential for future mortality. It appears MPB-caused mortality has peaked in the southern Lemhi Mountains, but forests in the northern areas of the Salmon and Challis show a likelihood of future mortality. Other areas likely to see high future mortality due the MPB are in the forested mountain ranges southeast of Yellowstone National Park. The majority of the Black Hills displays low to moderate risk, with isolated areas at high risk of mortality over the next 5 years. However, when looking at ADS-mapped MPB outbreaks over the past 10 years, mortality in the Black Hills could be much more severe. In addition, the ADS data were only available to 2010; thus some of the expected mortality may already be occurring. Based on recent insect outbreaks and the predicted increase in temperatures, it is likely that the trend of severe MPB outbreaks will continue to occur.

Future WSBW-caused mortality could potentially be high throughout central portions of the Middle Rockies. Areas within the Big Belt and Crazy Ranges show a high potential for mortality due to the WSBW. Other areas of high mortality are a little more isolated, with much of the ecoregion displaying low-moderate potential for future mortality.

WPBR is currently responsible for a high percentage of whitebark pine mortality in the Middle Rockies. However, because it usually takes the infected host tree a long time to die, the majority of the ecoregion is classified as having only a moderate risk of mortality over the next 5 years. WPBR is still a major threat because it shares the same host trees as the MPB. Thus, most whitebark pines in the Middle Rockies have a high chance of mortality in the future.

Analyses show a mainly low to moderate risk for future mortality caused by Douglas-fir beetle, SB, and subalpine fir mortality, and areas at risk are isolated in the ecoregion. However, areas at risk of future mortality include areas in the Bighorn Range. Other areas with future mortality potential are small and more isolated in areas of the Absaroka and Teton Ranges.

4.3 VULNERABILITY OF MAJOR TREE SPECIES TO CLIMATE CHANGE OVER NEXT 50 YEARS

It remains difficult to draw conclusions from the climate change data presented in this analysis. Climate change models are highly variable and often difficult to predict. In this case, the resolution of the spatial data is an important factor to consider.

Widespread temperature increases (1.9 to 2.4°C) are expected across the entire Middle Rockies for the 2050-2069 time period. The predicted seasonal changes indicate many of the mountain ranges and higher elevations could see an increase in temperature that could affect the freeze/thaw cycles, specifically in the Wind River and Bighorn Ranges. The increased temperatures could also increase evapotranspiration rates, affecting plant growth by reducing water content to dead vegetation.

There is significant potential for increased mortality due to disease and insect infestation in susceptible areas. Increasing temperatures due to climate change allow more time for the MBP to complete its life cycle, which allows populations to grow more quickly than in the past (Bentz et al. 2010). Based on the current trends of increased outbreaks associated with increased temperatures, it is assumed that there will be a higher population of MPB in the Middle Rockies. The combination of dry, dead vegetation and increased forest mortality could provide more flammable materials for wildfires.

5.0 REFERENCES

Bartos, D.L. and R.B. Campbell. 1998. Decline of quaking aspen in the interior west – examples from Utah. Rangelands 20(1):17-24.

Bentz, B.J., J. Regniere, C.J. Fettig, E.M. Hansen, J.L Hayes, J.A. Hicke, R.G. Kelsey, J.F. Negron, and S.J. Seybold. 2010. Climate change and bark beetles of the western United States and Canada: direct and indirect effects. Bioscience 60:602-613.

Burns, K.S., A.W. Schoettle, W.R. Jacobi, and M.F. Mahalovich. 2008. Options for the management of white pine blister rust in the Rocky Mountain region. General Technical Report RMRS-GTE-206. U.S.D.A. Forest Service, Rocky Mountain Research Station. March, 2008.

Daly, C., and G. Johnson. 2008. Climate mapping with PRISM. Oregon State University. Corvalis, OR

Daly, C., M.D. Halbleib, J.L. Smith, W.P. Gibson, M.K. Doggett, and D. Ojima. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the coterminous United States. International Journal of Climatology. DOI:10.1002/joc.1688.

Daly, C., D.R. Conklin, and M.H. Unsworth. 2009. Local atmospheric decoupling in complex topography alters climate change impacts. International Journal of Climatology. DOI:10.1002/joc.2007.

Eyre, F.H. 1980. Forest cover types of the United States and Canada. Society of American foresters. Washington, D.C.

Fairweather, M., G. Geils, M. Manthei. 2008. Aspen decline on the Coconino National Forest. In: M. McWilliaams, editor. Proceedings of the 55th Western International Forest Disease work conference. Sedona, AZ. 2008.

Geils, B.W., K.E. Hummer, and R.S. Hunt. 2010. White pines, *Ribes*, and blister rust: a review and synthesis. Forest Pathology. 40:147-185.

Guyon, J. and J. Hoffman. 2011. Survey of aspen disease in the Intermountain Region. USDA Forest Service. Forest Health Protection. State and Private Forestry. Intermountain Region.

Hagle, S.K., K.E. Gibson, and S. Tunnock. 2003. Field guide to diseases and insects pests of northern and central Rocky Mountain conifers. Report No. R1-03-08. USDA Forest Service, State and Private Forestry. Northern Region. Missoula, MT. Intermountain Region. Ogden Utah.

Hogg, E.H., J.P. Brandt, and M. Michaelian. 2008. Impact of regional drought on the productivity, dieback, and biomass of western aspen forests. Canadian Journal of Forest Research 1373-1384.

Idaho Lands. 2009. Idaho State Assessment of Forest Resources (SAFR). Issues, discussion, data, methodologist, and maps. Idaho Department of Lands. Multi-agency Core Assessment Team.

Jean, C., E. Shanahan, R. Daley, G. DeNitto, D. Reinhart, C. Schwartz. 2011. Monitoring white pine blister rust infection and mortality in whitebark pine in the Greater Yellowstone Ecosystem. In R. E. Keane, D. F. Tomback, M.P. Murray and C. Smith, M. [eds.], The future of high-elevation, five needle white pines in Western North America: proceedings of the high five symposium. 28-30 June 2010, 2011, Missoula, MT. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. RMRS-P-63. 376 pp.

Jenkins, M.J., E. Hebertson, W. Page, and C.A. Jorgensen. 2008. Bark beetles, fuels, fires and implications for forest management in the Intermountain West. Forest Ecology and Management 254:16-34.

Idaho Department of Lands. 2009. Forest Health Highlights. Idaho Department of Lands and USDA Forest Service. Forest Health Protection. http://www.idl.idaho.gov/bureau/ForestAssist/forest_health/fh-highlights-2009.PDF

Idaho Department of Lands. 2010. Forest Health Highlights. Idaho Department of Lands and USDA Forest Service. Forest Health Protection.

Johnson, Eric. 2012. *Aerial Detection Survey: Fact Sheet*. USDA Forest Service, Rocky Mountain Region, Fort Collins, CO. Accessed from http://www.fs.usda.gov/detail/r2/forest-grasslandhealth/?cid=fsbdev3_041634 on June 20, 2012.

Kaufman, M.R. G.H. Aplet, M. Babler, W.L. Baker, b. Bentz, M. Harrington, B.C. Hawkes, L. Stroh Huckaby, M.J. Jenkins, D.M. Kashian, R.E. Keane, D. Kulakowski, C. McHugh, J. Negron, J. Popp, W.H. Romme, T. Schoennagel, W. Shepperd, F.W. Smith, E. Kennedy Sutherland, D. Tinker, and T.T. Veblen. 2008. The status of our scientific understanding of lodgepole pine and mountain pine beetles – a focus on forest ecology and fire behavior. The Nature Conservancy, Arlington, VA. GFI technical report 2008-2.

Keane, R.D. 2000. The importance of wilderness to whitebark pine research and management. USDA Forest Service Proceedings RMRS –P-15-VOL-3.

Kearns, H.S.J., and W.R. Jacobi. 2007. The distribution and incidence of white pine blister rust in central and southeastern Wyoming and northern Colorado. Canadian Journal of Forest Research 37:462-472.

Kendall, K.C., D. Ayers, and D. Schirokauer. 1996. Limber poine status from Alberta to Wyoming. Nutcracker Notes 7:23-24. USDA Forest Service, Intermountain Research Station, IFSL. Missoula, MT.

King, J.N.; David, A.; Noshad, D.; Smith, J., 2010: A review of genetic approaches to the management of blister rust in white pines. For. Pathol. 40, 292–313.

Koteen, L. 2002. Climate change, whitebark pine, and grizzly bears in the Greater Yellowstone Ecosystem. In: Schneider, S.H., and T.L. Root, (eds.), Wildlife Responses to Climate Change: North American Case Studies. Island Press, Washington, D.C., U.S.A., pp. 343-414.

Larson, E.R., Kipfmueller, K.F., 2010. Patterns in whitebark pine regeneration and their relationships to biophysical site characteristics in southwest Montana, central Idaho, and Oregon, USA. Can. J. For. Res. 40, 476–487.

Livingston, R.L., J.E. Dewey, D.P. Beckman, L.E. Stipe. 2000. Distribution of the balsam woolly adelgid in Idaho. Western Journal of Applied Forestry 15(4):227-231.

Logan, J. A., and J. A. Powell. 2009. Ecological consequences of forest-insect disturbance altered by climate change. Pages 98–109 in F. H. Wagner, editor. Climate warming in western North America. University of Utah Press, Salt Lake City, Utah, USA.

Logan, J.A., W.F. Macfarlane, and L. Wilcox. 2010. Whitebark pine vulnerability to climate-driven mountain pine beetle disturbance in the Greater Yellowstone ecosystem. Ecological Applications 20:895-902.

Logan and Schoenagle 2010, email message to author, October 19, 2010.

Lundquist, J.E., B.W. Geils, and D.W. Johnson. 1992. First report of white pine blister rust on limber pine in South Dakota. Plant Dis 76:538.

McKinney, S.T. and D.F. Tomback. 2007. The influence of white pine blister rust on seed dispersal in whitebark pine. Canadian Journal of Forestry 37:1044-1057.

Means, R.E. 2010. Synthesis of lower treeline limber pine (*Pinus flexilis*) woodland knowledge, research needs, and management considerations. Oral presentation with forthcoming proceedings. High-Five Symposium: the future of high-elevation five-needle white pines in western North America. June 28-30. Missoula, MT.

Means, Robert E. 2011. Synthesis of Lower Treeline Limber Pine (*Pinus flexilis*) Woodland Knowledge, Research Needs, and Management Considerations. In: Keane, Robert e.; Tomback, Diana F.; Murray, Michael P.; smith, Cyndi M. eds. 2011. The future of high-elevation five-needle white pine in Western North America: Proceedings of the High Five Symposium 28-30 June, 2010.

Missoula, MT Proceedings RMRS-P-63. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain research Station. P 29-36.

Montana DNRC and USDA Forest Service & USDA Forest Service (Montana Department of Natural Resources & Conservation and USDA Forest Service). 2010. Montana's State Assessment of Forest Resources. Base Findings & GIS Methodology. Montana Department of Natural Resources and Conservation and USDA Forest Service, Northern Region, State and Private Forestry, Forest Health Protection. Missoula, MT.

Montana DNRC. 2009. Montana Forest Health Highlights. Montana Department of Natural Resources and Conservation and USDA Forest Service. Forest Health Protection. Website.

Montana DNRC. 2010. Montana Forest Health Highlights. Montana Department of Natural Resources and Conservation and USDA Forest Service. Forest Health Protection. Website.

O'Brien, M. P. Rodgers, K. Mueller, R. McWhorter, A. Rowley, B. Hopkin, B. Christensen, P. Demman. 2010. Guidelines for aspen restoration on the national Forests in Utah. Utah Forest Restporation Working Group – Ecology Committee. Western Aspen Alliance. Utah State University, Logan, UT.

Powell, J.A., and B.J. Bentz. 2009. Connecting phenological predictions with population growth rates for mountain pine beetle, an outbreak insect. Landscape Ecology. 24:657-672.

Powell, J.A., and J.A. Logan. 2005. Insect seasonality: circle map analysis of temperature-driven life cycles. Theoretical Population Biology 67:161–179.

Raffa, K.F., B.H. Aukema, B.J. Benz, A.L. Carroll, J.A. Hicke, M.G. Turner, and W.H. Romme. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. Bioscience 58:501-517.

Rehfeldt, G.E., D.E.Ferguson, and N.L. Crookston. 2009. Aspen, climate, and sudden decline in western USA. Forest Ecology and management 258:2353-2364.

Resler, L.M. and D.F. Tomback. 2008. Blister rust prevalence in krummholz whitebark pine: implications for treeline dynamics, northern Rocky Mountains, Montana, U.S.A. Arctic, Antarctic, and Alpine Research 40:161-170.

Samman, S. J. Logan. 2000. Assessment and response to bark beetle outbreaks in the Rocky Mountain area. Report to Congress from Forest Health Protection, Washington Office, Forest Service, USDA. General Technical Report RMRS-GTR-62. Ogden, UT.

Tania Schoenagle, email message to author, August 23, 2010.

Schuster, W.S., J.B. Minton, D.K. Yamaguchi, and C.A. Woodhouse. 1994. A comparison of limber pine (*Pinus flexilis*) ages at lower and upper treeline sites east of the continental divide in Colorado. American Midland Naturalist 133:101-111.

Schwandt, J.W. 2006. Whitebark pine in peril. A case for restoration. USDA Forest Service. R1-06-28.

Smith, J. and Hoffman, J. 1998. Status of white pine blister rust in Intermountain Region white pines. USDA Forest Service, Intermountain Region, Report No. R4-98-02.

St. Clair, S.B., J. Guyon, J. Donaldson. 2010. Quaking aspen's cuirrent and future status in western North America: the role of succession, climate, biotic agents and its clonal nature. Progress in Botany:71:371-400.

Steed, B.E. and H.S.J. Kearns. 2010. Damage agents and condition of mature aspen stands in the Northern Region. USDA Forest Service. Forest Health Protection Numbered Report 10-3.

Taylor, J.E. and Schwandt, J.W. 1998. Dothistroma needle blight on limber pine in Montana. USDA Forest Service, Northern Region, Rep. 98-4.

Tomback, D.F. and P. Achuff. 2010. Blister rust western forest biodiversity: ecology, values and outlook for white pines. Forest Pathology 40:186-225.

Tomback, D.F. and L.M. Resler. 2007. Invasive pathogens at alpine treeline: consequences for treeline dynamics. Physical Geography 28:397-418.

USDA Forest Service. 2005. Insect and Disease report. PNW. Accessed Online.

USDA Forest Service. 2010. Field guide to diseases and insects of the Rocky Mountain Region. Forest Health Protection, Rocky Mountain Research Station. General Technical Report RMRS-GTR-241. Fort Collins, CO.

USDA Forest Service. 1990. Silvics of North America. Volume 1. Conifers. USDA Forest Service. Agriculture Handbook 654.

