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Riparian and Groundwater-Dependent Ecosystems of the Bridger-Teton National Forest: An Assessment of Resources and Current Conditions

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Abstract

This assessment was conducted to provide information on the current conditions of riparian and groundwater-dependent ecosystems in relation to their natural range of variation on the Bridger-Teton National Forest. We summarized dominant riparian community types that are present on the Forest and described riparian fish and wildlife habitat. We used peer-reviewed literature, data from the Forest and other partners, and site visits to evaluate the status of five key ecosystem characteristics: (1) surface water and groundwater fluctuations, (2) water quality, (3) channel and floodplain dynamics, (4) composition and structure of riparian vegetation, and (5) composition of groundwater-dependent ecosystems. We determined that the primary stressors to riparian ecosystems on the Bridger-Teton National Forest were roads and related infrastructure, livestock grazing, long-term vegetation change, and climate change. Despite the presence of these stressors, nearly all key ecosystem characteristics were functioning within their natural range of variation on the Forest. Our results support the ecosystem assessment completed during the Forest plan revision process and can help inform decisionmaking related to restoration and/or maintenance of riparian and groundwater-dependent ecosystems on the Bridger-Teton National Forest.

Keywords: forest plan, key ecosystem characteristics, riparian vegetation, flow regime, channel morphology, floodplain, Wyoming, Greater Yellowstone Ecosystem

Cover photos

Clockwise from the left: Pacific Creek in the Snake River basin; Devil's Hole Creek in the Green River Basin; and riparian shrubs and graminoids near the Green River headwaters. Photos by D. Max Smith, USDA Forest Service.

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Background and Objectives

We conducted this assessment of riparian, wetland, and groundwater-dependent ecosystems (GDEs) as part of an agreement between the Forest Service, U.S. Department of Agriculture Intermountain Region (Region 4) and the Rocky Mountain Research Station. The objective was to assist with revision of national forest management plans under the 2012 Planning Rule (36 CFR Part 219). We designed methods to meet requirements outlined in the rule to complete a rapid assessment of ecological integrity that identifies and considers existing information and data relevant to the plan area. Ecological integrity is "the quality or condition of an ecosystem when its dominant ecological characteristics occur within the natural range of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human influence." The rule specifies that the assessments should address drivers and stressors, as well as structure, function, composition, and connectivity of terrestrial and aquatic ecosystems. Recognizing that ecological systems cross administrative boundaries, the rule uses an "all-lands approach" that requires consideration of how conditions outside the national forest influence resources on the Forest and how actions on the Forest impact resources beyond the boundary.

We prepared this assessment to help the Bridger-Teton National Forest (BTNF) understand ecological conditions under the current plan and identify needs-for-change to be addressed by the revised Forest plan. In this assessment, we provide an inventory of riparian ecosystems, GDEs, and wildlife habitat; describe key ecosystem characteristics (KECs) of these ecosystems; and synthesize available information to evaluate the current condition of KECs. The first draft of this report was completed in August of 2018. We incorporated comments from the Intermountain Regional Office and other reviewers into this revised report. Lists of scientific and common names, as well as acronyms, are at the end of this report.

Scale of Assessment and Study Area

Our analysis was completed at two spatial scales: the national forest and four geographic units within the BTNF (Wyoming, Windriver, Kemmerer, and Gros Ventre; fig. 1). These geographic units, which differ from one other in geology, ecology, and vegetation characteristics, were developed by the Forest for vegetation mapping (BTNF 2000). We evaluated aquatic, riparian, and wetland ecosystems, as well as GDEs at the scale of the geographic unit, and summarized results for the entire Forest.

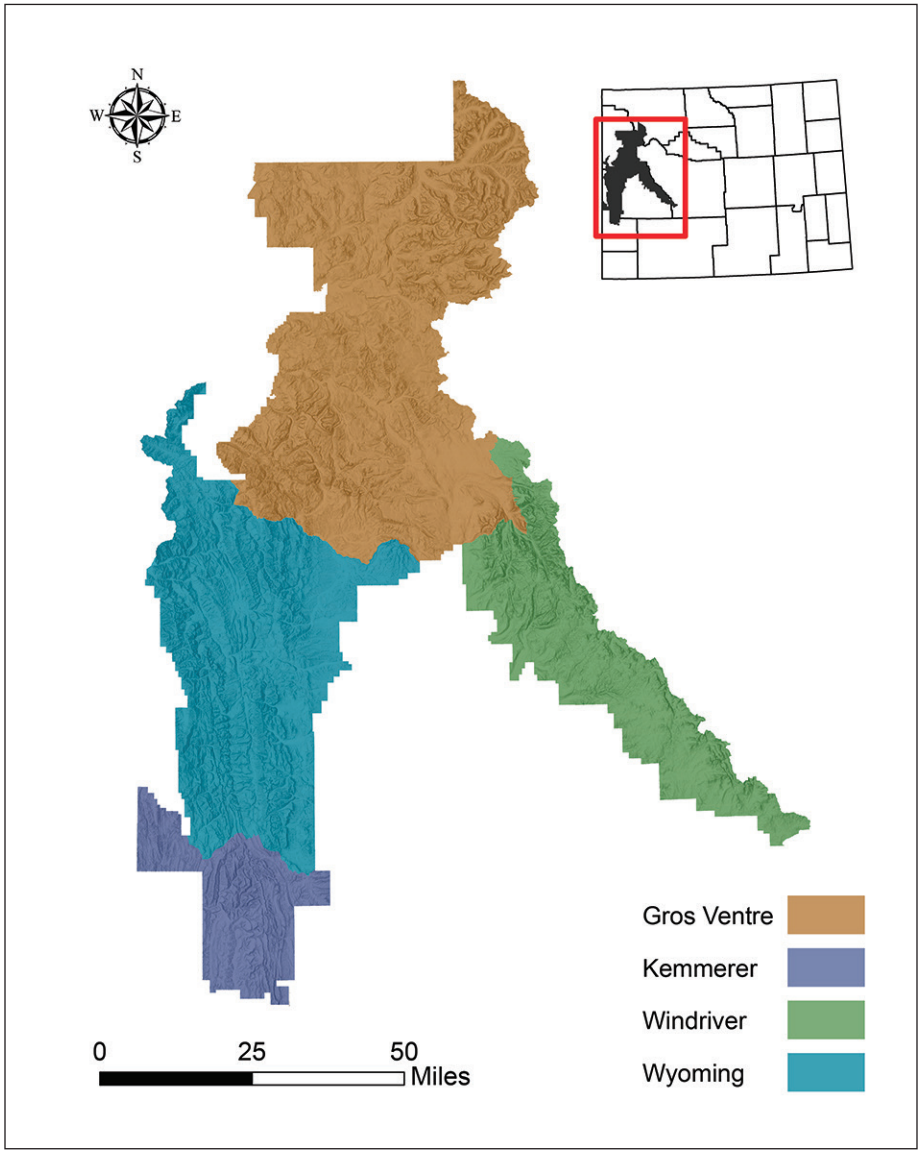


Figure 1—The four geographic units of the Bridger-Teton National Forest, Wyoming.

The 3.4 million-acre BTNF is located immediately south of Yellowstone National Park and just west of the Continental Divide in Western Wyoming. The Forest is characterized by relatively young glaciated mountains in the Central Rockies and alpine and mountain steppe climates. The terrain is highly mountainous and five ranges fall within the Forest. Additionally, major river drainages, including the Columbia, Colorado, and Missouri, have headwaters on the BTNF. The heterogeneity of the landscape, including diverse topography, soils, elevation, and microclimates, has allowed for the development of grasslands, coniferous forests, forb meadows, shrublands, aspen groves, and alpine tundra (Mueggler 1981).

Eleven Level IV ecoregions are represented on the BTNF (fig. 2; Chapman et al. 2004), the largest of which is the mid-elevation sedimentary mountains (fig. 3), which encompasses 35 percent of the Forest. These steep to moderately steep mountains remain glaciated and streams are generally perennial with moderate to high gradients and boulder, cobble, and bedrock substrates (Chapman et al. 2004). The temperature regime is cryic and

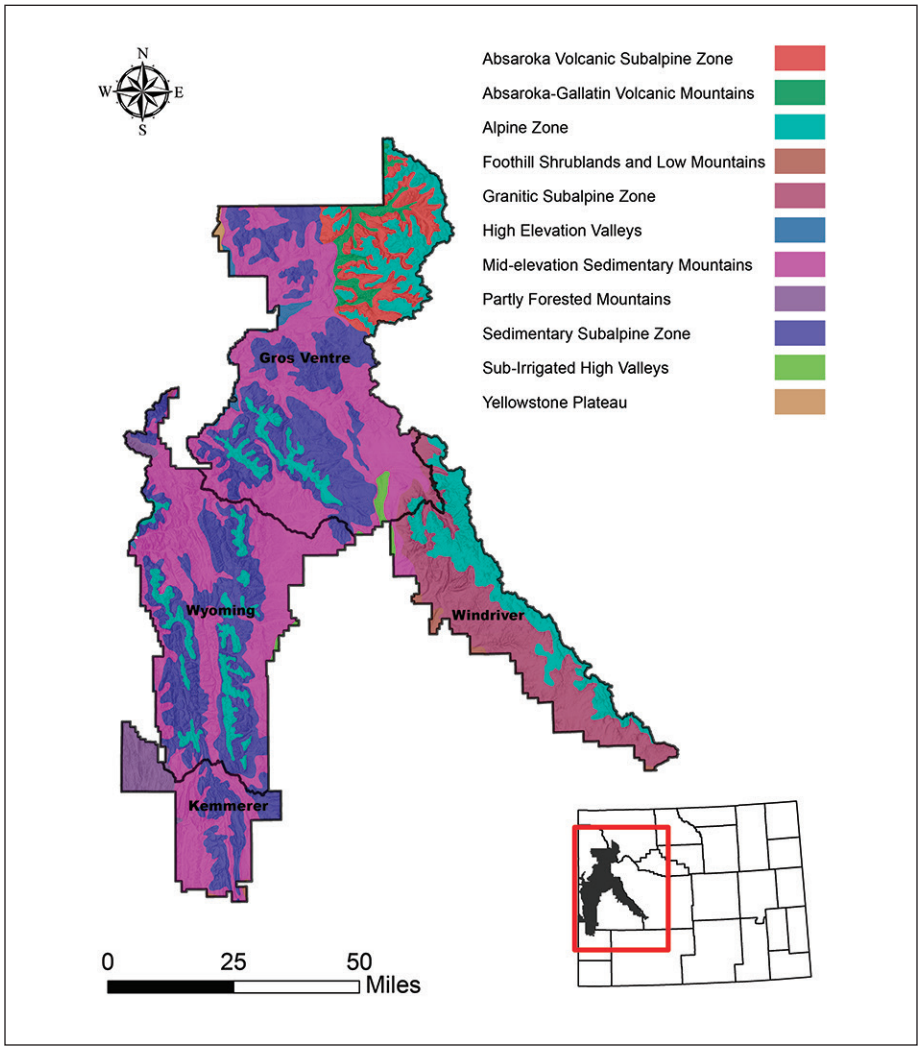


Figure 2—Level IV ecoregions of the Bridger-Teton National Forest, Wyoming.



Figure 3—The lower Gros Ventre River passes through the Mid-elevation Sedimentary Mountains ecoregion. Photo by D. Max Smith, USFS.

these landscapes receive 24–32 inches of mean annual precipitation. The vegetation communities of the mid-elevation sedimentary mountains are characterized by Douglas-fir (*Pseudotsuga menziesii*), lodgepole pine (*Pinus contorta*), and subalpine fir (*Abies lasiocarpa*), with some aspen (*Populus tremuloides*) groves present (Chapman et al. 2004).

The sedimentary subalpine zone is the next largest ecoregion on the Forest, occupying 28 percent of the BTNF. These mountains are glaciated with steep slopes. Streams tend to be perennial with moderate to high gradients and boulder, cobble, and bedrock substrates (Chapman et al. 2004). The temperature regime is cryic and these landscapes receive 30–50 inches of mean annual precipitation. The forests of the sedimentary subalpine zone are dominated by Engelmann spruce (*Picea engelmannii*) and subalpine fir. The vegetative communities may also include lodgepole pine, limber pine (*Pinus flexilis*), aspen, and whitebark pine (*Pinus albicaulis*). Mountain meadows contain silverberry (*Elaeagnus commutata*), potentilla, larkspur (*Delphinium* spp.), alpine timothy (*Phleum alpinum*), Idaho fescue (*Festuca idahoensis*), and yampa (*Penstemon yampaensis*; Chapman et al. 2004).

Fifteen percent of the BTNF is classified as the alpine zone ecoregion. These areas are composed of high elevation, glaciated peaks above timberline (Chapman et al. 2004). The landscape includes glacial features

such as tarns, moraines, u-shaped valleys, and cirques. The streams tend to be small and high gradient with perennial flows dominated by snowmelt. The temperature regime of these areas is cryic and they receive 40 to more than 70 inches of mean annual precipitation, the majority of which occurs as snow. The deep winter snowpacks of the alpine zone are an important water source to lower elevations (Chapman et al. 2004), with headwaters of many streams in the Middle Rockies, the Wyoming Basin, and the Northern Great Plains originating within this ecoregion (Chapman et al. 2014). There is limited vegetation within the alpine meadows and barren rock outcrops of these landscapes. Grasses, sedges, and forbs are the dominant vegetation with willows found in depressions and wet meadows. Spruce, fir, and pine trees are rare and are krummholz if present (Chapman et al. 2004).

The granitic subalpine ecoregion (fig. 4) encompasses 11 percent of the BTNF. These landscapes are heavily glaciated and contain many lakes. The mountains are high elevation with moderate to high gradient perennial streams with boulder, cobble, and bedrock substrates (Chapman et al. 2004). The temperature regime is cryic and these areas receive 20–60 inches of mean annual precipitation. The forests are dominated by Engelmann spruce and subalpine fir with some small stands of limber pine, whitebark pine, and lodgepole pine (Chapman et al. 2004).



Figure 4—The high peaks of the Wind River Range are within the Granitic Alpine Zone ecoregion. Photo by D. Max Smith, USFS.

The Absaroka Volcanic subalpine zone characterizes 5 percent of the Forest. Like the other ecoregions, these areas are glaciated with steep mountains and plateaus (Chapman et al. 2004). Streams are generally perennial with large sediment loads and moderate to high gradients. The temperature regime is characterized as cryic and these lands receive 30–50 inches of mean annual precipitation (Chapman et al. 2004). The vegetative communities are dominated by Engelmann spruce and subalpine fir, with some small stands of lodgepole pine and limber pine (Chapman et al. 2004). Understory species consist of mountain juniper (*Juniperus scopulorum*), mountain gooseberry (*Ribes montigenum*), buffaloberry (*Shepherdia* spp.), heartleaf arnica (*Arnica cordifolia*), milk vetch (*Astragalus* spp.), and sagebrush (*Artemisia* spp.). Whitebark pine with an understory of Idaho fescue, Ross sedge (*Carex rossii*), wheeler bluegrass (*Poa nervosa*), and silvery lupine (*Lupinus argenteus*) are present at the highest elevations (Chapman et al. 2004).

The rest of the Level IV ecoregions of the BTNF are represented on very small landscapes. The partly forested mountains occupy 2 percent; the Absaroka-Gallatin volcanic mountains occupy 2 percent; and the high elevation valleys, subirrigated high valleys, the foothill shrublands and low mountains, and the Yellowstone plateau all occupy less than 1 percent of the Forest. Despite their small size, the high elevation valleys and subirrigated high valleys contain disproportionate aquatic, riparian, and groundwater-dependent ecosystem resources. Both are unglaciated with large floodplains, terraces, and alluvial fans. These landscapes contain numerous wetlands, marshes, and streams that have been highly influenced by glaciation (Chapman et al. 2004).

Many of the ecoregions are found in more than one of the BTNF's geographic units. The largest unit on the Forest, Gros Ventre, encompasses approximately 1.5 million acres. The landscape of this unit is especially diverse, with nine ecoregions located within its boundaries: mid-elevation sedimentary mountains, sedimentary subalpine zone, alpine zone, Absaroka Volcanic subalpine zone, Absaroka-Gallatin volcanic mountains, granitic subalpine zone, high elevation valleys, subirrigated high valleys, and the Yellowstone plateau. The Wyoming unit contains approximately 1 million acres of the BTNF. Seven Level IV ecoregions are located within this unit: the alpine zone, sedimentary subalpine zone, mid-elevation sedimentary mountains, the granitic subalpine zone, subirrigated high valleys, high elevation valleys, and partly forested mountains. Nearly 600,000 acres of the Forest are located within the Windriver unit and five ecoregions are present: granitic subalpine zone, the alpine zone, mid-elevation sedimentary mountains, foothill shrublands and low mountains, and subirrigated high valleys. Kemmerer is the smallest unit, encompassing about 300,000 acres of the Forest. This unit contains five ecoregions including mid-elevation sedimentary mountains, sedimentary subalpine zone, foothill shrublands and low mountains, partly forested mountains, and high elevation valleys.

Riparian and Groundwater-Dependent Ecosystems of the Intermountain Region

Riparian Ecosystem Definitions

There are many definitions of riparian ecosystems, but three components are often included: (1) an interface of aquatic and terrestrial communities at a body of water, (2) landforms and organisms that are influenced by surface water and groundwater, and (3) plant communities differing in composition and/or structure from those in adjacent upland ecosystems (Dall et al. 1997; Gregory et al. 1991). At streams, riparian ecosystems are three-dimensional zones of direct interaction between terrestrial and aquatic systems. The first dimension extends longitudinally from the headwaters of a stream to its mouth, the second extends vertically from the groundwater zone to the canopy of vegetation, and the third extends laterally from the stream bed to the outer extent of the floodplain (Stanford and Ward 1988, 1993; Vannote et al. 1980). In the Western United States, riparian ecosystems are noted for covering a small percentage of the landscape, while supporting high levels of productivity and species richness, and providing essential wildlife habitat (Hansen et al. 1995; Johnson et al. 2018).

Groundwater-Dependent Ecosystem Definitions

The emergence of groundwater to the surface or near surface creates unique ecosystems in the arid and semiarid regions of the Western United States (Stevens and Meretsky 2008). Groundwater-dependent ecosystems (GDEs) are "communities of plants, animals and other organisms whose extent and life processes are dependent on access to or discharge of groundwater" (USDA FS 2012a, b). For the purposes of forest planning, GDEs include wetlands fed by groundwater; terrestrial vegetation and fauna sustained by shallow groundwater; ecosystems in streams and lakes fed by groundwater; caves and karst aquifers; aquifer systems; hyporheic and hypolentic zones; and springs (from Forest Service Manual (FSM) 2880.5). Many aquatic systems, including some stream segments and riparian wetlands along gaining river reaches, can therefore be considered GDEs as well. GDEs contribute to regional biodiversity by supporting specialized and endemic species, many of which are listed as threatened or endangered (Kreamer et al. 2015; Murray et al. 2006).

Springs are ecosystems entirely supported by groundwater. Various types of springs occur within Region 4 National Forests, each with features that promote regional biodiversity (Springer and Stevens 2009). Springs with surface pools provide lentic habitat for plants, vertebrates, and other biota. Spring runout channels provide unique lotic habitats due to relatively uniform water temperatures and low oxygen concentrations (Springer and Stevens 2009). These channels increase connectivity across the landscape for organisms associated with surface water systems. Runout channels may connect with streams or may terminate to subsurface flow while still

supporting aquatic and riparian species. Spring mounds composed of calcareous minerals, peat, and other substrates provide specialized habitat features as well. Vegetation communities sustained by springs often have greater structural diversity and therefore high value as wildlife habitat. Springs are also a critical source of drinking water for wildlife and livestock.

Aquifers are permeable rock or soil bodies that store and transmit groundwater in economic quantities (Heath 1983; USDA FS 2016). These extensive groundwater systems influence volume and temperatures of streams within the national forests and their larger landscapes. Alluvial aquifers typically occur in unconsolidated deposits of floodplains and valley bottoms. Bedrock aquifers occur in bedrock with primary openings such as lava tubes or secondary openings such as fractures and dissolution cavities (Heath 1983). Karst systems are specialized bedrock aquifers created by the chemical dissolution of carbonate bedrock, including limestone and dolostone. These systems are characterized by disrupted surface drainage, abundant enclosed depressions, and well-developed underground drainage systems, which may include caves (USDA FS 2016). Karst systems facilitate movement and discharge of groundwater in many parts of the region and host unique floras and faunas (Humphreys 2006).

Fens are wetlands that are primarily supported by groundwater, have a minimum depth (30–40 cm) of accumulated peat, and support unique plant communities (Bedford and Godwin 2003; Chadde et al. 1998; USDA FS 2007, 2012a). Fens can occur in isolated conditions, surrounded by upland vegetation, or be connected to streams and riparian ecosystems. Both connected and isolated GDEs provide critical habitats and ecosystem services (Cohen et al. 2016). In crystalline bedrock geologies, where karst systems and aquifers are absent, fens can play a similarly important role in modulating fluctuations in volume and temperature of streamflows (Bedford and Godwin 2003; Schimelpfenig et al. 2014).

Dynamics of Riparian and Groundwater-Dependent Ecosystems

Within Region 4 are mountain ranges and watersheds that differ from one another in geological history, disturbance regimes, and effects of human use. The legacy of bedrock formation and subsequent geological events control the dynamics of valley bottoms, streams and groundwater in a watershed. (Heath 1989; Waring 2011). Through processes of erosion, deposition, and dissolution, streams and groundwater work with available geological material to create and modify geomorphic features such as floodplains, gravel bars, terraces, and spring runout channels (Stanford et al. 2005).

These geomorphic features are occupied by plant communities that may change in structure and composition over several successional pathways (Gregory et al. 1991). The composition of communities and the nature of successional pathways are determined by a complex suite of factors that include geomorphic settings, surface and groundwater dynamics, disturbance regimes, wildlife interactions, and a number of anthropogenic influences (Padgett et al. 1989; Youngblood et al. 1985). In general, hydroriparian pioneer species, such as cottonwoods (*Populus* spp.) and willows (*Salix* spp.), establish on newly deposited sediment or scoured floodplains. Hydroriparian

pioneer trees and shrubs depend on flood disturbance and bare sediment for seedling establishment and require a connection with groundwater for survival and growth (Stromberg and Merritt 2016). As vegetation stabilizes the sediment and stream banks, soil development proceeds, allowing establishment of late-seral mesoriparian species (Winward et al. 2000; Youngblood et al. 1985). Late-seral communities may persist on geomorphic features until a subsequent disturbance occurs, allowing reestablishment of pioneer species and communities. If surface water and groundwater are limited, deep-rooted xeroriparian trees, xeroriparian shrubs, or desert shrubs will establish and thrive in valley bottoms (Lytle et al. 2017; Stromberg and Merritt 2016).

Beavers (*Castor canadensis*) exert a particularly strong influence on these dynamics through herbivory of woody plants and construction of dams and ponds. Beaver ponds distribute surface water and groundwater across valley bottoms, helping to maintain hydroriparian plant communities (Gurnell 1988; Naiman et al. 1988). Beaver dam complexes also influence the geomorphology of valley bottoms by creating low-gradient stream segments and associated habitats through a cyclical process of pond formation, sediment storage, and drainage (Westbrook et al. 2011).

Community Types

To describe the riparian ecosystems and GDEs in a region, groupings must be made based on biota, growth forms, associated landforms, hydrologic regimes, or other variables. In this assessment we created groups by summarizing classifications of plant communities that were developed for riparian ecosystems and GDEs. Several riparian community classifications have been developed for Region 4 National Forests and adjacent areas. We use community types from these classifications as our primary classification system for this assessment because they are useful for describing composition and structure of riparian ecosystems and for understanding development and long-term trajectories. Manning and Padgett (1995), Padgett et al. (1989), and Youngblood et al. (1985) developed community types that represent riparian ecosystems in Region 4 National Forests. Their community types are determined by the dominant canopy and understory species present, along with other associated species. Flow responses and successional statuses are not used for classification but are discussed in community type descriptions. Walford et al. (2001) also used riparian community types in their classification for the Shoshone National Forest in Northwestern Wyoming. In their riparian and wetland classification for the State of Montana, Hansen et al. (1995) defined *Habitat Types* based on site potential for climax plant associations. They also define *Community Types* as relatively stable nonclimax plant communities. Crowe and Clausnitzer (1997) classified riparian and wetland communities in Eastern Oregon using *Associations*, defined as late-seral or climax types dominating the canopy and understory, representing the vegetative potential of a fluvial surface. For our database, we compiled community types, habitat types, and associations that are likely to occur in Region 4 National Forests. For the purposes of our assessment, we refer to all of these classifications as community types.

Youngblood et al. (1985) identified eight dominance groups, which are collections of riparian community types based on dominant overstory plants in Eastern Idaho and Western Wyoming. These dominance groups are: (1) tree-dominated community types with coniferous or deciduous trees dominating the canopy, (2) mixed shrub-dominated community types with nonwillow shrubs and small deciduous trees dominating the canopy, (3–6) willow-dominated community types (*Salix geyeriana*, *Salix boothii*, *Salix wolfii*, and other willows), (7) graminoid-dominated community types, and (8) forb-dominated community types. To describe riparian ecosystems in our assessments, we modified the groupings to better reflect differences in structure and wildlife habitat, in a manner similar to Padgett et al.'s (1989) classification for Utah and Manning and Padgett's (1995) classification for Nevada. Our dominance groups, described below, are (1) coniferous tree (2) tall deciduous tree, (3) low deciduous tree, (4) tall willow, (5) low willow, (6) nonwillow shrub, and (7) herbaceous. We compiled results from the above classifications to build a database of community types and riparian dominance groups that are likely present in the national forests of Region 4 (Smith et al. unpublished data). We excluded community types from our database if the current range of a dominant plant species lies outside of Region 4, as mapped in the USDA Plants Database (https://plants.sc.egov.usda.gov).

In addition to community types, riparian guilds have been identified for woody plants in the Western United States (Hough-Snee et al. 2015; Stromberg and Merritt 2016). Plant species within guilds have shared functional traits, morphology, or environmental preferences that correspond to life history responses to surface water and groundwater regimes (Hough-Snee et al. 2015). In some cases, there is substantial overlap between riparian guilds and riparian community types. Where applicable, we reference riparian vegetation guilds within community types to describe life histories and environmental characteristics of dominant species.

Coniferous Tree Dominance Group

Coniferous tree-dominated community types often resemble adjacent upland forests in structure and composition (Gregory et al. 1991). Overstory species include *Abies lasiocarpa*, *Picea engelmannii*, *Picea pungens*, *Pinus contorta*, *Alnus incana*, *Populus tremuloides*, and *Populus angustifolia*. Dominant understory species include *Betula occidentalis*, *Cornus sericea*, *Dasiphora fruticosa*, and a number of mesic forbs and graminoids. These community types are found in narrow to broad valley bottoms with variable stream gradients (figs. 5 and 6). Communities have been sampled up to 11,200 feet in elevation. Geomorphic features are typically composed of floodplains and terraces adjacent to streams but also include benches, streambanks, toeslopes, and meadows. Ten coniferous tree-dominated types have been identified at springs and four types have been identified at fens. Water table depth fluctuates seasonally for most types but can remain 100 cm below the soil surface.



Figure 5—The coniferous tree-dominated types along Greys River include narrowleaf cottonwood in the overstory and red osier dogwood in the understory. Photo by D. Max Smith, USFS.



Figure 6—Coniferous tree-, tall deciduous tree-, and tall willow-dominated communities are found along Willow Creek in the Wind River geographic unit. Photo by the Bridger-Teton National Forest.

Some of these types may have resulted from invasion by conifers of sites previously dominated by graminoids, willows, cottonwoods, and other riparian plants. Soils are usually well-developed Mollisols and Inceptisols, with some types on poorly developed Entisols and others on organic Histosols. The overstory trees species in this group belong to a late-seral riparian vegetation guild characterized by long lifespan, sexual reproduction, shade tolerance, drought tolerance, and anaerobic soil intolerance (Hough-Snee et al. 2015). Composition of conifer-dominated types is stable in the absence of valley bottom disturbances. Fires, insect outbreaks, and floods from runoff or beaver dams may promote a shift to dominance by herbaceous plants, shrubs, or deciduous trees.

Tall Deciduous Tree Dominance Group

Dominant overstory trees include cottonwoods (*Populus angustifolia*, *Populus fremontii*, *Populus balsamifera*), aspens (*Populus tremuloides*), and boxelders (*Acer negundo*). Valley bottoms with tall deciduous tree-dominated types tend to be wider with lower gradients compared to those with coniferous-dominated groups. Six aspen-dominated types are associated with springs, while none are associated with fens. Communities were sampled at elevations up to 9,020 feet. These community types are frequently located on terraces adjacent to or away from stream channels. They are also located on streambanks, benches, bars, and other portions of the floodplain where water tables fluctuate but remain in contact with the rooting zone of tall deciduous trees (fig. 6).

Cottonwoods belong to mesoriparian and hydroriparian pioneer guilds characterized by low drought tolerance, low-moderate anaerobic soil tolerance, and vegetative reproduction (Hough-Snee et al. 2015; Stromberg and Merritt 2016). Boxelder-dominated types are persistent, barring major fluvial disturbance (Padgett et al. 1989). Cottonwood-dominated types quickly colonize sediment deposits or scoured floodplains. Cottonwoods are maintained on the landscape by disturbances, including flood and fire, which create bare substrate required for germination or induce sprouting (Kleindl 2015; Wilding et al. 2014). Stands will be replaced by late-seral community types if disturbances are suppressed. Soils are often Entisols where *Populus angustifolia* develops on recently deposited sediments. *Populus tremuloides*-dominated types are more frequently found in Mollisols, where soil development has had more time to occur. In some settings, aspen-dominated types are replaced by coniferous tree-dominated types in the absence of disturbances, such as fire, from which aspens can rapidly recover. In other settings, aspen types remain stable (Hansen et al. 1995).

Low Deciduous Tree Dominance Group

Stands of *Alnus incana*, *Betula occidentalis*, and other deciduous trees often occur on streambanks in valley bottoms of various widths and gradients. Sixteen types are associated with springs, while none are associated with fens. Communities have been sampled up to 9,200 feet in elevation. Given their proximity to active stream channels, these pioneering types establish following floods on newly deposited sediment or on scoured

banks. The roots of *Alnus incana* and *Betula occidentalis* are therefore helpful in stabilizing stream banks. Soils typically remain wet throughout the growing season, with aerated water moving rapidly through the soil column (Padgett et al. 1989). Most soils are Entisols, Inceptisols, or Mollisols, showing a range of development. Some vegetation types are found on organic Histosols as well.

Alnus incana and *Betula occidentalis* belong to a mesic shrub/tree guild characterized by moderate shade tolerance, low-moderate anaerobic soil tolerance, and sexual and vegetative reproduction (Hough-Snee et al. 2015). Depending on valley bottom characteristics, low deciduous-dominated types can persist in the absence of disturbance such as fire or disease. In some areas they are successional to late-seral shrub types or coniferous tree-dominated types (Hansen et al. 1995; Padgett et al. 1989).

Tall Willow Dominance Group

Numerous tall willow-dominated community types exist in a variety of settings and have understories dominated by various types of plants (figs. 6 and 7). Twenty-eight types are associated with springs and one type, *Salix boothii-Salix myrtillifolia*/*Carex scopulorum*, is associated with fens.



Figure 7—Willow-dominated community types are abundant along Devil's Hole Creek and other streams in the Kemmerer Geographic Unit. Photo by the Bridger-Teton National Forest.

Types dominated by *Salix geyeriana* and *Salix boothii* tend to occur in wide valleys, often with fine-textured, organic soils along low-gradient streams with perennially high water tables or frequent ponding (Youngblood et al. 1985). Types with *Carex utriculata* are often associated with active or drained beaver ponds. *Salix geyeriana* and *Salix boothii*-dominated types may persist as long as soil conditions remain wet or mesic. *Salix boothii* belongs to a mesoriparian shrub guild characterized by low-moderate anaerobic soil tolerance, low drought tolerance, and vegetative reproduction (Hough-Snee et al. 2015). *Salix geyeriana* is in a mesic shrub guild characterized by moderate shade tolerance, moderate anaerobic soil tolerance, and vegetative reproduction. Understory components may be affected by grazing if livestock can access willow stands. Soil drying may lead to succession to coniferous tree-dominated types.

Types dominated by *Salix drummondiana*, *Salix exigua*, and *Salix lasiandra*, occupy active fluvial areas with recent clearing and sediment deposition in narrow and wide valleys at a range of stream gradients. (Hansen et al. 1995). *Salix drummondiana* belongs to a mesic shrub guild characterized by moderate shade tolerance, moderate anaerobic soil tolerance, and vegetative reproduction. *Salix exigua* is in an upland disturbance shrub guild characterized by moderate shade tolerance, low-moderate anaerobic soil tolerance, and vegetative reproduction (Hough-Snee et al. 2015). These pioneering types often establish on features where succession to other types may not occur due to frequent flood scour and deposition. At sites that are more stable, *Salix drummondiana*-, *Salix exigua*-, and *Salix lasiandra*-dominated sites may persist or are successional to other willow-dominated types or coniferous tree-dominated types.

Low Willow Dominance Group

Low willow-dominated community types are typically located in broad valley bottoms at elevations up to 11,200 feet. Dominant overstory species include *Salix eastwoodiae*, *Salix glauca*, *Salix planifolia*, and *Salix wolfii*. Frequent understory species are *Carex aquatilis*, *Carex utriculata*, and *Deschampsia cespitosa*. Twelve types are associated with springs and three types are associated with fens. Low willow-dominated types are located on a variety of features including stream terraces and wet meadows associated with glaciated landscapes. Soil drying may also facilitate succession to conifer-dominated types.

Soils are Mollisols, Histosols, and Inceptisols, with some types in Entisols and a SAWO/CARO site in Alfisols. *Salix wolfii* belongs to a mesoriparian shrub guild characterized by low-moderate anaerobic soil tolerance, low drought tolerance, and vegetative reproduction. Communities dominated by low willows on wet organic soils are persistent, but lowered water tables and drying of wet meadows may encourage encroachment of conifers. Understory components may be affected by soil drying and grazing as well. Damage to willows from grazing and browsing encourages replacement by native or introduced species (Hansen et al. 1995).

Nonwillow Shrub Dominance Group

This group includes several types that differ in site conditions. Several groups are dominated by *Cornus sericea*, which is found in narrow to broad valley bottoms often adjacent to active channels. Streams are low to high gradient with elevations up to 8,840 feet. *Cornus sericea* is a pioneer species that colonizes stream bars and stabilizes banks (Hansen et al. 1995). One *Cornus sericea*-dominated type is associated with springs. Soils are Entisols, Inceptisols, and Mollisols with fluctuating water tables and aerated water moving through coarse soil layers. *Cornus sericea* belongs to a mesoriparian shrub guild characterized by low drought tolerance, low-moderate flood tolerance, and sexual and vegetative reproduction (Hough-Snee et al. 2015). In some settings, slow succession to coniferous or deciduous tree-dominated community types may occur (Youngblood et al. 1985).

Dasiphora fruticosa and *Artemisia cana* dominate nonwillow shrub types in moderate to broad valley bottoms adjacent to sagebrush, mountain brush, and forested uplands. Stream gradients are often low to moderate and at elevations up to 10,700 feet. Two *Artemisia cana*-dominated types and one *Dasiphora fruticosa*-dominated type are associated with springs. *Dasiphora fruticosa*- and *Artemisia cana*-dominated types are late-seral riparian communities that grade into drier upland communities. The shallow-rooted plants in these vegetation types do little to stabilize stream banks, relative to deeper-rooted plants. Understory components are affected by succession, water availability, and grazing. These types are usually found in well-developed Mollisols. Water tables are at intermediate depths and soils may dry during the growing season. *Dasiphora fruticosa* belongs to an upland disturbance guild characterized by moderate drought tolerance, variable anaerobic soil tolerance, and rhizomatous spread (Hough-Snee et al. 2015). A variety of other nonwillow shrub-dominated types are present as well, including *Betula glandulosa*/*Carex utriculata*, which is found at fens, and seven types associated with springs.

Herbaceous Dominance Group

Forb-dominated types often occur in confined, high-gradient stream bank settings surrounded by coniferous forest. Ten of these types are associated with springs and none are associated with fens. Soils are Entisols, Inceptisols, Mollisols, and Histosols. Some types, such as *Veratum californicum*, form dense, monospecific stands that are quite stable. Others, such as *Mertensia ciliata*, may be converted to other types through heavy grazing.

Graminoid-dominated types often occur in broad valley bottoms along low-gradient streams in floodplains and wet meadows (fig. 8). Twenty-six types are associated with springs and 11 are associated with fens. *Carex utriculata* and other sedges tend to occur in the wettest areas, including those associated with beaver ponds. Rushes, including *Schoenoplectus acutus*, are also associated with perennially saturated soils. Other sedges and rushes, and most grasses, are associated with drier portions of valley bottoms. Most graminoid-dominated types are found in well-developed Mollisols that have accumulated thick layers of organic matter. *Deschampsia cespitosa* is often found in Alfisols formed by movement of argillic clay into the soil horizons (Youngblood et al. 1985).



Figure 8—Extensive herbaceous-dominated community types are adjacent to stream channels and ponds in the Green River Valley. Photo by D. Max Smith, USFS.

Graminoids, such as *Carex aquatilis*, *Carex utriculata*, and *Typha latifolia*, can colonize recently exposed soil and form dense stands that persist if hydrological conditions are ideal and grazing disturbance is minimal (Hansen 1995). Others, such as *Carex nebrascensis* and *Juncus balticus*, are resistant to grazing and are maintained by this disturbance. Several herbaceous community types are dominated by introduced species including *Agrostis stolonifera*, *Bromus inermis*, *Poa pratensis*, and *Phelum pratense*. These species colonize recently disturbed sites and withstand high levels of grazing, facilitating their displacement of *Calamogrostis canadensis*, *Deschampsia cespitosa*, and other native graminoids.

Riparian Fish and Wildlife Habitat

Riparian ecosystems are critical habitats or critical components of habitat for numerous species of aquatic and terrestrial animals. Below are several examples of the importance of riparian ecosystems to fish and wildlife of the BTNF.

Large Mammals

Stream corridors are used as migration routes by elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), moose (*Alces alces*), and pronghorn antelope (*Antilocapra americana*), connecting patches of habitat within the Greater Yellowstone Ecosystem (BTNF 2014). Conifer-, willow-, and deciduous tree-dominated communities provide seasonal riparian habitat, including crucial winter range for elk and moose (Collins 1977). Riparian ecosystems also provide food and cover for grizzly bears (*Ursus horribilis*; Hansen et al. 1995; Walford et al. 2001). Grizzly bear habitat classified as riparian or wetland vegetation comprises 20,236 acres of the Gros Ventre unit. Low willow (12,379 acres) and marsh/fen (2,256 acres) types cover the largest amount of this area.

Native Fish

The BTNF contains headwaters of four of the continent's major drainage systems. This placement of the Forest has resulted in a rich assemblage of native fish, including four subspecies of cutthroat trout (*Oncorhynchus clarkii*; table 1). Cutthroat trout and other native fishes require cold, clear water and stream heterogeneity to complete their life cycles (Young 2008). Riparian ecosystems are instrumental in creating these conditions in mountain streams. Riparian vegetation filters sediment from overland flows, which helps to maintain water clarity (Correll 1997; Griffin et al. 2014). The root systems of sedges, willows, and other plants stabilize soils, allowing the creation of overhanging banks used by trout for hiding cover and thermal refugia (Winward 2000). The roots of live trees and the fallen trunks and branches of dead trees provide cover and create pools, which are important habitat features for juvenile fish (Moore and Gregory 1988). Willows and

Table 1—Stream miles within the historical ranges of cutthroat trout subspecies in geographic units of the BTNF.

Unit	Bonneville CT stream miles	Colorado River CT stream miles	Snake River CT stream miles	Yellowstone CT stream miles
Gros Ventre	0	226.8	1,770.5	574.7
Wyoming	31.2	275.8	1,087.8	0
Windriver	0	996.6	29.6	0
Kemmerer	152.4	270.3	48.5	0

low deciduous trees shade stream channels, thereby maintaining cool water temperatures during summer months (Beschta 1997).

Amphibians

Amphibians, including the boreal toad (*Anaxyrus boreas*) and Columbia spotted frog (*Rana luteiventris*), have declined throughout the Intermountain Region (Arkle and Pilliod 2015; Robinson et al. 1998). Breeding habitats of both species include wetlands and riparian areas at streams and springs with slow-moving or standing water, sedges, and other forms of emergent vegetation (McGee and Keinath 2004; Patla and Keinath 2005; Thompson 2019). These habitats are present in each geographic unit of the BTNF (table 2). Boreal toads also forage in riparian areas dominated by willows, conifers, and grasses (Bartelt et al. 2004). Riparian corridors are important pathways for dispersal of both species.

Birds

Many species of landbirds, including neotropical migrants, nest in the diverse community types associated with riparian ecosystems. Tall deciduous tree-dominated types have high structural diversity and are among the most valuable habitats for birds and other wildlife (Smith and Finch 2014). The large size of mature cottonwood trees makes them attractive nest sites for bald eagles (*Haliaeetus leucocephalus*) and other large birds. Cottonwoods and aspens are critical nesting areas for woodpeckers and other cavity-nesting birds (Hollenbeck and Ripple 2008; Saab and Vierling 2001). The canopies of tall deciduous trees are frequently used as foraging sites by foliage-gleaning birds during migration and the nesting season. Stands of tall willows are especially important nesting habitats for calliope hummingbirds (*Selasphorus calliope*), willow flycatchers (*Empidonax traillii*), and other neotropical migrants (Olechnowski 2008; Singer et al. 1994). Willow habitats at lower elevations (less than 7,900 feet) in the GYE have high productivity and are therefore strong population sources for these birds (Hansen et al. 2002; Hansen 2009). The presence of this habitat on national forest land is important for regional conservation, given losses and degradation on adjacent lands (Hansen and Rotella 2002).

Table 2—Estimates of extent of capable habitat for boreal toads and Columbia spotted frogs in each geographic unit. Data were compiled by the BTNF.

Unit	Stream miles—capable breeding habitat	Acres—capable breeding habitat
Gros Ventre	304.0	62,983.7
Wyoming	182.5	29,010.9
Windriver	23.9	6,043.5
Kemmerer	21.9	9,941.3

Many species of waterbirds breed in riparian ecosystems as well. Harlequin ducks nest in wide riparian zones with dense conifer- and willow-dominated types along high-velocity streams (Wiggins 2005). Herbaceous dominance groups in unconfined valley bottoms are used as nesting sites for marshbirds, including trumpeter swans (*Cygnus buccinator*) and sandhill cranes (*Grus canadensis*; BTNF 2014).

Greater sage-grouse (*Centrocercus urophasinaus*) is a species of concern proposed for listing as federally threatened. Brood-rearing habitat and priority areas for sage-grouse conservation are located within the BTNF (table 3). Though primarily associated with xeric sagebrush uplands, sage-grouse rely on willow-, nonwillow shrub-, and herbaceous-dominated riparian areas as critical components of summer brood-rearing habitat (Donnelly et al. 2016). During the summer, hens and broods will seek these mesic resources to forage on herbaceous vegetation and invertebrates as productivity declines elsewhere (Atamian et al. 2010; Fischer et al. 1996). The maintenance of these riparian areas is a critical component of sage-grouse conservation (Dzialak et al. 2011).

Beaver-Modified Habitats

By constructing dams and ponds, beavers exert a considerable influence on geomorphology and composition of valley bottoms. Beavers create dynamic habitats, such as willow stands and herbaceous-dominated wetlands (fig. 9), that are critical for wild ungulates, small mammals, amphibians, waterbirds, sage-grouse, and neotropical migrant birds (Arkle and Pilliod 2015; Frey and Malaney 2009; Hossack et al. 2015; McKinstry et al. 2001; Medin and Clary 1990, 1991). In the absence of beaver, willow, nonwillow shrub, and herbaceous riparian vegetation are confined to stream margins or disappear altogether as the water table declines (Chadde and Kay 1991). In some areas, beaver dam complexes maintain perennial flows in what are otherwise intermittent streams (Pollock et al. 2014), increasing the extent of riparian and aquatic habitats. Beaver dams can also improve trout habitat by increasing stream heterogeneity and regulating stream temperature (Weber et al. 2017).

Table 3—Area of geographic units designated as greater sage-grouse priority areas for conservation (PACs), as summer brood-rearing habitat by the BTNF, and riparian zones suitable for foraging within summer brood areas.

Unit	Acres—PACs	Acres—summer brood habitat	Acres—riparian foraging habitat
Gros Ventre	48,092	104,582	4,837
Wyoming	0	29,693	2,220
Windriver	3,000	11,507	847
Kemmerer	7,420	13,127	289



Figure 9—Beaver dam complexes maintain extensive willow- and herbaceous-dominated community types along North Horse Creek in the Wyoming Range geographic unit. Photo by D. Max Smith, USFS.

History of Anthropogenic Influences on Riparian and Groundwater-Dependent Ecosystems

There is evidence that humans have been present in the area comprising the Bridger-Teton National Forest for at least 11,200 years (Kornfeld et al. 2010). The first group believed to inhabit the area were present during the Paleo-Indian Period. Based on projectile points found to date, it is believed they were nomadic hunters that arrived following the receding glaciers and subsisted on Pleistocene mega-fauna including the wooly mammoth and giant species of bison, camels, and horses. Later, they may have shifted their subsistence to large species that persist in the present period including elk, deer, pronghorn, and bighorn sheep (*Ovis canadensis*).

Following the Paleo-Indians, the Archaic Period, from about 8,000 to 1,500 years before present, was characterized by rising temperatures and declining precipitation. The Archaic Indian population likely adapted to hunting smaller animals, and adopted gathering strategies to supplement their diets with plants. During the subsequent Late Prehistoric Period, from about 1,200 to 400 years before present, the bow and arrow replaced the spear and atlatl of the Archaic Period (Kornfeld et al. 2010). Farther east, large scale communal hunting of bison and antelope evolved with drive lines, jumps, and traps to increase efficiency. Prehistoric hunter-gatherers altered the landscape by hunting large mammals and igniting fires, but it is difficult to determine if these changes resulted in meaningful, long-lasting effects on riparian and wetland ecosystems (Gage and Cooper 2013). They also gathered food and materials at streams and springs, from plants such as cattail (*Typhus* spp.), chokecherry (*Prunus virginiana*), currant (*Ribes*), wildrye (*Elymus* spp.), and wild rose (*Rosa* spp.).

The Proto-Historic Period followed between approximately 1650 AD to first contact with Euro-American People (Kornfeld et al. 2010). It is defined as the period when Native Americans of the area first gained access to Euro-American goods such as horses, guns, metal goods, and trade beads, but before the actual arrival of Euro-Americans in the area. The Shoshone acquired such goods from people in the American Southwest who had acquired them from Spanish explorers. To this point, the Shoshone and other cultures had no written language, and no written record was kept. All that is known has been obtained from archaeological records.

By the time of Euro-American contact, the area of the BTNF was within the territories of several cultures, including the Cheyenne, Crow, Eastern Shoshone, and Shoshone-Bannock. As with other Native American groups, the activities of these cultures influenced the composition of the landscape, including riparian ecosystems and GDEs (Kretch III 1999). Prior to the introduction of horses and other livestock, groups made annual migrations throughout the Intermountain Region to track the seasonal abundance of

plants and animals. Nomadic groups ignited fires to improve hunting and foraging opportunities. These fires likely influenced the composition of riparian ecosystems in low and mid elevations of the Forest by preventing conifer encroachment and encouraged dominance by shrubs and trees capable of resprouting (Nowacki et al. 2012).

John Colter, member of the Lewis and Clark Expedition, abandoned the expedition before its return to St. Louis in 1806 and joined several fur trapping expeditions into present-day Wyoming. In the winter of 1807, Colter travelled to Jackson Hole and Yellowstone and developed trade relationships with the Crows and other nations (Morris 2004). In 1811-1813, representatives of John Jacob Astor's American Fur Company traveled through the area on their way to and from the Oregon coast (Larson 1990 History of Wyoming). Following these initial explorations, the streams and rivers of northwest Wyoming became known as prime beaver habitat, drawing trappers to the streams and traders to several rendezvous sites (fig. 10; BTNF 2001). Once extremely plentiful and widely marketed as "soft gold" for their soft pelts (Holm and Vaughn 1990), beaver numbers declined markedly from the early 1800s until the early 1900s when legislation was drafted to protect the declining species and restore the hydrology and ecosystem function of the streams (Kay 1994). Indeed, the Bridger-Teton National Forest takes its name, in part, from one famous guide and trapper, Jim Bridger.

