J. For. 112(5):474–483
http://dx.doi.org/10.5849/jof.13-086

silviculture

Regional Forest Landscape Restoration Priorities: Integrating Historical Conditions and an Uncertain Future in the Northern Rocky Mountains

Barry L. Bollenbacher, Russell T. Graham, and Keith M. Reynolds

National law and policy direct the management of the National Forests, with restoring resilient forest conditions being an overarching theme. Climate is a major driver of disturbances that affect ecosystems, especially those with vegetation that show large departures from historical conditions. Drought, fire, insects, and diseases are common forest stressors whose impacts are being exacerbated by climate change. These stressors are threatening the ecosystem services that people value in the forests of the northern Rocky Mountains. The forests of most concern are the dry ponderosa pine and Douglas-fir, moist western white pine mixed with western larch, and cool lodgepole pine mixed with quaking aspen and whitebark pine. Potential reductions in some ecosystem services pose a challenge in terms of not only direct biophysical consequences but also social and economic values that flow from these forests. Values at risk include forest integrity, wildlife habitat, watershed condition, fish habitat, recreation opportunities and investments, community infrastructure, and public safety. This article describes a decision support tool developed by the USDA Forest Service Northern Region in 2010 to support integrated restoration planning. The Northern Region's Integrated Restoration and Protection Strategy (IRPS) is premised on identifying historical conditions through application of the natural range of variability, comparing them with current conditions, and considering a broader range of future issues, including climate change. The IRPS assists managers in the complex task of evaluating factors that influence national forest planning efforts. The assessment and IRPS, by integrating ecological, social, and economic considerations, will help managers of national forests prioritize restoration opportunities using increasingly scarce financial resources. The IRPS will be most beneficial when associated with planning silvicultural practices and fire management directed at restoring the forests of the Northern Region to a more resilient condition.

Keywords: decision support system, forest restoration, forest planning

The National Forest Management Act of 1976 (NFMA) provides the basis for restoring National Forest System lands. For example, NFMA Sec. 4.(d)(1) states that

> It is the policy of the Congress that all forested lands in the National Forest System shall be maintained in appropriate forest cover with species of trees, degree of stocking, rate of growth, and conditions of stand designed to secure the maximum benefits of multiple use sustained yield management in accordance with land management plans.

In response to that policy, the 2012 Planning Rule implementing the NFMA incorporates social, economic, and ecological sustainability. An ecosystem approach developed through assessments and public collaboration is used for forest plans to develop desired conditions that maintain the diversity of plant and animal communities of a forest. Desired conditions are developed using, but not limited to, information such as the natural range of variability and the ecological, social, economic, and climate conditions of a forest. As such, managing National Forest System lands for ecological resiliency has become one of the major goals of the US Department of Agriculture (USDA) Forest Service. In 2010, the Northern Region of the Forest Service developed a decision support tool to inform planning efforts for restoration at large spatial scales. This decision process is rooted in reconstructing historical ecosystem structures and processes to gain ecological understanding. These reconstructions have come to be called the natural range of variability (NRV). Consideration of the role of changing climate is one key to understanding the link

Received November 22, 2013; accepted July 22, 2014; published online August 14, 2014.

Affiliations: *Barry L. Bollenbacher (bbollenbacher@fs.fed.us), USDA Forest Service, Northern Region, Missoula, MT. Russell T. Graham (rtgraham@fs.fed.us), USDA Forest Service, Rocky Mountain Research Station. Keith M. Reynolds (kreynolds@fs.fed.us), USDA Forest Service, Pacific Northwest Research Station.*

Acknowledgments. *Many people have been involved in development of the Integrated Restoration and Protection Strategy, and we acknowledge their contributions here. We also thank Melissa Hart and Lindy Larson for their editing assistance.*

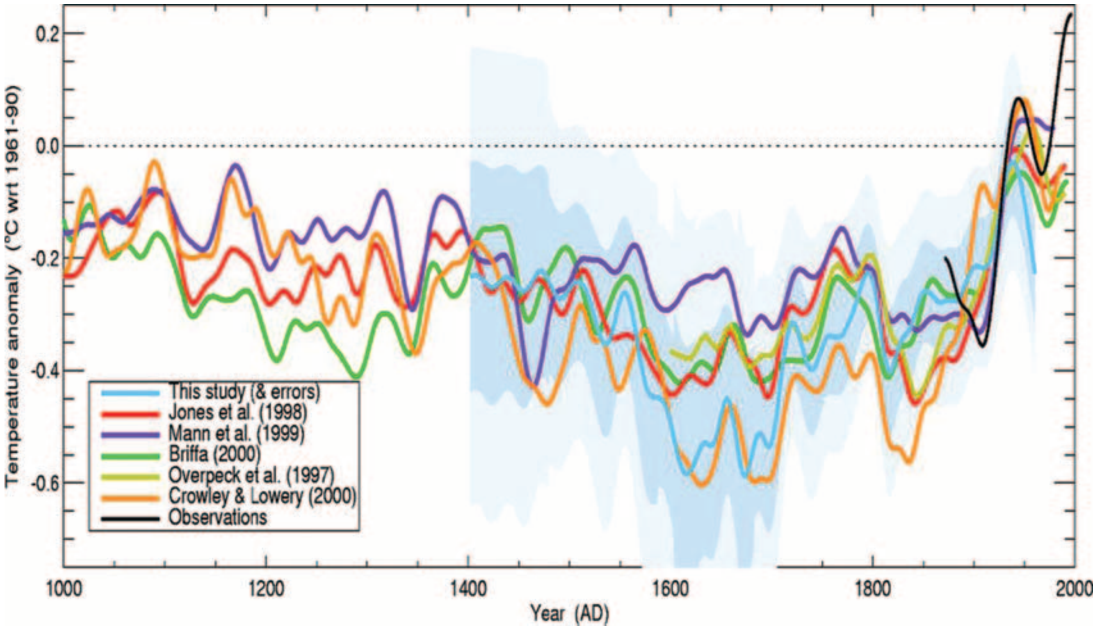

Figure 1. Likely temperature variation over the past 1,000 years. These data are a compilation of tree ring studies relating tree ring width to climate (Briffa et al. 2001).

among historical, current, and future forest conditions for several of the Northern Region's prominent forest types.

Observed and Projected Climate in the Northern Rocky Mountains

Observed Climate Trends and Forest Change

Past and future climates have and will continue to influence forest composition and disturbance regimes such as fire, insects, and diseases. How these stressors will affect ecosystems in the future is largely unknown. However, we do know specific aspects concerning climate that provide insight. Two noteworthy climate fluctuations were the medieval warm period (1000–1400 AD) followed by the mini-ice age (Figure 1). The Pacific Decadal Oscillation (PDO), El Nino, and La Nina temperature changes in the northern Pacific Ocean have major influences on the weather of the northwestern United States. The PDO temperature index for the past century correlates well with the occurrence of wildfires and bark beetle epidemics in the northern Rocky Mountains. Climate is recognized as a major driver of severe and widespread wildfires because all major fires in the northern Rockies have occurred during the warm phase of the PDO (McKenzie et al. 2004, Morgan et al. 2008). This trend was reinforced by the fire patterns between 2000 and 2007. In contrast, the cool summers of 2008, 2009, and 2010 resulted in few major fires in the northern Rockies. These changes in wildfires occurred with minimal changes to fuel and fire suppression capabilities during those years.

The PDO temperature index for the past century also correlates with bark beetle epidemics. In the northern Rockies during warm PDOs, major mountain pine beetle (MPB) epidemics have occurred in the periods 1920–1940 and 1970–1990, and in the current period beginning in 2001. From 1940 through 1975, the climate was cool and wet, which aided effective suppression that limited wildfires and promoted tree growth and which possibly minimized MPB outbreaks (Figure 2). However, these same conditions facilitated abundant forest regeneration and forest densification. As a result, since the PDO commencing in 1940, many forests in the northern Rockies have become more homogeneous and have changed fire regimes from nonlethal and mixed severity to more lethal (Quigley and Arbelbide 1997).

