Section IV. Assessments of Species and Species Assemblages

Chapter 16. Five-Needle Pine Forests and Woodlands

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Key Ecological Attributes

Distribution and Ecology

There are six species of five-needle white pines (family Pinaceae) that occur across the Rocky Mountains, two of which occur in the Wyoming Basin: limber and whitebark pine. The range of limber pine extends from southwestern Alberta and southeastern British Columbia, to New Mexico, Arizona, and eastern California, with disjunct populations in the Dakotas, Nebraska, eastern Oregon, eastern Nevada, and southern California (Smith and others, 2013). The overall distribution of whitebark pine includes coastal and Rocky Mountain ranges from British Columbia to Nevada and southern California. Although broadly distributed in Canada, many whitebark pine stands are geographically isolated at lower latitudes (Keane and Parsons, 2010). Nearly all whitebark pine in the United States occurs on Federal lands, about half of which is protected within national parks or wilderness areas (Keane, 2000). The Wyoming Basin encompasses the southern and eastern-most range of whitebark pine distribution in the Rocky Mountains.

Whitebark pine has been declining across its range over the past century (Kendall and Keane, 2001). Recovery of whitebark pine is expected to be slow due to the time required to reach sexual maturity coupled with reduced cone production and increased mortality from white pine blister rust (Jewett and others, 2011). Concerns about threats to whitebark pine led the U.S. Fish and Wildlife Service to conclude that listing it as threatened or endangered was warranted (Listing Priority Number 2) but precluded by higher-priority species (U.S. Fish and Wildlife Service, 2011).

Limber pine occurs in association with numerous overstory species across a broad ecological gradient from the lower foothills up to treeline, the broadest elevational range of any conifer species in the Rocky Mountains (Schoettle and Rochelle, 2000). Despite its broad elevational range and patchy distribution, limber pine can exhibit remarkable consistency in abundance among stands. In a recent study across 10 ecoregions of the mountain West, limber pine ranged between 13–20 percent of total basal area for elevations between 1,177 and 3,547 meters (m) (3,861.6 and 11,637.1 feet [ft]) (Windmuller-Campione and Long, 2015). In the Wyoming Basin, limber pine is found most commonly in juniper woodlands, montane/subalpine forests, and krumholz woodlands (Knight, 1994; Schoettle and Rochelle, 2000). Limber pine typically occurs in association with lodgepole pine, Engelmann spruce, whitebark pine, Douglas-fir, subalpine fir, ponderosa pine, Rocky Mountain juniper, and Utah juniper (Despain, 1973; Marston and Anderson, 1991).

Whitebark pine occurs within a much narrower elevational range than limber pine, and is generally restricted to the subalpine and timberline zones (Tomback and others, 2011). It typically occurs in windy, high-elevation or high-latitude areas, which is an indication of its tolerance of harsh conditions (Tomback and others, 2011). Whitebark pine may occur in association with lodgepole pine, Englemann spruce, and subalpine fir. The relative dominance of whitebark pine within stands depends on elevation, soils, topography, disturbance history, and seral stage (Tomback and others, 2011). Whitebark pine may attain canopy dominance following severe disturbances, such as fire, or in harsh conditions, such as krummholz woodlands (Tomback and others, 2011).

Although they can grow in a broad range of conditions, both limber and whitebark pines are poor competitors and consequently are often restricted to harsh environments, including windswept ridges, rocky areas, poor soils, steep slopes, and southern aspects. However, both

pine species also occur in more productive subalpine meadows (Knight, 1994; Schoettle and Rochelle, 2000; Tomback and others, 2001; Coop and Schoettle, 2009). In addition, the trees are relatively shade intolerant, slow growing, and often long-lived; whitebark pine can live up to 1,000 years (yr), and limber pine up to 1,500 yr (Schuster and others, 1995). Both species may occur as extensive, closed-canopy forests in more productive locations where they may maintain dominance for 200–1,500 yr (Coop and Schoettle, 2009; Tomback and others, 2011). Whitebark pine tolerates cold, dry conditions, but may decrease in abundance as either summer precipitation or drought increases (Tomback and others, 2011). Limber pine seedlings are relatively drought tolerant, which allows them to establish in more arid locations than whitebark pine (Brunelle and others, 2008).

Landscape Structure and Dynamics

The long- and short-term dynamics of five-needle pine forests and woodlands are shaped by interactions of fire, climate, disease, and insect outbreaks. These interactions lead to considerable spatial and temporal variation in stand structure and dynamics. Dispersal by seed-caching corvids, such as Clark's nutcracker and pinyon jay, influence regeneration patterns of five-needle pines following fire and beetle outbreaks (Tomback and others, 2011). Elevation, aspect, climate, and interactions among disturbances contribute to variation in stand structure and dynamics (Coop and Schoettle, 2009).

In foothill woodlands (where only limber pine occurs), fires are relatively rare, especially among steep rocky areas where fuel continuity is often low (Knight, 1994). Long-term climatic variation, especially drought, may play an major role in the dynamics of woodlands in these areas, but long-term stability of limber pine woodlands is indicated by the regular occurrence of limber pines that are 150 to 250 yr old (Thileneus, 1970; Means, 2011). During the early Holocene, limber pine was more common than it is today, and it has been suggested that many existing stands may be remnants of a more widespread distribution (Monahan and others, 2013). Limber pine dwarf mistletoe, unlike mistletoe in other conifer species, is highly virulent and kills the host trees, generally within a decade of infection (Kearns and Jacobi, 2007).

In montane and subalpine forests, fire and bark beetle outbreaks play a dominant role in the dynamics of five-needle pine forests. Fire regimes are spatially and temporally variable across the range of five-needle pines. Fire rotations range between 30–1,000 yr and vary with climate, topography, and forest structure (National Interagency Fuels, Fire, and Vegetation Technology Transfer, 2010; Tomback and others, 2011). On more productive sites, five-needle pines typically function as seral species in lodgepole pine or subalpine fir forests, and over decades or centuries, five-needle pine dominance typically decreases as other more shade-tolerant conifers increase in dominance (Tomback and others, 2011)

Episodic mountain pine beetle outbreaks can be primary disturbance agents in coniferous forests of the Rocky Mountains, especially lodgepole pine forests, and may affect more land area than fires during outbreak years (Logan and Powell, 2001; Raffa and others, 2008). However, widespread beetle outbreaks are uncommon because temperatures in high-elevation five-needle pine forests generally are not conducive to synchronized larval development and over-winter survival of mountain pine beetles (Brunelle and others, 2008; Jewett and others, 2011). The conditions that can lead to a shift from endemic to epidemic levels, like the most recent bark beetle outbreak throughout lodgepole pine forests of the Rocky Mountains, are believed to be a result of widespread drought, synchronicity in stand age structure of lodgepole pine over large landscapes, and warm temperatures that allowed an increase in over-winter survival of larvae and

a decrease in the number of years required for larvae to reach maturity (Brunelle and others, 2008; Bentz and others, 2010). There is historical evidence of both previous warm periods and widespread bark beetle outbreaks, suggesting that, although rare, the broad extent of the recent bark beetle outbreak might not be unprecedented (Logan and Powell, 2001; Brunelle and others, 2008). Outbreaks typically last a decade or more, and tree mortality is usually greatest for the largest trees (Brunelle and others, 2008). The current mountain pine beetle outbreak in lodgepole pine forests has greatly subsided in many areas (Colorado State Forest Service, 2014).

The food-caching behavior of Clark's nutcrackers and pinyon jays plays a large role in seed dispersal and regeneration of five-needle pines (Tomback and others, 2011). The large, nutritious seeds are preferred food sources, particularly whitebark pine, for Clark's nutcrackers. Indeed, whitebark pine has a mutualistic relationship with Clark's nutcrackers. The nutcracker's sharp, chisel-like bill is specialized to open whitebark pine cones, which remain closed at maturity (indehiscent), thereby increasing their duration of availability to nutcrackers and limiting their use by other species. The tendency of Clark's nutcrackers to cache seeds in forest openings and near rocks affects the regeneration patterns of five-needle pines and facilitates colonization of disturbed and sites where there is less competition from mature trees (Tomback and others, 2011). In contrast, the cones of limber pine open at maturity, and there is greater competition among seed predators for the pine seeds, which also can fall to the ground below the trees. Although the pinyon jay's reliance on pinyon pine is well known, the jays also feed on limber pine, particularly in juniper woodlands of the Wyoming Basin where pinyon pines do not occur (Balda, 2002). Both the Clark's nutcracker and pinyon jay cache seeds at considerable distances from where the seeds are initially harvested. On average both corvid species may fly up to 10–12 kilometers (km) (12.4 miles [mi]) before caching, but nutcrackers have been observed caching seeds >20 km (12.4 mi) from their source (Balda, 2002; Tomback and others, 2011).

The 2013−2027 National Insect and Disease Forest Risk Assessment (Krist and others, 2014) projects significant range-wide declines of both limber and whitebark pines from insects and disease. Whitebark pine is projected to decrease in basal area by 58 percent, and limber pine is forecasted to have a basal area decrease of 44 percent. Mountain pine beetle is projected to be the primary mortality agent for whitebark pine, accounting for 80−85 percent of the projected mortality, with white pine blister rust accounting for 25−30 percent of projected mortality. For limber pine, mountain pine beetle is projected to cause 20−80 percent of mortality, with white pine blister rust (1−20 percent) and dwarf mistletoe (25−30 percent) also contributing to mortality. Within the Rapid Ecoregional Assessment (REA) project area, the greatest projected declines in whitebark pine were at higher elevations along the western boundary of the REA with lower mortality rates along the range margins where the Bureau of Land management (BLM) whitebark pine stands are located. For limber pine, the greatest projected declines occur along the western and eastern boundaries of the REA with lower mortality rates in the south portion of the Big Horn Basin and in some of the interior mountain ranges.

Associated Species of Management Concern

Five-needle pines may function as keystone or foundation species because of their contribution to ecosystem functions (Tomback and others, 2011). The seeds of the whitebark pine provide a high nutritional food source for grizzly bear, especially during mast years (Tomback and others, 2011). Because of their ability to colonize sites with harsh conditions, the five-needle pines provide crucial ecological functions by colonizing disturbed sites, including burns and avalanche chutes, providing shade, or serving as nurse trees for other plants (Maher

and others, 2005; Kearns and Jacobi, 2007; Smith and others, 2013). The trees also help to retain snowpack and delay snowmelt (Kearns and Jacobi, 2007; Smith and others, 2013).

Change Agents

Development

Because five-needle pine forests commonly occur at higher elevations and along steep, rocky slopes, there is generally limited energy development, roads, agriculture, or grazing in these forests and woodlands. Neither pine species has commercial timber value in the Wyoming Basin. Timber management or restoration activities following fires or beetle outbreaks may present the greatest direct anthropogenic influences on these stands.

Altered Fire Regimes

Fire suppression has probably had limited effect on fire rotations in high-elevation forests, but locally may have affected the occurrence of fires in five-needle pine forests (Baker, 2009; Keane, 2010). It is often assumed that bark beetle outbreaks can lead to high fuel loads, thereby increasing the risk of severe fires, but empirical evidence for such altered fire behavior is limited and equivocal (Jenkins and others, 2008; Simard and others, 2011; Donato and others, 2013). Recent field studies indicate the risk of severe fire behavior may not increase or decrease after bark beetle outbreaks (Simard and others, 2011). Likewise, results from modeling efforts indicate the potential for reduction in most measures of fire intensity for up to 35 yr after bark beetle outbreaks (Simard and others, 2011). In the short-term, mountain pine beetles may reduce the risk of crown fires by thinning the canopy (Simard and others, 2011), but effects of outbreaks on surface fuels vary over time (Kulakowski and Veblen, 2007). Because weather generally may have a greater influence on fire behavior than amount or type of fuels in subalpine forests (Schoennagel and others, 2004; Littell and others, 2009), the recent bark beetle outbreak may not have a significant lasting effects on fire behavior in five-needle pine forests in the subalpine zone (Simard and others, 2011).

