Section IV. Assessments of Species and Species Assemblages

Chapter 15. Aspen Forests and Woodlands

By Natasha B. Carr, Steven L. Garman, Kirk R. Sherrill, and Cynthia P. Melcher

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Key Ecological Attributes

Distribution and Ecology

Quaking aspen is widely distributed throughout much of North America, occurring across the mountain West, Northeast United States, and most of forested Canada. Aspen occurs across a broad range of elevations but is most common where annual precipitation exceeds evapotranspiration (Shinneman and others, 2013). In the Wyoming Basin, the most extensive aspen forests are found primarily along the ecoregion periphery, although smaller stands occur locally within sagebrush shrublands and in the Owl Creek, Green, Shirley, Ferris, Seminoe, and South Big Horn Mountains, as well as the Little Mountain Ecosystem, Rattlesnake Range, and Commissary Ridge. Aspen-stand structure can be quite variable depending on local biophysical conditions. The largest trees and most extensive forests occur in areas with limited topographical relief and moist, fertile soils, whereas smaller stands of stunted trees may occur in the alpine zone or in wet microsites surrounded by xeric shrublands (Knight, 1994; Shinneman and others, 2013).

Physiological characteristics of aspen contribute to its broad distribution. These characteristics include a high tolerance to stress compared to that of other *Populus* species, an ability to respond to environmental conditions by producing smaller or larger leaves, more tolerance to cold temperatures and shorter growing seasons than most hardwoods, leaf petioles that promote leaf-cooling through fluttering, a high rate of photosynthesis, and photosynthetic bark (Shepperd and others, 2006). Aspen are clonal and regenerate primarily through sprouting from their extensive underground root systems. They can reproduce by seed, but this does not happen frequently (Shepperd and others, 2006; Long and Mock, 2012). Mature stems inhibit sucker development, but when the overstory is killed or removed, suckering increases, thus promoting a new cohort of overstory stems.

Landscape Structure and Dynamics

Aspen stands in the Wyoming Basin have been categorized into several functional types (using plant associations, elevation, topography, and soils) (Rogers and others, 2014). The two most common types are (1) mountain slope forests occurring in montane and subalpine zones, generally at elevations >2,590 meters (m) (8,500 feet [ft]), and (2) foothill woodlands, generally at elevations of <2,590 m (8,500 ft) (Knight, 1994). Mountain slope aspen may form pure stands, but usually it occurs in association with conifer species, including Douglas-fir, lodgepole pine, Engelmann spruce, and subalpine fir (Knight, 1994). Foothill aspen usually occurs in relatively discrete and often small stands where soils are deeper and more mesic than they are in the surrounding terrain, which is dominated by sagebrush or deciduous shrublands (Knight, 1994). Typically, aspen is the dominant tree species in stands of foothill aspen, which also may include juniper, limber pine, chokecherry, and serviceberry (Knight, 1994). Locally, some stands may include both mountain slope and foothill aspen, thus forming a continuum along an elevational gradient; at lower elevations, these stands exhibit characteristics of foothill aspen, and with increasing elevation they gradually shift to the structure and function of mountain slope aspen (Kurzel and others, 2007).

Aspen is often considered to depend on fire for long-term persistence, yet aspen may form relatively stable stands in the absence of fire (Shinneman and others, 2013; Rogers and others, 2014). Fire regimes of aspen forests and woodlands vary spatially and temporally with variations in stand composition and structure, landscape context, and climate (Shinneman and others, 2013). Some aspen stands are fire-independent and rarely experience fire or are influenced by fire but do not depend on it for persistence. Both fire-independent and fire-influenced stands typically occur in areas that lack abundant conifers and are relatively stable in the absence of fire (Shinneman and others, 2013). In contrast, aspen stands mixed with conifer are typically seral and require fire or other severe disturbances to maintain canopy dominance over the more shade-tolerant conifers (Kurzel and others, 2007; Shinneman and others, 2013). Other causes of episodic die-back in the canopy (including aspen senescence or insect outbreaks in conifers) can lead to pulses of aspen regeneration (Kurzel and others, 2007; Pelz and Smith, 2013). Aspen also may co-dominate the forest canopy with conifers for prolonged periods, sometimes exceeding 150 years) (Kurzel and others, 2007).

In the Wyoming Basin, foothill aspen stands typically persist in the absence of fire (Knight, 1994). Multiage stand structures are common, as aspen may regenerate beneath the mature canopy (Knight, 1994; Kashian and others, 2007). If, however, these aspen woodlands are subjected to prolonged, severe drought or intense and chronic herbivory by large mammals, sagebrush and other shrubs may expand within the stands and ultimately the aspen may disappear (Bartos, 2001).

Mountain slope aspen in the Wyoming Basin is generally fire-dependent (Knight, 1994). Because the dynamics of these forests across broad landscapes are driven by infrequent natural disturbances, the degree of aspen dominance can vary over decades or centuries, in part due to variations in time since fire (Kulakowski and others, 2006). The recent widespread outbreak of mountain pine beetle in mixed aspen-conifer forests may promote a shift in dominance due to conifer mortality in the overstory and subsequent release of understory aspen from conifer suppression in the overstory (Diskin and others, 2011). The degree to which aspen expands following bark beetle outbreak will depend on the degree of overstory mortality, stem density and age of aspen trees, grazing pressure, and other site conditions (Pelz and Smith, 2013). Aspen is expected to be favored in areas where mortality of competing conifers is high, which results in larger canopy gaps (Pelz and Smith, 2013).

Widespread, severe drought and unusually warm temperatures also can contribute to large-scale aspen canopy die-off, known as sudden aspen decline (SAD) (Worrall and others, 2008; Anderegg and others, 2013). Recent widespread occurrence of SAD was associated with extreme moisture stress resulting from the combination of high summer temperatures and low soil moisture (Anderegg and others, 2013). Where suckers and the root mass remain viable, aspen forests have the potential to recover, but many severely affected stands have limited regeneration potential, which ultimately can lead to the loss of those stands (Worrall and others, 2013). Local factors that increase vulnerability to SAD include moisture stress, typically found at lower elevations and on southwestern aspects; outbreaks of insects and other pathogens; and high levels of herbivory (Kashian and others, 2007; Worrall and others, 2008). Aspen are susceptible to a variety of diseases, but diseases rarely kill live trees in otherwise healthy stands (Hinds, 1985).

Herbivory by wild ungulates, including elk, mule deer, and moose, can have significant effects on aspen regeneration. Aspen suckers, twigs, and bark are highly palatable to wild ungulates and are used as a principal winter food source in many areas (DeByle and Winokur, 1985; Bartos and Campbell, 1998). At low levels, browsing can enhance nutrient cycling and plant growth (Lindroth and Sinclair, 2013; Seager and others, 2013). At high levels, however, browsing can suppress or eliminate aspen sprouts, leading to decreased recruitment into the canopy and even the death of the stand (Eisenburg and others, 2013; Seager and others, 2013). The effects of herbivory on the dynamics of aspen stands depends on many factors, including ungulate population levels, predator-prey dynamics, fire occurrence, and accessibility of aspen stands (Eisenberg and others, 2013).

Associated Species of Management Concern

Aspen forests support a rich diversity of understory plants, invertebrates, and wildlife species (DeByle and Winokur, 1985), particularly in the central Rocky Mountains, where aspen forests are key contributors to regional biological diversity (Campbell and Bartos, 2001). Aspen trees and the highly productive herbaceous understory represent a major food source for native ungulates (DeByle and Winokur, 1985). Aspen is also a primary food for beavers (DeByle, 1985). Cavity-nesting birds in the western United States often favor aspen over other tree species (Dobkin and others, 1995) and, in the "sea of sage" that typifies many parts of the Wyoming Basin and other intermountain basins, migratory songbirds make significant use of aspen forests as stopover sites during migration (Bowen and others, 2013). Snowshoe hares, major prey items for the Canada lynx, also inhabit aspen forests.

Change Agents

Development

Energy and Infrastructure

Development, including infrastructure associated with energy development, can have direct and indirect effects on aspen. Occurrence of roads in aspen stands increases the proportion of edges, which may cause changes in micro-climatic conditions. Additionally, secondary and tertiary roads often are used as travel routes by wild and domestic ungulates; this results in greater browsing pressure along these pathways. Increased browsing could exacerbate the effects of SAD by decreasing the potential for stand regeneration (Shepperd and others, 2006). Recreation pressures, such as hunting, camping, and off-highway vehicle traffic may be greater where roads provide access to aspen stands.

Agricultural Activities

Agricultural activities, including cultivation, livestock use, and forestry practices, can directly and indirectly affect aspen forests. Locally, water diversions for croplands could affect aspen forests by altering soil moisture. Proximity of agriculture (such as irrigated pastures and alfalfa fields) to aspen could increase herbivory pressure from wild ungulates that may use these agricultural lands. Domestic ungulates also forage in aspen stands (Kay and Bartos, 2000). Although aspen has limited commercial timber value in the Wyoming Basin, forestry practices used to remove conifer trees, including thinning and clearcutting, can affect aspen stand structure and dynamics.

Altered Fire Regime

Generally, it has been assumed that fire suppression has reduced fire frequency, thereby facilitating increased stem density and expansion of conifers in aspen forests (Knight, 1994).

Because fire suppression is a relatively recent phenomenon, however, it probably has had little effect on fire regimes except perhaps in the lower montane where fires were more frequent (Baker, 2009). There is little evidence that fire regimes have been altered in mountain slope forests, and historically, fires were relatively rare in foothill woodlands (Baker, 2009; Shinneman and others, 2013). In the Wyoming Basin, prescribed fire is sometimes used to stimulate aspen regeneration, primarily for native ungulate forage. Interactions between wildfire, fire-management practices, and ungulate herbivory can pose significant risks to aspen persistence, especially during prolonged drought. In areas where the intensity of herbivory from wild and domestic ungulates is high, wildfire and prescribed fire can lead to the loss of aspen stands if postfire regeneration is suppressed by ungulates (Seager and others, 2013).

Invasive Species

Although invasive plant species occur in aspen forests (Chong and others, 2001), they do not appear to be a major concern for aspen in the Wyoming Basin. Roads, however, as well as logging and fire, can facilitate the spread of nonnative, invasive plants into aspen stands. For example, Canada thistle and common mullein can increase locally in burned sites.

Climate Change

Over the long term, changes in precipitation and temperature have the potential to shift the bioclimatic envelope that is conducive for aspen to higher elevations and latitudes (Rehfeldt and others, 2009). The ability of aspen to withstand or keep pace with rapid climate shifts is of concern given its limited regeneration by seed. Because many aspen forests and woodlands suffering from SAD occur at the species' margin of ecological tolerance, they are especially vulnerable to climate change (Rehfeldt and others, 2009; Worrall and others, 2013). On the other hand, some climate-change models project that fire frequency and severity could increase in mid-elevation forests (Westerling and others, 2011), which could favor aspen in some circumstances (Romme and others, 2005; Kulakowski and others, 2013).

Rapid Ecoregional Assessment Components Evaluated for Aspen

A generalized, conceptual model was used to highlight some of the key ecological attributes and Change Agents affecting aspen forest and woodlands (fig. 15–1). Key ecological attributes addressed by the REA include (1) the distribution of mountain slope and foothill aspen, (2) landscape structure (patch size, structural connectivity, and core area), and (3) landscape dynamics (aspen dynamics, aspen-conifer ecotone dynamics, and sudden aspen declines) (table 15–1). The Change Agents evaluated for aspen include development (especially roads) and climate change (table 15–2). Ecological values and risks used to assess the conservation potential of aspen forests and woodlands by township are summarized in table 15–3. Core Management Questions and Integrated Management Questions and the associated summary maps and graphs are provided in table 15–4.

Methods Overview

We used LANDFIRE Existing Vegetation Types (EVT) to classify aspen into foothill and mountain slope functional types based on contextual properties (adjacency to shrublands or montane and subalpine conifer forest types) and elevation. We used the resulting distribution map to quantify baseline conditions for aspen. Because the spatial attributes of aspen vary by functional type, we quantified most key ecological attributes for each type separately. We assessed development levels in the two functional types using the Terrestrial Development Index (TDI) map, and then used the resulting output to calculate patch size and structural connectivity. We mapped the structural connectivity of baseline aspen for each functional type at three interpatch distances using the connectivity analysis: local (0.27 kilometers [km]; 0.17 miles [mi]), landscape (1.35 km; 0.84 mi), and regional (6.48 km; 4.03 mi) levels.

Preliminary analyses indicated that the surface footprint of transportation (roads and railroads) was the only development variable that overlapped the baseline aspen map by more than 1 percent (transportation overlap was 6.12 and 7.08 percent for mountain slope and foothill aspen, respectively); consequently this was the only development variable used to quantify edge effects (table 15–2). Because levels of livestock and wild ungulate herbivory are often high along aspen-road edges, we evaluated the amount of core area (interior portions of patch for specified buffer width) within 60 m (196.9 ft) of roads that intersected aspen stands. We used the percent of core area within the road buffer as an index of protection from herbivory as well as from human disturbance resulting from road access.