Projected Climate Trends and Forest Change

All global climate models (GCMs) project surface temperature warming in the northern Rockies in all seasons regardless of uncertainties in modeling or greenhouse gas emissions (Nakicenovic and Swart 2000, Meehl et al. 2007). Nationally, the National Oceanic and Atmospheric Administration[1] has predicted that 77% of weather stations will have reported increased maximum temperatures and 94% of stations will have reported increased minimum temperatures.

Management and Policy Implications

Contemporary forest management begins with two questions: "Why here?" and "Why now?" The Integrated Restoration and Protection Strategy (IRPS) includes multiple management objectives and uses a set of very complex variables to identify high-priority watersheds for restoration. Thus, IRPS is an excellent tool for addressing these questions. By attaining the most efficient solution, IRPS can offer management actions that are often constrained by limited budgets while addressing social needs. In general, forests resilient to wildfires, insects, and diseases, likely to be exacerbated by a changing climate, offer the greatest opportunity for supplying ecosystem services to people living in and visiting the Northern Region. Because of its transparency, the IRPS enables the Northern Region to have constructive dialogue among external public groups, internal specialists, and line officers in setting forest restoration priorities in the face of a changing climate and uncertain budgets.

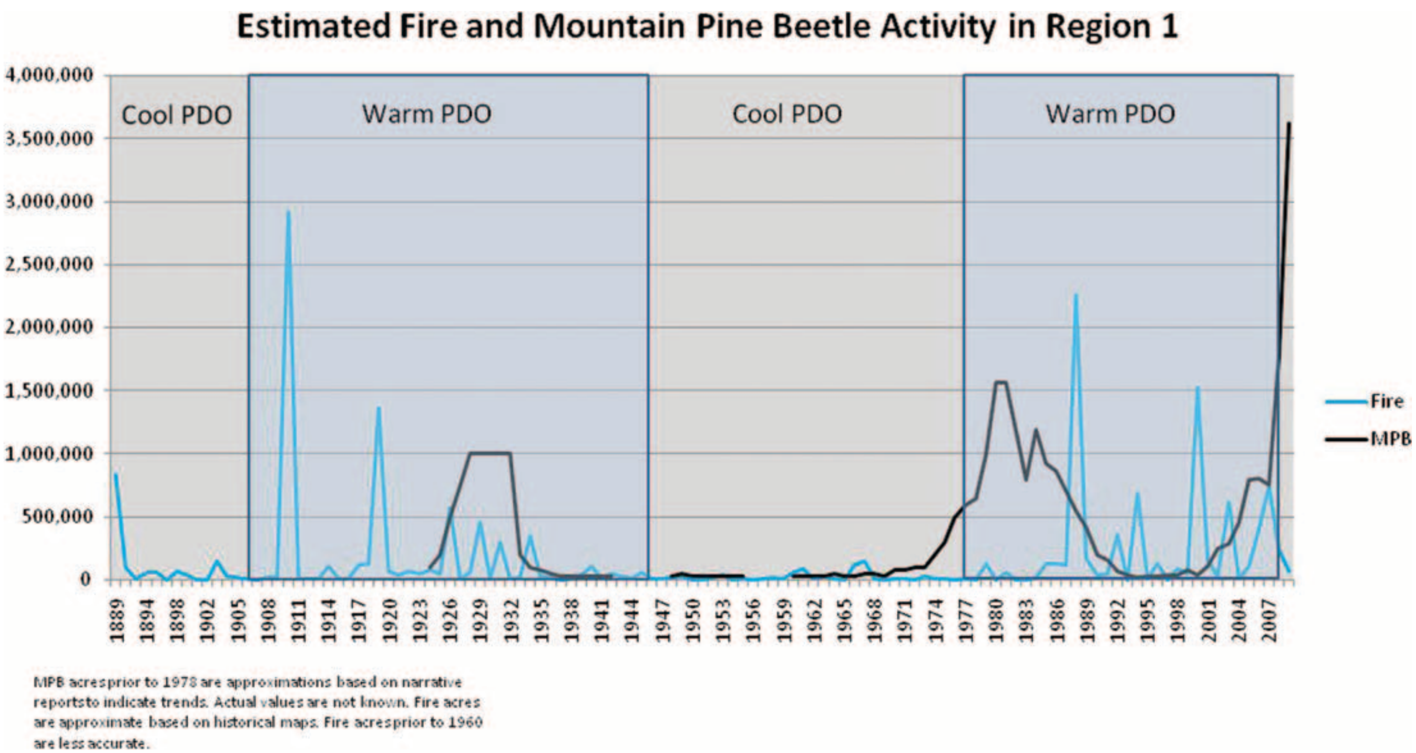

Figure 2. Within the Northern Region of the USDA Forest Service, both MPB and wildfire activity are related to changes in ocean temperatures of the northern Pacific Ocean as shown by the PDO.

Table 1. Modeled effects of future wildfire characteristics in many forested regions of western North America (Flanigan et al. 2005a).

Effects	Reference(s)
Longer fire seasons	Brown et al. (2004b), Nitschke and Innes (2008)
Increased number of days with high fire danger	Brown et al. (2004b)
Increased frequency of ignitions	Price and Rind (1994), Bachelet et al. (2007)
More frequent episodes of extreme fire behavior	Nitschke and Innes (2008)
Increased frequency of large fires	Westerling and Bryant (2008)
Increased area burned	Bachelet et al. (2001), McKenzie et al. (2004), Flanigan et al. (2005b), Bachelet et al. (2007), Lenihan et al. (2008)
Increased risk of property and resource loss	Westerling and Bryant (2008), Nitschke and Innes (2008)
More frequent occurrence of lethal fire effects in ponderosa pine forests if physiological stress occurs as a result of increasing winter drought	Keeling and Sala (2012)

These projected temperature increases by 2040 exceed the observed 20th century year-to-year variability. Many climate models have also projected increases in precipitation during the winter and decreases in summer, but these changes are comparable to 20th century variability. Beyond midcentury, climate change projections are less certain because they depend increasingly on greenhouse gas emission rates. Based on these climate trends and projected warming that may persist for decades if not centuries, there may be significant changes in how wildfires, insects, and diseases impact forests (Bentz et al. 2009, Littell et al. 2010). Statistical models, mechanistic simulation models, and landscape disturbance models that have been used to evaluate future wildfire characteristics in many forested regions of western North America project many potential effects (Table 1).

Potential implications of these changes in fire regimes include the following:

• An increase in area occupied by early seral forests and a decrease in area occupied by late seral forests (Brown et al. 2004b, Chmura et al. 2011).

• A decrease in the area occupied by nonfire-adapted species (e.g., hemlock, true firs, and spruce) (Chmura et al. 2011).

• Increased tree mortality from stressors singly and in combination such as drought, insects, diseases, and fire (Westerling et al. 2011, Keeling and Sala 2012).

• The potential for persistent shifts in vegetation composition and structure (Loehman et al. 2011, Westerling et al. 2011, Marlon et al. 2012).

Application of NRV to Prominent Northern Rocky Mountain Forest Types

During the last two decades, ecologists have increasingly relied on reconstructions of historical ecosystem structures and processes to gain ecological understanding. These historical reconstructions have come to be called the NRV and use the concept of historical/natural conditions and processes within some range, in which they varied (Tinker et al. 2003, Veblen 2003, Brown et al. 2004a, Dillon et al. 2005, Meyer et al. 2005, Nonaka and Spies 2005). The concept of NRV has been suggested as a framework for coarse filter conservation strategies (Haufler et al. 1996, Landres et al. 1999). NRV concepts were developed in part to better understand how disturbance, vegetation, and other ecosystem components interact and in turn how their interaction affects biophysical elements such as plants, animals, fish, and soil and water resources. Historical perspectives increase our understanding of the dynamic nature of land-