Introduced Disease

White pine blister rust (hereafter blister rust) (Schoettle, 2004; Kearns and Jacobi, 2007) is native to Eurasia. It was introduced to western North America in 1910, and spread to the Wyoming Basin by the 1940s (Geils and others, 2010). All North American white pines are susceptible to this pathogen and serve as primary hosts (Kearns and Jacobi, 2007). Species in the genus *Ribes* are the primary alternate hosts required by the pathogen to complete its life cycle, but *Castilleja* and *Pedicularis* also serve as hosts (Kearns and Jacobi, 2007). The fungus invades needles, branches, and stems, where it can produce tree-girdling cankers that initially lead to reduced cone production and ultimately tree mortality, typically within a decade of infection. Because the fungal spores are wind-dispersed, they are capable of traveling hundreds of kilometers (Kearns and Jacobi, 2007). Incidence of blister rust in limber pine in and adjacent to the Wyoming Basin between 2002 and 2004 was highly variable (Kearns and Jacobi, 2007); infection of trees occurred on 55 percent of survey plots, and incidence averaged 15.5 percent. More northern and eastern plots had higher degrees of infection, which decreased with increasing elevation (Kearns and Jacobi, 2007). In the Greater Yellowstone area, 45 percent of whitebark

pines were dead (from either bark beetles or blister rust), and 83 percent were infected by blister rust (Bockino and Tinker, 2012). Wind patterns and suitability of moisture levels can lead to a patchy distribution of suitable sites for blister rust across broad regions (Larson, 2011). Occurrence of blister rust can increase susceptibility to bark beetle attack and could increase the severity of bark beetle outbreaks by weakening trees' defenses (Larson, 2011; Bockino and Tinker, 2012).

Climate Change

Climate change has the potential to affect the distribution of five-needle pines as well as the occurrence of fire, bark beetle outbreaks, and blister rust infection rates. Because of their occurrence at tree line, five-needle pines could potentially expand upslope with increasing temperatures, but lower elevation limber pine woodlands may be especially vulnerable to increasing temperatures because they are constrained topographically (Monahan and others, 2013; Moyes and others, 2013). Whitebark pine is favored over lodgepole pine by cold and wet climates, so a shift to warmer and drier climates may favor lodgepole pines (Brunelle and others, 2008). Range shifts in whitebark pine under future climates may be facilitated by the presence of nurse trees (Maher and Germino, 2005, 2006).

Temperature increases could affect bark beetle population dynamics and increase the occurrence of outbreaks by decreasing the number of years for larvae to reach maturity, increasing overwinter survival, and increasing the frequency of outbreaks at upper elevations (Monahan and others, 2013). Indeed, a 2−3 °C (3.6−5.4 °F) increase in temperature could result in a shift from a 2−3 yr beetle life cycle to a 1-yr life cycle, which promotes synchronicity of beetle populations and helps the beetles overcome tree defenses (Logan and others, 2001). In addition, warmer temperatures can exacerbate the effects of drought, which can lead directly to tree mortality and increase the potential for bark beetle outbreaks and blister rust infection (Brunelle and others, 2008; Monahan and others, 2013). The complex interactions between blister rust, bark beetles, climate, and fire create considerable uncertainty in how climate scenarios may play out on the landscape, but there is concern that if resistance to blister rust does not increase in five-needle pine populations, the long-term persistence of these species is at serious risk (Larson, 2011; Tomback and others, 2011).

Rapid Ecoregional Assessment Components Evaluated for Five-Needle Pine Forests and Woodlands

A generalized, conceptual model was used to highlight some of the key ecological attributes and Change Agents affecting five-needle pine forests and woodlands (fig. 16–1). Key ecological attributes addressed by the REA include (1) the distribution of baseline five-needle pine forests and woodlands, (2) landscape structure (patch sizes and structural connectivity), and (3) landscape dynamics (fire and bark beetle occurrence) (table 16–1). The Change Agents evaluated include development, white pine blister rust, and climate change (table 16–2). Ecological values and risks used to assess the conservation potential for five-needle pine forests and woodlands by township are summarized in table 16–3. Core and Integrated Management Questions and the associated summary maps and graphs are provided in table 16–4.

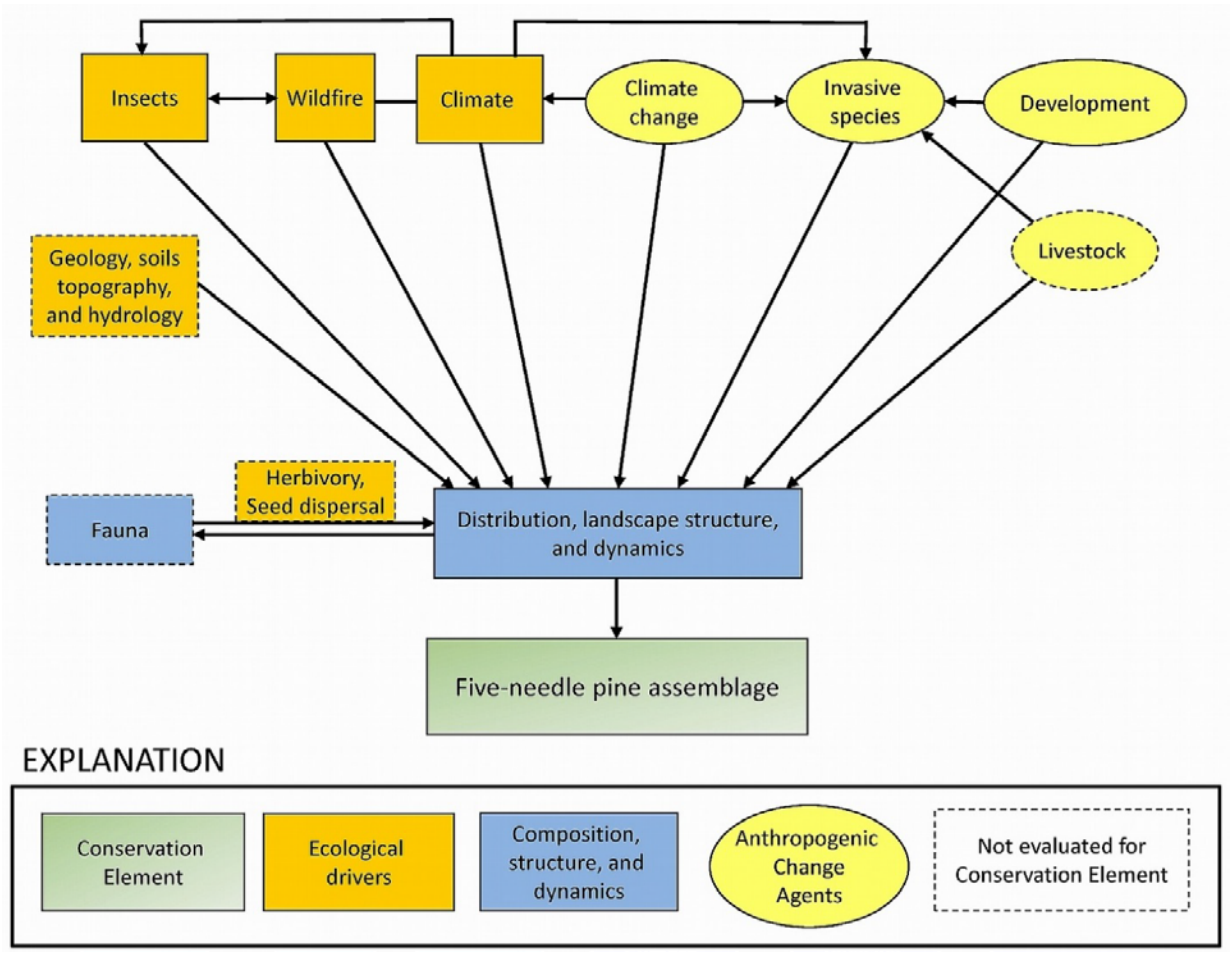

Figure 16−1. Generalized conceptual model for five-needle pine forests and woodlands for the Wyoming Basin Rapid Ecoregional Assessment (REA). Biophysical attributes and ecological processes regulating the occurrence, structure, and dynamics of five-needle pine forests and woodlands are shown in orange rectangles; additional ecological attributes are shown in blue rectangles; and anthropogenic Change Agents that affect key ecological attributes are shown in yellow ovals. The dashed lines indicate components not addressed by the REA. Livestock is a Change Agent that was not addressed due to the lack of regionwide data.

Table 16−1. Key ecological attributes and associated indicators of baseline five-needle pine forests and woodlands[1] for the Wyoming Basin Rapid Ecoregional Assessment.

[km, kilometer; mi, mile]

Attributes	Variables	Indicators
Amount and distribution	Total area (by species)	Distribution of limber and whitebark pine[1]
Landscape structure	Patch size	Patch-size frequency distribution
	Structural connectivity[2]	Interpatch distances that provide an index of structural connectivity of baseline patches at local (1.08 km; 0.65 mi), landscape (4.5 km; 2.83 mi), and regional (9.09 km; 5.65 mi) levels
Landscape dynamics	Fire and bark beetle occurrence[3]	Locations of fires (since 1980) and bark beetle mortality (since 1997)

[1] Baseline conditions are used as a benchmark to evaluate changes in the total area and landscape structure of five-needle pine forests and woodlands due to Change Agents. Baseline conditions are defined as the potential current distribution of five-needle pines derived from compiled distribution data from U.S. Department of Agriculture Forest Service, reGAP, and LANDFIRE without explicit inclusion of Change Agents (see Chapter 2—Assessment Framework).

[2] Structural connectivity refers to the proximity of patches at local, landscape, and regional levels but does not reflect species-specific measures of connectivity. See Chapter 2—Assessment Framework.

[3] See Wildland Fire section in the Appendix.

Table 16−2. Anthropogenic Change Agents and associated indicators influencing five-needle pine forests and woodlands for the Wyoming Basin Rapid Ecoregional Assessment.

[km^2, square kilometer; mi^2, square mile; km, kilometer; mi, mile]

Change Agents	Variables	Indicators
Development	Terrestrial Development Index[1]	Percent of five-needle pine forests and woodlands in seven development classes using a 16-km^2 (6.18-mi^2) moving window
		Patch-size frequency distribution for five-needle pine forests and woodlands that are relatively undeveloped or have low development scores compared to baseline conditions
		Interpatch distances that provide an index of structural connectivity for relatively undeveloped patches at local (2.97 km; 1.85 mi), landscape (5.13 km; 3.19 mi), and regional (11.9 km; 7.39 mi) levels
Introduced disease	White pine blister rust	Risk of white pine blister rust occurrence for limber pine in Wyoming and Colorado[2]
	Infection and mortality from white pine blister rust and bark beetles	Percent of infected, dead, and healthy trees[3]
Climate change	Projected temperature and precipitation	Potential distribution of limber and whitebark pine derived from the projected distribution of the bioclimatic envelope in 2030[4]

[1] See Chapter 2—Assessment Framework.

[2] Risk model output for Wyoming and Colorado from Kearns and others (2014)

[3] Data for limber pine from Cleaver (2014); data for whitebark pine Greater Yellowstone Whitebark Pine Monitoring Working Group (2013).

[4] Bioclimatic envelope represents the climatic conditions conducive for five-needle pine forests and woodlands, derived from Rehfeldt and others (2012) using climate scenario I (Canadian Centre for Climate Modelling and Analysis, ver. 3, emissions scenario A2).

Table 16−3. Landscape-level ecological values and risks for five-needle pine forests and woodlands. Ranks were combined into an index of conservation potential for the Wyoming Basin Rapid Ecoregional Assessment.

		Relative rank			
	Variables[1]	Lowest	Medium	Highest	Description[2]
Values	Area	<2	2−18	>18	Percent of township classified as five-needle pines
Risks	Terrestrial Development Index (TDI)	<1	1−3	>3	Mean TDI score by township

[1] Township was used as the analysis unit for conservation potential on the basis of input from the Bureau of Land Management. A minimum area threshold of total area per township was established for five-needle pines to minimize the effects of extremely small areas and put greater emphasis on large areas (see table A−19 in the Appendix).

[2] See tables 16–1 and 16–2 for description of variables.

Table 16−4. Management Questions addressed for five-needle pine forests and woodlands for the Wyoming Basin Rapid Ecological Assessment.