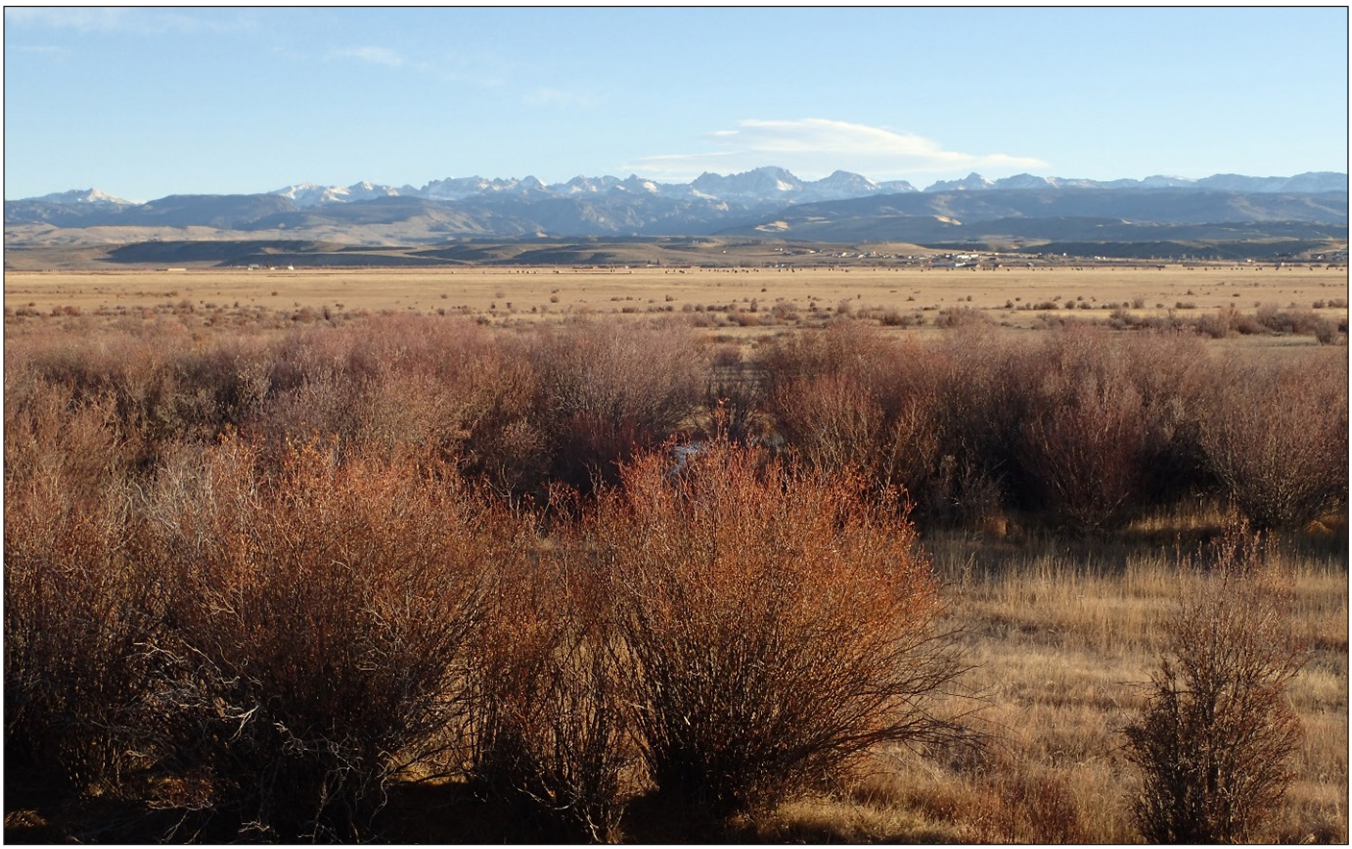


Figure 10—The upper Green River Valley was the site of an annual rendezvous for trading beaver pelts harvested along the region's streams. Photo by D. Max Smith, USFS.

Timber harvesting has occurred in what is now the Bridger-Teton National Forest since the late 1800s (Knight 1994). Much of it was done in what has been referred to as the Tie Hack Era, so-called because the primary objective was to retrieve timber for use in making railroad ties (Alexander and Reilly 1987). Among the effects of unregulated timber harvest were damage to streamside vegetation during tie-drives, soil compaction, soil disturbance, and proliferation of logging roads. On March 30th, 1891, President Benjamin Harrison created the Yellowstone Park Timber Land Reserve near the eastern and southern boundary of Yellowstone National Park (Alexander 1987). On February 22, 1897, President Grover Cleveland created the Teton Forest Reserve from 829,440 acres of public domain land. This area, which lies south of the original Yellowstone Park Timber Land Reserve, is now part of Grand Teton National Park and the Bridger-Teton National Forest. The establishment of the national forests that now comprise the BTNF resulted in managed harvest of timber resources. Timber continues to be harvested in the Bridger-Teton National Forest, but the primary products have shifted from railroad ties to other products, including lumber, posts and poles, house logs and log furniture. Timber sales have declined markedly since peaking in 1992 (Taylor et al. 2008).

Grazing was common and unregulated in northwestern Wyoming as early as 1881 (Calef 1960). Forage, not trees, has historically been the most important commodity from the national forests of the arid west, including the Bridger-Teton National Forest (Alexander 1987; Brower 2000). Among the effects of unregulated grazing were depletion of vegetative cover at streams, springs, and uplands (BTNF 2001). Following creation of the BTNF, Forest allotments were established to manage the numbers of cattle and sheep grazing the Forest and the period of time in the Forest. Grazing permits were given to landowners with year-round livestock operations near the Forests. As a result, the number of cattle and sheep grazing the Forest declined, lessening their impacts on watersheds and riparian ecosystems. Numbers of beef cattle permitted in the Forest have been relatively stable since 1970, whereas sheep numbers have declined steadily (Taylor et al. 2008).

Fire is a natural phenomenon. A century of unnatural fire suppression coupled with rising temperatures over the last decade has resulted in greater biomass accumulation and a greater risk and incidence of wildfires (Busenberg 2004). Although peaks of forest fires occurred during the Medieval Anomaly (ca. 950–1250 AD) and again during the late 1800s, we are currently in a period of significant forest fire deficit, similar to what occurred during the Little Ice Age (1400–1700 AD) that is beginning to be addressed by recent fires in the Western United States (Marlon et al. 2012). The recent increase in forest fires has the potential to temporarily increase sediment flux in riparian areas and alter plant species communities.

Distribution of Riparian Ecosystems in the Bridger-Teton National Forest

The riparian ecosystems assessed in this report occur along perennial and intermittent streams, at springs, and at isolated bodies of water. To describe the distribution of areas that can be considered riparian ecosystems, we combined spatial data layers representing geomorphology, surface flows, groundwater, and vegetation. These features have been used to map riparian ecosystems, but each has their limitations (Goetz 2006; Salo and Theobald 2016). Mapping geomorphic features associated with riparian ecosystems can demonstrate their potential extent, but changes in hydrology, natural or anthropogenic, may have limited the development or persistence of riparian ecosystems, thereby resulting in an overestimation of riparian extent. Conversely, mapping vegetation may underestimate riparian extent because riparian understory species may be obscured by overstory vegetation and facultative riparian species may be incorrectly classified as upland (Salo and Theobald 2016). By mapping areas where vegetation has been classified as riparian, we show the current, minimum distribution of riparian ecosystems in the Forests. By also mapping portions of valley bottoms influenced by surface flows and groundwater, we show where riparian ecosystems currently have the potential to exist.

Data Sources

We combined data from several sources to describe the distribution of riparian ecosystems (table 4). A map of riparian ecosystem extent was prepared for the BTNF by the Forest Service Washington office (Abood et al. 2012). This map incorporates 50-year flood heights from stream gage data, a 10-meter digital elevation model, soil units (hydric, drainage class, flood frequency, and hydrological soil group), and National Wetland Inventory data. We obtained flowline data from the National Hydrography Dataset (NHD) to represent the locations of perennial and intermittent streams. We mapped the current distribution of riparian vegetation using existing vegetation data generated by the BTNF (BTNF 2007). We selected vegetation types classified as riparian to create a layer representing this

Table 4—Characteristics of riparian ecosystem distribution, by geographic unit.

Unit	Perennial stream miles	Intermittent stream miles	50-yr floodplain acres (% of unit)	Potential riparian acres (% of unit)	Acres of riparian vegetation (% of unit)
Gros Ventre	2,572.0	3,051.4	151,860.3 (10)	178,925 (11.7)	59,265.5 (3.9)
Wyoming	1,394.7	2,116.7	75,079.8 (7)	84,431 (8.2)	24,848.7 (2.4)
Windriver	1,110.3	703.2	29,406.5 (5)	40,122 (6.8)	16,511.9 (2.8)
Kemmerer	471.1	396.6	20,257.1 (6)	22,134 (7.0)	8,369.5 (2.7)

measure of riparian distribution. We combined the 50-year floodplain and riparian vegetation layers to create maps showing the potential extent of riparian ecosystems, as well as the current extent of riparian vegetation (see appendix D).

Current Distribution of Riparian Ecosystems

According to the datasets we obtained, potential riparian ecosystems comprise a substantial portion of the BTNF, ranging from 12 percent of the total area in the Gros Ventre unit to 7 percent of the total area in the Windriver and Kemmerer units (table 4). Large stands of riparian vegetation are associated with unconsolidated deposits in valley bottoms, as well as glaciated terrain in mountain headwaters. With numerous streams featuring low-gradient, unconfined valley bottoms, the Gros Ventre unit supports the greatest extent of riparian vegetation mapped in the Forest (appendix D).

Distribution of Groundwater-Dependent Ecosystems in the Bridger-Teton National Forest

Distribution of springs, karst systems, aquifers, and fens is influenced by geology, climate, and anthropogenic activities. The 2012 Planning Rule (36 CFR Part 219) recognizes that groundwater, GDEs, and their associated resources are vital to forest health and sustainability, as well as local and regional biodiversity. Still, most national forests have limited knowledge of the landscape-scale distribution of GDEs. We compiled information and data from multiple sources to describe the known distribution of GDEs so they can be more readily acknowledged in forest planning activities.

The distribution of GDEs is influenced by underlying geology, terrain, and land formation processes. The geologic units of the BTNF are igneous, sedimentary, and metamorphic. Granitic and metamorphic rocks are dominant in the Wind River Range, sedimentary rocks are dominant in the ranges of the Kemmerer and Wyoming units, and a mix of volcanic, granitic, and sedimentary rocks form the ranges of the Gros Ventre unit (BTNF 2001, 2004; Gruell 1980; Wells et al. 2015). Mountain ranges of the BTNF originated through various geological processes, with subsequent glacial periods crafting the landforms that currently exist in the landscape (Cooper and Andrus 1994). Following these periods, valley bottoms and low elevation floodplains were filled with glacial outwash and alluvial deposits, which provide groundwater storage and transport. Porous, fractured, and dissolved geologies of mountain ranges allow recharge of groundwater and are additional drivers of GDE distribution at lower elevations. High elevation glacial activity influences GDE distribution in areas such as the Wind River Range.

Karst systems and bedrock aquifers form where permeable rock allows the infiltration, storage, and transport of water. Karst systems are subterranean passages dissolved into limestone, dolomite, or other soluble bedrocks, with large passageways often occurring at fault zones (Mills 1989). Epikarst occurs in solution-enlarged fractures and cavities that temporarily store and transport groundwater without recharging regional aquifers. Pseudokarst systems transport water through passageways of noncarbonate bedrock such as volcanic deposits and piped sandstone. Bedrock aquifers form in layers of sandstone, limestone, and other permeable rocks and are often confined by impermeable units such as shales and crystalline rocks (Mills 1989).

On the BTNF, springs form at the contacts, joints, and faults of disparate geologies. Groundwater reaches the surface at springs by either moving through low-permeability rock or unmodified fissures or through large cavities. In many cases, springs emerge at a fault line scarp (Whiting and

Stamm 1995). Due to their location at faults, spring distribution in this region can be influenced by geologic activity. Changes in flow patterns, including creation and desiccation of GDEs due to altered groundwater flow paths has resulted following earthquakes and landslides (Wood et al. 1985).

Fens occur in historically glaciated features such as cirques and outwash channels (Chadde et al. 1998) and two major types have been identified in the Rocky Mountains: valley peatlands and subalpine peatlands (Bursik 1990; Heidel et al. 2017). Valley fens form around lakes and ponds at relatively low elevations in major river valleys. Subalpine peatlands are more common and tend to occur along low-gradient subalpine streams (Chadde et al. 1998).

GDE distribution is also driven by regional climate and local weather patterns, particularly annual variation in snowpack and snow water equivalent. Their continued existence relies on discharge from groundwater and recharge to these groundwater systems depends on the distribution, amount and timing of precipitation, evapotranspirative losses, snow cover thickness, snowmelt characteristics, and land use/land cover (Klove et al. 2014). Areas with high precipitation, particularly areas that accumulate slow melting snow, are important sources of recharge and are influential to water table depth. Typical climate patterns that include low humidity and prolonged dry periods on the BTNF significantly limit the development of fens, which require specific hydrology to allow the accumulation of peat (Bedford and Godwin 2003; Chadde et al. 1998). The distribution of springs in the Gros Ventre Range is highly reliant on precipitation for groundwater recharge (Mills 1989).

Data Sources

We combined several sources of data to map potential distribution of GDEs in the BTNF (table 5). We obtained shapefiles representing karst, pseudokarst, and principal aquifers from the U.S. Geological Survey (Epstein et al. 2002; USGS 2003). We mapped the location of springs using two shapefiles: one with points from the NHD and another with points from a BTNF geodatabase. We obtained a shapefile showing the distribution of potential fens from the Colorado Natural History Program (CNHP). The CHNP identified potential fens using National Wetland Inventory data and analysis of aerial imagery (Smith and Lemly 2018). This spatial dataset is the best estimate of fen coverage available for the Forest but still requires field verification. GDE distribution maps are available in appendix E.

Distribution of Springs

The Spring Stewardship Institute (SSI) has documented 139 springs and seeps on the BTNF (appendix E). All of these GDEs originated from the NHD layer, which typically underestimates the true number of springs and does not provide information on their condition. A total of 254 springs are mapped in a BTNF geodatabase, many of which are in the same locations as NHD springs. Notable springs include Kendall Warm Springs, which is the sole habitat for an endangered fish (fig. 11), and Periodic Spring, which is a rare coldwater geyser (fig. 12).



Figure 11—Kendall Warm Springs is the only body of water home to the endangered Kendall Warm Springs dace. Photo by D. Max Smith, USFS.



Figure 12—The Periodic Spring is a coldwater geyser in the Wyoming geographic unit. Photo by D. Max Smith, USFS.

Given differences in number of springs mapped among geographic units, differences in geology of geographic units, and low levels of stressors in much of the Forest, geologic setting is likely the primary driver of spring distribution in the BTNF. Density of mapped springs is greatest in the sedimentary Kemmerer unit (table 5) and is lowest in the Windriver unit, which is largely composed of Precambrian bedrock.

Distribution of Fens

The CNHP mapped 9,943 potential fens on the Forest, with 47 percent of these fens in the Windriver unit, 43 percent in the Gros Ventre unit, 9 percent in the Wyoming unit, and 1 percent in the Kemmerer unit (appendix E). Total area of potential fens is greatest at the Gros Ventre unit, but density of likely fens is greatest at the Wind River unit (table 6).

Distribution of Aquifers and Karst

Potential karst systems are distributed throughout the Wyoming and Kemmerer units (appendix E). Areas of potential karst are also present in the Gros Ventre unit (table 5). Principal aquifers are present in the lower elevations of each unit, with the Wyoming unit having the largest area. Portions of aquifers composed of Colorado Plateau sandstone are present in all units. A portion of Pacific Northwest basaltic aquifer is present in the Gros Ventre unit, and a portion of Upper Tertiary sandstone aquifer is present in the Wyoming unit.

Table 5—Characteristics of GDEs, by geographic unit.

Unit	BTNF springs (# per acre)	NHD springs (# per acre)	Acres of potential karst (% of unit)	Acres principal aquifers (% of unit)
Gros Ventre	93 (0.0001)	61 (0.00004)	235,025.9 (15.4)	81,510.6 (5.3)
Wyoming	85 (0.0001)	27 (0.00003)	345,527.5 (33.6)	139,414.3 (13.5)
Windriver	2 (0.000003)	0	4,415.3 (0.7)	50,665.9 (8.5)
Kemmerer	74 (0.0002)	51 (0.0002)	152,340.3 (48.4)	31,172.2 (9.9)

Table 6—Area of potential fens in each unit. Data were provided by the Colorado Natural Heritage Program.

Unit	Likely fen acres (% of unit)	Possible fen acres (% of unit)	Low confidence fen acres (% of unit)
Gros Ventre	1,671.2 (0.1)	2,238.2 (0.1)	3,992.3 (0.3)
Wyoming	34.7 (0.003)	179.9 (0.02)	138.7 (0.1)
Windriver	2,426.9 (0.4)	987.0 (0.2)	669.5 (0.1)
Kemmerer	32.4 (0.01)	36.4 (0.01)	138.7 (0.04)

Existing Condition of Riparian and Groundwater-Dependent Ecosystems

Methodology

Key Ecosystem Characteristics

To assess the current condition of riparian ecosystems and GDEs, we selected characteristics of ecosystem integrity and sustainability: (1) surface water and groundwater fluctuations, (2) water quality, (3) channel and floodplain dynamics, (4) composition and structure of riparian vegetation, and (5) composition of GDEs. These KECs were selected in accordance with current planning rules and include measures of composition, structure, function, and connectivity.

Drivers, Stressors, and Indicators

We reviewed scientific literature and agency reports to identify drivers and stressors that influence the KECs listed above (table 7). We also selected indicators of the status of each KEC in relation to its NRV that could be evaluated with available data. We quantified stressors (table 8) and indicators of KECs at the scale of the geographic unit in each Forest. For each KEC, we

Table 7—Drivers, stressors, and indicators measured for assessment of riparian and groundwater-dependent ecosystems.

Key ecosystem characteristic	Drivers	Stressors	Indicators
Surface and groundwater fluctuations	Temperature, precipitation, geologic setting, beaver activity	Roads, diversions, dams, mining, timber harvest, wildfire, fire suppression, insects and disease, grazing, climate change	Conifer and upland encroachment, water quantity score, deviation in winter temperature and precipitation
Water quality	Geologic setting, chemistry of precipitation, hydrologic regime, dissolution of organic and mineral substances	Wildfire, agriculture, development, diversions, mining, grazing, roads, recreation, nitrogen deposition, loss of wetlands and riparian cover, mass wasting, water proximity, soil contamination	Impaired waters score, water quality problems score, macroinvertebrates score
Channel and floodplain dynamics	Geologic setting, terrain, hydrologic regime, large woody debris, beaver activity, stabilizing vegetation	Grazing, dams, diversions, development, timber harvest, roads, recreation, invasive species, climate change, spring development	Woody debris presence, channel shape and function, riparian function, bank erosion, habitat complexity, floodplain area, wildfire
Composition and structure of riparian vegetation	Temperature, precipitation, geologic setting, beaver activity, terrain, hydrologic regime, large woody debris, beaver activity	Roads, diversions, dams, mining, timber harvest, wildfire, fire suppression, insects and disease, grazing, climate change, development, roads, recreation, invasive species	Conifer and upland encroachment, riparian recruitment, beaver habitat
Composition of GDEs	Water availability, geomorphic setting, sediment dynamics, thermal activity	Spring development, livestock use, wild ungulate use, recreational use, ditching, channelization, droughts, earthquakes	NA

Table 8—Values of stressors by geographic unit.

Unit	% High severity burn	% Mod. severity burn	% Floodplain mod/high severity burn	% Floodplain high/ very high wildfire hazard potential	% Insects & disease	Diversion density	Road density	Floodplain road density	Trail density	Floodplain trail density	Floodplain recreation sites
Gros Ventre	4.3	7.8	5.4	21	8.4	0.00001	0.0007	0.0012	0.0007	0.002	0.00007
Wyoming	1.6	3.0	2.5	16	14.1	0.00004	0.0010	0.0022	0.0009	0.002	0.00018
Windriver	2.0	4.4	2.3	12	17.7	0.00001	0.0005	0.0009	0.0008	0.001	0.00010
Kemmerer	1.6	2.9	1.8	19	9.2	0.00001	0.0014	0.0031	0.0009	0.003	0.00010

Table 8 (continued)—Values of stressors by geographic unit.

Unit	% Harvested	% Harvests clearcut	% Unit RMU	% RMU active	Nitrogen deposition	% Floodplain conv. to agriculture	% Floodplain conv. to developed	Wildlife feed grounds	Mass wast.	Road & trail maint.	Prox. to water	Soil cont.
Gros Ventre	1.9	74.8	47.6	69.5	3.3	0.2	1.1	10	1.3	1.9	1.9	1.5
Wyoming	2.7	68.4	86.8	81.8	3.6	0.3	1.2	9	2.0	2.2	2.7	1.9
Windriver	0.1	65.2	67.3	78.2	3.3	0.1	0.5	5	1.0	2.3	1.8	1.6
Kemmerer	2.7	58.0	99.1	100.0	3.6	0.3	0.8	0	2.0	2.4	2.2	1.7

used indicator values to calculate an index of NRV status. If we determined that the indicator had little or no alteration, it was given a score of 5; moderate alteration was given a score of 3; and substantial alteration was given a score of 1. The criteria for determining the level of alteration varied among KECs and are described in the sections below. The scores for each geographic unit were summed and divided by the potential total to give a percentage rating for each. Units were determined to be within the NRV, moderately altered from the NRV, or outside the NRV based on this score.

Data Sources

We obtained several datasets from the USDA Forest Service and outside agencies. Each dataset provided multiple variables that we used to quantify stressors and indicators of KECs. We used both spatially explicit data and data collected at field sites. Descriptions of variables and data sources are located in appendix A.

We used two raster files generated by the LANDFIRE program to estimate the area of riparian vegetation affected by conversion to conifers, upland shrubs and grasses, and invasive plants. The Existing Vegetation Type (EVT) raster represents the current distribution of the terrestrial ecological systems classification, for the western hemisphere, through 2016. A terrestrial ecological system is defined as a group of plant community types (associations) that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients. EVT is mapped using decision tree models, field data, Landsat imagery, elevation, and biophysical gradient data (LANDFIRE 2018). The biophysical setting raster (BPS) represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement and is based on both the current biophysical environment and an approximation of the historical disturbance regime.

We used two datasets constructed for the national forests. The Terrestrial Condition Assessment (TCA) compiled nationwide data to evaluate ecological integrity at the landscape scale (Cleland et al. 2017). The Watershed Condition Classification (WCC) is an effort to evaluate watersheds on all Forest Service lands. The WCC uses a paneling process to score indicators of integrity functionality of watersheds (Potyondy and Geier 2011). Watersheds are assigned a condition class based on the indicator scores.

To incorporate field-based data, we obtained results from the Wyoming Habitat Assessment Methodology (WHAM) Program (Quist et al. 2005). These data were collected at stream segments in each geographic unit. WHAM surveys typically characterize portions of drainages selected with specific aims such as identification of reference reaches, documentation of pre/post project conditions, or assessment of stream suitability for cutthroat trout or beaver.

We used two biological indicators, the Wyoming Stream Integrity Index (WSII) and the Wyoming River Invertebrate Prediction and Classification System (WYRIVPACS), to determine aquatic life use support (Hargett et

al. 2005, 2011). These data are collected from wadeable perennial streams by the Wyoming Department of Environmental Quality using targeted riffle macroinvertebrate surveys (WDEQ 2017). This method is preferred because riffle habitat tends to provide diverse and abundant samples of benthic macroinvertebrates and the same riffle habitat can be sampled over time (WDEQ 2017).

To describe floodplain extent, we used the 50-year flood map described in the previous section. We included spatial data provided by the NHD and the BTNF as well.

Data Analyses

R-CAT

Following methods used in the Riparian Condition Assessment Toolbox (MacFarlane et al. 2016), we estimated the percentage of valley bottoms associated with perennial streams converted from riparian vegetation to conifers, upland shrubs and grasses, and invasive species. We masked the LANDFIRE EVT and BPS rasters to a shapefile representing valley bottoms associated with perennial streams (Baker et al. in press; Carlson 2009). We calculated the percentage of valley bottom surrounding each NHD stream reach with riparian vegetation in the BPS raster and the percentage with riparian, conifers, upland vegetation, and invasive plants in the EVT. Using these values, we calculated mean percentage converted to conifers, upland plants, and invasive species.

Correlations

To account for nonnormal and ordinal data, we used Spearman Correlation (r_S), which ranges from -1 to +1, to examine associations between stressors and indicators at the watershed scale. We systematically compared the stressor value for each watershed (e.g., road density, percent of watershed burned at high severity, diversion density) to corresponding indicator values (e.g., WCC water quality score, percent of riparian converted to upland cover) to obtain Spearman's r_S. We considered r_S values of less than -0.7 to be indicative of strongly negative associations and r_S values greater than +0.7 to be indicative of strongly positive associations. Weak associations were identified by a r_S value between +0.3 and +0.7 or -0.3 and -0.7. Finally, a r_S value between -0.3 and +0.3 indicated no association between the stressor and indicator.

Surface Water and Groundwater Fluctuations

Structure, function, connectivity, and composition of riparian and freshwater systems are highly influenced by fluctuations in surface water and groundwater. The timing, frequency, magnitude, rate of change, and duration of high and low flows are critical components of a stream's natural flow regime (Poff et al. 1997). Flooding is an important natural disturbance (Resh et al. 1998) that contributes to high aquatic and terrestrial habitat heterogeneity, allows exchange of organic matter and nutrients between the stream and its floodplain, and recharges hyporheic and groundwater systems (Junk et al. 1989; Poff et al. 1997; Stanford et al. 2005). Succession occurs during low flows, with the establishment and growth of riparian vegetation

on recently scoured or deposited substrates (Stromberg et al. 1991; Whited et al. 2007). Low flows are often supported by groundwater sources that are maintained by infiltration from rainfall and snowmelt (Poff et al. 1997). Growth, survival, distribution, and composition of riparian vegetation is associated with fluctuations in water table levels and the overall depth to groundwater (Horton et al. 2001; Shafroth et al. 2000; Smith et al. 1998). Finally, many plant and animal species associated with riparian ecosystems evolved with natural water cycles and depend on fluctuations that occur within the natural range of variation for magnitude, timing, and duration (Lytle 2004; Poff et al. 1997; Stanford et al. 2005).

GDE flow regimes differ from those of runoff-dominated surface water systems. Spring and wetland GDEs experience less extreme high and low flows than streams and rivers that include a snowmelt signal (Whiting and Stamm 1995). GDEs flow at bankfull approximately 20 percent of the time and baseflow in these systems tends to be about 65 percent of the bankfull discharge (Whiting and Stamm 1995). In contrast, surface water systems only reach bankfull 2–4 percent of the time and base flows are generally about 10 percent of bankfull flows (Whiting and Stamm 1995). Additionally, the timing of flows in GDEs is distinct compared to that of streams and rivers. GDE peak discharge typically occurs in late summer and fall (Whiting and Stamm 1995) compared to the high flows of surface water systems that occur in response to snowmelt in spring and early summer (Whiting and Stamm 1995). Overall, the hydrographs of GDE flows are muted compared to surface water streams (Whiting and Moog 2001; Whiting and Stamm 1995). The timing, reliability, and reduced extremism of GDE discharge is important for species that are associated with GDEs and has implications for the base flows observed in surface water systems during late summer.

Drivers

Natural flow regimes of groundwater and surface water systems on the BTNF are primarily driven by climate, glacial presence, beaver activity, and geology. The climate of the Forest is strongly influenced by topography (Fontaine et al. 2002) with large variations in local conditions driven by elevation and aspect (Gruell 1980). Elevations on the BTNF range from 6,500 to over 13,000 feet (Bragg et al. 2000). Mountains impede weather systems, resulting in an extreme annual vertical precipitation gradient (Fontaine et al. 2002; Hall et al. 2012). While rain is the dominant precipitation type at lower elevations, low valleys and southfacing slopes are characterized by semiarid conditions (Gruell 1980). Above 7,000 feet, 75 percent of precipitation occurs as snow (Gruell 1980). Significant snowpack begins to accumulate in October (Fontaine et al. 2002) and depths can exceed 100 inches at high elevations (Gruell 1980). Snowmelt tends to begin in April and May, but the timing is strongly controlled by elevation (Fontaine et al. 2002). Snow can remain at high altitudes until mid June or July and provides the primary source of discharge in small streams across the Forest (Persico 2012).

Hydrographs on the BTNF are snowmelt-dominated, with peak flow typically occurring during May, June, and early July (Gruell 1980). Summer thunderstorms can produce rapid and wide fluctuations in flow, but they do not contribute significantly to annual runoff (Gruell 1980). The region experiences natural cycles of wet and dry periods that are related to the El Niño-Southern Oscillation (Redmond and Koch 1991; Wise 2010a). Reconstructed streamflow records from 1591–2005 demonstrate that the Forest has experienced severe decadal droughts, including the 1930s Dust Bowl and similar sustained low flow conditions from 1626–1634 (Wise 2010b). Past studies have shown that streamflow in the BTNF and surrounding areas are highly responsive to drought conditions (Persico 2012; Wise 2010b). During the 1930s, discharges were recorded at their lowest levels in 300 years, snowmelt occurred earlier, summer base flows were diminished, and perennial streams transitioned to ephemeral systems (Persico 2012).

The hydrologic response of drainages depends on their geology. Relative to other ranges within the Rocky Mountains, features on the BTNF are geologically young (Gruell 1980) and composed of complex mixes of landforms and processes (Bragg et al. 2000). The permeability of these features depends on the fracturing of bedrock below shallow soils (Fontaine et al. 2002). There are five river basins with variable hydrology and geology present on the Forest: the Bear, Platte, Green, Bighorn, and Snake (fig. 13). The Snake River Basin is the largest, occupying 58 percent of the BTNF, followed by the Green, which encompasses 32 percent of the Forest. The Bighorn, Bear, and Platte basins occupy very small sections of the BTNF, 6, 3, and 1 percent, respectively.

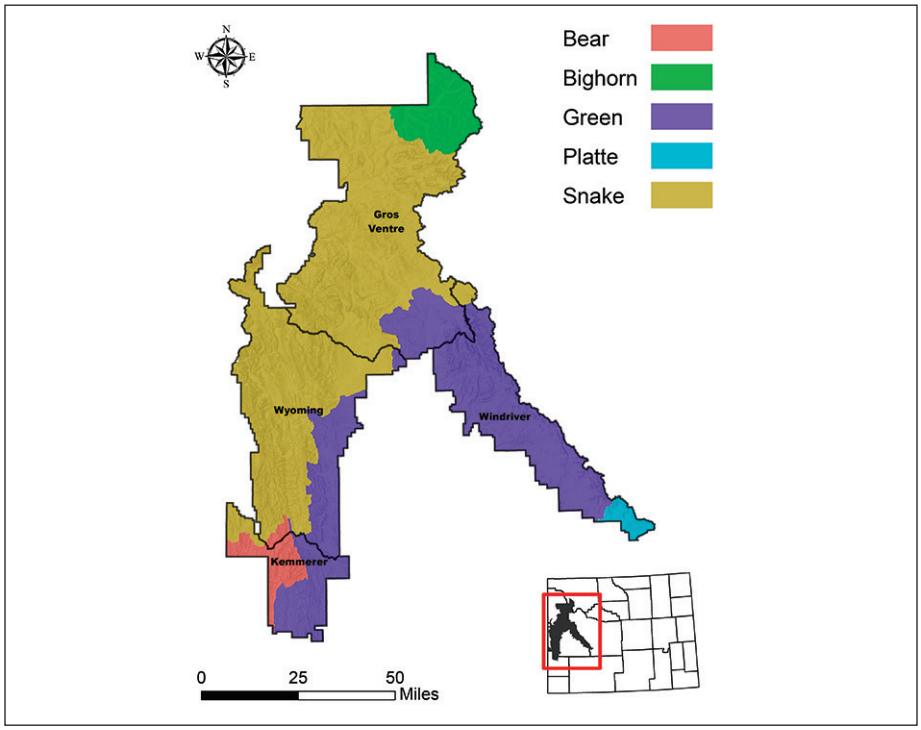


Figure 13—River basins of the Bridger-Teton National Forest, Wyoming.

The Snake River Basin has a complex geology, with faults, fractures, and karst systems controlling groundwater circulation in this basin by redirecting flow depending on hydraulic pressure (Taboga et al. 2014b). The most common locations for discharge from groundwater systems are direct flows into alluvial sediment and from springs located where faults direct flow upward (Taboga et al. 2014b). Infiltration of rain and snow, along with seepage from streams, recharges the groundwater systems of the Snake River Basin (Taboga et al. 2014b). The Green River Basin is divided by anticlines, including the Rock Springs uplift (Clarey et al. 2010). The total recharge in this basin is estimated to be 50,000–100,000 acre-feet per year (Clarey et al. 2010) and the estimated yield is approximately equivalent. Shallow groundwater in the Green River Basin tends to pass through fractured aquifers and discharge to surface water systems, sustaining base flows (Clarey et al. 2010). In the Bighorn River Basin, geologic settings range from simple to complex, and their configuration influences the movement and availability of water (Taucher et al. 2012). In the section of the Bighorn Basin present on the Forest, there are high amounts of precipitation and estimated recharge. The eroded terrain restricts aquifer continuity and storage, with most groundwater in perched or isolated aquifers that are substantial sources of surface water flows (Taucher et al. 2012). The Bear River Basin, which occupies a large amount of the Kemmerer unit, stores a substantial quantity of groundwater (Taboga et al. 2014a). Recharge in this basin ranges from 0–37 inches per year, with the least occurring in the basins and the most occurring in mountain ranges (Taboga et al. 2014a).

With 25 of the 38 named glaciers in Wyoming located in the Wind River Range (Hall et al. 2012), glacial meltwater plays a significant role in water fluctuations in some parts of the Forest. Most of the BTNF's glaciers are located on north and east facing aspects on the eastern side of the Continental Divide (Hall et al. 2012). While the main driving factor of streamflow is snowmelt, glaciers in the Wind River Range are linked to dramatic shifts in the hydrologic regimes of glaciated watersheds (Bell et al. 2012). Where they are present, a larger percentage of streamflow occurs in late summer, annual variation in runoff is less, and peak flow is delayed (Bell et al. 2012). Studies in the Wind River Range have demonstrated that compared to groundwater inputs and rain, glacial meltwater is a large and consistent contributor to streamflow, particularly during the late summer months (Cable et al. 2011; Pochop et al. 1990).

Dam building by beavers drives natural flow regimes by modulating peaks and troughs of the yearly hydrograph, particularly when a series of dams exist within a single drainage (Rosell et al. 2005). Beaver dams increase the storage capacity of catchments by absorbing and retaining water during high flows. Discharge is then released slowly, leading to higher base flows during late summer. Beaver ponds and their dams enhance the depth, extent, and duration of inundation during flooding and elevate the water table during both high and low flows (Westbrook et al. 2006). Significant beaver populations within a drainage can result in a transition from intermittent

to perennial flow and make aquatic and riparian ecosystems more resistant and resilient to the effects of drought and climate change (Pollock et al. 2014; Rosell et al. 2005). Beaver populations of the Greater Yellowstone Ecosystem have historically been highly variable and influenced by climate, with large reductions observed during severe droughts (Persico and Meyer 2012). Due to interactions between climate and management practices since Euro-American settlement, no period within historical times can be used to appropriately define reference conditions for beaver population size (Persico and Meyer 2012). Nevertheless, declines in beaver populations began prior to 1950 and are presumed to be the result of wolf extirpation, food resource depletion due to elevated beaver populations in the 1920s, and episodes of prolonged severe drought that began in the 1930s and have continued to the present (Persico and Meyer 2012).

Stressors

Stressors to water fluctuations include activities and forces that alter the timing, frequency, magnitude, duration, or rate of change of natural flows or that impact the hydrologic connectivity between ground and surface water systems. These forces can be natural or anthropogenic. On the BTNF they include wildfire, vegetation mortality due to insects and disease, drought, diversions, roads and trails, timber harvest, livestock grazing, and altered temperature and precipitation regimes (table 8).

Natural disturbances to water fluctuations include wildfire, vegetation mortality due to insects and disease, and drought. Following fire, certain topographies burnt at high severity are prone to flash flooding, debris flows, or severe erosion that can reduce connectivity between ground and surface water systems (Doerr et al. 2006; Ice et al. 2004). Water fluctuations can be influenced by widespread vegetation mortality, which tends to increase late summer infiltration to groundwater systems (Bearup et al. 2014). Sustained drought or moist periods are linked to expected changes in water levels throughout the study area (Persico 2012). Even though wildfire, vegetation mortality, and drought are natural stressors, their impacts can be amplified by human activities. For example, fire suppression efforts have contributed to larger fuel loads that can contribute to larger, more severe fires (Dennison et al. 2014). Anthropogenic climate change can alter temperature and precipitation regimes across the Forest (Cleland et al. 2017) and intensify drought conditions.

Anthropogenic stressors to water fluctuations include grazing, timber harvest, construction of roads and trails, or diversions. Grazing sheep, cattle, and large elk herds reduce vegetative cover in uplands and riparian areas. This loss decreases soil stability, increases runoff and flooding, and increases downcutting and channel incision. Overall, this process increases depth to the water table and can cause perennial water sources to run dry (Krueper 1993). On the BTNF, overgrazing from large elk herds has been linked to flooding and mudflows (Croft and Ellison 1960). Additionally, Marston (1994) provided examples of channel incision and lowered water tables as a result of overgrazing throughout western Wyoming. Depending on how timber harvest

projects are managed, largescale removal of trees can increase surface runoff and provide a source of sediment that disrupts natural networks between ground and surface water systems (Bosch and Hewlett 1982). Roads and trails can decrease infiltration and increase surface runoff by altering hillslope contours and adding impervious surfaces to the landscape (Forman and Alexander 1998; Pickering et al. 2009; Reid and Dunn 1984). Additionally, roads and trails provide an unnatural source of fine sediment that fills lakes, wetlands, and streams; and they can obstruct natural flow paths between surface and groundwater systems (Forman and Alexander 1998; Pickering et al. 2009; Reid and Dunn 1984). Finally, diversions alter hydrologic connectivity and contribute to changes in components of the natural flow regime (Winter et al. 1998).

Natural flow regimes are influenced by climate change in numerous ways. Altered temperature and precipitation regimes can result in reduced snowpack, earlier snowmelt, and more precipitation in the form of rain. Together, these forces can alter the natural timing and magnitude of high and low flows (Cayan 1996; Hamlet et al. 2005). Warmer temperatures that alter the distribution of phreatophytic plants and increase evapotranspiration can also influence fluctuations in ground and surface water systems (Chen et al. 2011; Rind et al. 1990; Weiss et al. 2009). On the BTNF, the average temperature between 2010 and 2014 in all four seasons has increased compared to the previous century (Cleland et al. 2017). Precipitation has generally remained consistent (Cleland et al. 2017). Natural groundwater and surface water fluctuations are strained by these changes in climate, and any additional stressors act cumulatively (IAP 2016).

Indicators

We used conifer and upland encroachment, the WCC mean water quantity score, as well as deviations in winter temperature and precipitation as indicators of the condition of water fluctuations in surface water systems (table 9). Encroachment of conifers and other upland species into riparian zones is a process associated with altered flow regimes (Macfarlane 2016). Increased upland cover tends to reduce turnover and lock landforms in place, ultimately modifying water yield and timing of fluctuations and allowing for more upland encroachment (Huxman et al. 2005; Macfarlane 2016). We used R-CAT (Macfarlane 2016) analysis to determine the percentage

Table 9—Indicator values for groundwater and surface water fluctuations within each geographic unit on the BTNF.

Unit	% Conifer encroachment	% Upland encroachment	Mean water quantity score	Deviation in winter temperature	% Deviation in winter precipitation
Gros Ventre	4.9	7.1	2.0	2.0	-2.4
Wyoming	7.0	9.2	2.0	2.0	0.2
Windriver	2.5	3.7	1.5	2.0	-2.9
Kemmerer	7.6	11.1	1.5	2.3	1.0

of valley bottoms converted from riparian vegetation to conifer or upland cover for each geographic unit. We used the average water quantity score for each unit as determined by the WCC (Potyondy and Geier 2011). This indicator addresses changes in the natural flow regime with respect to magnitude, duration, or timing of the natural streamflow hydrograph. A score of 1 indicates that hydrographs have minor or no alterations from natural conditions; a score of 2 indicates that peak and base flows are maintained, but that changes to the timing, rate of change, and/or duration of mid-range discharges has occurred; and a score of 3 indicates the natural flow regime is significantly departed from the natural hydrograph (Potyondy and Geier 2011). Flow regimes throughout the Western United States have been altered by anthropogenic warming and the associated changes in snowpack (Safeeq et al. 2015). As a primary control on snow accumulation is winter temperature (Safeeq et al. 2015), where we used deviation in winter temperature and precipitation from the TCA (Cleland et al. 2017) as indicators of current condition of water fluctuations in each geographic unit.

We used WHAM data from reference reaches across the Forest to understand beaver abundance but did not incorporate the information into the indicator. WHAM bins percent of reach impacted by beaver activity into 6 categories: 0, 1–5, 6–25, 26–50, 51–75, and greater than 76 percent. Seventy-two percent of reference reaches had no beaver activity; 13 percent had 1–5 percent of the reach impacted; 4 percent had beaver activity that impacted 6–25 percent of the reach; and 4 percent of reference reaches fell into the fourth category of 26–50 percent. Lastly, the fifth and sixth bins with high beaver activity described 1 percent of reference reaches each. See appendix F for additional information on stressors and indicators within each geographic unit.

We did not identify any data that were sufficient for evaluating water fluctuations at GDEs on the Forest. We used the Wyoming State Water Plans to summarize groundwater fluctuations for the basins present on the Forest, but these summaries are not specific to the BTNF. More data is needed to determine the NRV status of water fluctuations at GDEs on the Forest.

Surface Water and Groundwater Fluctuations on the Bridger-Teton National Forest

Water fluctuations in surface water systems on the BTNF appear to be resistant and resilient to multiple interacting stressors. Based on encroachment of conifer and upland species, water quantity, and deviations in winter precipitation and temperature, the entire Forest was within the NRV for fluctuations in surface water systems. We were unable to assess water fluctuations at GDEs on the Forest due to a lack of data. While river basin assessments completed by the State of Wyoming indicate that water fluctuations of groundwater systems on the Forest are likely within the NRV, it was not possible to determine whether local stressors on the BTNF had resulted in excessive fluctuation of water levels, alterations to flow patterns, or drying of soils that would negatively affect GDE biota.

Our results are consistent with other studies that have shown that the hydrologic integrity of headwaters in Western Wyoming is generally in good condition, especially relative to that of low elevation streams that have experienced more development and diversion. The WCC identified less than 3 percent of watersheds as having significant departures from the natural hydrograph. An assessment of reservoir surface area, total surface water withdrawals, and total consumptive water use throughout the Greater Yellowstone Ecosystem concluded that mountainous watersheds, including those on the BTNF, have high hydrologic integrity (Van Kirk and Benjamin 2001). Finally, the headwaters of the Snake River Basin have been identified as high-quality snowmelt-dominated streams with the majority of reaches exhibiting unaltered hydrographs and natural flow regimes (BTNF 2014).

A number of factors have likely contributed to the resilience and resistance of water fluctuations on the BTNF. These systems have experienced natural sustained and severe drought, including those that occurred during the 1930s and the 1600s (Persico 2012; Watson et al. 2009; Wise 2010b). While drought may be within the NRV for the system, long-term dry periods, such as those predicted for the region, reduce surface flows and recharge to aquifers, ultimately resulting in loss of riparian and perennial stream habitat across the landscape (Persico 2012). Additionally, despite a decrease in winter precipitation, the TCA characterized nearly the whole BTNF as in good or very good condition for winter precipitation and overall precipitation exposure (Cleland et al. 2017). Good precipitation condition may contribute to maintaining the NRV status of groundwater and surface water fluctuations on the majority of the Forest. Thirdly, the presence of glaciers in the Wind River Range has likely preserved natural water fluctuations in that unit of the Forest. Glacial meltwater maintains streamflow in the Wind River Range, particular during the late summer and early fall of drier years (Cable et al. 2011; Cheesbrough et al. 2009). However, the area occupied by Wind River glaciers decreased by an average of 25 percent between 1985 and 2005 (Cheesbrough et al. 2009). If the Wind River glaciers continue to shrink, streamflow is likely to decline during critical times like late summer and during drought (Cable et al. 2011).

Overall, roads and trails, particularly those located within floodplains, and grazing were the most common stressors to groundwater and surface water fluctuations on the BTNF. Based on Spearman's r_S , there were weak positive correlations between upland encroachment and watershed road miles, floodplain road miles, watershed trail miles, floodplain trail miles, grazed acres, and actively grazed acres. We observed weak positive correlations between conifer encroachment and watershed road miles, floodplain road miles, watershed trail miles, floodplain trail miles, grazed acres, and actively grazed acres. There also was a weak correlation between diversion density and degraded water quantity scores. We did not observe any correlation between our indicators of water fluctuation condition and the percentages of a watershed burned at high severity, impacted by vegetation mortality, or within a timber harvest project. However, these stressors may interact with roads, trails, or grazing or have localized effects within specific watersheds.

There were slightly more than 2,800 miles of roads across the Forest with 66 percent classified as unimproved (Cleland et al. 2017). Approximately 450 miles of roads were located within floodplains, with greater potential to alter flow regimes. Throughout national forests in Wyoming, road building had been linked to negative impacts that resulted from poor planning (Wyoming Forest Study Team 1971). Improved design, location, and building practices has helped reduce the impacts of these features (Wyoming Forest Study Team 1971).

Approximately 67 percent of the BTNF is located within a grazing allotment and 80 percent of those are classified as active. Grazing began on what would become the Forest in the late 1800s. At that time there was no prohibition on public lands, resulting in overuse by both sheep and cattle (Allan 1973; Bailey 2003). Areas within the Kemmerer unit were used for stock raising and grazing (Bailey 2003), which continues to be reflected in the high number of active grazing permits in this area. With the establishment of the national forest, trespass grazing was reduced and range management improved (Allan 1973). Changes in rules and regulations from 1965–1989 resulted in improved grazing management practices (Borman and Johnson 1990). The BTNF's allotment management plans outline proper use criteria, such as percentage utilization and stubble heights, to trigger movement between units, reducing the impacts from grazing. Nevertheless, evidence of the desertification effects of overgrazing remains in some locations on the BTNF (Roadifer et al. 2008; Sweeney et al. 2003). In addition to cattle and sheep, high grazing pressure from elk has affected water fluctuations on the Forest (Croft and Ellison 1960). Herds depleted vegetation and generated soil erosion comparable to overgrazed livestock ranges in areas that had never been grazed by livestock. These degraded conditions were linked to enhanced hydrological activity including damaging floods (Croft and Ellison 1960).

While precipitation regimes across the Forest have not changed substantially, seasonal temperatures have increased (Cleland et al. 2017). In our analysis of watersheds, indicators of increased aquatic habitat fragmentation were associated with large reductions in winter precipitation. Additionally, increased winter temperatures were correlated with greater percentages of floodplains converted to nonriparian cover. Several studies have documented changes in natural flow regimes in the region and throughout the Western United States (Christensen et al. 2004; Regonda and Rajagopalan 2005; Rood et al. 2008). The timing of snowmelt has shifted to earlier in the spring, with the date of spring snowmelt in the Wind River Range occurring up to or greater than 20 days earlier when compared to the mid-20th century (Hall et al. 2012). This shift in timing is likely related to recent severe droughts in the late 20th and early 21st centuries (Persico 2012). The average annual Palmer Hydrological Drought Index in the region displays a trend toward increasingly severe and more frequent droughts over the last 100 years (McMenamin et al. 2008). The years 2000–2007 were characterized by mild to extreme drought, with 2000–2003 being the driest consecutive 4-year period in the last century (Debinski et al.

2010). Throughout the Greater Yellowstone Ecosystem, this trend has been linked to significant decreases in annual river discharges, earlier snowmelt, decreased summer baseflows, transition from perennial to intermittent flows, reduced wetland cover, and diminished recharge to groundwater systems (McMenamin et al. 2008; Persico 2012).

Water Quality

Water quality describes the complex biogeochemical interactions that occur within aquatic and riparian ecosystems. The ecology of freshwater systems depends on inputs of sediment, nutrients, temperature, dissolved oxygen, and pH (Bilotta and Brazier 2008; Dauer et al. 2000; Johnston 1991; Sanchez et al. 2007). These characteristics impact the structure and function of streams, lakes, and GDEs in various ways. Furthermore, aquatic systems, particularly aquifers and hyporheic zones, provide the fundamental ecosystem service of nutrient transformation and biological filtration that results in drinking water for numerous communities (Boulton 2005). As surface waters become more polluted, sources of good water quality, especially groundwater resources, will be important refugia for considerable biodiversity and water sources for human consumption.

Drivers

The biogeochemistry of aquatic systems is driven by geology, chemistry of precipitation, the length of time water is in contact with certain soil and rock types, mixing of cold and thermal water sources, glacial presence, and the dissolution of organic and mineral substances from vegetation, soil, and rocks (Yee and Souza 1987). These factors influence the concentrations of dissolved substances and the temperature of ground and surface water systems. The underlying geology of some watersheds naturally contribute certain constituents to both surface water systems and GDEs (Domenico and Schwartz 1998). As water moves through flow pathways, it comes in contact with soil particles and bedrock that provide sources of constituents such as calcium, sodium, carbonates, and other elements. The length of time in contact with geologic formations influences the concentrations and types of constituents dissolved in water. Additionally, geology influences total dissolved solids through the types of rock present and how it weathers (Domenico and Schwartz 1998). The chemistry of precipitation impacts the types of minerals and the rates they dissolve in solution (Douglas 1968; Reid et al. 1981). Glaciers can influence water quality in various ways as they retreat (Moore et al. 2009). Weathering processes change as areas exposed by deglaciation are introduced to new environments, shifting chemical signature and composition (Moore et al. 2009). Additionally, the loss of glaciers on the landscape can result in increases in water temperature and suspended sediment concentrations (Moore et al. 2009). Water quality is further influenced by natural leaching of organic matter and nutrients from soil (Qualls and Haines 1992), as well as biological processes within the riparian zone and aquatic environment that alter the chemical composition of water (Hill 1996; Osborne and Kovacic 1993).

Examples of the influence of geology on water quality exist across parts of the Forest. The weathering of igneous and metamorphic minerals in the Wind River Range and the Wasatch Formation affects water draining these areas (Chafin and Kimball 1992). Water sampled from near surface geologic formations is freshest in recharge areas of the mountains and becomes saltier as it moves through geologic units into the lower elevation basins (Chafin and Kimball 1992). However, the chemical composition and over all concentrations of spring discharges across the Forest are as variable within individual geologic units as they are between different geologies (DeLong 1986). Precipitation has been documented to impact water quality in various ways across the Forest. Chafin and Kimball (1992) identified it as a likely source of approximately 15 percent of chloride present in tributaries to the Green River Basin. Wetter and drier years are associated with variation in annual loads and average concentrations, with less precipitation linked to reduced sediment loads and greater solute concentrations (DeLong 1986). Intermittent and ephemeral streams tend to accumulate salts during dry periods and concentrations are high when channels begin to flow (DeLong 1986). In the headwater areas present on the BTNF, overland runoff that results from precipitation dilutes dissolved solid concentrations of perennial baseflows (DeLong 1986).