The occurrence of disturbance from fire (since 1980) or insect mortality since 1997 (table 15–1) was used as an index of potential aspen dynamics. Perimeters of fires and areas with insect mortality were compiled from several sources. Recent disturbance in mountain slope aspen stands was used to identify areas with potential for competitive release from conifer in the overstory. To identify areas where aspen and conifer stands have potential for expansion in the next several decades, we quantified conifer occurrence and mortality within 30 m (98.4 ft) of existing mountain slope aspen. Disturbance in adjacent conifer forests was used to indicate potential aspen expansion. Adjacent conifer forests with more than 25 percent conifer that had not been affected by fire or bark beetles since 1997 were used to indicate areas with high conifer-expansion potential. We assumed that greater proportions of conifer in areas adjacent to aspen indicate greater potential for conifer expansion when evaluated across broad landscapes. However, most mountain slope aspen was classified as mixed-conifer aspen; consequently, full evaluation of conifer-expansion potential requires local (stand-level) data.

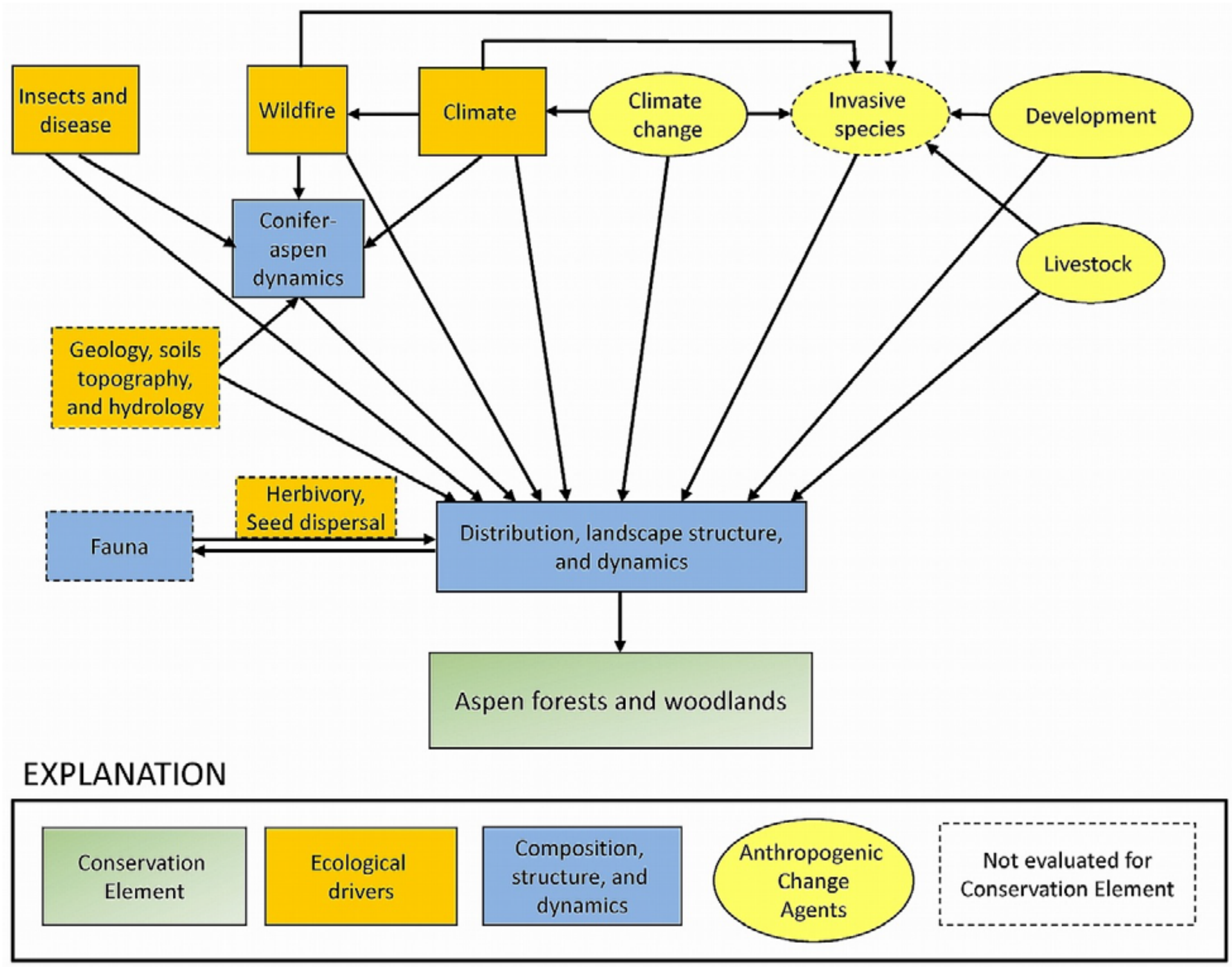


Figure 15−1. Generalized conceptual model for aspen forests and woodlands for the Wyoming Basin Rapid Ecoregional Assessment (REA). Biophysical attributes and ecological processes regulating the occurrence, structure, and dynamics of aspen stands are shown in orange rectangles; additional ecological 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. Native and domestic ungulate herbivory was addressed indirectly. The role of ecological drivers varies by ecological context, such as between foothill and mountain slope aspen. For example, fire and other disturbances typically play a greater role in mountain slope aspen, whereas drought and sudden aspen decline can have greater magnitude of effects in foothill aspen.

Table 15−1. Key ecological attributes and associated indicators of baseline aspen forests and woodlands[1] for the Wyoming Basin Rapid Ecoregional Assessment.

[km, kilometer; mi, mile; m, meter; ft, foot]

Attributes	Variables	Indicators
Amount and distribution	Total area by functional type (foothill and mountain slope)	Distribution derived from LANDFIRE[2]
Landscape structure	Patch size by functional type	Patch-size frequency distribution
	Structural connectivity[3]	Interpatch distances that provide an index of structural connectivity for baseline patches at local (0.27 km; 0.17 mi), landscape (1.35 km; 0.84 mi), and regional (6.48 km; 4.03 mi) scales[3]
	Core area by functional type	Percent core area (areas >60 m [197 ft] from nonforest edges)
Landscape dynamics	Aspen stand dynamics[4]	Aspen competitive release from conifer overstory derived from recent bark beetle outbreaks (since 1997) and fire occurrence (since 1980) in mountain slope aspen
	Aspen-conifer ecotone dynamics[5]	Potential for aspen expansion derived from bark beetle outbreaks and recent fire occurrence in 30-m (98-ft) buffer around mountain slope aspen[5]
		Potential for conifer expansion derived from percent conifer in a 30-m (98-ft) buffer around mountain slope aspen lacking recent disturbance from fire or bark beetle outbreaks
	Risk for sudden aspen decline	Derived from Rehfeldt and others (2009)

[1] Baseline conditions are used as a benchmark to evaluate changes in the total area and landscape structure of aspen due to Change Agents. Baseline conditions are defined as the potential current distribution of aspen derived from LANDFIRE without explicit inclusion of Change Agents (see Chapter 2—Assessment Framework and the Appendix).

[2] Aspen functional type (foothill and mountain slope) determined by context of adjacent cover types derived from LANDFIRE Existing Vegetation Types (see Appendix).

[3] 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.

[4] See Wildland Fire section in the Appendix.

[5] We used >25 percent of conifers in buffers as a threshold indicating potential for conifer expansion.

Table 15–2. Anthropogenic Change Agents and associated indicators influencing aspen forests and woodlands for the Wyoming Basin Rapid Ecoregional Assessment.

[km^2, square kilometer; mi^2, square mile; km, kilometer; mi, mile; m, meter; ft, foot]

Change Agents	Variables	Indicators
Development	Terrestrial Development Index[1]	Percent of aspen forests in seven development classes using a 16-km^2 (6.18 mi^2) moving window
		Patch size frequency distribution for aspen that is relatively undeveloped or has low development scores compared to baseline conditions
		Inter-patch distances that provide an index of structural connectivity for relatively undeveloped patches at local (0.27 km; 0.17 mi), landscape (5.13 km; 3.19 mi), and regional (12.69 km; 7.89 mi) levels
	Transportation	Percent of core area >60 m [197 ft] from non-forest and road edges[2]
Climate change	Projected temperature and precipitation	Potential aspen distribution derived from the projected distribution of the bioclimatic envelope in 2030[3]

[1] See Chapter 2—Assessment Framework for description of Terrestrial Development Index.

[2] Percent of core area was used as an index of protection from herbivory.

[3] Bioclimatic envelope represents the bioclimate conditions conducive for aspen, derived from Rehfeldt and others (2012) for climate scenario I (Canadian Centre for Climate Modelling and Analysis, ver. 3, emissions scenario A2).

We used projections of the bioclimatic envelope developed by Rehfeldt and others (2009) for aspen in 2030 using climate scenario I (Canadian Centre for Climate Modeling and Analysis Coupled Global Model, ver. 3 [CCCM3], emissions scenario A2) to evaluate areas that currently have a greater risk for SAD. Existing aspen that fell outside the distribution of the projected bioclimatic envelope in 2030 was considered to be at greater risk of SAD (Rehfeldt and others, 2009). We used SAD risk to evaluate how the loss of aspen at risk for SAD could affect aspen structural connectivity. We also evaluated the structural connectivity for aspen forests that were at low risk of SAD and were relatively undeveloped (TDI score ≤1 percent) to examine how development may further influence connectivity of aspen in the project area.

To evaluate the potential change in the distribution of aspen forests and woodlands, we used the aspen bioclimatic envelope model developed by Rehfeldt and others (2012) for climate scenario I (CCCM3, emissions scenario A2) for 2030. Current and projected bioclimatic envelopes were used to identify areas where aspen distribution had the potential to increase, decline, or remain the same. We then overlaid the resulting map on the baseline aspen map to identify existing areas that have the potential to change in climate scenario I.

Although large aspen stands have high ecological value, naturally occurring small, isolated stands contribute to aspen connectivity in the Wyoming Basin. To evaluate landscape-level ecological values, we used the area of aspen patches to represent mountain slope aspen value and stepping stone function (defined as contributing to regional-level connectivity only) to represent foothill aspen value, and we used the maximum rank for each township for the overall value rank. The TDI score and risk for SAD were used to represent landscape-level risks. Ranks for values and risks were combined into an overall index of conservation potential for each township (table 15–3). 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 the Appendix for additional details on the methods.

Table 15−3. Landscape-level ecological values and risks for aspen forests and woodlands. Ranks were combined into an index of conservation potential for the Wyoming Basin Rapid Ecoregional Assessment.

[SAD, sudden aspen decline]

		Relative rank			
	Variables[1]	Lowest	Medium	Highest	Description[2]
Values	Area	<0.19	0.19–3.24	>3.24	Percent of township classified as aspen
	Stepping stone function	<1.67	1.67–2.34	>2.34	Mean stepping stone rank by township. Connected at regional levels only = 3; connected at landscape and regional levels = 2; connected at all levels = 1
Risks	Terrestrial Development Index (TDI)	<1	1–3	>3	Mean TDI score by township
	Road effects on aspen core areas	>10	1–10	<1	Percent of core area by township
	Sudden aspen decline (SAD) risk	<1.67	1.67–2.34	>2.34	Mean risk by township: low and high SAD risk are given values of 1 and 3, respectively, and averaged 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 aspen communities to minimize the effects of extremely small areas and put greater emphasis on conservation potential of large areas (see table A−19 in the Appendix).

[2] See tables 15–1 and 15–2 for description of variables.

Table 15–4. Management Questions addressed for aspen forests and woodlands for the Wyoming Basin Rapid Ecoregional Assessment.

Core Management Questions	Results
Where are the two baseline aspen functional types (mountain slope and foothill), and what is the total area of each?	Figure 15–2
Where does development pose the greatest threat to baseline aspen, and where are the relatively undeveloped areas?	Figures 15–3 and 15–4
How has development fragmented baseline aspen, and where are the large, relatively undeveloped patches?	Figures 15–5 and 15–6
Where are aspen core areas, and how is core area affected by the presence of roads and railroads?	Figures 15–7 and 15–8
Where are baseline aspen stands with high levels of structural connectivity, and which stands function as stepping stones?	Figure 15–9
Where are potential barriers and corridors that may affect animal movements among baseline aspen patches?	Figure 15–10
Where does aspen have a greater vulnerability to sudden aspen decline on the basis of climatic risk factors, and how would the loss of these stands affect the structural connectivity of aspen?	Figure 15–11
Where are mountain slope aspen-conifer ecotones with potential for conifer or aspen expansion, and which aspen stands may undergo competitive release as a result of recent disturbances?	Figure 15–12
What is the potential distribution of aspen in 2030?	Figure 15–13
Integrated Management Questions	**Results**
How does risk from development vary by land ownership or jurisdiction for mountain slope and foothill aspen?	Table 15–5, figure 15–14
Where are the townships with the greatest landscape-level ecological values?	Figure 15–15
Where are the townships with the greatest landscape-level risks?	Figure 15–16
Where are the townships with the greatest conservation potential?	Figure 15–17

Key Findings for Management Questions

Where are the two baseline aspen functional types (mountain slope and foothill), and what is the total area of each (fig. 15–2)?