Core Management Questions	Results
Where are the baseline five-needle pine stands (whitebark and limber pine), and what is the total area of each?	Figure 16–2
Where does development pose the greatest threat to baseline five-needle pine forests and woodlands, and where are the relatively undeveloped areas?	Figures 16–3 and 16–4
How has development fragmented baseline five-needle pine forests and woodlands, and where are the large, relatively undeveloped patches?	Figures 16–5 and 16–6
Where are baseline five-needle pine stands with high structural connectivity and stands that function as stepping stones?	Figure 16–7
Where are potential barriers and corridors that may affect animal movements among baseline five-needle-pine patches?	Figure 16–8
Where have recent fires and bark beetle outbreaks occurred in baseline five-needle pine stands, and what is the total area affected?	Figures 16–9 and 16–10
Which limber pine stands in Wyoming and Colorado are at risk for white pine blister rust?	Figure 16–11
How have white pine blister rust and bark beetles affected the health of five-needle pine stands?	Figure 16–12
What is the potential distribution of five-needle pines in 2030?	Figures 16–13 and 16–14
Integrated Management Questions	**Results**
How does development risk vary by land ownership or jurisdiction for five-needle pine forests and woodlands?	Table 16–5, figure 16–15
Where are the townships with the greatest landscape-level ecological values?	Figure 16–16
Where are the townships with the greatest landscape-level risks?	Figure 16–17
Where are the townships with the greatest conservation potential?	Figure 16–18

Methods Overview

We compiled distribution maps of limber and whitebark pine from several sources (table 16–1) to map the baseline distribution of five-needle pines. We assessed development levels for the assemblage using the Terrestrial Development Index (TDI) map, and then used the resulting output to calculate patch size and structural connectivity metrics. We mapped the structural connectivity of baseline patches at three interpatch distances derived from connectivity analysis: local (1.08 kilometers [km]; 0.67 miles [mi]), landscape (4.50 km; 2.80 mi), and regional (9.09 km; 5.65 mi) levels. We used development levels to identify areas that may function as barriers or corridors by overlaying relatively undeveloped habitat patches on the TDI map. Data sources for recent fire (1980−2012) and bark beetle (1997−2012) occurrence are provided in table 16–1. We summarized stand-level bark beetle and blister rust infection and mortality data provided by

Cleaver (2014) and Greater Yellowstone Whitebark Pine Working Group (2013). We used the results of Kearns and others (2014) to map potential risk of blister rust for limber pine.

To evaluate the potential for change in the distribution of five-needle pines, we used the bioclimatic envelope models developed by Rehfeldt and others (2012) for limber and whitebark pine using climate scenario I (Canadian Centre for Climate Modeling and Analysis Coupled Global Model, ver. 3 [CCCM3], emissions scenario A2) in 2030. Current and projected bioclimatic envelopes were used to identify areas where five-needle pines had the potential to increase, decline, or remain the same. We then overlaid the resulting map of bioclimatic envelopes on the baseline five-needle pine distribution map to identify existing stands that have the potential to change using climate scenario I. We used the same approach to assess the effects of climate change on the bioclimatic envelope of whitebark pine in 2030, 2060, and 2090.

Landscape-level ecological values (area of five-needle pines) and risk (TDI score) were compiled into an overall index of conservation potential for each township (table 16–3). Landscape-level values and risks, and conservation potential rankings are intended to provide a synthetic overview of the geospatial datasets developed to address Core Management Questions in the REA. Because rankings are very sensitive to the input data used and the criteria used to develop the ranking thresholds, they are not intended as stand-alone maps. Rather, they are best used as an initial screening tool to compare regional rankings in conjunction with the geospatial data for Core Management Questions and information on local conditions that cannot be determined from regional REA maps. See Chapter 2—Assessment Framework and Appendix for additional details on source data and methods.

Key Findings for Management Questions

Where are the baseline five-needle pine stands (whitebark and limber pine), and what is the total area of each (fig. 16–2)?

- Five-needle pines, especially whitebark pine, are broadly distributed at upper elevations of the Wind River and Absaroka Mountains, and Wyoming Front. At lower elevations, limber pine occurs in smaller stands across the Granite, Big Horn and Laramie Mountains.
- Collectively, five-needle pines cover 9,273 square kilometers (km^2), or 5.2 percent, of the project area (fig. 16–2).
- Limber pine accounts for 74 percent of the total area of five-needle pine.

Where does development pose the greatest threat to baseline five-needle pine forests and woodlands, and where are the relatively undeveloped areas (figs. 16−3 and 16−4)?

- Development levels are relatively low for five-needle pines compared to other communities and species, primarily as a consequence of their occurrence at high elevations and in steep terrain where development is low (figs. 16−3 and 16−4).
- A total of 62.2 percent of the five-needle pine forests and woodlands are relatively undeveloped.
- TDI scores are lower for whitebark pine compared to limber pine. Relatively undeveloped areas compose 83 percent of whitebark pine area but only 2.5 percent have TDI scores >5 percent, indicating high levels of development. In contrast, relatively undeveloped areas compose 53.9 percent of limber pine area and 3.8 percent have TDI scores >5 percent (fig. 16–4).

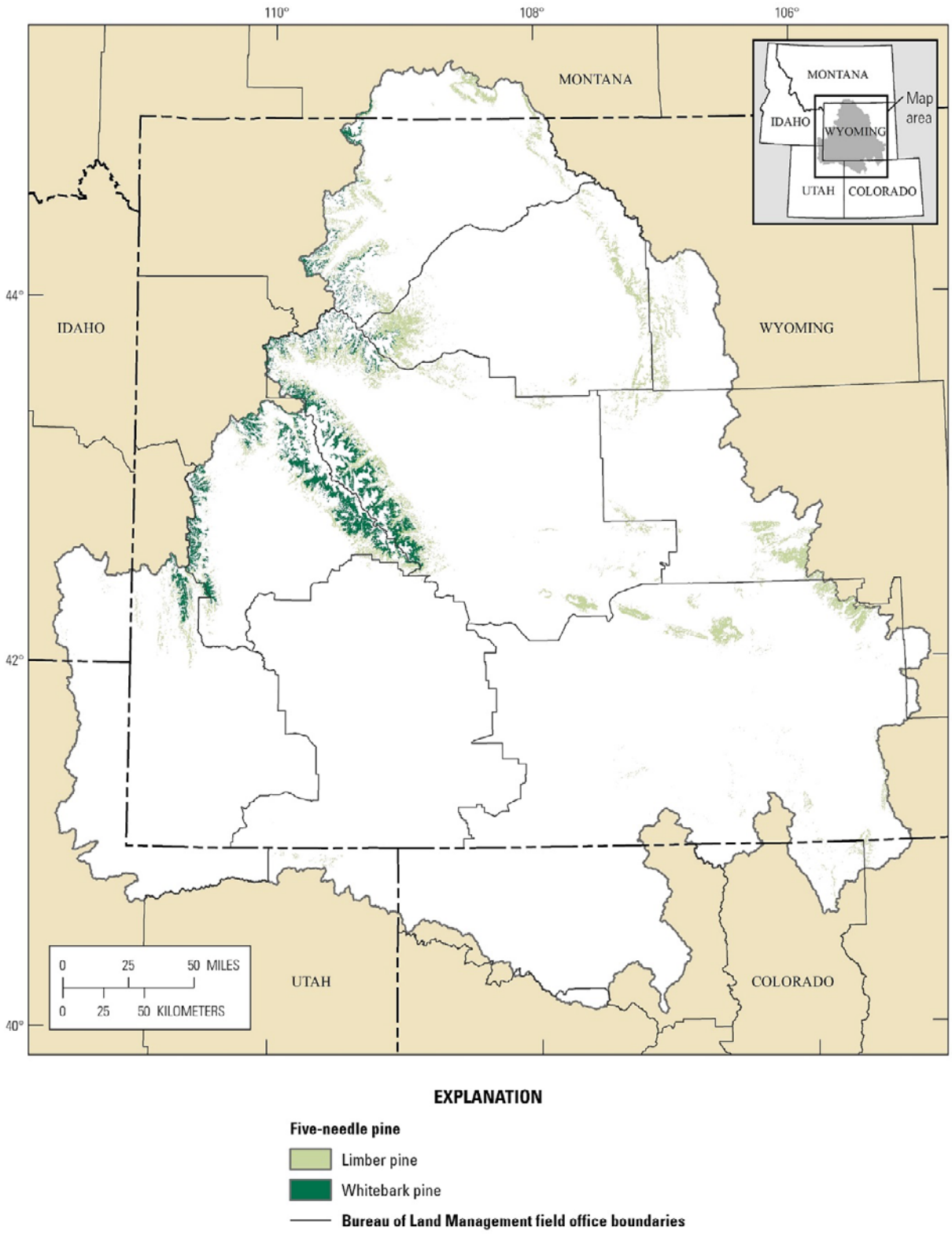

Figure 16−2. Distribution of baseline five-needle pine forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area.

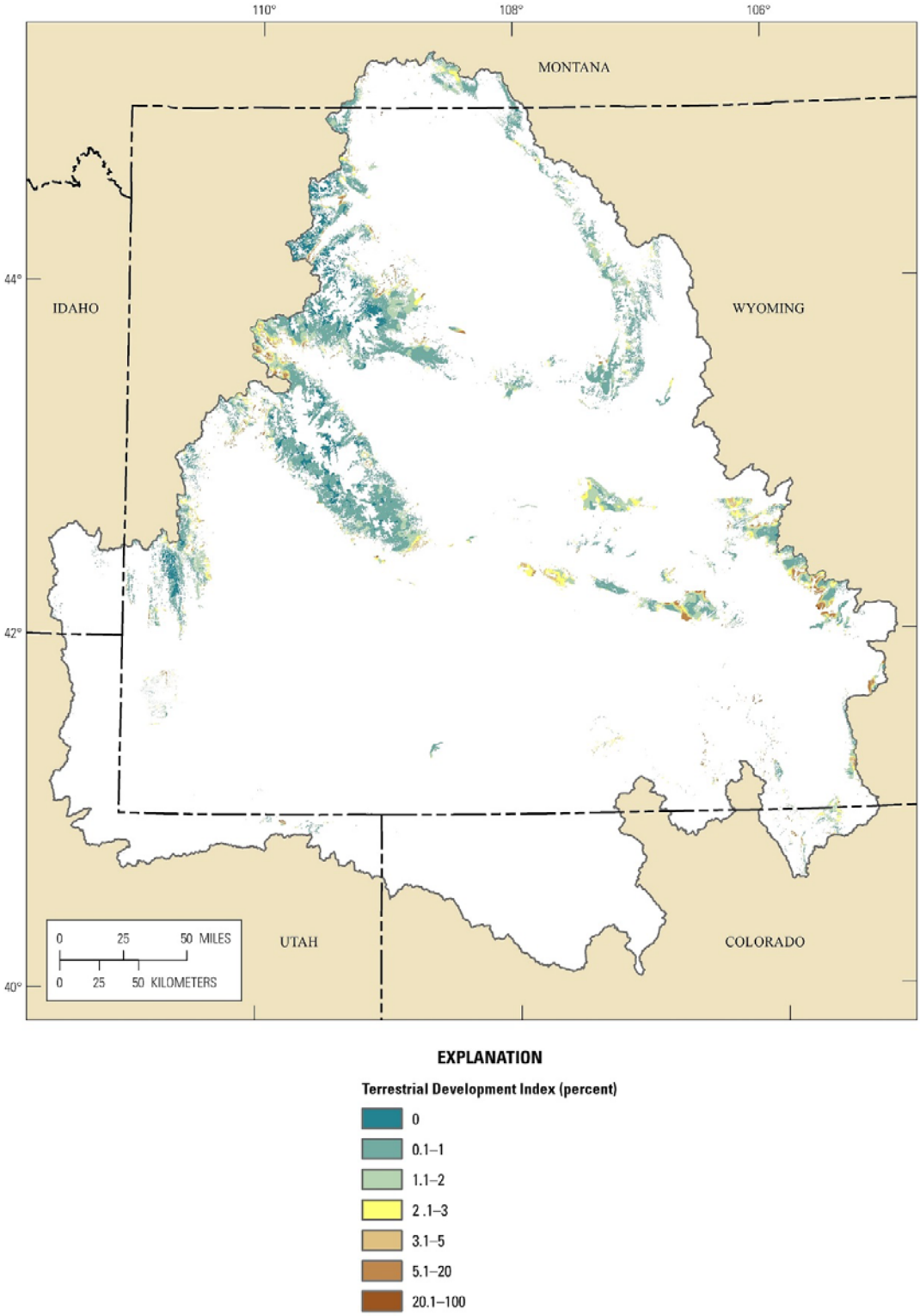

Figure 16−3. Terrestrial Development Index scores for baseline five-needle pine forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area.