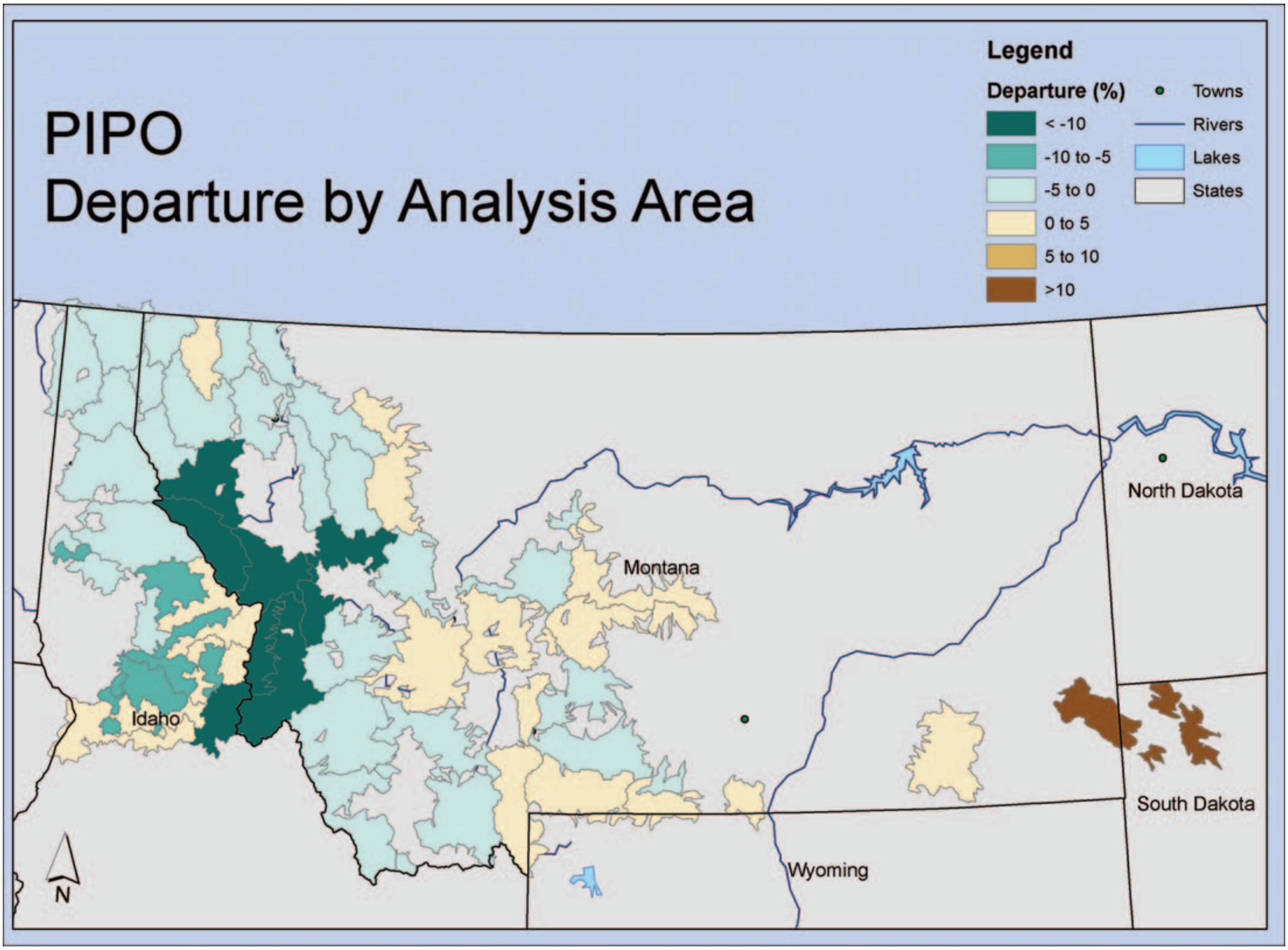

Figure 3. Departure from historic conditions of the ponderosa pine type in the Northern Region, USDA Forest Service. Negative departure values indicate less of a type and positive values more of a type than what historically occurred on the landscape. PIPO, ponderosa pine.

scapes and provide a frame of reference for assessing current patterns and processes (Swetnam et al. 1999).

The Northern Region National Forests used this process in developing a NRV for vegetation and define it as the range of variation in spatial, structural, compositional, and temporal characteristics of ecosystem elements as affected by climatic fluctuations and disturbances (Keane et al. 2008, Wiens et al. 2012). The NRV analysis focuses on forest composition, structure, landscape pattern, and processes (disturbance and succession) and has been used to help identify desired conditions for the future. The concept of comparing current vegetation conditions with both the historical and potential future conditions is described by Gartner et al. (2008). The knowledge gained from this approach can then be used to help inform adaptation activities and tactics in regard to management decisions that may need to be made regarding how climate change may affect future landscape conditions and how adaptation strategies are developed (Keane et al. 2008, Wiens et al. 2012). Given these insights, climate change adaptive strategies such as fostering resistance and resiliency in forest ecosystems can be considered. In addition, NRV comparisons can be used to characterize desired conditions in forest plan revision efforts. To illustrate the usefulness of the NRV concept to forest planning efforts, the following discussion summarizes pertinent departures from NRV conditions for prominent forest cover types of the northern Rocky Mountains.

Dry Ponderosa Forests—Fire Frequency

With departure of historically open grown ponderosa pine as an example, this species is often the only one that can colonize the hot dry surface conditions of a disturbed site within the dry forests of western and central Montana (Figure 3). Over time, as it develops, it provides a shaded environment where less heat-tolerant Douglas-fir can establish. Under the historic low-severity fire regime, the thick barked ponderosa pines survive frequent forest fires and the thinner bark Douglas-fir or ponderosa pine seedlings do not. When frequent fires were sustained, the ponderosa pine forest developed into large patches of open grown old-growth structure intermixed with small openings that can persist for centuries, provided moisture and temperature regimes do not dramatically change. During a cool wet climate period, along with fire exclusion, ponderosa pine forests allowed Douglas-fir and/or dense ponderosa pine to become established. Over decades, such forests became