- Mountain slope aspen covers 4,350 km^2 (1,680 mi^2) and foothill aspen covers 465 km^2 (179 mi^2) in the project area.
- Mean elevation of mountain slope aspen is 2,537 m (8,323 ft), whereas mean elevation of foothill aspen is 2,201 m (7,221 ft).
- Only 10 percent of aspen forests and woodlands in the project area are within the Wyoming Basin ecoregion proper; of that, 70 percent is mountain slope and 30 percent is foothill aspen. Most aspen (90 percent) is within the ecoregion buffer, 93 and 7 percent of which is mountain slope and foothill aspen, respectively.

Where does development pose the greatest threat to baseline aspen and where are the relatively undeveloped areas (figs. 15–3 and 15–4)?

- Development levels for foothill aspen are greater than those for mountain slope aspen, with only 20.7 percent of foothills aspen in relatively undeveloped areas (TDI score $\leq$1 percent), and 31.9 percent had TDI score >3 percent, indicating high levels of development (figs. 15–3 and 15–4).
- In contrast, 45.6 percent of mountain slope aspen is relatively undeveloped, and 13.8 percent had TDI score >3 percent (fig. 15–4).
- Roads and railroads contribute more than other development variables to the TDI score for both aspen functional types; adjacent agriculture also contributes to a greater TDI score in some locations. Likewise, the only development variable that directly overlaps aspen stands by more than 1 percent is roads: overlap with mountain slope and foothill aspen is 6.1 and 7.1 percent, respectively. Urban, energy, and minerals development contribute only minimally to the TDI score for aspen.

How has development fragmented baseline aspen, and where are the large, relatively undeveloped patches (figs. 15–5 and 15–6)?

- Baseline aspen patches are generally small, with approximately 50 percent of mountain slope aspen and 75 percent of foothill aspen occurring in patches <1 km^2 (0.39 mi^2) (figs. 15–5 and 15–6).
- Development has effectively fragmented aspen into smaller patches relative to baseline conditions. All patches of relatively undeveloped aspen are <0.1 km^2 (0.04 mi^2), whereas 23.5 percent of baseline mountain slope aspen patches and 13.5 percent of baseline foothill aspen patches are >50 km^2 (19.31 mi^2) (fig. 15–5).

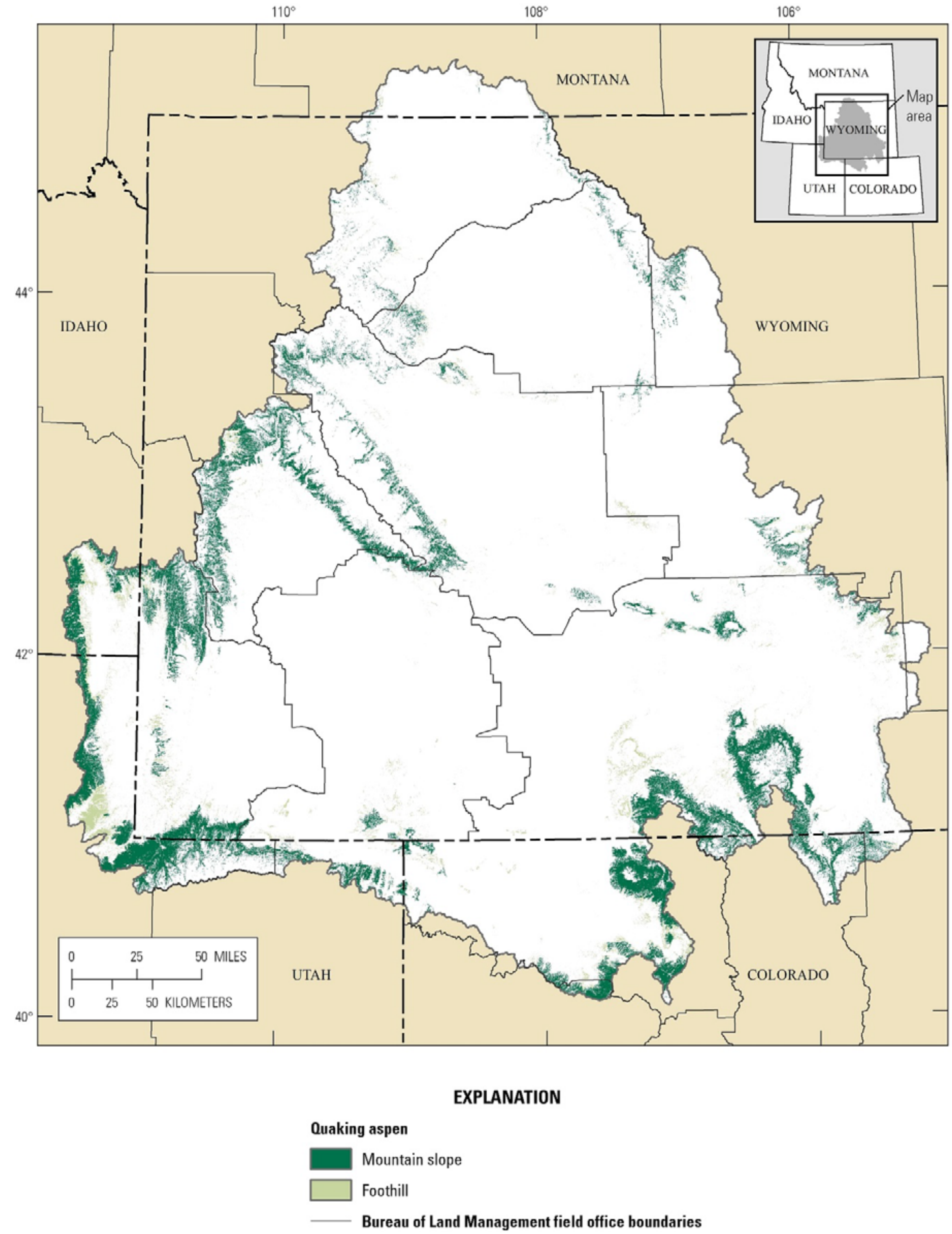
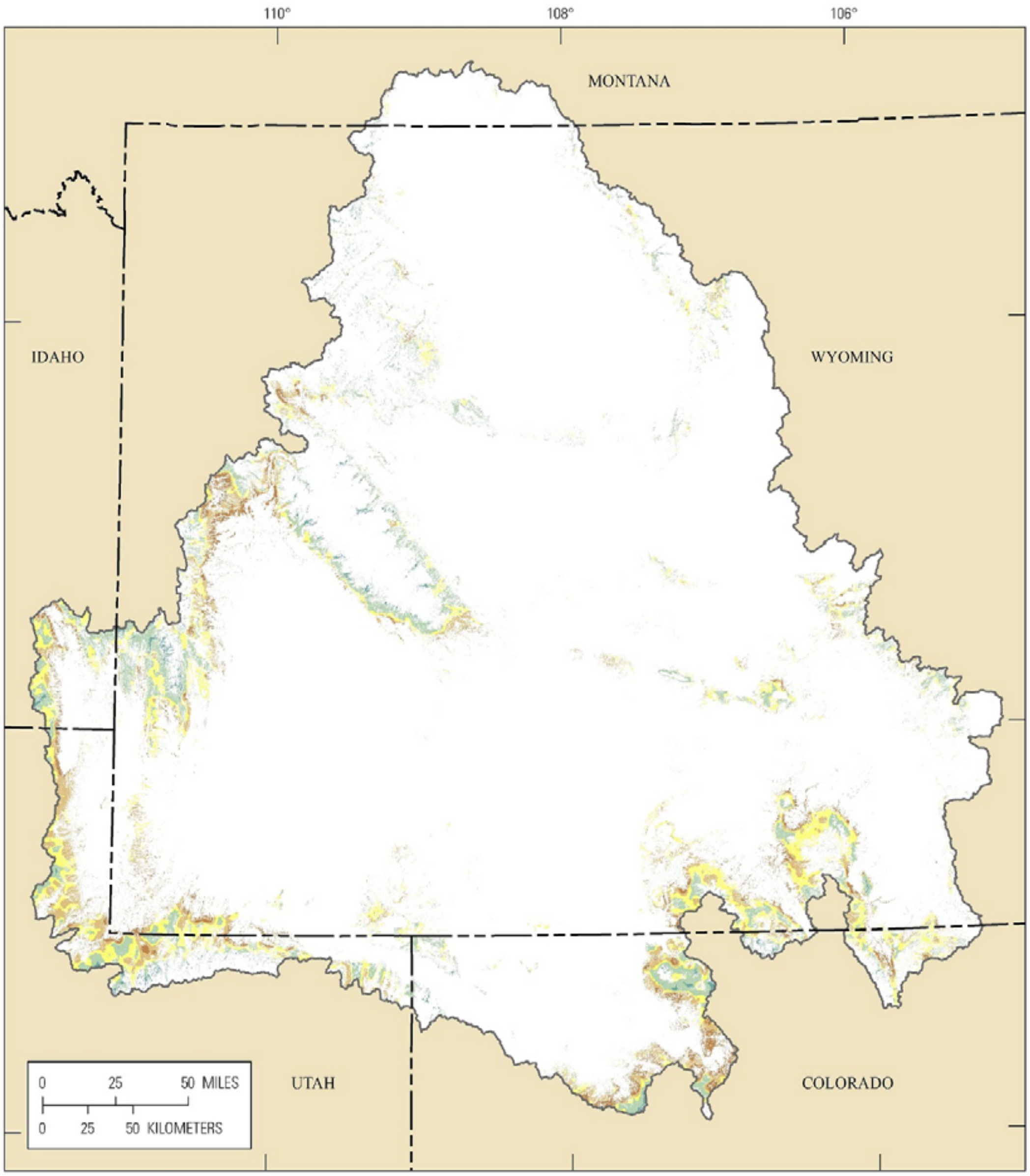


Figure 15–2. Distribution of baseline mountain slope and foothill aspen in the Wyoming Basin Rapid Ecoregional Assessment project area.



EXPLANATION

Terrestrial Development Index (percent)

- 0
- 0.1–1
- 1.1–2
- 2 .1–3
- 3.1–5
- 5.1–20
- 20.1–100

Figure 15−3. Terrestrial Development Index scores for aspen forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area.

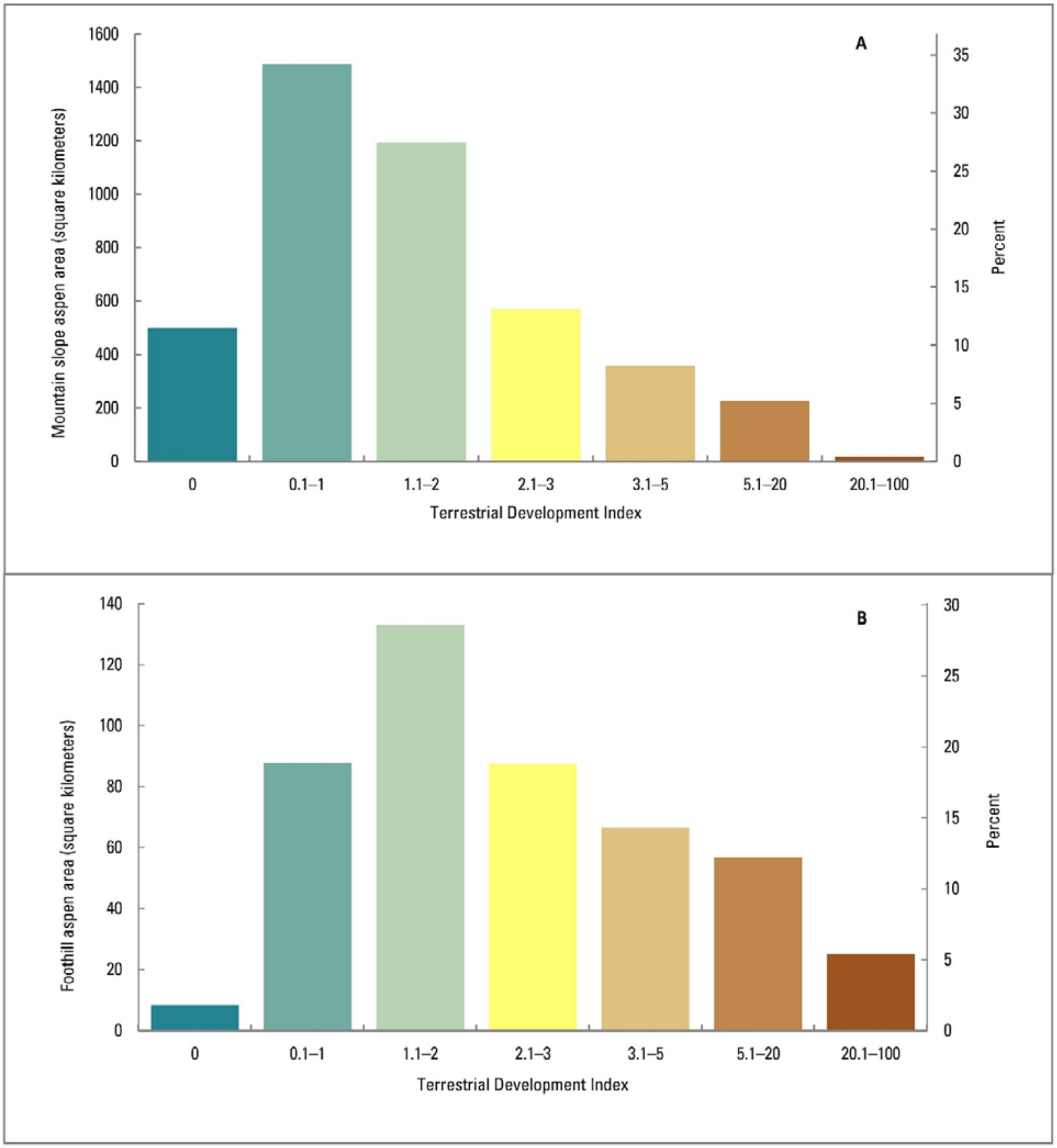


Figure 15−4. Area and percent of aspen as a function of the Terrestrial Development Index in the Wyoming Basin Rapid Ecoregional Assessment project area for (*A*) mountain slope and (*B*) foothill aspen.