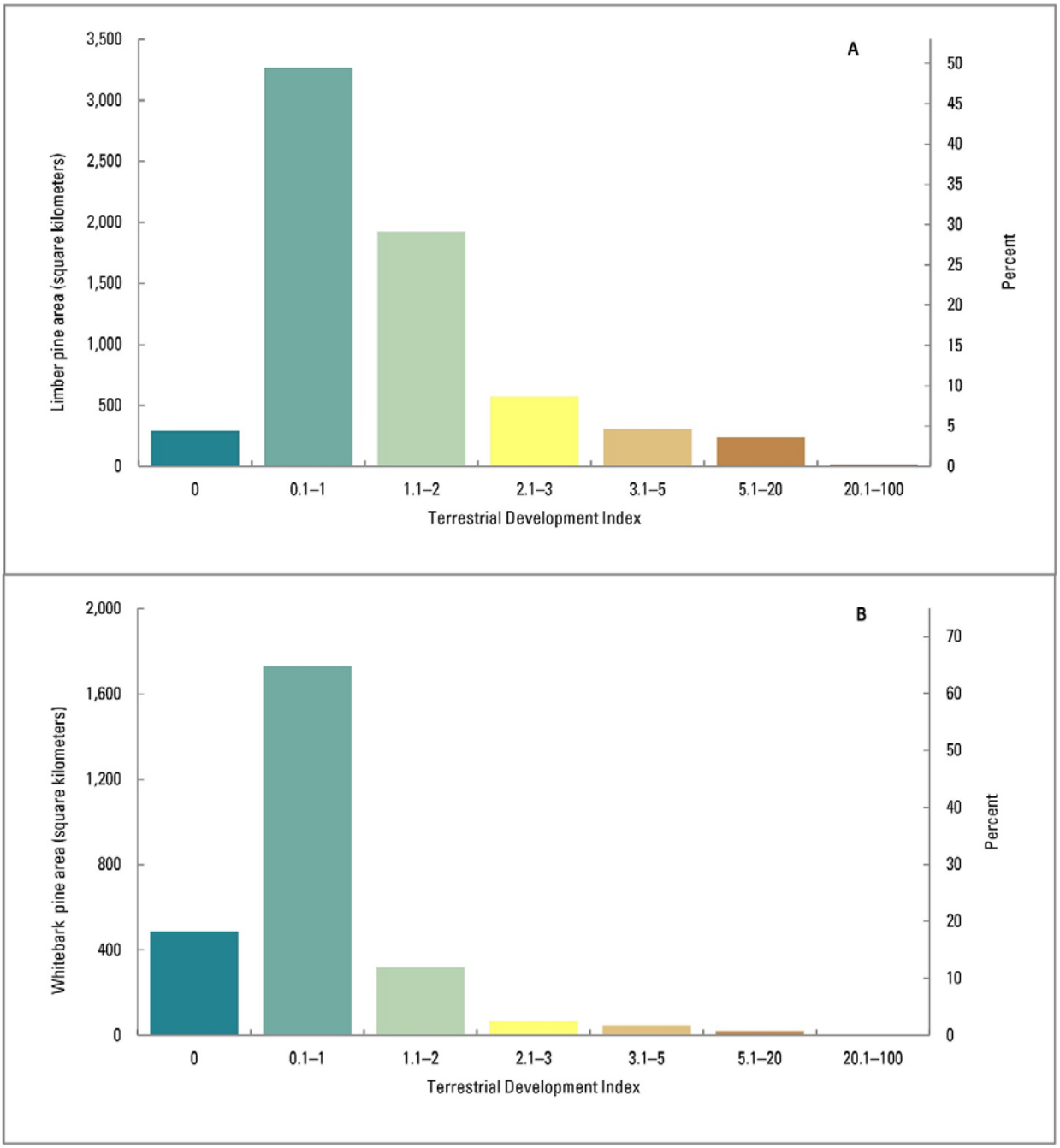

Figure 16−4. Area and percent of baseline (*A*) limber pine and (*B*) whitebark pine as a function of the Terrestrial Development Index in the Wyoming Basin Rapid Ecoregional Assessment project area.

How has development fragmented baseline five-needle pine forests and woodlands, and where are the large, relatively undeveloped patches (figs. 16−5 and 16−6)?

- Patch sizes for baseline, areas with low development, and relatively undeveloped areas of five-needle pines are generally similar, except for the largest patch sizes (figs. 16−5 and 16−6).
- Development is greatest in the smaller patch sizes at lower elevations (limber pine only), but roads at higher elevations have fragmented the largest patches >1,000 km^2 (386.1 mi^2).

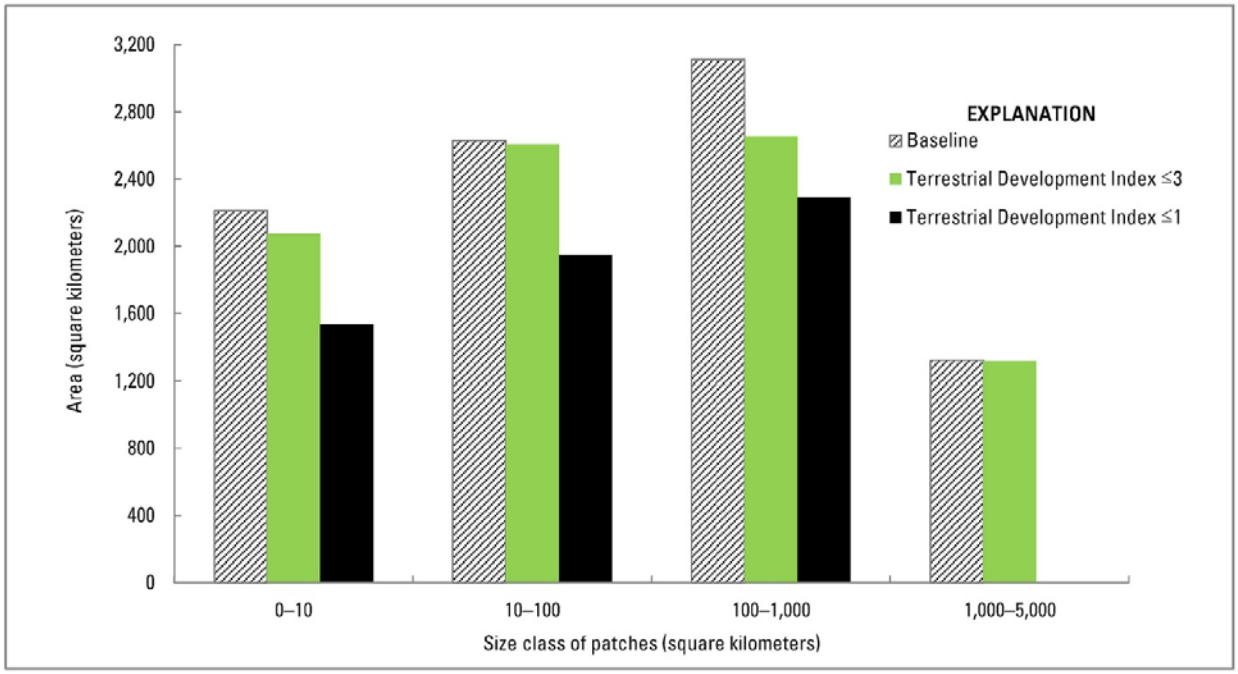

Figure 16−5. Area of five-needle pine forests and woodlands as a function of patch size for baseline conditions and two development levels: (1) Terrestrial Development Index (TDI) score ≤3 and (2) TDI score ≤1 percent (relatively undeveloped areas) in the Wyoming Basin Rapid Ecoregional Assessment project area.

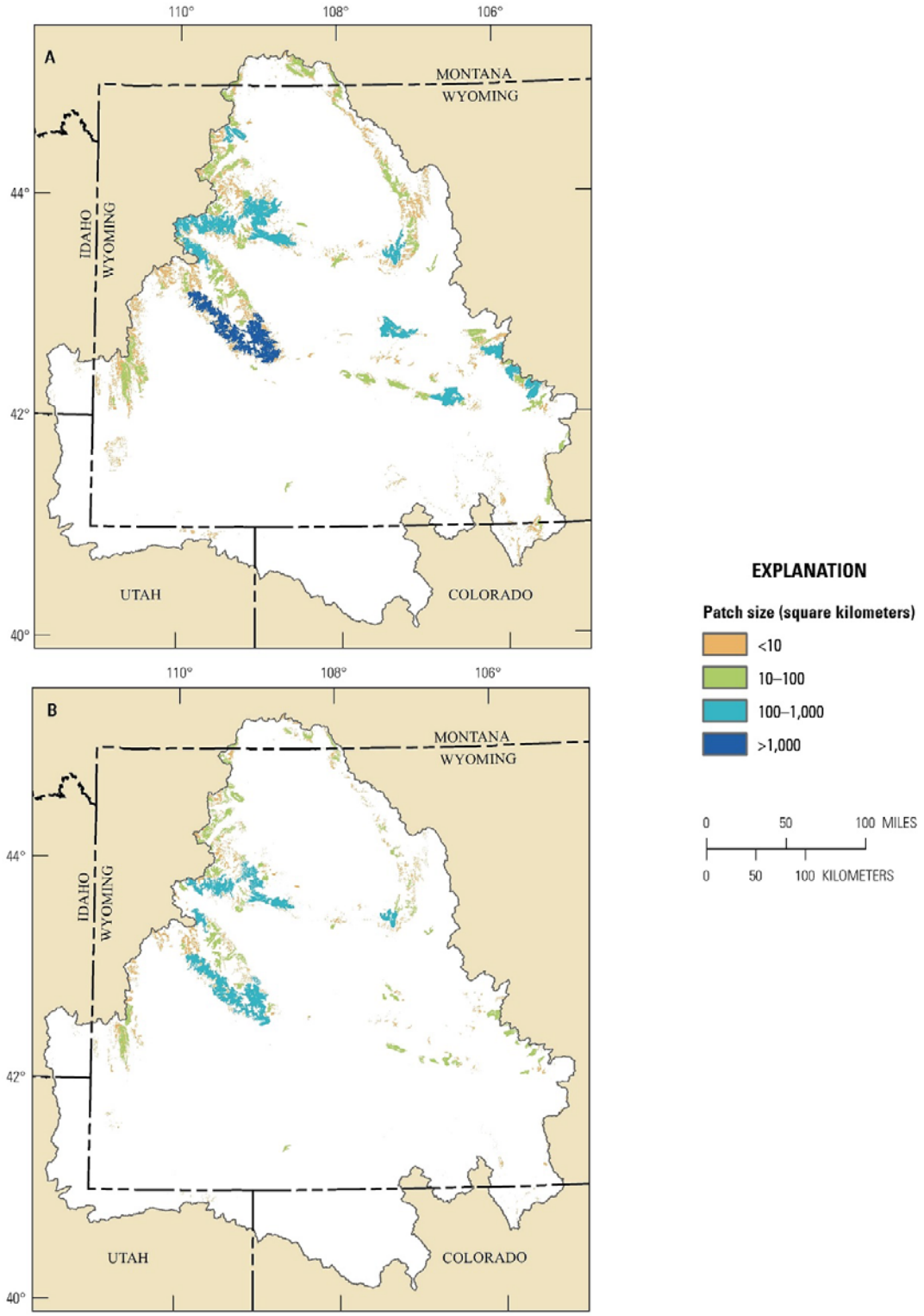

Figure 16−6. Patch sizes of five-needle pine forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area for (*A*) baseline and (*B*) relatively undeveloped areas (Terrestrial Development Index score ≤1 percent).

Where are baseline five-needle pines stands with high structural connectivity, which stands function as stepping stones (fig. 16–7)?

- Five-needle pine stands at lower elevations are small and isolated, leading to relatively large interpatch distances. At higher elevations, stands are typically well connected and have low development in the adjacent ecological communities, which may enhance recolonization by Clark's nutcrackers following tree mortality due to fire, bark beetles, or blister rusts, and facilitate regional shifts in response to climate change. Regional connectivity of baseline stands occurs at an interpatch distance of 9.09 km (0.65 mi) and 11.9 km (7.39 mi) for relatively undeveloped patches.
- Nonetheless, the large interpatch distances fall within the distances flown by Clark's nutcrackers and pinyon jays for seed caching (Tomback and others, 2011; Balda, 2002). Isolated patches of five-needle pine may serve as "stepping stones," thereby increasing structural connectivity among larger complexes of five-needle pine patches or patch complexes.
- Patches that are connected at local levels (1.08 km; 0.65 mi) may provide crucial food sources for pinyon jay flocks. The home range of pinyon jays is variable and depends on flock size, food availability, the amount of human use, among other factors. In Arizona, pinyon jay home range varied between 14 km^2 (5.41 mi^2) and 64 km^2 (24.71 mi^2) (Balda, 2002). High levels of development could diminish structural connectivity among patches. Decreased food availability as a result of blister rust or bark beetle occurrence could exacerbate the fragmenting effects of development and may lead to longer flights for the jays to find reliable food sources.

Where have recent fires and bark beetle outbreaks occurred in baseline five-needle pine forests and woodlands, and what is the total area affected (figs. 16–9 and 16–10)?