US Geological Survey, National Biological Information Infrastructure, Gap Analysis Program (GAP). February 2010. National Land Cover,Version 1, Available at http://www.gap.uidaho.edu/landcoverviewer.html (Accessed: October 2010).

Warwell, M.V., G.E. Rehfeldt, N.L. Crookston. 2007. Modeling contemporary climate profiles of whitebark pine (*Pinus albicaulis*) and predicting responses to global warming. Conference proceedings. Whitebark pine: a Pacific coast perspective. USDA Forest Service R6-NR-FHP-2007-01.

Worrrall, J.J., L. Egeland, T. Eager, R.A. Mask, E.W. Johnson, P.A. Kemp, W.D. Sheppard. 2008. Rapid mortality of *Populus tremuloides* in southwestern Colorado, USA. Forest Ecology and Management 255(3-4):686-696.

Worrall, J.J., S.B. Marchetti, L. Egeland, R.A. Mask, T. Eager, and B. Howell. 2010. Effects and etiology of sudden aspen decline in southwestern Colorado, USA. Forest Ecology and Management 260(5):638-648.

Woods Hole Research Center http://www.whrc.org/mapping/nbcd/indtemex.html.

6.0 LINKS TO FOREST INSECT AND DISEASE CONDITION REPORTS (AERIAL DIRECTION SURVEYS)

Idaho Forest Insect and Disease Conditions Report. 2004. Idaho Department of Lands and USDA Forest Service Northern & Intermountain Region. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/fsbdev3_015300.pdf

2010 Aerial Detection Survey Summary for Wyoming. Tables. USDA Forest Service Region 2 Montana Forest Insect and Disease Conditions and Program Highlights -2010. Compiled by Montana DNRC and USDA Forest Service R1. http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5275798.pdf

Harris, J.L. and R2 FHP staff. 2011. Forest Health conditions, 2009-2010, in (R2) Rocky Mountain region. USDA Forest Service. Renewable Resources, Forest Health Protection, R2-11-RO-31. 108 pp. https://fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5306176.pdf