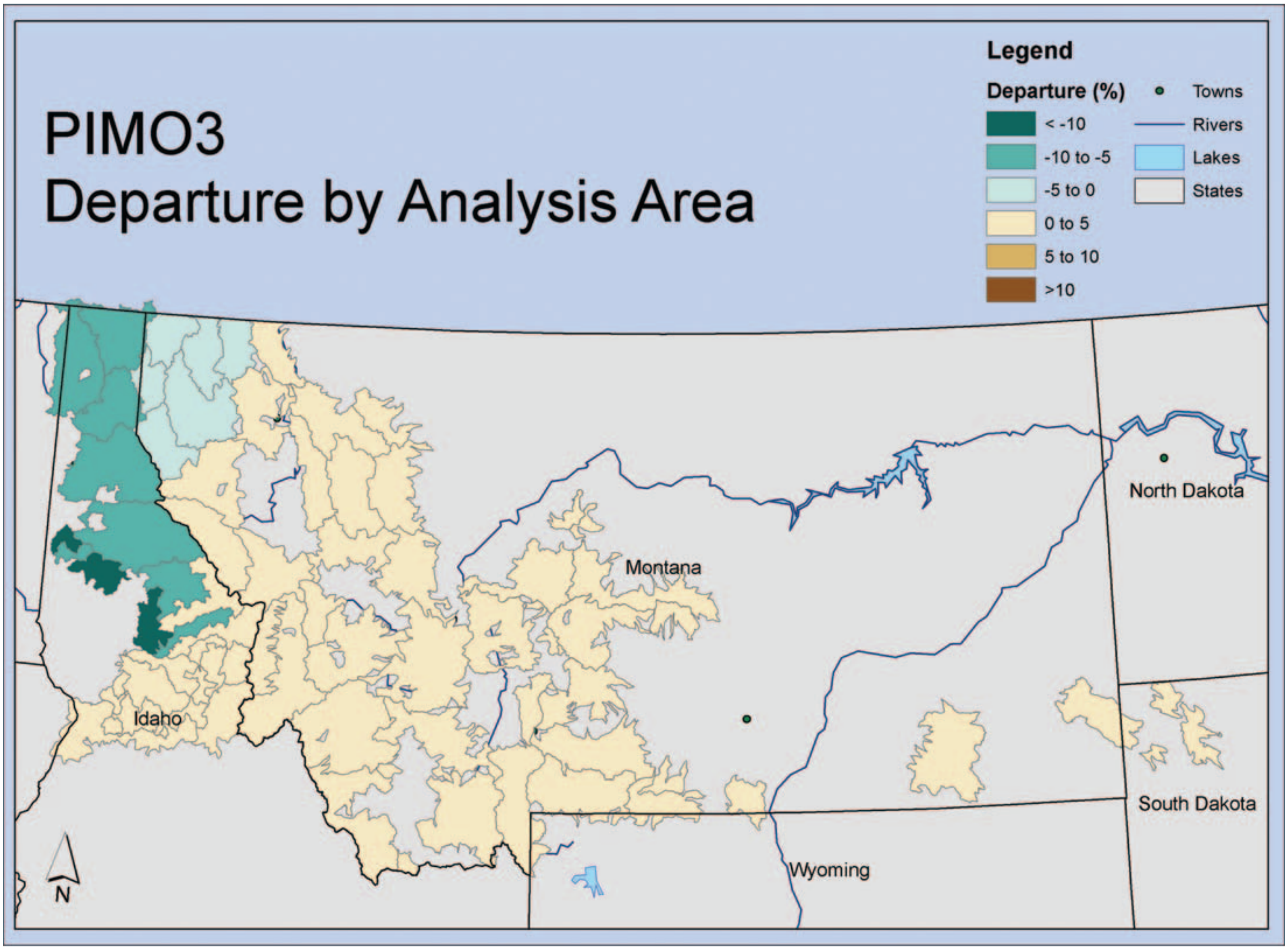

Figure 4. Departure from historic conditions of the western white pine type in the Northern Region, USDA Forest Service. Because of white pine blister rust, bark beetles, and harvesting, the occurrence of western white pine has decreased dramatically in northern Idaho. Negative departure values indicate less of a type and positive values more of a type than what historically occurred on the landscape. PIMO3, western white pine.

dominated by dense Douglas-fir that exceeded measures of cover and density compared with what historically occurred on the landscape. The increased biomass and structural homogeneity allow large crown fires that reinitiate stand development, and if the forest reburns, these areas may become nonforested due to loss of seed, limited soil moisture, and high surface soil temperature (Keeling and Sala 2012, Turner et al. 2013).

Western White Pine Stands—White Pine Blister Rust

Historically, western white pine was a common tree species in the region, particularly in northern Idaho, and dominated a very large part of the moist habitat types. Across its range, the western white pine cover type is now estimated to be <5% of what it was at the turn of the 20th century (Neuenschwander et al. 1999) (Figure 4). In the early part of the 20th century, white pine blister rust (a Eurasian disease) was accidentally introduced to western North America. Combined with a MPB outbreak in western white pine in this area (Neuenschwander et al. 1999), this exotic disease has been the primary cause for the loss of white pine in this area. With the loss of white pine, there have been large increases in the amount of Douglas-fir and grand fir-dominated forests and a major acceleration of forest succession toward shade-tolerant, late-successional true-firs, western hemlocks, and western red cedars. Western white pine had the ability to form a stable, relatively long-lived forest that was perpetuated by a combination of mixed-severity and stand-replacing wildfires (Monnig and Byler 1992, Zack and Morgan 1994, Harvey et al. 1995).

Dry Mixed Conifer Stands—Root Disease

In natural mixed-species stands, western white pine, ponderosa pine, and western larch were most resistant to root pathogens that frequently killed Douglas-fir and the late seral true firs. In these historic forests, insects, and diseases probably served as stabilizing agents, removing the maladapted late seral species and favoring the early seral pines and western larch (Harvey et al. 1999). Thus, over the first 150 years or so of a mixed-species stand's life, western white pine and western larch would dominate (Rockwell 1917, Monnig and Byler 1992, Hoff and McDonald 1994). Currently, with the absence of western white pine and de-

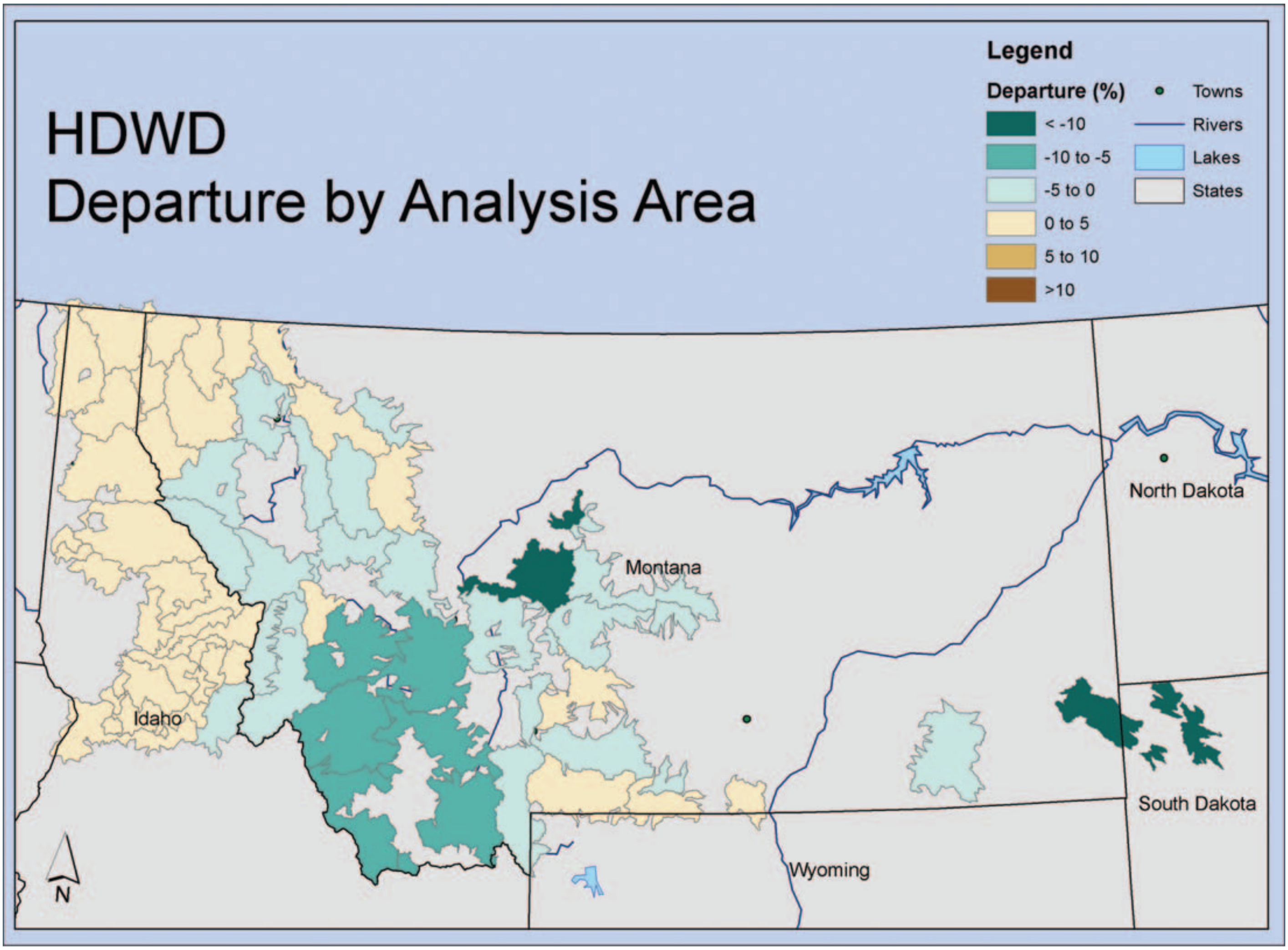

Figure 5. Departure from historic conditions of the hardwood forest type in the Northern Region, USDA Forest Service. Quaking aspen in particular has experienced sharp declines within the Region. Negative departure values indicate less of a type and positive values more of a type compared with what historically occurred on the landscape. HDWD, hardwood.

creased amounts of ponderosa pine and western larch, root pathogens have transformed from thinning agents into major stand-change agents. Depending on the habitat type, root pathogens may either stall succession in a diseased shrub/sapling/open pole condition or accelerate succession toward shade-tolerant species. The resulting forests are much more susceptible to drought and severe wildfire than historical forests (Byler and Hagle 2000).