- Recent disturbances have affected a total of 363 km^2 (46.3 percent) of five-needle pine forests in the Wyoming Basin (figs. 16–9 and 16–10).
- Bark beetle outbreaks account for 82 percent of all disturbances in five-needle pine stands.
- Mortality from fire and bark beetles is highly variable.
- Bark beetles have affected 55.7 percent of whitebark pine area, compared to 35.7 percent of limber pine area (fig. 16–10).

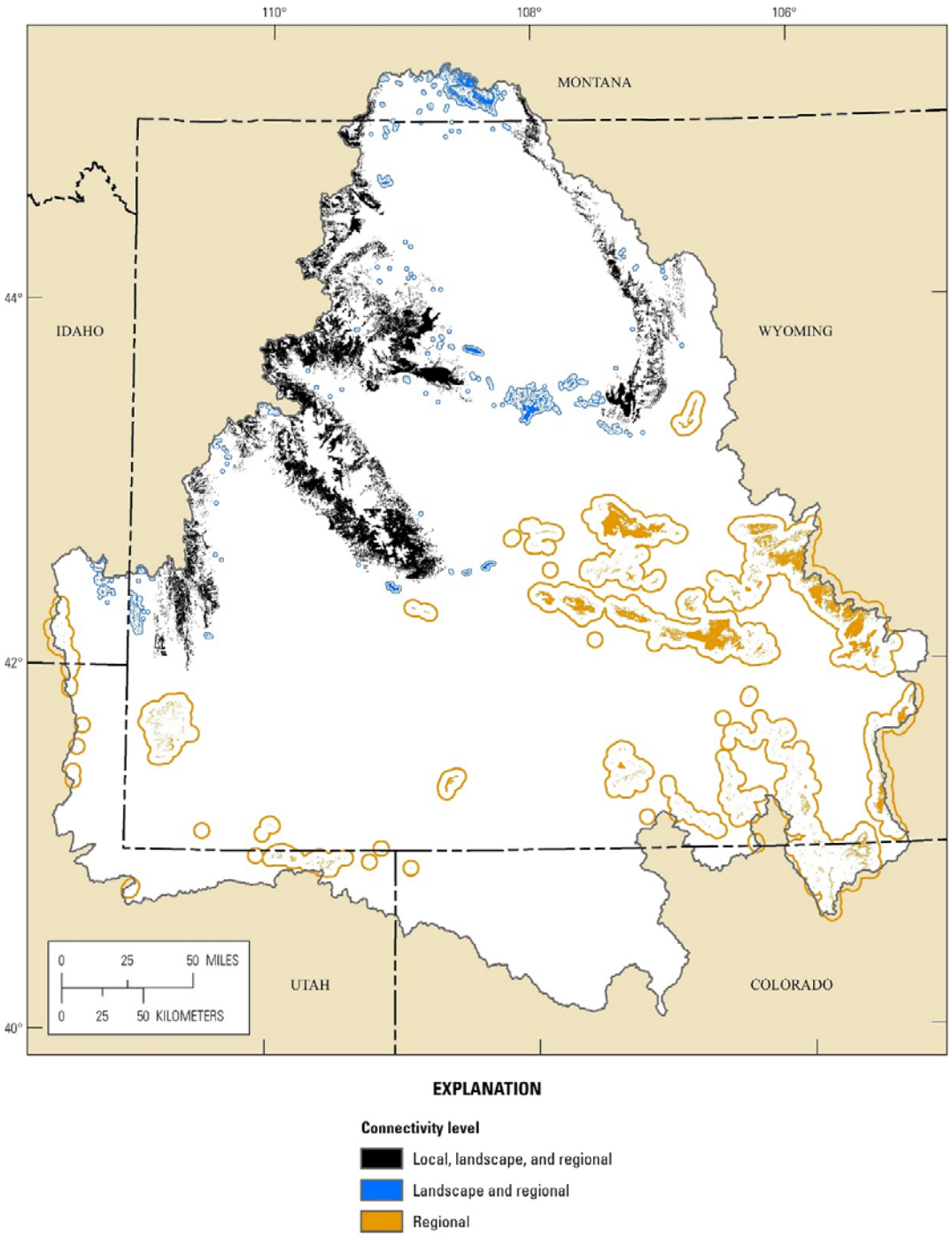

Figure 16−7. Structural connectivity of baseline five-needle pine forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. Black polygons include large and highly connected patches, primarily whitebark pine. Blue polygons include limber pine patches that contribute to both landscape and regional connectivity. Orange polygons represent clusters of isolated limber pine woodlands, which may be used by pinyon jay flocks in winter, and can serve as stepping stones connecting five-needle pine forests across broad expanses of sagebrush shrublands, thereby contributing to regional connectivity.

Where are potential barriers and corridors that may affect animal movements among baseline five-needle-pine patches (fig. 16–8)?

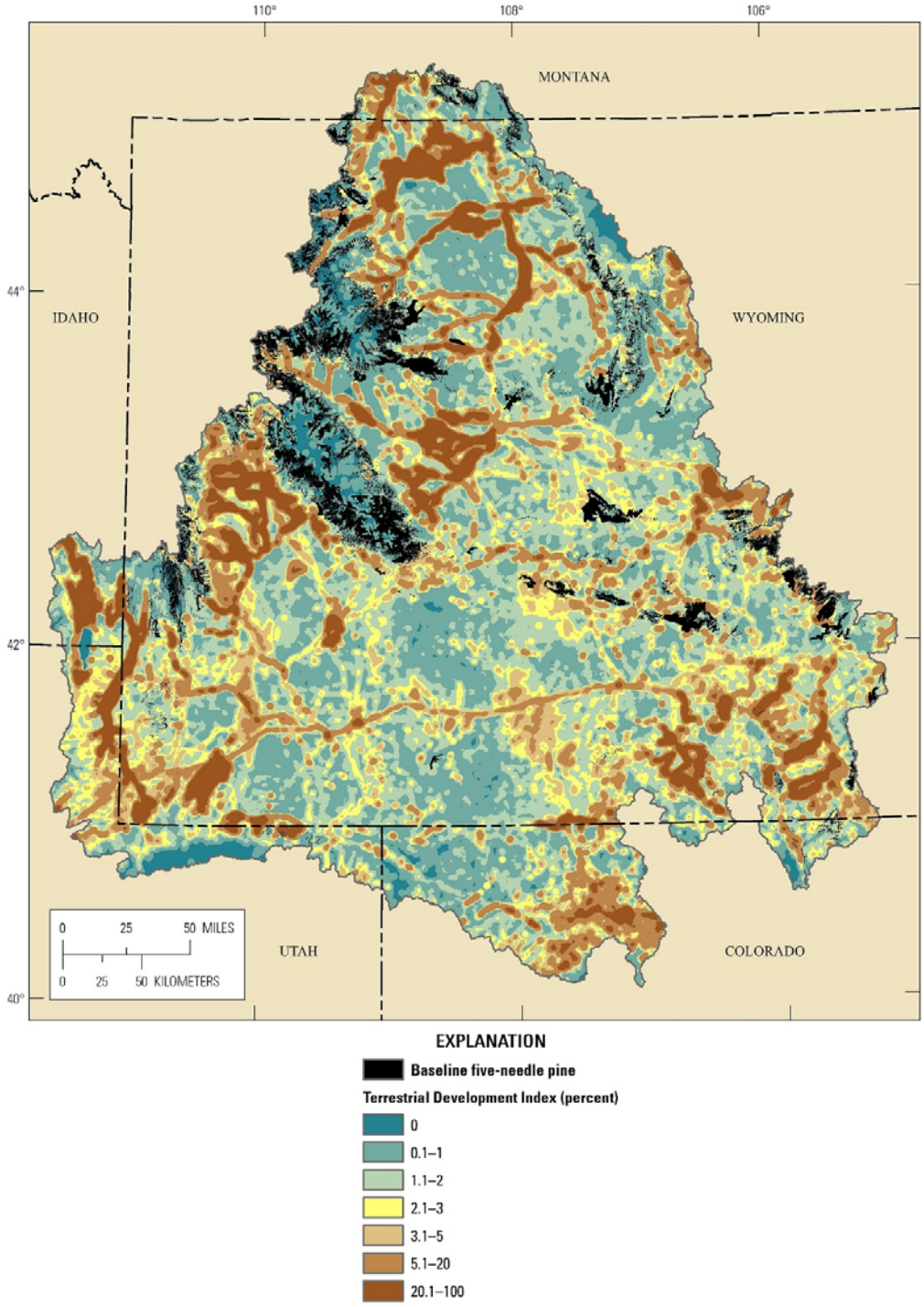

Figure 16−8. Potential barriers and corridors as a function of the Terrestrial Development Index (TDI) score for lands surrounding baseline five-needle pine stands. Higher TDI scores (for example, >5 percent) represent potential barriers to movement among relatively undeveloped patches. Lower TDI scores (for example, <2 percent) represent potential corridors for movements among patches.

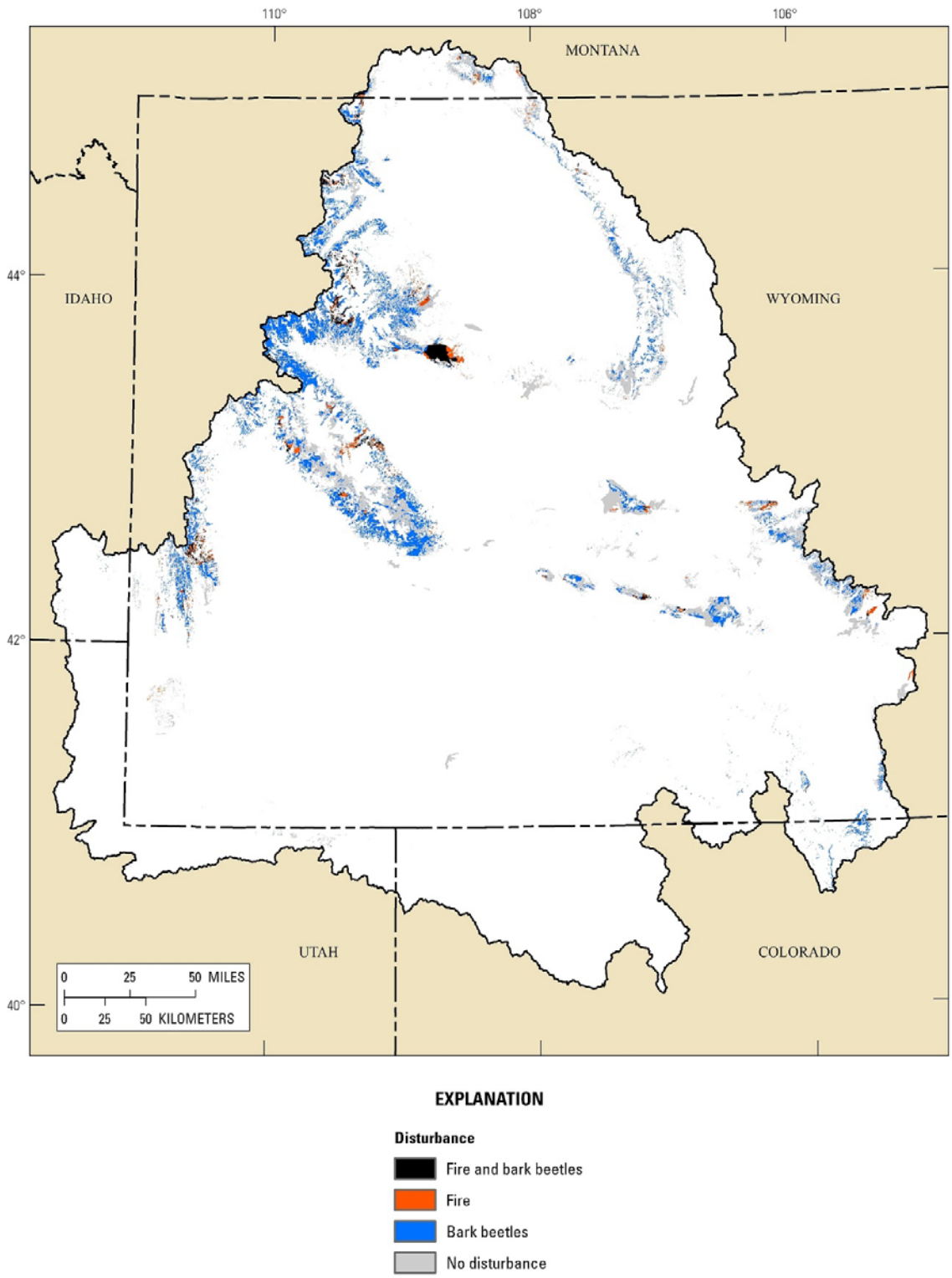

Figure 16−9. Occurrence of fire (since 1980) and bark beetles (since 1997) in baseline five-needle pine forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. Bark beetle occurrence is based on aerial flights; not all areas were surveyed, especially lower elevations.