THIS PAGE INTENTIONALLY LEFT BLANK

FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK

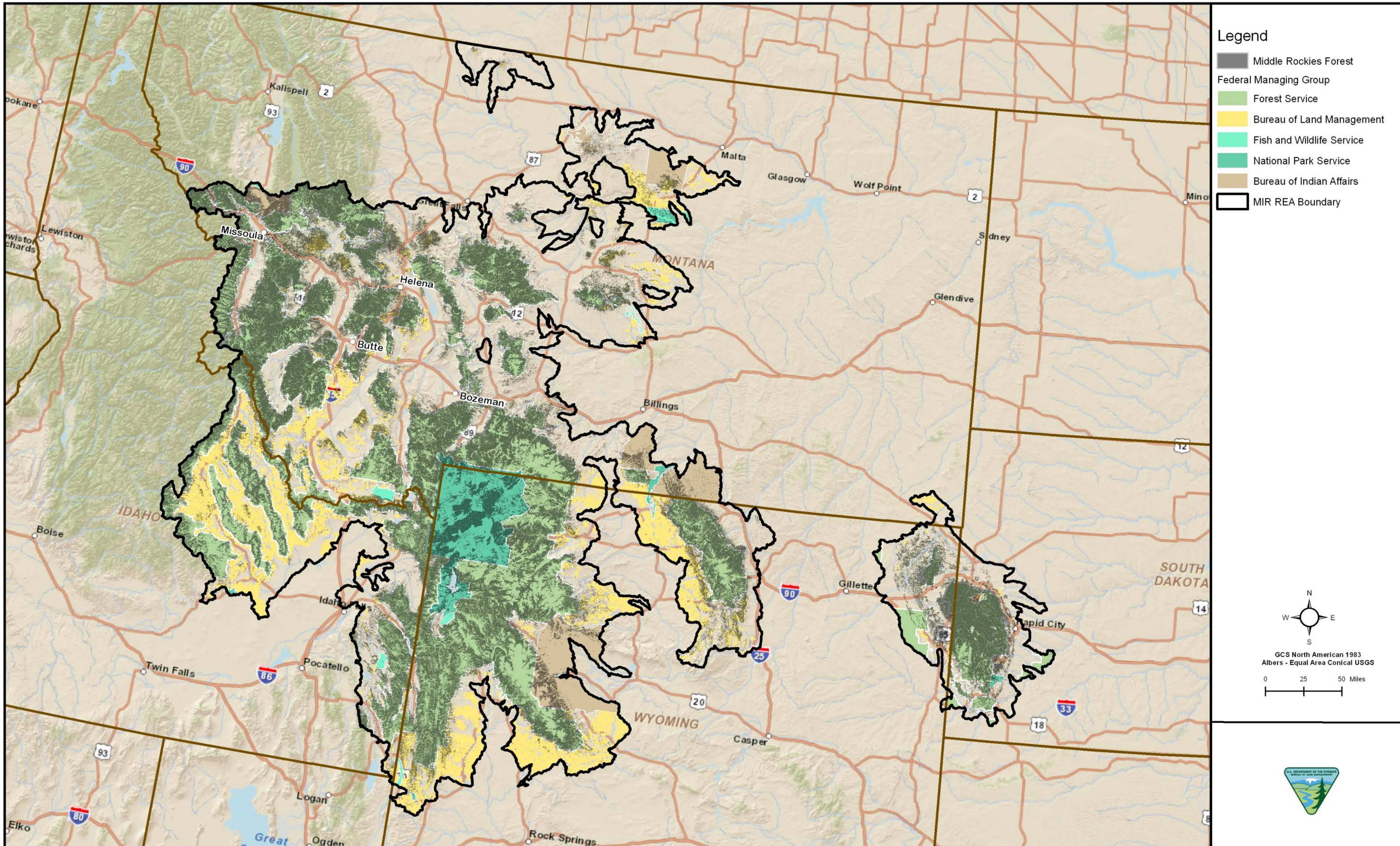


Figure 1-1. Middle Rockies on Major Federal Lands

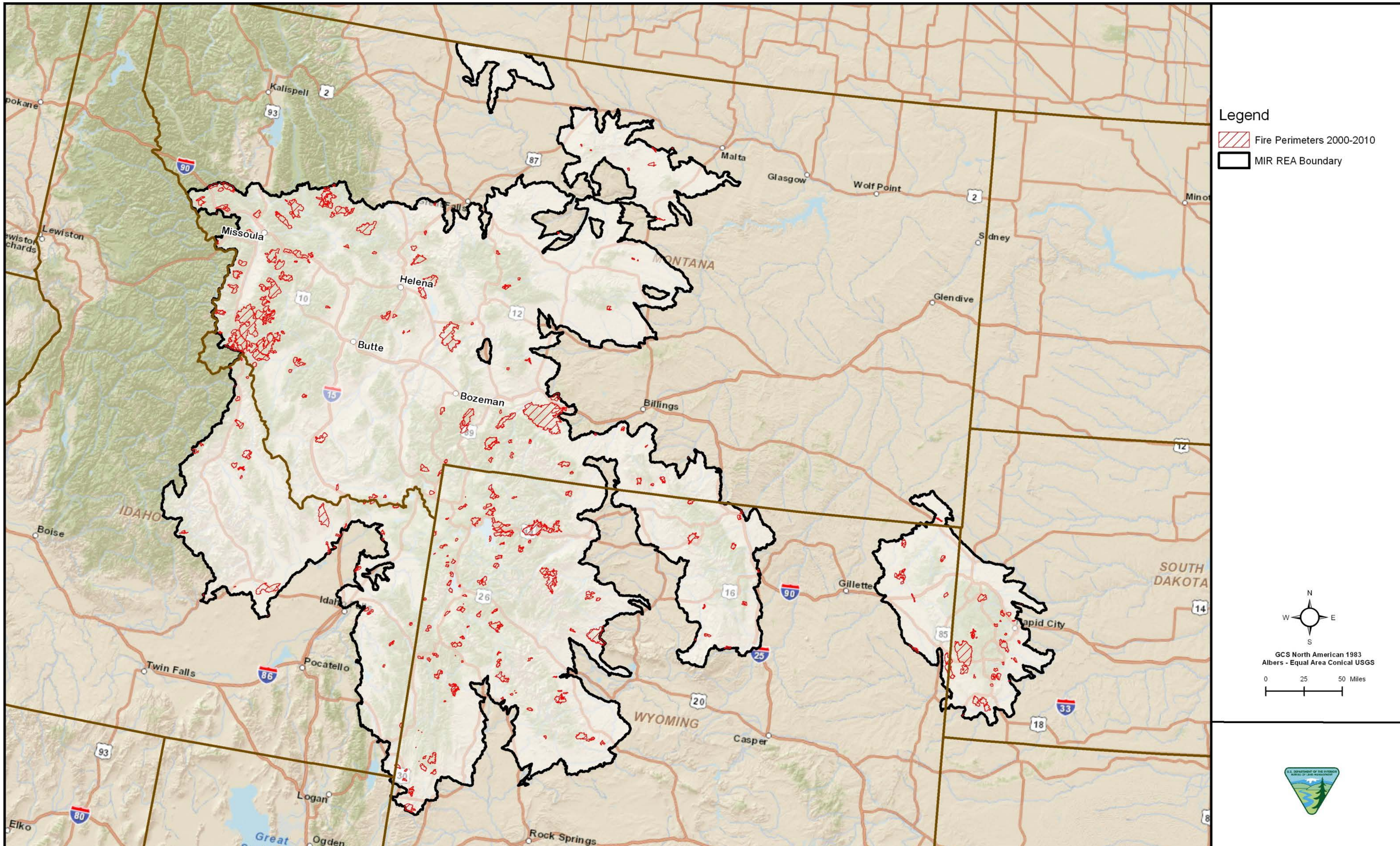


Figure 2-1. **MTBS Fire Perimeters 2000-2010**

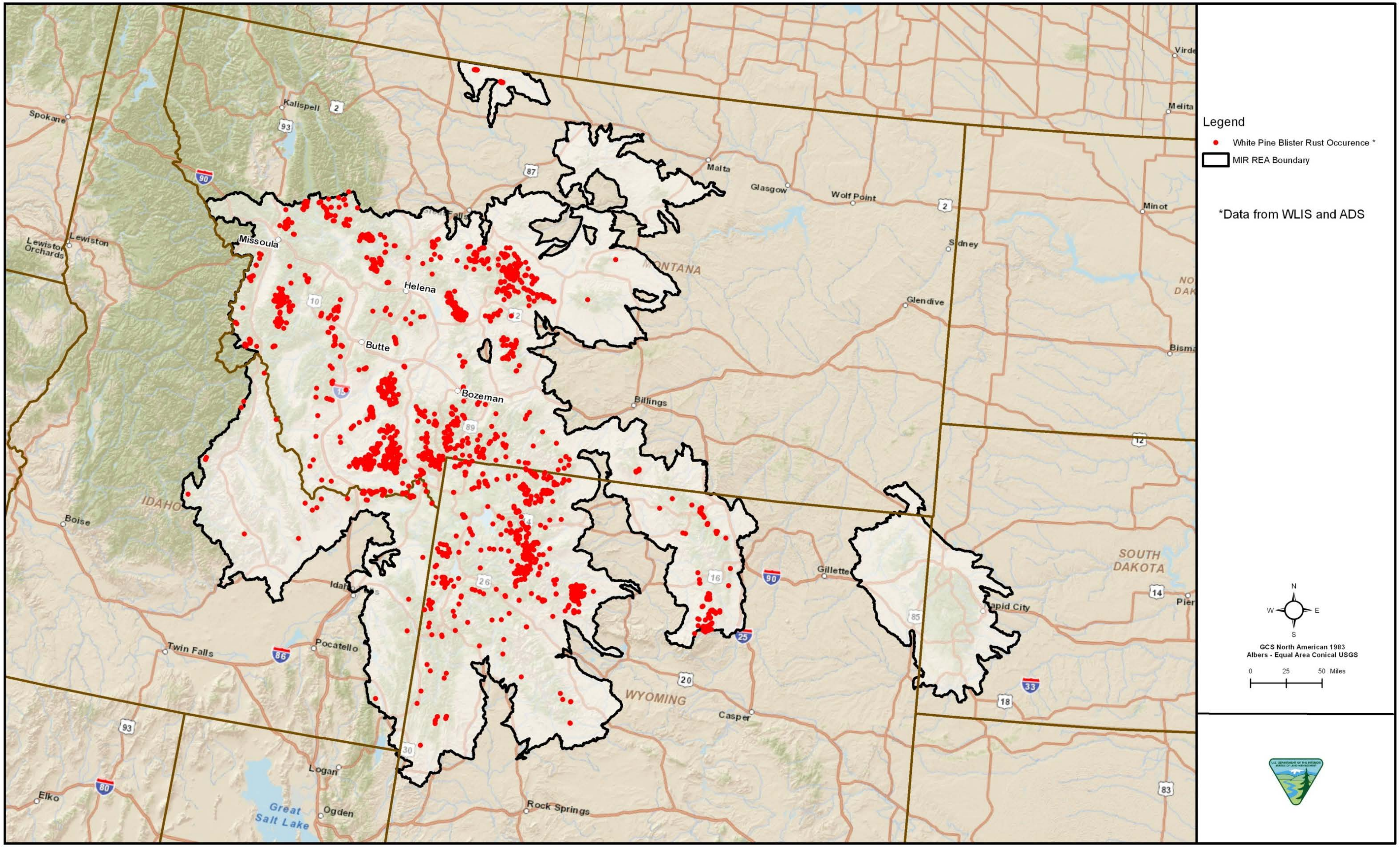


Figure 2-2. Middle Rockies White Pine Blister Rust Presence

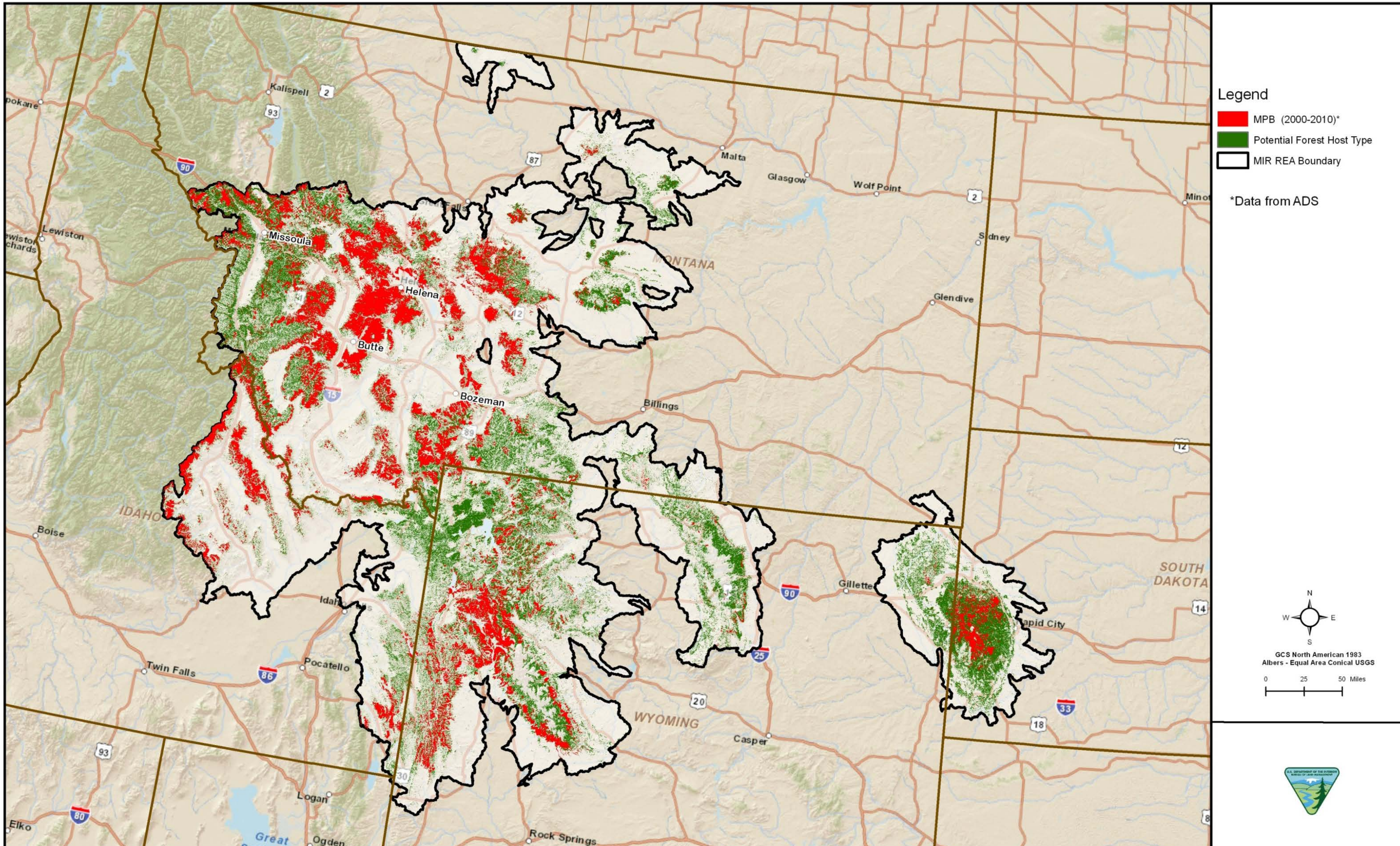