Stressors

Stressors to water quality include forces that alter temperature, suspended sediments, and the concentrations of nutrients, minerals, or pollutants (table 8; Bilotta and Brazier 2008; Dauer et al. 2000; Johnston 1991; Sanchez et al. 2007). Concentrations can be influenced by increasing their input or changing the amount of water in the system (Yee and Souza 1987). Large nutrient loads can cause algal blooms that ultimately lead to eutrophication (Anderson et al. 2002; Smith et al. 1999). Large inputs of sediments can reduce the depth of channels, lakes, and ponds (Einstein 1950) and fine sediment can obstruct interstitial spaces that link surface and groundwater systems (Richards and Bacon 1994; Wood and Armitage 1997). Shallower streams and lakes and systems with diminished groundwater inputs tend to have increased water temperature (Poole and Berman 2001). Stream temperature can be further increased by the loss of riparian vegetation that shades aquatic systems (Poole and Berman 2001). Large inputs of sediment can affect water quality by transporting pollutants that threaten municipal water supplies and aquatic species. Fine sediments suspended in the water column limit light penetration, leading to reduced primary production and impacts to trophic relations (Wood and Armitage 1997).

Stressors to water quality can be generated by natural and anthropogenic forces. Wildfires are a natural stressor that can temporarily increase nutrient and sediment inputs and remove shade-providing riparian vegetation (Shakesby and Doerr 2003; Spencer et al. 2003). Many freshwater ecosystems have evolved with regular and frequent fire occurring in their watersheds. Historically, aquatic systems with high degrees of connectivity and robust species populations were resilient to the temporary effects of fire

on water quality (Dunham et al. 2007). With fragmentation and extensive anthropogenic stressors, refugia for species and functional aquatic systems are diminished (Neville et al. 2009).

Anthropogenic factors that influence water quality include burning of fossil fuels, agriculture, diversions, roads, recreation, and loss of riparian zones. Fossil fuel combustion and high intensity agriculture have increased nitrogen deposited from the atmosphere (Carpenter et al. 1998). Additionally, runoff from fertilized fields or grazed areas can increase nutrient inputs to aquatic systems (Carpenter et al. 1998; Yee and Souza 1987). Diversions and pumping remove water from the system and can increase the concentration of dissolved minerals and solutes (Liu et al. 2003). Roads, particularly those located within floodplains, are unnatural sources of sediment and are linked to altered levels of heavy metals, salinity, turbidity, and dissolved oxygen (Forman and Alexander 1998). Livestock grazing primarily influences water quality by increasing sedimentation and water temperature by trampling banks and browsing shade-providing vegetation (Armour et al. 1991; Fleischner 1994). While Gary et al. (1983) found that seasonal cattle grazing at moderate stocking rates did result in the deposition of manure and urine directly into streams, they only identified minor reductions in water quality that were not long term. Similarly, Buckhouse and Gifford (1976) did not identify significant changes in fecal and total coliform production from grazing use. However, recreation areas, including trails and campsites, can increase sediment inputs and affect water quality through refuse disposal (Crabill et al. 1999; Varness et al. 1978). Lastly, wetlands and riparian zones are very effective at trapping sediments and nutrients. In fact, Gilliam (1994) identified these areas as the most important factor influencing nonpoint-source pollutants and essential for surface water quality protection. Globally, riparian areas are shrinking, with potential deleterious effects to water quality (Verhoeven et al. 2006).

Indicators

We used three indicators to determine the NRV status of surface water quality in each geographic unit (table 10): mean WCC impaired waters score, mean WCC water quality problems score, and the biological condition. We used the average WCC impaired waters score for watersheds located within each unit. This indicator is considered in good condition if no State-listed

Table 10—Water quality indicator values within each geographic unit.

Unit	Impaired waters	Water quality problems	% Streams—full support
Gros Ventre	1.0	1.2	80.9
Wyoming	1.0	1.1	80.8
Windriver	1.0	1.6	87.5
Kemmerer	1.0	1.1	73.3

impaired or threatened waterbodies are located within each watershed; it is considered in fair condition if less than 10 percent of stream miles or lake area are listed on the 303(d) or 305(d) lists; it is considered in poor condition if more than 10 percent of stream miles or lake area are water quality limited (Potyondy and Geier 2011). Similarly, we used the mean WCC water quality problems score of watersheds located within each unit. This indicator is considered in good condition if a watershed has no documented evidence of excessive sediment, nutrients, chemical pollution, or other issues above natural levels; it is considered in fair condition if consumption advisories exist in localized areas or if there are localized incidence of elevated sediment, nutrients, chemicals, or contamination. It is considered in poor condition if consumption advisories extend over large areas, if there are excessive sediment, nutrients, or chemicals, and if there is extensive or frequent contamination (Potyondy and Geier 2011). To determine the status of these two indicators, we used thresholds defined in the WCC (Potyondy and Geier 2011).

The biological condition indicator was determined using the Wyoming River Invertebrate Prediction and Classification System (RIVPACS) observed/expected ratio and the WSII. RIVPACS assesses the biological condition of a stream by comparing observed macroinvertebrates with the expected macroinvertebrate community of a system lacking anthropogenic stressors (Hargett et al. 2005). The WSII is a quantitative multimetric biological model that uses benthic macroinvertebrates to assess biological condition of wadeable streams (Hargett et al. 2011). The scores for RIVPACs and WSII are entered into an aquatic life narrative category decision matrix that produces a final biological condition of "full-support," "indeterminate," or "partial/non-support." A biological condition of "full-support" indicates the stream is comparable to reference conditions in terms of pH, temperature, sulfate, total phosphorus, nitrate-nitrogen, total nitrogen, alkalinity, hardness, total suspended soils, turbidity, chloride, dissolved oxygen, and conductivity (WDEQ 2017). We calculated a percentage of streams within each geographic unit that were classified as full-support. We also examined repeated measures for trends in water quality.

We did not identify any data that were sufficient for evaluating water quality at GDEs on the Forest. We used the Wyoming State Water Plans to summarize groundwater quality for the basins that are present on the Forest, but these summaries are not specific to the BTNF. More data are needed to determine the NRV status of GDE water quality on the Forest.

Water Quality on the Bridger-Teton National Forest

Surface water quality on the BTNF has been resistant to multiple interacting stressors. Based on indicators of surface water systems, 100 percent of the Forest was within the NRV for water quality. Impaired waters were not an issue in any geographic unit, with the mean WCC score signifying that there were no State-listed impaired or threatened waterbodies. Minor water quality problems were present in all four units, indicative of issues with excessive sediment, nutrients, or chemical pollution

above background levels. Despite increased WCC water quality problem scores, especially in Windriver, all units were classified in good functioning condition. The biological condition determined by RIVPACs and WSII indicated no alteration in the Gros Ventre, Wyoming, and Windriver units. The Kemmerer unit appeared to be slightly less resistant or resilient to water quality stressors as fewer stream reaches were classified as fully supportive in terms of biological condition. We were unable to assess the NRV status of water quality at GDEs on the Forest due to lack of data. While river basin assessments completed by the state of Wyoming suggest that groundwater quality is likely within the NRV, it was not possible to determine whether local stressors on the BTNF had led to insufficient water quality or an accumulation of chemicals that would negatively affect the productivity or composition of GDE biotic communities.

The most common stressors to water quality on the BTNF were roads, recreation, and livestock grazing, with some observed effects from soil contamination. There were weak negative correlations between the biological condition indicator and the densities of highways and light duty roads, meaning that streams in watersheds with more of these road types were less likely to fully support aquatic biota. While the WCC indicated that 84 percent of watersheds were in good condition in terms of road and trail density, 70 percent of watersheds were considered functional-at-risk or impaired in regards to meeting best management practices for road and trail maintenance. Only 23 percent of watersheds had no more than 10 percent of road and trail length within 300 feet of streams and waterbodies and 46 percent of watersheds were classified functional-at-risk or impaired in terms of mass wasting from these features. There was a weak negative correlation between the biological condition indicator and the number and density of recreation facilities located within floodplains, indicating that greater presence of recreation facilities within floodplains is associated with reduced water quality. Water quality problems including excessive sediment, nutrients, and chemicals showed weak positive correlations with larger deviations in summer temperatures and greater exceedance of soil critical loads. We did not observe any correlations between the WCC impaired waters and stressors.

The WCC did indicate soil contamination issues across the Forest, with both Kemmerer and Wyoming categorized as functional-at-risk. This attribute addresses various sources of contaminants such as mines, dumping, drug labs, spills, and atmospheric deposition (Potyondy and Geier 2011). While the TCA showed that critical loads, or the amount of acidic sulfur and nitrogen that can be buffered by soils, were not exceeded anywhere on the Forest (Cleland et al. 2017), long-term lake and bulk precipitation monitoring have shown increasing trends in nitrate, inorganic nitrogen, and ammonium (Grenon et al. 2010). These trends within lakes, such as Hobbs and Black Joe, are of concern as the average total nitrogen deposition for over 20 years has exceeded the critical load identified for high alpine lakes in the Rocky Mountains and Greater Yellowstone Ecosystem (Grenon et al. 2010).

Our results are supported by Statewide assessments of water quality, which indicate that the majority of streams in the mountainous region that contains the Forest are in the "least disturbed" condition and that water quality improved between 2004–2011 (Hargett and ZumBerge 2013). Statewide surveys document an increase from 66–81 percent of perennial mountain streams in the least-disturbed biological condition (Hargett and Zumberge 2013). Additionally, the Wyoming Department of Environmental Quality has conducted assessments in some of the watersheds on the Forest: Coantag Creek (WDEQ 2002), Dry Piney Creek (WDEQ 2003), Giraffe Creek (WDEQ 2002), Rock Creek (WDEQ 1998), and Salt Creek (Thomas Fork) (WDEQ 2005). These watersheds were selected for monitoring because inconclusive or anecdotal data indicated potential water quality issues. Alkalinity and dissolved oxygen exceeded established standards in some locations, but all other indicators of water quality including temperature, pH, conductivity, turbidity, total suspended solids, chlorides, sulfates, phosphorus loads, and nitrogen loads were within acceptable ranges.

Assessments, conducted between 2000–2003, summarize chemical stressors to water quality in Wyoming streams (Peterson et al. 2007). Streams located in the mountainous region, which includes the BTNF, tended to have larger percentages affected by phosphorous, but nitrogen loads and specific conductance were comparable to levels throughout the western United States (Peterson et al. 2007). The chronic value for chloride concentrations (230 mg/L) was not exceeded anywhere in the mountainous region and all pH values were within the acceptable range (Peterson et al. 2007). The type and level of stressors to water quality within the mountainous region have shifted over time. Prior to 2007, the largest stressors in order of percent of stream length impacted were riparian disturbance, channel instability, total suspended solids, total phosphorus, nitrogen, salinity, and sulfates. By 2011, the largest stressors in order of percent of stream length impacted were channel instability, riparian disturbance, total suspended solids, total phosphorus and salinity, nitrogen, and sulfates were extremely limited (Hargett and ZumBerge 2013). See appendix G for additional information on stressors and indicators within each geographic unit.

Channel and Floodplain Dynamics

Riparian areas include aquatic and terrestrial habitats dispersed across a geomorphological template that is formed by the movement of sediment and water within the channel, and between the channel and the floodplain (Junk et al. 1989; Stanford et al. 2005). The distribution of habitats across this template is driven by various patterns and processes operating across spatial and temporal scales including flooding, channel avulsion, cut and fill alluviation, recruitment of large wood, and regeneration of vegetation (Stanford et al. 2005). Streamflow in particular is a master variable that strongly influences channel and floodplain structure. High flows connect the stream to its floodplain, enabling the exchange of organic matter and energy (Junk et al. 1989; Poff et al. 1997). They also play an important role in the life cycle of many riparian vegetation species by dispersing seeds and scouring the channel, resulting in bare substrate needed for seedling

recruitment. Low flows allow for the establishment and growth of vegetation and successional rebuilding (Salo et al. 1986; Stanford et al. 2005; Thomaz et al. 2007). Complex floodplains with diverse and highly dynamic aquatic and terrestrial habitats are more productive (Junk et al. 1989; Thoms 2003), have higher biodiversity (Hauer et al. 2016; Ward et al. 1999), and are more resistant and resilient to disturbance (McCluney et al. 2014). Runout channels are "groundwater-fed streams that emerge from springs or within groundwater-fed wetlands" (USDA FS 2012a). Spring runout channels can be distinguished from those dominated by runoff by their flow regimes and sediment inputs (Griffiths et al. 2008). It is important to assess the condition of these unique downstream reaches of springs or wetlands because they can support unusual aquatic and wetland biota and these features are especially vulnerable to spring development.

Drivers

Major drivers of channel and floodplain dynamics include the underlying geology, topography, and characteristics of the surrounding terrain. Much of the forest is composed of steep mountains in various geologic settings (Chapman et al. 2004). High gradients and some presence of bedrock substrates in the mid elevation sedimentary mountains, sedimentary subalpine zone, alpine zone, granitic subalpine zone, and Absaroka Volcanic subalpine zone limit floodplain development and channel dynamics (Chapman et al. 2004). Volcanic settings, such as the Absaroka-Gallatin Volcanic Mountains and the Absaroka Volcanic subalpine zone, support heavy sediment loads, particularly after storm events and during snowmelt (Chapman et al. 2004). The high elevation valleys and subirrigated high valleys only make up a small proportion of the Forest, but they contain large floodplains and channels with diverse aquatic habitats (Chapman et al. 2004).

Large woody debris within channels creates complex floodplains by altering water velocity, creating locations of scour and deposition, stabilizing streambanks, and creating pool habitats (Gurnell et al. 2002). The frequency and volume of wood within channels is influenced by the vegetative communities of the surrounding terrain. Drainages on the BTNF tend to have mixed land cover, with forest generally present on northern and eastern slopes and high elevations and patches of sagebrush and grassland occurring on southern and western facing aspects (Bragg et al. 2000). Stream gradient, size, and condition of forests near the channel account for variability in the frequency and volume of large woody debris, as well as stream substrate and channel shape (Al-Chokhachy et al. 2010; Bragg et al. 2000).

In addition to geology and terrain, flooding is a driver of channel and floodplain dynamics on the BTNF. The timing, frequency, duration, and magnitude of flood pulses influence the extent and condition of riparian zones associated with aquatic habitats (Poff et al. 1997). Most of the hydrographs on the Forest are dominated by a strong snowmelt signature in early summer. Approximately 57 percent of streams on the BTNF are intermittent or ephemeral, limiting the development of their associated floodplains.

A final driver of channel and floodplain dynamics is beaver activity. Beavers modify stream morphology by cutting wood and building dams that effectively trap sediment, create and maintain wetlands, alter the structure and dynamics of the riparian zone, and lead to the formation of wide, low-gradient alluvial plains as the associated ponds fill with sediment (Gurnell et al. 1998; Naiman et al. 1988). These meadows contribute to a step pattern along the stream's longitudinal profile. Additionally, beaver dams slow water velocity and create variable substrates throughout the channel. Structures built by beavers increase the heterogeneity of channel widths and depths and the diversity of morphological features. Overall, beaver dams encourage stable channels with more complex floodplains (Gurnell et al. 1988; Pringle et al. 1988). Because of the stabilizing effects of beaver activity, it is common to deliberately introduce beaver during restoration efforts (Gurnell et al. 1988) to aggrade entrenched channels, raise water tables, and expand riparian habitat (Pollock et al. 2007).

The primary drivers of spring runout channel dynamics are flow regimes and sediment inputs (Griffiths et al. 2008; Whiting and Stamm 1995). The hydrographs of spring-dominated channels tend to be less variable than runoff channels (Whiting and Moog 2001). Sediments in spring channels tend to be variable in size with cobbles and boulders generally only present at the head of springs. Typically, springflow-dominated channels lack fine sediments or algae, indicating that sediments are regularly flushed from the system (Whiting and Moog 2001; Whiting and Stamm 1995). The muted hydrograph and limited sediment inputs that are characteristic of springs lead to channels with steep banks and dense vegetative cover, armored beds, greater sinuosity, weakly developed bars and lower width-to-depth ratios (Griffiths et al. 2008; Whiting and Moog 2001; Whiting and Stamm 1995).

Stressors

Floodplain characteristics such as channel dimensions, gradient, substrate size and type, and riparian vegetative cover are influenced by natural and anthropogenic stressors. The stability of channels and their substrates can be altered by streambank armoring, removal of riparian vegetation, agriculture, road building, logging, and grazing (table 8; Peterson et al. 2007). These types of activities can also disturb the structure of riparian areas, in turn influencing the system's capacity to reduce erosion, capture surface flow, and filter sediments, nutrients, and other contaminants (Peterson et al. 2007).

Livestock grazing can have numerous impacts on floodplain condition, including trampling banks, over-widening streams, decreasing stabilizing vegetation, and increasing unnatural sediment from trailing (George et al. 2002; Thibault et al. 1999). With European settlement of the West came overgrazing and the removal of vegetation from landscapes (Rapport and Whitford 1999). As protective vegetation was destroyed, runoff became more sporadic and large amounts of sediment were introduced to channels (Armour et al. 1991; Packer 1953). Systems became out of balance between the supplies of water, and sediment and streams were not able to clear depositional material (Armour et al. 1991). Larger peak flows that resulted

from the loss of vegetation caused channels to become incised and the water table to be lowered. Riparian plants were left in drier soils and ultimately replaced by upland species, leading to an overall reduction in the size of the floodplain (Belsky et al. 1999).

Stressors such as road construction, recreation, mining, and wildfire can impact channel and floodplain dynamics by altering sediment inputs or disrupting the connection between the channel and its floodplain (Bellmore et al. 2012; Benda et al. 2003; Forman and Alexander 1998; Jones et al. 2000; Trombulak and Frissell 2000). In addition to providing an unnatural source of fine sediment, roads disrupt floodplain development by confining or crossing the stream. Roads that parallel streams often limit movement of the channel and road crossings cause streams to become wider and shallower with flattened banks (Forman and Alexander 1998; Jones et al. 2000; Trombulak and Frissell 2000). Trails and campgrounds can have similar effects by increasing sediment inputs and causing trampling of stream banks. Artificial banks built to protect roads and recreation structures disconnect the stream from its floodplain and simplify the structure of the system (Forman and Alexander 1998; Jones et al. 2000; Trombulak and Frissell 2000). Similarly, mining can have negative impacts on channel and floodplain dynamics by reducing streams to single channels, which limits channel migration and cut and fill alluviation (Bellmore et al. 2012). High-severity wildfires can increase sediment inputs to streams and remove riparian vegetation, further altering channel and floodplain dynamics (Benda et al. 2003).

Activities that alter the natural flow regimes, and therefore the distribution of floodplain habitats, include timber harvest, diversions, invasive species, and altered temperature and precipitation regimes. Depending on how timber harvest is managed, it may affect floodplain structure (Bosch and Hewlett 1982). Clear cuts can increase sedimentation and alter the timing and magnitude of surface runoff. The frequency of landslides usually increases following harvest, in turn leading to more debris flows that can alter channel morphology and the amount of in-stream wood (Benda et al. 2005). Dams and diversions decrease the magnitude of floods that reshape the geomorphological template, connect a stream to its floodplain, and transport sediment downstream (Winter et al. 1998). Dams can starve systems of sediment, resulting in channel incision and coarser substrate (Kondolf 1997). Furthermore, regulated reaches have 79 percent less active floodplain area and 3.6 times more inactive floodplain area that comparable unregulated reaches (Graf 2006). Regulation reduces floodplain complexity by 37 percent and interior Western rivers are most susceptible to these changes (Graf 2006). Certain types of invasive species withdraw more groundwater than native riparian vegetation, causing the water table to lower and conditions to become drier (Di Tomaso 1998; Ehrenfeld 2003). These invasions can initiate a positive feedback loop in which drier conditions facilitate more invasive species and an even lower water table, eventually leading to an incised channel with no connection to its floodplain and a loss of riparian cover (Macfarlane et al. 2017). Lastly, warmer and drier conditions can alter flow regimes and reduce inundation that drives floodplain dynamics (Dukes and Mooney 2004; Stromberg et al. 2007).

Stressors to the condition of spring runout channels include forces or activities that alter spring flow regimes, sediment inputs, or channel structure (USDA FS 2012a). Diversions, regulation, and spring development can alter the amount of flow in the channel as well as the timing or magnitude of pulses (Kendy and Bredehoeft 2006; Sophocleous 2002). Road construction, recreation, and livestock grazing can increase the sediment load and overwhelm the system with sediment that cannot be cleared. These activities can also lead to trampled channel banks and shallower channels. Runout channels affected by trampling, erosion, entrenchment, ditching, or redirection of flow can lead to extreme degradation or the complete elimination of a runout channel.

Indicators

We used seven indicators of channel and floodplain dynamics to determine the NRV status for each geographic unit: presence and recruitment of large woody debris, channel shape and function, percentage of functional riparian areas, percentage of streambanks impacted by erosion, aquatic habitat complexity, floodplain acres per stream mile, and percentage of floodplains burned by low and moderate severity fire between 1984–2014 (table 11).

The presence and recruitment of large woody debris was determined using the average WCC score for each geographic unit. This indicator was considered to be functioning properly with little or no alteration if large woody debris was present and continuing to be recruited at natural rates in systems that evolved with wood near the stream; it was considered in fair condition with moderate alteration if woody debris was present, but not recruited at a natural rate because of management activities; it was considered in poor condition with substantial alteration if systems with expected debris lacked wood with the result being poor riparian and aquatic habitat conditions including unstable streambanks and inadequate pools.

Channel shape and function was also determined using the average WCC score for each geographic unit. To be considered in good condition with little or no alteration, width-to-depth ratios were in a range expected in the absence of human influence, less than 5 percent of the channel showed signs of widening, and channels were vertically stable. This indicator was

Table 11—Level of indicators for channel and floodplain dynamics within each geographic unit.

Unit	Large woody debris	Channel shape & function	% Reaches—functional riparian	% Reaches—10% bank erosion	Habitat complexity	Floodplain acre/stream mile	% Floodplain burned—moderate severity
Gros Ventre	1	1.2	95	60	0.64	29.5	1.2
Wyoming	1.6	1.4	84	54	0.61	22.1	2.4
Windriver	1.1	1.1	95	79	0.64	26.4	2.2
Kemmerer	1.5	1.4	91	68	0.64	19.7	1.7

considered in fair condition with moderate alteration if width-to-depth ratios and vertical stability were maintained in all locations not affected by disturbance, between 5–25 percent of the channel had increases in with-to-depth ratios, and degradation was limited to small sections with some channels no longer connected to their floodplains. Channel shape and function was in poor condition with substantial alteration if more than 25 percent of channels had greater width-to-depth ratios than expected under natural conditions, extensive gullied reaches exist and were increasing, and more than 50 percent of channels are disconnected from the floodplain or are braided due to sediment loads.

We used WHAM data to determine percent of functional riparian areas, streambank erosion, and aquatic habitat complexity. We calculated the percent of WHAM sites within each geographic unit that recorded a functional riparian area that had a high water table and the ability to trap sediment. Similarly, we calculated the percent of WHAM sites that had less than 10 percent of streambank erosion on both right and left banks. We determined aquatic habitat complexity by incorporating the percentage of each reach classified as pool, riffle, and run into Simpson's Dominance and calculating the mean for each geographic unit. We compared all three values to those calculated for WHAM reference reaches on the Forest to determine the level of alteration for each unit.

We calculated floodplain acres per stream mile using the 50-year floodplain map (Abood et al. 2012) and the NHD flowline. We used wilderness areas on the BTNF to determine reference conditions for this ratio. We used Monitoring Trends in Burn Severity (MTBS) data and the 50-year floodplain map to determine the percentage of floodplains impacted by moderate fire severity and compared the value for each unit to reference conditions from wilderness areas on the Forest.

Channel and Floodplain Dynamics on the Bridger-Teton National Forest

Channel and floodplain dynamics overall have been resistant and resilient to multiple, interacting stressors. Based on indicators, 100 percent of the BTNF was within the NRV for channel and floodplain dynamics. Within the Windriver unit, all seven indicators were comparable to reference conditions. Indicators in the Gros Ventre unit showed little or no evidence of alteration except for bank erosion, which was moderately altered compared to WHAM reference reaches. In the Kemmerer unit, bank erosion and floodplain acres per stream mile were moderately altered from reference conditions. In the Wyoming unit, riparian function and bank erosion were moderately altered from reference conditions.

The most common stressors to channel and floodplain dynamics on the BTNF were grazing, recreation sites within floodplains, and altered temperature and precipitation regimes. Secondary stressors that were present, but had impacted smaller percentages of the landscape, included

high-severity wildfire, timber harvests, roads, trails, invasive species within floodplains, and diversions. We observed weak positive correlations between encroachment of conifers and upland species and the percentage of watershed located within active range management units, road density, and trail density. There were weak associations between degradation of aquatic habitat indicator that addresses habitat fragmentation, large woody debris, and channel shape and function and the percent of roads classified as unimproved, percent of watershed within active range management unit, watershed road density, percent of floodplain converted to agriculture, road density within the 50-year floodplain, and deviations in spring, summer, winter, and fall precipitation. Larger percentages of channels in poor condition with regard to shape and function were weakly correlated with road density within the floodplain, miles of unimproved roads, and increased timber harvest. Riparian zones were generally more functional in watersheds with a high percentage of land within the 50-year floodplain, high stream density, and high habitat complexity. Bank erosion was more common in watersheds with greater cover of exotic and invasive species in the floodplain, greater proximity of roads and trails to water, and increased conifer and upland encroachment.

The Wyoming Game and Fish Department has used the WHAM to evaluate watershed conditions including function and management concerns. These reports have been completed for some watersheds on the BTNF including the Little Greys River (Sweeney 2003) and the LaBarge (Roadifer and Sexauer 2008). The reports identified negative impacts to channels and floodplains from roads, fire suppression, grazing, and recreation. Both reports documented unnatural sediment loads attributed to roads and identified locations where a road had confined or separated a river from the historic floodplain. A century of successful fire suppression has resulted in reduced habitat and vegetation age class diversity in streams and their associated riparian areas (Roadifer and Sexauer 2008; Sweeney 2003). Grazing was identified as a primary stressor in both watersheds, with evidence of historic and current degradation including trampling of vegetation and streambanks and lowered water tables. Finally, the assessments documented impacts from various recreation activities including campsites within floodplains, hiking, mountain biking, ATV use, and horseback riding. These activities are linked with excessive erosion, littering, trampling of vegetation and streambanks, and disconnection of streams from floodplains (Roadifer and Sexauer 2008; Sweeney 2003). See appendix H for additional information on stressors and indicators within each geographic unit.

We were unable to evaluate the dynamics of spring runout channels on the Forest due to insufficient information. GDE monitoring with PFC reports or Level I and II inventory could categorize if runout channels across the Forest are functioning naturally and whether they were entrenched, eroded, or otherwise substantially altered.

Composition and Structure of Riparian Vegetation

Riparian vegetation is fundamentally coupled to the hydrology, geomorphology, and habitat quality of valley bottoms. As described above, the composition and the structure (both vertical and horizontal) of riparian vegetation are influenced by surface flows, groundwater, and floodplain features. In turn, riparian vegetation influences water quality, surface water and groundwater fluctuations, and valley bottom dynamics (Griffin et al. 2014; Pollock et al. 2009; Winward 2000). Cottonwoods, boxelders, and other tall deciduous trees provide nest sites and seasonal foraging opportunities for wildlife, including dozens of bird species (Smith and Finch 2014). By maintaining a connection with groundwater, deep-rooted trees and shrubs transport this resource to aboveground communities throughout a floodplain (Smith and Finch 2017). Sedges, rushes, and grasses provide cover and forage for amphibians, reptiles, waterbirds, and small mammals (Frey and Malaney 2009; Medin and Clary 1990, 1991). Evaluation of composition and structure of vegetation is therefore critical to assessing the condition of riparian ecosystems.

A complete description of the composition and structure of riparian vegetation is not feasible at the scale of this assessment because of the dynamic nature of these ecosystems and inconsistent field data for much of the Forest. We therefore focus on indicators derived from spatial data and field studies.

Drivers and Stressors

The drivers and stressors of this KEC have been previously described for surface water and groundwater fluctuations and channel and floodplain dynamics. Natural drivers are climate, glacial presence, beaver activity, geology, topography, large woody debris, and characteristics of the surrounding terrain. Stressors are wildfire, fire suppression, vegetation mortality due to insects and disease, drought, diversions, roads and trails, timber harvest, livestock grazing, altered temperature and precipitation regimes, streambank armoring, removal of riparian vegetation, agriculture, recreation, mining, and invasive species.

Indicators

We combined data from several sources to describe the composition and structure of riparian ecosystems. To identify likely riparian plant communities in the BTNF, we compiled a list of community types sampled in Western Wyoming (Youngblood et al. 1985), the Uinta and Wasatch Mountains (Padgett et al. 1989), and the Shoshone National Forest (Walford et al. 2001), as well riparian habitat types in Southern Montana (Hansen et al. 1995). When selecting community types from classifications outside of the BTNF, we only used types described at elevations at or above the 5,600 feet, the minimum elevation of the Forest. For the purposes of this report, we refer to all classifications as community types. We organized community types into dominance groups based on their dominant overstory species. To approximate the area and location of these dominance groups in the BTNF, we clipped a shapefile of existing vegetation (BTNF 2007) to the 50-year floodplain map developed by Abood et al. (2012). We also included existing

vegetation classified as riparian that was outside of the 50-year floodplain. Finally, we obtained photos of streams and riparian ecosystems to verify the presence of community types where possible. Our compilation of dominance groups and community types can be used by managers to predict composition and structure of riparian vegetation based on elevation, geomorphic features, and soil types.

We used conifer encroachment and upland vegetation encroachment, developed from LANDFIRE, as indicators of changes in composition and structure of riparian vegetation for each geographic unit (appendix I). We also summarized field data from the WHAM program for each unit (table 12). We calculated the percentage of stream segments (WHAM sites) that showed signs of riparian recruitment, showed signs of upland invasion, had adequate food to support beavers, and had adequate building material for beaver dams. To complement the field data, we examined qualitative descriptions in reports from surveys that used Multiple Indicator Monitoring, Properly Functioning Condition, and WHAM methodologies.

Composition and Structure of Riparian Vegetation on the Bridger-Teton National Forest

We identified 117 riparian community types that are associated with streams and likely present in the BTNF. The number of community types within dominance groups varies from 10–30 (see appendix B). According to the existing vegetation map, the most widespread group is conifer-dominated, followed by willow-dominated, nonwillow shrub-dominated, herbaceous-dominated, and deciduous tree-dominated (table 13). Maps of riparian dominance groups are included in appendix I.

Table 12—Indicator values for riparian composition within each geographic unit on the BTNF.

Unit	% Conifer encroachment	% Upland encroachment	% Reaches—riparian recruitment	% Reaches—upland invasion (WHAM)
Gros Ventre	4.9	7.1	63.4	35.0
Wyoming	7.0	9.2	62.7	48.5
Windriver	2.5	3.7	77.1	27.8
Kemmerer	7.6	11.1	63.7	48.2

Table 13—Percent cover of riparian area in each geographic unit by riparian dominance groups as determined using maps of existing vegetation and the 50-year floodplain.

Unit	% Conifer	% Deciduous tree	% Willow	% Nonwillow shrub	% Herbaceous
Gros Ventre	38.5	1.9	29.2	14.1	13.8
Wyoming	37.7	3.0	27.2	17.7	12.6
Windriver	36.9	4.6	21.7	4.7	28.8
Kemmerer	25.1	11.0	32.4	22.8	8.5
BTNF	37.1	3.1	28.0	14.5	15.0

Using indicators derived from spatial data and field data, we determined that riparian composition was within the NRV in all four geographic units, but the riparian recruitment indicator provided evidence of moderate alteration in the Gros Ventre, Wyoming, and Kemmerer units. Changes in composition within some riparian reaches include conifer and upland encroachment, which may be caused by fire suppression or hydrological changes such as reduction in beaver activity. Reduction in willow and aspen recruitment was noted at several locations, particularly sites that were heavily grazed or located near winter feedgrounds for elk (BTNF 2017; Gruell 1980). There were weak positive correlations between upland encroachment and floodplain road miles, grazed acres, and actively grazed acres. We also observed weak positive correlations between conifer encroachment and floodplain road density, watershed trail miles, floodplain trail miles, and timber harvest acres. Livestock grazing is most widespread at the Kemmerer and Wyoming units. Spatial data show little evidence of conversion to invasives but field reports indicate that herbaceous species including bull thistle and Canada thistle have invaded riparian areas in several parts of the Forest (appendix I). Potential avenues of invasion include roads, recreation sites, and livestock grazing.

Composition of Groundwater-Dependent Ecosystems

The current composition of plants, animals, and other biota must be evaluated to inform management decisions affecting GDEs (Kreamer et al. 2015). An understanding of the composition of aquatic and riparian communities in reference to natural conditions is needed to determine where there is a need for change. GDEs in the BTNF include aquifers, karst systems, fens, and springs. Given the limited information on biotic communities associated with aquifers and karst, we limit our analysis of composition to fens and springs.

Drivers

Water availability and geomorphic setting are the primary bottom-up drivers of GDE composition (Cooper and Merritt 2012; Magee and Kentula 2005; Stevens and Meretsky 2008). Climate and geology interact to shape volume and chemistry of groundwater, which is a determinant of plant and animal community composition of springs and fens (Chimner et al. 2010; Lemly and Cooper 2011). In fens of the Mountain West, composition and structure of vegetation is largely influenced by physical and chemical characteristics (Chimner et al. 2010; Lemly and Cooper 2011; Wolf and Cooper 2015). Peatland plant communities vary among geomorphic settings such as sloping fens, patterned fens, and floating mat fens. This variation is driven by gradients in water table depth and duration of surface inundation (Cooper and Andrus 1994). Fens are typically dominated by herbaceous vegetation, particularly sedges and mosses, but shrubs and trees are present is some situations (Hansen et al. 1995; Lemly and Cooper 2011). Rich fens, fed by high pH water from carbonate bedrock, have high species richness whereas poor fens, with low pH from iron-rich bedrock, have low species richness but support plant species typically found in other regions (Chimner et al. 2010; Chimner 2011).

Stressors

Springs are among the ecosystems most threatened by anthropogenic activities in the Western United States. (Stevens and Meretsky 2008). Spring developments for irrigation and livestock include installation of headboxes, diversion of flows to troughs and other structures, and construction of ponds within GDEs. These activities can have adverse effects on plants and animals at GDEs, but in some situations, spring-dependent species persist in developed springs (Unmack and Minckley 2008).

Wildlife and livestock directly affect spring ecosystems through grazing and browsing of vegetation. Grazing and browsing can also cause soil compaction, hummocking, headcutting, and other disturbance. Effects of recreation include vegetation trampling, soil compaction, and alteration of the natural runout channels for soaking pools. Natural stressors to spring ecosystems include wildfire, which directly impacts plant and animal communities, drought cycles, and geological events, such as earthquakes (Wood et al. 1985). As a result of fire suppression, competition for groundwater by encroaching conifers and sagebrush reduce extent of willows and wetland vegetation at springs (Gruell 1980).

In fens and other wetlands, disturbance to soils by ditching, trailing, and stream incision can cause drying, resulting in oxidation and degradation of peat (Chimner and Cooper 2003). As in riparian ecosystems, wetland vegetation and soil are vulnerable to grazing, browsing, and trampling.

Indicators

We compiled GDE community types identified by riparian specialists (Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985,) as being associated with springs and fens in and near the BTNF. We added community types identified by Cooper and Andrus (1994) in fens of the Wind River Range. Recent information regarding composition of GDEs was unavailable for much of the Forest, so we did not evaluate the NRV status of this KEC.

Composition of Groundwater-Dependent Ecosystems on the Bridger-Teton National Forest

We identified 53 riparian community types that likely occur at springs and 26 types that likely occur at fens in the BTNF (see appendix C). Surveys are needed to describe composition of fens that likely occur in the other geographic units. In addition, plant and animal communities remain undescribed at springs located throughout the Forest.

Summary

Overall Patterns and Trends

As a result of its geographic and geological setting, the BTNF has an abundance of perennial streams and riparian ecosystems. Given their importance to migratory wildlife and riparian-obligate species, the integrity of these ecosystems is an important measure of the health of the Greater Yellowstone Ecosystem. We determined that, despite the presence of anthropogenic stressors, nearly all KECs are operating within their NRV throughout the Forest. This result is not unexpected, as much of the Forest is protected as wilderness, with hundreds of miles of wild and scenic streams.

Our mapping of riparian vegetation revealed that over 50 percent of riparian cover is dominated by conifers or willows. This result indicates that habitat for moose, elk, and numerous bird species is abundant on the Forest. Herbaceous-dominated types, critical for amphibians, marshbirds, and other taxa, are created and maintained by beaver dams in each geographic unit. Deciduous tree-dominated community types are rare in the Forest relative to other types. Aspen and cottonwood trees are critical habitat components for a variety of wildlife. Maintenance of deciduous tree-dominated vegetation is therefore a high priority in forest management.

In assessing KECs, we determined that the primary stressors of riparian ecosystems are: (1) roads and related infrastructure, (2) livestock grazing, (3) long-term vegetation change, and (4) climate change. Below we describe Forest-wide patterns for each stressor.

Effects of roads, trails, and other recreation infrastructure is a primary stressor to riparian and aquatic ecosystems in the BTNF. In addition to well-documented effects of roads on stream and vegetation dynamics, roads may decrease reproductive success for riparian-nesting birds by increasing rates of cowbird parasitism, corvid predation, noise disturbance, and habitat loss (DeLong and Egan 2017). Roads influence riparian ecosystems in each geographic unit, but road density and road effects are greatest in the watersheds of the Wyoming and Kemmerer Units (appendix J).

Portions of the BTNF have a long history of livestock grazing, but we found that current levels have not moved stream, channel, and floodplain dynamics outside of their NRVs. Grazing has its greatest influence in the Wyoming and Kemmerer units, where it is most widespread. In reviewing results of riparian surveys, we found that severity of grazing effects on soil and vegetation vary widely both within and among geographic units. Further research is needed to better understand resistance and resilience to this stressor and whether it is influenced by beaver activity, vegetation composition, geological settings, or other factors.

Several factors have been linked to long-term changes in forest vegetation, which have considerable implications for riparian ecosystems. Invasive plant species, most of which are herbaceous, are present throughout the Forest, with hotspots in each geographic unit (appendix J). Wildfire influences plant communities in many settings of the BTNF, including valley bottoms (Gruell 1980). Successful fire suppression in the 20th century has likely contributed to replacement of aspen, cottonwood, and willow by conifers and other upland vegetation types. Loss of available aspen stands results in reduction in density and durability of beaver dams, which influence the geomorphology of valley bottoms, the composition of riparian plant communities, and the availability of wildlife habitat. Pressure by wild ungulates has increased in some areas during the last century as a result of their proximity to winter feedgrounds for elk combined with moose herbivory. Browsing reduces the height and extent of willows, which impacts terrestrial and aquatic wildlife habitat. Browsing of willows, cottonwoods, and aspens further limits resources available for beaver. Controlled burns or managed wildfire may be necessary to restore aspen stands, which could bolster beaver activity in nearby streams.

Climate change is emerging as a stressor to both riparian and groundwater-dependent ecosystems. Changes in winter air temperature have been noted throughout the Forest, with the greatest increases in the Gros Ventre and Kemmerer units (appendix J). Changes in amount and timing of precipitation have been projected and observed as well. Projected increases in summer temperature will impact amount and timing of surface flows and glacial retreat. These changes have direct effects on surface flows and groundwater recharge, which will in turn affect vegetation and wildlife. With its high elevations and abundant aquatic resources, the BTNF will likely serve as refugia for numerous organisms in a warming climate. Maintenance of functions such as groundwater discharge and stream shading by riparian vegetation will be critical to regional conservation in this scenario.

Management Issues/ Data Gaps

GDEs

Existing information on the distribution, composition, and condition of GDEs was lacking across the Forest. We used NWI and NHD databases to locate springs and groundwater-dependent wetlands, but both underestimate the true number on the Forest. Our GDE map is incomplete but is an initial indicator of the distribution and relative density of GDE resources. We found no assessments of any GDEs on the BTNF. There is a need for GDE inventories and more thorough biological assessments of spring and GDE wetland resources. Monitoring is needed to identify stressors and determine the condition of distribution, water fluctuations, water quality, and run out channels at GDEs across the BTNF. Level II spring surveys incorporating inventories of flora and fauna should be conducted in managed and reference portions of the Forest to develop a better understanding of anthropogenic effects on GDEs. The NHD spring layer and the Colorado Natural Heritage Program fen database serve as frameworks to conduct on-the-ground surveys and assessments. The glaciers of the Wind River Range create conditions

unique among the forests in the Intermountain Region. Studies of distribution and composition of any GDEs associated with these glaciers will provide important baseline data for climate change assessments.

The Spring Stewardship Institute (SSI) database includes documented GDE locations and information from the scientific literature and unpublished reports by governmental agencies and nongovernmental organizations. It is currently difficult to access data for the BTNF in the SSI database. We recommend incorporating existing datasets and future data collected by the Forest into the SSI database to preserve valuable field data and make information available to wider audiences.

Beavers

Beaver activity is a driver of many of the KECs assessed in this report including water quality, water fluctuations, and channel and floodplain dynamics. Current levels of beaver activity are partially documented by WHAM data, which captures percentages of reaches impacted by beaver activity, but there does not appear to be any monitoring of beaver populations on the Forest (Don DeLong, U.S. Forest Service, Jackson, WY, personal communication, May 10, 2018). Robust beaver populations would increase the resistance and resilience of freshwater systems to the effects of climate change and potential drought. More information is needed to determine if the current population is comparable in size and distribution to historic levels and locations.

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Appendix A. Data Used to Assess Riparian Ecosystems and GDEs

Table A1—A list of the data used to assess riparian and groundwater-dependent ecosystems of the Bridger-Teton National Forest.

Variable	Source(s)	Explanation
50-year floodplain acres	U.S. Forest Service	Floodplain area generated with data representing 50-year flood heights, valley bottom widths, riparian soils, and wetland coverage
CT stream miles	National Hydrography Dataset, U.S. Geological Survey	Total length of perennial streams within the historical distribution of cutthroat trout
Stream miles—capable breeding habitat	Bridger-Teton National Forest	Total length of streams determined to be capable breeding habitat for boreal toads and Columbia spotted frogs
Acres—capable breeding habitat	Bridger-Teton National Forest	Total area determined to be capable breeding habitat for boreal toads and Columbia spotted frogs
Acres—PACs	Bridger-Teton National Forest	Area of designated greater sage-grouse priority areas for conservation within each unit
Acres—summer brood habitat	Bridger-Teton National Forest	Area of habitat used by greater sage-grouse hens and their broods
Acres riparian foraging habitat	Bridger-Teton National Forest, U.S. Forest Service 50-year floodplain map	Area of riparian habitat used by greater sage-grouse hens and their broods
Perennial stream miles	National Hydrography Dataset	Total length of stream segments with year-round surface flows
Intermittent stream miles	National Hydrography Dataset	Total length of stream segments with seasonal surface flows and accessible groundwater
Potential riparian	U.S. Forest Service 50-year floodplain map, BTNF existing vegetation map	Potential riparian estimated by combining 50-year floodplain map and map of vegetation classified as riparian by BTNF
Acres of riparian vegetation	BTNF existing vegetation map	Area of vegetation classified as riparian by BTNF
BTNF springs	Bridger-Teton National Forest	Number of springs per acre, as mapped by the BTNF
NHD springs (# per acre)	National Hydrography Dataset	Number of springs per acre, as mapped by the NHD
Acres of potential karst (% of unit)	U.S. Geological Survey	Amount of area with carbonate bedrock with the potential for karst formation

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Table A1 (continued)—A list of the data used to assess riparian and groundwater-dependent ecosystems of the Bridger-Teton National Forest.

Variable	Source(s)	Explanation
Acres principal aquifers (% of Unit)	U.S. Geological Survey	Amount of area with principle bedrock aquifers
Likely fen acres	Colorado Natural History Program	Amount of area covered by wetlands that are determined to be likely fens, based on aerial photo interpretation
Possible fen acres	Colorado Natural History Program	Amount of area covered by wetlands that are determined to be possible fens, based on aerial photo interpretation
Low confidence fen acres	Colorado Natural History Program	Amount of area covered by wetlands that are determined to be low confidence fens, based on aerial photo interpretation
% High severity burn	U.S. Forest Service Terrestrial Condition Assessment	Percentage of the area burned by high severity wildfires between 1984 and 2014
% Moderate severity burn	U.S. Forest Service Terrestrial Condition Assessment	Percentage of the area burned by high severity wildfires between 1984 and 2014
% Floodplain high/very high wildfire hazard potential	U.S. Forest Service Terrestrial Condition Assessment	Percentage of 50-year floodplain with high or very high wildfire hazard potential
% Floodplain mod/high severity burn	U.S. Forest Service Terrestrial Condition Assessment	Percentage of 50-year floodplain experiencing moderate to high severity wildfire between 1984 and 2014
% Insects & disease	U.S. Forest Service Terrestrial Condition Assessment	Percentage of geographic unit with tree mortality resulting from insect and disease outbreaks
Diversion density	Wyoming Water Development Office	Number of water diversion points per acre
Road density	U.S. Forest Service Terrestrial Condition Assessment	Road miles per acre of geographic unit
Floodplain road density	U.S. Forest Service Terrestrial Condition Assessment, U.S. Forest Service 50-year floodplain map	Road miles per 50-year floodplain acre
Trail density	U.S. Forest Service National Dataset	Recreation trail miles per acre
Floodplain trail density	U.S. Forest Service National Dataset, U.S. Forest Service 50-year floodplain map	Trail miles per 50-year floodplain acre
Floodplain recreation sites	U.S. Forest Service National Dataset, U.S. Forest Service 50-year floodplain map	Number of recreation sites per 50-year floodplain acre
% Harvested	U.S. Forest Service National Dataset	Percentage of the area with timber harvest
% Harvests clearcut	U.S. Forest Service National Dataset	Percentage of the area with timber harvest using clearcut methods
% Unit RMU	U.S. Forest Service National Dataset	Percentage of the area overlapping range management units (grazing leases)

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Table A1 (continued)—A list of the data used to assess riparian and groundwater-dependent ecosystems of the Bridger-Teton National Forest.

Variable	Source(s)	Explanation
% Unit RMU active	U.S. Forest Service National Dataset	Percentage of the area overlapping actively grazed range management units
Nitrogen deposition	U.S. Forest Service Terrestrial Condition Assessment	Average amount of nitrogen deposition (kg/ha/yr)
% Floodplain conv. to agriculture	Riparian Condition Assessment Toolbox	Mean percentage of valley bottoms converted from riparian vegetation to agriculture
% Floodplain conv. to developed	Riparian Condition Assessment Toolbox	Mean percentage of valley bottoms converted from riparian vegetation to developed land
Wildlife feed grounds	U.S. Forest Service National Dataset	Number of wildlife (primarily elk) feedgrounds in the unit
Mass wast.	U.S. Forest Service Watershed Condition Classification	Total area affected by mass wasting
Road & trail maint.	U.S. Forest Service Watershed Condition Classification	Indicator of road and trail maintenance
Prox. to water	U.S. Forest Service Watershed Condition Classification	Indicator of the proximity to water of roads and trail features
% soil cont.	U.S. Forest Service Watershed Condition Classification	Percentage of the geographic unit affected by soil contamination
Conversion to conifer	Riparian Condition Assessment Toolbox	Mean proportion of confiner encroachment occurring along stream reaches
Conversion to grass/shrub	Riparian Condition Assessment Toolbox	Mean proportion of upland vegetation encroachment occurring along stream reaches
Water quantity score	U.S. Forest Service Watershed Condition Classification	Indicator of change in magnitude, duration and timing in relation to natural hydrograph
Winter temperature deviation	U.S. Forest Service Terrestrial Condition Assessment	Change in winter temperature (°F)
Winter precipitation deviation	U.S. Forest Service Terrestrial Condition Assessment	Percent change in winter precipitation
WCC impaired waters	U.S. Forest Service watershed Condition Classification	Percentage of water bodies listed as impaired by the state
WCC water quality problems	U.S. Forest Service watershed Condition Classification	Indicator water quality issues above natural or background levels
% Streams-full support	Wyoming River Invertebrate Prediction and Classification System	Indicator that streams are comparable to reference conditions in terms of water quality
WCC large woody debris	U.S. Forest Service Watershed Condition Classification	Indicator of the presence and recruitment of large woody debris
Channel shape and function	U.S. Forest Service Watershed Condition Classification	Indicator that width-depth ratio is within expected range

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Table A1 (continued)—A list of the data used to assess riparian and groundwater-dependent ecosystems of the Bridger-Teton National Forest.