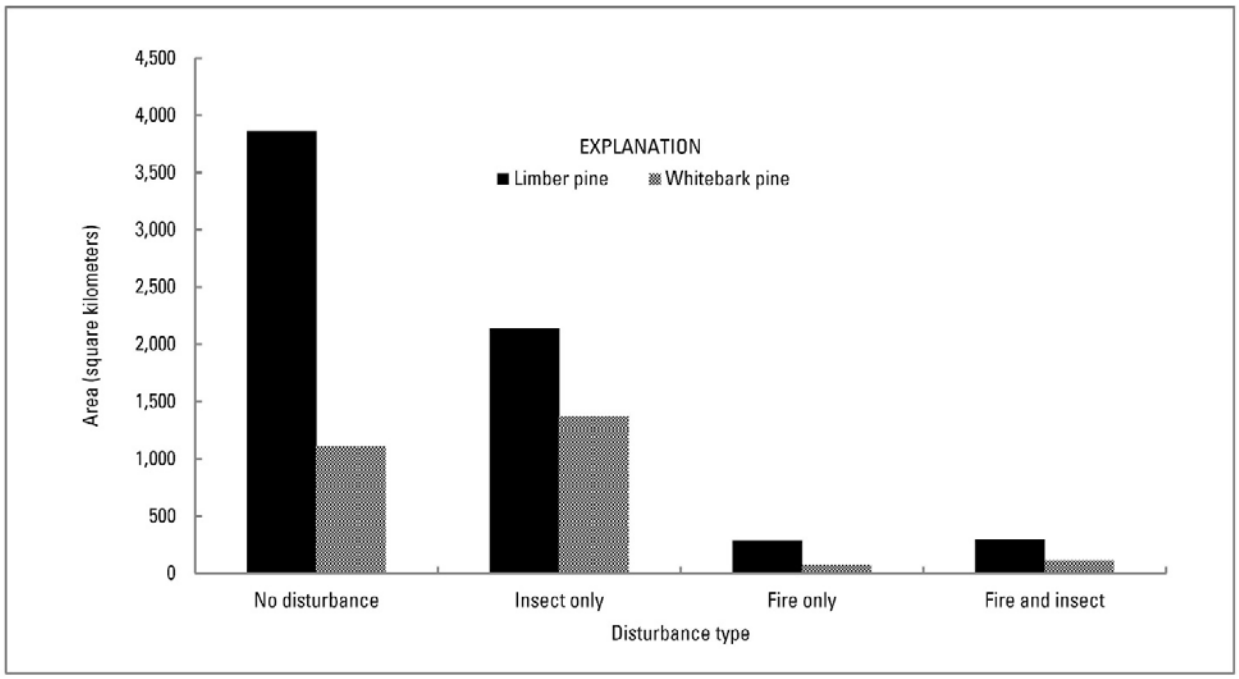

Figure 16−10. Area of baseline limber and whitebark pine forests and woodlands undisturbed and recently disturbed by insect and (or) fire occurrence in the Wyoming Basin Rapid Ecoregional Assessment project area (derived from fig. 16–9). Total area of limber pine in the project area is 6,601 square kilometers (km^2) (2,548.7 square miles [mi^2]) and 2,672 km^2 (1,031.7 mi^2) for whitebark pine.

Which limber pine stands in Wyoming and Colorado are at risk for white pine blister rust (fig. 16–11)?

- According to a model developed by Kearns and others (2014), 29 percent of limber pine stands in the Wyoming Basin are at risk from blister rust.
- The blister rust risk is widespread across the basin, with the exception of small stands of five-needle pines scattered throughout the Basin.

How have white pine blister rust and bark beetles affected the health of five-needle pine stands (fig. 16–12)?

- Blister rust infection and mortality from blister rust and mountain pine beetles is highly variable but widespread across the Wyoming Basin (Greater Yellowstone Whitebark Pine Monitoring Working Group, 2013; Cleaver, 2014). Most sampled areas had both dead and infected trees (Greater Yellowstone Whitebark Pine Monitoring Working Group, 2013), illustrating the widespread but heterogeneous occurrence of blister rust and bark beetles. Only a few sampled areas lack evidence of blister rust infection, and these are in the Sierra Madre Range.
- On average, uninfected live trees compose <50 percent of the plots sampled. Only a few areas have more than 75 percent of uninfected trees, and only one sampled area has 100 percent uninfected live trees.

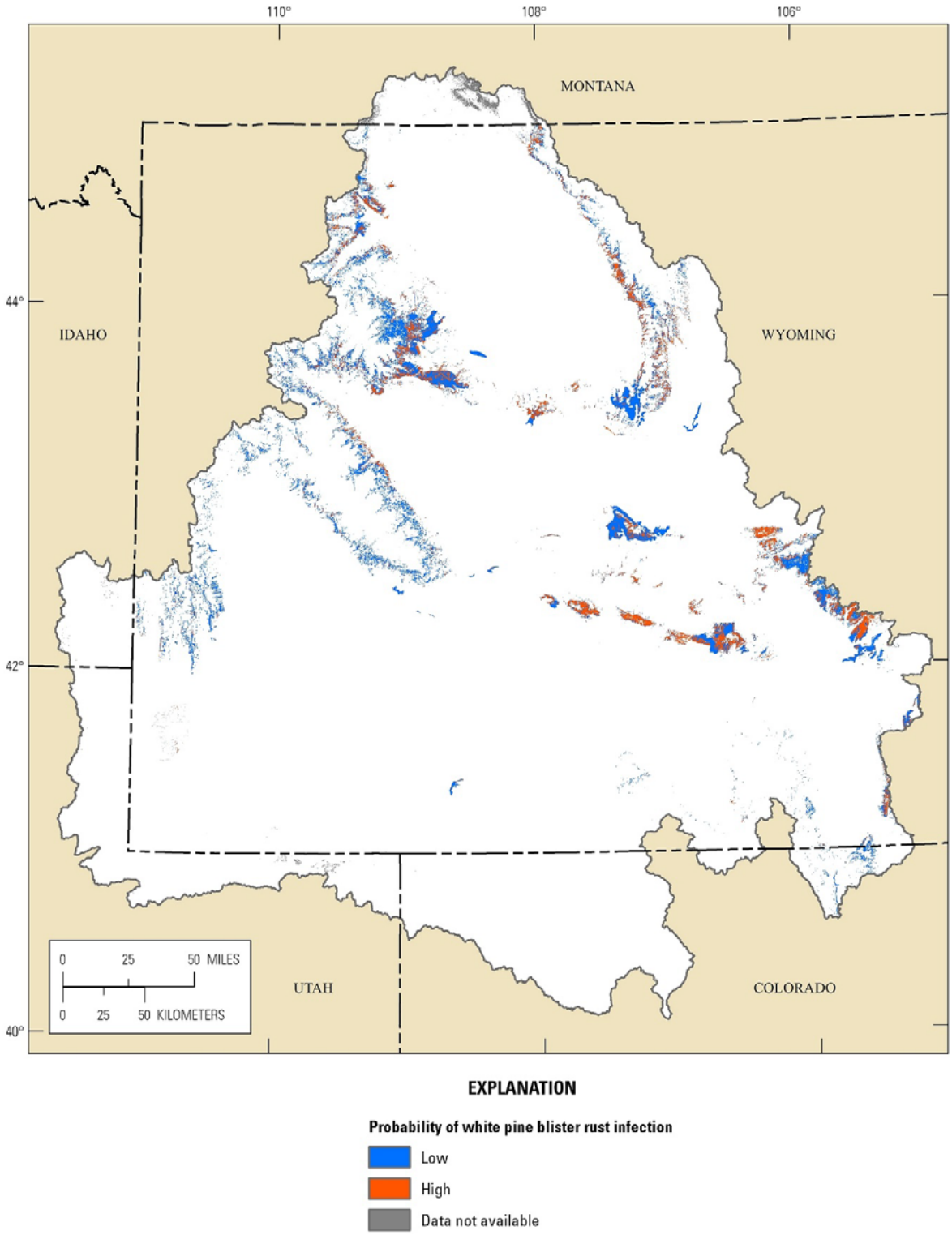

Figure 16−11. Limber pine stands at risk of infection by white pine blister rust in Colorado and Wyoming (derived from Kearns and others, 2014).

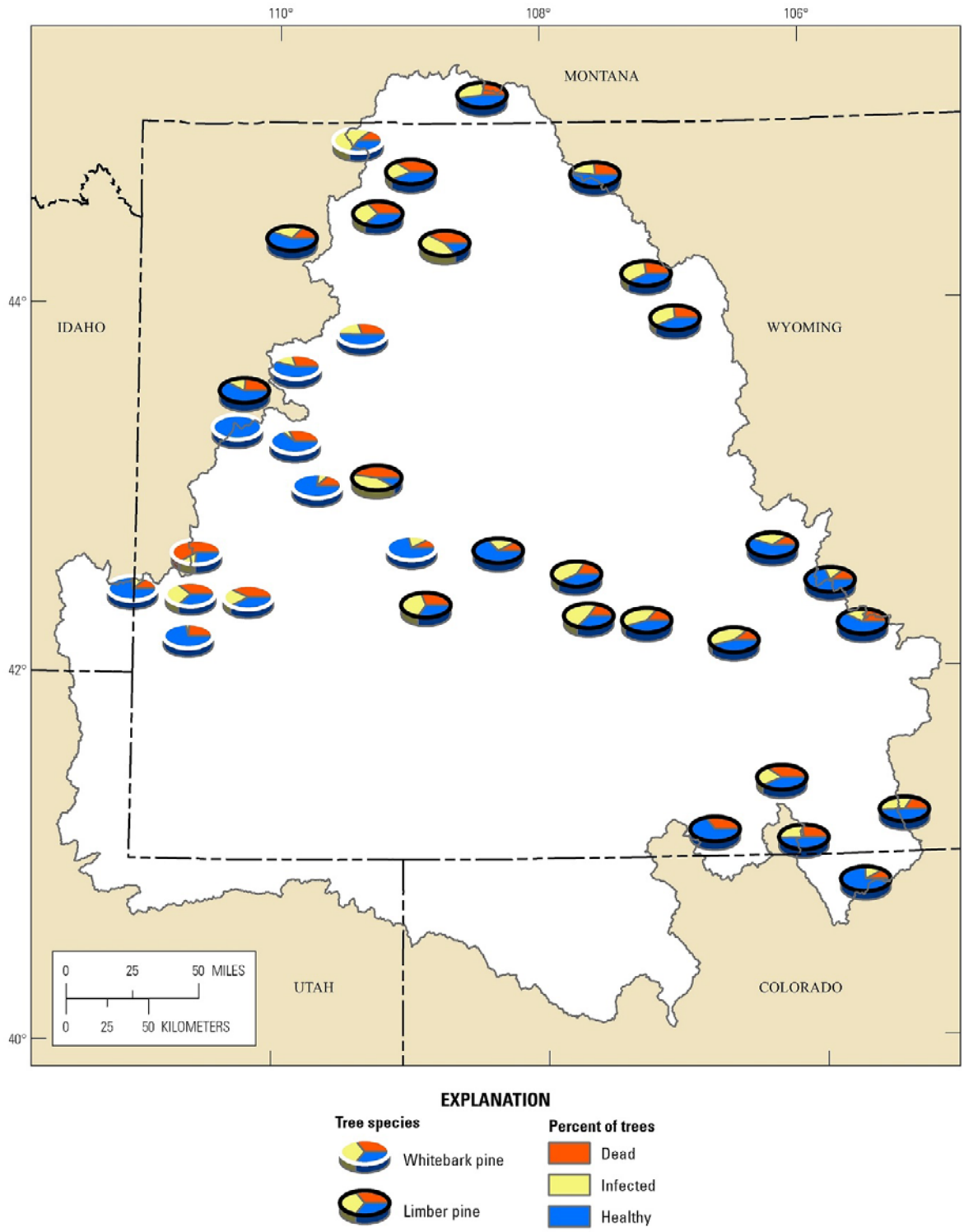

Figure 16−12. Ratio of healthy, dead, and infected five-needle pine trees. Pie charts represent the average of multiple survey plots derived from data on bark beetles and white pine blister rust that have occurred in whitebark pine stands of the Greater Yellowstone Ecosystem (Greater Yellowstone Whitebark Pine Monitoring Working Group, 2013) and limber pine stands throughout Wyoming and Colorado (Cleaver, 2014).