Mixed Lodgepole Pine, Quaking Aspen, and Whitebark Pine Stands—MPB

The mixed lodgepole pine, quaking aspen, and whitebark pine forests of central Montana are significantly different from historical forests as a result of wildfires and timber harvests between 1890 and 1940. After 1940, during a cool PDO and effective fire suppression, disturbance was reduced, resulting in the homogenization of these pine-dominated forests and the gradual exclusion of quaking aspen (Figure 5). Such a dynamic in lodgepole pine forests has prevailed in central Montana, central and western Canada, and the central Rocky Mountains. The resulting large expanses of homogenized forests are very susceptible to MPB epidemics, which are very responsive to habitat and climate conditions (McGregor et al. 1981, Safranyik and Shore 1992). MPB outbreaks tend to occur during warm and dry conditions and can cease after extreme winter cold (Logan and Bentz 1999).

During the 20th century, MPB caused widespread tree mortality in the northern Rockies (Evenden 1934, 1944). MPB outbreaks during the period 1920–1930 and from the late 1970s to early 1980s killed large expanses of lodgepole pine in Idaho and Montana. These epidemics were very similar to the most recent outbreak beginning in 2001 (Cole and Amman 1980, McGregor and Cole 1985).

In addition to lodgepole pine forests, whitebark pine forests are susceptible to MPB, and an outbreak in this forest type occurred in the 1920s. However, over the last decade, an unprecedented level of MPB activity has occurred in high-elevation whitebark pine forests across much of the western United States and Canada (Gibson 2008). There is considerable concern over whitebark pine because, in addition to MPB, fire exclusion and white pine blister rust have contributed to significant declines in the species across its range in western North America, a decline that could be further exacerbated by a warming climate

(Keane and Parsons 2010, Keane et al. 2012). Without management intervention, losses of this species across its range could have major consequences for biodiversity and threaten the species existence (Tomback 2007).

Integrated Restoration and Protection Strategy

During 2010–2011, Northern Region resource specialists updated the Integrated Restoration and Protection Strategy (IRPS) first completed in 2006, using the decision support system methods and models implemented in the Ecosystem Management Decision Support System (Reynolds et al. 2003, Reynolds 2006). Their goal was to provide a consistent, transparent, and reproducible approach to identifying and prioritizing restoration opportunities by subwatersheds across the Region.

The updated IRPS now provides information to help forests and districts assess ecological conditions, assess risks to related ecosystem services, describe ecosystems that can cope with future disturbances, and identify and prioritize potential subwatersheds for accomplishing goals and objectives of forest and grassland plans. Such goals include implementing projects that restore land and water resources, providing wildfire protection to communities, and producing sustainable and resilient forests and grasslands. IRPS also provides information on values that may be vulnerable or at risk to wildfires, insects, and diseases to help forests and districts develop integrated land management projects.

Important assumptions about ecological trends disclosed in the IRPS include the following:

• Expect warmer temperatures, similar precipitation, with drier summers, resulting in increasing moisture deficits (Littell et al. 2009).

• Expect increases in the number and size of severe wildfires (Littell et al. 2010, Dillon et al. 2011, Keane et al. 2012, Keeling and Sala 2012, Turner et al. 2013).

• Expect increasing bark beetle activity (Bentz et al. 2009).

• Expect shade-intolerant tree species to cope more effectively with possible future climate scenarios than shade-tolerant species (Chmura et al. 2011).

• Expect persistent shifts in vegetation compositions and structures (Loehman et al. 2011, Westerling et al. 2011, Marlon et al. 2012).

Considering these assumptions, a framework for restoring forest conditions to be more resilient include the following:

• Restoring a higher proportion of shade-intolerant tree species such as ponderosa pine, western larch, and western white pine should enable forests to cope more effectively with climate change and increasing disturbance, and these restored forests should have a greater capacity to persist compared with those more dominated by shade-tolerant species (Chmura et al. 2011).

• Reducing forest density should help forests cope with increasing moisture deficits and intense wildfire (Chmura et al. 2011).

• Restoring size and age class diversity arranged in patches and patterns of these conditions should minimize disturbances from affecting large landscapes and encourage forest regeneration (Turner et al. 2013).

The IRPS framework not only considered forest vegetation but also included a number of other themes related to social concerns and expectations:

Theme 1—Vegetation resilience
Theme 2—Terrestrial species habitat
Theme 3—Water quantity and quality
Theme 4—Aquatic species
Theme 5—Past investments in recreation settings and new opportunities
Theme 6—Public safety and infrastructure protection by addressing current MPB outbreaks and the resulting fire risks to communities and recreation sites

An example is the forest resiliency model (e.g., not only vegetative resilience but also soil, water, and wildlife). Forest departure was incorporated with the influence that stressors, probably exacerbated by a changing climate, may affect forests. Although incomplete, such information can be estimated by determining how stressors probably modified forest composition and structure under variable climates of the past. The forest resiliency model provided a spatial answer to the planning question, "Which forests are most vulnerable to loss of important elements (e.g., trees, wildlife, and soils) in a changing climate and where are there opportunities to restore them to a more resilient condition?" This IRPS model included several value and stressor attributes. Values related to loss of resiliency, which focus on departure from the desired condition (as informed by NRV), were weighted at 70% and include dominance forest type (25%), tree size (5%), and warm-dry forest type canopy cover (40%). Stressors were weighted at 30% and include current insect occurrence (15%), crown fire burn probability (20%), and bark beetle hazard (5%).

Application of the model over the Northern Region subwatersheds identified those that have the greatest and least opportunity for ecosystem restoration (Figure 6). When all six themes are included in one model, an integrated solution for multiple resource opportunities for restoration can be identified. By doing so, site-specific treatment prescriptions informed by the IRPS can be developed that have the best opportunity of restoring the targeted ecosystems (Figure 7). As part of informing local management prescriptions, the IRPS provides context for such actions and describes their impacts and vulnerabilities related to climate change (Bollenbacher 2013). For example, at the landscape scale, the IPRS can show where forest heterogeneity and pattern may limit the extent of large uncharacteristically severe disturbances such as wildfires and/or bark beetle epidemics using mechanical and fire tools (Turner et al. 2013). In addition, by highlighting where moisture deficits may occur because of changing climates, the IPRS can show where wildfires, insects, and diseases may be at higher levels. By doing so, management strategies stressing climate adapted species (e.g., seral and genetically appropriate) compositions and structures (e.g., densities, grouping, and arrangement) that will allow the forest to have the capacity to cope with future levels of disturbance can be promoted (Table 2).

Before IPRS, planning and execution of management actions ranging from vegetation treatments to travel planning were most often developed on forests and even ranger districts in response to local conditions and local stakeholders. However, issues such as sustaining salmon, steelhead, and other fish habitat, maintaining vibrant forest industries, addressing wildfire hazard and response, providing big game habitat, and providing small and large carnivore (e.g., Canadian lynx and grizzly bear) habitat transcend many forest and regional boundaries and go beyond most state, private, and federal land borders (Quigley and Arbelbide 1997). The IPRS allows the Forest Service to set management priorities using a rational process that can address broad-scale issues that will provide context and understanding