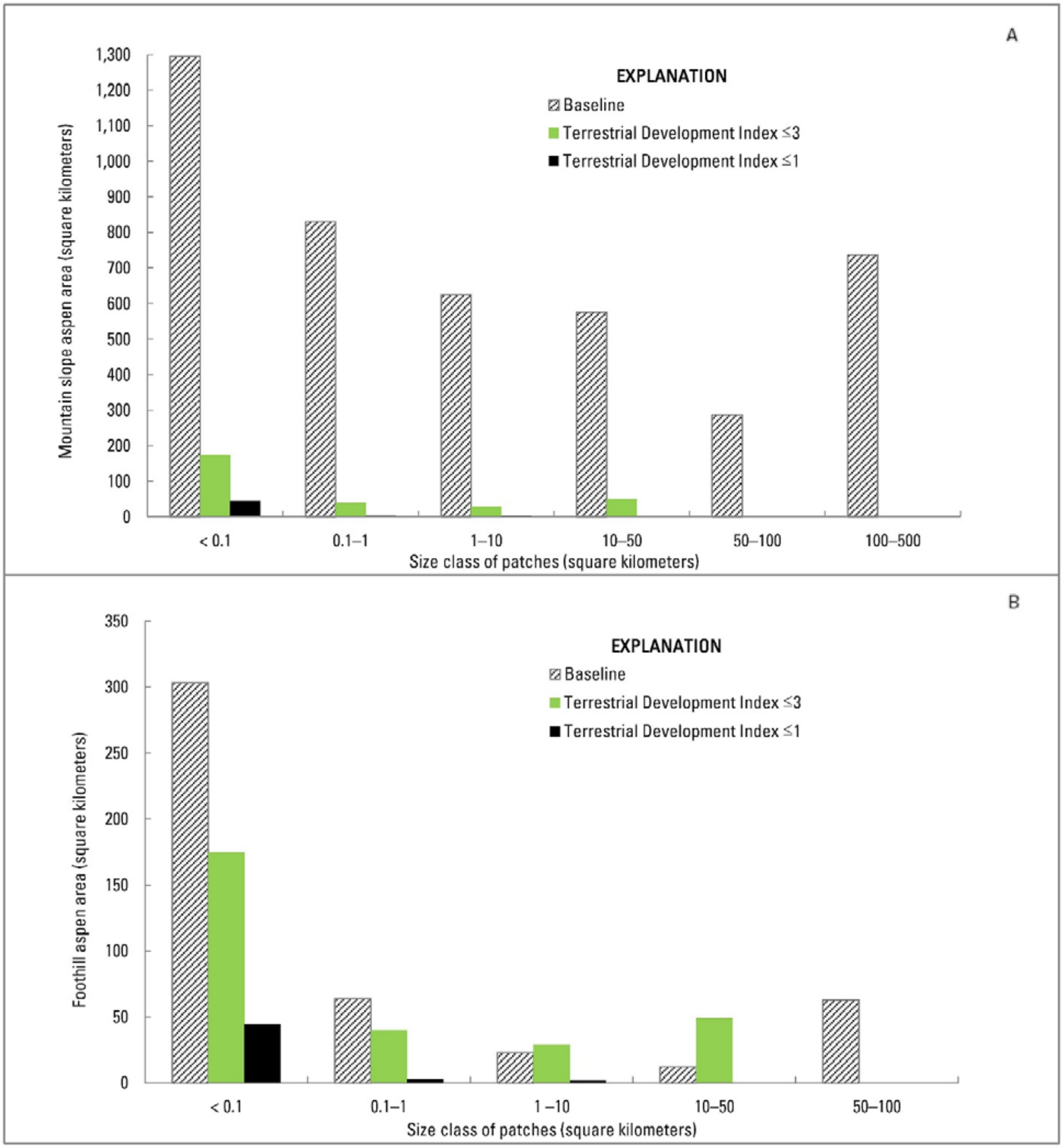


Figure 15−5. Area of aspen as a function of patch size for baseline conditions and two development levels: Terrestrial Development Index (TDI) score <u><</u>3 percent, and TDI score <u><</u>1 percent (relatively undeveloped areas) in the Wyoming Basin Rapid Ecoregional Assessment project area. (*A*) mountain slope aspen and (*B*) foothill aspen.

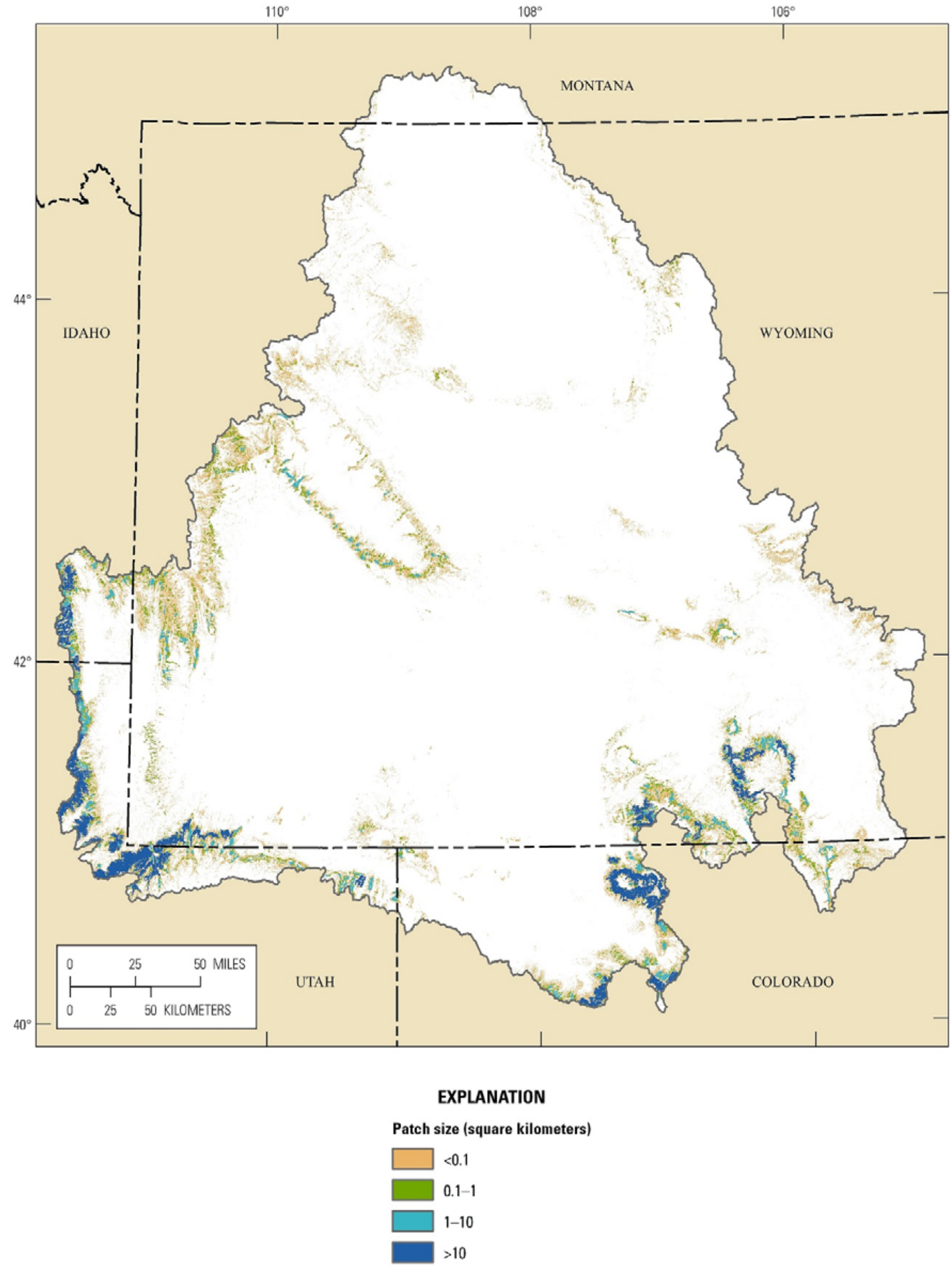


Figure 15−6. Baseline aspen patch sizes in the Wyoming Basin Rapid Ecoregional Assessment project area.

Where are aspen core areas, and how is core area affected by the presence of roads and railroads (figs. 15–7 and 15–8)?

- Baseline aspen has a large proportion of nonforest edge, and core area accounts for only 35 percent of mountain slope and 10 percent of foothill aspen area (figs. 15–7 and 15–8).
- Edges created by roads, and to a very limited extent railroads, dramatically decrease the amount of core area. Little core area remains in foothill aspen, and core area decreases to 9 percent of mountain slope aspen, when road and railroad edges are included (figs. 15–7 and 15–8).

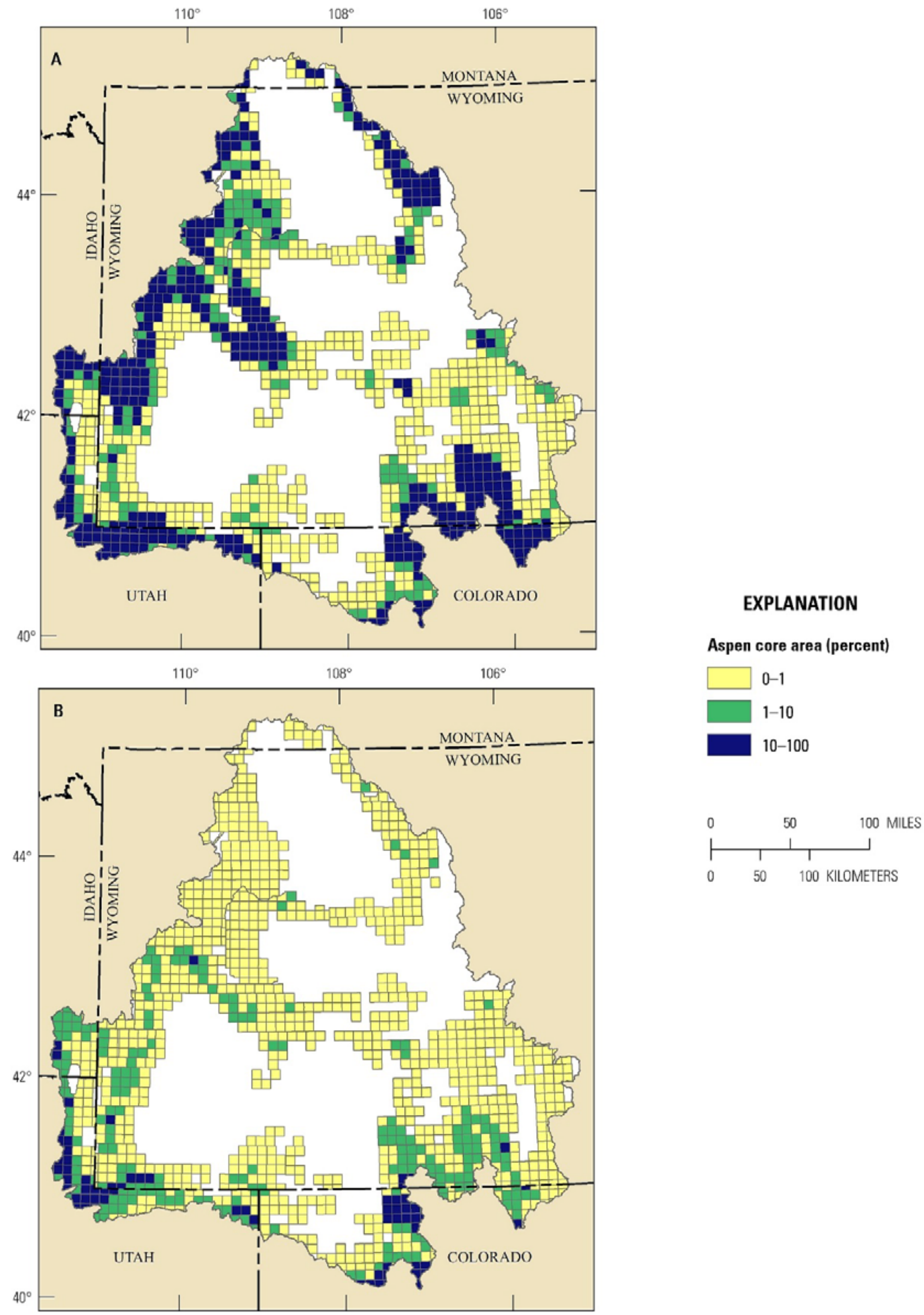


Figure 15−7. Percent of core area for aspen forests and woodlands, summarized by township, in the Wyoming Basin Rapid Ecoregional Assessment project area. Core area is defined as the percent of baseline aspen >60 meters (197 feet) from edges for (*A*) nonforest edges only and (*B*) nonforest and road/railroad edges.