Variable	Source(s)	Explanation
% Reaches—functional riparian	Wyoming Habitat Assessment Methodology	Percentage of sites with a functional riparian area that had a high water table and the ability to trap sediment
% Reaches—10% bank erosion	Wyoming Habitat Assessment Methodology	Percentage of sites with less than 10% of streambank erosion on both right and left banks
Habitat complexity	Wyoming Habitat Assessment Methodology	Mean Simpson's Dominance score, incorporating percentages of each reach classified as pool, riffle, and run
Floodplain acre/stream mile	Wyoming Habitat Assessment Methodology	Ratio of 50-year floodplain map area and stream length
% Reaches—riparian recruitment	Wyoming Habitat Assessment Methodology	Percentage of stream reaches with observed recruitment of riparian vegetation
% Reaches—upland invasion	Wyoming Habitat Assessment Methodology	Percentage of stream reaches with observed invasion of upland plant species

Appendix B. Riparian Dominance Groups and Community Types That Are Expected to Occur in the Bridger-Teton National Forest

Table B1—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
Conifer	Conifer/*Aconitum columbianum*	6,000–10,500	Terraces and streambanks / moist to wet soils with organic matter in upper horizons	*Abies lasiocarpa, Picea engelmannii, Pinus contorta, Pseudotsuga menziesii, Populus tremuloides, Senecio triangularis, Mertensia ciliata, Delphinium occidentale, Saxifraga odontoloma, Cardamine cordifolia, Streptopus amplexifolius, Pyrola* spp.*, Osmorhiza* spp.	Padgett et al. 1989
	Conifer/*Actaea rubra*	5,730–9,000	Terraces and streambanks / fine- to coarse-textured Entisols and Mollisols with seasonally high water table	*Pseudotsuga menziesii, Abies lasiocarpa, Picea engelmannii, Picea pungens, Populus tremuloides, Spiraea betulifolia, Ribes* spp.*, Lonicera involucrata, Symphoricarpos* spp.*, Rosa* spp.*, Rubus idaeus, Amelanchier alnifolia, Prunus virginiana, Carex geyeri, Maianthemum stellatum, Galium triflorum, Geranium richardsonii, Thalictrum fendleri*	Hansen et al. 1995; Padgett et al. 1989
	Conifer/ *Calamagrostis canadensis*	3,800–10,500	Terraces, benches and meadows / Inceptisols, Mollisols, and Histosols with varying textures and water tables	*Picea engelmannii, Abies lasiocarpa, Pinus contorta, Pinus albicaulis, Lonicera involucrata, Ribes* spp.*, Salix* spp.	Hansen et al. 1995; Padgett et al. 1989; Youngblood et al. 1985
	Conifer/*Cornus sericea*	3,600–8,240	Terraces, benches, and streambanks / Entisols, Inceptisols, and Mollisols on frequently deposited and scoured alluvium	*Picea engelmannii, Picea pungens, Abies lasiocarpa Pinus contorta, Alnus incana., Betula occidentalis, Rosa* spp.*, Ribes* spp.*, Salix boothii, Salix drummondiana, Actaea rubra, Symphyotrichum foliaceum, Galium triflorum, Geranium richardsonii, Equisetum arvense*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Youngblood et al. 1985
	Conifer/*Dasiphora fruticosa*	8,000–9,000	Terraces / Mollisols with long-term development and seasonally high water tables	*Pinus contorta, Symphyotrichum spathulatum, Danthonia intermedia, Deschampsia cespitosa, Trisetum spicatum*	Padgett et al. 1989

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Conifer/ *Deschampsia cespitosa*	9,000–11,200	Terraces and toeslopes / fine-textured soils with cobbles and stones and seasonally high water tables	*Picea engelmannii, Pinus contorta, Populus tremuloides, Vaccinium cespitosum, Vaccinium scoparium, Carex scirpoidea, Danthonia intermedia, Caltha leptosepala, Polygonum bistortoides, Sibbaldia procumbens, Antennaria microphylla, Geum rossii*	
	Conifer/*Elymus glaucus*	8,000–10,000	Terraces / wet, loamy Inceptisols and Mollisols	*Picea pungens, Picea engelmannii, Abies lasiocarpa, Pinus contorta, Alnus incana, Rosa* spp.*, Salix boothii, Vaccinium* spp.*, Calamagrostis canadensis, Danthonia intermedia, Trisetum spicatum, Geranium richardsonii, Caltha leptosepala, Trollius laxus, Osmorhiza* spp.*, Symphyotrichum spathulatum*	Padgett et al. 1989
	Conifer/*Equisetum arvense*	2,880–9,200	Terraces, floodplains, and meadows / Entisols, Inceptisols, and Mollisols with variable textures, often humic and wet	*Picea pungens, Picea engelmannii, Abies lasiocarpa, Pinus contorta, Lonicera involucrata, Rosa* spp.*, Amelanchier alnifolia, Carex aquatilis, Elymus glaucus, Gernaium richardsonii, Senecio triangularis, Maianthemum stellatum*	Hansen et al. 1995; Padgett et al. 1989; Youngblood et al. 1985
	Conifer/*Galium triflorum*	2,800–8,200	Terraces, benches, and floodplains / Entisols and Mollisols with variable textures	*Picea pungens, Picea engelmannii, Abies lasiocarpa, Pinus contorta, Ribes* spp.*, Lonicera involucrata, Symphoricarpos* spp.*, Rosa* spp.*, Actaea rubra, Maianthemum stellatum, Geranium richardsonii, Senecio triangularis, Thalictrum occidentale, Fragaria virginiana, Symphyotrichum foliaceum*	Hansen et al. 1995; Youngblood et al. 1985
	Conifer/*Ledum glandulosum*	4,600–8,800	Meadows / moderate- to poorly drained Inceptisols and Mollisols with variable textures	*Picea engelmannii, Abies lasiocarpa, Pinus contorta, Calamagrostis canadensis, Vaccinium scoparium, Arnica latifolia*	Hansen et al. 1995
	Conifer/*Streptopus amplexifolius*	4,100–8,800	Terraces and streambanks / loams and silty clay loams	*Picea engelmannii, Abies lasiocarpa, Menziesia ferruginea, Vaccinium membranaceum, Ribes* spp.*, Rubus parviflorus, Arnica latifolia, Thalictrum occidentale, Senecio triangularis, Galium triflorum, Osmorhiza* spp.*, Pyrola* spp.	Hansen et al. 1995

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
Tall deciduous tree	*Acer negundo/ Cornus sericea*	6,500	Terraces and benches / Entisols, Inceptisols, and Mollisols with varying textures and seasonally high water tables	*Betula occidentalis, Alnus incana, Acer grandidentatum, Salix lutea, Salix exigua, Rosa* spp., *Ribes* spp., *Symphoricarpos* spp., *Maianthemum stellatum, Poa pratensis, Heracleum maximum, Osmorhiza* spp., *Arctium lappa, Taraxacum officinale*	Padgett et al. 1989
	Acer negundo/ Equisetum arvense	6,000	Terraces / fine-loamy and coarse-loamy soils	*Maianthemum stellatum, Mentha arvensis, Agrostis stolonifera, Elymus glaucus, Poa pratensis*	Padgett et al. 1989
	Cottonwood/*Acer grandidentatum*	4,800–6,300	Terraces / relatively dry, loamy Mollisols	*Populus angustifolia, Acer negundo, Mahonia repens, Symphoricarpos* spp., *Poa pratensis, Elymus glaucus, Maianthemum stellatum, Osmorhiza* spp.	Padgett et al. 1989
	Cottonwood/*Betula occidentalis*	4,760–7,480	Terraces, floodplains, and streambanks / well-drained, loamy Mollisols and Entisols	*Populus angustifolia, Acer grandidentatum, Juniperus* spp., *Cornus sericea, Rosa* spp., *Ribes* spp., *Rhus trilobata, Symphoricarpos* spp., *Poa pratensis, Bromus inermis, Osmorhiza* spp., *Equisetum arvense*	Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001
	Cottonwood/ *Cornus sericea*	2,000–7,300	Terraces, benches, floodplains, and bars / Entisols, Inceptisols, and Mollisols with varying textures and water tables	*Populus angustifolia, Populus balsmamifera, Pseudotsuga menziesii , Alnus incana, Juniperus* spp., *Betula occidentalis, Salix bebbiana, Salix lutea, Lonicera involucrata, Ribes* spp., *Rosa* spp., *Symphoricarpos* spp., *Poa pratensis, Calamagrostis canadensis, Bromus inermis, Elymus glaucus, Galium triflorum, Osmorhiza* spp., *Maianthemum stellatum*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Cottonwood/ Herbaceous	2,000–6,700	Terraces and bars / primarily Entisols	*Populus angustifolia, Populus balsmamifera, Poa pratensis, Phleum pratense, Taraxacum officinale, Achillea millefolium, Tanacetum vulgare, Centaurea stoebe*	Hansen et al. 1995
	Cottonwood/*Poa pratensis*	3,840–8,040	Terraces / coarse-textured Entisols, Inceptisols, and Mollisols with low water tables	*Populus angustifolia, Picea pungens, Picea engelmannii,Lonicera involucrata, Ribes* spp., *Rosa* spp., *Symphoricarpos* spp., *Elymus galucus, Fragaria virginiana, Geranium viscosissimum, Osmorhiza* spp.	Padgett et al. 1989; Youngblood et al. 1985

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Cottonwood/recent alluvial bar	3,100–6,700	Bars / coarse-textured Entisols with high water tables	*Populus angustifolia, Populus balsmamifera, Salix exigua, Elaeagnus commutata, Rosa* spp.*, Salix lutea, Salix melanopsis, Agrostis stolonifera, Phleum pratense, Trifolium hybridum*	Hansen et al. 1995; Walford et al. 2001
	Cottonwood / Symphoricarpos occidentalis	3,100–6,700	Terraces, floodplains, and bars / Entisols, Inceptisols, and Mollisols	*Populus angustifolia, Populus balsmamifera, Ribes* spp.*, Rosa* spp.*, Elaeagnus commutata, Poa pratensis, Bromus inermis, Glycyrrhiza lepidota, Agrostis stolonifera, Cirsium arvense*	Hansen et al. 1995; Walford et al. 2001
	Populus tremuloides/ Calamagrostis canadensis	2,800–6,450	Terraces / Entisols and Mollisols	*Rosa* spp.*, Symphoricarpos* spp.*, Alnus incana, Fragaria virginiana, Phleum pratense, Symphyotrichum spathulatum, Geranium* spp.*, Equisetum arvense*	Hansen et al. 1995
	Populus tremuloides/ Cornus sericea	2,400–6,900	Terraces / Entisols and Mollisols with variable textures	*Alnus incana, Rosa* spp.*, Rubus idaeus, Equisetum arvense, Galium triflorum, Maianthemum stellatum, Actaea rubra, Geum macrophyllum*	Hansen et al. 1995
	Populus tremuloides/ Osmorhiza occidentalis	5,080–5,750	Streambanks / Mollisols	*Amelanchier alnifolia, Rubus parviflorus, Thalictrum occidentale, Actaea rubra, Heracleum maximum*	Hansen et al. 1995
	Populus tremuloides/Poa pratensis	2,400–9,000	Terraces, benches, and floodplains / Entisols and Mollisols	*Rosa* spp.*, Phleum pratense, Taraxacum officinale, Fragaria virginiana*	Hansen et al. 1995
Low deciduous tree	*Alnus incana*	3,760–6,700	Terraces, floodplains, and streambanks / Entisols and inceptisols	*Cornus sericea, Ribes* spp.*, Senecio triangularis, Galium triflorum, Epilobium ciliatum, Heracleum maximum, Cinna latifolia, Urtica dioica, Athyrium filix-femina, Streptopus amplexifolius*	Hansen et al. 1995
	Alnus incana/ Cornus sericea	5,700–7,840	Streambanks / Entisols and Mollisols with varying textures, formed from alluvial deposition and scouring	*Betula occidentalis, Salix lutea, Lonicera involucrata, Ribes* spp.*, Rosa* spp.*, Maianthemum stellatum, Heracleum maximum, Mertensia* spp.*, Agrostis stolonifera*	Manning and Padgett 1995; Padgett et al. 1989
	Alnus incana/ Equisetum arvense	5,900–8200	Floodplains, streambanks, and meadows / Entisols and Mollisols with varying textures and high water tables	*Salix lutea, Salix boothii, Lonicera involucrata, Ribes* spp.*, Cornus sericea, Agrostis stolonifera, Poa pratensis, Carex pellita, Carex utriculata, Mentha arvensis, Maianthemum stellatum*	Padgett et al. 1989; Walford et al. 2001

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Alnus incana/ mesic forb	5,600–9,200	Terraces, floodplains, and streambanks / Entisols, Inceptisols, and Mollisols with varying textures and seasonally high water tables	*Lonicera involucrata, Ribes* spp.*, Rosa* spp.*, Symphoricarpos* spp.*, Cornus sericea, Heracleum maximum, Aconitum columbianum, Mertensia* spp.*, Hydrophyllum fendleri, Maianthemum stellatum, Geranium richardsonii, Actaea rubra, Urtica dioica, Agrostis stolonifera, Poa pratensis, Elymus glaucus*	Manning and Padgett 1995; Padgett et al. 1989
	Alnus incana/ mesic graminoid	5,600–9,000	Benches, floodplains, streambanks, and bars / loamy and organic Entisols, Inceptisols, and Mollisols with high water tables	*Betula occidentalis, Salix bebbiana, Salix exigua, Salix lutea, Ribes* spp.*, Rosa* spp.*, Rubus* spp., *Poa pratensis, Agrostis stolonifera, Poa palustris, Glyceria* spp.*, Calamagrostis canadensis, Elymus glaucus, Carex aquatilis, Carex utriculata, Geranium richardsonii, Taraxacum officinale, Trifolium* spp.*, Thalictrum fendleri, Equisetum arvense, Cirisium* spp.	Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001
	Alnus incana/ Ribes hudsonianum	6,700	Streambanks / Entisols, and Mollisols with varying textures and fluctuating water tables	*Alnus viridis, Cornus sericea, Heracleum maximum, Maianthemum stellatum, Actaea rubra*	Youngblood et al. 1985
	Betula occidentalis	3,000–6,000	Terraces, floodplains, and streambanks / Entisols	*Cornus sericea, Rosa* spp.*, Poa pratensis, Agrostis stolonifera*	Hansen et al. 1995
	Betula occidentalis/ Cornus sericea	6,020–8320	Terraces, benches, floodplains, and streambanks / Entisols, Inceptisols, and Mollisols with varying textures and high or low water tables	*Populus angustifolia, Alnus incana, Salix bebbiana, Ribes* spp.*, Rosa* spp.*, Carex utriculata, Equisetum* spp.*, Maianthemum stellatum, Urtica dioica, Heracleum maximum, Actaea rubra, Galium triflorum, Glyceria striata, Poa* spp.*, Elymus glaucus*	Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001
	*Betula occidentalis/*mesic forb	6,000–8,300	Terraces and streambanks / Entisols and Mollisols with varying textures and seasonally high water tables	*Alnus incana, Salix* spp.*, Maianthemum stellatum, Heracleum maximum, Aconitum columbianum, Equisetum arvense, Geranium richardsonii, Poa pratensis, Agrostis stolonifera, Elymus glaucus, Carex microptera*	Manning and Padgett 1995; Padgett et al. 1989

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Betula occidentalis/Poa pratensis	6,000–7,800	Terraces and streambanks / Entisols and Mollisols with varying textures and seasonally low water tables	*Alnus incana, Salix boothii, Salix bebbiana, Juniperus* spp.*, Rosa* spp.*, Lonicera involucrata, Ribes* spp.*, Glyceria striata, Agrostis stolonifera, Juncus arcticus, Carex pellita, Carex utriculata, Carex nebrascensis, Trifolium* spp.*, Taraxacum officinale, Cirsium arvense*	Manning and Padgett 1995; Padgett et al. 1989
Tall willow	*Salix bebbiana*	3,230–7,600	Terraces / Mollisols and Histosols	*Poa pratensis, Phleum pratense, Agrostis stolonifera, Solidago canadensis*	Hansen et al. 1995
	Salix boothii/ Calamagrostis canadensis	6,100–9,000	Benches and streambanks / clayey and loamy Mollisols with variable water tables	*Salix drummondinana, Lonicera involucrata, Ribes* spp.*, Carex utriculata, Thalictrum fendleri, Mertensia ciliata, Geum macrophyllum*	Padgett et al. 1989; Youngblood et al. 1985
	Salix boothii/Carex aquatilis	7,400–8,800	Terraces / fine and loamy Mollisols; Histosols with varying degrees of organic matter decomposition; wet and saturated soils	*Salix drummondinana, Lonicera involucrata, Betula glandulosa, Ribes* spp.*, Caltha leptosepala, Deschampsia cespitosa, Carex utriculata, Geranium richardsonii, Polemonium* spp.*, Saxifraga odontoloma, Geum macrophyllum*	Padgett et al. 1989
	Salix boothii/Carex nebrascensis	6,900	Benches / Mollisols; Histosols with decomposed organic matter; high water tables	*Salix lutea, Salix bebbiana, Glyceria striata, Carex utriculata, Carex simulata, Juncus arcticus, Mentha arvensis, Veronica americana, Polemonium* spp.	Padgett et al. 1989; Youngblood et al. 1985
	Salix boothii/Carex utriculata	5,900–9,200	Terraces, floodplains, and streambanks / Entisols, Inceptisols, and Mollisols with varying textures; Histosols with undecomposed organic matter; water tables at or near the soil surface	*Salix drummondinana, Salix wolfii, Lonicera involucrata, Ribes* spp.*, Betula glandulosa, Dasiphora fruticosa, Carex aquatilis, Carex microptera, Carex disperma, Juncus arcticus, Equisetum arvense, Maianthemum stellatum, Calamagrostis canadensis, Symphyotrichum foliaceum, Fragaria virginiana, Chamerion angustifolium, Castilleja miniata*	Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix boothii/ Equisetum arvense	6,000–8,900	Streambanks / loamy Entisols and Mollisols; Histosols; seasonally high water tables	*Salix drummondinana, Lonicera involucrata, Ribes,* spp.*, Saxifraga odontoloma, Geranium richardsonii, Geum macrophyllum*	Padgett et al. 1989; Youngblood et al. 1985

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	*Salix boothii/*mesic forb	5,300–10,300	Benches, floodplains, and meadows / Entisols, Inceptisols, and Mollisols with varying textures and frequently high water tables	*Salix drummondinana, Salix bebbiana, Betula occidentalis, Betula glandulosa, Rosa* spp.*, Ribes* spp.*, Dasiphora fruticosa, Symphyotrichum foliaceum, Fragaria virginiana, Maianthemum stellatum, Mertensia ciliata, Equisetum arvense, Chamerion angustifolium, Juncus arcticus, Calamagrostis canadensis, Carex microptera, Elymus trachycaulus, Poa pratensis*	Padgett et al. 1989; Walford et al. 2001
	*Salix boothii/*mesic graminoid	6,700–9,800	Terraces, benches, floodplains, and streambanks / Entisols, Inceptisols, and Mollisols with varying textures; Histosols with decomposed organic matter; high water tables	*Salix geyeriana, Salix drummondiana, Salix planifolia, Salix wolfii, Dasiphora fruticosa, Juncus arcticus, Carex microptera, Deschampsia cespitosa, Carex aquatilis, Carex norvegica, Carex praticola, Carex pellita, Calamagrostis canadensis, Achillea millefolium, Symphyotrichum* spp.*, Fragaria virginiana*	Padgett et al. 1989; Walford et al. 2001
	Salix boothii/Poa palustris	6,200–7,600	Terraces / loamy Mollisols with high water tables	*Salix geyeriana, Carex utriculata, Maianthemum stellatum, Cirisium arvense, Mertensia ciliata, Symphyotrichum foliaceum*	Padgett et al. 1989; Youngblood et al. 1985
	Salix boothii/Poa pratensis	5,800–9,820	Terraces / Entisols, Inceptisols, and Mollisols with varying textures and water tables	*Salix drummondiana, Salix exigua, Lonicera involucrata, Rosa* spp.*, Crataegus douglasii, Amelanchier alnifolia, Symphoricarpos* spp.*, Cornus sericea, Agrostis stolonifera, Bromus* spp.*, Phleum pratense, Symphyotrichum foliaceum, Fragaria virginiana, Taraxacum officinale, Rudbeckia occidentalis*	Padgett et al. 1989; Youngblood et al. 1985
	Salix boothii/Salix wolfii	7,780–9,480	Terraces and floodplains / loamy Entisols and Inceptisols with high water tables	*Deschampsia cespitosa, Carex praticola, Elymus trachycaulus, Achillea millefolium, Astragalus alpinus, Fragaria virginiana, Potentilla gracilis, Taraxacum officinale*	Walford et al. 2001

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Salix boothii/ Maianthemum stellatum	6,000–7,400	Benches / Entisols, Inceptisols and well-developed Mollisols with varying textures	*Salix drummondiana, Ribes* spp.*, Lonicera involucrata, Heracleum maximum, Mertensia ciliata, Thalictrum fendleri, Galium triflorum, Angelica* spp.*, Solidago canadensis, Urtica dioica, Fragaria virginiana, Symphyotrichum foliaceum, Potentilla gracilis, Poa pratensis, Deschampsia cespitosa, Carex utriculata, Poa palustris, Bromus ciliatus*	Youngblood et al. 1985
	Salix drummondiana	2,320–9,760	Terraces and benches / loamy and sandy Entisols, Inceptisols, and Mollisols; Histosols; high water tables	*Salix boothi, Populus angustifolia, Poa pratensis, Equisetum arvense, Pedicularis groenlandica*	Hansen et al. 1995; Manning and Padgett 1995; Walford et al. 2001
	Salix drummondiana/ Calamagrostis canadensis	2,320–7,800	Terraces / Entisols, Mollisols, and Histosols	*Salix boothii, Calamagrostis stricta, Equisetum arvense, Geum macrophyllum, Symphyotrichum foliaceum*	Hansen et al. 1995
	Salix drummondiana/ Carex utriculata	2,320–7,800	Terraces / Entisols, Mollisols, and Histosols	*Salix geyeriana, Salix boothii, Calamagrostis canadensis, Carex aquatilis, Carex vesicaria, Geum macrophyllum, Epilobium ciliatum*	Hansen et al. 1995
	Salix exigua	2,550–8,000	Benches and streambanks, bars / loamy and sandy Entisols and Mollisols with variable water tables	*Cornus sericea, Prunus virginiana, Salix lutea, Salix geyeriana, Salix boothii, Rosa* spp.*, Ribes* spp.	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989
	Salix exigua/ Equisetum arvense	7,100	Terraces / Entisols and Mollisols of varying textures with variable to high water tables	*Salix boothii, Salix drummondiana, Cornus sericea, Lonicera involucrata, Ribes* spp.*, Calamagrostis canadensis, Carex utriculata, Poa palustris, Poa pratensis, Geum macropyllum*	Youngblood et al. 1985
	*Salix exigua/*mesic forb	6,560–8,060	Terraces, benches, streambanks, and meadows / loamy Inceptisols and Mollisols with variable water tables	*Rosa* spp.*, Ribes* spp.*, Heracleum maxium, Maianthemum stellatum, Urtica dioica, Mertensia* spp.*, Senecio serra, Thalictrum fendleri, Elymus glaucus, Calamagrostis canadensis, Agrostis stolonifera*	Manning and Padgett 1995; Padgett et al. 1989

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	*Salix exigua/*mesic graminoid	6,000–7,700	Terraces and meadows / fine and loamy Entisols, Inceptisols, and Mollisols; Histosols with partially decomposed organic matter; seasonally high water tables	*Salix lutea, Salix boothii, Alnus incana, Betula occidentalis, Carex nebrascensis, Juncus arcticus, Carex pellita, Agrostis stolonifera, Mentha arvensis, Veronica americana, Geum macropyllum, Equisetum arvense*	Padgett et al. 1989
	Salix exigua/Poa pratensis	5,900–7,100	Terraces, streambanks, and bars / Entisols, Inceptisols, and Mollisols with varying textures and variable tables	*Salix drummondiana, Salix lutea, Salix melanopsis, Cornus sericea, Lonicera involucrata, Rosa* spp.*, Agrostis stolonifera, Elymus glaucus, Phleum pratense, Symphyotrichum foliaceum, Fragaria virginiana, Equisetum hyemale, Melilotus officinalis, Solidago* spp.*, Lupinus* spp.	Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix geyeriana	4,410–7,330	Terraces / Entisols and Mollisols	*Salix boothii, Poa pratensis, Geum macropyllum, Poa palustris, Phleum pratense, Agrostis stolonifera*	Hansen et al. 1995; Padgett et al. 1989
	Salix geyeriana/ Calamagrostis canadensis	4,820–10,000	Benches, floodplains, and streambanks / fine and loamy Entisols and Mollisols with seasonally high water tables	*Salix boothii, Salix drummondiana, Salix eastwoodiae, Ribes* spp.*, Lonicera involucrata, Carex utriculata, Carex microptera, Deschampsia cespitosa, Poa palustris, Poa pratensis, Symphyotrichum foliaceum, Galium boreale, Potentilla gracilis, Packera paupercula, Taraxacum officinale*	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix geyeriana/ Carex aquatilis	8,500–9,500	Meadows / fine and loamy Mollisols; Histosols with decomposed organic matter	*Salix boothii, Salix bebbiana, Salix wolfii, Salix planifolia, Carex utriculata, Deschampsia cespitosa, Calamagrostis canadensis, Phleum alpinium, Geum macropyllum, Thalictrum fendleri, Polemonium occidentale, Galium trifidum, Caltha leptosepala*	Padgett et al. 1989

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Salix geyeriana/ Carex utriculata	4,800–9,000	Terraces, benches, floodplains, streambanks, and meadows / Entisols, Inceptisols, and Mollisols with varying textures; Histosols with partially decomposed organic matter; water table at or near surface	*Salix boothii, Salix drummondiana, Lonicera involucrata, Ribes* spp.*, Dasiphora fruticosa, Carex aquatilis, Glyceria* spp.*, Equisetum arvense, Geum macrophyllum, Calamagrostsis canadensis, Poa palustris, Poa pratensis*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix geyeriana/ Deschampsia cespitosa	6,400–9,300	Floodplains and meadows / fine and loamy Inceptisols, Alfisols, and Mollisols	*Carex microptera, Juncus arcticus, Poa pratensis, Taraxacum officinale, Geum macrophyllum, Symphyotrichum* spp.*, Fragaria virginiana*	Padgett et al. 1989
	Salix geyeriana/ mesic forb	7,000–10,000	Terraces, benches, floodplains, and meadows / Entisols and Mollisols with varying textures and seasonally high water tables	*Salix boothii, Ribes* spp.*, Lonicera involucrata, Pinus contorta, Dasiphora fruticosa, Thalictrum occidentale, Potentilla gracilis, Heracleum maximum, Valeriana occidentalis, Aconitum columbianum, Angelica arguta, Poa pratensis, Elymus glaucus, Astragalus alpinus, Fragaria virginiana, Antennaria corymbosa, Symphyotrichum foliaceum, Equisetum arvense, Pedicularis groenlandica, Carex microptera*	Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix geyeriana/ mesic graminoid	5,960–8,800	Terraces, benches, floodplains, and meadows / Entisols, Inceptisols, and Mollisols with varying textures; Histosols with undecomposed and decomposed organic matter; water table variable or at soil surface	*Salix boothii, Salix wolfii, Dasiphora fruticosa, Carex praticola, Carex microptera, Juncus arcticus, Deschampsia cespitosa, Poa pratensis, Fragaria virginiana, Symphyotrichum foliaceum, Potentilla gracilis, Achillea millefolium, Taraxacum officinale*	Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001
	Salix geyeriana/ Poa palustris	6,700–8,000	Terraces, benches, floodplains, and meadows / fine and loamy Mollisols with seasonally high water table	*Salix boothii, Salix drummondiana, Salix bebbiana, Carex aquatilis, Carex utriculata, Carex microptera, Poa pratensis, Deschampsia cespitosa, Elymus glaucus, Glyceria* spp.*, Solidago canadensis, Potentilla gracilis, Geum macrophyllum*	Padgett et al. 1989; Youngblood et al. 1985

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Salix geyeriana/ Poa pratensis	6,600	Terraces and meadows / fine and loamy Mollisols; Histosols with decomposed organic matter; seasonally high water table	*Lonicera involucrata, Ribes* spp., *Fragaria virginiana, Maianthemum stellatum, Potentilla gracilis, Juncus arcticus, Poa pratensis*	Youngblood et al 1985.
	Salix lutea	3,660–7,000	Terraces, benches, and streambanks / Entisols, Inceptisols, and Mollisols with varying textures	*Salix drummondiana, Lonicera involucrata, Ribes* spp., *Equisetum arvense, Actaea rubra, Angelica arguta, Symphyotrichum foliaceum, Geranium richardsonii, Saxifraga odontoloma, Senecio triangularis*	Hansen et al. 1995; Manning and Padgett 1995; Youngblood et al. 1985
Low willow	*Salix barclayi-Salix wolfii*	6,950	Floodplains and toeslopes / Histosols with high water tables and undecomposed organic material	*Juncus arcticus, Carex utriculata, Carex aquatilis, Symphyotrichum foliaceum*	Walford et al. 2001
	Salix eastwoodiae	7,800	Streambanks/ no soil information	*Salix drummondiana, Lonicera involucrata, Mertensia ciliata, Saxifraga odontoloma, Thalictrum occidentale*	Youngblood et al. 1985
	Salix eastwoodii/ Carex aquatilis	8,980–9,920	Floodplains / loamy Inceptisols; Histosols; high water tables	*Carex utriculata, Carex norvegica, Carex microptera, Erigeron peregrinus*	Walford et al. 2001
	Salix eastwoodiae/ mesic graminoid	8,125–9,600	Floodplains / loamy Inceptisols with high water tables	*Salix planifolia, Salix boothii, Salix geyeriana, Dasiphora floribunda, Carex praegracilis, Deschampsia cespitosa, Juncus arcticus, Symphyotrichum foliaceum, Fragaria virginiana, Senecio sphaerocephalus*	Walford et al. 2001
	Salix glaucus	9,980	Terraces / no soil information	*Salix planifolia, Calamagrostis canadensis, Mertensia ciliata*	Walford et al. 2001
	Salix planifolia/ Calamagrostis canadensis	9,000–10,000	Streambanks, and meadows / Mollisols and Histosols with seasonally high water tables	*Mertensia ciliata, Deschampsia cespitosa, Phleum alpinum, Poa* spp., *Carex illota, Carex aquatilis, Ligusticum tenuifolium, Sedum* spp.	Padgett et al. 1989
	Salix planifolia/ Caltha leptosepala	9,060–9,920	Floodplains / loamy Entisols, Inceptisols, and Mollisols with high water tables	*Salix eastwoodiae, Salix wolfii, Trollius laxus, Antennaria corymbosa, Symphyotrichum foliaceum, Deschampsia cespitosa, Carex microptera, Phleum alpinum,*	Walford et al. 2001

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Salix planifolia/ Carex aquatilis	5,740–11,000	Floodplains, streambanks, and meadows / loamy Inceptisols and Mollisols; Histosols with undecomposed and partially decomposed organic matter; high water tables	*Salix wolfii, Salix boothii, Betula glandulosa, Dasiphora fruticosa, Caltha leptosepala, Agrostis* spp.*, Carex utriculata, Carex canescens, Deschampsia cespitosa, Calamagrostis canadensis, Galium trifidum, Pedicularis groenlandica, Ligusticum tenuifolium, Sedum* spp.*, Symphyotrichum spathulatum, Senecio sphaerocephalus*	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001
	Salix planifolia/ Carex scopulorum	9,480–10,680	Floodplains / loamy Mollisols; Histosols with undecomposed organic material; high water tables	*Salix eastwoodiae, Salix nivalis, Carex utriculata, Deschampsia cespitosa, Caltha leptosepala*	Manning and Padgett 1995; Walford et al. 2001
	Salix planifolia/ Deschampsia cespitosa	9,980–11,200	Terraces and meadows / sandy and loamy Inceptisols and Mollisols; Histosols with partially decomposed organic matter; seasonally high water tables	*Betula glandulosa, Dasiphora fruticosa, Salix glauca, Ligusticum tenuifolium, Caltha leptosepala, Polygonum bistortoides, Sedum* spp.*, Erigeron peregrinus, Deschampsia cespitosa, Danthonia intermedia, Phleum alpinum, Juncus drummondii, Carex paysonis*	Padgett et al. 1989; Walford et al. 2001
	Salix wolfii	9,140	Floodplains / loamy Entisols	*Not described*	Walford et al. 2001
	Salix wolfii/Carex aquatilis	6,400–9,900	Terraces, floodplains, streambanks, and meadows / Entisols, Inceptisols, and Mollisols with varying textures; Histosols with varying levels of organic matter decomposition; seasonally high to perennially high water tables	*Betula glandulosa, Dasiphora fruticosa, Carex utriculata, Deschampsia cespitosa, Juncus arcticus, Poa pratensis, Pedicularis groenlandica, Polemonium occidentale, Symphyotrichum foliaceum, Fragaria virginiana*	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix wolfii/Carex nebrascensis	6,600–8,100	Benches / loamy Mollisols, Histosols with undecomposed organic matter, water tables at surface	*Betula glandulosa, Carex simulata, Deschampsia cespitosa, Symphyotrichum foliaceum, Pedicularis groenlandica, Polemonium occidentale*	Youngblood et al. 1985
	Salix wolfii/Carex utriculata	6,600–8,600	Terraces and meadows / fine and loamy Entisols, Alfisols, and Mollisols with high water tables	*Betula glandulosa, Dasiphora fruticosa, Salix boothii, Carex aquatilis, Polemonium occidentale, Symphyotrichum foliaceum, Fragaria virginiana*	Padgett et al. 1989; Youngblood et al. 1985

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Salix wolfii/ Deschampsia cespitosa	6,550–9,070	Terraces, benches, and meadows / clayey and loamy Inceptisols and Mollisols; Histosols with decomposed organic material; high water tables	*Betula glandulosa, Dasiphora fruticosa, Salix boothii, Carex microptera, Poa pratensis, Symphyotrichum foliaceum, Hymenoxys hoopesii, Solidago canadensis, Fragaria virginiana, Geum macrophyllum, Polemonium occidentale, Senecio* spp.	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	*Salix wolfii/*mesic forb	6,200–9,260	Terraces, benches, and floodplains / loamy Entisols and Mollisols with moderate to high water tables	*Betula glandulosa, Dasiphora fruticosa, Ribes* spp.*, Poa pratensis, Deschampsia cespitosa, Carex microptera, Fragaria virginiana, Symphyotrichum foliaceum, Geum macrophyllum, Hymenoxys hoopesii, Polemonium occidentale*	Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix wolfii/Poa pratensis	6,990–8,820	Floodplains / loamy Entisols and Mollisols with high water tables	*Salix drummondiana, Salix boothii, Carex microptera, Carex norvegica, Fragaria virginiana, Trifolium repens*	Walford et al. 2001
Nonwillow shrub	*Artemisia cana/ Deschampsia cespitosa*	6,900–9,200	Meadows / Alfisols and Mollisols with seasonally high water tables	*Carex scirpoidea, Carex praegracilis, Juncus arcticus, Poa pratensis, Polygonum bistortoides, Potentilla gracilis*	Padgett et al. 1989
	Artemisia cana/Festuca idahoensis	6,500–8,400	Terraces and benches / fine and loamy Mollisols with moderately fluctuating water tables	*Dasiphora fruticosa, Artemisia tridentata, Carex microptera, Fragaria virginiana, Hymenoxys hoopesii, Potentilla gracilis*	Hansen et al. 1995; Youngblood et al. 1985
	Atremisia cana/ Poa pratensis	7,500–7,700	Terraces, benches, and meadows / fine-loamy and sandy-skeletal soils with low water tables	*Hymenoxys hoopesii, Fragaria virginiana, Potentilla gracilis, Valeriana occidentalis, Symphyotrichum* spp.	Padgett et al. 1989; Youngblood et al. 1985
	Cornus sericea/ Galium triflorum	6,600	Terraces / Entisols, Inceptisols, and Mollisols with varying textures and moderately fluctuating water tables	*Salix boothii, Salix lutea, Crataegus douglasii, Alnus incana, Betula occidentalis, Ribes* spp.*, Rosa* spp.*, Maianthemum stellatum, Actaea rubra, Angelica arguta, Equisetum arvense, Heracleum lanatum, Elymus glaucus, Poa pratensis*	Youngblood et al. 1985

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Cornus sericea/ Heracleum maximum	6,600–7,000	Benches and streambanks / Entisols, Inceptisols, and Mollisols with varying textures, organic matter, and moderately fluctuating water tables	*Salix drummondiana, Crataegus douglasii, Rosa* spp.*, Galium triflorum, Geum macrophyllum, Maianthemum stellatum, Mertensia ciliata*	Padgett et al. 1989; Youngblood et al. 1985
	Dasiphora fruticosa/ Deschampsia cespitosa	6,000–9,500	Terraces, floodplains, and meadows / fine and loamy Inceptisols, Alfisols, and Mollisols with seasonally high water tables	*Salix wolfii, Artemesia cana, Carex microptera, Carex praegracilis, Poa pratensis, Fragaria virginiana, Hymenoxys hoopesii, Potentilla gracilis*	Hansen et al. 1995; Padgett et al. 1989; Youngblood et al. 1985
	Dasiphora fruticosa/Festuca idahoensis	6,500–8,200	Benches / clayey and loamy Mollisols with seasonally high water tables	*Fragaria virginiana, Hymenoxys hoopesii, Potentilla gracilis*	Youngblood et al. 1985
	Dasiphora fruticosa/Poa pratensis	7,690–10,000	Terraces, floodplains, and meadows / fine and loamy Inceptisols and Mollisols with seasonally high water tables	*Atremisia cana,Potentilla gracilis, Antennaria* spp.*, Symphyotrichum* spp.*, Fragaria virginiana, Festuca idahoensis, Poa pratensis, Geum triflorum*	Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Kalmia microphylla/Carex scopulorum	6,400–7,950	Streambanks and meadows / Histosols with undecomposed organic matter	*Carex nigricans, Danthonia intermedia, Gentiana calycosa, Symphyotrichum foliaceum, Dodecatheon jeffreyi, Ligusticum tenuifolium*	Hansen et al. 1995
	Rhamnus alnifolia	6,800	Terraces / fine and loamy Mollisols with variable water tables	*Elymus glaucus, Calamagrostis canadensis, Galium triflorum, Heracleum maximus, Maianthemum stellatum*	Youngblood et al. 1985
	Rosa woodsii	2,150–5,600	Terraces / silty and loamy Entisols, Inceptisols, and Mollisols	*Symphoricarpos* spp.*, Poa pratensis*	Hansen et al. 1995
Herbaceous	*Agrostis stolonifera*	2,800–7,000	Bars and meadows / fine and loamy Entisols and Mollisols; Histosols with decomposed organic matter	*Carex nebrascensis, Schedonorus pratensis, Juncus arcticus, Taraxacum officinale, Equisetum hyemale*	Hansen et al. 1995
	Bromus inermis	3,590–6,700	Terraces / Entisols and Mollisols	*Carex praticola*	Hansen et al. 1995

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Calamagrostis canadensis	3,500–9,800	Terraces, benches, floodplains, streambanks, and meadows / Entisols, Inceptisols, and Mollisols with varying textures; Histosols with partially decomposed organic matter; high and fluctuating water tables	*Pinus contorta, Salix boothii, Poa pratensis, Symphyotrichum foliaceum, Equisetum arvense, Geum macrophyllum, Taraxacum officinale*	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001
	Caltha leptosepala	9,000–10,200	Meadows / clayey Inceptisols, Histosols with decomposed organic matter; water tables at the soil surface	*Carex aquatilis, Carex utriculata, Carex simulata, Carex pellita, Deschampsia cespitosa, Pedicularis groenlandica, Equisetum arvense*	Padgett et al. 1989
	Carex aquatilis	2,300–11,000	Benches, floodplains, streambanks, and meadows / clayey and loamy Inceptisols and Mollisols; Histosols with varying levels of organic matter decomposition; water table usually at soil surface	*Salix planifolia, Carex utriculata, Carex canescens, Carex microptera, Carex praeceptorum, Poa pratensis, Juncus arcticus, Deschampsia cespitosa, Symphyotrichum foliaceum, Polemonium occidentale*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Carex buxbaumii	9,700–10,500	Meadows / Entisols; Histosols with undecomposed and decomposed organic matter; water table at soil surface	*Carex aquatilis, Carex saxatilis, Deschampsia cespitosa, Caltha leptosepala, Pedicularis groenlandica, Ligusticum tenuifolium*	Padgett et al. 1989
	Carex pellita	5,200–9,200	Terraces, floodplains, and meadows / loamy Inceptisols and Mollisols, Histosols with varying levels of organic matter decomposition; moderately high water tables	*Poa pratensis, Deschampsia cespitosa, Carex aquatilis, Juncus arcticus, Mentha arvense, Taraxacum officinale, Equisetum arvense*	Manning and Padgett 1995; Padgett et al. 1989
	Carex microptera	6,300–9,500	Terraces, benches, and meadows / fine and loamy Entisols, Inceptisols, and Mollisols with seasonally high water tables	*Carex utriculata, Deschampsia cespitosa, Poa pratensis, Symphyotrichum foliaceum, Fragaria virginiana, Taraxacum officinale, Geum macrophyllum, Hymenoxys hoopesii, Heracleum maximum*	Manning and Padgett 1995; Padgett et al. 1989; Youngblood et al. 1985

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Carex nebrascensis	3,300–9,200	Terraces, benches, streambanks, and meadows / clayey and loamy Inceptisols and Mollisols; Histosols with decomposed and partially decomposed organic matter; high water tables	*Juncus arcticus, Deschampsia cespitosa, Poa palustris, Eurybia integrifolia, Polemonium occidentale*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Youngblood et al. 1985
	Carex utriculata	2,200–9,800	Terraces, benches, floodplains, streambanks, and meadows / Entisols, Inceptisols, and Mollisols with varying textures; Histosols with partially decomposed and decomposed organic matter; water tables at surface	*Carex aquatilis, Carex vesicaria, Carex atherodes, Carex simulata, Carex microptera, Polemonium occidentale, Deschampsia cespitosa, Poa pratensis, Geum macrophyllum*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Carex scopulorum	6,500–10,600	Terraces and meadows / Fine and loamy Entisols and Inceptisols; Histosols with partially decomposed organic matter; high water tables	*Salix planifolia, Caltha leptosepala, Carex illota, Deschampsia cespitosa, Juncus mertensianus, Packera* spp.	Hansen et al. 1995; Manning and Padgett 1995; Walford et al. 2001
	Carex simulata	5,800–9,300	Terraces, benches, floodplains, and meadows / Inceptisols and Mollisols with varying textures; Histosols with undecomposed and partially decomposed organic matter; high water tables	*Salix wolfii, Carex aquatilis, Carex utriculata, Deschampsia cespitosa, Pedicularis groenlandica*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Danthonia intermedia	9,400	Meadows / loamy Inceptisols and Mollisols with seasonally high water tables	*Carex microptera, Agrostis scabra, Juncus drummondii, Symphyotrichum foliaceum, Erigeron ursinus, Phleum alpinum, Festuca brachyphylla, Poa pratensis, Deschampsia cespitosa*	Padgett et al. 1989

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Deschampsia cespitosa	5,030–11,000	Terraces, floodplains, and meadows / fine and loamy Entisols, Inceptisols, Alfisols, and Mollisols; Histosols with undecomposed and partially decomposed organic matter; wet soils with seasonally high water tables	*Carex aquatilis, Carex utriculata, Carex microptera, Carex scopulorum, Poa pratensis, Symphyotrichum foliaceum, Potentilla gracilis, Geum macrophyllum, Calamagrostis canadensis, Phleum alpinum, Antennaria corymbosa*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Eleocharis palustris	2,200–9,900	Benches, streambanks, and meadows / fine and loamy Inceptisols and Mollisols; Histosols with partially decomposed organic matter; water table at or near the soil surface	*Eleocharis acicularis, Alopecurus aequalis, Hippuris vulgaris, Utricularia macrorhiza, Potamogeton* spp., *Ranunculus aquatilis, Juncus arcticus, Hordeum brachyantherum, Poa pratensis*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989
	Eleocharis quinqueflora	4,940–10,000	Streambanks and meadows / Mollisols; Histosols with varying levels of organic matter decomposition; perennially saturated soils	*Carex aquatilis, Trichophorum cespitosum, Pedicularis groenlandica, Eleocharis rostellata*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989
	Elymus cinereus	6,100	Terraces and floodplains / loamy Mollisols with seasonally high water tables	*Poa pratensis, Achillea millefolium*	Walford et al. 2001
	Equisetum fluviatile	2,600–6,040	Streambanks / Entisols, Mollisols, and Histosols	*Not described*	Hansen et al. 1995,
	Glyceria borealis	2,200–5,940	Streambanks and meadows / Entisols, Mollisols, and Histosols	*Eleocharis palustris, Eleocharis acicularis, Glyceria striata*	Hansen et al. 1995
	Juncus arcticus	3,200–9,400	Terraces, benches, and floodplains, Meadows / fine and loamy Inceptisols and Mollisols; Histosols with undecomposed organic matter; variable water tables	*Carex aquatilis, Carex utriculata, Carex petasata, Deschampsia cespitosa, Phleum alpinum, Poa pratensis, Potentilla gracilis, Fragaria virginiana, Symphyotrichum foliaceum, Sonchus arvensis, Trifolium hybridum*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985

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Table B1 (continued)—Riparian and wetland community types that are expected to occur in the Bridger-Teton National Forest.