Figure 2-3. Middle Rockies Mountain Pine Beetle ADS Data 2000-2010

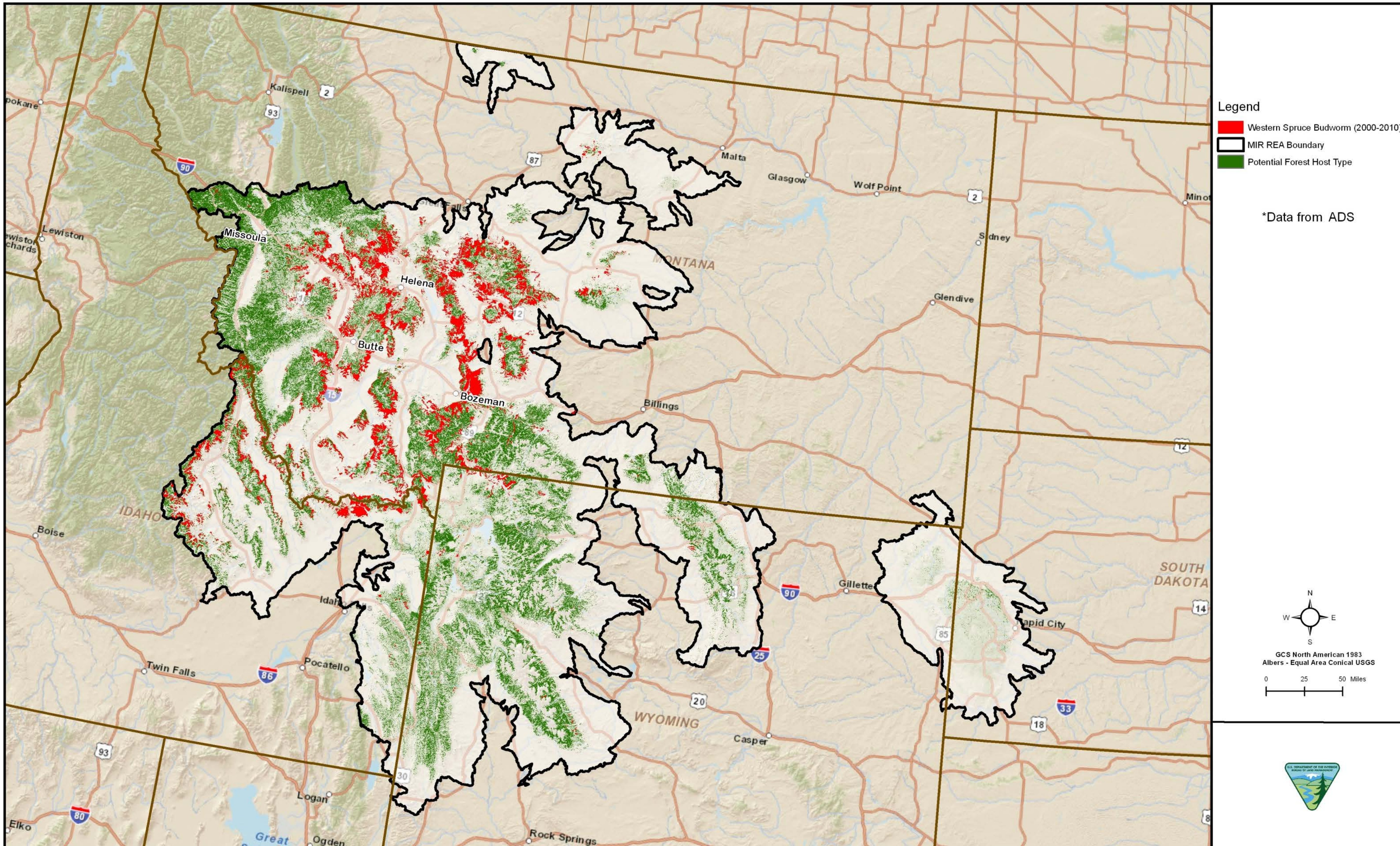


Figure 2-4. Western Spruce Budworm ADS Data 2000-2010

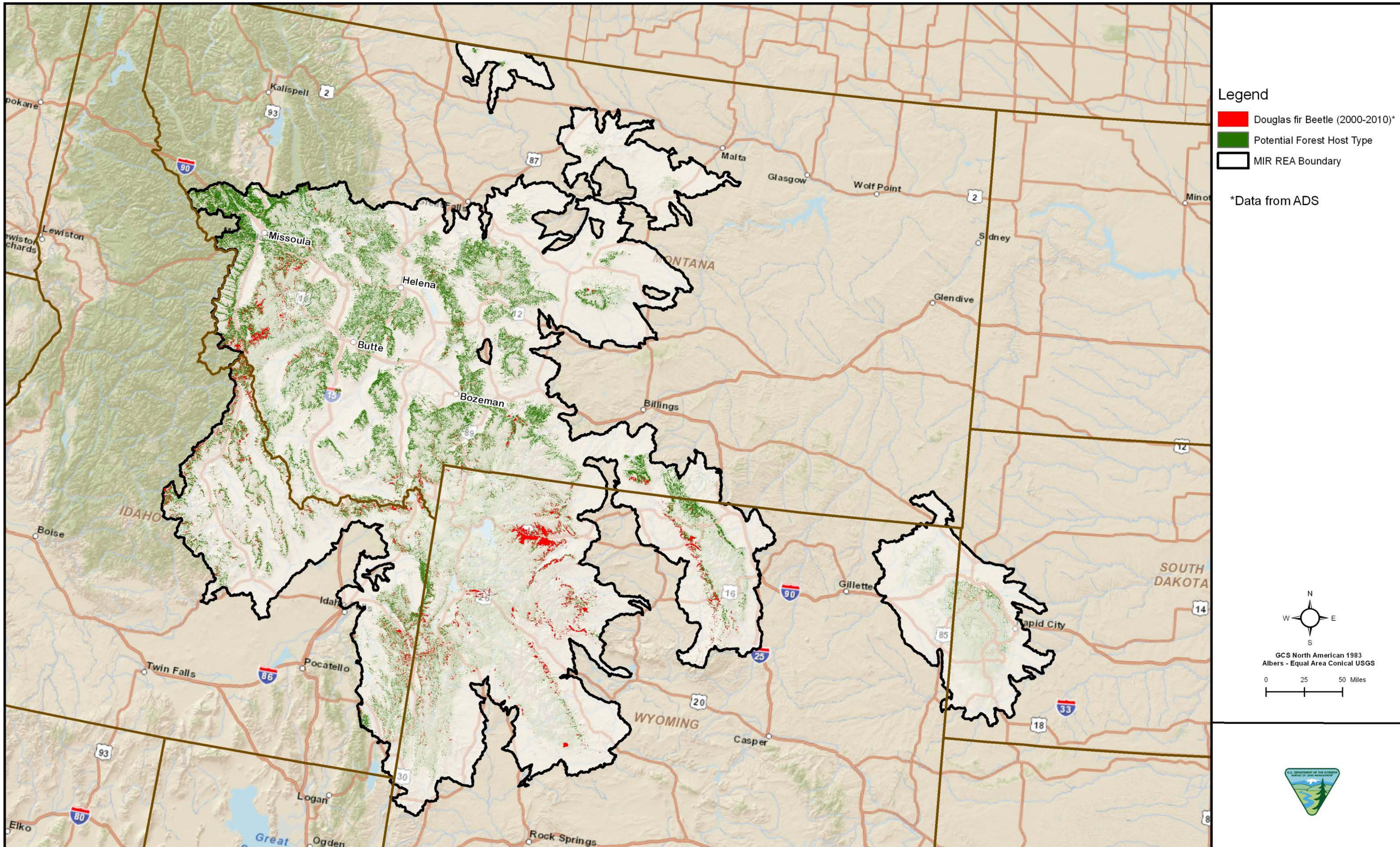


Figure 2-5. Douglas Fir Beetle ADS Data 2000-2010

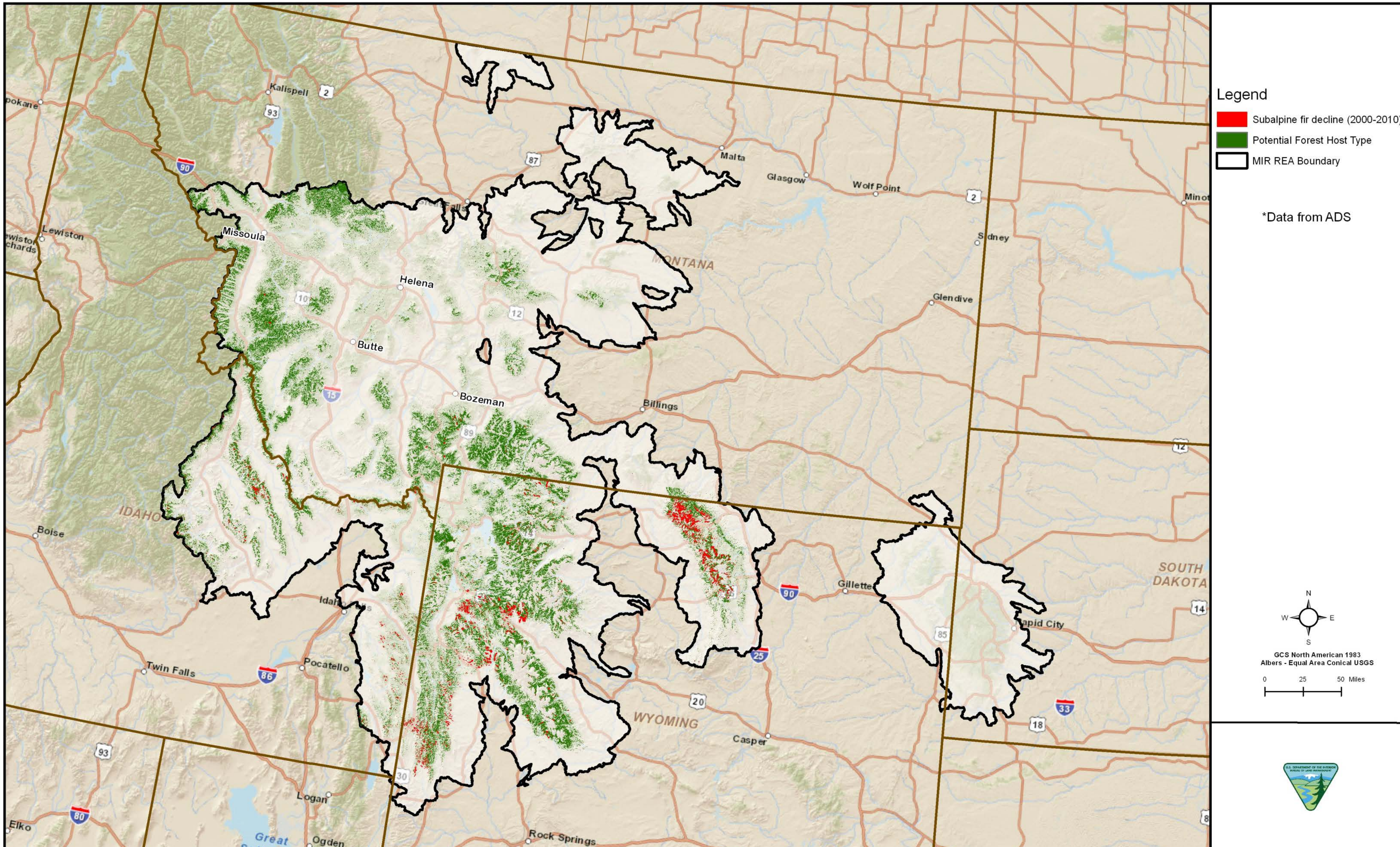


Figure 2-6. Subalpine Fir Decline ADS Data 2000-2010

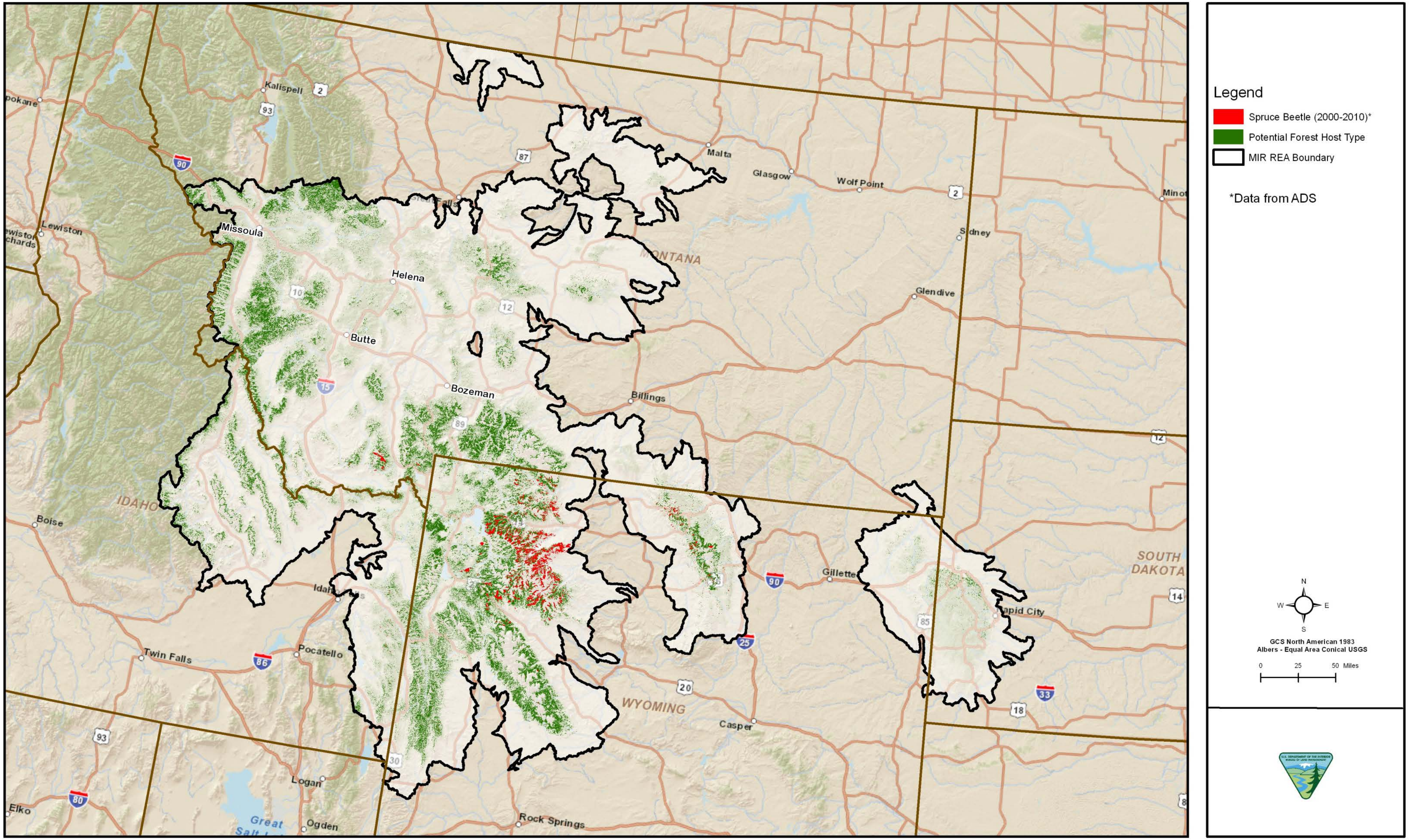


Figure 2-7. **Spruce Beetle ADS Data 2000-2010**

Source: Guyon and Hoffman 2011.