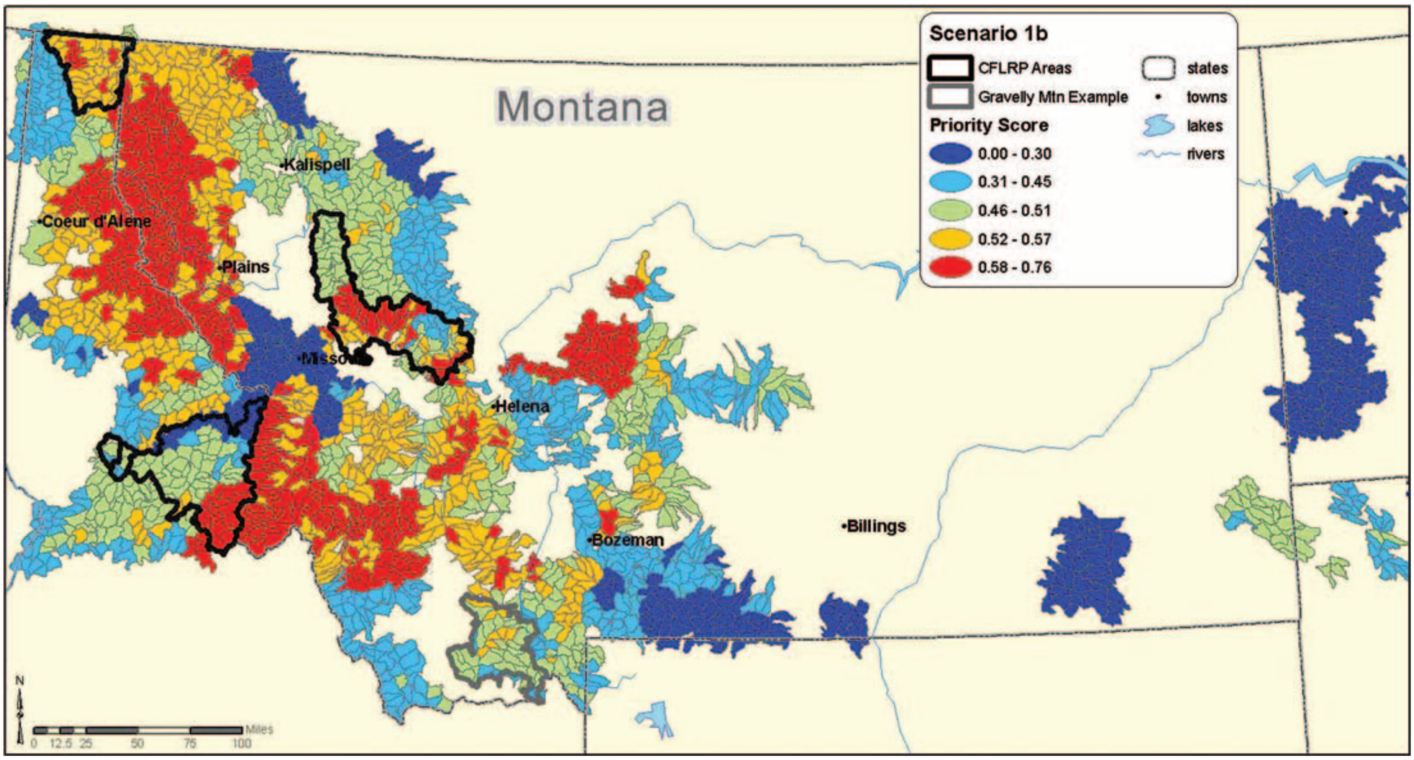

Figure 6. IRPS model results for forest resiliency across all subwatersheds in the Northern Region, USDA Forest Service. Higher priority scores (red) indicate areas with the most opportunity to restore forest ecosystem components, and lower scores (dark blue) represent areas with the fewest opportunities. CFLRP, Collaborative Forest Landscape Restoration Program.

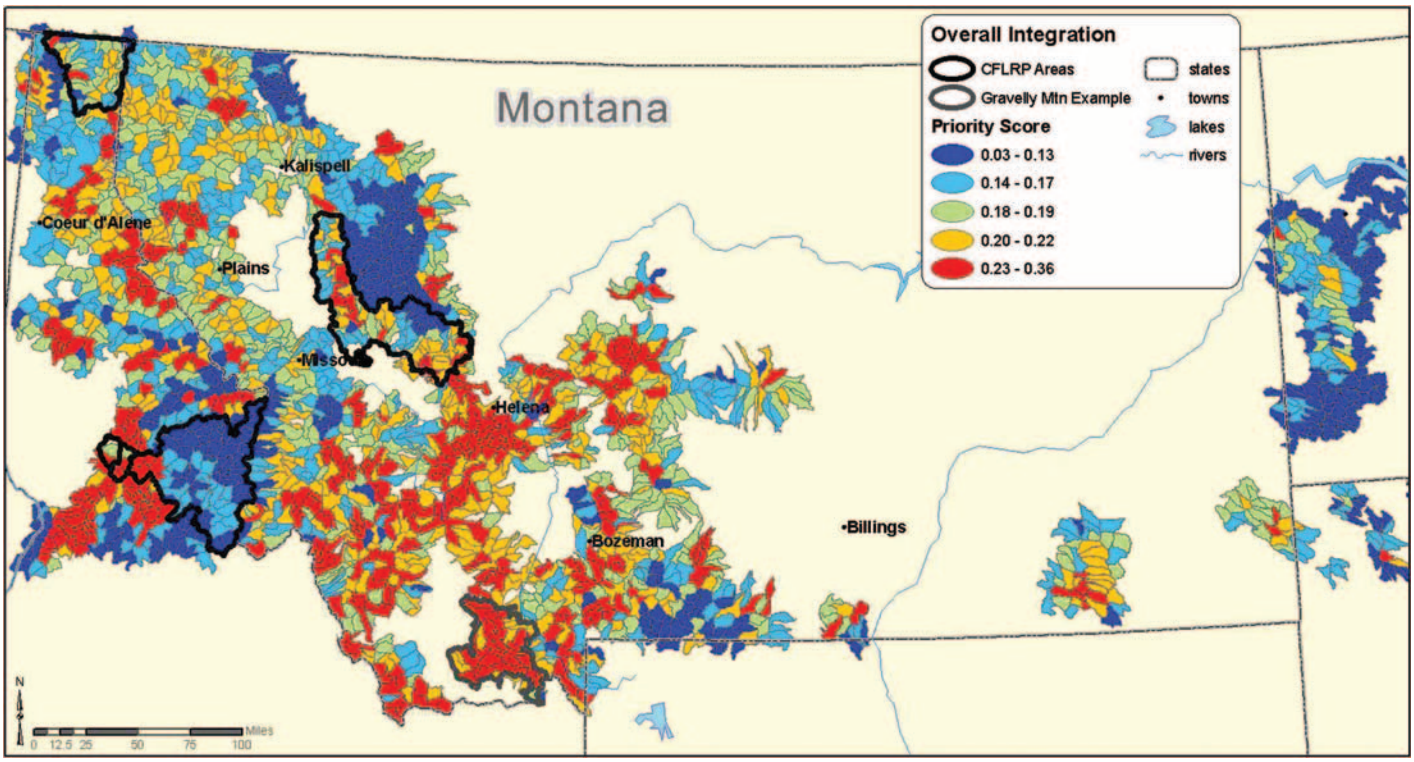

Figure 7. Overall IRPS model results integrated across all themes for all subwatersheds in the Northern Region, USDA Forest Service. Higher priority scores (red) indicate areas with the most opportunity to restore forest ecosystem components, and lower scores (dark blue) represent areas with the fewest opportunities. This map represents a multiple use objective, which often is a basis for the purpose and need for project initiation. CFLRP, Collaborative Forest Landscape Restoration Program.

Table 2. Recommendations for silvicultural practices and adaptation tactics for tree species in the Northern Region of the USDA Forest Service.

Tree species	Adaptation tactics and silvicultural practices to consider
Ponderosa pine	Reduce forest density in all successional stages. Consider some shift in distribution on dryer margins, plant ponderosa pine on sites where Douglas-fir or grand fir has replaced ponderosa pine considering NRV, in areas not on dryer margins.
Douglas-fir	Reduce forest density in all successional stages. Consider some shift in species distribution on dryer margins. On moist sites, shift to western white pine, ponderosa pine, and western larch where they occurred historically to reduce impacts of root disease.
Grand fir	Shift to western white pine, ponderosa pine, and western larch to reduce impacts of root disease. Maintain grand fir on moist habitats within the current mixed mesic forest.
Cedar	Consider shifts in species distribution to areas where less moisture deficit will occur in the future.
Hemlock	Shift to western white pine, ponderosa pine, and western larch where they occurred historically to reduce impacts of root disease.
White pine	Aggressively plant rust-resistant white pine especially on sites where less soil moisture deficit is expected.
Whitebark pine	Plan for a diversity of successional stages primarily using fire to achieve this resource benefit and reforest via planting improved stock where the opportunity exists. Wildfire to achieve multiple resource benefits is a significant tool to restore whitebark pine.
Spruce	Distribution may contract to northerly aspects and soils with potential to have minimal moisture deficit: manage spruce more intensively on these sites.
Subalpine fir	Distribution may contract to the northerly aspects and soils with potential to have minimal moisture deficit: manage for subalpine fir on these sites.
Larch	Distribution may contract to the northerly aspects and soils with potential to have minimal moisture deficit: manage more intensively on these sites with reduced stocking levels compared to current levels.
Mountain hemlock	Distribution may contract to the northerly aspects and soils with potential to have minimal moisture deficit: manage mountain hemlock on these sites.
Lodgepole pine	Manage for landscape heterogeneity of pattern and successional stages; manage for reduced stocking levels.
Aspen	Encourage increases in disturbance by more regeneration of quaking aspen within current lodgepole pine forests. Plan for potential distribution to contract to the more northerly aspects and/or where soils have the potential to have minimal moisture deficit and manage quaking aspen more intensively on these sites.

to local management actions, especially in the face of an uncertain climate.