Dominance group	Community type	Elevation range (feet)	Geomorphic features/soils	Associated species	References
	Mertensia ciliata	7,900–9,370	Benches, floodplains, and streambanks / loamy Entisols and Mollisols with seasonally high water tables	*Carex microptera, Poa palustris, Senecio triangularis, Heracleum maximum, Geranium richardsonii, Hymenoxys hoopesii, Saxifraga odontoloma*	Padgett et al. 1989; Manning and Padgett 1995; Youngblood et al. 1985
	Poa palustris	3,040–6,700	Terraces, streambanks, and meadows / Entisols and Mollisols with varying textures and high water tables	*Juncus arcticus, Phleum pratense, Potentilla gracilis, Geum macrophyllum*	Hansen et al. 1995; Youngblood et al. 1985
	Poa pratensis	3,590–8,600	Terraces, benches, and meadows / fine and loamy Inceptisols and Mollisols, often with low water tables	*Phleum pratense, Galium boreale, Fragaria virginiana, Potentilla gracilis, Achillea millefolium*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Youngblood et al. 1985
	Schoenoplectus acutus	2,180–6,650	Streambanks / Entisols, Mollisols, and Histosols	*Not described*	Hansen et al. 1995
	Typha latifolia	1,950–6,350	Floodplains and streambanks / fine-textured Entisols and Mollisols with accumulated organic matter and water tables often at the soil surface	*Typha angustifolia, Eleocharis palustris, Glyceria* spp.*, Phalaris arundinacea, Mentha arvensis, Veronica americana, Polygonum amphibium*	Hansen et al. 1995; Padgett et al. 1989
	Veratrum californicum	7,440–10,500	Benches and meadows / fine and loamy Inceptisols and Mollisols with high water tables, often saturated by snowmelt	*Delphinium occidentale, Rudbeckia occidentalis, Thalictrum fendleri, Hymenoxys hoopesii, Mertensia* spp.	Manning and Padgett 1995; Padgett et al. 1989; Youngblood et al. 1985

Appendix C. Dominance Groups and Community Types That Are Expected to Occur at Groundwater-Dependent Ecosystems in the Bridger-Teton National Forest

Table C1—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
Conifer	Conifer/*Aconitum columbianum*	Springs	*Abies lasiocarpa, Picea engelmannii, Pinus contorta, Pseudotsuga menziesii, Populus tremuloides, Senecio triangularis, Mertensia ciliata, Delphinium occidentale, Saxifraga odontoloma, Cardamine cordifolia, Streptopus amplexifolius, Pyrola* spp.*, Osmorhiza* spp.	Padgett et al. 1989
	Conifer/ *Equisetum arvense*	Springs, fens	*Picea pungens, Picea engelmannii, Abies lasiocarpa, Pinus contorta,Lonicera involucrata, Rosa* spp.*, Amelanchier alnifolia,Carex aquatilis, Elymus glaucus, Gernaium richardsonii, Senecio triangularis, Maianthemum stellatum*	Hansen et al. 1995; Padgett et al. 1989; Youngblood et al. 1985
	Conifer/*Galium triflorum*	Springs	*Picea pungens, Picea engelmannii, Abies lasiocarpa, Pinus contorta, Ribes* spp.*, Lonicera involucrata, Symphoricarpos* spp.*, Rosa* spp.*, Actaea rubra, Maianthemum stellatum, Geranium richardsonii, Senecio triangularis, Thalictrum occidentale, Fragaria virginiana, Symphyotrichum foliaceum*	Hansen et al. 1995; Youngblood et al. 1985
	Conifer/ *Streptopus amplexifolius*	Springs	*Picea engelmannii, Abies lasiocarpa, Menziesia ferruginea, Vaccinium membranaceum, Ribes* spp.*, Rubus parviflorus, Arnica latifolia, Thalictrum occidentale, Senecio triangularis, Galium triflorum, Osmorhiza* spp.*, Pyrola* spp.	Hansen et al. 1995
Tall deciduous tree	*Populus tremuloides/ Cornus sericea*	Springs	*Alnus incana, Rosa* spp.*, Rubus idaeus, Equisetum arvense, Galium triflorum, Maianthemum stellatum, Actaea rubra, Geum macrophyllum*	Hansen et al. 1995
	Populus tremuloides/ Osmorhiza occidentalis	Springs	*Amelanchier alnifolia, Rubus parviflorus,Thalictrum occidentale, Actaea rubra, Heracleum maximum*	Hansen et al. 1995
	Populus tremuloides/Poa pratensis	Springs	*Rosa* spp.*, Phleum pratense, Taraxacum officinale, Fragaria virginiana*	Hansen et al. 1995
Low deciduous tree	*Alnus incana*	Springs	*Cornus sericea, Ribes* spp.*, Senecio triangularis, Galium triflorum, Epilobium ciliatum, Heracleum maximum, Cinna latifolia, Urtica dioica, Athyrium filix-femina, Streptopus amplexifolius*	Hansen et al. 1995

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Table C1 (continued)—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
	Alnus incana/ mesic forb	Springs	*Lonicera involucrata, Ribes* spp.*, Rosa* spp.*, Symphoricarpos* spp.*, Cornus sericea, Heracleum maximum, Aconitum columbianum, Mertensia* spp.*, Hydrophyllum fendleri, Maianthemum stellatum, Geranium richardsonii, Actaea rubra, Urtica dioica, Agrostis stolonifera, Poa pratensis, Elymus glaucus*	Manning and Padgett 1995; Padgett et al. 1989
	Alnus incana/ Ribes hudsonianum	Springs	*Alnus viridis, Cornus sericea, Heracleum maximum, Maianthemum stellatum, Actaea rubra*	Youngblood et al. 1985
	Betula occidentalis	Springs	*Cornus sericea, Rosa* spp.*, Poa pratensis, Agrostis stolonifera*	Hansen et al. 1995
	Betula occidentalis/ mesic forb	Springs	*Alnus incana, Salix* spp.*, Maianthemum stellatum, Heracleum maximum, Aconitum columbianum, Equisetum arvense, Geranium richardsonii, Poa pratensis, Agrostis stolonifera, Elymus glaucus, Carex microptera*	Manning and Padgett 1995; Padgett et al. 1989
	Betula occidentalis/Poa pratensis	Springs	*Alnus incana, Salix boothii, Salix bebbiana, Juniperus* spp.*, Rosa* spp.*, Lonicera involucrata, Ribes* spp. *Glyceria striata, Agrostis stolonifera, Juncus balticus, Carex pellita, Carex utriculata, Carex nebrascensis, Trifolium* spp.*, Taraxacum officinale, Cirsium arvense*	Manning and Padgett 1995; Padgett et al. 1989
Tall deciduous tree	*Populus tremuloides/ Cornus sericea*	Springs	*Alnus incana, Rosa* spp.*, Rubus idaeus, Equisetum arvense, Galium triflorum, Maianthemum stellatum, Actaea rubra, Geum macrophyllum*	Hansen et al. 1995
	Populus tremuloides/ Osmorhiza occidentalis	Springs	*Amelanchier alnifolia, Rubus parviflorus, Thalictrum occidentale, Actaea rubra, Heracleum maximum*	Hansen et al. 1995
	Populus tremuloides/Poa pratensis	Springs	*Rosa* spp.*, Phleum pratense, Taraxacum officinale, Fragaria virginiana*	Hansen et al. 1995
Tall willow	*Salix Bebbiana*	Springs	*Poa pratensis, Phleum pratense, Agrostis stolonifera, Solidago canadensis*	Hansen et al. 1995
	Salix boothii/ Carex aquatilis	Springs	*Salix drummondinana, Lonicera involucrata, Betula glandulosa, Ribes* spp.*, Caltha leptosepala, Deschampsia cespitosa, Carex utriculata, Geranium richardsonii, Polemonium* spp.*, Saxifraga odontoloma, Geum macrophyllum*	Padgett et al. 1989
	Salix boothii/ Carex nebrascensis	Springs	*Salix lutea, Salix bebbiana, Glyceria striata, Carex utriculata, Carex simulata, Juncus balticus, Mentha arvensis, Veronica americana, Polemonium* spp.	Padgett et al. 1989; Youngblood et al. 1985

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Table C1 (continued)—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
	Salix boothii/ Carex utriculata	Springs	*Salix drummondinana, Salix wolfii, Lonicera involucrata, Ribes* spp., *Betula glandulosa, Dasiphora fruticosa, Carex aquatilis, Carex microptera, Carex disperma, Juncus balticus, Equisetum arvense, Maianthemum stellatum, Calamagrostis canadensis, Symphyotrichum foliaceum, Fragaria virginiana, Chamerion angustifolium, Castilleja miniata*	Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix boothii/ Equisetum arvense	Springs	*Salix drummondinana, Lonicera involucrata, Ribes,* spp., *Saxifraga odontoloma, Geranium richardsonii, Geum macrophyllum*	Padgett et al. 1989; Youngblood et al. 1985
	Salix boothii/ mesic forb	Springs	*Salix drummondinana, Salix bebbiana, Betula occidentalis, Betula glandulosa, Rosa* spp., *Ribes* spp., *Dasiphora fruticosa, Symphyotrichum foliaceum, Fragaria virginiana, Maianthemum stellatum, Mertensia ciliata, Equisetum arvense, Chamerion angustifolium, Juncus balticus, Calamagrostis canadensis, Carex microptera, Elymus trachycaulus, Poa pratensis*	Padgett et al. 1989; Walford et al. 2001
	Salix boothii/ Maianthemum stellatum	Springs	*Salix drummondiana, Ribes* spp., *Lonicera involucrata, Heracleum maximum, Mertensia ciliata, Thalictrum fendleri, Galium triflorum, Angelica* spp., *Solidago canadensis, Urtica dioica, Fragaria virginiana, Symphyotrichum foliaceum, Potentilla gracilis, Poa pratensis, Deschampsia cespitosa, Carex utriculata, Poa palustris, Bromus ciliatus*	Youngblood et al. 1985
	Salix drummondiana	Springs	*Salix boothi, Populus angustifolia, Poa pratensis, Equisetum arvense, Pedicularis groenlandica*	Hansen et al. 1995; Manning and Padgett 1995; Walford et al. 2001
	Salix drummondiana/ Calamagrostis canadensis	Springs	*Salix boothii, Calamagrostis stricta, Equisetum arvense, Geum macrophyllum, Symphyotrichum foliaceum*	Hansen et al. 1995
	Salix drummondiana/ Carex utriculata	Springs	*Salix geyeriana, Salix boothii, Calamgrostis canadensis, Carex aquatilis, Carex vesicaria, Geum macrophyllum, Epilobium ciliatum*	Hansen et al. 1995
	Salix geyeriana	Springs	*Salix boothii, Poa pratensis, Geum macropyllum, Poa palustris, Phleum pratense, Agrostis stolonifera*	Hansen et al. 1995; Padgett et al. 1989
	Salix geyeriana/ Calamagrostis canadensis	Springs	*Salix boothii, Salix drummondiana, Salix eastwoodiae, Ribes* spp., *Lonicera involucrata, Carex utriculata, Carex microptera, Deschampsia cespitosa, Poa palustris, Poa pratensis, Symphyotrichum foliaceum, Galium boreale, Potentilla gracilis, Packera paupercula, Taraxacum officinale*	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985

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Table C1 (continued)—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
	Salix geyeriana/ Carex aquatilis	Springs	*Salix boothii, Salix bebbiana, Salix wolfii, Salix planifolia, Carex utriculata, Deschampsia cespitosa, Calamagrostis canadensis, Phleum alpinium, Geum macropyllum, Thalictrum fendleri, Polemonium occidentale, Galium trifidum, Caltha leptosepala*	Padgett et al. 1989
	Salix geyeriana/ Carex utriculata	Springs	*Salix boothii, Salix drummondiana, Lonicera involucrata, Ribes* spp.*, Dasiphora fruticosa, Carex aquatilis, Glyceria* spp.*, Equisetum arvense, Geum macrophyllum, Calamagrostsis canadensis, Poa palustris, Poa pratensis*	Manning and Padgett 1995; Padgett et al. 1989; Hansen et al. 1995; Walford et al. 2001; Youngblood et al. 1985
	Salix geyeriana/ mesic graminoid	Springs	*Salix boothii, Salix wolfii, Dasiphora fruticosa, Carex praticola, Carex microptera, Juncus balticus, Deschampsia cespitosa, Poa pratensis, Fragaria virginiana, Symphyotrichum foliaceum, otentilla gracilis, Achillea millefolium, Taraxacum officinale*	Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001
	Salix lutea	Springs	*Salix drummondiana, Lonicera involucrata, Ribes* spp.*, Equisetum arvense, Actaea rubra, Angelica arguta, Symphyotrichum foliaceum, Geranium richardsonii, Saxifraga odontoloma, Senecio triangularis*	Hansen et al. 1995; Manning and Padgett 1995; Youngblood et al. 1985
Low willow	*Salix barclayi-Salix wolfii*	Springs	*Juncus balticus, Carex utriculata, Carex aquatilis, Symphyotrichum foliaceum*	Walford et al. 2001
	Salix candida/ Carex utriculata	Fens	*Salix planifolia, Carex aquatilis, Deschampsia cespitosa, Glyceria striata, Symphyotrichum foliaceum, Packera streptanthifolia, Gentianopsis thermalis*	Hansen et al. 1995; Walford et al. 2001
	Salix eastwoodiae	Springs	*Salix drummondiana, Lonicera involucrata, Mertensia ciliata, Saxifraga odontoloma, Thalictrum occidentale*	Youngblood et al. 1985
	Salix eastwoodii-Calamagrostis canadensis	Fens	*Vaccinium uliginosum, Aulacomnium palustre, Salix planifolia, Calamagrostis canadensis, Deschampsia cespitosa, Carex lachenalii, Arnica mollis, Potentilla diversifolia, Veronica wormskjoldii, Symphyotrichum spathulatum, Agrostis humilis, Juncus drummondii*	Cooper and Andrus 1994

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Table C1 (continued)—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
	Salix planifolia-Caltha leptosepala	Fens	*Vaccinium uliginosum, Gaultheria humifusa, Aulacomnium palustre , Phyllodoce empetriformis, Carex nigricans, Packera streptanthifolia, Tomenthypnum nitens, Deschampsia cespitosa, Antennaria corymbosa, Carex lachenalii, Trollius laxus, Rhodiola rhodantha, Erigeron peregrinus, Arnica mollis, Juncus mertensianus, Potentilla diversifolia, Veronica wormskjoldii, Symphyotrichum spathulatum, Agrostis humilis, Juncus drummondii, Carex aquatilis, Drepanocladus aduncus, Bryum pseudotriquetrum, Pedicularis groenlandica*	Cooper and Andrus 1994
	Salix planifolia/ Carex aquatilis	Springs	*Salix wolfii, Salix boothii, Betula glandulosa, Dasiphora fruticosa, Caltha leptosepala, Agrostis* spp.*, Carex utriculata, Carex canescens, Deschampsia cespitosa, Calamagrostis canadensis, Galium trifidum, Pedicularis groenlandica, Ligusticum tenuifolium, Sedum* spp.*, Symphyotrichum spathulatum, Senecio sphaerocephalus*	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001
	Salix planifolia/ Deschampsia cespitosa	Springs	*Betula glandulosa, Dasiphora fruticosa, Salix glauca, Ligusticum tenuifolium, Caltha leptosepala, Polygonum bistortoides, Sedum* spp.*, Erigeron peregrinus, Deschampsia cespitosa, Danthonia intermedia, Phleum alpinum, Juncus drummondii, Carex paysonis*	Padgett et al. 1989; Walford et al. 2001
	Salix wolfii/Carex aquatilis	Springs	*Betula glandulosa, Dasiphora fruticosa, Carex utriculata, Deschampsia cespitosa, Juncus balticus, Poa preatensis, Pedicularis groenlandica, Polemonium occidentale, Symphyotrichum foliaceum, Fragaria virginiana*	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Salix wolfii/Carex nebrascensis	Springs	*Betula glandulosa, Carex simulata, Deschampsia cespitosa, Symphyotrichum foliaceum, Pedicularis groenlandica, Polemonium occidentale*	Youngblood et al. 1985
	Salix wolfii/Carex utriculata	Springs	*Betula glandulosa, Dasiphora fruticosa, Salix boothii, Carex aquatilis, Polemonium occidentale, Symphyotrichum foliaceum, Fragaria virginiana*	Padgett et al. 1989; Youngblood et al. 1985
Nonwillow shrub	*Artemisia cana/Festuca idahohensis*	Springs	*Dasiphora fruticosa, Artemisia tridentata, Carex microptera, Fragaria virginiana, Hymenoxys hoopesii, Potentilla gracilis*	Hansen et al. 1995; Youngblood et al. 1985
	Atremisia cana/ Poa pratensis	Springs	*Hymenoxys hoopesii, Fragaria virginiana, Potentilla gracilis, Valeriana occidentalis, Symphyotrichum* spp.	Padgett et al. 1989; Youngblood et al. 1985

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Table C1 (continued)—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
	Dasiphora fruticosa/ Deschampsia cespitosa	Springs	*Salix wolfii, Artemesia cana, Carex microptera, Carex praegracilis, Poa pratensis, Fragaria virginiana, Hymenoxys hoopesii, Potentilla gracilis*	Hansen et al. 1995; Padgett et al. 1989; Youngblood et al. 1985
	Rhamnus alnifolia	Springs	*Elymus glaucus, Calamagrostis canadensis, Galium triflorum, Heracleum maximus, Maianthemum stellatum*	Youngblood et al. 1985
	Rosa woodsii	Springs	*Symphoricarpos* spp.*, Poa pratensis*	Hansen et al. 1995
	Vaccinium uliginosum	Fens	*Kalmia polifolia, Gaultheria humifusa, Sphagnum teres, Aulacomnium palustre, Salix planifolia, Phyllodoce empetriformis, Carex nigricans, Packera streptanthifolia, Calamagrostis canadensis, Erigeron peregrinus, Juncus mertensianus, Potentilla diversifolia, Agrostis humilis, Carex aquatilis, Eleocharis quinqueflora, Carex bigelowii*	Cooper and Andrus 1994
Herbaceous	*Calamagrostis canadensis*	Fens	*Aulacomnium palustre, Salix planifolia, Juncus mertensianus, Phleum alpinum, Carex aquatilis, Viola epipsila, Bryum pseudotriquetrum*	Cooper and Andrus 1994
	Caltha leptosepala	Springs	*Carex aquatilis, Carex utriculata, Carex simulata, Carex pellita, Deschampsia cespitosa, Pedicularis groenlandica, Equisetum arvense*	Padgett et al. 1989
	Carex aquatilis	Springs, fens	*Salix planifolia, Carex utriculata, Carex canescens, Carex microptera, Carex praeceptorum, Poa pratensis, Juncus balticus, Deschampsia cespitosa, Symphyotrichum foliaceum, Polemonium occidentale*	Manning and Padgett 1995; Padgett et al. 1989; Hansen et al. 1995; Walford et al. 2001; Youngblood et al. 1985
	Carex aquatilis-Viola epipsila	Fens	*Carex utriculata, Menyanthes trifoliata, Calliergon stramineum, Sphagnum subsecundum, Sphangnum teres, Polytrichum strictum, Eleocharis quinqueflora, Drepanocladus aduncus, Carex canescens, Calliergonella cuspidata, Pedicularis groenlandica, Caltha leptosepala, Vaccinium uliginosum, Packera streptanthifolia, Carex illota, Meesia triquetra,Calamagrostis canadensis, Deschampsia cespitosa, Salix planifolia, Aulacomnium palustre*	Cooper and Andrus 1994
	Carex bigelowii-Caltha leptosepala	Fens	*Eleocharis quinqueflora, Drepanocladus aduncus, Carex canescens, Drepanocladus exannulatus, Pedicularis groenlandica, Carex lachenalii, Salix planifolia, Rhodiola rhodantha*	Cooper and Andrus 1994
	Carex buxbaumi	Fens	*Carex aquatilis, Carex saxatilis, Deschampsia cespitosa, Caltha leptosepala, Pedicularis groenlandica, Ligusticum tenuifolium*	Padgett et al. 1989

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Table C1 (continued)—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
	Carex canescens	Fens	*Eleocharis quinqueflora, Drepanocladus aduncus, Calliergonella cuspidata, Carex bigelowii*	Cooper and Andrus 1994
	Carex illota-Philonotis fontana	Fens	*Aulacomnium palustre, Salix planifolia, Carex nigricans, Packera streptanthifolia, Meesia triquetra, Deschampsia cespitosa, Rhodiola rhodantha, Juncus mertensianus, Carex bigelowii, Bryum pseudotriquetrum, Pedicularis groenlandica, Caltha leptosepala*	Cooper and Andrus 1994
	Carex pellita	Springs	*Poa pratensis, Deschampsia cespitosa, Carex aquatilis, Juncus balticus, Mentha arvense, Taraxacum officinale, Equisetum arvense*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989
	Carex lasiocarpa	Fens	*Carex aquatilis, Carex utriculata, Carex canescens, Carex buxbaumi, Carex pellita*	Padgett et al. 1989;
	Carex limosa	Fens	*Carex aquatilis, Eleocharis quinqueflora, Eriophorum scheuchzeri, Pedicularis groenlandica, Menyanthes trifoliata*	Hansen et al. 1995; Padgett et al. 1989; Walford et al. 2001
	Carex limosa-Menyanthes trifoliata	Fens	*Comarum palustre*	Cooper and Andrus 1994
	Carex nebrascensis	Springs	*Juncus balticus, Deschampsia cespitosa, Poa palustris, Eurybia integrifolia, Polemonium occidentale*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Youngblood et al. 1985
	Carex nigricans-Packera streptanthifolia	Fens	*Aulacomnium palusrte, Salix planifolia, Tomentypnum nitens, Deschampsia cespitosa, Antennaria corymbosum, Carex lachenalii, Trollius laxus, Rhodiola rhodantha, Juncus mertensianus, Potentilla diversifolia, Veronica wormskjoldii, Symphyotrichum spathulatum, Agrostis humilis, Eleocharis quinqueflora, Pedicularis groenlandica, Caltha leptosepala*	Cooper and Andrus 1994
	Carex utriculata	Springs, fens	*Carex aquatilis, Carex vesicaria, Carex atherodes, Carex simulata, Carex microptera, Polemonium occidentale, Deschampsia cespitosa, Poa pratensis, Geum macrophyllum, Sphagnum platyphyllum, Drepanocladus aduncus, Pedicularis groenlandica*	Cooper and Andrus 1994; Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Carex saxatilis	Fens	*Carex aquatilis, Carex utriculata, Carex canescens, Eriophorum scheuchzeri, Pedicularis groenlandica, Caltha leptosepala, Deschampsia cespitosa*	Padgett et al. 1989

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Table C1 (continued)—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
	Carex scopulorum	Springs	*Salix planifolia, Caltha leptosepala, Carex illota, Deschampsia cespitosa, Juncus mertensianus, Packera* spp.	Hansen et al. 1995; Manning and Padgett 1995; Walford et al. 2001
	Carex simulata	Springs, fens	*Salix wolfii, Carex aquatilis, Carex utriculata, Deschampsia cespitosa, Pedicularis groenlandica*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Deschampsia cespitosa	Springs	*Carex aquatilis, Carex utriculata, Carex microptera, Carex scopulorum, Poa pratensis, Symphyotrichum foliaceum, Potentilla gracilis, Geum macrophyllum, Calamagrostis canadensis, Phleum alpinum, Antennaria corymbosa*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Deschampsia cespitosa-Antennaria corymbosa	Fens	*Carex nigricans, Carex lachenalii,, Erigeron peregrinus, Arnica mollis, Juncus mertensianus, Potentilla diversifolia, Veronica wormskjoldii, Symphyotrichum spathulatum, Juncus drummondii, Phleum alpinum, Polytrichum strictum, Carex bigelowii, Pedicularis groenlandica, Caltha leptosepala*	Cooper and Andrus 1994
	Eleocharis palustris	Springs	*Eleocharis acicularis, Alopecurus aequalis, Hippuris vulgaris, Utricularia macrorhiza, Potamogeton* spp., *Ranunculus aquatilis, Juncus balticus, Hordeum brachyantherum, Poa pratensis*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989
	Eleocharis quinqueflora	Springs, fens	*Carex aquatilis, Trichophorum cespitosum, Pedicularis groenlandica, Eleocharis rostellata*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989
	Eleocharis quinqueflora-Drepanocladus aduncus	Fens	*Carex utriculata, Carex aquatilis, Calliergon stramineum, Calliergon trifarium, Bryum pseudotriquetrum, Pedicularis groenlandica, Caltha leptosepala*	Cooper and Andrus 1994
	Juncus balticus	Springs	*Carex aquatilis, Carex utriculata, Carex petasata, Deschampsia cespitosa, Phleum alpinum, Poa pratensis, Potentilla gracilis, Fragaria virginiana, Symphyotrichum foliaceum, Sonchus arvensis, Trifolium hybridum*	Hansen et al. 1995; Manning and Padgett 1995; Padgett et al. 1989; Walford et al. 2001; Youngblood et al. 1985
	Isoetes bolanderi-Warnstorfia sarmentosa	Fens	*Callitriche* spp.	Cooper and Andrus 1994

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Table C1 (continued)—Riparian and wetland community types that are expected to occur at GDEs in the BTNF.

Dominance group	Community type	GDE type	Associated species	References
	Nuphar lutea-Potamogeton natans	Fens	*Potamogeton perfoliatus, Utricularia vulgaris, Potamogeton alpinus*	Cooper and Andrus 1994
	Potamogeton richardsonii	Fens	*NA*	Cooper and Andrus 1994
	Sparganium angustifolium-Callitriche spp.	Fens	*NA*	Cooper and Andrus 1994
	Veratrum californicum	Springs	*Delphinium occidentale, Rudbeckia occidentalis, Thalictrum fendleri, Hymenoxys hoopesii, Mertensia* spp.	Manning and Padgett 1995; Padgett et al. 1989; Youngblood et al. 1985

Appendix D. Distribution of Riparian Ecosystems in Geographic Units of the Bridger-Teton National Forest

Methods

We combined several sources of data in a GIS to describe the extent of riparian ecosystems in the Forest and in geographic units. To estimate current area of riparian ecosystems, we obtained a riparian extent map of the BTNF (Abood et al. 2012). This map represents areas near perennial and intermittent streams that are within the 50-year floodplain and are therefore inundated frequently enough to be considered riparian. The map also includes wetlands and hydric soil units within valley bottoms. The 50-year floodplain map is therefore a useful indicator of potential riparian ecosystem extent, as represented by hydrological conditions. We also examined a shapefile of existing vegetation to identify the current extent of riparian ecosystems, as represented by vegetation types. We calculated miles of perennial and intermittent stream channels, using data from the National Hydrography Dataset. We used the State geologic map compilations from the U.S. Geological Survey to identify geological features associated with patterns of riparian distribution.

Unit Summaries

Gros Ventre

There are approximately 2,572 perennial stream miles and 3,051 intermittent stream miles in the Gros Ventre unit. These streams are part of the Snake River, Yellowstone River, and Colorado River Basins. Riparian vegetation is abundant throughout the unit, but stands are especially extensive in unconsolidated terrains of the Yellowstone River headwaters, the Gros Ventre River headwaters, the Hoback River headwaters, the upper Green River, and lower Blackrock Creek (fig. D1). Bands of riparian vegetation are less extensive in the carbonate rocks of the Gros Ventre Range. Potential riparian extent is 178,925 acres, or 12 percent of the unit. BTNF mapping classifies 4 percent (59,266 acres) of cover as riparian vegetation.

Wyoming

There are approximately 1,395 perennial stream miles and 2,117 intermittent stream miles in the Wyoming geographic unit. Most streams are within the Colorado and Snake River Basins, with a small percentage in the Great Basin. Riparian ecosystems are abundant throughout the unit but are especially extensive in unconsolidated terrains of the upper Hoback River and tributaries, North Horse Creek, and other streams on the Western slopes of the Wyoming Range (fig. D2). Potential riparian extent is 84,431 acres, or 8 percent of the unit. BTNF mapping classifies 2 percent (24,848 acres) of cover as riparian vegetation.

Windriver

There are approximately 1,110 perennial stream miles and 703 intermittent stream miles in the Wind River geographic unit. Streams feed into the Colorado River and Sweetwater River Basins. Riparian corridors or patches of riparian vegetation are distributed throughout the unit. Formation of extensive floodplains is somewhat limited by the crystalline terrain of the Wind River Mountains. Areas with extensive stands include the unconsolidated terrain of the Big Sandy River and the glaciated headwaters of Boulder Creek (fig. D3). Potential riparian extent is 40,122 acres, or 7 percent of the unit. BTNF mapping classifies 3 percent (16,512 acres) of cover as riparian vegetation.

Kemmerer

There are approximately 471 perennial stream miles and 397 intermittent stream miles in the Kemmerer unit. These streams drain into the Colorado River Basin, the Snake River Basin, and the Great Basin. Riparian ecosystems are abundant throughout the unit but are especially extensive in the sedimentary terrain of Hobble Creek and the unconsolidated terrains of Henry's Fork Creek and Fontanelle Creek (fig. D4). Potential riparian extent is 22,134 acres, or 7 percent of the unit. BTNF mapping classifies 3 percent (8,370 acres) of cover as riparian vegetation.

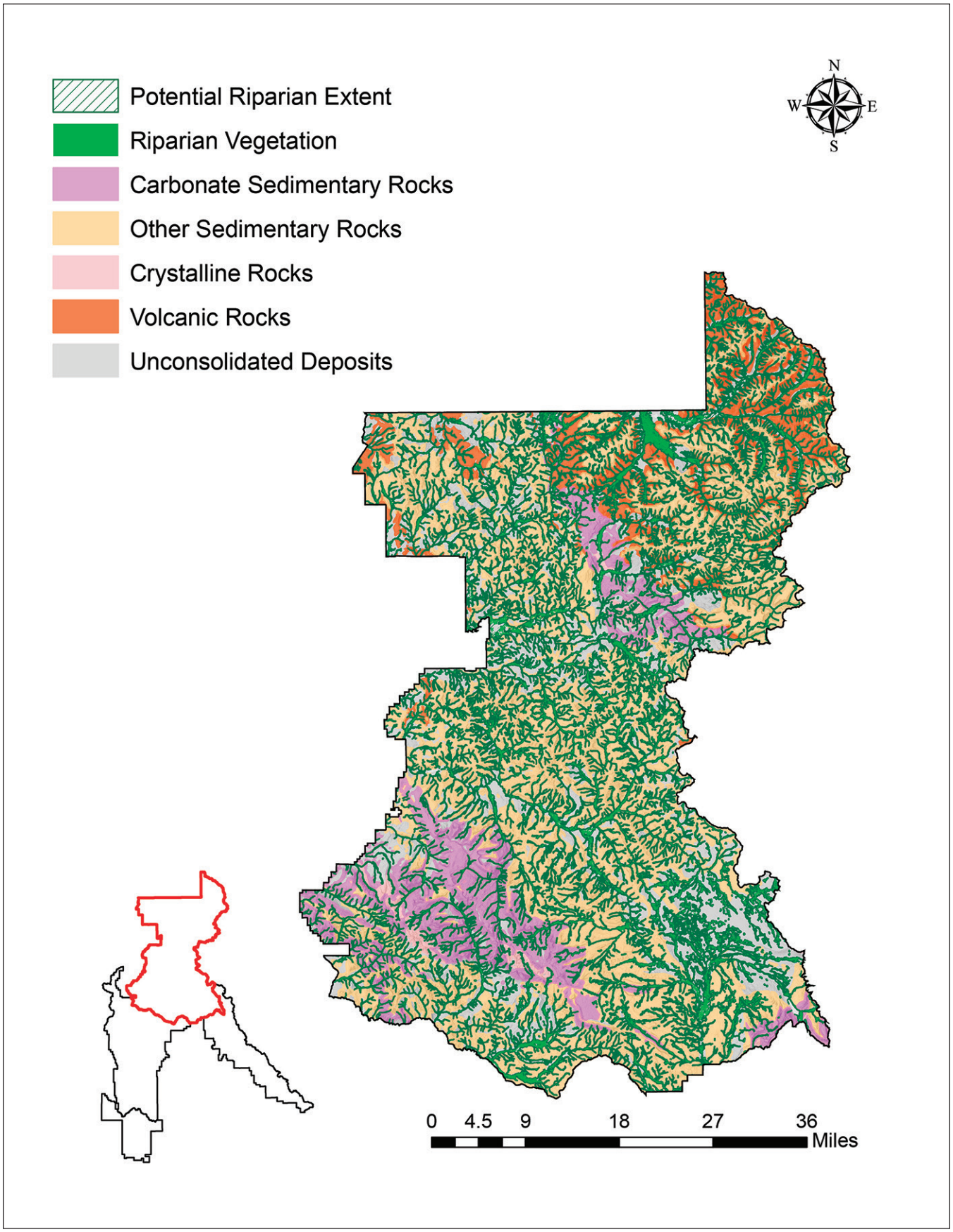


Figure D1—Distribution of riparian ecosystems in the Gros Ventre geographic unit.

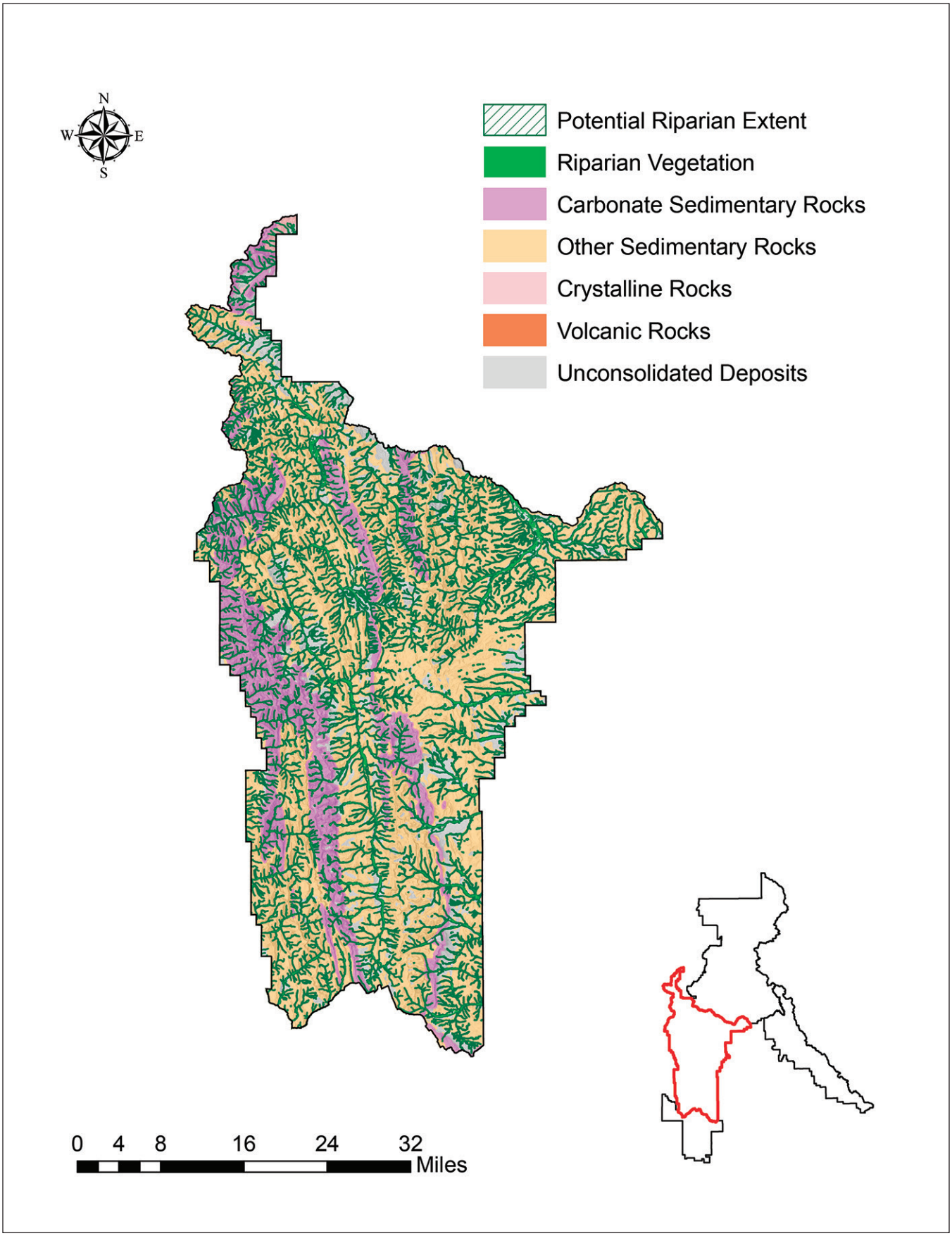


Figure D2—Distribution of riparian ecosystems in the Wyoming geographic unit.

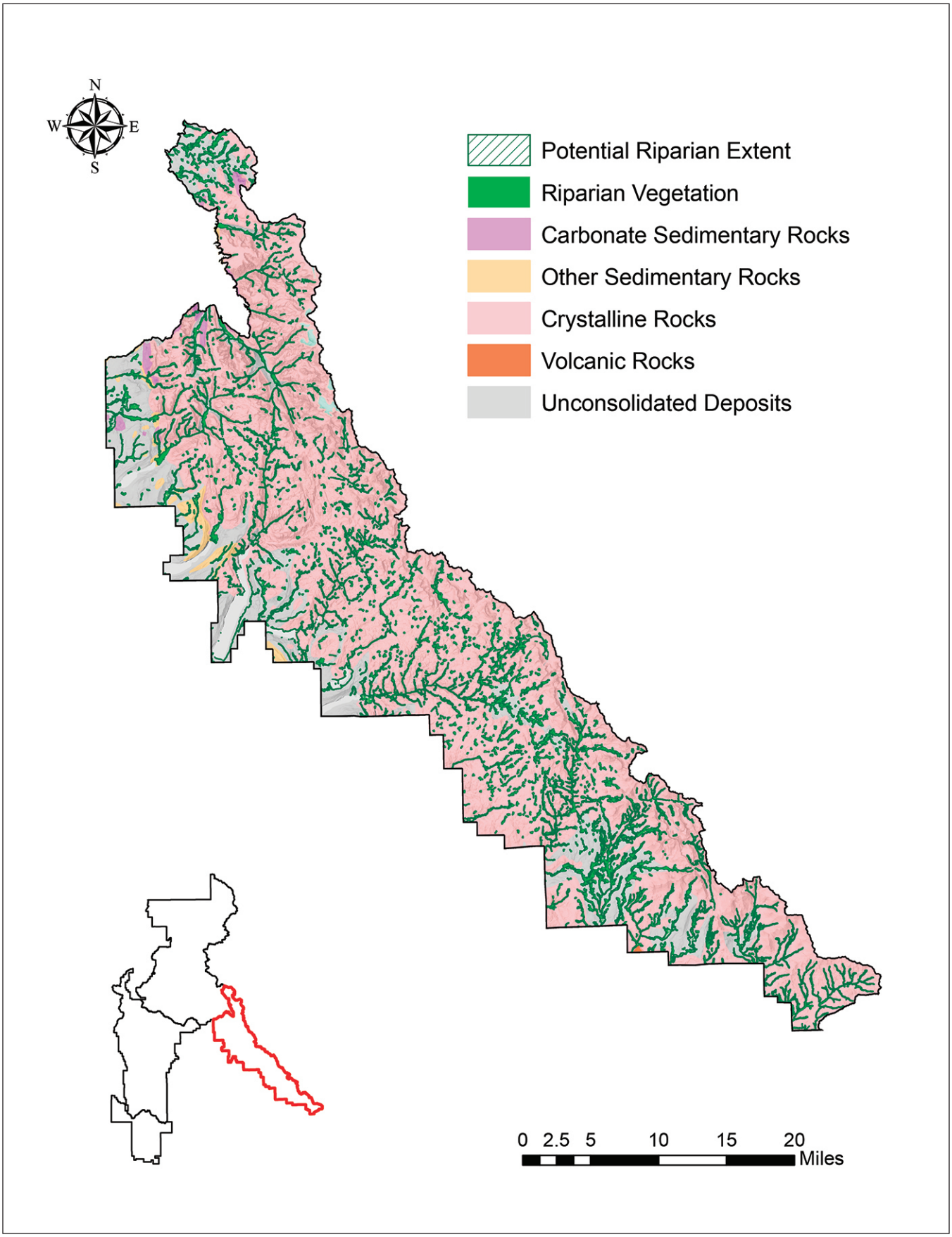


Figure D3—Distribution of riparian ecosystems in the Windriver geographic unit.

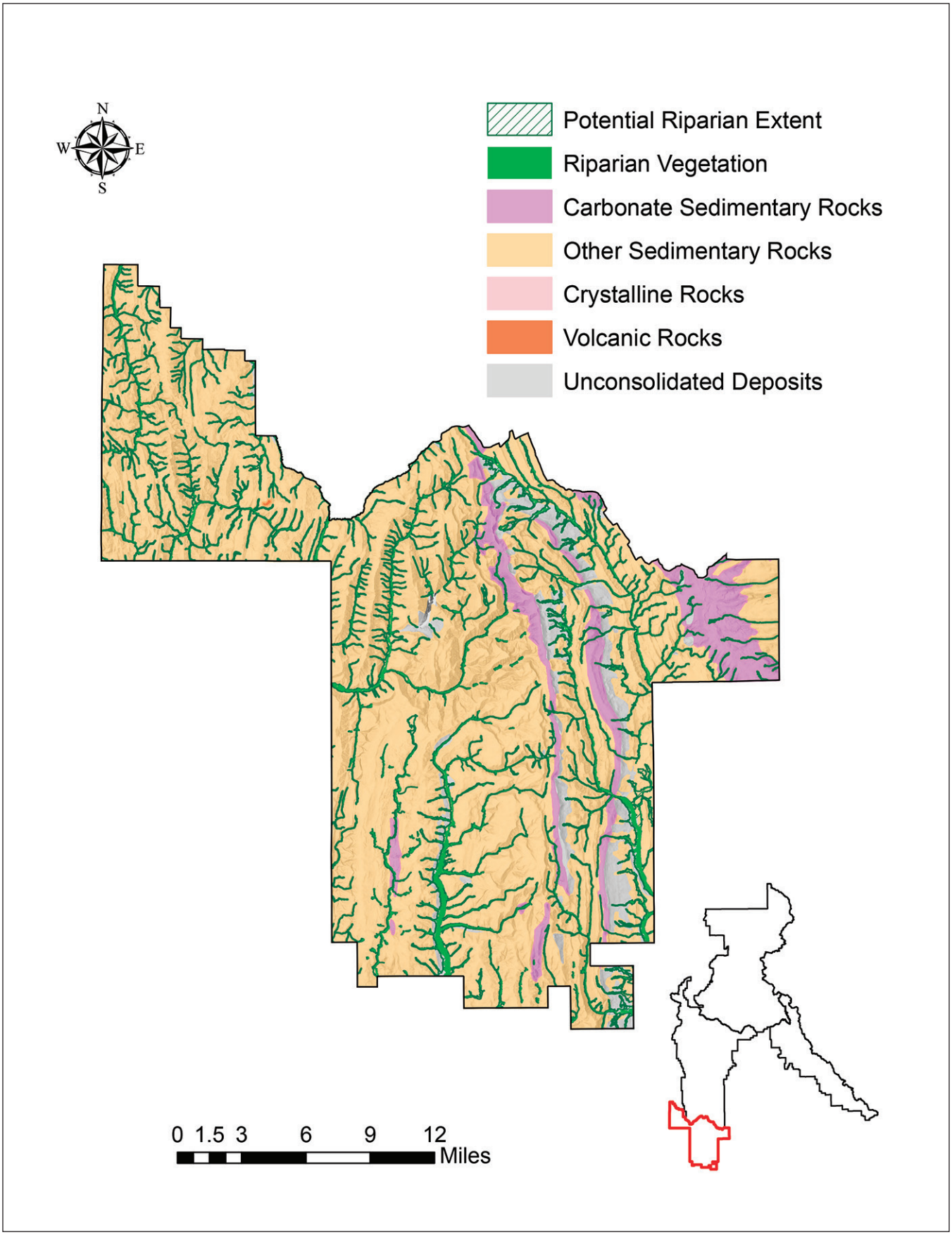


Figure D4—Distribution of riparian ecosystems in the Kemmerer geographic unit.

Appendix E. Distribution of GDEs in Geographic Units of the Bridger-Teton National Forest

Methods

Below we describe the potential distribution of GDEs in each geographic unit. We obtained shapefiles of spring distribution from the National Hydrography Dataset (NHD) and a BTNF geodatabase. To describe fen distribution, we use results from a fen mapping program conducted by the Colorado Natural Heritage Program (CNHP). Fens were mapped using aerial photography, topographic maps, and NWI data (Smith and Lemly 2018). Confidence was ranked based on photo evidence of vegetation and hydrological conditions, and by landscape position of potential fens (Smith and Lemly 2018). We used the CNHP shapefile depicting likely, possible, and low confidence fens to estimate the number and area of fens in each geographic unit. We used shapefiles created by the U.S. Geological Survey to map karst, principal aquifers, and other geological units. We displayed faults, also mapped by the USGS, which can create sites for groundwater discharge or transport groundwater (Kreamer and Springer 2008).

Unit Summaries

Gros Ventre

The Gros Ventre unit contains several distinct geological features including a portion of the Absaroka Range, the Gros Ventre Range, the Mt. Leidy Highlands, and the Washakie Range. Sedimentary rocks dominate the Gros Ventre Range, volcanic rocks dominate the Absaroka Range, and a mixture of igneous, sedimentary, and metamorphic rocks are distributed throughout (fig. E1; USGS 2003). This geology is conducive to groundwater storage and recharge throughout the unit.

There are 61 springs mapped by NHD (0.00004/acre) and 93 springs (0.0001/acre) mapped in the BTNF geodatabase. There are numerous springs mapped in the sedimentary landscape of the Gros Ventre Range and the mountains of the northwestern corner of the unit. Many of these springs are associated with faults. There are no springs mapped by NHD in the Absaroka Range in the northeastern corner of the unit. Given the typical prevalence of springs in faulted volcanic settings (Whiting and Stamm 1995), it is likely that numerous springs are present but unmapped in this remote Wilderness area.

Over 15 percent of the Gros Ventre unit is composed of carbonate bedrock with potential for karst formation. Most of these deposits are associated with the Gros Ventre Range. Other areas include a band of sedimentary bedrock in the northern portion of the unit in the Pacific Creek and Buffalo Fork watersheds. Just over 5 percent of the unit has underlying aquifers. A large section of Colorado Plateau sandstone aquifer is located in the southern portion of the unit and a small portion of Pacific Northwest basaltic aquifer is located at the northwestern corner of the unit.

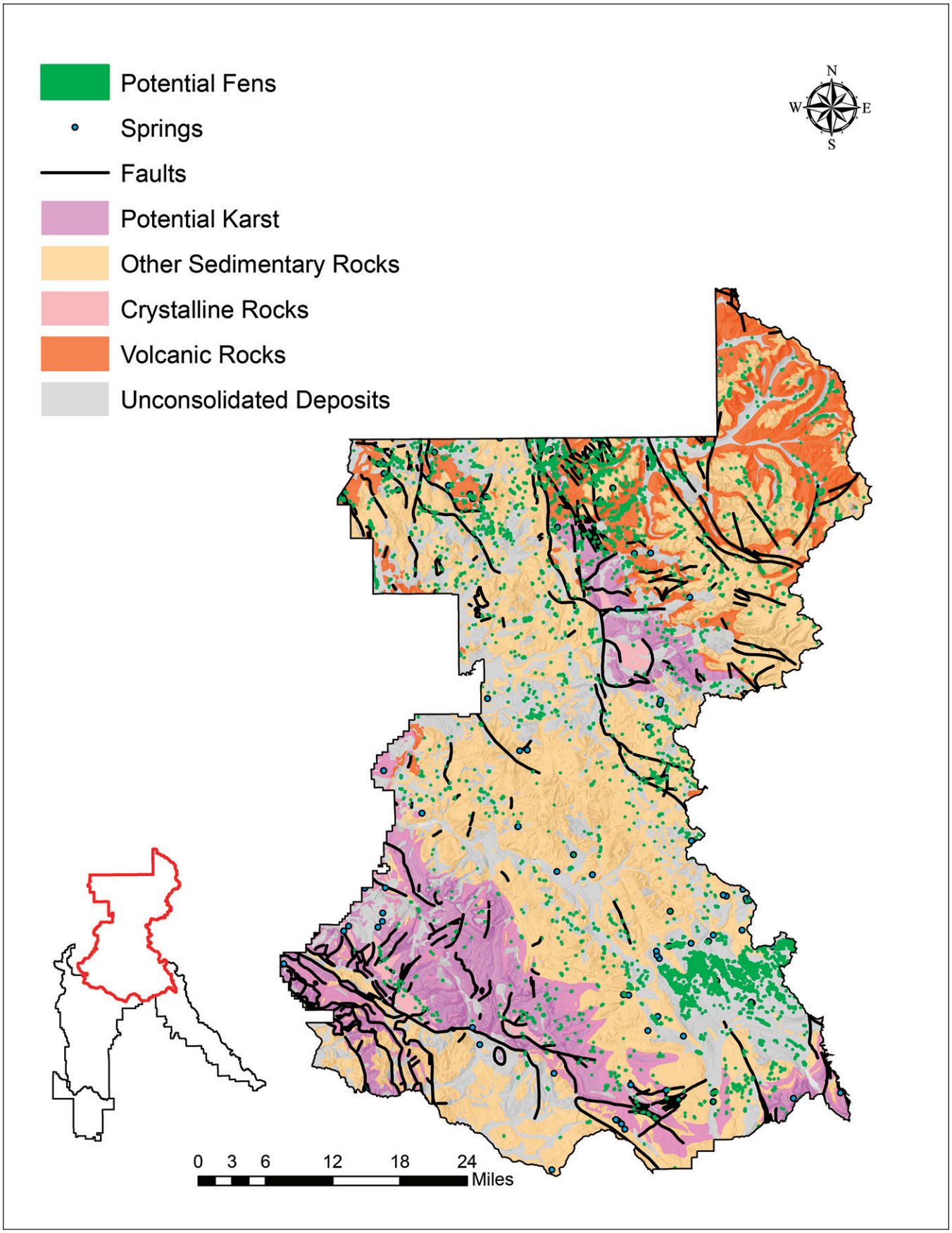


Figure E1—Distribution of groundwater-dependent ecosystems in the Gros Ventre geographic unit.

The CNHP mapped 4,247 potential fens in this geographic unit. Of these, likely fens cover 1,671.2 acres (0.1 percent of the unit), possible fens cover 2,238.2 acres (0.1 percent), and low confidence fens cover 3,992.3 acres (0.3 percent). The Gros Ventre unit contains the largest potential fens in the Forest (Smith and Lemly 2018). There is a large concentration of likely fens in the Gros Ventre River headwaters and the Wagon Creek watershed of Green River Basin in the southeastern corner of the unit. Likely fens are also distributed across the northern and southern portions of the unit. Possible and low confidence fens are more evenly distributed across the unit.

Wyoming

This unit is largely composed of the folded, faulted, and fractured sedimentary units of the Overthrust Belt (BTNF 2001). There are 27 springs mapped by NHD (0.00003/acre) and 85 springs (0.0001/acre) mapped in the BTNF geodatabase. Many springs at the southern end of the unit are associated with faults (fig. E2). Over 30 percent of the Wyoming unit is composed of carbonate bedrock with potential for karst formation. Most of these deposits are associated with the Salt River Range. Nearly 14 percent of the unit has underlying aquifers. Portions of Colorado Plateau sandstone aquifers are located along the east side of the unit and a portion of Upper Tertiary sandstone aquifer is located along the western edge.

CNHP mapped 854 potential fens in the unit. Of these, likely fens cover 34.7 acres (0.003 percent of the unit), possible fens cover 179.9 acres (0.02 percent), and low confidence fens cover 1,305.1 acres (0.1 percent). The few likely and possible fens are scattered across the unit. Low confidence fens are located throughout the unit as well, with clusters in the Salt Creek and Wyoming ranges.

Windriver

Groundwater storage, transmission, and discharge are limited in the granitic and metamorphic rocks that dominate this range (fig. E3). Mapped GDEs in the unit are primarily wetlands, including fens, which are associated with glacial activity (Cooper and Andrus 1994). There are only 2 springs (0.000003/acre) mapped in the BTNF geodatabase. There are no springs mapped by NHD in this unit. Given the crystalline bedrock composition of the Wind River Range, karst is nearly absent from this unit. Nearly 9 percent of the area overlaps portions of Colorado Plateau sandstone aquifers.

CNHP mapped 4,748 potential fens in the unit. Of these, likely fens cover 2,426.9 acres (0.4 percent of the unit), possible fens cover 987.0 acres (0.2 percent), and low confidence fens cover 669.5 acres (0.1 percent). This unit had the highest density of potential fens in the Forest. Likely fens were most abundant in the watersheds of North Fork of Silver Creek, Upper Boulder Creek, Upper Pole Creek, and Washakie Creek-East Fork River.

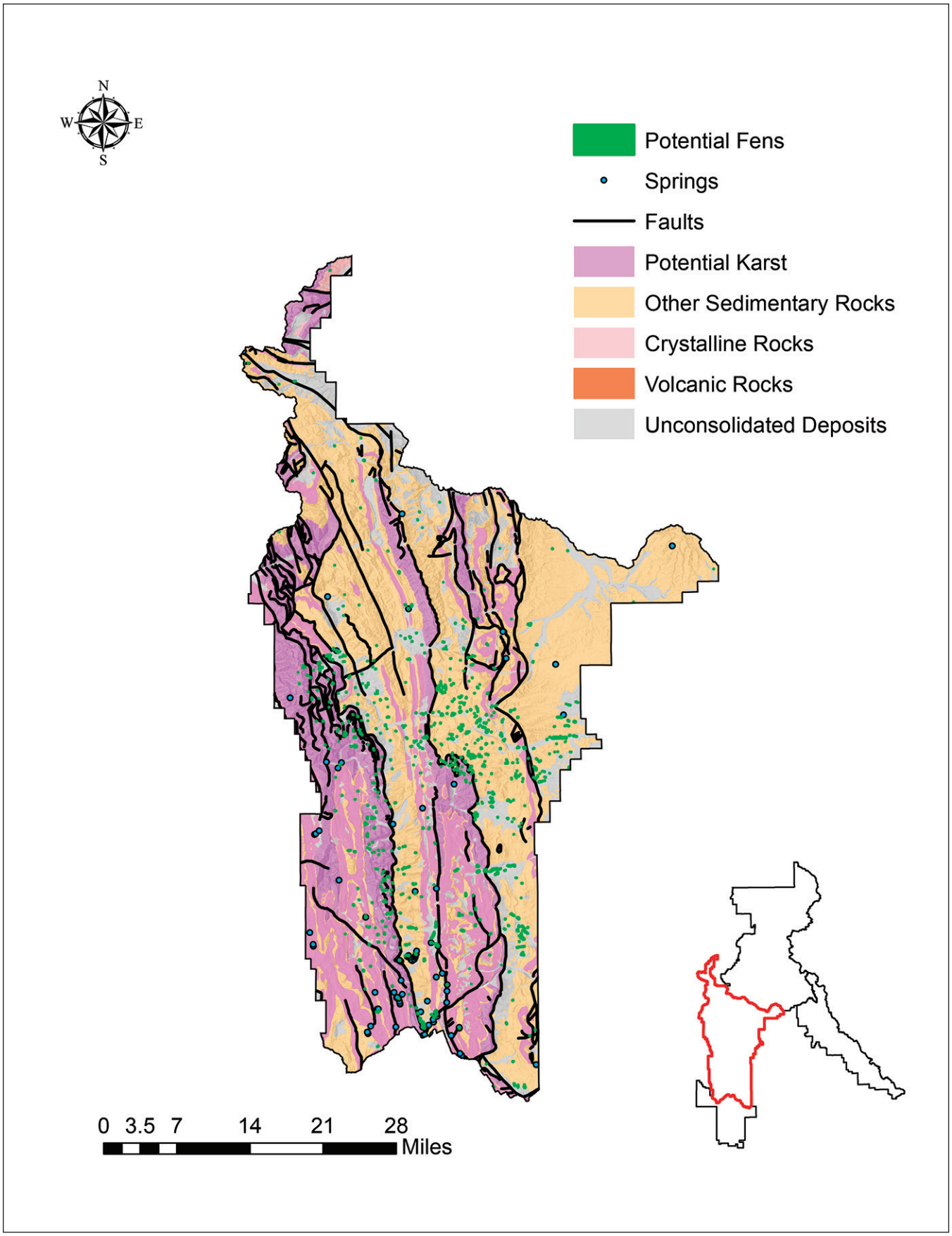


Figure E2—Distributions of groundwater-dependent ecosystems in the Wyoming geographic unit.