What is the potential distribution of five-needle pine forests and woodlands in 2030 (figs. 16−13 and 16−14)?

- The distribution of bioclimatic conditions conducive for five-needle pines is projected to decrease by 2030 for climate scenario I, although the models indicate some areas with potential for expansion (fig. 16–13*A*).
- Large areas that currently support limber pine woodlands are projected to have the potential for decline by 2030 using the climate-change scenarios examined (fig. 16–13*B*).
- The distribution of bioclimatic conditions conducive for whitebark pine is projected to move upslope by 2030, but some climate models indicate the potential for subsequent contraction of high-elevation stands by 2090 (figure 2–18 includes additional climate scenarios and time periods).
- For the climate scenario modeled here, 4.7 percent of whitebark pine may be vulnerable to decline by 2030; 34.4 percent by 2060, and 78.1 percent by 2090.

How does risk from development vary by land ownership or jurisdiction for five-needle pine forests and woodlands (table 16–5, fig. 16–15)?

- Most of the five-needle pine woodlands in the Wyoming Basin are found on U.S. Department of Agriculture Forest Service and BLM lands (table 16–5).
- Five-needle pine woodlands occurring on U.S. Department of Agriculture Forest Service, tribal, and other Federal lands had >76 percent of the area with the lowest risk from development, whereas only 43.7 percent of BLM lands had the lowest risk from development (fig.16−15).

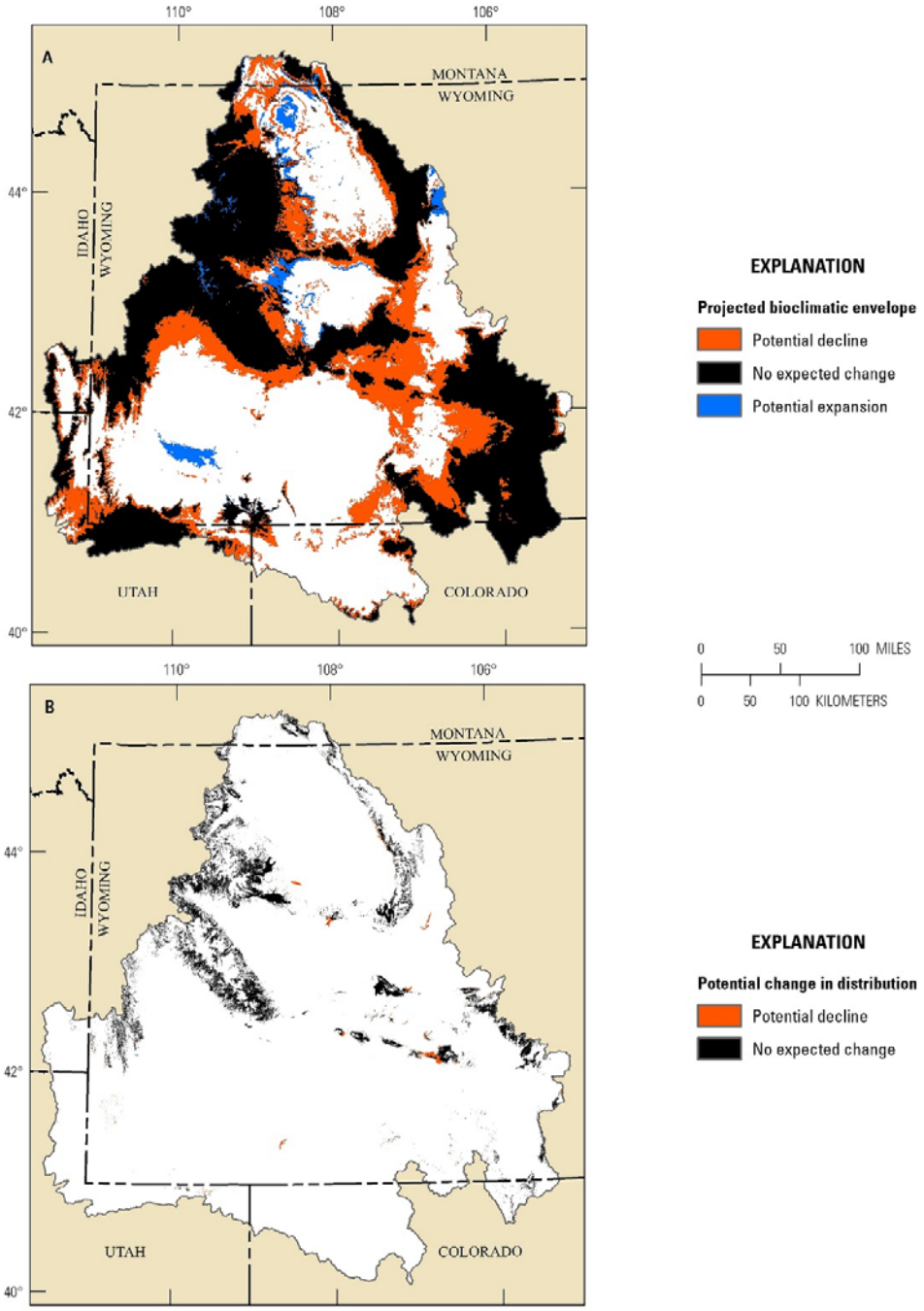

Figure 16−13. Potential effects of climate change on five-needle pine forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. (*A*) Projected changes in the bioclimatic envelope for five-needle pines derived from Rehfeldt and others (2012) for climate scenario I in 2030. Orange indicates areas with potential for decline because current and projected envelope distributions do not coincide. Black indicates areas not expected to change because the current and projected envelope distributions overlap. Blue indicates potential for expansion into areas that are outside the current envelope distribution. (*B*) Potential changes in baseline five-needle pines derived from overlap with the projected bioclimatic envelope distribution (as represented in *A*).

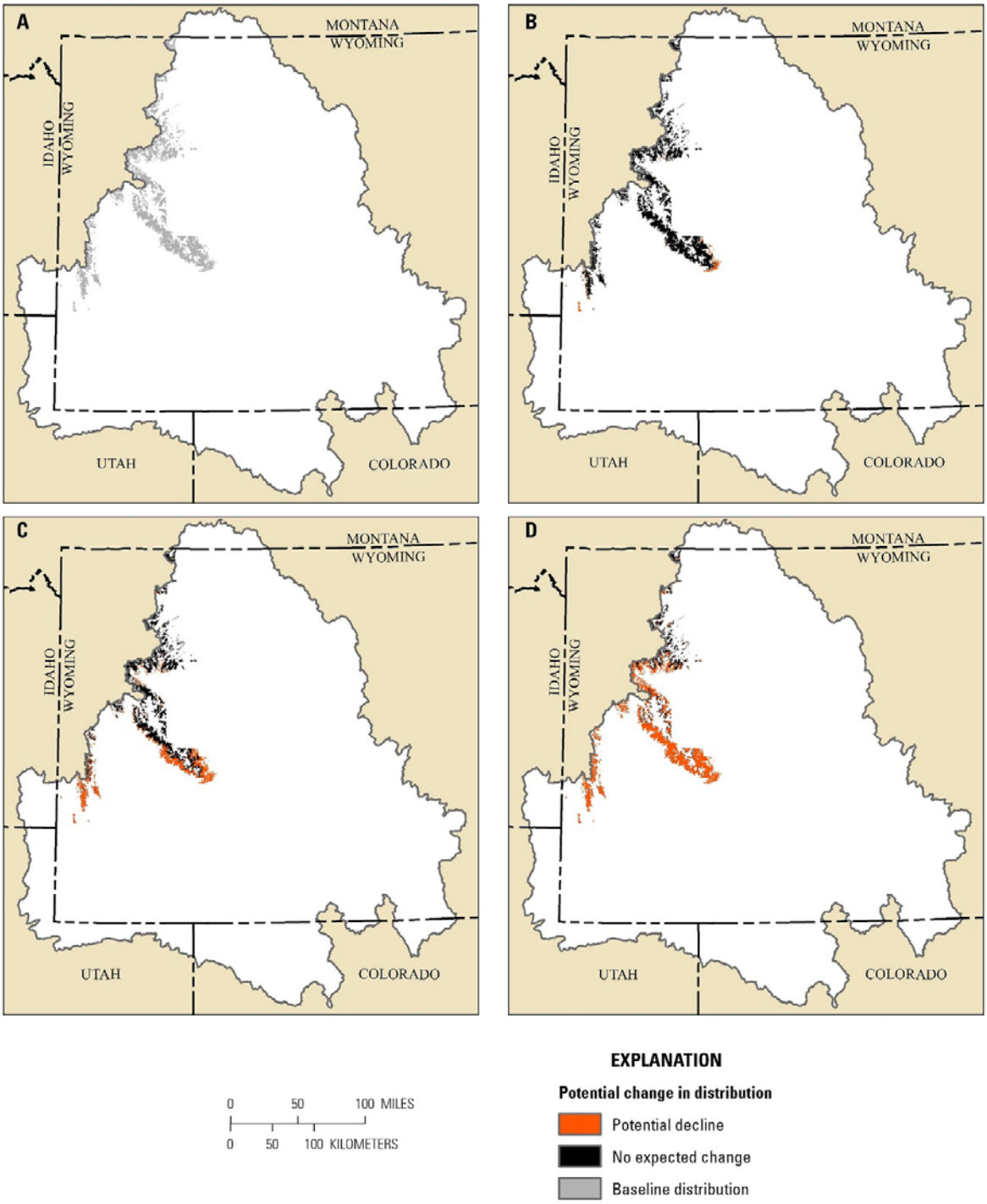

Figure 16−14. Potential effects of climate change on the distribution of whitebark pine in the Wyoming Basin Rapid Ecoregional Assessment project area. (*A*) Current baseline distribution. Changes to current distribution derived from the distribution of bioclimatic envelope for whitebark pine in (*B*) 2030; (*C*) 2060; and (*D*) 2090 (derived from Rehfeldt and others, 2012) for climate scenario I. Red represents where whitebark pine currently occurs but falls outside the distribution of the projected envelope. Black represents areas where existing whitebark pine falls within distribution of the projected envelope.

Table 16−5. Area and percent of five-needle pine forests and woodlands by land ownership or jurisdiction in the Wyoming Basin Rapid Ecoregional Assessment project area.

[km^2, square kilometer]

Ownership or jurisdiction	Total five-needle pine		Whitebark pine	Limber pine
	km^2	Percent	km^2	km^2
Forest Service[1]	4,640	50.0	2,412	2,228
Bureau of Land Management	1,770	19.1	34	1,736
Private	1,584	17.1	1,541	43
Tribal	743	8.0	12	731
State/County	454	4.9	1	453
Private conservation	69	0.8	0	69
Other Federal[2]	8	0.1	0	8

[1] U.S. Department of Agriculture Forest Service.

[2] National Park Service, and Bureau of Reclamation.