Endnote

1. For more details, see www.ncdc.noaa.gov/oa/climate/research/cag3/na.html.

Literature Cited

BACHELET, D., J.M. LENIHAN, AND R.P. NEILSON. 2007. The importance of climate change for future wildfire scenarios in the western United States. P. 22–41 in *Regional impacts of climate change: Four case studies in the United States.* Pew Center on Global Climate Change, Arlington, VA.

BACHELET, D., R.P. NEILSON, J.M. LENIHAN, AND R.J. DRAPEK. 2001. Climate change effects on vegetation distribution and carbon budget in the United States. *Ecosystems* 4:164–185.

BENTZ, B.J., C.J. FETTIG, E.M. HANSEN, J. HICKE, J.L. HAYES, R. KELSEY, J. LUNDQUIST, ET AL. 2009. *Climate change and western bark beetles: Rapid threat assessment.* Western Wildlands Environmental Threats Assessment Center, USDA For. Serv., Prineville, OR. 57 p.

BOLLENBACHER, B.L. 2013. *Climate change vulnerability assessment and adaptation strategies for forests in the Northern Region.* USDA For. Serv., Staff Rep., Northern Region, Missoula, MT. 94 p.

BRIFFA, K.R., T.J. OSBORN, F.H. SCHWEINGRUBER, I.C. HARRIS, P.D. JONES, S.G. SHIYATOV, AND E.A. VAGANOV. 2001. Low-frequency temperature variations from a northern tree ring density network. *J. Geophys. Res.* 106 (D3):2929–2941.

BROWN, R.T., J.K. AGEE, AND J.F. FRANKLIN. 2004a. Forest restoration and fire: Principles in the concept of place. *Conserv. Biol.* 18(4): 903–912.

BROWN, T.J., B.L. HALL, AND A.L. WESTERLING. 2004b. The impact of twenty-first century climate change on wildland fire danger in the western United States: An applications perspective. *Climatic Change* 62:365–388.

BYLER, J.W., AND S.K. HAGLE. 2000. *Succession functions of forest pathogens and insects: Ecosections M332a and M333d in northern Idaho and western Montana. Summary.* USDA For. Serv., FHP Rep. No. 00-09, Northern Region, Forest Health Protection, State and Private Forestry, Missoula, MT. 37 p.

CHMURA, D.J., P.D. ANDERSON, G.T. HOWE, C.A. HARRINGTON, J.E. HALOFSKY, D.L. PETERSON, D.C. SHAW, AND J.B. ST. CLAIR. 2011. Forest responses to climate change in the northwestern United States: Ecophysiological foundations for adaptive management. *For. Ecol. Manage.* 261:1121–1142.

COLE, W.E., AND G.D. AMMAN. 1980. *Mountain pine beetle dynamics in lodgepole pine forests. Part I: Course of an infestation.* USDA For. Serv., Gen. Tech. Rep. INT-89, Intermountain Forest and Range Experiment Station, Ogden, UT. 56 p.

DILLON, G.K., Z.A. HOLDEN, P. MORGAN, M.A. CRIMMINS, E.K. HEYERDAHL, AND C.H. LUCE. 2011. Both topography and climate affected forest and woodland burn severity in two regions of the western US, 1984 to 2006. *Ecosphere* 2(12):130.

DILLON, G.K., D.H. KNIGHT, AND C.B. MEYER. 2005. *Historic range of variability for upland vegetation in the Medicine Bow National Forest, Wyoming.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-139, Rocky Mountain Research Station, Fort Collins, CO. 85 p.

EVENDEN, J.C. 1934. *History of the mountain pine beetle infestation in the lodgepole pine stands of Montana.* USDA Bureau of Entomology, Forest Insect Investigation Rep., Forest Insect Laboratory, Coeur d'Alene, ID. 29 p.

EVENDEN, J.C. 1944. *Montana's thirty-year mountain pine beetle infestation.* USDA For. Serv., Insert Rep., Northern Region, Missoula, MT. 16 p.

FLANIGAN, M.D., B.D. AMIRO, K.A. LOGAN, B.J. STOCKS, AND E.M. WOTTON. 2005a. Forest fires and climate change in the 21st century. *Mitig. Adapt. Strategies Glob. Change* 11:847–859.

FLANIGAN, M.D., K.A. LOGAN, B.D. AMIRO, W.R. SKINNER, AND B.J. STOCKS. 2005b. Future area burned in Canada. *Climatic Change* 72:1–16.

GARTNER, S., K.M. REYNOLDS, P.F. HESSBURG, S. HUMMEL, AND M. TWERY. 2008. Decision support for evaluating landscape departure and prioritizing forest management activities in a changing environment. *For. Ecol. Manage.* 256:1666–1676.

GIBSON, K. 2008. *The influence of mountain pine beetle on high elevation whitebark pine ecosystems*. USDA For. Serv., Unpubl. For. Health Protection Staff Rep., Northern Region, Missoula, MT. 49 p.

HARVEY, A.E., R.T. GRAHAM, AND G.I. MCDONALD. 1999. Tree species composition change—Soil organism interaction: Potential effects on nutrient cycling and conservation processes in interior forests. P. 137–145 in *Proc.: Pacific Northwest forest and rangeland soil organism symposium.* USDA For. Serv., Gen. Tech. Rep. PNW-GTR-461, Pacific Northwest Research Station, Portland, OR.

HARVEY, A.E., P.F. HESSBURG, J.W. BYLER, G.I. MCDONALD, J.C. WEATHERBY, AND B.E. WICKMAN. 1995. Health declines in western interior forests: Symptoms and solutions. P. 88–99 in *Proc. of conference on ecosystem management in western interior forests*, Baumgartner, D.M., and R.L. Everett (eds.). Department of Natural Resource Sciences, Washington State Univ., Pullman, WA.

HAUFLER, J.B., C.A. MEHL, AND G.J. ROLOFF. 1996. Using a coarse filter approach with a species assessment for ecosystem management. *Wildl. Soc. B.* 24:200–208.

HOFF, R.J., AND G.I. MCDONALD. 1994. Disease and insect resistance in conifers associated with the cedar/hemlock ecosystem. P. 151–155 in *Interior cedar-hemlock-white pine forests: Ecology and management,* Baumgartner, D.M., J.E. Lotan, and J.R. Tonn (eds.). Washington State Univ., Cooperative Extension, Spokane, WA.

Keane, R.E., L.E. Holsinger, R.A. Parsons, and K. Gray. 2008. Climate change effects on historical range and variability of two large landscapes in western Montana, USA. *For. Ecol. Manage.* 254:375–389.

Keane, R.E., and R.A. Parsons. 2010. Restoring whitebark pine forests of the Northern Rocky Mountains, USA. *Ecol. Restor.* 28(1):56–70.

Keane, R.E., D.F. Tomback, C.A. Aubry, A.D. Bower, E.M. Campbell, C.L. Cripps, M.B. Jenkins, et al. 2012. *A range-wide restoration strategy for whitebark pine (Pinus albicaulis).* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-279, Rocky Mountain Research Station, Fort Collins, CO. 106 p.