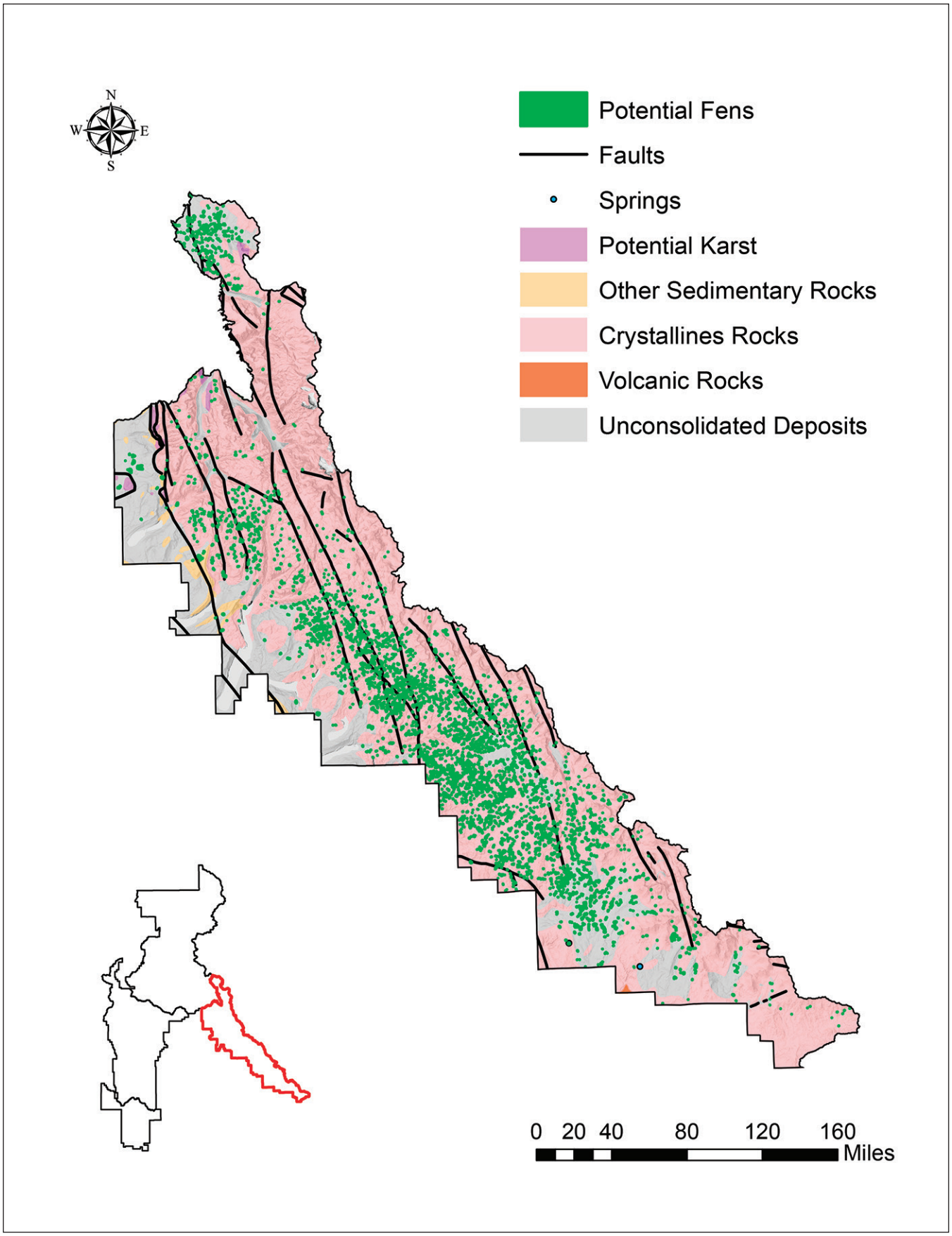


Figure E3—Distribution of groundwater-dependent ecosystems in the Windriver geographic unit.

Kemmerer

This unit contains several folded, faulted, and fractured sedimentary units of the Overthrust Belt (BTNF 2001). There are 51 springs mapped by NHD (0.0002/acre) and 74 springs (0.0002/acre) mapped in the BTNF geodatabase, giving Kemmerer the highest spring density mapped on the Forest. Many springs are associated with faults and potential karst (fig. E4).

Nearly 50 percent of the Kemmerer unit is composed of carbonate bedrock with potential for karst formation. Nearly 10 percent of the unit has underlying Colorado Plateau sandstone aquifers.

CNHP mapped 94 potential fens. Of these, likely fens cover 32.4 acres (0.01 percent of the unit), possible fens cover 36.4 acres (0.01 percent), and low confidence fens cover 138.7 acres (0.04 percent). Potential fens are limited in this unit and several likely fens are located near Commissary Ridge.

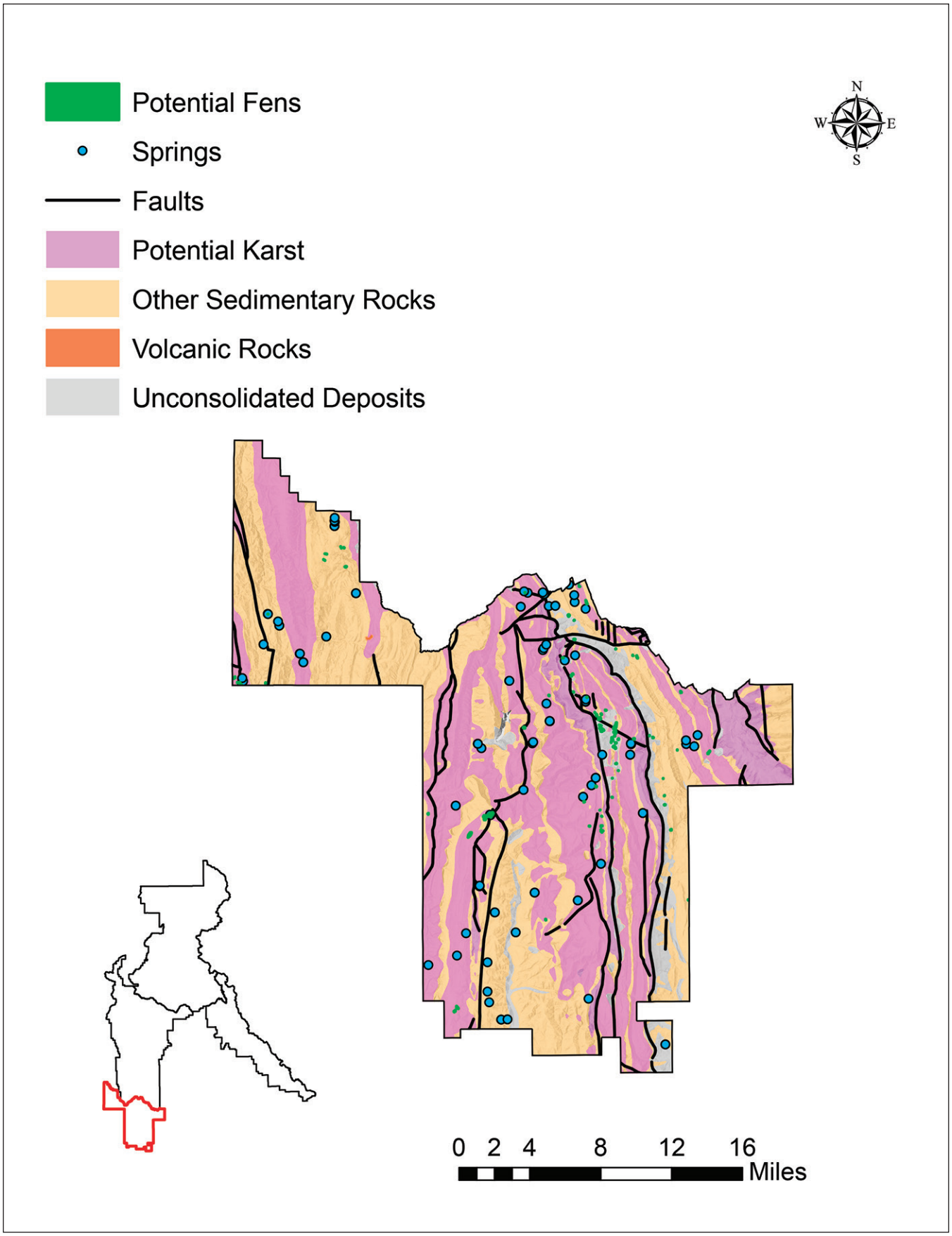


Figure E4—Distribution of groundwater-dependent ecosystems in the Kemmerer geographic unit.

Appendix F. Surface Water and Groundwater Fluctuations

Methods

We scored five indicators for water fluctuations in surface water systems based on whether they showed evidence of no, moderate, or substantial alteration. The indicators included conifer encroachment, upland encroachment, a water quantity score, deviations in winter precipitation, and deviations in winter temperature. If the indicator had little or no alteration, it was given a score of 5; moderate alteration was given a score of 3; and substantial alteration was given a score of 1 (table F1). The thresholds for moderate and substantial alteration for each indicator were determined from the literature or from the data sources. We used reference reaches within Wilderness areas on the BTNF to determine alteration thresholds for floodplain acres per stream mile and the percent of floodplains burned at moderate severity. The scores for each unit were summed and divided by the potential total of 25 to give a percentage rating for each.

We evaluated NRV status based on how many indicators provided evidence of moderate or substantial alteration from the NRV. We considered units to be within the NRV for groundwater and surface water fluctuations if the index was greater than 77 percent, meaning at least 3 indicators showed no evidence of alteration and no more than one indicator showed evidence of substantial alteration. Units were classified as moderately altered from the NRV if the index was between 50 and 76 percent, which is equivalent to at least 2 indicators showing evidence of substantial and moderate alteration. Finally, we classified units as outside the NRV if the index was less than 50 percent. This score is equivalent to multiple indicators showing evidence of substantial alteration and no more than one indicator showing evidence of no alteration from the NRV. We also used WHAM data related to beaver activity and upland infiltration to compare percentages for each unit to overall reference conditions on the Forest. We did not incorporate these values into the index.

Table F1—Thresholds for evaluating indicators of surface and groundwater fluctuations in regard to alteration from NRV.

Indicator	Data source	Little or no alteration	Moderate alteration	Significant alteration
Conifer encroachment	R-CAT	< 33%	33% < x < 66%	> 66%
Upland encroachment	R-CAT	< 33%	33% < x < 66%	> 66%
Water quantity score	WCC	≤ 1.6	1.7 ≤ x ≤ 2.2	> 2.3
Deviation in winter temperature	TCA	< 2 ˚F	2 ˚F ≤ x < 3.2 ˚F	≥ 3.2 ˚F
Deviation in winter precipitation	TCA	< 5%	5% < x < 10%	> 10%

We were unable to identify any data sources for determining the NRV status of water fluctuations at GDEs on the Forest. We used river basin assessments completed by the State of Wyoming to describe recharge and yield to groundwater systems present on the BTNF, however there was insufficient information in these reports to determine whether local stressors were altering fluctuations and degrading GDEs.

Unit Summaries

Gros Ventre

Stressors in this unit included roads, grazing, and altered temperature and precipitation regimes. While the road density of Gros Ventre is relatively low for the Forest (0.0007 road miles per acre) and the TCA indicated only 1.7 percent of the unit is in poor or very poor condition due to roads, 62 percent of road miles were classified as unimproved. Like roads, the percentage of this unit impacted by grazing is relatively low (48 percent), but 70 percent of those acres are actively grazed. It appears grazing has had limited impacts on the hydrologic function of rangelands. Based on the WCC, 99.7 percent of the Gros Ventre unit had properly functioning rangelands that are capable of capturing, storing, and safely releasing water from rainfall, runoff, and snowmelt.

The Gros Ventre area has experienced changes in temperature and precipitation regimes. Average winter temperatures from 2010 to 2014 are 2.0 °F warmer than the previous century. According to the TCA (Cleland et al. 2017), 2 percent of Gros Ventre was considered in poor condition in regard to temperature exposure. The remaining 98 percent was in very poor condition. There has been reduced precipitation during the summer and winter months but large increases in spring and fall precipitation. The average decrease in winter precipitation in recent years has been 2.4 percent, which is relatively high compared to the rest of the Forest. The TCA concluded that 25 percent of the Gros Ventre unit was in good condition in terms of precipitation exposure. The remaining 75 percent was in very good condition.

WHAM data indicated that beaver activity in Gros Ventre is similar to reference reaches across the Forest. Sixty percent of reaches had no beaver activity; 12 percent of reaches had 1 to 5 percent impacted by beaver; 14 percent had 6 to 25 percent of reaches impacted by beaver; 5 percent of reaches each were classified as 26 to 50 and 51 to 75 percent impacted by beaver activity. Eighty-six percent of WHAM reaches in Gros Ventre recorded that upland infiltration was occurring, which is greater than the 66 percent recorded for Forest reference conditions. The average WCC water quantity score of watersheds within the Gros Ventre unit was 2, indicating stream hydrographs were moderately departed from natural flow regimes in most watersheds. Upland encroachment was observed at 7.1 percent of valley bottoms and conifer encroachment was observed at 4.9 percent of valley bottoms in Gros Ventre. Of the five indicators of surface water and groundwater fluctuations, two provided evidence of moderate alteration from the NRV in the Gros Ventre unit and three indicators showed no evidence

of alteration from the NRV. The overall surface water and groundwater fluctuation index was 84 percent and this unit was considered **within** the NRV.

Wyoming

Stressors in the Wyoming unit included roads throughout the unit and within the floodplain, trails throughout the unit and within the floodplain, timber harvest, and livestock grazing. The Wyoming unit has a relatively high road density for the Forest (0.001 road miles per acre) and 64 percent of road miles were classified as unimproved. Additionally, this unit has relatively high road density within floodplains compared to the rest of the Forest (0.002 miles/floodplain acre). Nevertheless, the TCA indicated only 2 percent of the unit is in very poor condition due to roads (Cleland et al. 2017). There are 0.0009 trail miles per acre in the Wyoming unit and there are 0.002 trail miles per floodplain acre, both of which are relatively high compared to the rest of the Forest. Only 1.9 percent of the unit has experienced timber harvest, but 68 percent of those harvests were clear cuts that may affect water fluctuations. Eighty-seven percent of the Wyoming unit falls within grazing allotments and 82 percent of the allotments were active, which is relatively high for the Forest. It appears grazing has had limited impacts on the hydrologic function of rangelands. According to the WCC, 77.2 percent of the Wyoming unit has properly functioning rangelands that are capable of capturing, storing, and safely releasing water from rainfall, runoff, and snowmelt. The remaining 21.3 percent of the unit was determined to have reversible loss in the hydrologic functioning of rangeland vegetation.

The Wyoming unit has experienced changes in temperature and precipitation regimes, with warmer temperatures recorded in all 4 seasons between 2010 and 2014 compared to the previous century. According to the TCA, 100 percent of the Wyoming unit is in poor condition in terms of temperature exposure (Cleland et al. 2017). However, 100 percent of this unit is also considered in very good condition in regard to precipitation exposure (Cleland et al. 2017). There was reduced precipitation in the summer, slightly more precipitation during the winter, and large amounts of additional precipitation in fall and spring. Winter temperatures have increased by 2.0 °F and winter precipitation has increased by 0.21 percent.

Beaver activity in the Wyoming unit differed from reference conditions due to larger percentages of reaches impacted by beavers. Thirty-six percent of WHAM samples sites had no evidence of beaver activity; 21 percent of reaches were classified as having 1–5 percent of reaches impacted by beaver; 13 percent of reaches fell into the 6–25 percent category; 9 percent of reaches had 26–50 percent impacted by beaver activity; 5 percent of WHAM sites recorded 51–75 percent beaver impact and 3 percent had greater than 75 percent. Sixty-four percent of WHAM reaches recorded that upland infiltration was occurring, which is comparable to the 66 percent classified by reference conditions. The average WCC water quantity score for watersheds in the Wyoming unit was 2.0, indicating an overall moderate departure of hydrographs from natural flow regimes. Upland encroachment

was observed at 7.0 percent of valley bottoms and conifer encroachment was observed at 9.2 percent of valley bottoms in Wyoming unit. Of the five indicators of surface water and groundwater fluctuations, two provided evidence of moderate alteration from the NRV in the Wyoming unit and three indicators showed no evidence of alteration from the NRV. The overall surface water and groundwater fluctuation index was 84 percent and this unit was considered **within** the NRV.

Windriver

Stressors in the Windriver unit included vegetation mortality due to insects and disease and grazing. Eighteen percent of the unit has experienced vegetation mortality and defoliation due to insects and disease. The TCA indicated that 58 percent of the unit was in poor or very poor condition in terms of disturbance from insects and pathogens. Sixty-seven percent of the unit is located within grazing allotments and 78 percent of the allotments were active, which is relatively low compared to the rest of the Forest. It appears grazing has had limited impacts on the hydrologic function of rangelands. Based on the WCC, 86.5 percent of the Windriver unit has properly functioning rangelands that are capable of capturing, storing, and safely releasing water from rainfall, runoff, and snowmelt. The remaining 13.5 percent of the unit was classified has having reversible loss in hydrologic function.

The Windriver unit had experienced changes in temperature and precipitation regimes, with warmer average temperatures recorded in all four seasons. In recent years, there has been less summer and winter precipitation and increased precipitation in spring and fall. According to the TCA, 100 percent of the Windriver unit was in good or very good condition in terms of precipitation exposure. However, the TCA also concluded that 100 percent of the unit was in poor or very poor condition for temperature exposure. Winter temperatures had increased by an average of 2.0 °F and winter precipitation had decreased by an average of 2.9 percent throughout the unit, which is greater than any other unit on the BTNF.

Beavers may provide some resilience to the loss of precipitation, as the Windriver unit has the most reaches classified in the greater than 75 percent impacted by beaver (13 percent of reaches) on the Forest. However, it also has the largest percentage of reaches classified as having no beaver activity (79 percent). Sixty-three percent of WHAM reaches recorded that upland infiltration was occurring, which was comparable to the 66 percent recorded by reference reaches. The average WCC water quantity score for watersheds in the Windriver unit was 1.5, which indicated that hydrographs exhibited only minor departure from natural conditions in most watersheds. Upland encroachment was observed at 3.7 percent of valley bottoms and conifer encroachment was observed at 2.5 percent of valley bottoms in the Windriver unit. Of the five indicators of surface water and groundwater fluctuations, one provided evidence of moderate alteration from the NRV in the Windriver unit and four indicators showed no evidence of alteration from the NRV. The overall surface water and groundwater fluctuation index was 92 percent and this unit was considered **within** the NRV.

Kemmerer

Stressors in the Kemmerer unit included roads throughout the unit and within the floodplain, trails throughout the unit and within the floodplain, timber harvest, and livestock grazing. The road density for the Kemmerer unit (0.001 road miles per acre) was greater than any other unit on the Forest and 68 percent of road miles were classified as unimproved. Road density within floodplains (0.003 road miles per floodplain acre) was also greater than any other units on the Forest. Nevertheless, the TCA indicated only 4 percent of the unit was considered in poor or very poor condition in terms of road density. There were 0.009 trail miles per acre in the Kemmerer unit, which is relatively high for the Forest and there were 0.003 trail miles per floodplain acre, which is greater than any other unit. Approximately 2.7 percent of the unit was within a timber harvest project and 58 percent of these were clear cuts that can influence water fluctuations. Kemmerer had the largest percentage of land within grazing allotments (99 percent) of units on the Forest and 100 percent were active. It appears that the high levels of grazing in the Kemmerer unit have impacted rangeland hydrologic function in some locations. According to the WCC, 71.3 percent of the unit has properly functioning rangelands that are capable of capturing, storing, and safely releasing water from rainfall, runoff, and snowmelt. Twenty-three percent of Kemmerer was classified as having a reversible loss in hydrologic function of rangelands. Finally, 5 percent of the unit had rangelands that had lost the capacity to provide these ecosystem services.

The Kemmerer unit had experienced changes in temperature and precipitation regimes, with warmer temperatures recorded in all four seasons. Precipitation has increased in all four seasons in recent years, especially in fall and spring. According to the TCA, precipitation exposure was very good on all of Kemmerer. However, temperature exposure was in very poor condition on 100 percent of the Kemmerer unit. Winter temperatures had increased by 2.3 °F, more than any other unit on the Forest, and winter precipitation had increased by 1 percent.

We were unable to examine beaver activity in the Kemmerer unit because 33 percent of WHAM sites had not recorded any data for this attribute. Seventy-one percent of WHAM reaches recorded that upland infiltration was occurring, which is slightly greater than the 66 percent recorded at reference reaches. The average WCC water quantity score for watersheds in the Kemmerer unit was 1.5, indicating only minor departures of the hydrograph from natural flow regimes in most watersheds. Upland encroachment was observed at 11.1 percent of valley bottoms in this unit and conifer encroachment was observed at 7.6 percent of valley bottoms. Of the five indicators of surface water and groundwater fluctuations, one provided evidence of moderate alteration from the NRV in the Kemmerer unit and four indicators showed no evidence of alteration from the NRV. The overall surface water and groundwater fluctuation index was 92 percent and this unit was considered **within** the NRV.

GDEs

Snake River Basin

The Snake River Basin is the largest basin present on the Forest and is located within all four geographic units. The majority of both Gros Ventre and the Wyoming units are composed of the Snake River Basin. A very large amount of groundwater is stored in this basin, but its complex geology has inhibited understanding of groundwater storage and movement (Taboga et al. 2014b). Groundwater naturally discharges to springs, streams, and wetlands and is lost through evapotranspiration, with the annual recharge limited by natural discharge and pumping. Average annual recharge in the parts of the Snake River Basin located within the State of Wyoming range from 1 to 35 inches per year, with more occurring in the mountains (Taboga et al. 2014b). Precipitation is the ultimate groundwater source and the majority of it occurs as snowfall at higher elevations. Recharge is most efficient in the Teton, Absaroka, Gros Ventre, Salt River, Snake River, and Wyoming mountain ranges. The most common consumptive uses throughout the basin include irrigation and stock watering, industrial uses, municipal supply, and recreational uses such as snow-making at ski resorts and irrigation for golf courses (Taboga et al. 2014b). No control areas, or locations where groundwater uses are actively managed by an advisory board due to excessive well interference, are designated in the Snake River Basin (Taboga et al. 2014b).

Green River Basin

The Green River Basin occupies the second largest area of the BTNF and is also located within all four geographic units. The majority of the Windriver unit and about half of Kemmerer is composed of the Green River Basin. Groundwater in this basin is contained in unconsolidated deposits and bedrock formations with wide variability in the quantity available from different geologic units (Clarey et al. 2010). Shallow groundwater is generally controlled by topography and drainage patterns, ultimately discharging to streams. Within bedrock, groundwater is present in open spaces and flows through permeable or connected pathways.

Recharge and discharge is controlled by groundwater flow zones and outcrop areas. Groundwater and surface water resources of the Green River Basin are particularly interconnected through complex interactions, making quantity and availability of groundwater highly variable (Clarey et al. 2010). Recharge primarily occurs from precipitation, but on local scales human activities may provide additional water. The estimated annual recharge for the entire Green River Basin is 130,000 acre-feet, with most occurring at high elevations such as those present on the Forest. Comparatively the estimated annual discharge for the basin is 129,000 acre-feet. Groundwater is stored in unconsolidated deposits and in fractures and caves. Based on permits, the most common consumptive uses in the Green River Basin are domestic, monitoring, stock, coalbed natural gas, industrial, irrigation, and municipal. Because the basin is arid, human activity in the Green River relies on groundwater sources (Clarey et al. 2010). The Wyoming State Water Plan determined that there is no area within the Green River Basin in which groundwater has been depleted to the point of requiring a control

area. However, groundwater levels are responsive to drought, with declines ranging from a few feet to tens of feet across the State of Wyoming during the 1999-2007 drought (Clarey et al. 2010).

Bighorn River Basin

The Bighorn River Basin occupies a relatively small percentage of the BTNF, entirely located within the Gros Ventre unit. Groundwater recharge and flow in this basin is affected by near-surface geologic structures, especially aquifer outcrop areas (Taucher et al. 2012). Generally, the greatest amounts of groundwater are available within alluvial aquifers throughout the basin. Annual recharge is estimated to range from 1 inch in the basins to more than 55 inches in the mountains, which receive more precipitation, have longer snowpacks, lose less to evapotranspiration, and have structural features like faults and fractures that enhance recharge (Taucher et al. 2012). This amount of recharge constitutes a substantial percentage of stored and available groundwater, indicating that groundwater resources in the Bighorn Basin are likely sustainable. The State Water Plan estimates that the average annual precipitation in this basin was 18.5 million acre-feet and the average annual outflow was 6.8 million acre-feet, leaving approximately 11.7 million acre-feet for nonconsumptive and consumptive use and groundwater recharge. The most common withdrawals and consumptive uses in the Bighorn River Basin are agriculture (irrigation and stock), municipal, noncommunity public water systems, rural domestic, recreation and environmental, industrial, and mining. While no control areas had been established in this basin by 2009, declines in groundwater levels of the Wind River and Flathead aquifers had been recorded (Taucher et al. 2012).

Bear River Basin

The Bear River Basin occupies a relatively small percentage of the BTNF and occurs almost entirely within the Kemmerer unit. This basin is composed of deeply eroded geologies with a system of ridges and valleys known as the Overthrust Belt. The complex geology of this basin includes deformed bedrock formations with widely variable porosity severed and bound by faults that structurally control compartments of groundwater (Taboga et al. 2014a). This geologic setting results in intricate recharge-discharge interactions between surface and groundwater systems. The average annual precipitation in the Bear River Basin is 1,398,195 acre-feet, which provides the ultimate source of recharge (Taboga et al. 2014a). Approximately 74 percent of that precipitation is lost through evapotranspiration, 14 percent recharges to aquifers, and 12 percent exits the basin as stream outflow. The most common withdrawals and consumptive uses include irrigation, stock watering, industrial uses, community and noncommunity public supplies, rural domestic, and other minor uses (Taboga et al. 2014a). Depletion of surface and groundwater from these uses only comprises 0.3 percent of precipitation (Taboga et al. 2014a). The estimated recharge of 14,000 to 50,000 acre-feet per year far exceeds the average annual withdrawals and there were no designated control areas in the Bear River Basin by 2014. However, trends from 2001 to 2011 indicate reductions in the amount of water entering the system due to overall drier conditions (Taboga et al. 2014a).

Platte River Basin

Only a very small portion of the Platte River Basin exists on the Forest and it is entirely located within the Windriver unit. The Platte River Basin as a whole is very large and extends across southeastern Wyoming. The basin has complex geologic elements with their configurations influencing the availability of groundwater resources (Taucher et al. 2013). Precipitation is the ultimate source of recharge and is estimated to total 19,677,577 acre-feet for the whole basin. Recharge rates range from less than 1 inch in basins to more than 28 inches per year in the mountains, where recharge is most efficient. However, these high rates over mountainous outcrop areas do not necessarily translate to large quantities of stored groundwater. Nevertheless, shallow groundwater in alluvial and bedrock aquifers is well-documented throughout the interior basins (Taucher et al. 2013). Natural discharge in the Platte River Basin occurs as flow from springs, wetlands, lakes, subsurface seepage into streams, and leakage between geologic units. These flows are predominantly controlled by topography, vegetation, and stream drainage patterns. Common withdrawal and consumptive uses include irrigation, stock watering, industrial uses, community and noncommunity public supply, rural domestic, and other minor uses. While three control areas have been established in response to declining groundwater levels associated with heavy withdrawals primarily for irrigation, these are all located in eastern Wyoming, near the Nebraska border and are not representative of groundwater fluctuation conditions on the BTNF (Taucher et al. 2013).

Appendix G. Water Quality

Methods

We scored three indicators of water quality in surface water systems based on whether they showed evidence of no, moderate, or substantial alteration: impaired waters, water quality problems, and percentage of reaches classified as fully supportive of biological communities (table G1). Indicators determined to have little or no alteration were given a score of 5, while moderately altered indicators were scored as a 3, and substantially altered indicators were given a score of 1. The thresholds for each indicator were determined by the methods established for each data source. The scores for each unit were summed and divided by the potential total of 15 to determine a final water quality score.

We evaluated NRV status based on how many indicators provided evidence of moderate or substantial alteration from the NRV. We considered units to be within the NRV for water quality if the index was greater than 74 percent, meaning at least 2 indicators showed no evidence of alteration and no more than 1 indicator showed evidence of moderate alteration. Units were classified as moderately altered from the NRV if the index was between 46 and 74 percent, which is equivalent to at least 2 indicators showing evidence of substantial or moderate alteration. Finally, we classified units as outside the NRV if the index was less than 45 percent. This score is equivalent to multiple indicators showing evidence of substantial alteration.

Unit Summaries

Gros Ventre

Stressors in this unit included roads, trails, and grazing. The overall road density in Gros Ventre was 0.0007 road miles per acre and the road density within floodplains was 0.001 road miles per floodplain acre. There were 0.0007 trail miles per acre throughout the unit and the trail density within floodplains was 0.002 trail miles per floodplain acre. These densities are linked to functional-at-risk ratings for road and trail maintenance and proximity to water within the WCC. There were 0.00007 recreation sites per floodplain acre in this unit, which was the lowest of any unit on the Forest.

Table G1—Threshold values for indicators of water quality NRV status.

Indicator	Data source	Little or no alteration	Moderate alteration	Substantial alteration
Impaired waters	WCC	< 1.6	1.7 < x < 2.2	> 2.3
Water quality problems	WCC	< 1.6	1.7 < x < 2.2	> 2.3
% Full support	RIVPAC/WSII	> 80%	65 < x < 80%	< 65%

Approximately 3.3 kg/ha/yr of nitrogen was deposited across the landscape in Gros Ventre. Based on the TCA, this indicates a moderate alteration from ecological integrity. Nevertheless, the entire unit is considered in very good condition in terms of terrestrial eutrophication. Additionally, the WCC indicates that soil contamination is not an issue in this unit, with a classification of properly functioning. R-CAT results showed that conversions to agriculture or development were not stressors in this unit, affecting only 0.15 percent and 1.1 percent of riparian areas, respectively. Approximately 70 percent of this unit experienced active grazing, which is the lowest of all units on the Forest. There were 0.00001 diversions per acre in this unit, which is comparable to most of the Forest and the WCC indicates that flow characteristics were in properly functioning condition.

The mean impaired waters score based on the WCC was 1.0, indicating that no State-listed impaired or threatened water bodies were located in Gros Ventre. The mean WCC water quality problems score was 1.2, indicating minor issues with excessive sediment, nutrients, chemical pollution above background levels and little evidence of acidification, toxicity, or eutrophication. Eighty-one percent of sites sampled for biological condition fully supported aquatic life. Of the three water quality indicators, none showed evidence of alteration from the NRV. The overall water quality index score was 100 percent and Gros Ventre was considered **within** the NRV for surface water quality.

Wyoming

Stressors in this unit included roads, trails, recreation sites within floodplains, soil contamination, and grazing. There are 0.001 road miles per acre in this unit and the road density within floodplains is 0.002 road miles per floodplain acre. Additionally, there are 0.0009 trail miles per acre in the Wyoming unit and the floodplain trail density was 0.002 miles per acre. According to the WCC, road and trail maintenance in this unit is considered functional-at-risk, as is mass wasting from these features. Additionally, the proximity of these features to water was considered in poor and impaired condition. There were 0.0002 recreation sites per floodplain acre in the Wyoming unit, which is greater than any other unit on the Forest. Approximately 3.6 kg/ha/yr of nitrogen is deposited across the landscape in this unit. Based on the TCA, this indicates a moderate alteration from ecological integrity. Nevertheless, the entire unit was considered in very good condition in terms of terrestrial eutrophication. The WCC indicated that soil contamination is a moderate stressor in this unit, classified as functional-at-risk. R-CAT results indicated that conversions of riparian areas to agriculture or development were relatively high for the Forest but were not stressors in this unit, affecting only 0.3 percent and 1.2 percent of riparian areas respectively. Approximately 82 percent of this unit was actively grazed. There were 0.00004 diversions per acre in the Wyoming unit, more than any other unit on the Forest. This was associated with the largest value for flow characteristic under the WCC, but it was still considered to be properly functioning.

The mean WCC impaired waters score was 1.0, indicating that no State-listed impaired or threatened water bodies were located in the Wyoming unit. The mean WCC water quality problems score was 1.1, indicating that watersheds in this unit had only minor issues with excessive sediment, nutrients, or chemical pollution. Eighty-one percent of sites sampled for biological condition fully supported aquatic life. Of the three water quality indicators, none showed evidence of alteration from the NRV. The overall water quality index score was 100 percent and Wyoming was considered **within** the NRV for surface water quality.

Windriver

Stressors in this unit included roads, trails, and grazing. There were 0.0005 road miles per acre throughout the Windriver unit and the road density within floodplains was 0.0008 road miles per floodplain acre. These were the lowest road densities for any unit on the Forest. There were 0.0008 trail miles per acre throughout the unit and trail density within floodplains was 0.001 trail miles per floodplain acre. Despite having relatively low road and trail densities, road and trail maintenance was considered in impaired condition within the WCC. Additionally, their proximity to water was considered functional-at-risk. There were 0.0001 recreation sites per acre, which was not considered a stressor to water quality. Approximately 3.3 kg/ha/yr of nitrogen was deposited across the landscape in this unit. Based on the TCA, this indicated a moderate alteration from ecological integrity, but the entire Windriver unit was considered in very good condition in terms of terrestrial eutrophication. Additionally, the WCC indicated that soil contamination was not an issue in this unit, with a classification of properly functioning. R-CAT results indicated that conversions of riparian areas to agriculture or development were the lowest on the Forest in this unit, affecting only 0.1 percent and 0.5 percent of riparian areas respectively. Approximately 78 percent of this unit was actively grazed.

The mean impaired waters score based on the WCC was 1.0, indicating that no State-listed impaired or threatened water bodies were located in the Windriver unit. The mean water quality problems score based on WCC data was 1.6, indicating that watersheds in this unit had minor issues with excessive sediment, nutrients, or chemical pollution and little evidence of acidification, toxicity, or eutrophication. Eighty-eight percent of sites sampled for biological condition fully supported aquatic life. Of the three water quality indicators, none showed evidence of alteration from the NRV. The overall water quality index score was 100 percent and Windriver was considered **within** the NRV for surface water quality.

Kemmerer

Stressors in this unit included roads, trails, soil contamination, and grazing. There were 0.001 road miles per acre throughout the unit and the floodplain road density 0.003 road miles per floodplain acre. These were the largest road densities of any unit on the BTNF. The trail density throughout the unit was 0.0009 trail miles per acre and within floodplains the trail density was 0.003 trail miles per floodplain acre. These were the largest trail

densities of any unit on the Forest. According to the WCC, mass wasting from these features and their proximity to water were both considered functional-at-risk and road and trail maintenance in the Kemmerer unit was in poor condition. There were 0.0001 recreation sites per floodplain acre, which was not considered a stressor to water quality. Approximately 3.6 kg/ha/yr of nitrogen is deposited across the landscape in Kemmerer, the largest of any unit on the BTNF. Based on the TCA, this indicated a moderate alteration from ecological integrity, but the entire unit was considered in very good condition in terms of terrestrial eutrophication. Nevertheless, the WCC indicated soil contamination was an issue in this unit, with a classification of functional-at-risk. R-CAT results indicated that conversion of riparian areas to agriculture or development was not a stressor in this unit, affecting only 0.3 percent and 0.8 percent of riparian areas respectively. One hundred percent of the Kemmerer unit was actively.

The mean impaired waters score based on the WCC was 1.0, indicating that no State-listed impaired or threatened water bodies were located in the Kemmerer unit. The mean water quality problems score based on WCC data was 1.1, indicating only minor issues with excessive sediment, nutrients, or chemical pollution and little evidence of acidification, toxicity, or eutrophication. Seventy-three percent of sites sampled for biological condition fully supported aquatic life. Of the three water quality indicators, one provided evidence of alteration from the NRV and two showed no evidence of alteration from the NRV. The overall water quality index score was 87 percent and Kemmerer was considered **within** the NRV for surface water quality.

GDEs

Snake River Basin

The Snake River Basin is the largest of those present on the Forest. The majority of the Gros Ventre and Wyoming units are made up of this basin. Groundwater quality, especially that of more minor aquifers, is driven by the type and density of vegetation in recharge areas, mineral composition, grain size, transmissivity, circulation rate, and temperature (Taboga et al. 2014b). Total dissolved solids range from less than 1,000 mg/L, which can be used for any domestic purpose, to greater than 300,000 mg/L in briny deep aquifers that are unsuitable for virtually any use. The quality of groundwater is generally good in locations where recharge from streams dominate as the unconsolidated materials filter sediment, bacteria, and contaminants (Taboga et al. 2014b). Where bedrock recharge dominates, the quality of alluvial groundwater reflects the composition of surrounding formations, generally with increased concentrations of total dissolved solids. In most of the basin, the concentrations of total dissolved solids are elevated with respect to EPA standards; however, in areas with high rates of recharge which are expected on the Forest, total dissolved solids are diluted. Several groundwater samples throughout the basin reveal elevated concentrations of sulfate, chloride, fluoride, iron, and manganese with respect to EPA standards (Taboga et al. 2014b).

Green River Basin

The Green River Basin is the second largest basin present on the BTNF. It makes up the majority of the Windriver unit, approximately half of the Kemmerer unit, and smaller percentages of the Gros Ventre and Wyoming units. In the Green River Basin, groundwater quality generally decreases with depth and distance from recharge area (Clarey et al. 2010). It is highly variable throughout the basin, reflecting the complex geologic setting. The concentration of total dissolved solids throughout the basin tends to be high relative to EPA standards, which is related to the arid climate and limited recharge. In areas with greater infiltration, such as those located on the Forest, total dissolved solids are expected to be diluted. Samples throughout the basin showed evidence of high concentrations of sulfate, chloride, fluoride, iron, and manganese in relation to EPA standards (Clarey et al. 2010).

Bighorn River Basin

The Bighorn River Basin is relatively small and entirely located within the Gros Ventre unit. Groundwater quality in the Bighorn River Basin is best closer to recharge areas and decreases with depth as it is modified by chemical reactions that occur during infiltration and percolation (Taucher et al. 2012). Drivers of groundwater quality include vegetation and mineral composition in the recharge area, grain size, transmissivity, circulation rate, and aquifer temperature. Groundwater quality in the Bighorn River Basin tends to be good in locations where recharge from streams is dominant and where sand and gravel filter sediment, bacteria, and contaminants (Taucher et al. 2012). Where recharge from bedrock sources occurs, groundwater quality reflects that of the surrounding formations and tends to have higher concentrations of total dissolved solids. Concentrations of total dissolved solids tend to be elevated with respect to EPA standards throughout the basin, but they are diluted in areas of high recharge such as those located in mountainous areas. Water samples from this basin also indicate high concentrations of sulfate, chloride, fluoride, iron, and manganese relative to EPA standards (Taucher et al. 2012).

Bear River Basin

The Bear River Basin represents a small percentage of the Forest and is almost entirely located within the Kemmerer unit. Factors affecting groundwater quality in this basin include the characteristics of the vegetative community in recharge areas, mineral composition, grain size, transmissivity, circulation rate, and aquifer temperature (Taboga et al. 2014a). The best quality groundwater is located in the outcrop areas of mountainous regions with generally better circulation. Quality and circulation are reduced rapidly with increased depth (Taboga et al. 2014a). Groundwater quality is also generally good in locations where recharge from streamflow is dominant. In these locations, sand, gravel, and other unconsolidated materials filter sediment, bacteria and some contaminants from surface waters (Taboga et al. 2014a). Where recharge from bedrock sources is dominant, the quality of groundwater reflects that of surrounding formations and generally have higher concentrations of total dissolved solids. Within the basin, the

concentration of total dissolved solids ranges from 500 mg/L, which is suitable for any domestic purposes, to greater than 300,000 mg/L, which is unsuitable for basically any use (Taboga et al. 2014a). Throughout most of the basin, the concentration of total dissolve solids tends to be high relative to EPA standards, even in shallow wells. This is likely a result of the arid climate and low recharge rates. In addition to total dissolved solids, many groundwater samples had elevated concentrations of sulfate, chloride, fluoride, iron, and manganese with respect to EPA standards (Taboga et al. 2014a).

Platte River Basin

The Platte River Basin represents a very small section of the Forest, entirely located within the Windriver unit. Factors affecting groundwater quality in this basin include characteristics of the vegetative community at recharge areas, mineral composition, grain size, transmissivity, circulation rate, and aquifer temperature (Taucher et al. 2013). The quality of groundwater is generally best in recharge areas and deteriorates with depth as the water is affected by chemical reactions during the infiltration process and by circulation in the aquifer. Where streams are hydraulically connected to the alluvial aquifer, the water quality reflects that of the stream (Taucher et al. 2013). In locations where discharge from bedrock sources dominates, groundwater quality is related to the surrounding formations and typically has elevated concentrations of total dissolved solids. Groundwater quality ranges from 1,000 mg/L, which is suitable for any domestic use, to greater than 200,000 mg/L (Taucher et al. 2013). In general, concentrations of total dissolved solids tend to be elevated relative to EPA standards, which is likely a result of limited recharge in an arid environment. Additionally, samples from throughout the basin had high concentrations of sulfate, chloride, fluoride, iron, and manganese (Taucher et al. 2013).

Appendix H. Channel and Floodplain Dynamics

Methods

We scored seven indicators for channel and floodplain dynamics based on whether they showed evidence of little or no, moderate, or substantial alteration from reference conditions: presence of large woody debris, channel shape and function, percentage of functional riparian area, bank erosion, habitat complexity, floodplain acre per stream mile, and percent of floodplain burned at moderate severity. If the indicator for each geographic unit showed evidence of little or no alteration, it was given a score of 5; moderate alteration was given a score of 3; substantial alteration was given a score of 1 (table H1). The thresholds for moderate and substantial alteration for each indicator were determined from the literature or from the data sources. The scores for each unit were summed and divided by the potential total of 35 to give a percentage rating for each. We evaluated NRV status based on how many indicators provided evidence of moderate or substantial alteration from the NRV. We considered units to be within the NRV for groundwater and surface water fluctuations if the index was greater than 77 percent. Units were classified as moderately altered from the NRV if the index was between 50 and 76 percent. Finally, we classified units as outside the NRV if the index was less than 50 percent.

Unit Summaries

Gros Ventre

Stressors in this unit included high severity wildfire, livestock grazing, altered winter temperature, and altered winter precipitation. Over 66,000 acres have burned at high severity in Gros Ventre, which is about 4 percent

Table H1—Threshold values for indicators of channel and floodplain dynamics.

Indicator	Data source	Little or no alteration	Moderate alteration	Substantial alteration
Large woody debris	WCC	≤ 1.6	1.7 ≤ x ≤ 2.2	≥ 2.3
Channel shape and function	WCC	≤ 1.6	1.7 ≤ x ≤ 2.2	≥ 2.3
Functional riparian	WHAM	> 90% yes	70% < x < 89%	< 70%
Bank erosion	WHAM	> 75%	50% < x < 75%	< 50%
Habitat complexity	WHAM	D > 0.59	0.53 < D < 0.58	D < 0.53
Floodplain acre/stream mile	50-year floodplain map & NHD flowline	> 20.9 acres/mile	< 20.8 acres/mile	< 3.5 acres/mile
% Floodplain burned—moderate severity	50-year floodplain map & MTBS	< 18.4%	> 18.5%	> 29.6%

of the unit. An additional 119,000 acres, or 8 percent of the Gros Ventre unit, had burned at moderate severity. There were approximately 505,500 acres located within range management units and 69 percent of these were actively grazed. However, grazing was the most limited in this unit compared to the rest of the Forest. Average winter temperatures had increased by 2 °F and winter precipitation had decreased by 2.4 percent. There were 0.0007 road miles per acre and 0.0007 trail miles per acre in Gros Ventre. Within floodplains in this unit there were 0.001 road miles per acre and 0.002 trail miles per acre. Between 10 and 25 percent of roads and trails were located within 300 feet of streams and water bodies and best management practices for the maintenance of designed drainage features were applied to only 50 to 75 percent of the roads, trails, and water crossings within watersheds in the unit according to the WCC. There were 11 recreation sites located within floodplains in Gros Ventre, which is relatively high for the Forest. Approximately 29,300 acres in this unit have experienced timber harvest, with 75 percent of those acres having been clear cut. There were 0.00001 diversions per acre in Gros Ventre, which is relatively low for the Forest, and the WCC indicated that these diversions had not substantially affected the flow characteristics of streams. Conversion of riparian areas to invasive vegetation had only impacted 0.03 percent of floodplains and was not a stressor in this unit. WHAM documented two examples of large activities and one example of small activity impacting reaches. These disturbances included timber harvest, cattle grazing, and trail crossings.

Over 10 percent of Gros Ventre was within the 50-year floodplain, the largest of any unit on the Forest. There were 29 floodplain acres per stream mile, which is also greater than any other unit on the Forest. The presence of larger floodplains in Gros Ventre reflected that this unit had more total stream miles (5,383 miles) and more perennial stream miles (2,321 miles) than any other geographic unit on the BTNF. Fifty-seven percent of streams in this unit were intermittent and there were no ephemeral streams present. U-shaped valleys are common in Gros Ventre, with 53 percent of WHAM sites located in these formations, 26 percent located within V-shaped valleys, and 16 percent in flat bottoms. Habitat fragmentation was limited, with more than 95 percent of historic aquatic habitats still connected according to the WCC. Large woody debris was present and continuing to be recruited in the expected reaches at near natural rates. Channel shape and function were considered to be properly functioning with vertically stable channels and less than 5 percent of streams showing evidence of widening. Ninety-five percent of WHAM sites displayed high water tables and had riparian areas with the capacity to trap sediment. Sixty percent of WHAM sites had between 0 and 10 percent of banks affected by erosion. The average habitat complexity score for aquatic habitat complexity was 0.64, which was comparable to reference reaches. Only 1.2 percent of floodplains in Gros Ventre had burned at moderate severity. Of the seven indicators of channel and floodplain dynamics, six showed no evidence of alteration from the NRV and one indicator showed evidence of moderate alteration from the NRV. Of the seven channel and floodplain dynamics indicators, only one showed evidence of

moderate alteration from the NRV. The remaining six indicators showed no evidence of alteration. The overall index score was 94 percent and channel and floodplain dynamics were considered **within** the NRV in Gros Ventre.

Wyoming

Stressors in this unit include livestock grazing, recreation sites within the floodplain, and altered winter temperature. There were approximately 893,200 acres located within range management units and 82 percent of those were actively grazed. There were more actively grazed acres in the Wyoming unit than any other unit on the BTNF. There were 14 recreation sites located within floodplains, which is greater than any other unit on the Forest. Average winter temperatures have increased by 2 °F in recent years. There were 0.001 road miles per acre and 0.0009 trail miles per acre within the Wyoming unit. Both road density and trail density are relatively high compared to other units on the BTNF. While neither the TCA nor the WCC indicated road or trail density as a stressor, mass wasting from these features, their proximity to water, and their maintenance condition were identified as stressors to channel and floodplain dynamics. The WCC indicated that few roads in the Wyoming unit were on landforms subject to mass wasting with moderate evidence of active movement and damage. Additionally, more than 25 percent of roads and trails were located within 300 feet of streams and waterbodies and the best management practices for maintenance of designed drainage features were applied to 50 to 75 percent of roads, trails, and water crossings in this unit. Approximately 16,500 acres (2 percent) of this unit had experienced high severity fire and an additional 31,300 acres (3 percent) of the unit had experienced moderate severity wildfire. Over 28,200 acres had been harvested for timber, and of these acres, 68 percent were clear cut. There were 43 diversions (0.00004 diversions/acre) in this unit, which is more than any other unit on the BTNF. Nevertheless, the WCC indicated that flow characteristics were in properly functioning condition. Conversion of floodplain habitat to invasive vegetation had only impacted 0.03 percent of floodplains and was not a stressor in this unit. WHAM surveys documented several large and small disturbance activities. The large disturbances were generally from cattle grazing, with noted effects to riparian vegetation and streambanks. In disturbed locations, the surveys noted encroachment of nonnative species. In addition to grazing, some sites were affected by timber harvest. The small activities affecting floodplain dynamics primarily consisted of roads, culverts, and trail crossings.

Seven percent of the Wyoming unit was located within the 50-year floodplain, which was relatively high for the Forest. There were 22 floodplain acres per stream mile, which was relatively low compared to other units on the Forest. The Wyoming unit had 3,428 total stream miles, fewer than only the Gros Ventre unit. Of these stream miles, only 38 percent are perennial, with the rest primarily intermittent and 0.5 percent ephemeral. There were several different valley forms represented in the Wyoming unit including flat bottoms (6 percent), troughs (15 percent), U-shaped (35 percent), and V-shaped (38 percent). The average stream gradient is 4 percent, but there

are some very high-gradient reaches. Habitat fragmentation was limited, with more than 95 percent of historic aquatic habitats still connected according to the WCC. Large woody debris was present and continued to be recruited in the expected reaches at near natural rates. Channel shape and function were considered to be properly functioning, with vertically stable channels and less than 5 percent of streams showing evidence of widening. Eighty-four percent of WHAM reaches had functional riparian systems with high water tables and the capacity to trap sediment. Fifty-four percent of WHAM reaches had between 0 and 10 percent of banks impacted by erosion. The average habitat complexity value was 0.61, which was comparable to reference conditions. About 2.4 percent of floodplains had burned at moderate severity. Of the seven channel and floodplain dynamics indicators, two showed evidence of moderate alteration from the NRV. The remaining five indicators showed no evidence of alteration. The overall index score was 89 percent and channel and floodplain dynamics were considered **within** the NRV in the Wyoming unit.