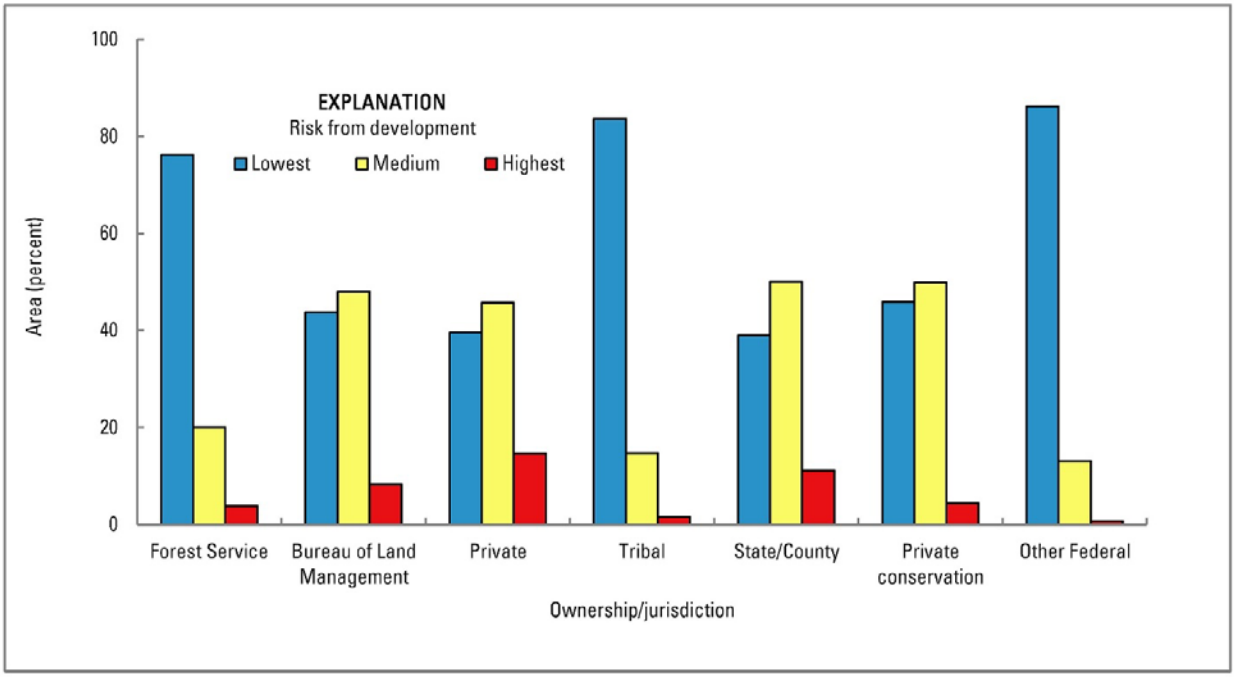

Figure 16−15. Relative ranks of risk from development, by land ownership or jurisdiction, for five-needle pine forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. Rankings are lowest (Terrestrial Development Index [TDI] score <1 percent), medium (TDI score 1−3 percent), and highest (TDI score >3 percent). [Forest Service, U.S. Department of Agriculture Forest Service]

Where are the townships with the greatest landscape-level ecological values, and where are the townships with the greatest landscape-level risks (fig. 16–16)?

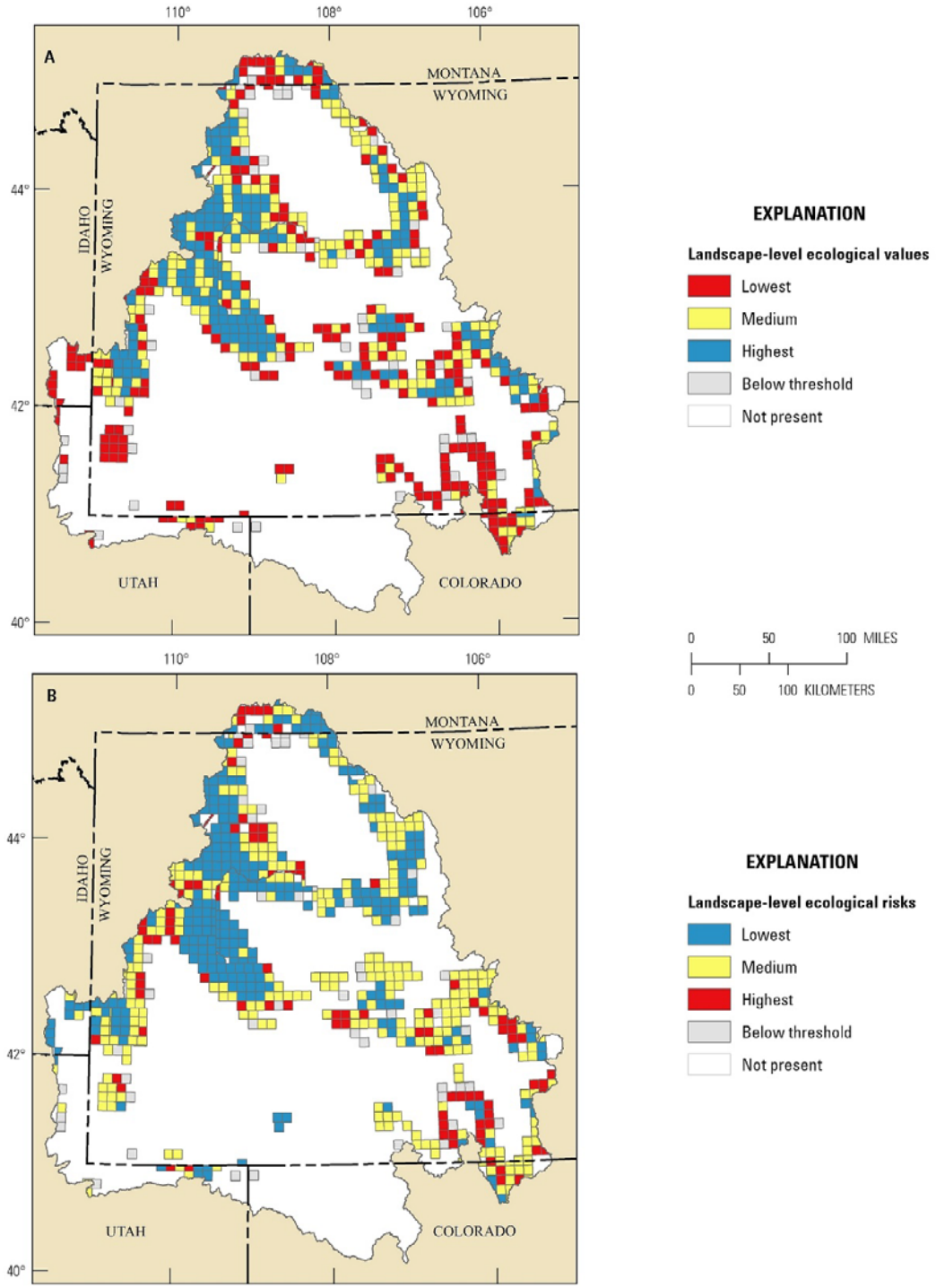

Figure 16−16. Ranks of landscape-level ecological values and risks for five-needle pine forests and woodlands, summarized by township, in the Wyoming Basin Rapid Ecoregional Assessment project area. (*A*) Landscape-level values based on area and (*B*) landscape-level risks based on Terrestrial Development Index (see table 16−3 for overview of methods).

Where are the townships with the greatest conservation potential (fig. 16–17)?

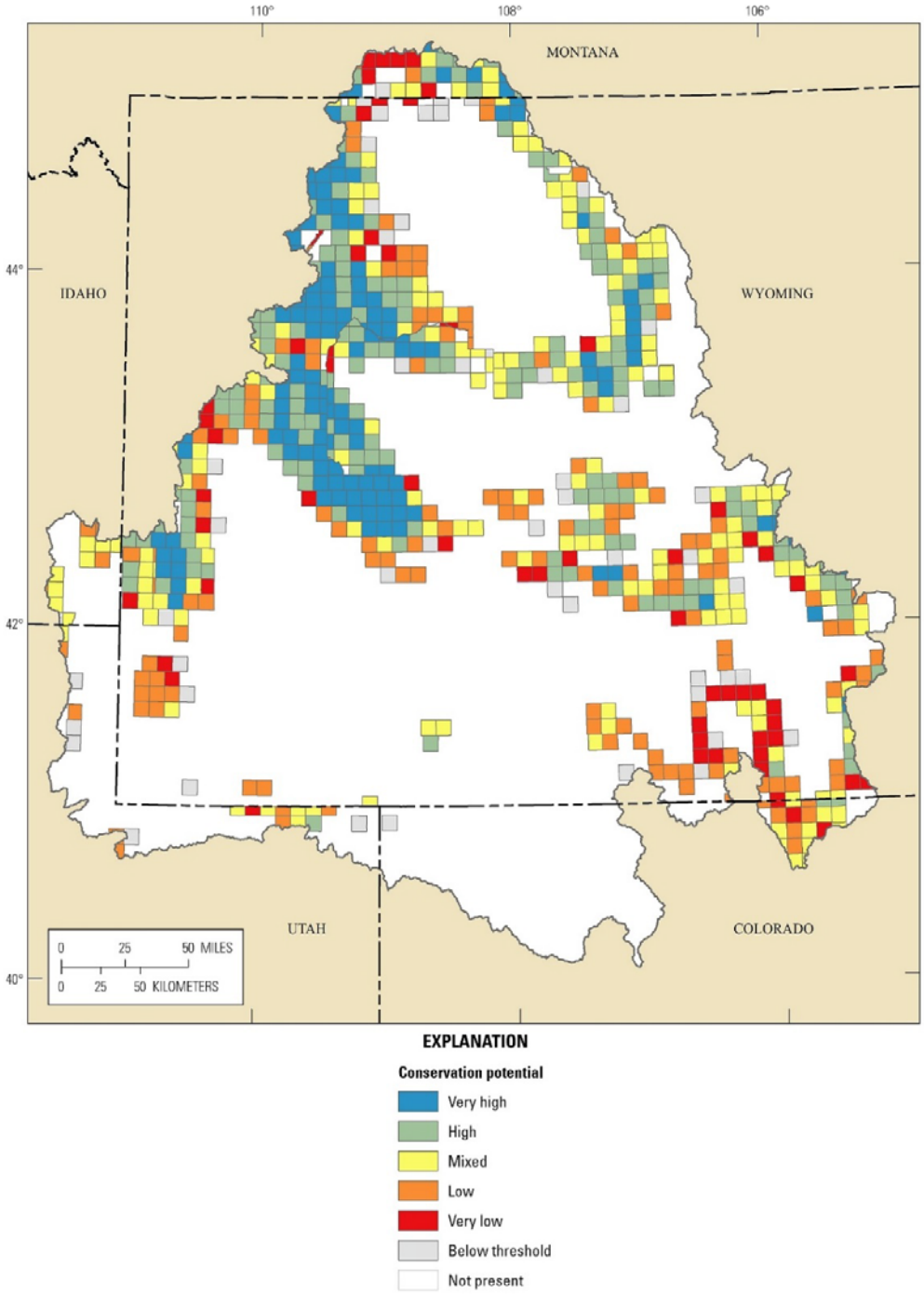

Figure 16−17. Conservation potential of five-needle pine forests and woodlands, summarized by township, in the Wyoming Basin Rapid Ecoregional Assessment project area. Highest conservation potential identifies areas that have the highest landscape-level values and the lowest risks. Lowest conservation potential identifies areas with the lowest landscape-level values and the highest risks. Ranks of conservation potential are not intended as stand-alone summaries and are best interpreted in conjunction with the geospatial datasets used to address Core Management Questions.

Summary

Five-beedle pines are broadly distributed in the foothills at upper elevations in the Wyoming Basin. Most whitebark pine, however, occurs along the periphery of the project area. Whitebark pine composed 28.9 percent of the total five-needle pine distribution in the Basin. Almost 70 percent of five-needle pine is under Federal jurisdiction; U.S. Department of Agriculture Forest Service lands have a greater proportion of whitebark pine, whereas Bureau of Land Management (BLM) lands have a greater proportion of limber pine.

Although stand-level information (such as mortality rates, blister rust occurrence, stand structure, and regeneration) will be necessary for full assessment of the condition of five-needle pine forests, the landscape-scale information summarized herein provides information crucial for understanding regional threats to five-needle pine forests. In contrast to most other communities and species, development poses a relatively limited and localized threat to five-needle pine stands, which are more common at higher elevations and along steeper rocky slopes, where development levels are low. The highest Terrestrial Development Index scores occur in limber pine stands at lower elevations, but roads at higher elevations fragment some of the largest whitebark pine stands.

The widespread and virulent nature of white pine blister rust is of particular concern for the long-term viability of five-needle pine forests and woodlands in the Wyoming Basin. Although the five-needle pines are adapted to, and may benefit from, the forest openings created by fire and bark beetles, the extent of the recent bark beetle outbreak compounds the risks posed by blister rust (Tomback and others, 2011). Most areas are currently at high risk for blister rust, and the remaining areas at lower risk are still vulnerable to infection because blister rust spores can readily disperse across large distances (Kearns and others, 2014). The time required for these pine species to reach sexual maturity and the isolated nature of many five-needle pine stands could delay recovery time following the widespread bark beetle outbreak. This could negatively affect Clark's nutcracker and pinyon jay populations and, in turn, further slow the recovery of five-needle pine stands (McKinney and others, 2009; Tomback and others, 2011). As a result, the occurrence of five-needle pines on the landscape may decrease in the short term. This also could affect some grizzly bear populations that rely on whitebark pine seeds (Tomback and others, 2011). Projected changes in the bioclimatic envelope for five-needle pine for certain climate scenarios indicate the potential for additional declines in five-needle pine forests and woodlands over the next 75 yr. Both species are forecasted to decrease significantly in basal area (a surrogate for tree density) in the next 15 yr (Krist and others 2014). Of note is the forecast for smaller declines along the range margin of whitebark pine where the BLM stands are located and in the interior of the REA where limber pine occurs exclusively on BLM and private lands.

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