Keeling, E.G., and A. Sala. 2012. Changing growth response to wildfire in old-growth ponderosa pine trees in montane forests of north central Idaho. *Glob. Change Biol.* 18:1117–1126.

Landres, P.B., P. Morgan, and F.J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. *Ecol. Appl.* 9(4):1179–1188.

Lenihan, J.M., D. Bachelet, R.P. Neilson, and R. Drapek. 2008. Response of vegetation distribution, ecosystem productivity, and fire to climate change scenarios for California. *Climatic Change* 87(Suppl. 1):S215–S230.

Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2009. Forest ecosystems, disturbance, and climatic change in Washington State, USA. P. 255–284 in *The Washington climate change impacts assessment: Evaluating Washington's future in a changing climate,* Elsner, M.M., J.S. Littell, and L.W. Binder (eds.). Climate Impacts Group, Univ. of Washington, Seattle, WA.

Littell, J.S., E.E. Oneil, D. McKenzie, J.A. Hicke, J.A. Lutz, R.A. Norheim, and M.M. Elsner. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. *Climatic Change* 102:129–158.

Loehman, R.A., J.A. Clark, and R.E. Keane. 2011. Modeling effects of climate change and fire management on western white pine (*Pinus monticola*) in the Northern Rocky Mountains, USA. *Forests* 2:832–860.

Logan, J.A., and B.J. Bentz. 1999. Model analysis of mountain pine beetle (Coleoptera: Scolytidae) seasonality. *Environ. Entomol.* 28: 924–934.

Marlon, J.R., P.J. Bartlein, D.G. Gavin, C.J. Long, R.S. Anderson, C.E. Briles, K.J. Brown, et al. 2012. Long-term perspective on wildfires in the western USA. *Proc. Natl. Acad. Sci. USA* 109(9):E535–E543.

McGregor, M.D., G.D. Amman, and W.E. Cole. 1981. Hazard-rating lodgepole pine for susceptibility to mountain pine beetle infestation. P. 99–104 in *Hazard rating systems in forest insect pest management: Symposium Proceedings, 1980 July 31–August 1, Athens, GA*, Hedden, R.L., S.J. Barras, and J.E. Coster (tech. coords.). USDA For. Serv., Gen. Tech. Rep. WO-27, Washington, DC.

McGregor, M.D., and D.M. Cole. (eds.). 1985. *Integrating management strategies for the mountain pine beetle with multiple resource management of lodgepole pine forests.* USDA For. Serv., Gen. Tech. Rep. INT-174, Intermountain Forest and Range Experiment Station, Ogden, UT. 68 p.

McKenzie, D., Z. Gedalof, D.L. Peterson, and P. Mote. 2004. Climatic change, wildfire, and conservation. *Conserv. Biol.* 18(4): 890–902.

Meehl, G., C. Covey, T. Delworth, M. Latif, B. McAvaney, J. Mitchell, R. Stouffer, and K. Taylor. 2007. The WCRP CMIP3 multi-model dataset: A new era in climate change research. *Bull. Am. Meteor. Soc.* 88: 1383–1394. [Climate model output archived at www-pcmdi.llnl.gov/ipcc/about_ipcc.php.]

Meyer, C.B., D.H. Knight, and G.K. Dillon. 2005. *Historic range of variability for upland vegetation in the Bighorn National Forest, Wyoming.* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-140, Rocky Mountain Research Station, Fort Collins, CO. 94 p.

Monnig, E.C., and J.W. Byler. 1992. *Forest health and ecological integrity in the Northern Rockies.* USDA For. Serv., Forest Pest Manage. Rep. 92-7; 2nd ed., R1-92-130, Northern Region, Missoula, MT. 18 p.

Morgan, P., E.K. Heyerdahl, and C.E. Gibson. 2008. Multi-season climate synchronized forest fires throughout the 20th century, Northern Rockies, USA. *Ecology* 89:717–728.

Nakicenovic, N., and R. Swart. (eds.). 2000. *Special report on emissions scenarios: A special report of Working Group III of the Intergovernmental Panel on Climate Change.* Cambridge Univ. Press, Cambridge, UK. 599 p.

Neuenschwander, L.F., J.W. Byler, A.E. Harvey, G.I. McDonald, D.S. Ortiz, H.L. Osborne, G.C. Snyder, and A. Zack. 1999. *White pine and the American west: A vanishing species—Can we save it?* USDA For. Serv., Gen. Tech. Rep. RMRS-GTR-35, Rocky Mountain Research Station, Fort Collins, CO. 20 p.

Nitschke, C.R., and J.L. Innes. 2008. Climatic change and fire potential in South-Central British Columbia, Canada. *Glob. Change Biol.* 14(4):841–855.

Nonaka, E., and T.A. Spies. 2005. Historical range of variability in landscape structure: A simulation study in Oregon, USA. *Ecol. Appl.* 15(5):1727–1746.

Price, C., and D. Rind. 1994. The impact of a 2× CO_2 climate on lightning-caused fires. *J. Climate* 7:1484–1494.

Quigley, T.M., and S.J. Arbelbide (tech. eds.). 1997. *An assessment of ecosystem components in the interior Columbia basin and portions of the Klamath and Great Basins: Vol. 2.* USDA For. Serv., Gen. Tech. Rep. PNW-GTR-405, 4 vol., Pacific Northwest Research Station, Portland, OR. 2066 p.

Reynolds, K.M. 2006. EMDS 3.0: A modeling framework for coping with complexity in ecosystem assessment and environmental planning. *Sci. China Ser. E* 49:63–75.

Reynolds, K.M., S. Rodriguez, and K. Bevans. 2003. *User guide for the Ecosystem Management Decision Support System*, version 3.0. Environmental Systems Research Institute, Redlands, CA.

Rockwell, F.I. 1917. *Western white pine bulletin.* USDA For. Serv., Northern Rocky Mountain District, Office of Silviculture, Missoula, MT. 310 p.

Safranyik, L., and T.L. Shore. 1992. *Susceptibility and risk-rating systems for the mountain pine beetle in lodgepole pine stands.* Forestry Canada, Pacific Yukon Reg. Info. Rep. No. BC-X-336, Victoria, BC, Canada. 12 p.

Swetnam, T.W., C.D. Allen, and J.L. Betancourt. 1999. Applied historical ecology: Using the past to manage for the future. *Ecol. Appl.* 9(4):1189–1206.

Tinker, D.B., W.H. Romme, and D.G. Despain. 2003. Historic range of variability in landscape structure in subalpine forests of the Greater Yellowstone Area, USA. *Landsc. Ecol.* 18:427–439.

Tomback, D.F. 2007. Overview of whitebark pine ecosystems: Ecological importance and future outlook. P. 6–19 in *Whitebark pine: A Pacific Coast perspective; 2006 August 27–31; Ashland, OR*, Goheen, E.M., and R.A. Sniezko (eds.). USDA For. Serv., Tech. Rep. R6-NR-FHP-2007-01, Pacific Northwest Region, Ashland, OR.

Turner, M.G., D.C. Donato, and W.H. Romme. 2013. Consequences of spatial heterogeneity for ecosystem services in changing forest landscapes: Priorities for future research. *Landsc. Ecol.* 28(6):1081–1097.

Veblen, T.T. 2003. Historic range of variability of mountain forest ecosystems: Concepts and applications. *For. Chron.* 79(2):223–226.

Westerling, A.L., and B.P. Bryant. 2008. Climate change and wildfire in California. *Climatic Change* 87(Suppl. 1):S231–S249.

Westerling, A.L., M.G. Turner, E.A.H. Smithwick, W.H. Romme, and M.G. Ryan. 2011. Continued warming could transform Greater Yellowstone fire regimes by mid-21st century. *Proc. Natl. Acad. Sci. USA* 108(32): 13165–13170.

Wiens, J.A., G.D. Hayward, H.D. Safford, and C.M. Giffen (eds.). 2012. *Historical environmental variation in conservation and natural resource management.* Wiley-Blackwell, Oxford, UK. xiv + 337 p.

Zack, A.C., and P. Morgan. 1994. *Fire history on the Idaho Panhandle National Forests.* USDA For. Serv., Idaho Panhandle National Forests, Unpubl. Rep., Coeur d'Alene, ID. 44 p.