Windriver

Stressors in this unit included livestock grazing, recreation sites within the floodplain, altered winter temperature, and altered winter precipitation. Nearly 400,000 acres were located within range management units and 78 percent were actively grazed. There were only 4 recreation sites located within floodplains, but the density (0.06 sites per floodplain acre) was relatively high for the Forest. Winter temperatures had increased by 2 °F in recent years and winter precipitation had decreased by 2.9 percent, a larger reduction than any other unit on the Forest. While neither the TCA nor the WCC indicated road or trail density as a stressor, the proximity of these features to water and their maintenance condition were considered stressors. Between 10 and 25 percent of roads and trails were located within 300 feet of streams and waterbodies. The best management practices for drainage features were applied to less than 50 percent of roads, trails, and water crossings in watersheds throughout the unit, causing this indicator to be considered in poor condition. Approximately 12,000 acres (2 percent) of this unit had experienced high severity wildfire and an additional 26,300 acres had been burned at moderate severity. There were 0.00001 diversions per acre, which is a relatively low density for the Forest. The WCC indicated that these diversions were not affecting flow characteristics, which were in properly functioning condition. Conversion of floodplain habitat to invasive vegetation had only impacted 0.0003 percent of floodplains, the least amount of any unit on the Forest. Only 694 acres of the Windriver unit had been harvested for timber and 65 percent of these acres were clear cut. WHAM described grazing and recreation as large disturbance activities impacting riparian areas, however nearly all were having limited impacts, resulting in minor erosion or invasive species encroachment. By far the most common small disturbance activity recorded by WHAM was trails located within floodplains.

Six percent of the Windriver unit was located within the 50-year floodplain, which was relatively low for the Forest. Nevertheless, there were 26 floodplain acres per stream mile, which was relatively high compared to other units. There were 1,513 total stream miles in this unit, of which 53 percent were perennial. Several valley forms were represented in this unit: canyons (1 percent), flat bottom (4 percent), trough (7 percent), U-shaped (28 percent), and V-shaped (12 percent). The average stream gradient was 4.8 percent, but some very high-gradient reaches were also present. Habitat fragmentation was limited, with more than 95 percent of historic aquatic habitats still connected according to the WCC. Large woody debris was present and continued to be recruited in the expected reaches at near natural rates. Channel shape and function were considered to be properly functioning, with vertically stable channels and less than 5 percent of streams showing evidence of widening. Ninety-five percent of WHAM reaches had functional riparian areas with high water tables and the capacity to trap sediment. Seventy-nine percent of WHAM reaches had 0 to 10 percent of banks impacted by erosion. The average habitat complexity was 0.64, which was comparable to reference conditions. About 2.2 percent of floodplains had burned at moderate severity. Of the seven indicators of channel and floodplain dynamics, none showed evidence of alteration from the NRV. The overall index score was 100 percent and channel and floodplain dynamics were considered **within** the NRV in Windriver.

Kemmerer

Stressors in this unit included livestock grazing, recreation sites within the floodplain, and altered winter temperature. Ninety-nine percent of the Kemmerer unit were located within range management units and of these 100 percent were actively grazed. There were only two recreation sites located within the floodplain, but the density of sites per floodplain acre were relatively high. Winter temperatures were 2.3 °F warmer in recent years, the largest increase in winter temperature of all units on the Forest. There were 0.001 road miles per acre throughout the unit and 0.003 road miles per floodplain acre in Kemmerer. These densities were the highest of any unit on the Forest. While neither the TCA nor the WCC indicated road density as a stressor to channel and floodplain dynamics in the Kemmerer unit, mass wasting from these features, their proximity to water, and their maintenance condition were identified as stressors. The WCC indicated that a few roads were on unstable landforms subject to mass wasting with moderate evidence that erosion or road damage had occurred. Between 10 and 25 percent of roads and trails were located within 300 feet of streams and waterbodies and best management practices for drainage features were applied to less than 50 percent of roads, trails, and water crossings. The Kemmerer unit had experienced the least amount of high severity (4,900 acres) and moderate severity (9,200 acres) fire of all units on the BTNF. There were only 0.00001 diversions per acre in this unit and the WCC indicated that flow characteristics were in properly functioning condition.

Conversion of floodplain habitat to invasive vegetation had only impacted 0.01 percent of floodplains and was not considered a stressor to channel and floodplain dynamics. Winter precipitation had increased by 1 inch, which may contribute to increased resilience of floodplain systems in the Kemmerer unit. Approximately 2.7 percent of this unit had experienced timber harvest and 58 percent of these acres were clear cut. The primary large disturbance activity documented by WHAM was cattle grazing, which had influenced bank stability and soils in some locations. Additionally, roads were noted as large disturbance activities, but their impacts were limited to very few reaches. Small disturbance activities noted by WHAM were trails, roads, and stream crossings. Their impacts were extremely limited.

Only 6.5 percent of the Kemmerer unit was located within the 50-year floodplain, the least of all units on the Forest. Additionally, there were 20 floodplain acres per stream mile, which is the lowest ratio of all units on the BTNF. This is likely a result of limited perennial streams. There were only 492 total stream miles in Kemmerer, less than any other unit. Of these, 44 percent were perennial. Seventeen percent of stream miles were ephemeral, with no floodplain development expected. Valley forms tend to be U-shaped (45 percent) or V-shaped (51 percent), but one trough and one flat bottom were recorded by WHAM. The average gradient of WHAM sites was 2.1 percent, but a few high-gradient streams were also sampled. More than 95 percent of historic aquatic habitats were still connected. Large woody debris remained present and continued to be recruited in the expected reaches at near natural rates. Channels were vertically stable and less than 5 percent of streams showed evidence of widening. Ninety-one percent of WHAM samples sites had functional riparian areas with high water tables and the ability to trap sediment. Sixty-eight percent of WHAM reaches had less than 10 percent of banks impacted by erosion. The average habitat complexity value was 0.64, which was comparable to reference conditions. Slightly less than 2 percent of floodplains had burned at moderate severity. Of the seven indicators of channel and floodplain dynamics, five showed no evidence of alteration from the NRV and two showed evidence of moderate alteration. The overall index score was 89 percent and channel and floodplain dynamics were considered **within** the NRV in the Kemmerer unit.

Appendix I. Composition and Structure of Riparian Vegetation

Methods

We calculated riparian vegetation conversion as an indicator of riparian ecosystem composition. Using the R-CAT methodology and LANDFIRE spatial data, we estimated the percentage of valley bottom surrounding perennial streams that was affected by conifer encroachment, upland encroachment, and invasive species. Following methods outlined by McFarlane et al. (2016), we obtained existing vegetation type (EVT) and biophysical setting (BPS) rasters from the LANDFIRE program. We masked the rasters to a Hydro-geomorphic Valley Classification (HGVC) shapefile from USFS. This shapefile contains valley bottoms associated with perennial streams. We used the EVT and BPS rasters to compare remote sensed vegetation with vegetation expected to be present prior to Euro-American settlement. With these data we calculated the percentage of each valley bottom segment that has been converted by conifer encroachment, upland encroachment, and invasive plants. We compared results among geographic units and valley bottom classifications.

We also used WHAM field data to calculate percentage of stream segments showing signs of riparian vegetation recruitment, percentage affected by upland invasion, percentage with adequate vegetation for beaver food, and percentage with vegetation adequate for beaver dam building materials. We scored four of the above indicators based on whether they showed evidence of moderate or substantial alteration (table I1). The scores for each geographic unit were summed and divided by the potential total of 20 to give a percentage rating for each. Units were considered within the NRV for groundwater and surface water fluctuations if the index was greater than 71 percent, moderately altered from the NRV if the index was between 50 percent and 70 percent, and outside the NRV if the index was less than 49 percent.

Table I1—Threshold values for indicators of riparian composition.

Indicator	Data source	Little or no alteration	Moderate alteration	Significant alteration
Conifer encroachment	R-CAT	< 33%	33% < x < 66%	> 66%
Upland encroachment	R-CAT	< 33%	33% < x < 66%	> 66%
Riparian recruitment	WHAM	> 75%	50% < x < 75%	< 50%
Upland encroachment	WHAM	< 50%	50% < x < 75%	> 75%

Unit Summaries

Gros Ventre

Within the 50-year floodplain, 45 percent of mapped vegetation is dominated by conifers, 19 percent by willows, 17 percent by nonwillow shrubs, 14 percent by herbaceous plants, and 2 percent by deciduous trees (fig. I1). Given these results, conifer-dominated types compose the greatest area of riparian ecosystems, followed by a combination of tall willow- and low willow-dominated types.

Riparian community types are undescribed for much of this geographic unit. Community types have, however, been described in the adjacent Wyoming geographic unit (Youngblood et al. 1985) and the Shoshone National Forest (Walford et al. 2001). Hansen et al. (1995) described habitat types and community types for southern Montana, which has some topographic and geological similarities. The types described by these authorities are listed in appendix B.

Active livestock allotments cover 33 percent of the unit. The nine winter feedgrounds for elk in and near this unit concentrate browsing on willows and other plants (BTNF 2017). Roads and other forms of infrastructure facilitate spread of invasive species. Areas of high or very high wildfire potential, an indicator of fire suppression, cover 21 percent of the unit. Twenty-three percent of the 50-year floodplain was burned by wildfire between 1984 and 2014. There are 21 points of diversion (0.00001/acre) mapped by the Wyoming Water Development Office.

R-CAT results indicate that 5 percent of the area in valley bottoms is affected by conifer encroachment, 7 percent is affected by upland encroachment, and less than 1 percent is affected by invasive species. WHAM level I surveys were conducted at 123 stream segments. Results indicated that recruitment of riparian vegetation was occurring at 63 percent of segments and upland encroachment was occurring at 35 percent. Lack of willow recruitment was documented at Flat Creek, which is affected by cattle and elk. Conifer encroachment was noted at several streams. Willows were abundant at the upper Snake River. Vegetation adequate for beaver food was present at 37 percent of segments and vegetation for building material was present at 25 percent of segments. Reports from MIM surveys in managed portions of the geographic unit describe extensive invasion of Canada thistle, increased forbs (West Goosewing, Big Cow), and other weeds (Tepee Creek). Heavy browsing on willows and other shrubs were noted at Alkali Creek, Big Cow Creek, and the upper Green River, which also showed light influences of grazing and recreation. Of the four riparian vegetation composition and structure indicators, three showed no evidence of alteration from the NRV and one showed evidence of moderate alteration. The overall composition and structure index was 90 percent and this unit was considered **within** the NRV.

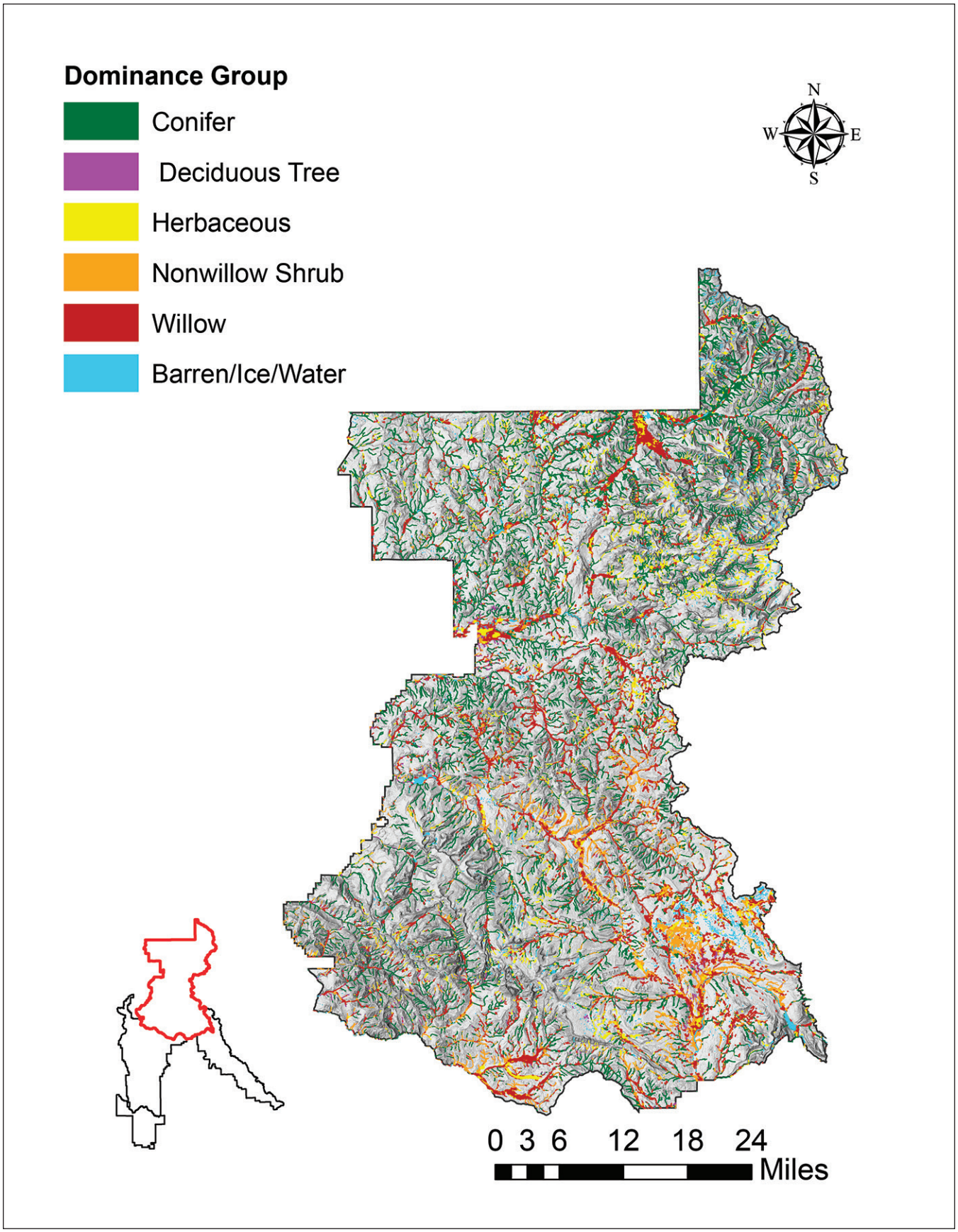


Figure I1—Riparian dominance groups in the Gros Ventre geographic unit.

Wyoming

Within the 50-year floodplain, 42 percent of vegetation is dominated by conifers, 3 percent by deciduous trees, 13 percent by herbaceous plants, 20 percent by nonwillow shrubs, and 19 percent by willows (fig. I2). Riparian community types were described for the region including the Wyoming geographic unit by Youngblood et al. (1985). The Greys River watershed contains the most diverse willow communities of the BTNF (BTNF 2004).

Active livestock allotments cover 71 percent of the unit. Fires were effectively suppressed during much of the 20th century (BTNF 2004), resulting in declines in aspen regeneration. The 10 winter feedgrounds for elk in and near this unit concentrate browsing on willows and other plants. Roads influence riparian ecosystems, as do several species of noxious weeds (BTNF 2004). Recreation, timber harvest, and coal mines have impacted streams in the Greys River watershed (BTNF 2004). Areas of high or very high wildfire potential, an indicator of fire suppression, cover 16 percent of the unit. Twelve percent of the 50-year floodplain was burned by wildfire between 1984 and 2014. There are 43 points of diversion mapped by the Wyoming Water Development Office, giving this unit the highest density of diversions on the Forest (0.00004/acre).

R-CAT results indicate that 7 percent of the area in valley bottoms is affected by conifer encroachment, 9 percent is affected by upland encroachment, and less than 1 percent is affected by replacement by invasive species. WHAM level I surveys were conducted at 268 stream segments. Recruitment of riparian vegetation was occurring at 63 percent and upland encroachment was occurring at 49 percent of segments. Vegetation adequate for beaver food was present at 51 percent of segments and building material was present at 44 percent of segments. At several locations, willows were present, but aspen was unavailable.

A Level 2 WHAM assessment was conducted in the Little Greys River Watershed in 2002. Willow and sedge communities dominate lower elevations in the watershed, with willow and alder communities dominant in the upper elevations. Conifers are encroaching because of fire suppression, road effects, and changing water cycles. Roads limit the size of riparian zones and act as corridors for invasive plants. Regeneration of cottonwoods is absent in one segment because the road has cut off the floodplain. Other human influences include recreation in floodplains and livestock use. (Sweeney 2003). Invasive/increasing species include Wyethia at Fawn Creek, Canada and bull thistle at East Miners Creek, Canada thistle and tansy at Pass Creek, and Canada thistle at West Miners Creek. Of the four riparian vegetation composition and structure indicators, three showed no evidence of alteration from the NRV and one showed evidence of moderate alteration. The overall composition and structure index was 90 percent and this unit was considered **within** the NRV.

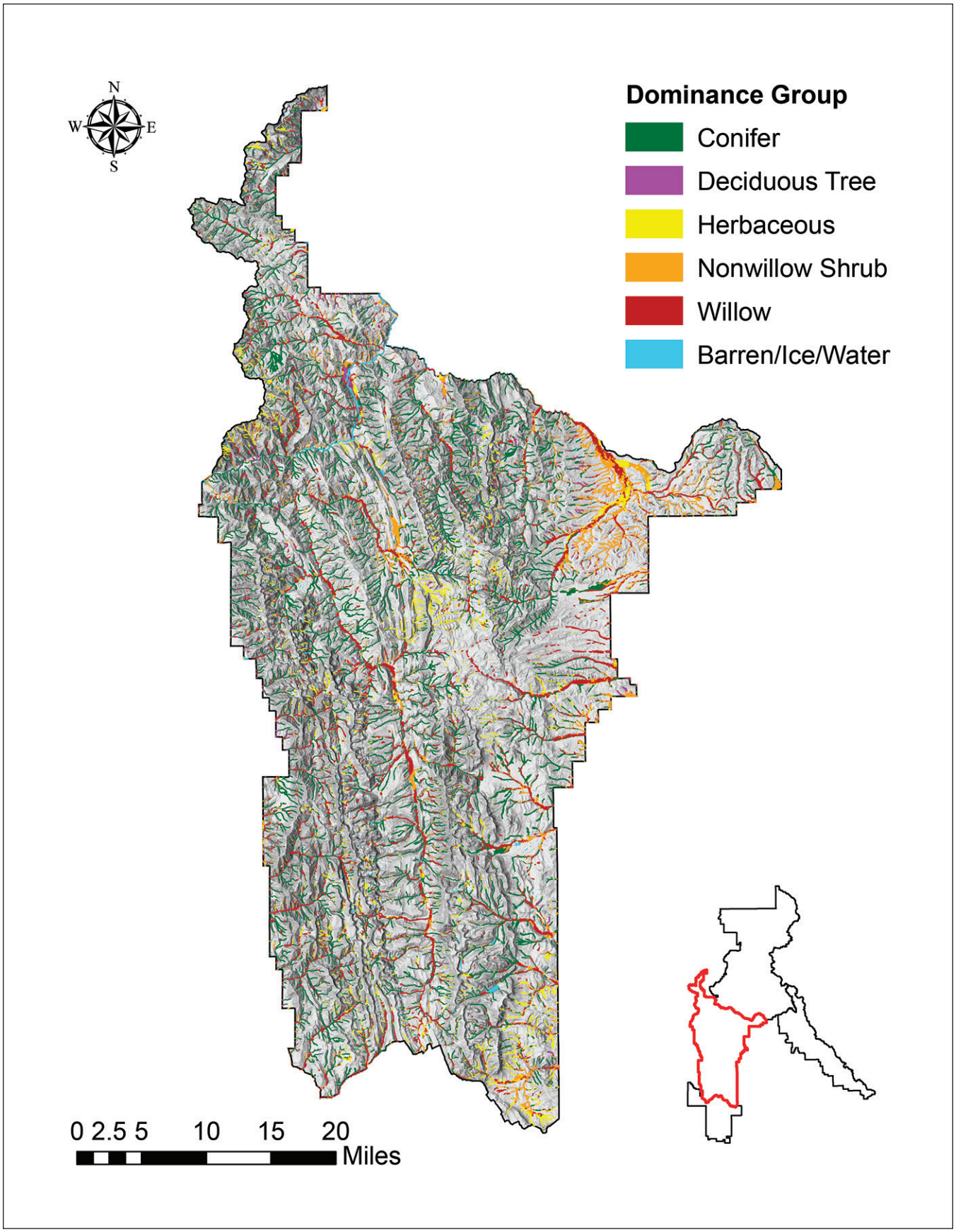


Figure I2—Riparian dominance groups in the Wyoming geographic unit.

Windriver

Within the 50-year floodplain, 50 percent of vegetation is dominated by conifers, 6 percent by deciduous trees, 21 percent by herbaceous plants, 6 percent by nonwillow shrubs, and 12 percent by willows (fig. I3).

Riparian community types have not been described for much of this geographic unit. Community types have, however, been described in the nearby Wyoming geographic unit (Youngblood et al. 1985), the adjacent Shoshone National Forest (Walford et al. 2001), and the Uinta Mountains in Utah (Padgett et al. 1989), which have some topographic and geologic similarities to the Wind River Range. In addition, Hansen et al. (1995) described habitat types and community types for southern Montana, which also has topographic and geological similarities. The types described by these authorities are listed in table 13.

Active livestock allotments cover 53 percent of the unit. The five winter feedgrounds for elk near this unit concentrate browsing on willows and other plants (BTNF 2017). Areas of high or very high wildfire potential, an indicator of fire suppression, cover 12 percent of the unit. Ten percent of the 50-year floodplain was burned by wildfire between 1984 and 2014. There are 6 points of diversion (0.00001/acre) mapped by the Wyoming Water Development Office.

R-CAT results indicate that 3 percent of the area in valley bottoms is affected by conifer encroachment, 4 percent is affected by upland encroachment, and less than 1 percent is affected by replacement by invasive species. WHAM level I surveys were conducted at 745 stream segments. Recruitment of riparian vegetation was occurring at 77 percent and upland encroachment was occurring at 28 percent of segments. Vegetation for beaver food was present at 23 percent of stream segments and building material was present at 24 percent of segments. Many of the segments were too steep or at too high an elevation for beaver dams. Reports from stream surveys indicate that willows were absent from expected locations at Dutch Joe Creek, resulting in absence of beavers. Woody vegetation and beaver dams were reported along other streams, however. Of the four riparian vegetation composition and structure indicators, none showed evidence of alteration from the NRV. The overall composition and structure index was 100 percent and this unit was considered **within** the NRV.

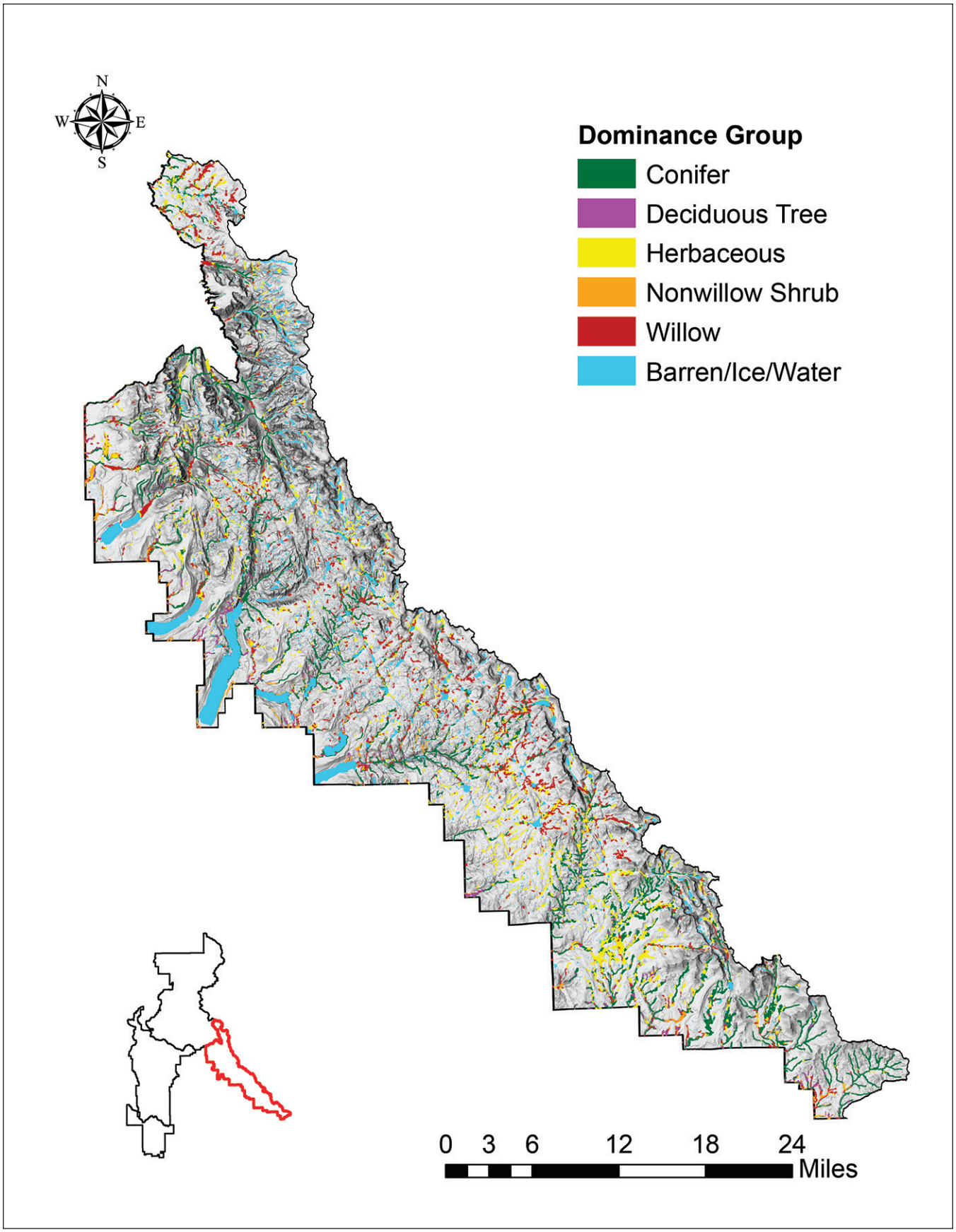


Figure I3—Riparian dominance groups in the Windriver geographic unit.

Kemmerer

Within the 50-year floodplain, 27 percent of vegetation is dominated by conifers, 12 percent by deciduous trees, 7 percent by herbaceous plants, 25 percent by nonwillow shrubs, and 28 percent by willows (fig. I4). Riparian community types were described for the region including the Kemmerer geographic unit by Youngblood et al. (1985).

Active livestock allotments cover nearly 100 percent of the unit. Fires were effectively suppressed during much of the 20th century (BTNF 2001), resulting in declines in aspen regeneration. Roads influence riparian ecosystems, as do several species of noxious weeds (BTNF 2001). Areas of high or very high wildfire potential, an indicator of fire suppression, cover 19 percent of the unit. Eight percent of the 50-year floodplain was burned by wildfire between 1984 and 2014. There are 4 points of diversion (0.00001/acre) mapped by the Wyoming Water Development Office.

R-CAT results indicate that 8 percent of the area in perennial valley bottoms is affected by conifer encroachment, 11 percent is affected by upland encroachment, and less than 1 percent is affected by replacement by invasive species. WHAM level I surveys were conducted at 135 stream segments. Recruitment of riparian vegetation was occurring at 64 percent of segments and upland encroachment was occurring at 48 percent of segments. Vegetation adequate for beaver food was present at 40 percent of segments and vegetation for building material was present at 31 percent of segments. At several locations, willows were present, but aspen was unavailable. WHAM level II surveys were conducted in the LeBarge Creek Watershed. Vegetation measurements and subsequent remeasurements showed increases in Salix, decreases in Carex, increases in Juncus, and increases in upland components. There was an overall decrease in riparian vegetation trend at the Packsaddle Riparian Complex, a static or slightly upward trend at Nameless Creek Complex, and an apparent downward trend for the LeBarge Meadows Complex. Willow communities were generally in good condition, but herbaceous communities lacked the expected sedge component. A combination of heavy grazing pressure and loss of beaver dam function may explain this absence. Restoration of aspen stands near streams is necessary to restore the former functionality of beaver dam complexes (Roadifer and Sexauer 2008). Of the four riparian vegetation composition and structure indicators, three showed no evidence of alteration from the NRV and one showed evidence of moderate alteration. The overall composition and structure index was 90 percent and the unit was considered **within** the NRV.

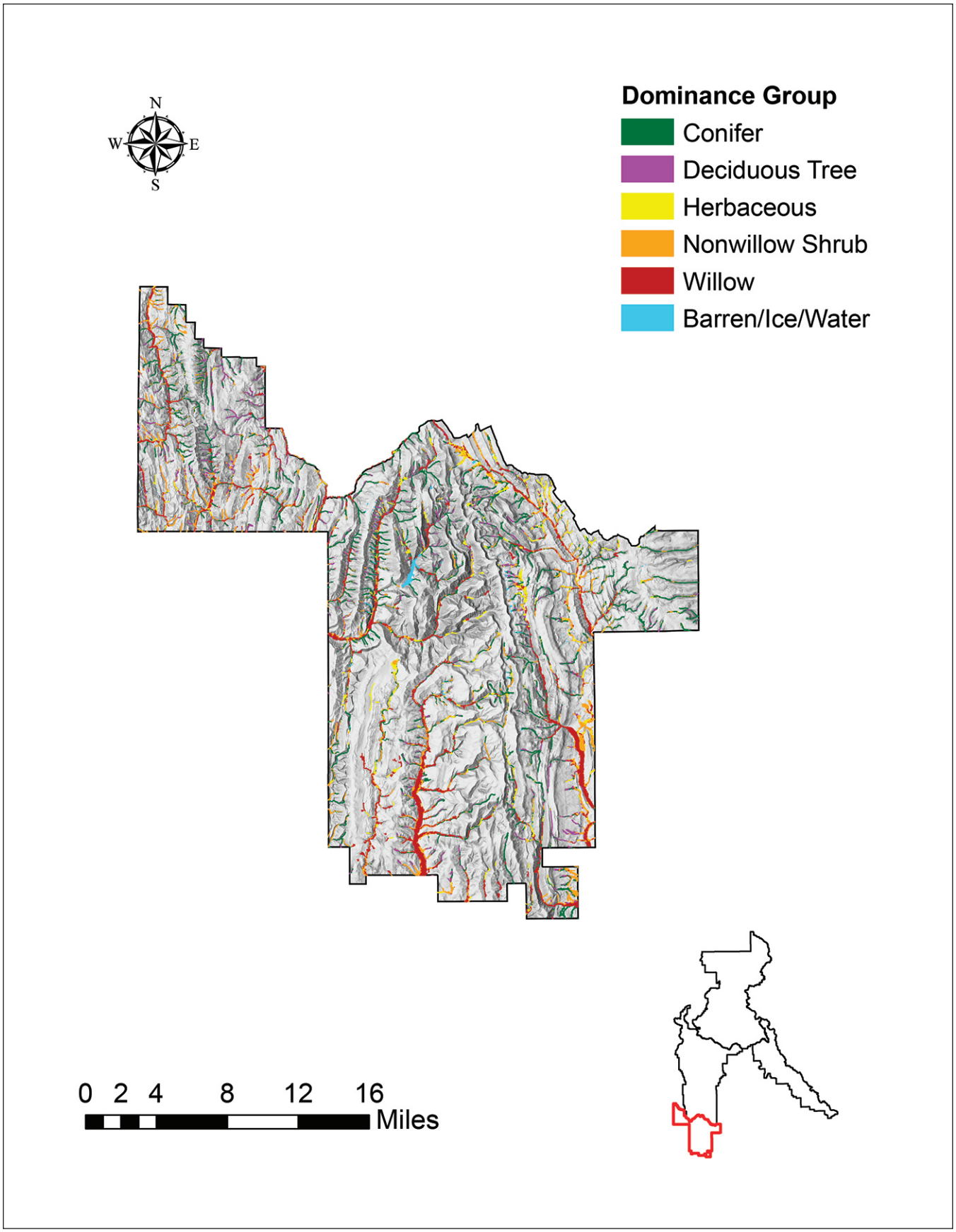


Figure I4—Riparian Dominance groups in the Kemmerer geographic unit.

Appendix J. Watershed Maps

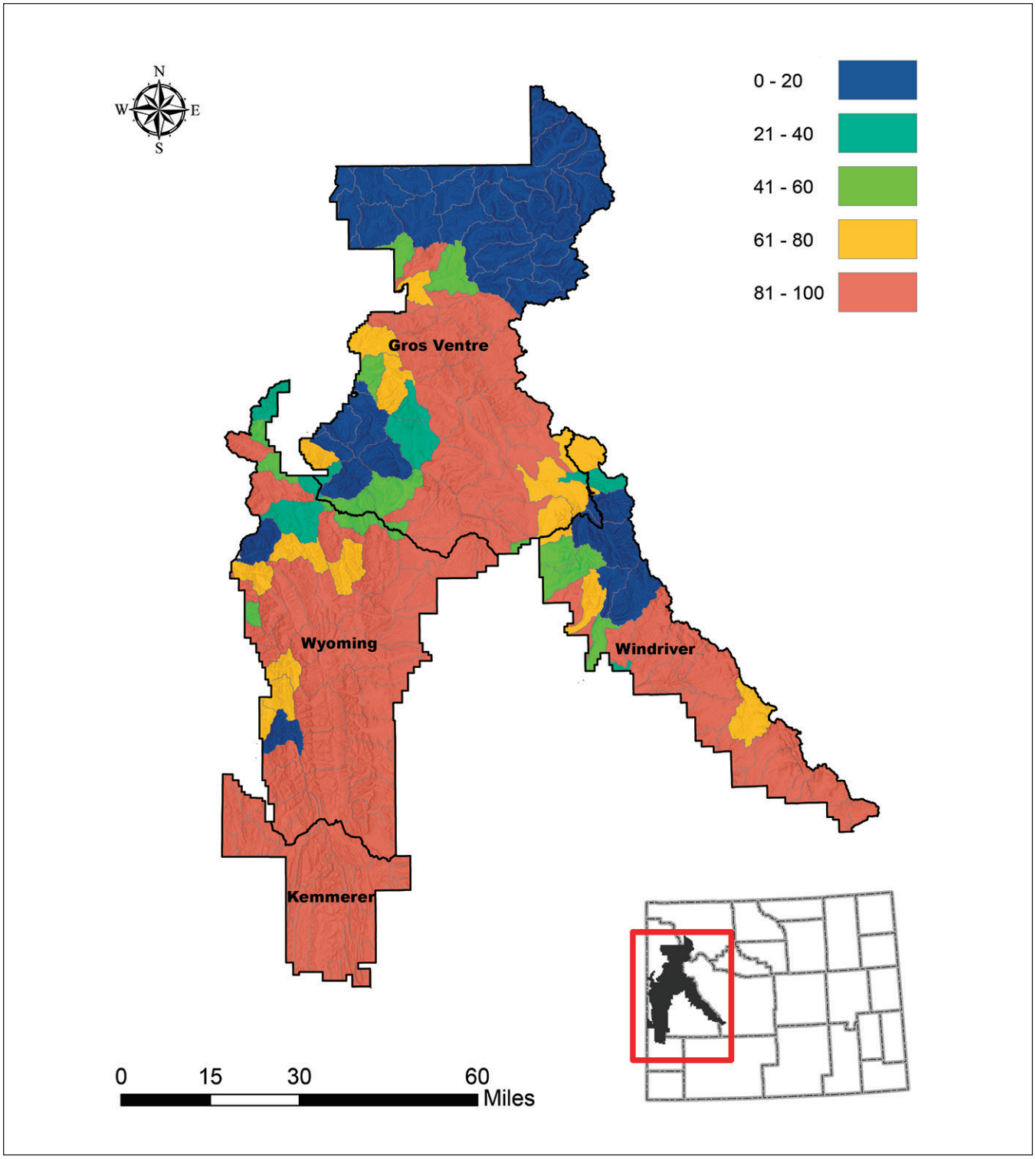


Figure J1—Percent of watershed within a range management unit.

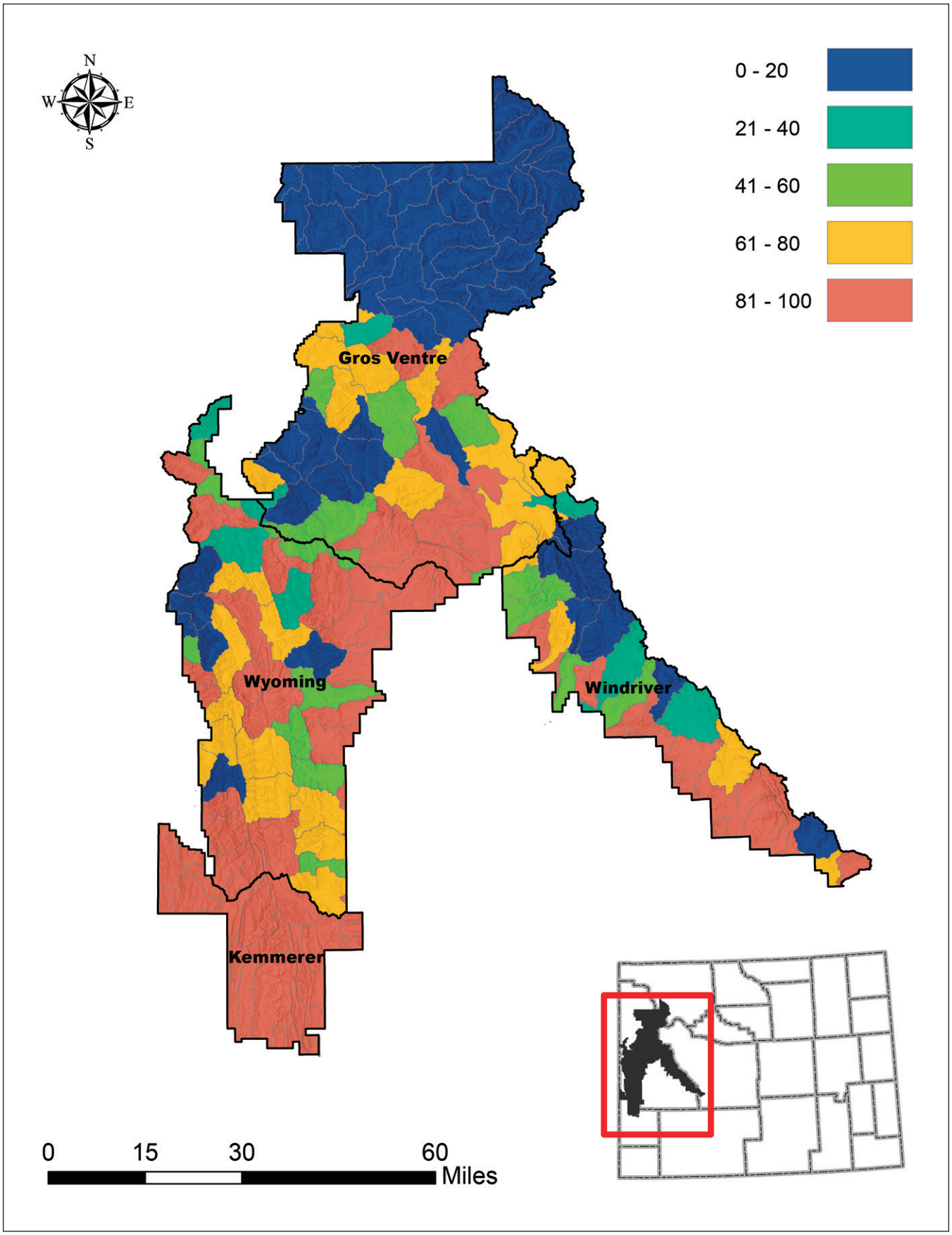


Figure J2—Percent of watershed within an active range management unit.

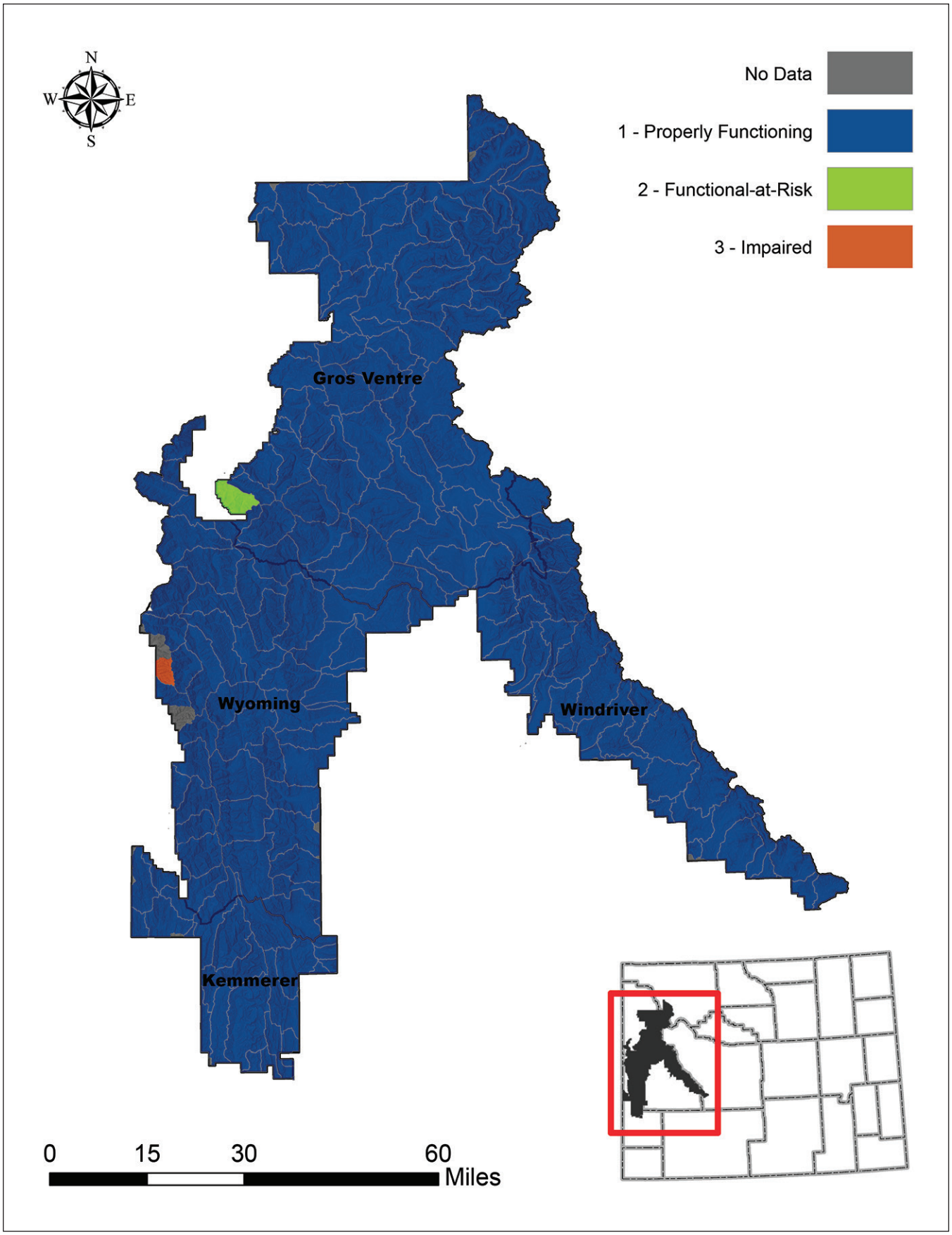


Figure J3—Impaired waters classification determined by the WCC.

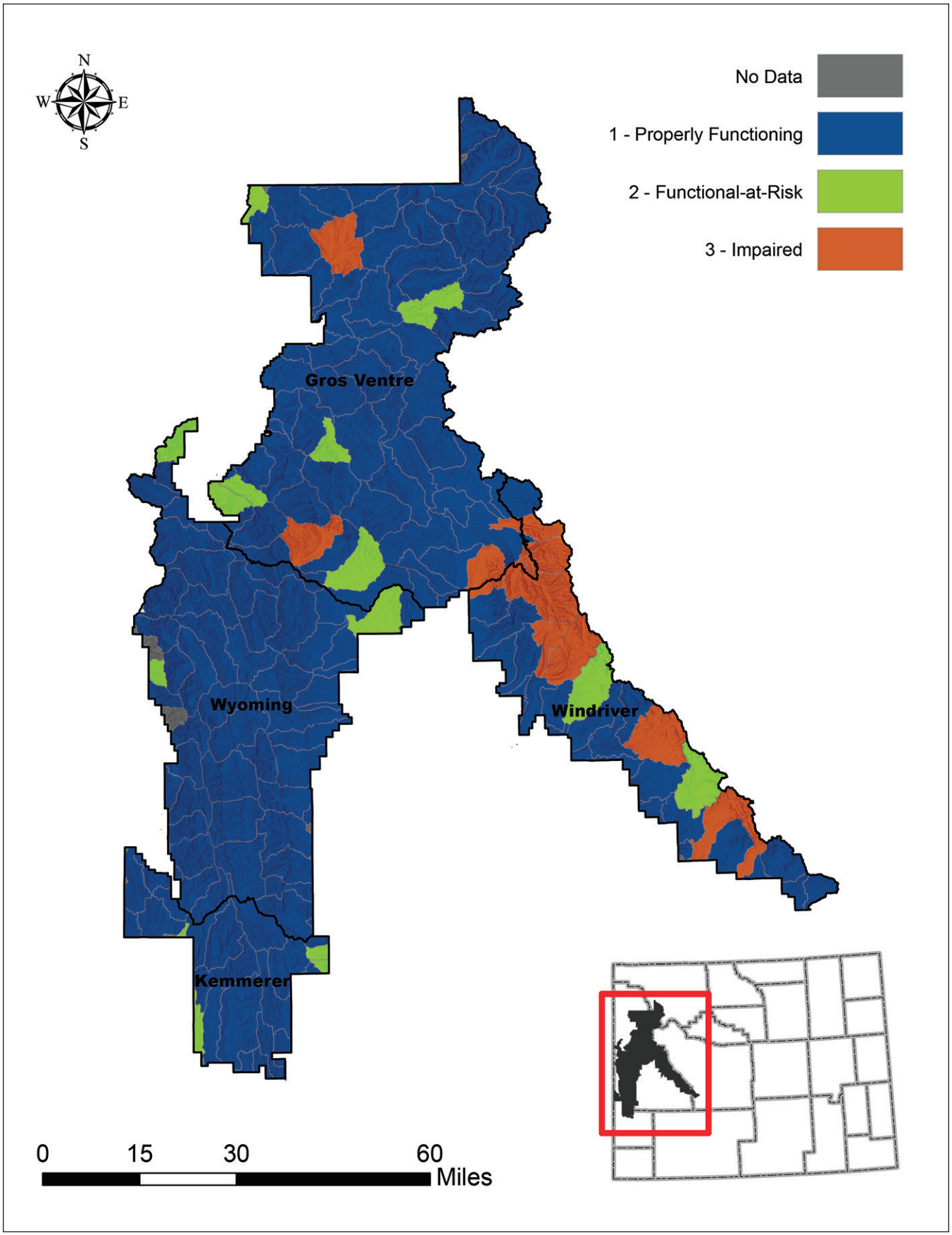


Figure J4—Water quality problems including excessive sediment, nutrients, and chemical pollution as determined by the WCC.

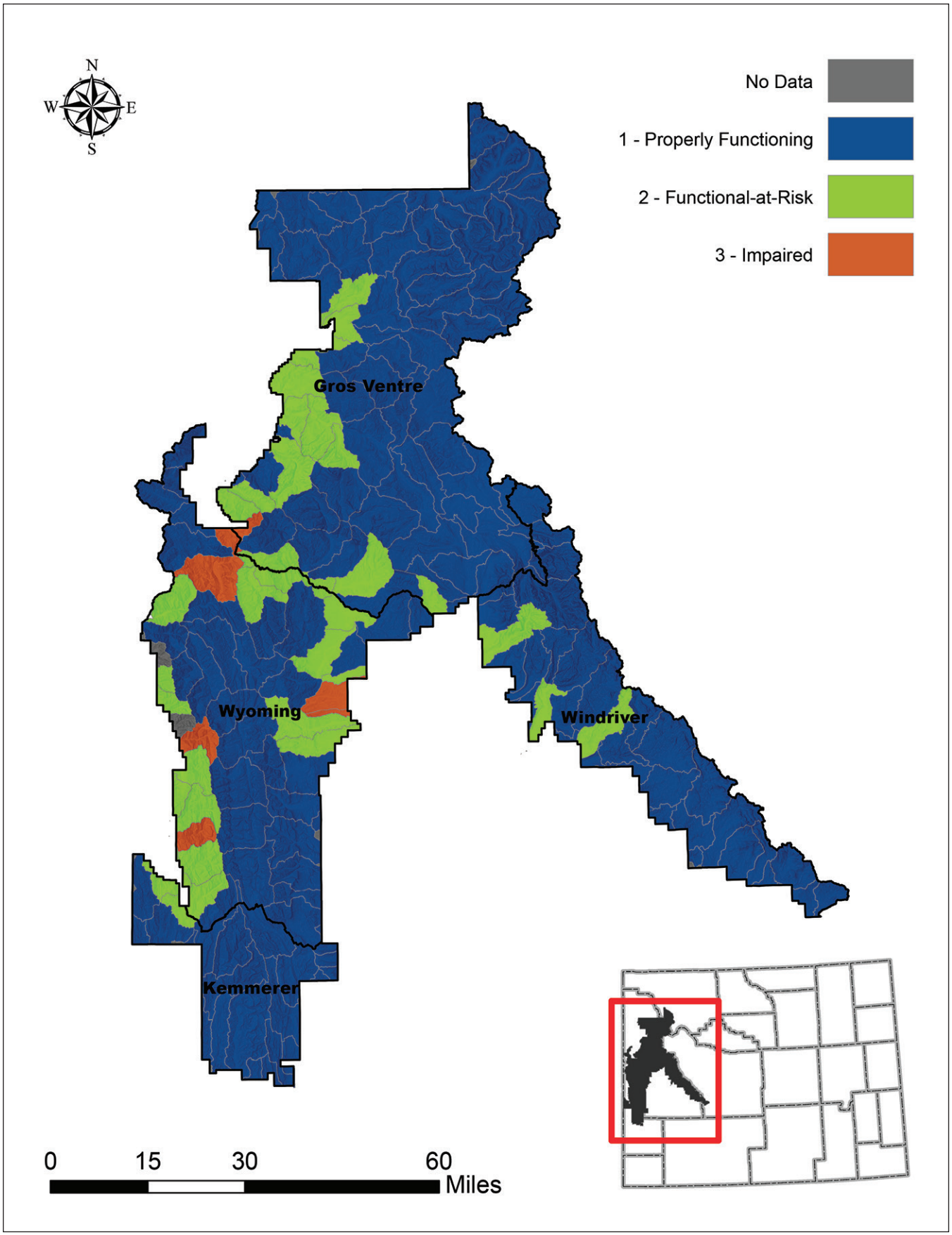


Figure J5—Flow characteristics describing whether a watershed has primarily free-flowing rivers and streams, unmodified lakes, and no or limited groundwater withdrawals as classified by the WCC.