Figure 2-8. Aspen Decline Range in Western United States

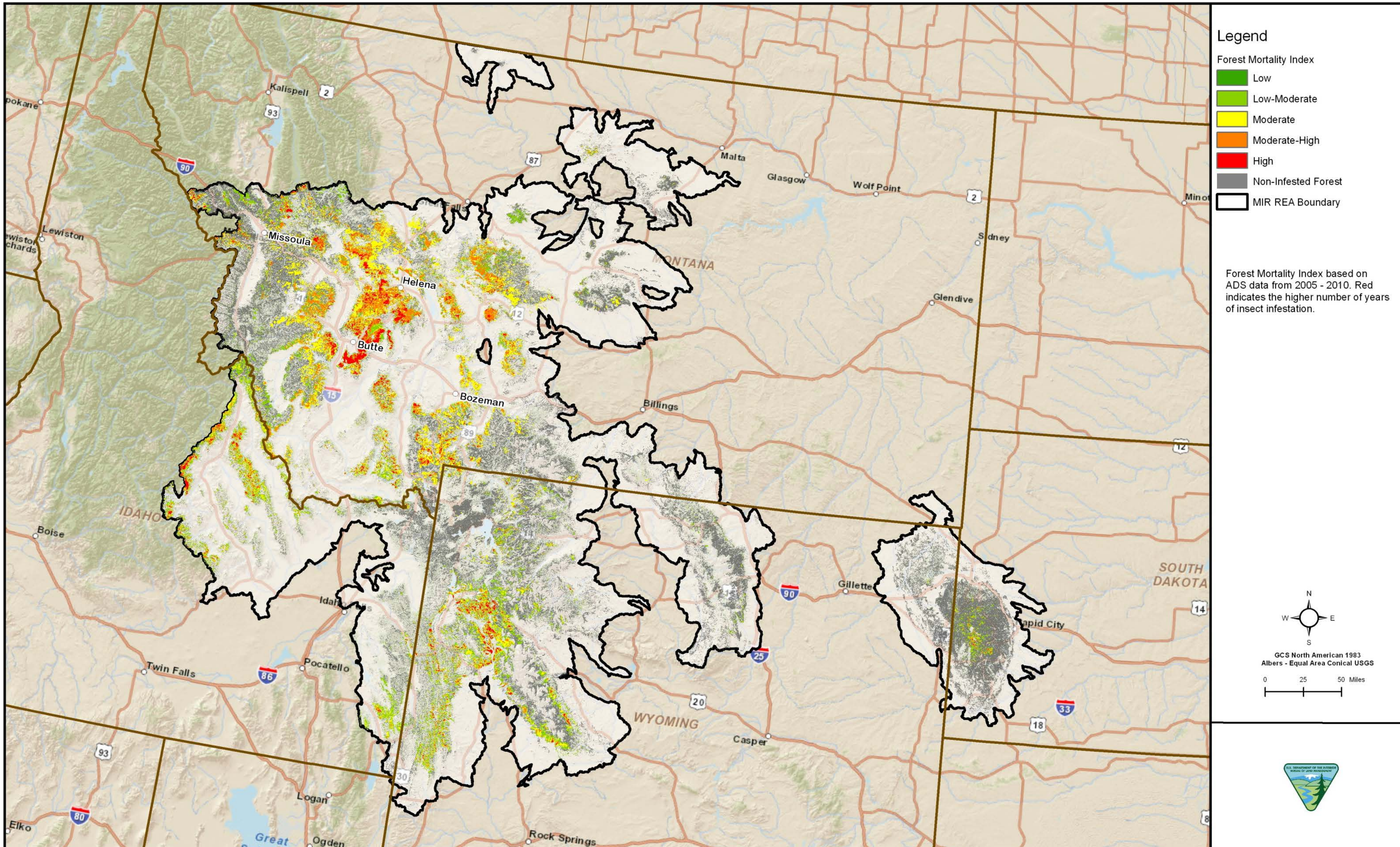


Figure 3-1. Mountain Pine Beetle Future Mortality Index 2000-2005

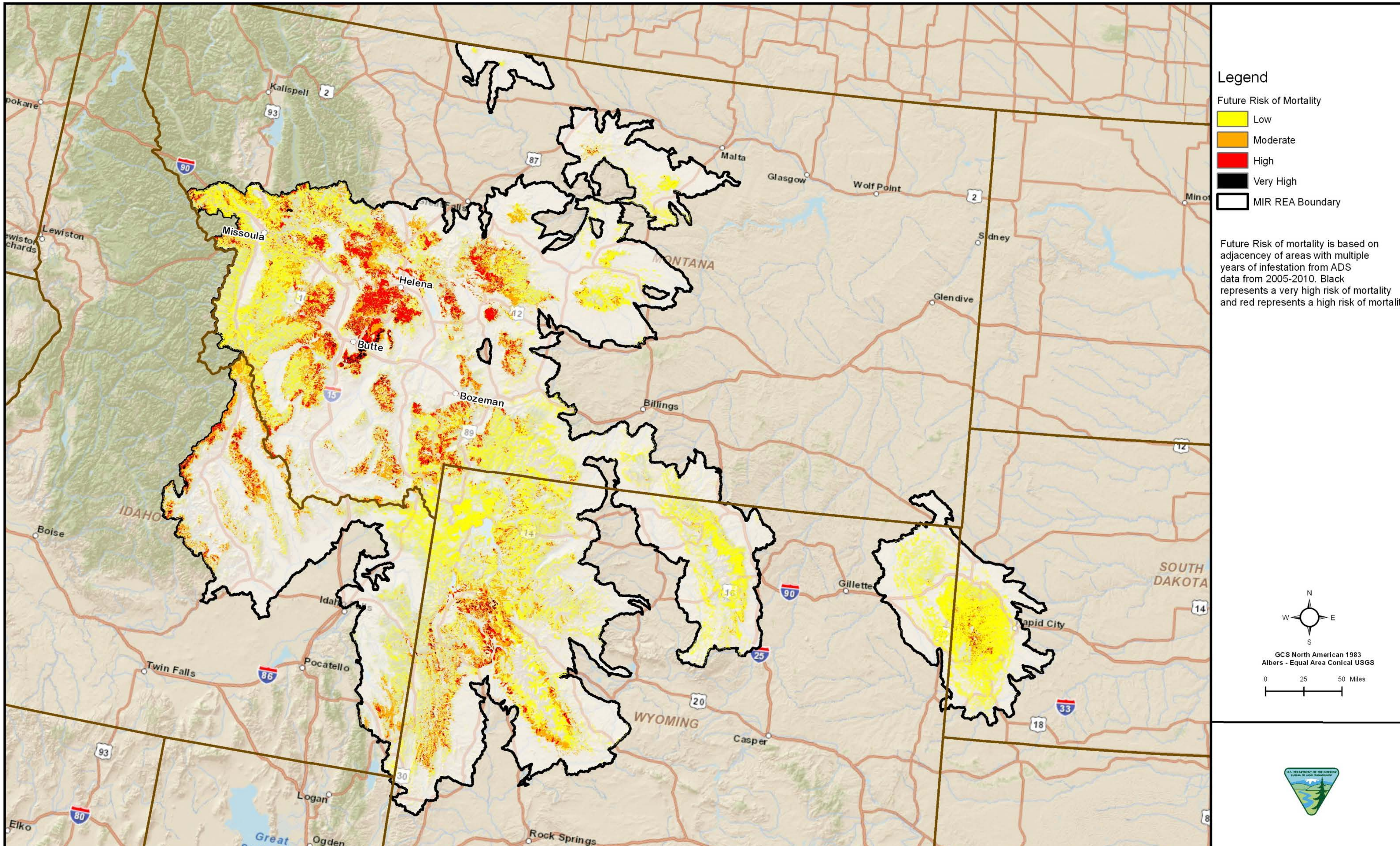


Figure 3-2. **Mountain Pine Beetle Future Risk (5 years)**

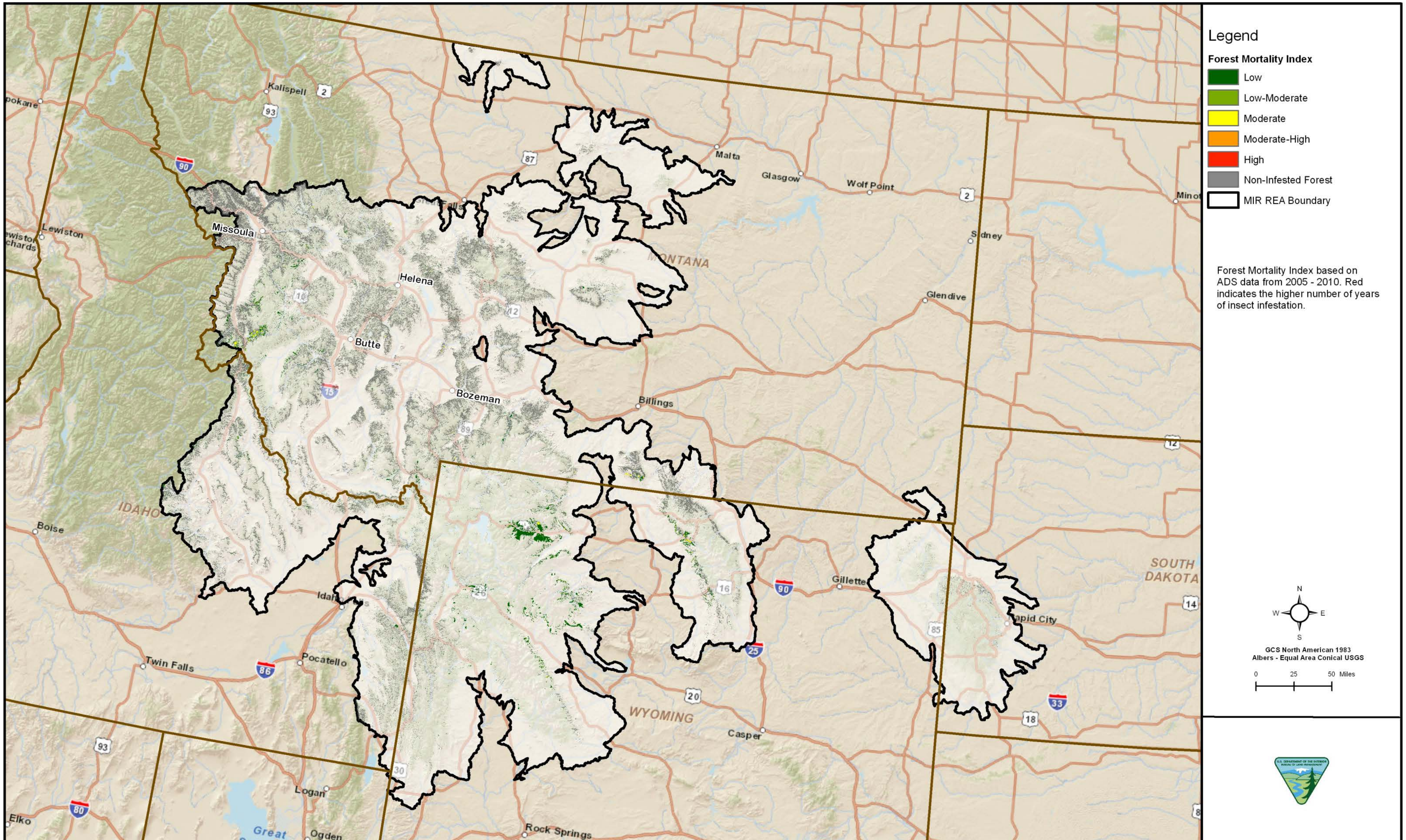


Figure 3-3. Douglas-Fir Forest Mortality Index 2000-2005

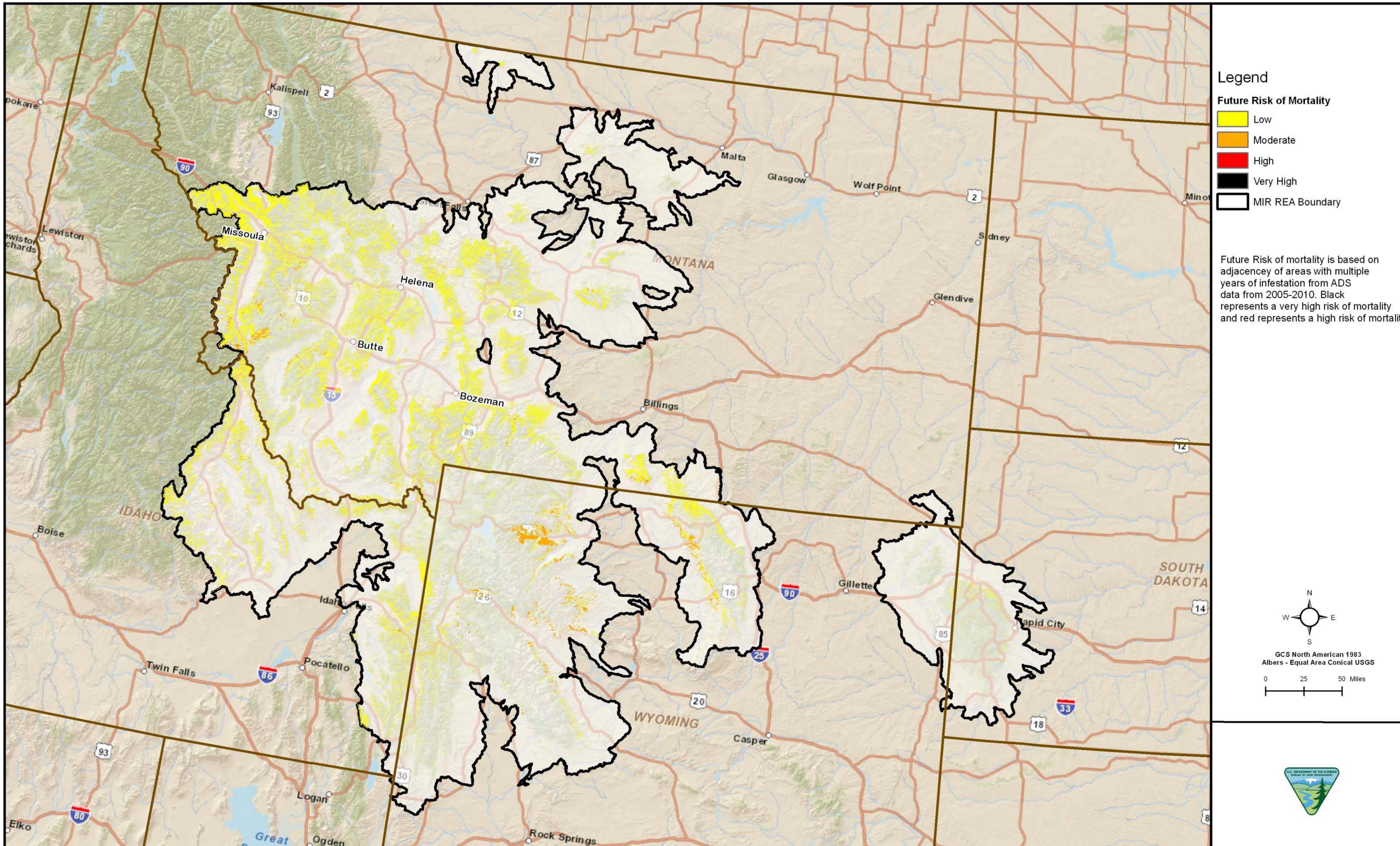


Figure 3-4. Douglas-Fir Future Risk (5 years)

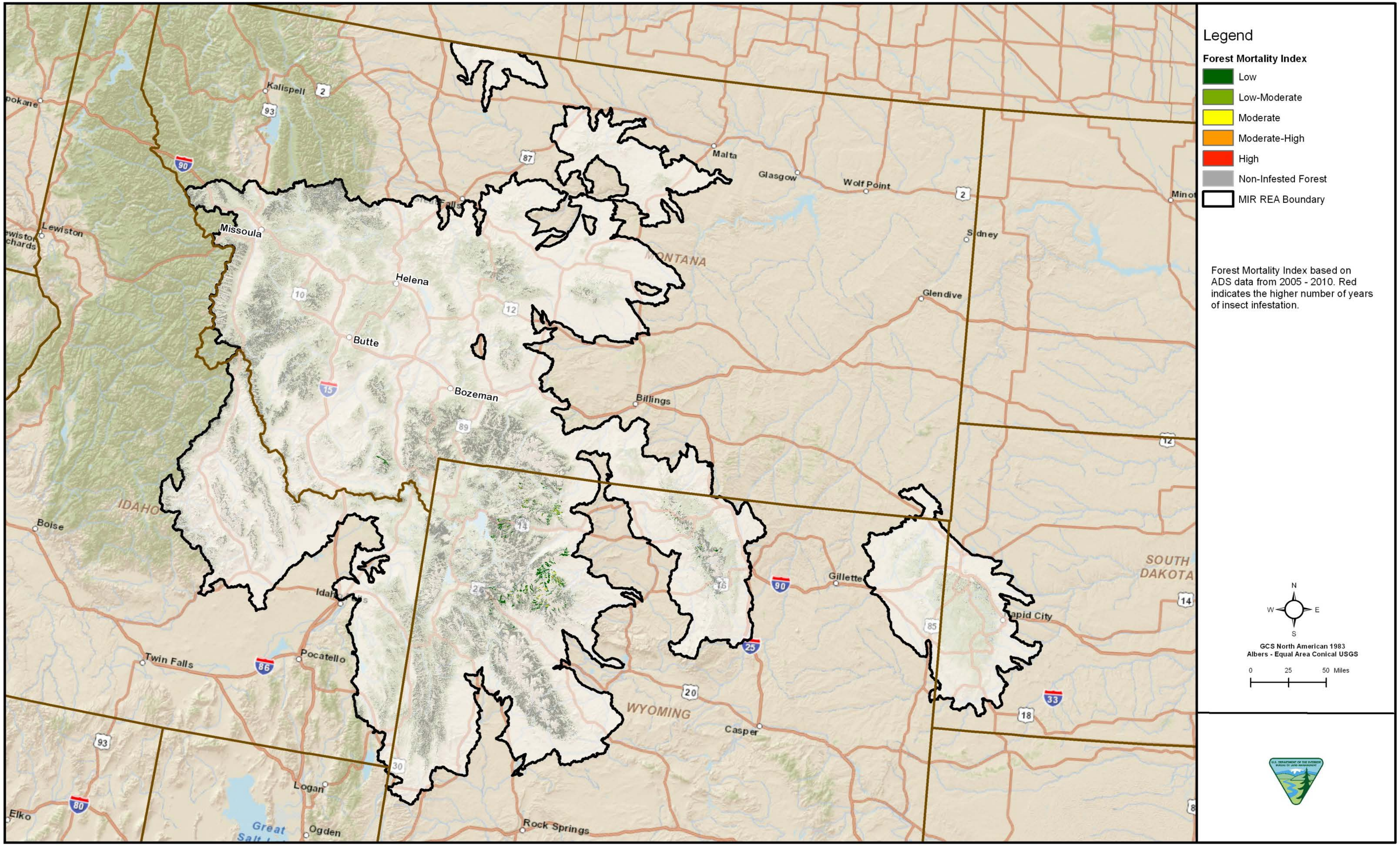


Figure 3-5. Spruce Beetle Forest Mortality Index 2000-2005

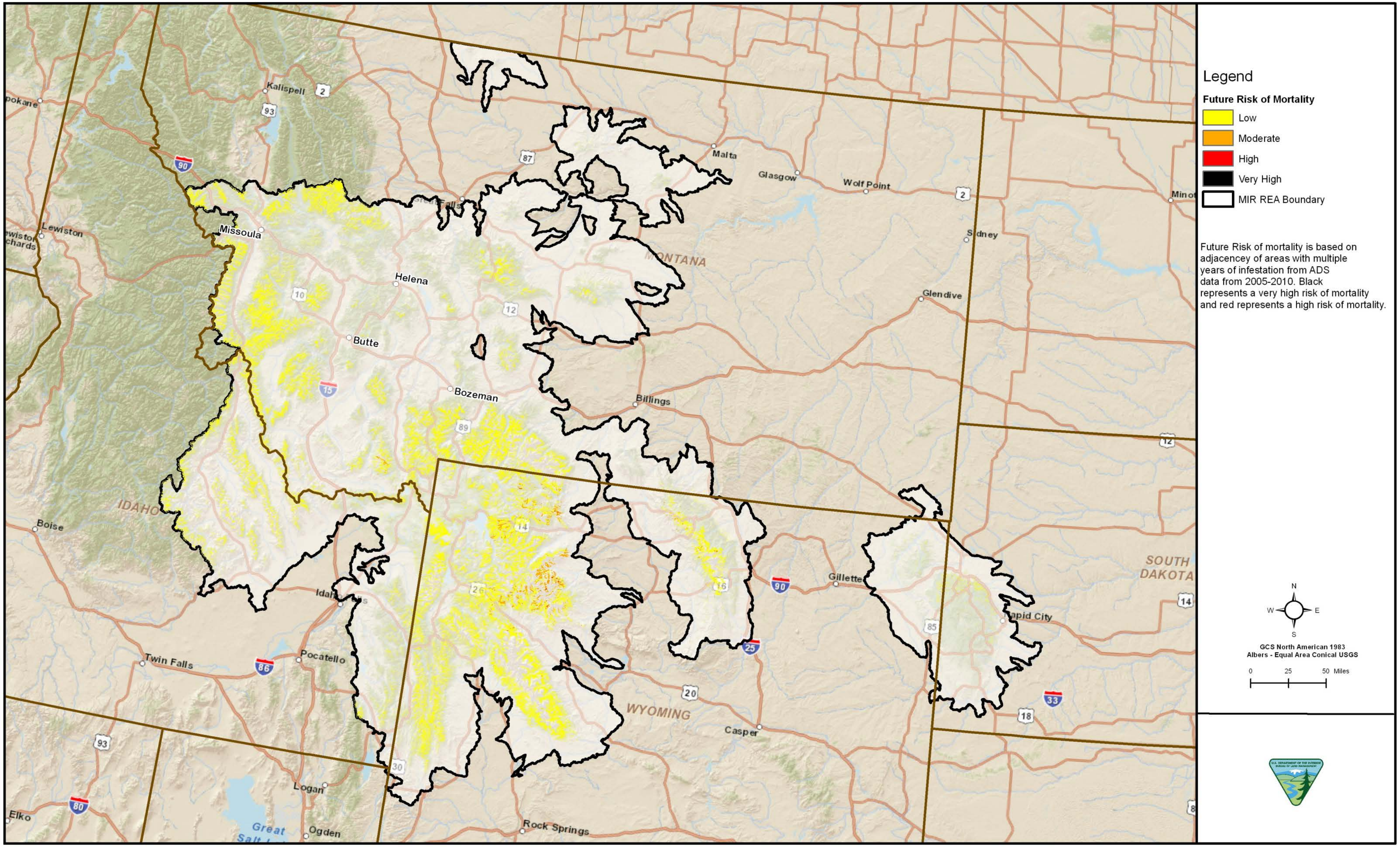


Figure 3-6. Spruce Beetle Future Risk (5 years)