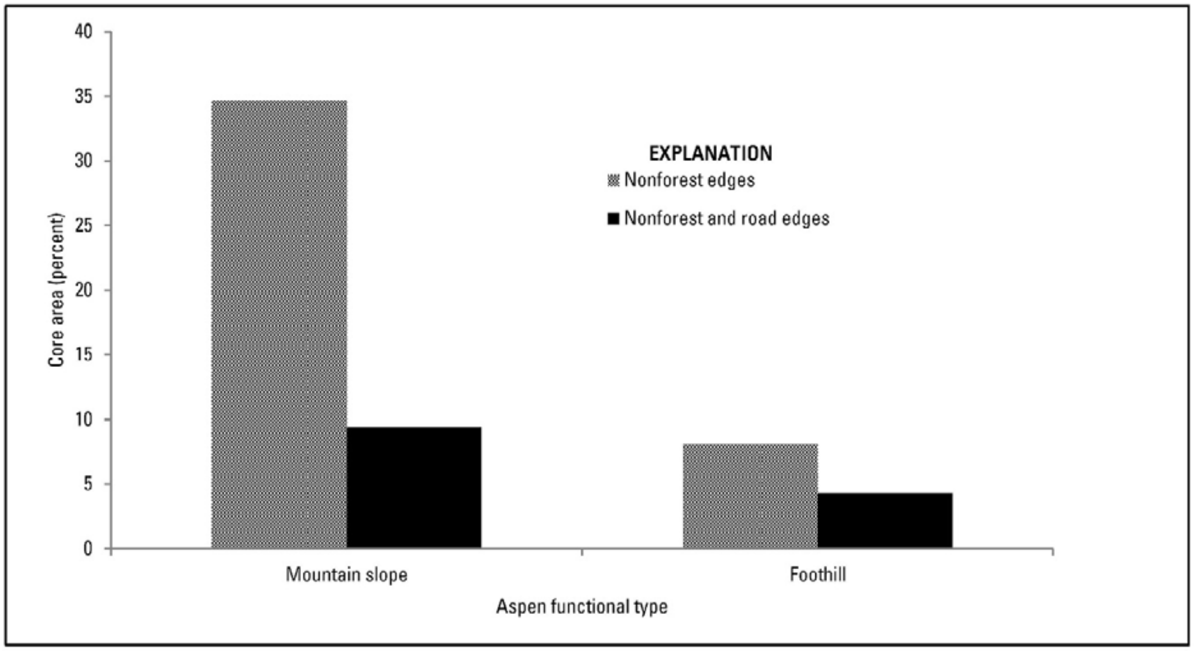


Figure 15−8. Core area of aspen, by functional type, in the Wyoming Basin Rapid Ecoregional Assessment project area. Core area is defined as the percent of baseline aspen >60 meters (197 feet) from edges. This was evaluated for nonforested edges only and for nonforest and road/railroad edges combined.

Where are baseline aspen stands with high levels of structural connectivity, and which stands function as stepping stones (fig. 15–9)?

- Foothill aspen patches are relatively small and lack structural connectivity to the largest aspen forests at local and landscape levels, whereas mountain slope aspen patches have greater connectivity at local, landscape, and regional levels, particularly around the perimeter of the project area.
- Foothill aspen patches function as stepping stones across the dominant sagebrush steppe landscape of the Wyoming Basin and contribute to regional connectivity, particularly between the eastern and western portions of the project area.
- Development has greatly diminished structural connectivity of aspen at landscape and regional levels. Regional connectivity among baseline aspen forest and woodlands occurs at an interpatch distance of 6.48 km (4.03 mi) but is 12.69 km (7.89 mi) for relatively undeveloped areas. Baseline landscape-scale connectivity increases from 1.35 km (0.84 mi) to 5.13 km (3.19 mi) for relatively undeveloped areas.

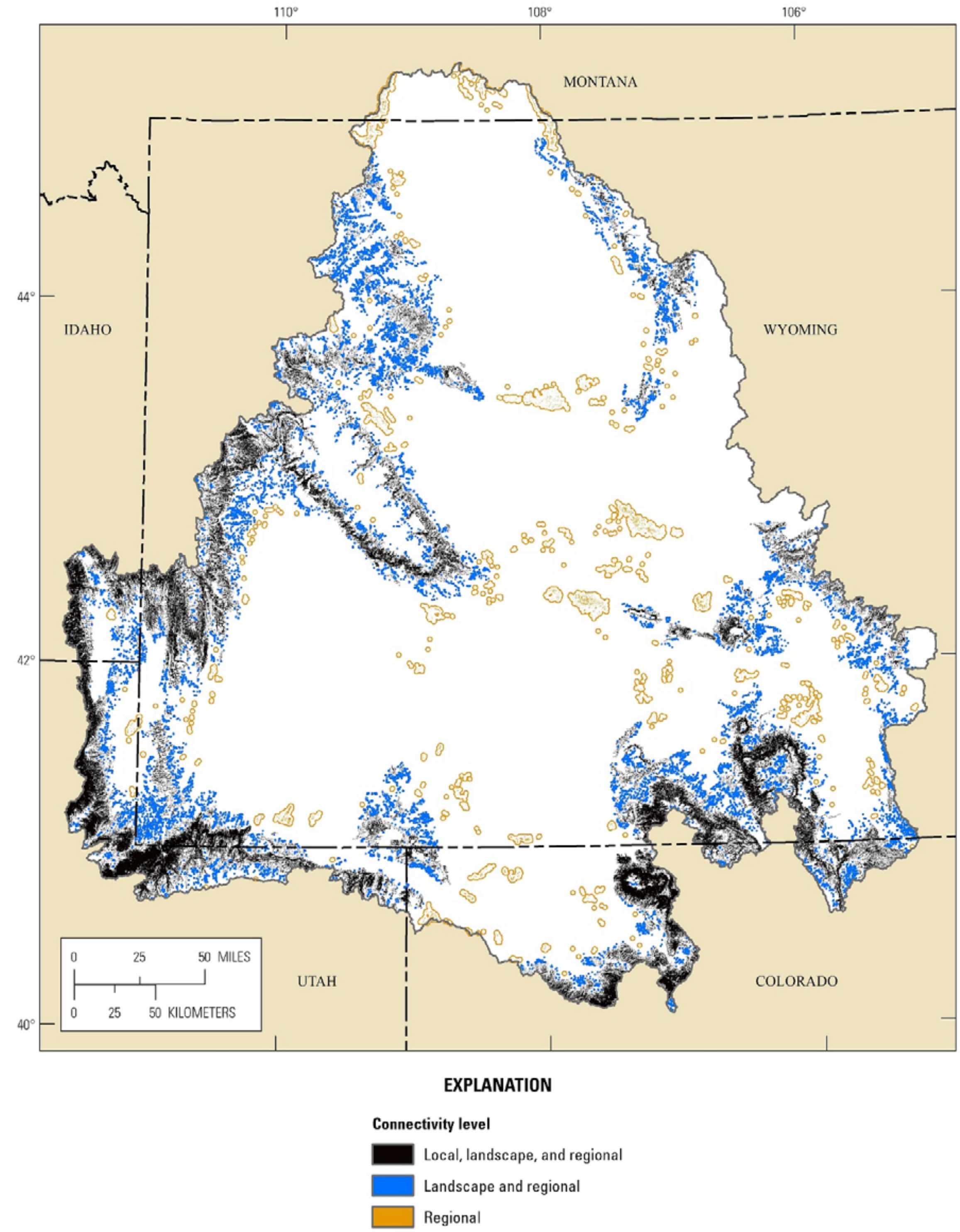


Figure 15−9. Structural connectivity of baseline aspen forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. Black polygons include large and highly connected aspen patches. Blue polygons include aspen patches that contribute to both landscape and regional connectivity. Orange polygons represent clusters of isolated aspen patches, which can serve as stepping stones across broad expanses of sagebrush shrublands.

Where are potential barriers and corridors that may affect animal movements among baseline aspen patches (fig. 15–10)?

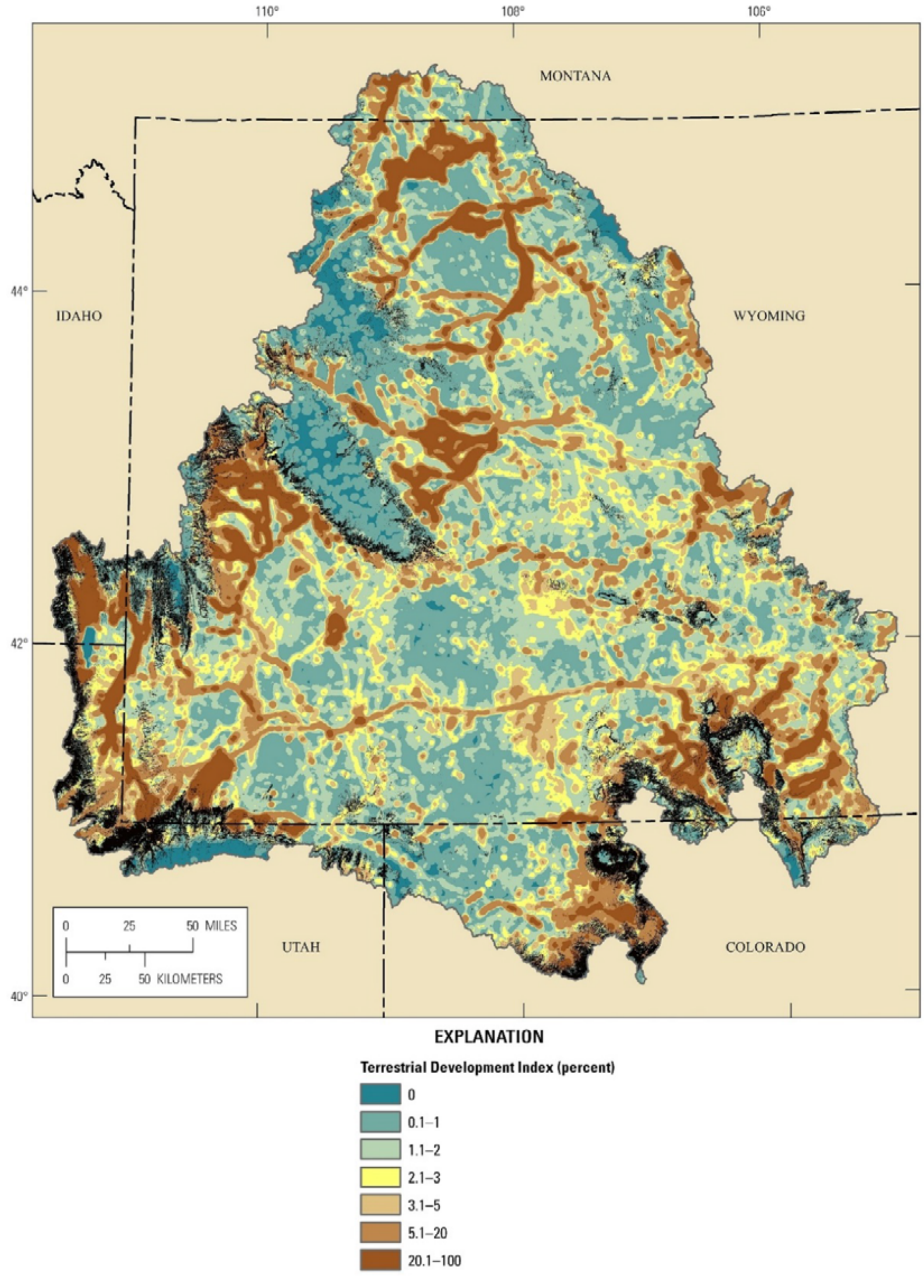


Figure 15−10. Potential barriers and corridors as a function of the Terrestrial Development Index (TDI) score for lands surrounding baseline aspen. Higher TDI scores (for example, >5 percent) represent potential barriers to movement among relatively undeveloped patches. Lower TDI scores (for example, <2 percent) represent potential corridors for movements among patches.