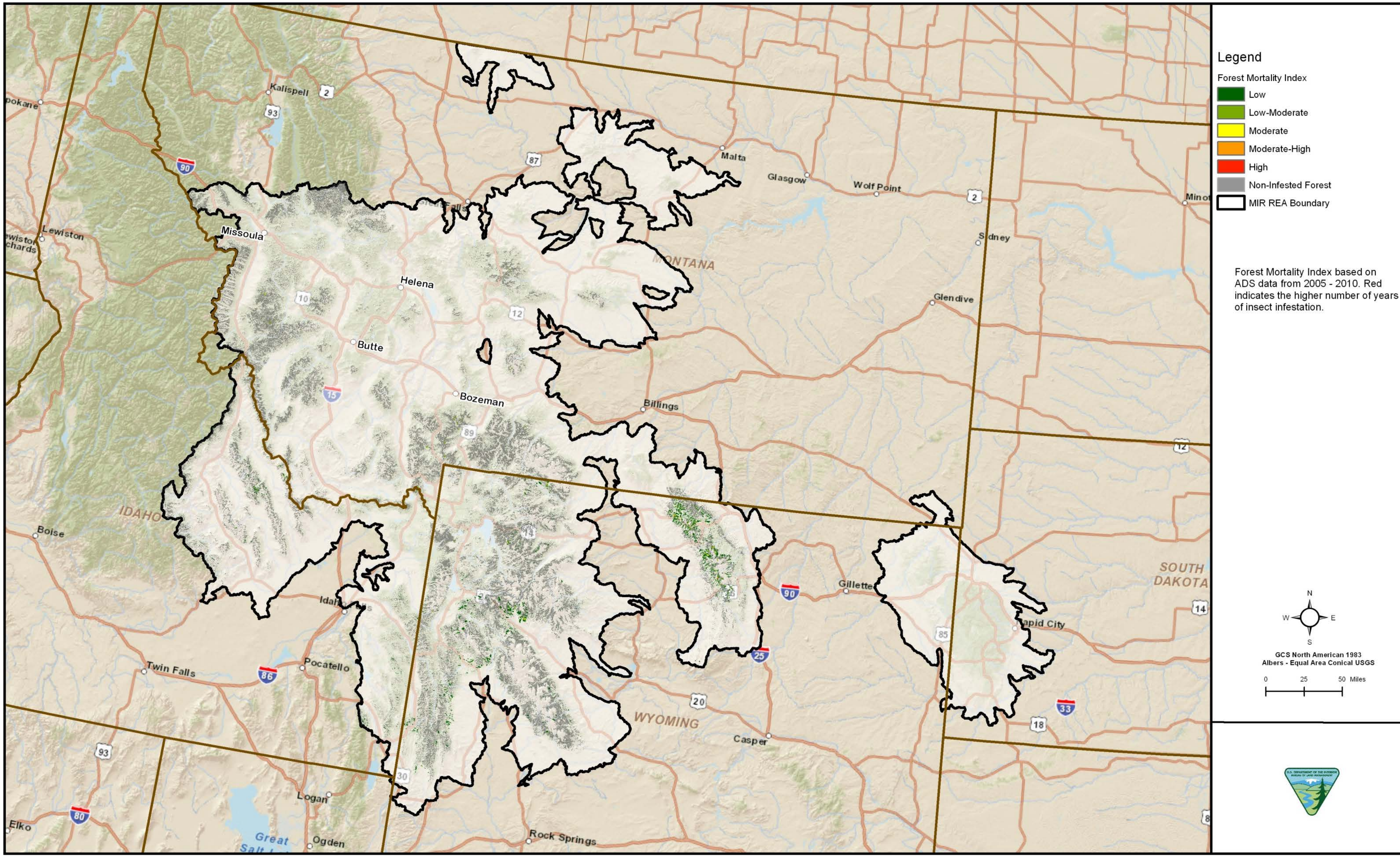


Figure 3-7. **Subalpine Fir Decline Forest Mortality Index 2000-2005**

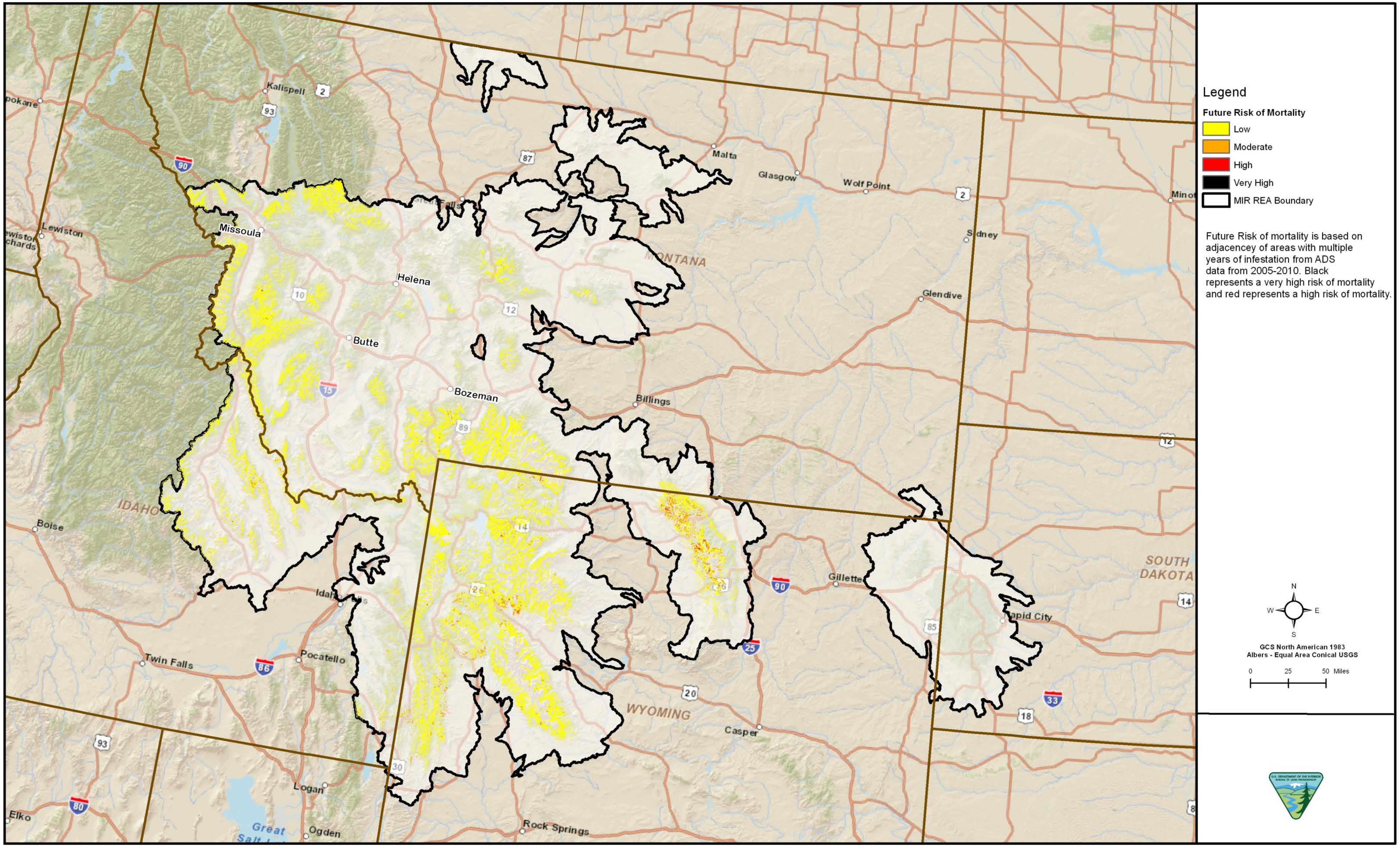


Figure 3-8. Subalpine Fir Decline Future Risk (5 years)

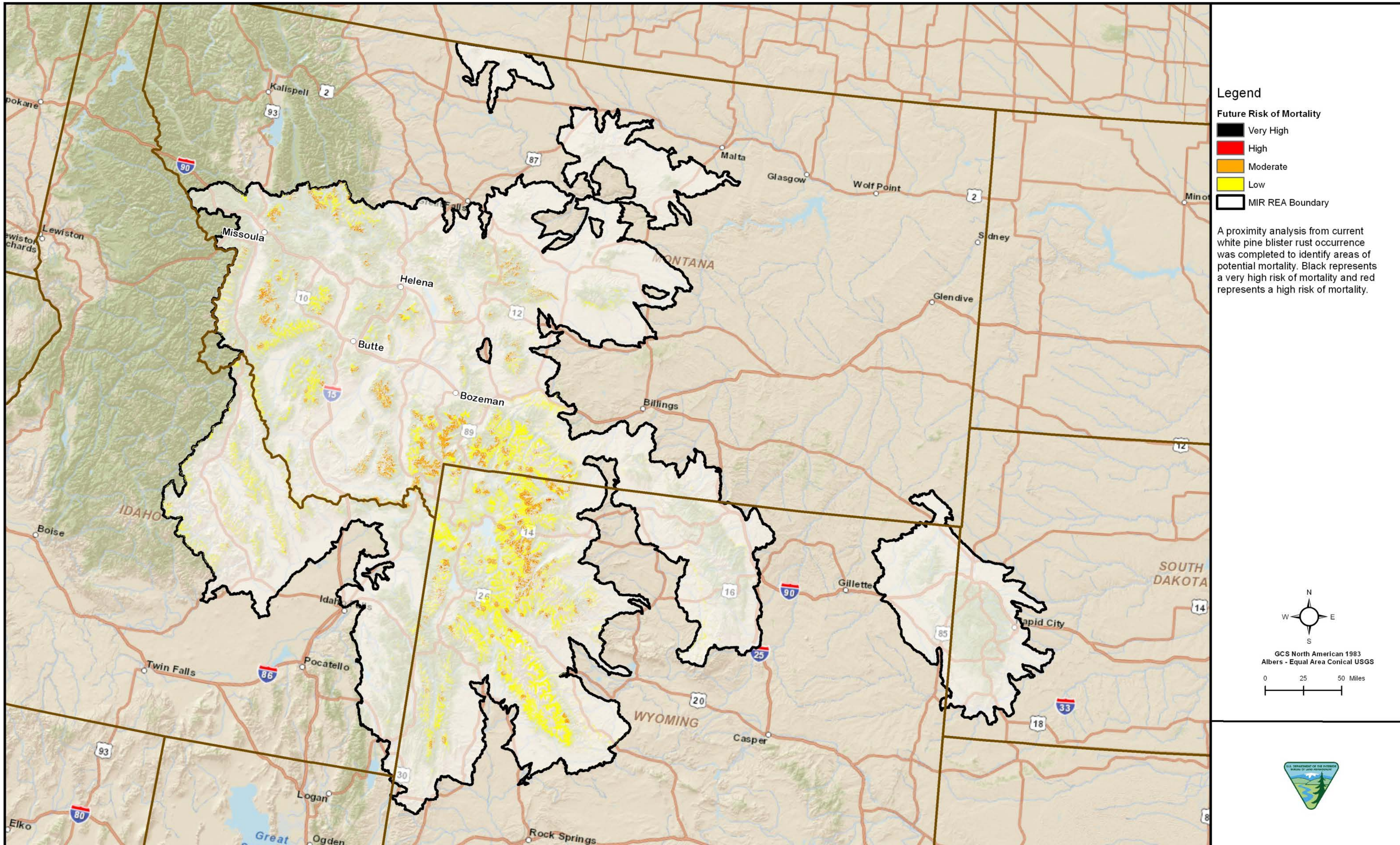


Figure 3-9. Whitepine Blister Rust Future Risk (5 years)

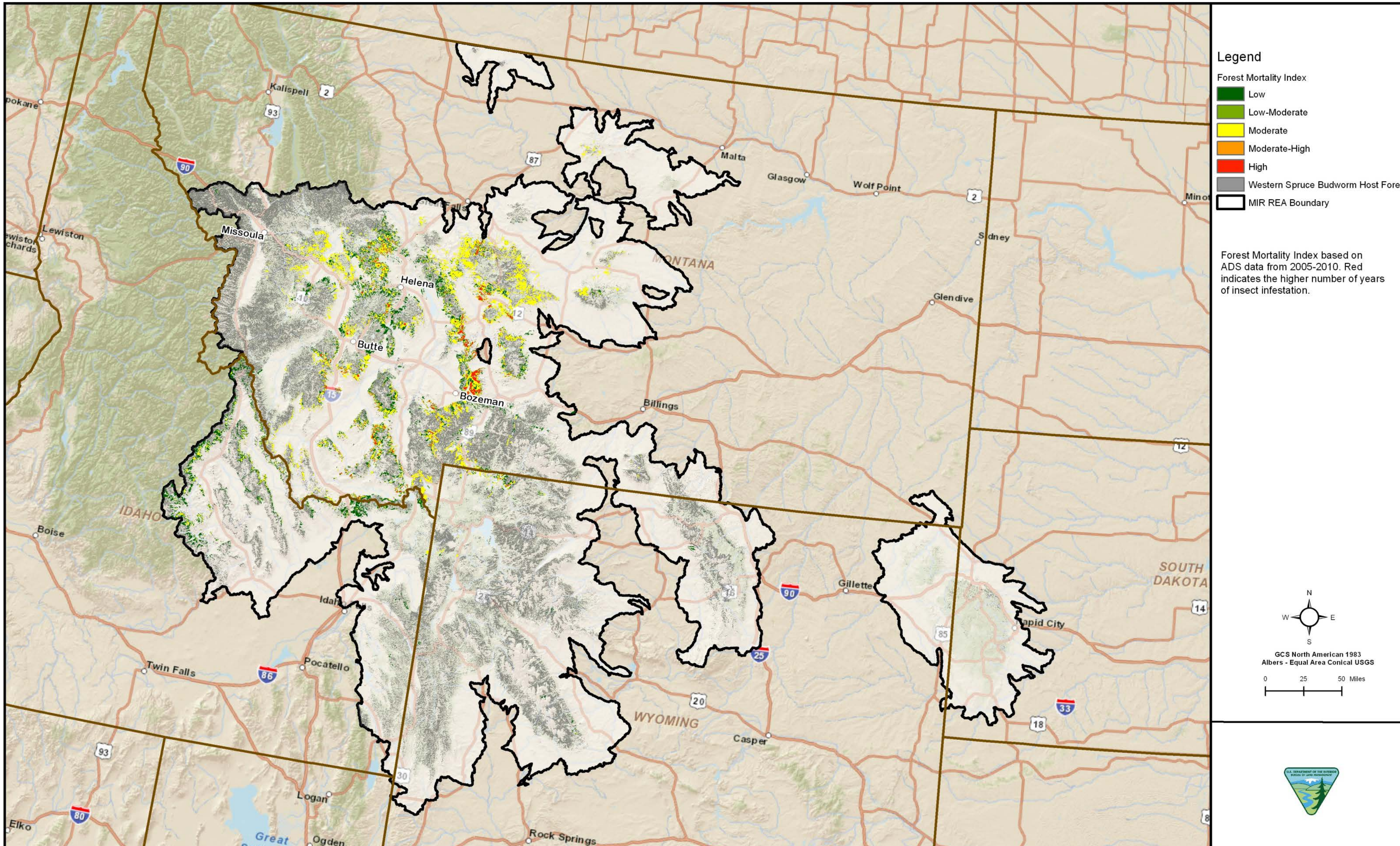


Figure 3-10. **Western Spruce Budworm Forest Mortality Index 2000-2005**

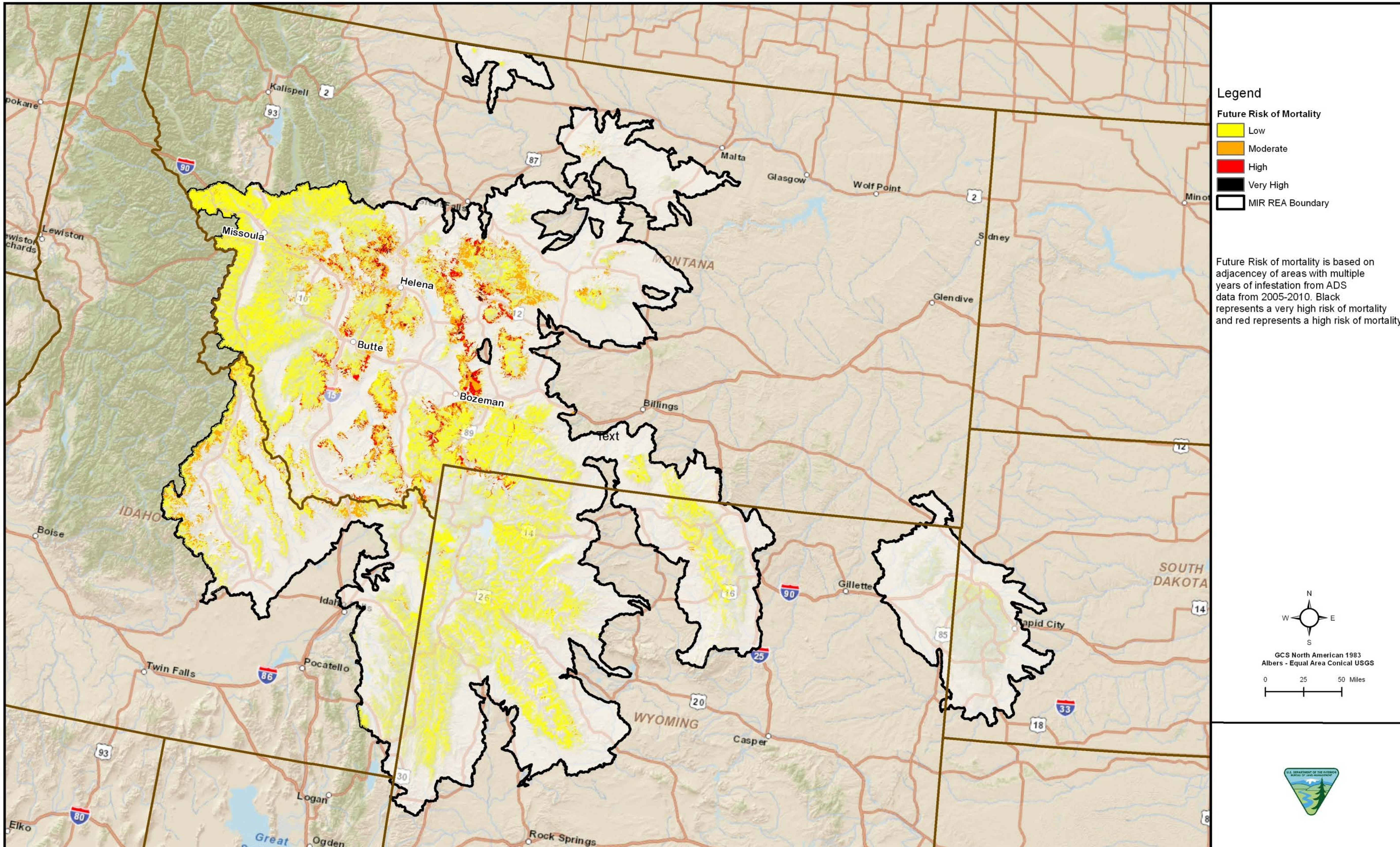


Figure 3-11. Western Spruce Budworm Future Risk (5 years)