Where does aspen have a greater vulnerability to sudden aspen decline on the basis of climatic risk factors, and how would the loss of these stands affect the structural connectivity of aspen (fig.15–11)?

- Ninety-two percent of foothill aspen is vulnerable to drought and high temperatures that contribute to risk of SAD, whereas 32 percent of mountain slope aspen is vulnerable.
- Many stands at risk for SAD contribute disproportionately to aspen structural connectivity at regional levels. These stands often occur in areas with high levels of development; thus, the loss of stands to SAD could further erode structural connectivity.

Where are mountain slope aspen-conifer ecotones with potential for conifer or aspen expansion, and which aspen stands may undergo competitive release as a result of recent disturbances (fig. 15–12)?

- Recent bark beetle outbreaks and fires are expected to promote aspen dominance in existing aspen stands by killing conifers in the overstory, and they may create opportunities for aspen expansion in adjacent conifer forests.
- A total of 2,474 km^2 (955.2 mi^2), or 51 percent, of aspen has been recently disturbed by fire or bark beetle outbreaks. Approximately 92 percent of the disturbance was caused by bark beetles.
- Additionally, 2,903 km^2 (1,120.9 mi^2) of conifer forests adjacent to aspen (within 30 m [98.4 ft] of aspen) have been disturbed by fire or bark beetles since 1997. Whether aspen expands into recently disturbed areas depends on the degree of overstory mortality, the amount of aspen present, herbivory levels, and other local factors (Pelz and Smith, 2013).
- Only 6.7 percent of mountain slope aspen occurs along ecotones with high conifer densities (>25 percent of conifers within 30 m [98.4 ft]. These areas may have potential for conifer expansion; however, mountain slope aspen is typically classified in LANDFIRE as mixed aspen-conifer and consequently includes an unknown proportion of conifer. Variation in percent of conifer at finer scales of resolution than evaluated here could affect the potential for conifer expansion.

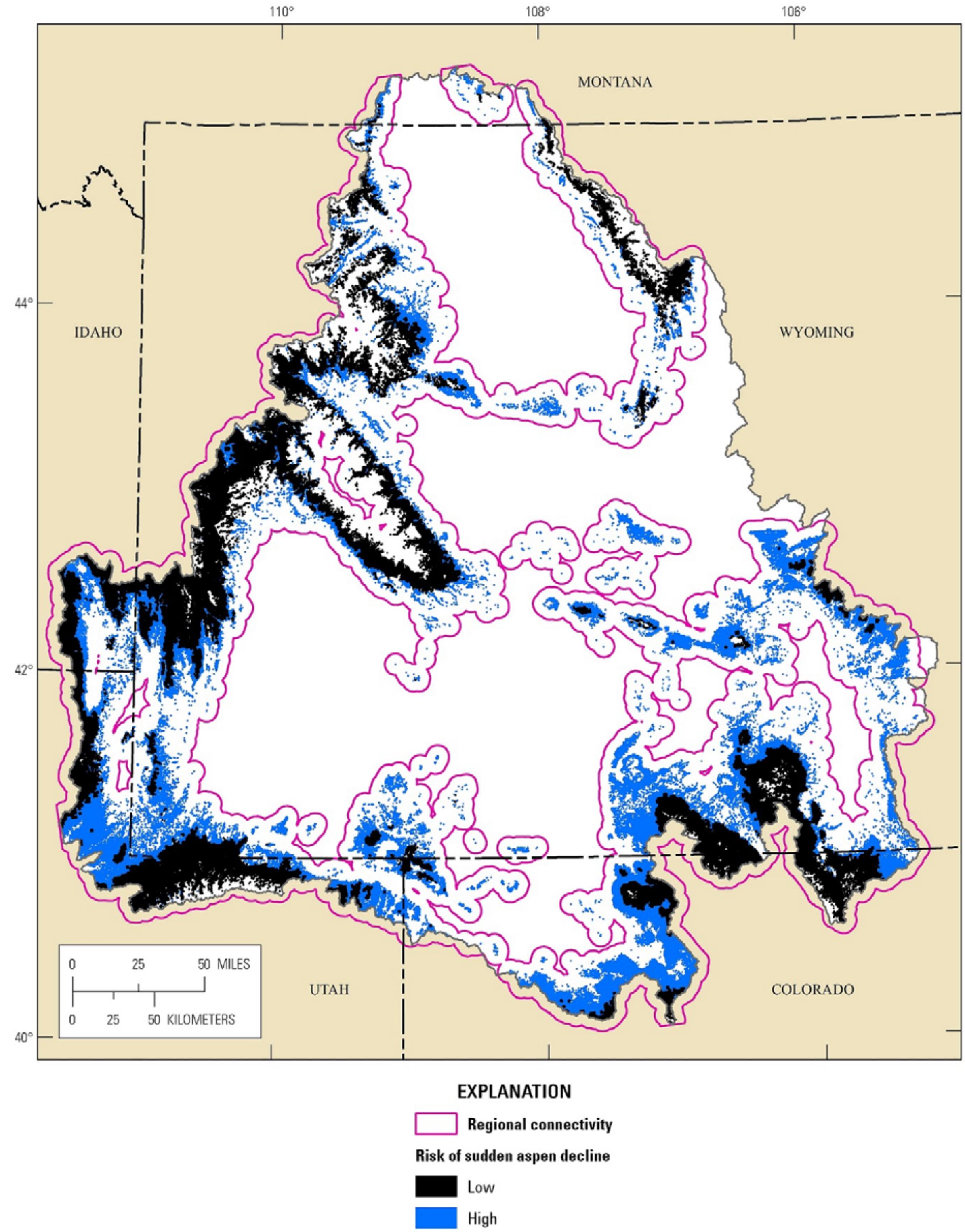


Figure 15−11. The risk for sudden aspen decline (SAD) in relation to regional connectivity of baseline aspen forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. Loss of aspen to SAD could lead to loss of regional aspen connectivity in the Wyoming Basin.

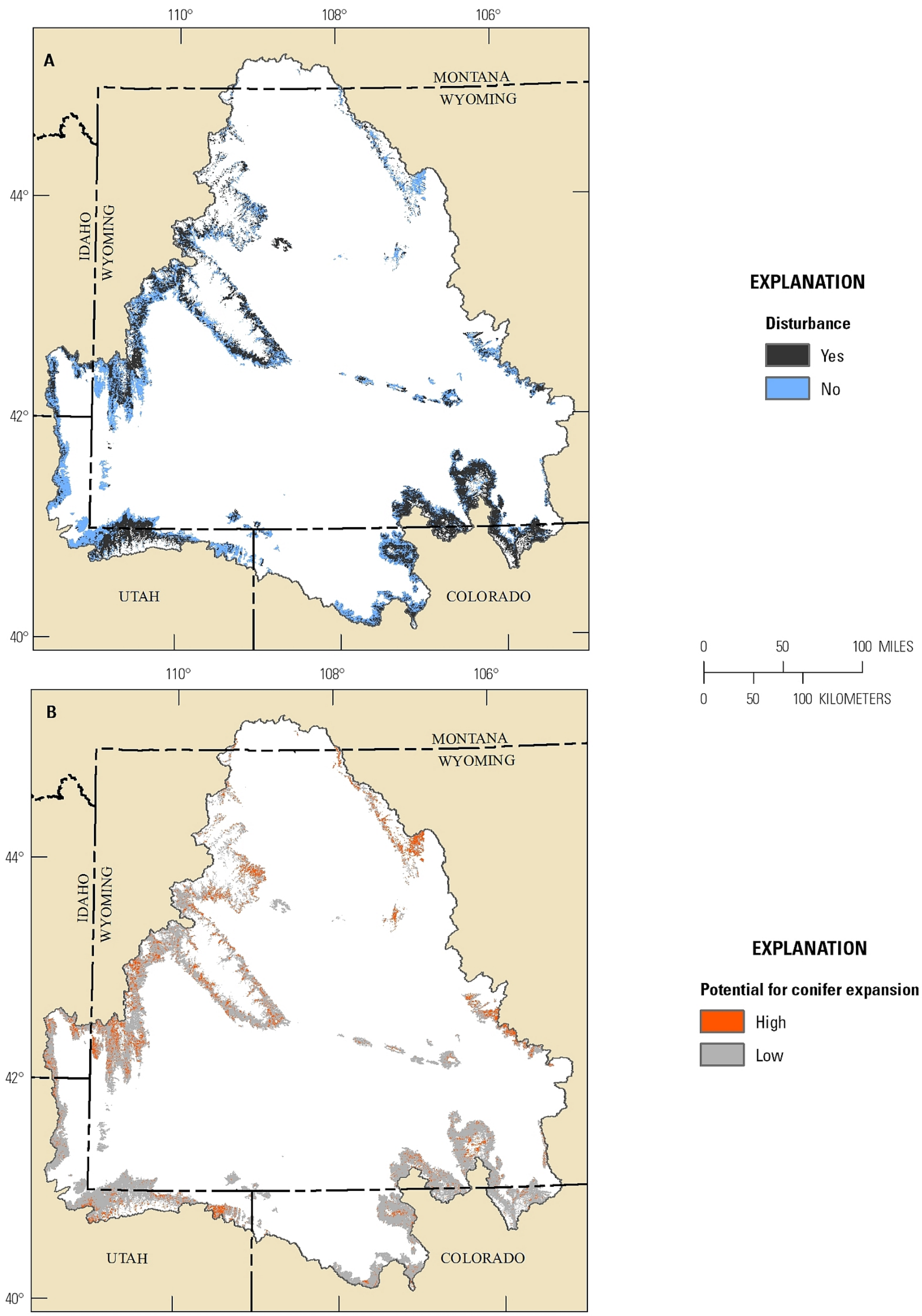


Figure 15–12. Potential changes in mountain slope aspen-conifer ecotone dynamics as a function of recent disturbances from fire (since 1980) or bark beetle outbreaks (since 1997) in Wyoming Basin Rapid Ecoregional Assessment project area. (*A*) Locations of bark beetle disturbances in aspen, and (*B*) potential for conifer expansion derived from proximity of mixed-conifer forests to aspen stands.

What is the potential distribution of aspen in 2030 (fig. 15–13)?

- Thirty-one percent of mountain slope aspen and 87 percent of foothill aspen are projected to fall outside the distribution of bioclimatic conditions conducive for aspen in 2030 for climate scenario I (fig. 15−13). The aspen bioclimatic envelope is projected to move upslope (fig. 15−13*A*), which could allow aspen to occur at higher elevations where currently it is absent (fig. 15−13*B*); however, where local hydrological conditions are more favorable, aspen may persist outside of the projected bioclimatic envelope. Indeed, 38 percent of baseline foothill aspen and 6 percent of baseline mountain slope aspen fall outside of the current bioclimatic envelope, indicating the limitations of the current model for predicting the occurrence of aspen in the Wyoming Basin, particularly for foothill aspen. The bioclimatic models are most useful for identifying potential vulnerabilities and to assess future risks.
- In 2030, 55 percent of the current bioclimatic envelope conducive to aspen is projected to persist for the climate scenario evaluated herein, and 44 percent has the potential to decline. The total area for potential upslope expansion equates to 17 percent of baseline aspen. These projections suggest that the potential loss of foothill aspen at lower elevations might not be balanced by the upslope shift of aspen in the project area for the future climate scenario evaluated.
- Aspen woodland is projected to be most at risk for decline provide crucial connectivity functions (stepping stones across sagebrush shrublands), such that the loss of these vulnerable aspen woodlands could lead to a loss of regional connectivity.