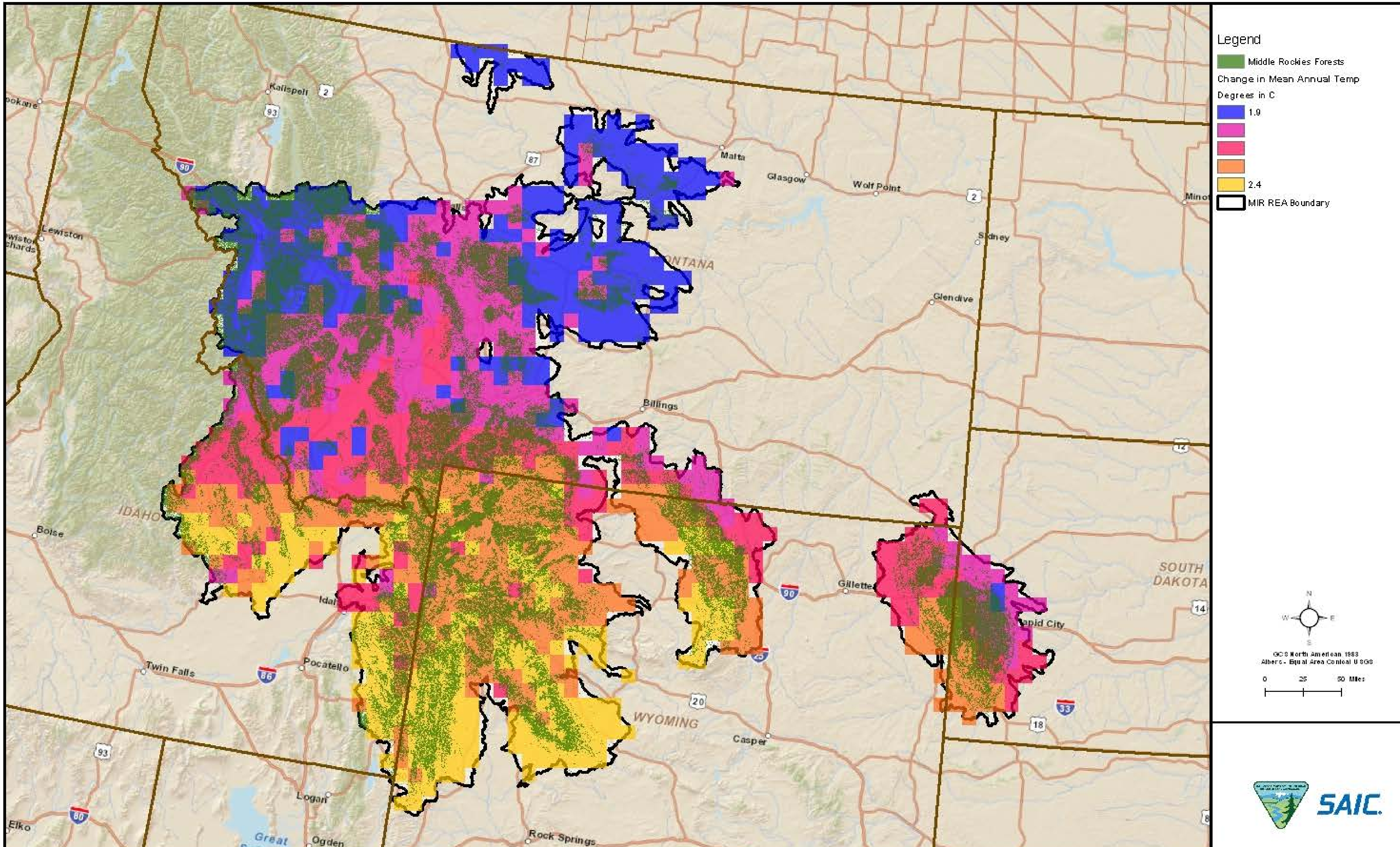


Figure 3-12. Middle Rockies Annual Temperature Change

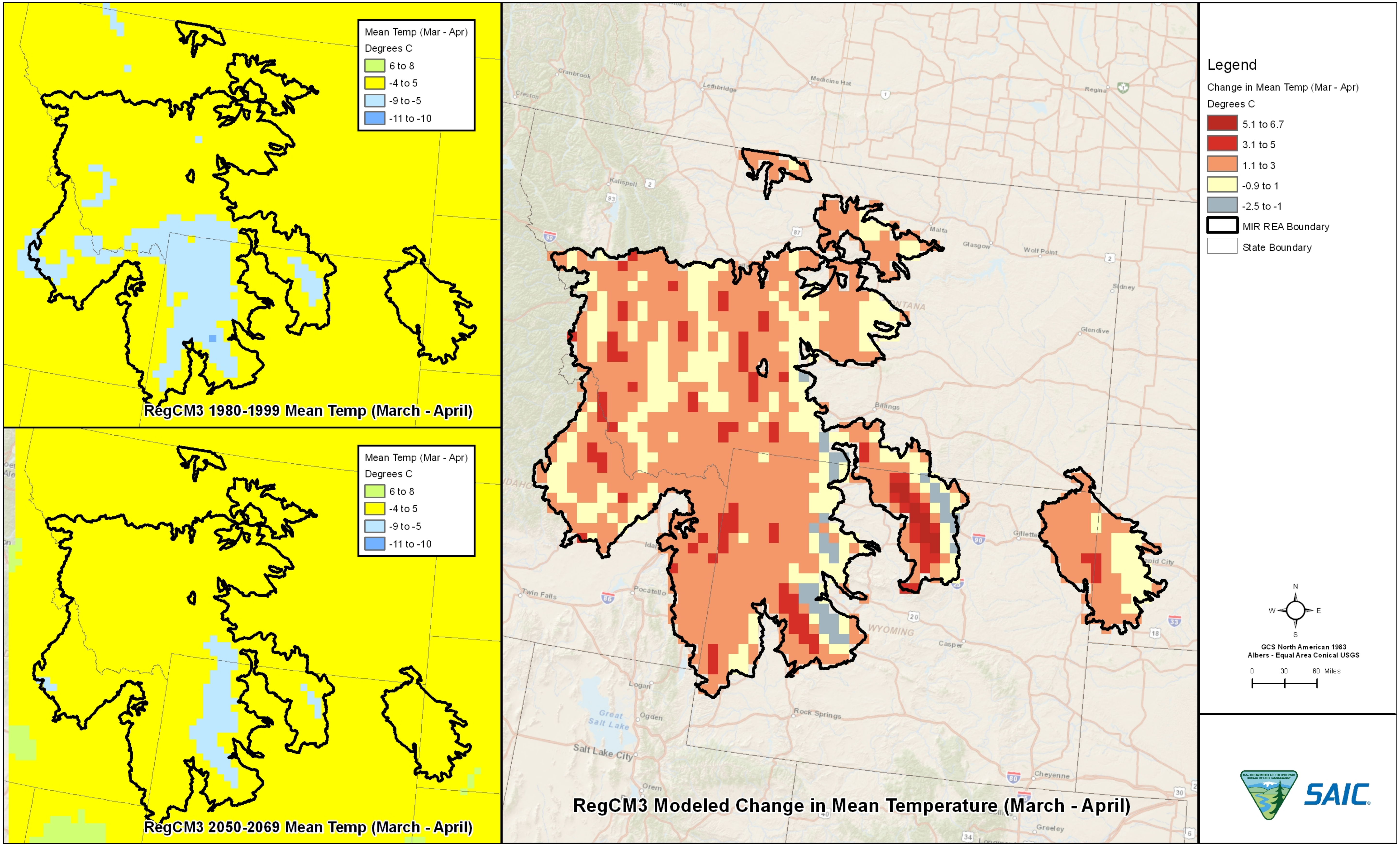


Figure 3-13. Middle Rockies Temperature March - April

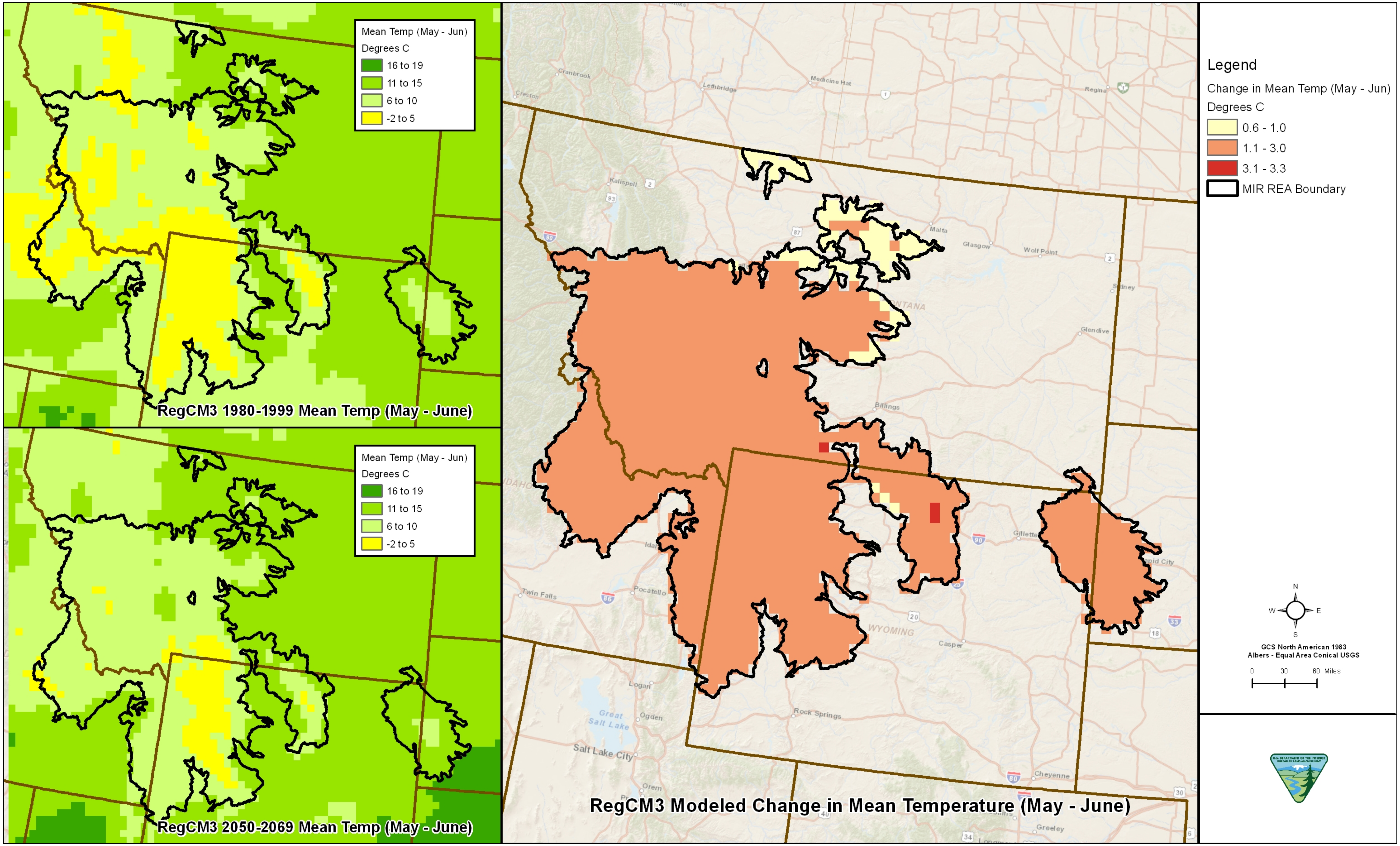


Figure 3-14. Middle Rockies Temperature May - June

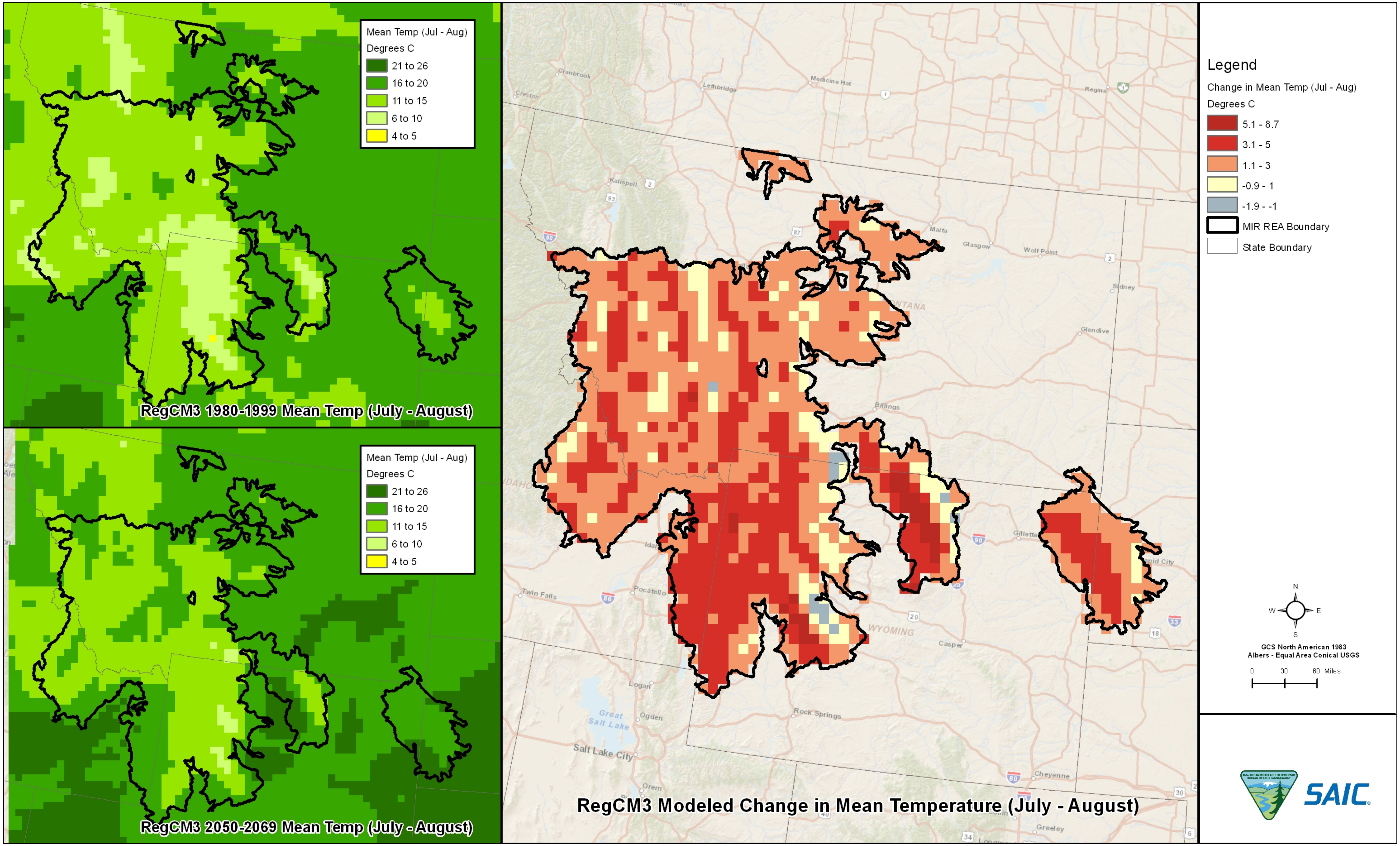


Figure 3-15. Middle Rockies Temperature July-August

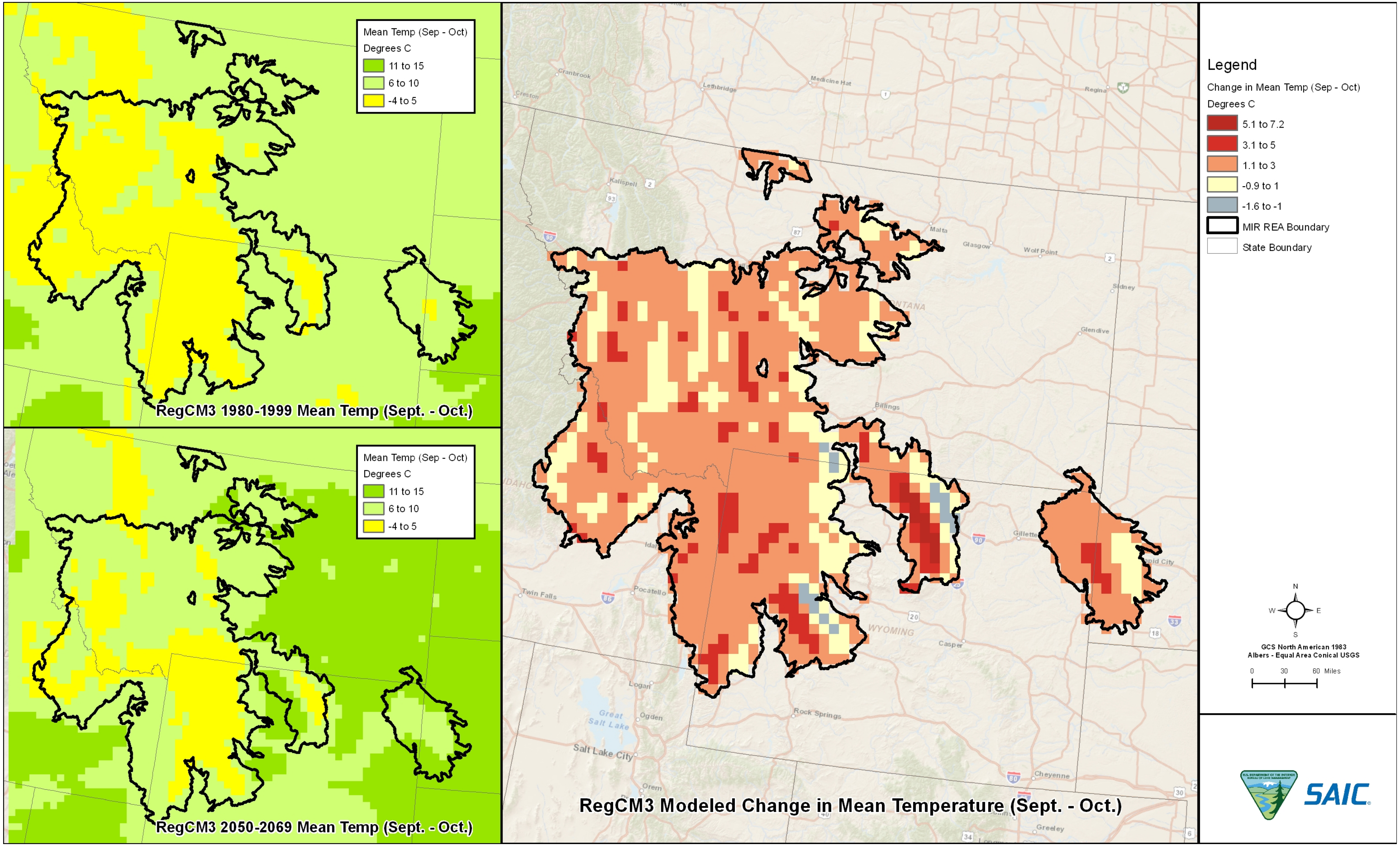


Figure 3-16. Middle Rockies Temperature September - October

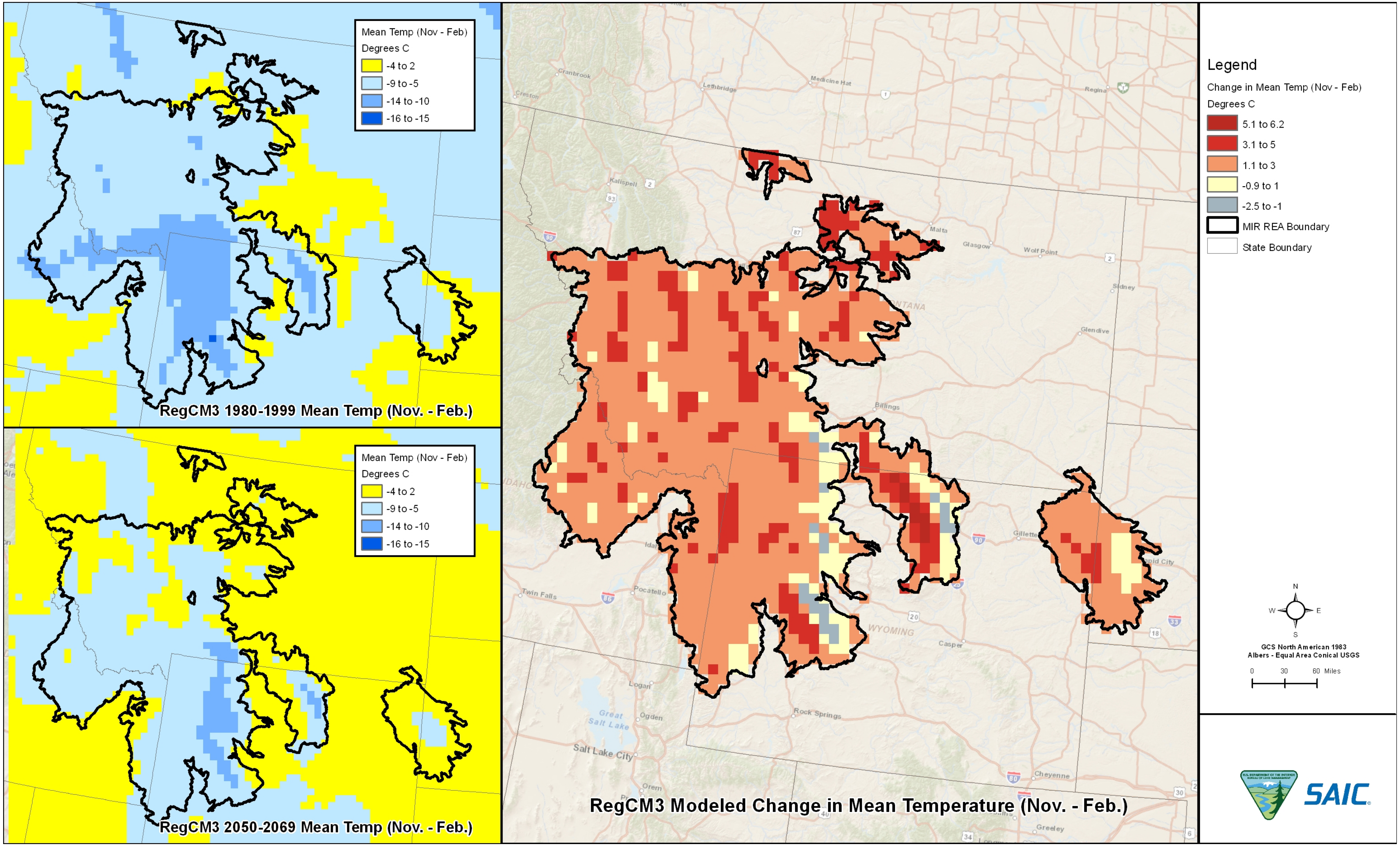


Figure 3-17. Middle Rockies Temperature November - February

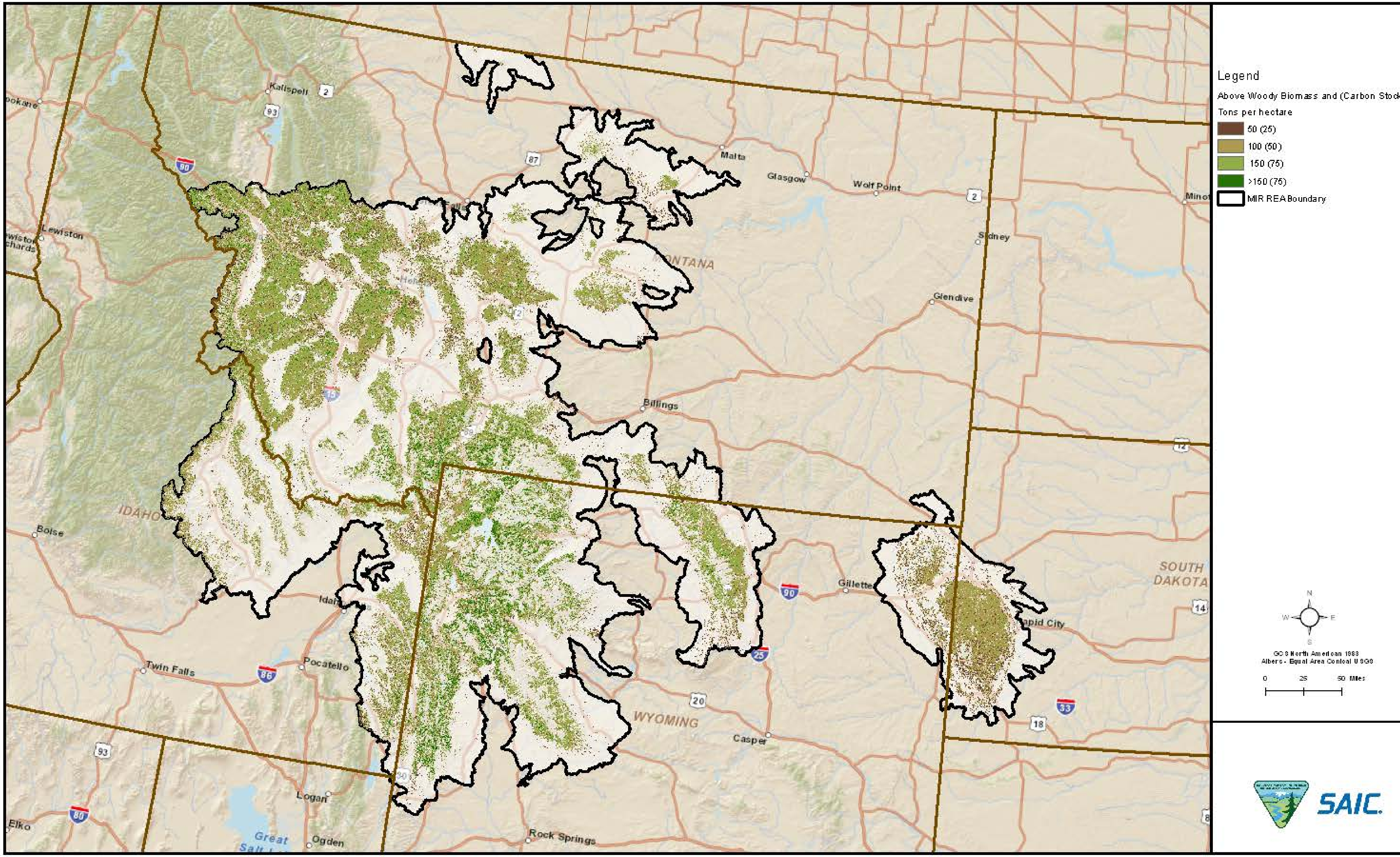


Figure 3-18. Current Middle Rockies Biomass and Carbon Stock

Data Request Method

Rapid Ecoregional Assessments (REAs)—National Operations Center, CO

Individual REA data layers and some other products are still available but are no longer being published.

If you would like to obtain more information, including data and model zip files* (containing Esri ModelBuilder files for ArcGIS 10.x and relevant Python scripts), please email **BLM_OC_REA_Data_Portal_Feedback_Team@blm.gov**.
*Note that a few models require software that BLM does not provide such as R, Maxent, and TauDEM.

Models associated with individual REAs may require data links to be updated to function properly. REA reports, technical appendices, and model overviews (for some REAs) contain detailed information to determine what products are available and what datasets are necessary to run a certain model.

Please include the report name and any specific data information that you can provide with your request.

Other BLM data can be found on the Geospatial Business Platform Hub (https://gbp-blm-egis.hub.arcgis.com).