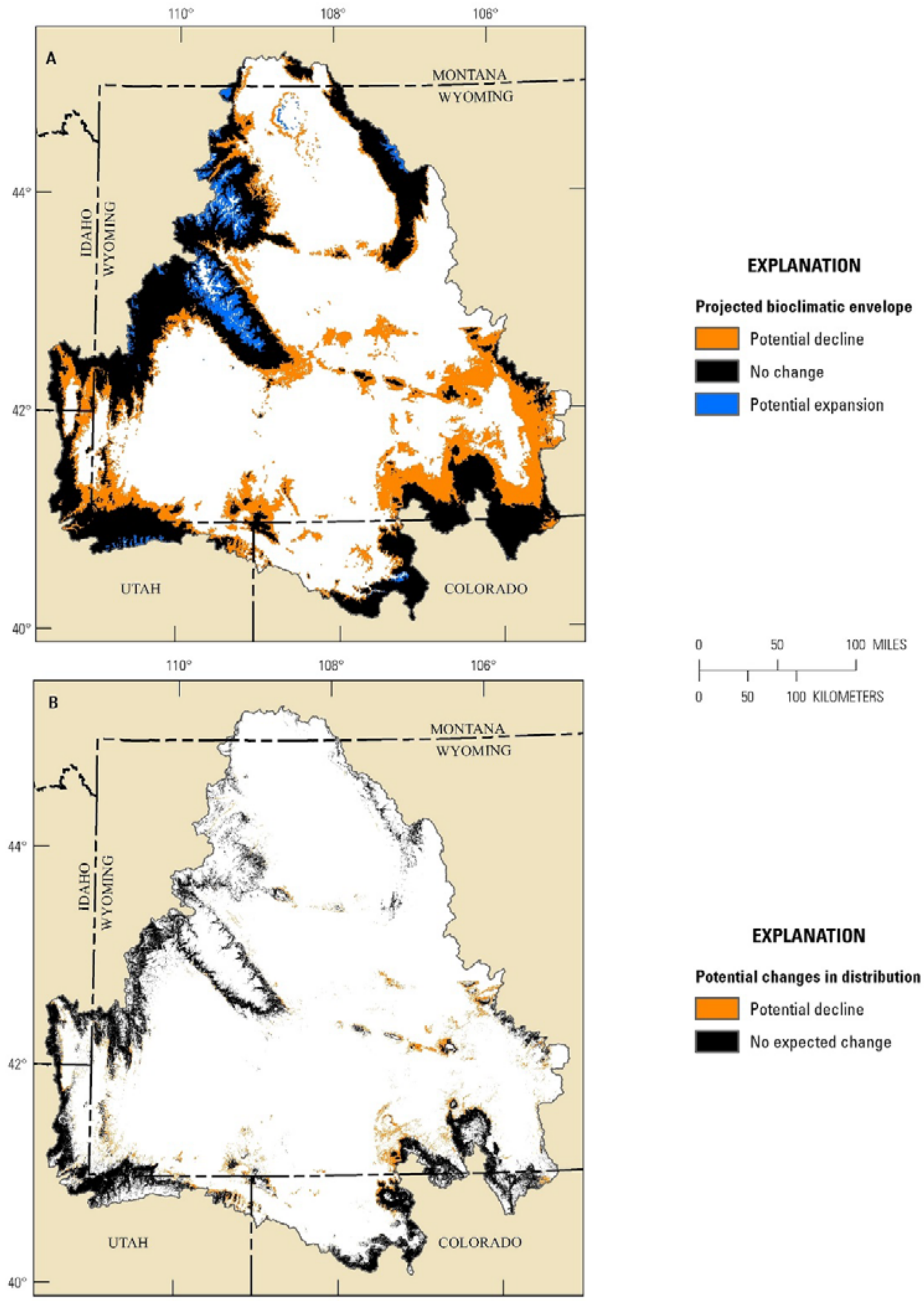


Figure 15−13. Potential effects of climate change on aspen forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. (*A*) Projected changes in the bioclimatic envelope for aspen derived from Rehfeldt and others (2012) for climate scenario I in 2030. Orange indicates areas with potential for decline because current envelope distributions do not coincide. Black represents 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 aspen derived from overlap with the projected bioclimatic envelope distribution (as represented in *A*).

How does risk from development vary by land ownership or jurisdiction for mountain slope and foothill aspen (table 15–5, fig. 15–14)?

- Overall, U.S. Department of Agriculture Forest Service lands encompass about half of aspen overall, mostly mountain slope aspen. Private lands account for a third of all aspen, but most of this is foothill aspen (table 15–5).
- Currently, the Bureau of Land Management (BLM) manages 11 percent of aspen (table 15–5).
- Tribal lands encompass the greatest proportion of foothill aspen with the lowest risk from development. U.S. Department of Agriculture Forest Service and other Federal lands, including National Park Service lands, have relatively low risk from development (fig. 15–14).
- Risks from development on BLM lands is somewhat mixed (fig. 15–14).

Table 15−5. Area and percent of aspen forests and woodlands, by land ownership or jurisdiction, in the Wyoming Basin Rapid Ecoregional Assessment project area.

[km^2, square kilometer]

	Total aspen		Mountain slope		Foothill	
Ownership or jurisdiction	Area (km^2)	Percent	Area (km^2)	Percent	Area (km^2)	Percent
Forest Service[1]	2,341	48.44	2,303	52.75	38	8.13
Private	1,603	33.16	1,310	30.01	292	62.63
Bureau of Land Management	550	11.39	465	10.64	86	18.37
State/County	164	3.39	127	2.90	37	7.99
Other Federal[2]	77	1.60	75	1.73	2	0.43
Tribal	53	1.09	46	1.06	6	1.38
Private conservation	42	0.87	38	0.86	4	0.95

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

[2] National Park Service, Bureau of Reclamation, and U.S. Fish and Wildlife Service.

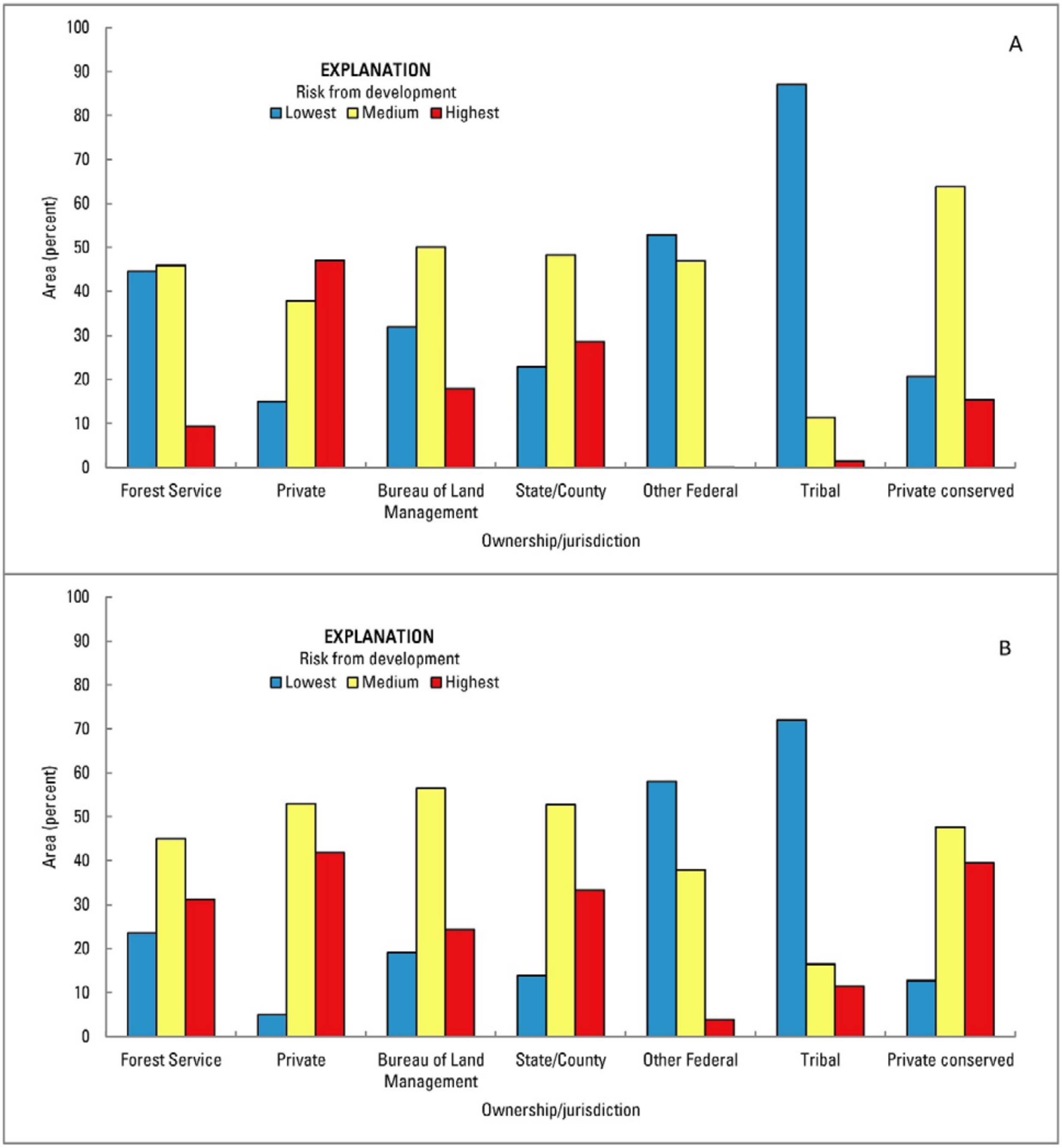


Figure 15−14. Relative ranks of risk from development, by land ownership or jurisdiction, for aspen forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. *(A)* Mountain slope aspen, and *(B)* foothill aspen. Rankings are lowest (Terrestrial Development Index [TDI] score <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 (fig. 15–15)?

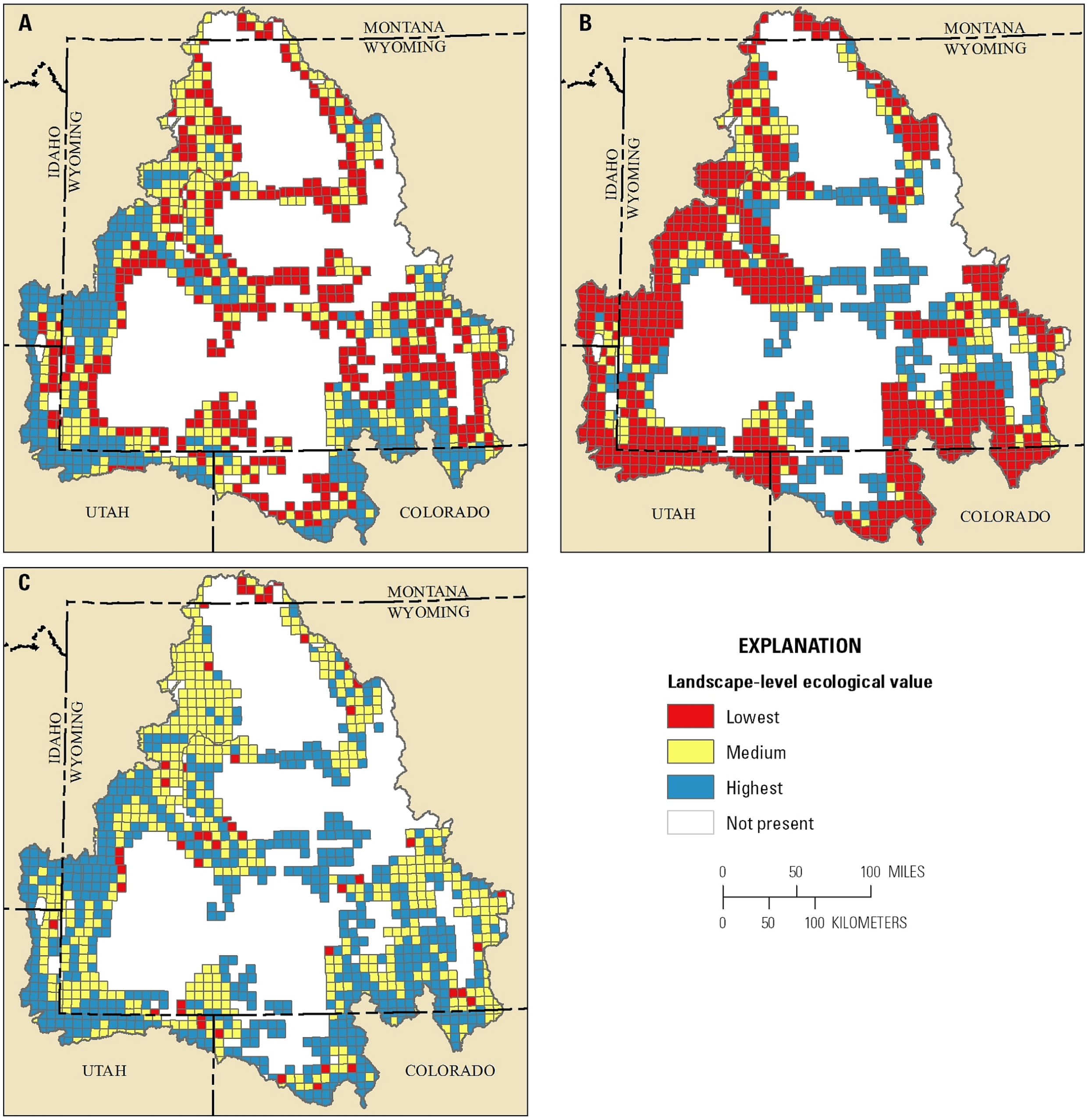


Figure 15–15. Ranks of landscape-level ecological values for aspen forests and woodlands, summarized by township, in the Wyoming Basin Rapid Ecoregional Assessment project area. *(A)* Total area, *(B)* stepping stone function, and *(C)* overall value ranks (see table 15–3 for overview of methods).

Where are the townships with the greatest landscape-level risks (fig. 15–16)?

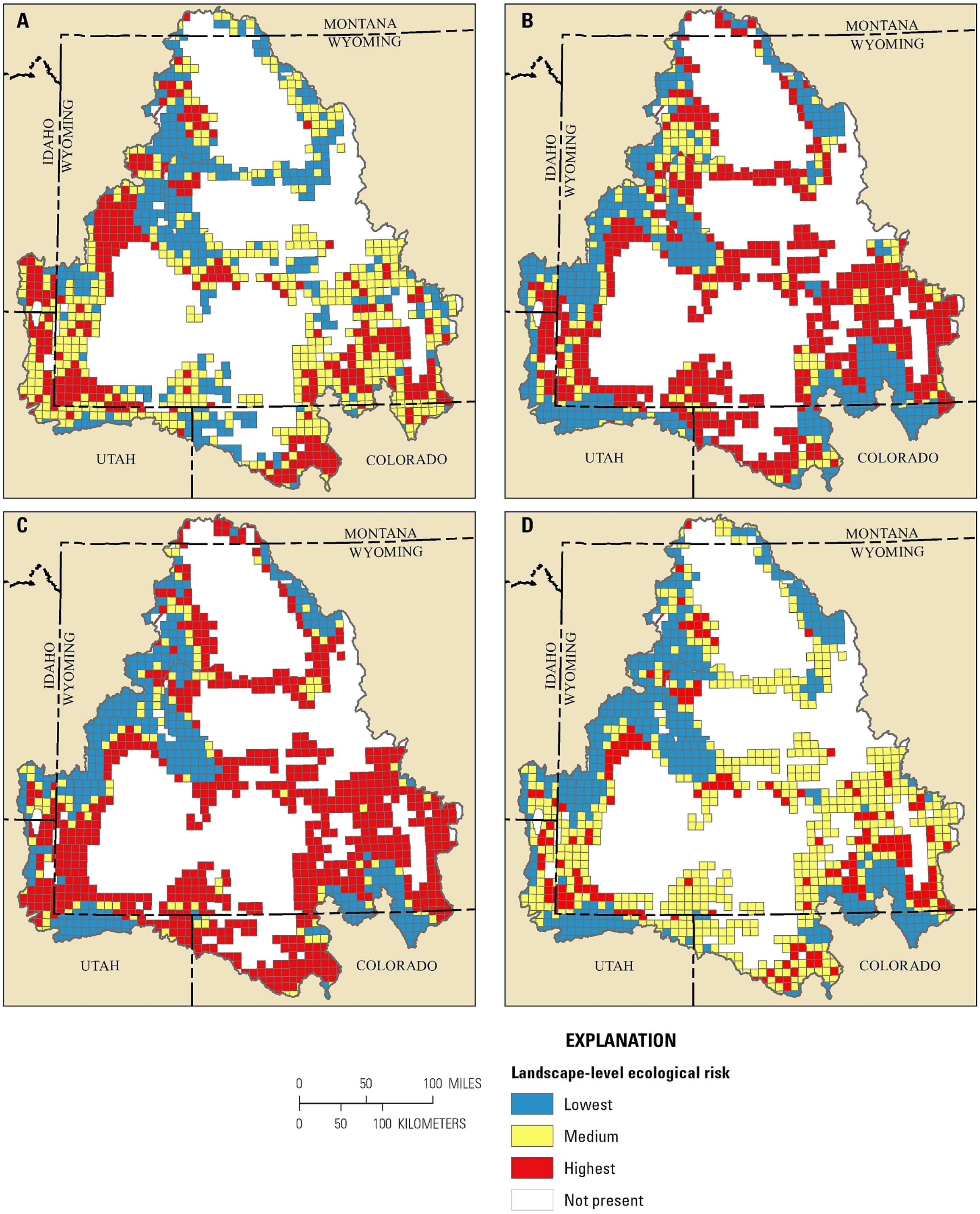


Figure 15–16. Ranks of landscape-level risks for aspen forests and woodlands in the Wyoming Basin Rapid Ecoregional Assessment project area. *(A)* Terrestrial Development Index, *(B)* core area including road/railroad effects, *(C)* risk for sudden aspen decline, and *(D)* overall risks (see table 15–3 for overview of methods).

Where are the townships with the greatest conservation potential (fig. 15–17)?

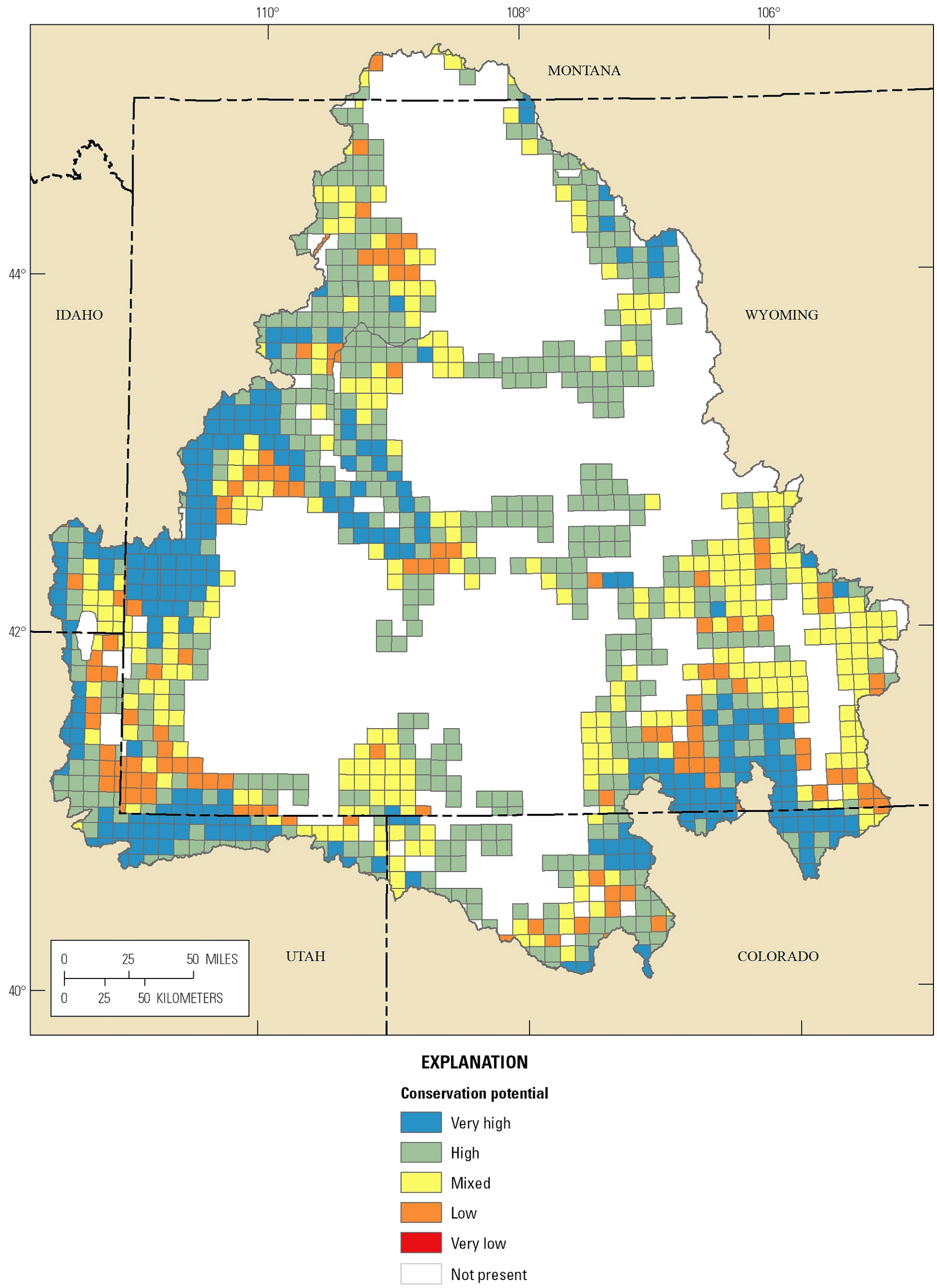


Figure 15–17. Conservation potential of aspen forests and woodlands, summarized by township, in the Wyoming Basin Rapid Ecoregional Assessment project area. Highest conservation potential identifies areas that have the highest landscape-level values and the lowest-level risks. Lowest conservation potential identifies areas with the lowest landscape-level values and the highest-level 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

Most of the aspen in the Wyoming Basin occurs along the ecoregion periphery, with 10 percent occurring in the Basin proper. Most of the aspen is classified as mountain slope and only 10 percent is foothill aspen. Over 66 percent of mountain slope aspen is currently managed by Federal and state agencies, including the largest relatively undeveloped areas (fig. 15–15), whereas only 42 percent of foothill aspen is currently managed by Federal and state agencies. Most of the federally managed foothill aspen falls under Bureau of Land Management jurisdiction, whereas most of the federally managed mountain slope aspen is managed by the U.S. Department of Agriculture Forest Service.

Although stand-level information (such as regeneration rates, overstory mortality, and age structure) will be necessary for full assessment of the condition of aspen forests, the landscape-level information summarized herein is crucial for understanding larger-scale threats to the ecological conditions and functions of aspen forests. Our results indicate that foothill aspen is more vulnerable to the Change Agents compared to mountain slope aspen in the Wyoming Basin. The cumulative effects of development, herbivory along natural or road edges, potential for sudden aspen decline (SAD), and projected climate changes are expected to have greater effects on foothill aspen due to the drier and hotter climate, smaller patch size, lower structural connectivity, and greater levels of development in proximity to foothill aspen compared to mountain slope aspen. Furthermore, proposed wind farms in proximity to foothill aspen may compound the threats to forest-dwelling songbirds and bats that use foothill aspen forests as migratory stopover sites (Bowen and others, 2013; Arnett and others, 2008).

Yet, foothill aspen woodlands contribute to local diversity and provide crucial structural connectivity functions in sagebrush landscapes of the Wyoming Basin. Mountain slope aspen, because of its dependence on fire and other severe disturbances, continuity along an elevational gradient, larger patch sizes, and the greater amount of core area, may be more resilient to stressors and have a greater potential for persistence under projected climate change compared to foothill aspen in the Wyoming Basin. Indeed, the recent widespread outbreak of bark beetles has created potential for competitive release and expansion of mountain slope aspen that may offset potential conifer expansion in aspen forests.

These results indicate that, compared to foothill aspen, mountain slope aspen is currently relatively secure in the Wyoming Basin Rapid Ecoregional Assessment project area and may not require active management to maintain it on the landscape. In contrast, foothill aspen represents significant management challenges because fire is not generally required to maintain the aspen stands, and management techniques used to simulate severe disturbances (such as prescribed fire or mechanical treatments), coupled with high overstory mortality from SAD, could lead to stand loss unless protection of aspen sprouts from grazing is provided (Shinneman and others, 2013). Yet, the small aspen patch size and adjacent land use can increase the potential for loss of stands due to high herbivory pressures that could occur following canopy removal or mortality. Much of the foothill aspen is privately owned and has high Terrestrial Development Index scores; thus, foothill aspen under BLM jurisdiction represents significant public ownership of vulnerable aspen woodlands that have crucial structural connectivity functions in the Wyoming Basin.

The highest conservation potential is generally at upper elevations along the periphery of the project area, which is predominantly mountain slope aspen (fig. 15–17). Likewise, many small isolated stands in the vicinity of Little Mountain (south of Rock Springs, the Granite Mountains, and in the highlands at the southern end of the Bighorn Basin) have high conservation potential and may serve as stepping stones. Most townships with high landscape-level values for foothill aspen (fig. 15–15*B*) also have moderate to high risk; for these areas, management challenges include potential local-scale degradation (such as road effects on core area), landscape-scale degradation from development (as indicated by high TDI scores), and risk from Change Agents (such as SAD). Townships with high management challenges indicate areas that may benefit from management activities that mitigate the potential risk from Change Agents, such as maintaining multiage stand structure in areas where risk of SAD is high (Shepperd and others, 2006). Likewise, these areas may be sensitive to management activities that could affect future vulnerability of the stands to Change Agents. For example, foothill aspen woodlands that have limited core area (and potentially high levels of herbivory) may have decreased potential for regeneration following prescribed burning or clearcutting, which could increase vulnerability to SAD and potential loss of the aspen stand (Shepperd and others, 2006). In addition, site-level information that represents data gaps at the regional scale (such as stand structure, stand health, regeneration rates, herbivory levels) can be used to validate the regional-level ranks and provide more detailed information necessary for decision-making.

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