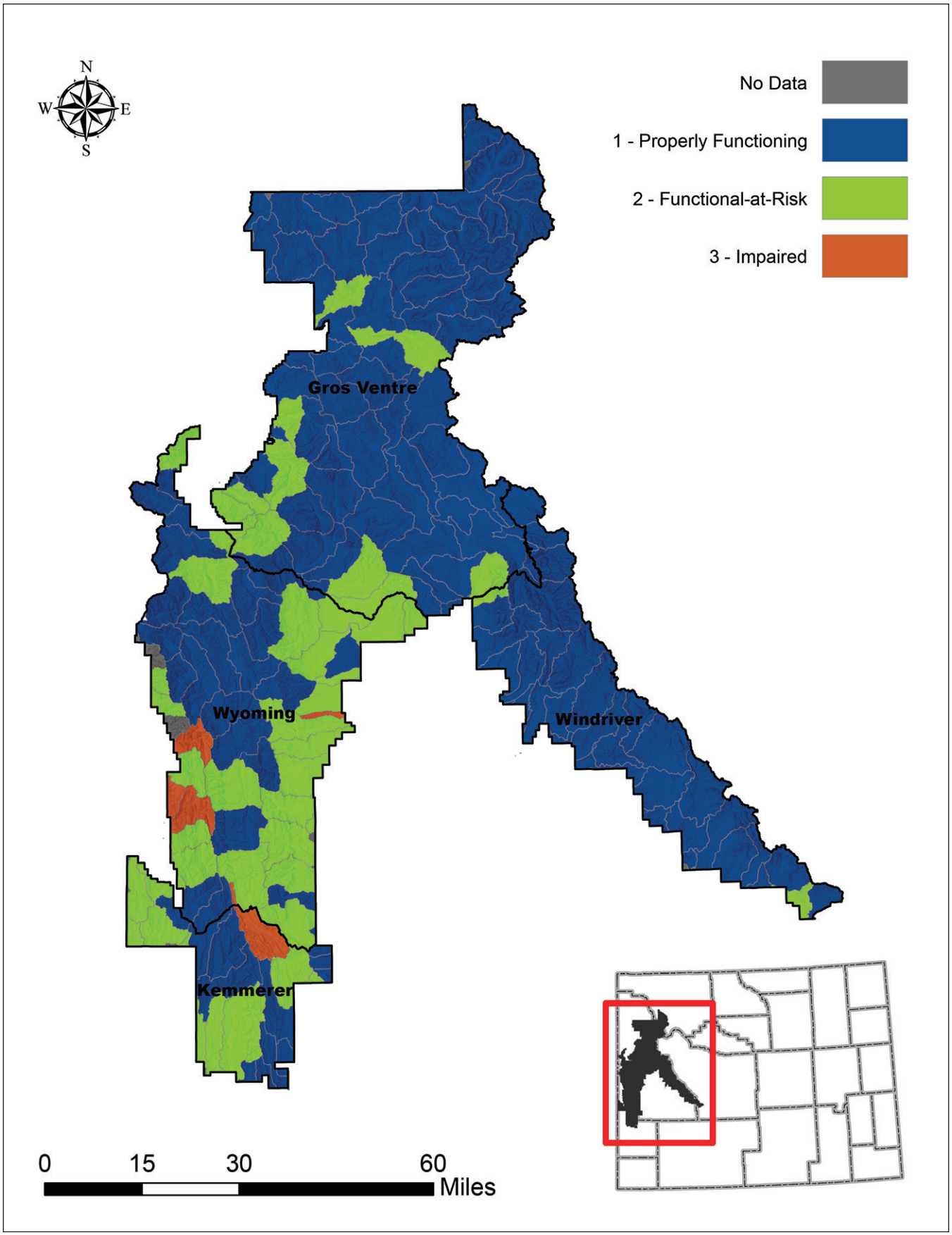


Figure J6—Levels of aquatic habitat fragmentation determined by the WCC.

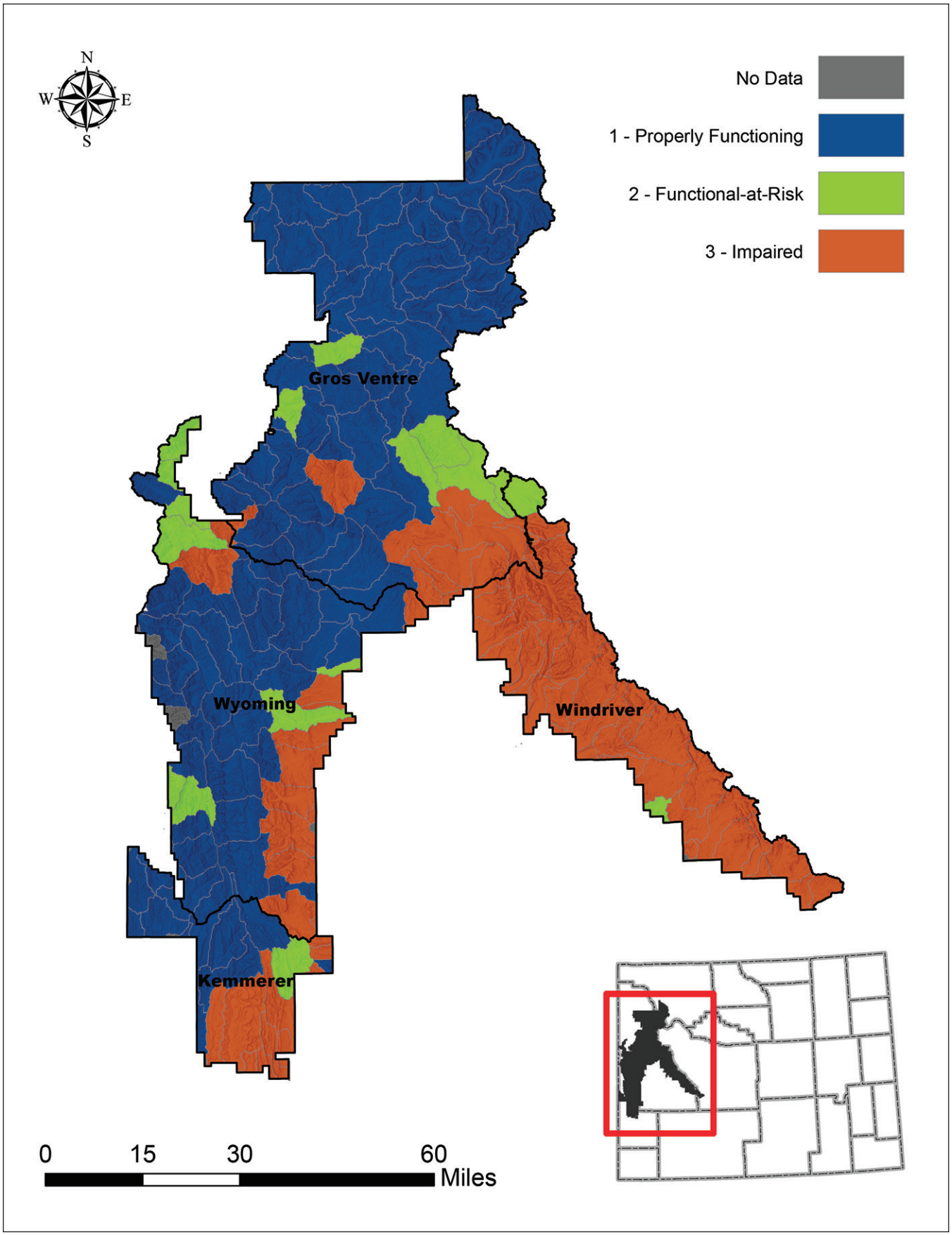


Figure J7—Condition of exotic and/or aquatic invasive species as determined by the WCC.

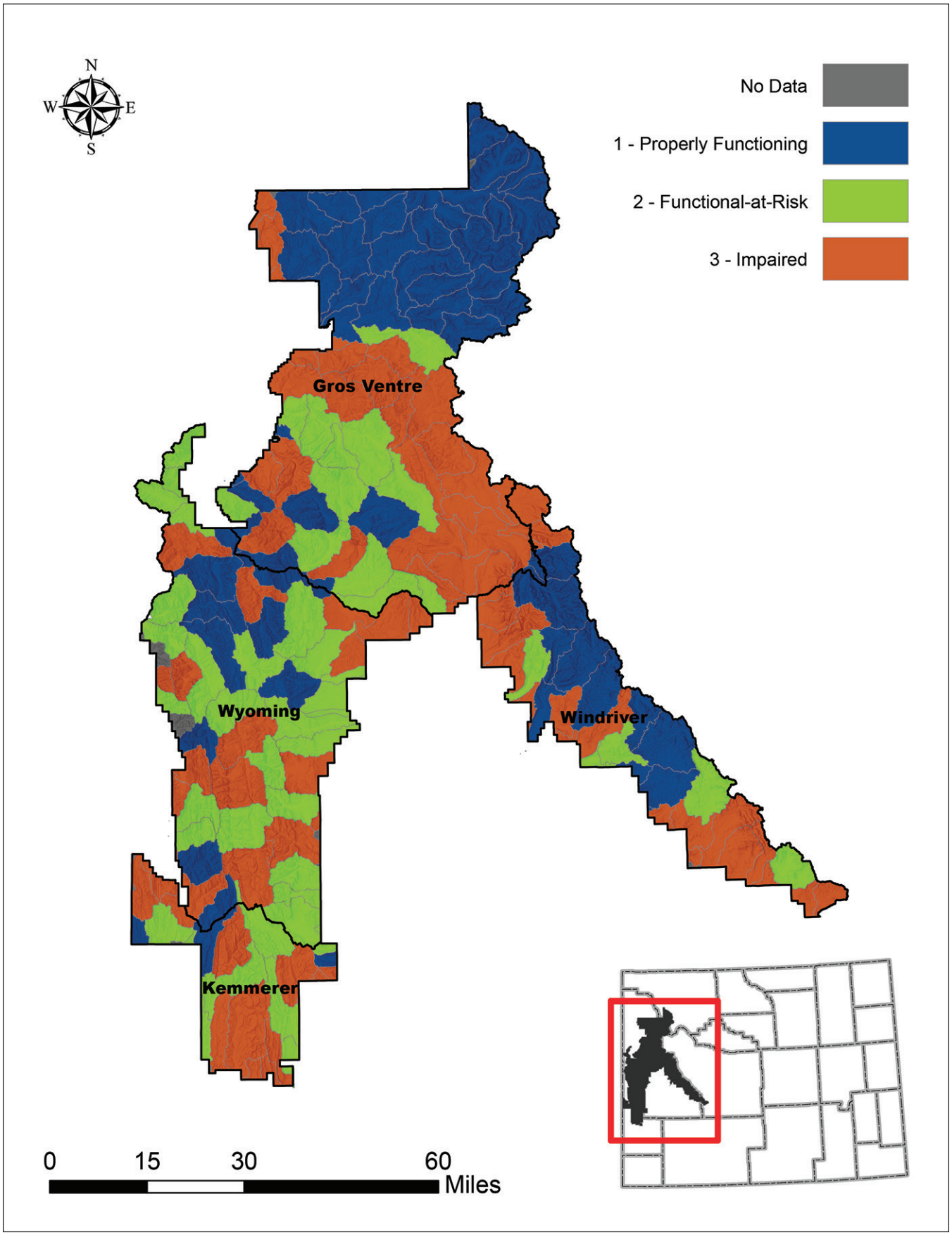


Figure J8—Applications of best management practices for maintenance of roads, trails, and water crossings within each watershed as determined by the WCC.

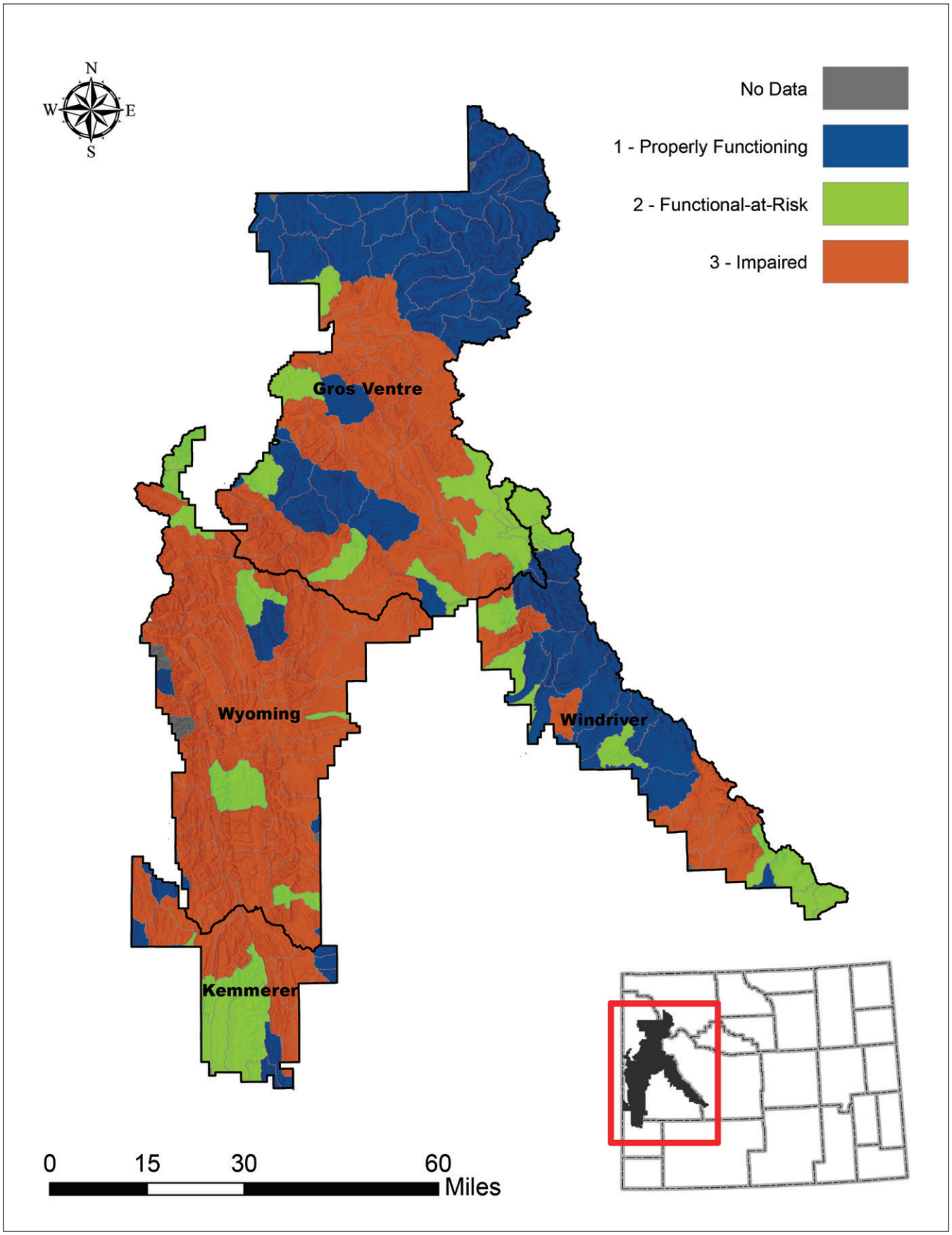


Figure J9—Proximity of roads and trails to streams and water bodies as determined by the WCC.

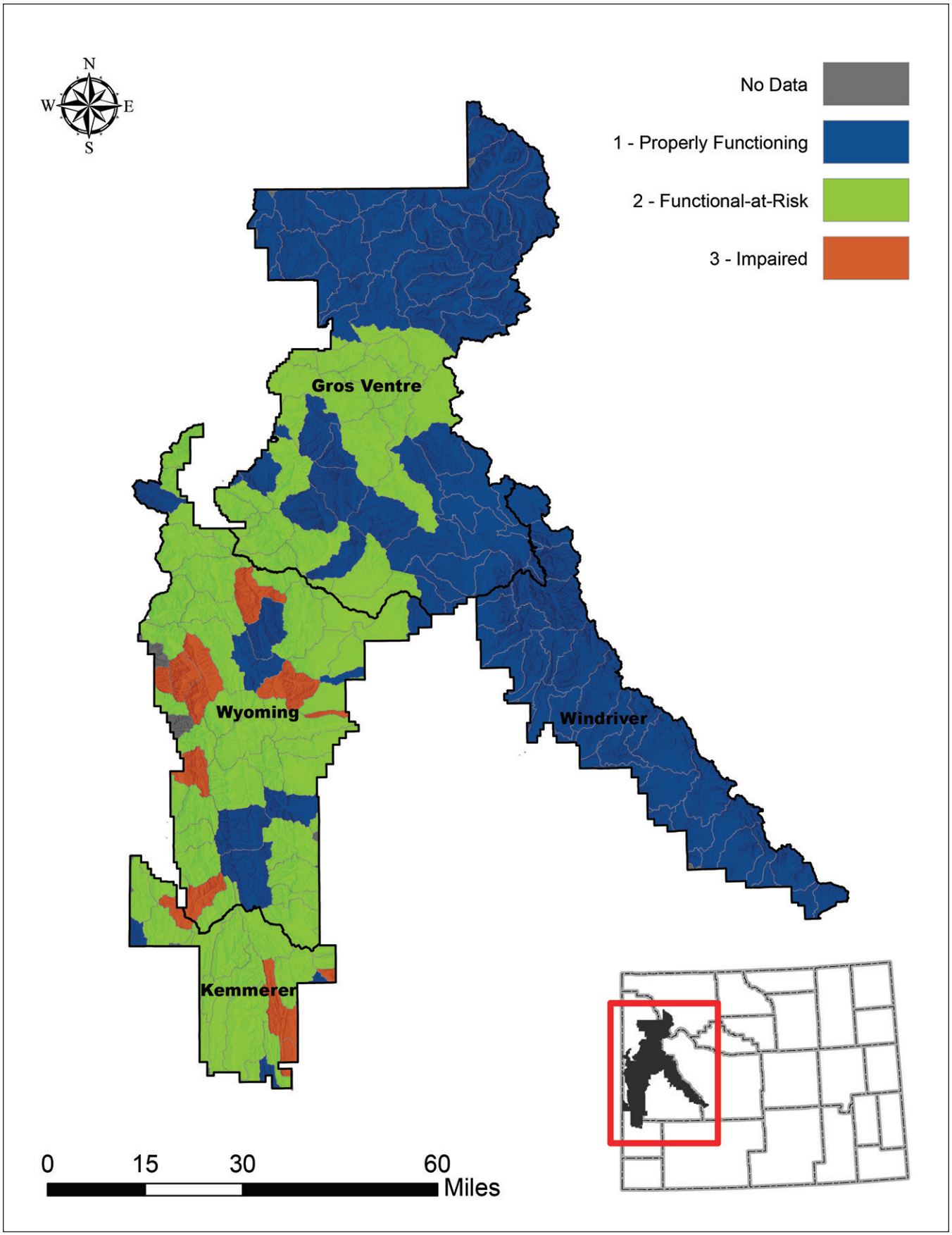


Figure J10—Condition of mass wasting from roads on unstable landforms as determined by the WCC.

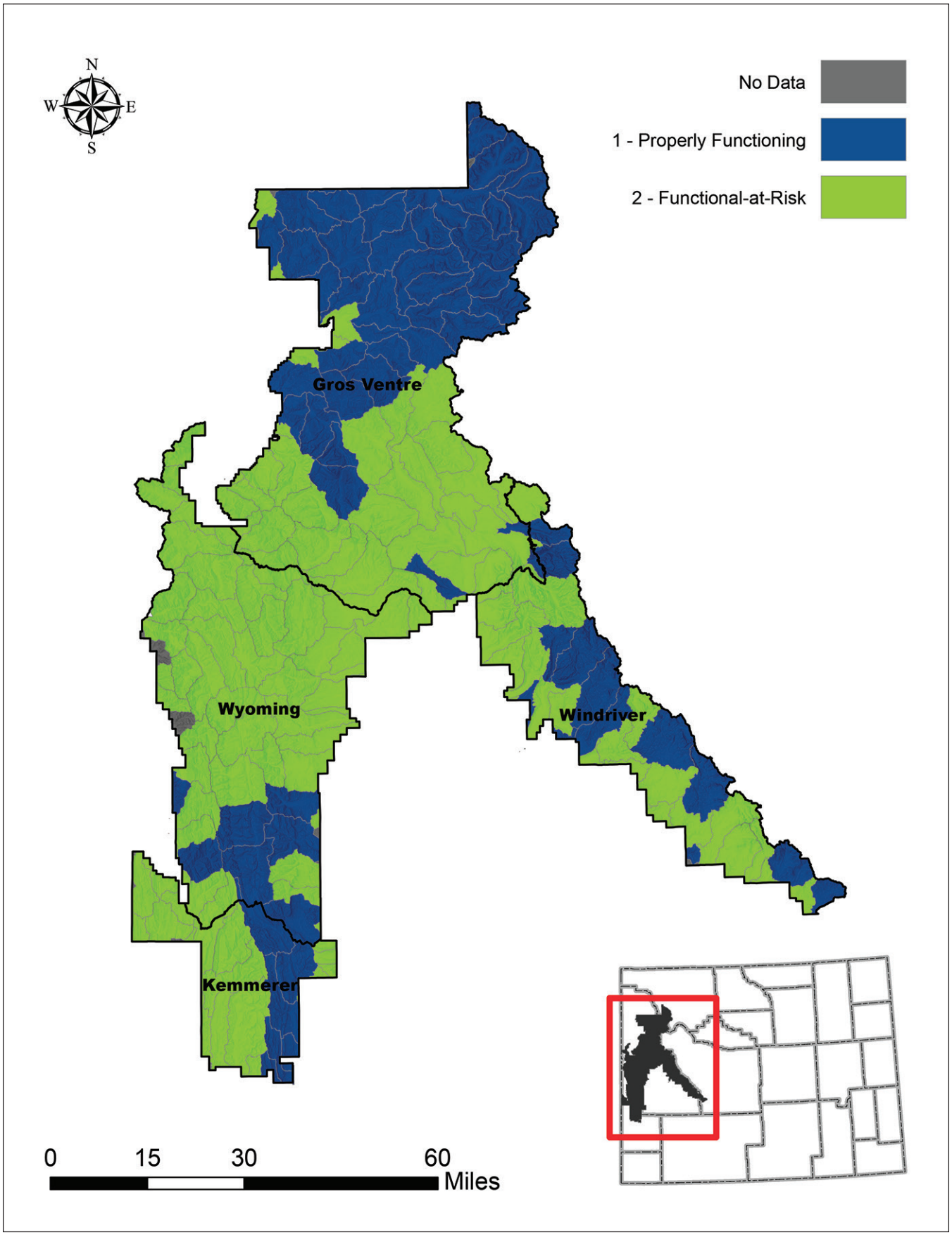


Figure J11—Condition of soil contamination due to atmospheric deposition or other activities as determined by the WCC.

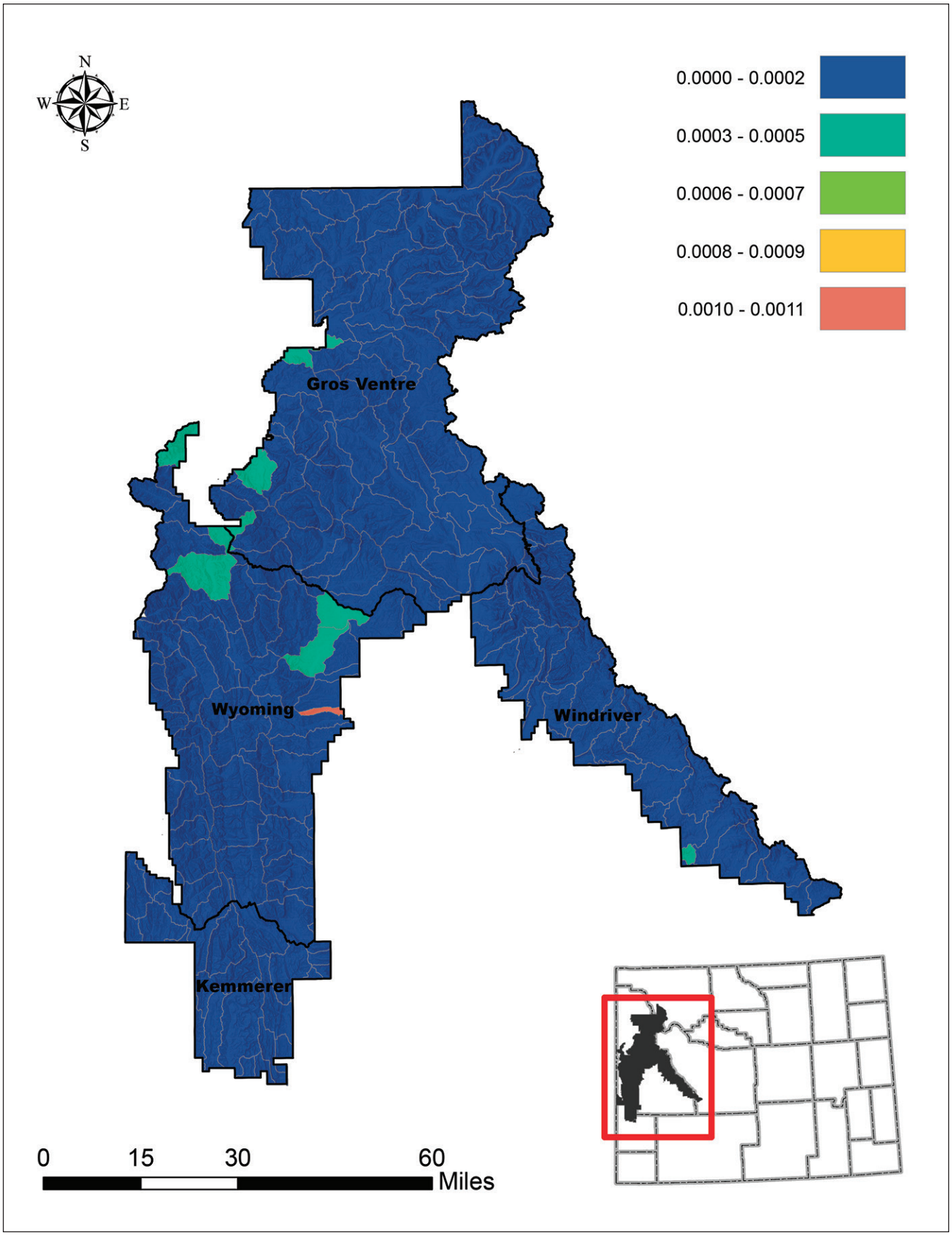


Figure J12—Diversions per acre within each watershed.

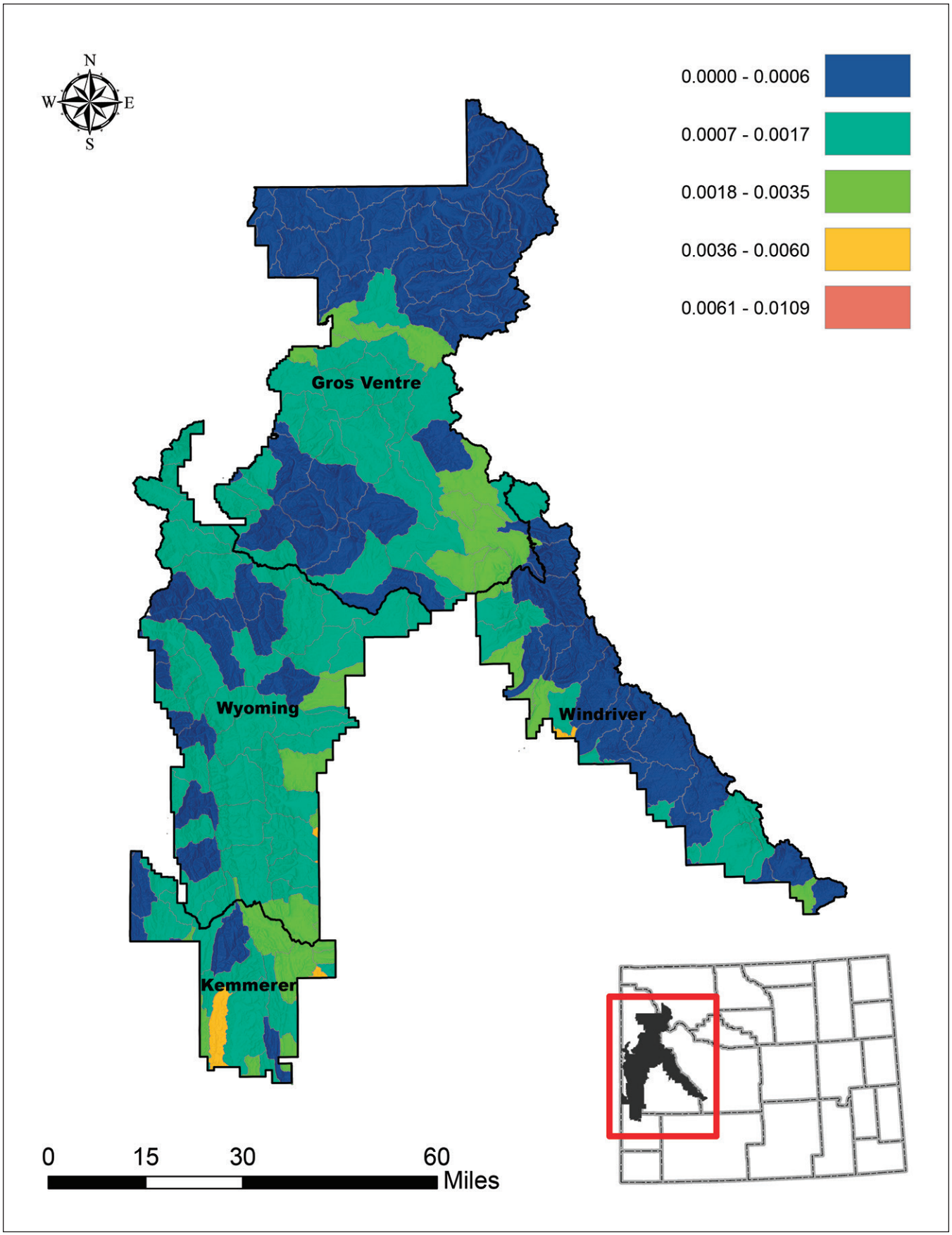


Figure J13—Road miles per acre within each watershed, determined using the roads layer from the TCA.

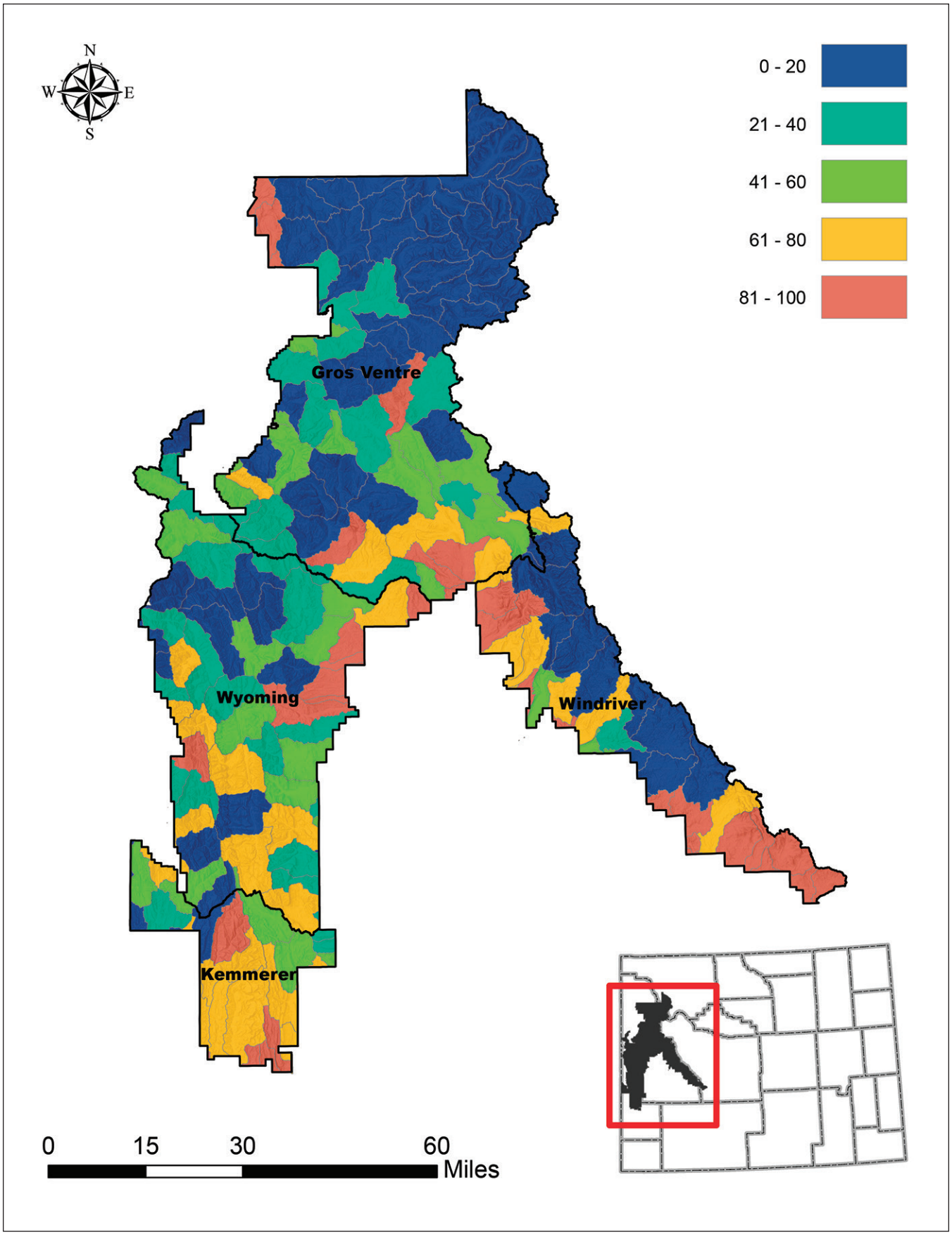


Figure J14—Percent of road miles within each watershed classified as unimproved by the TCA.

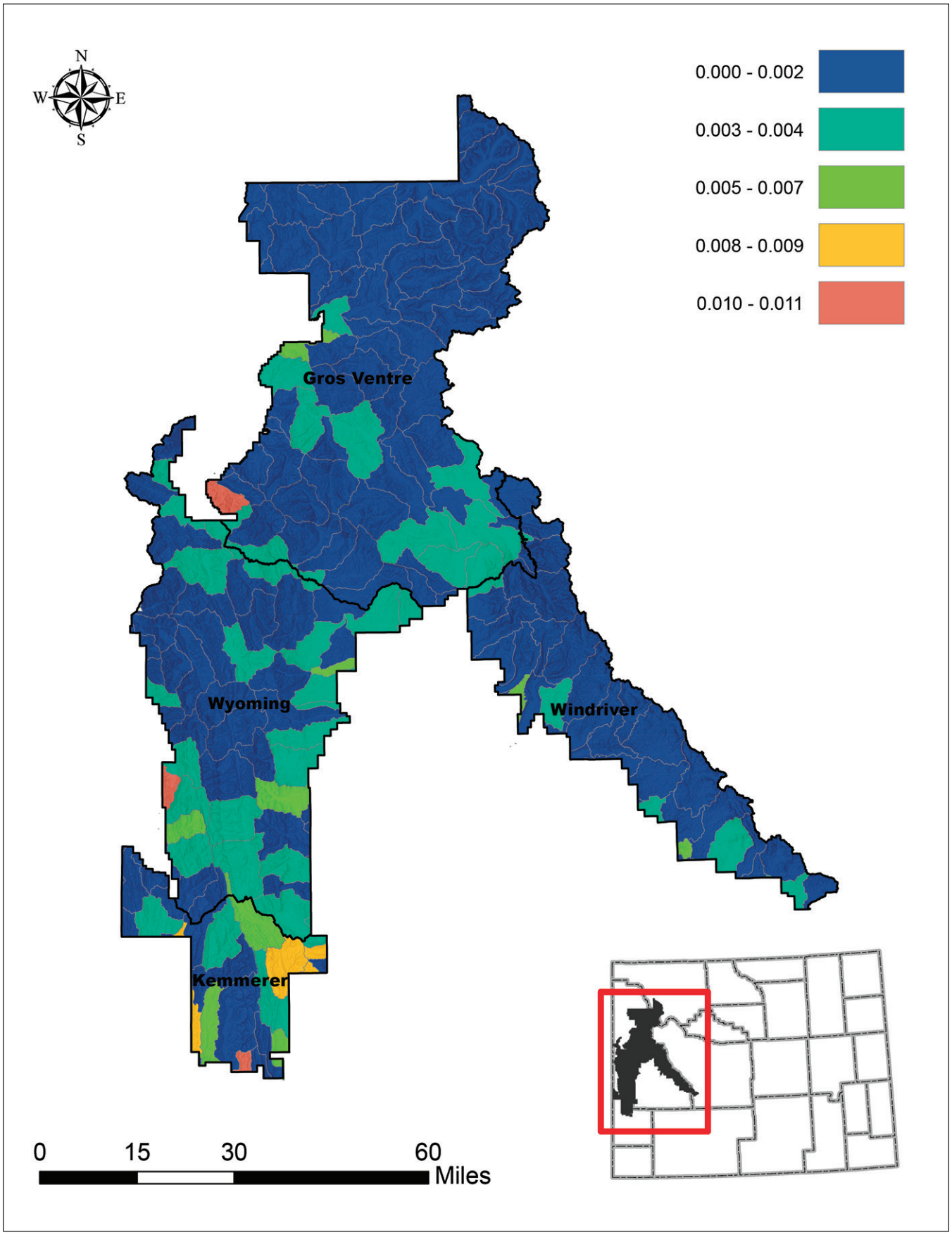


Figure J15—Road miles per floodplain acre within each watershed.

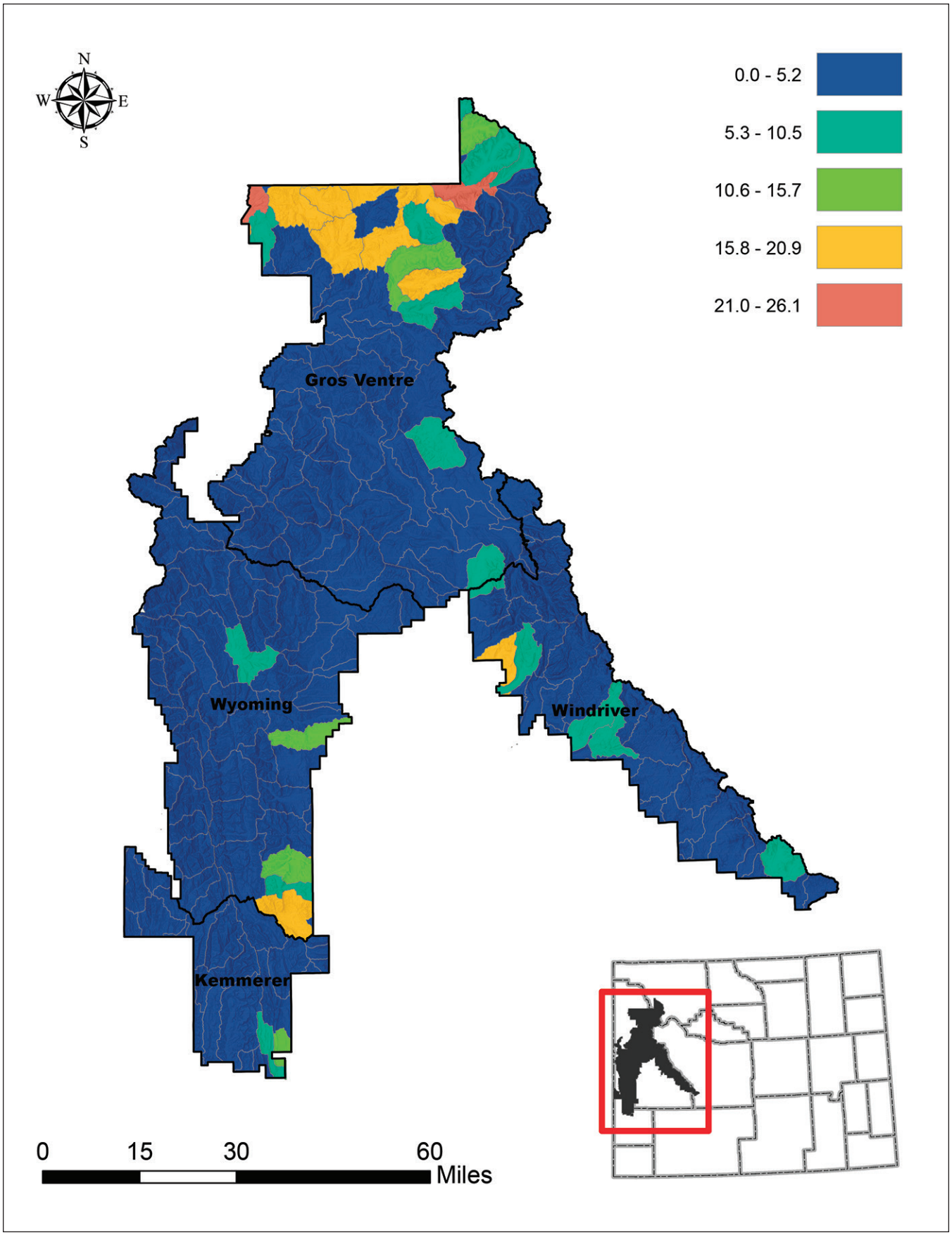


Figure J16—Percent of watershed burned at high severity since 1985. Determined using Monitoring Trends in Burn Severity data.

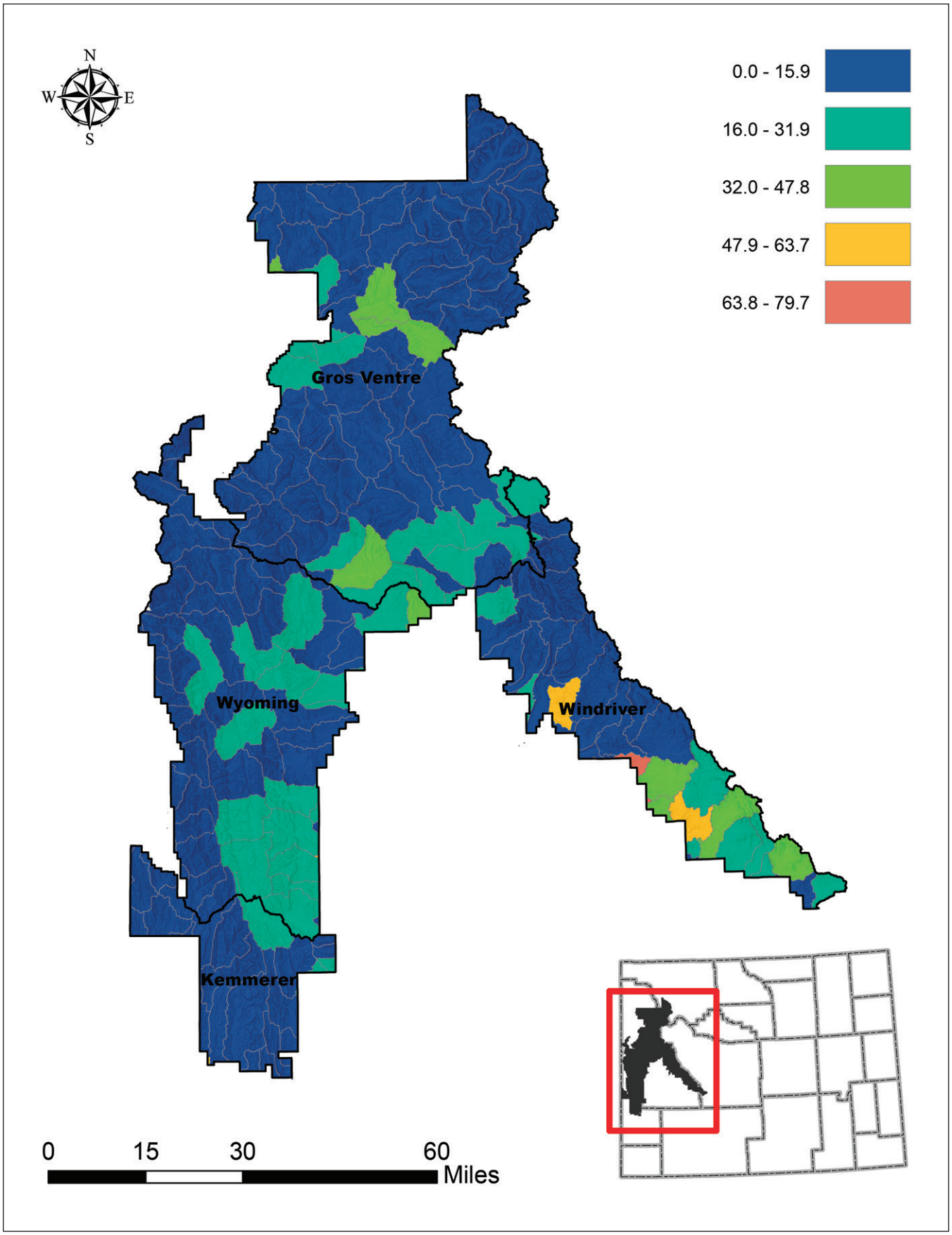


Figure J17—Percent of vegetation impacted by mortality due to insects and disease within each watershed. Determined using TCA data.

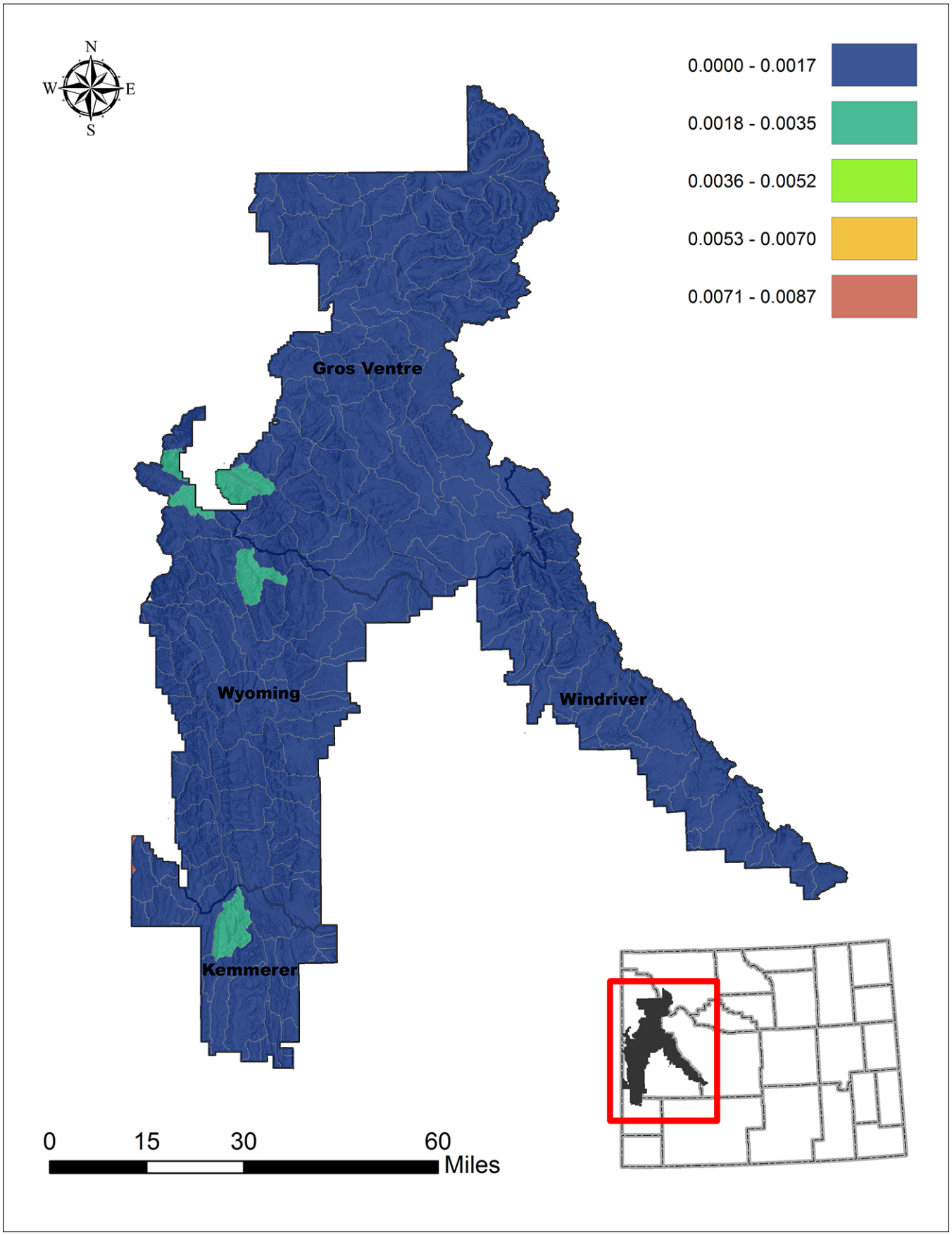


Figure J18—Trail miles per acre within each watershed.

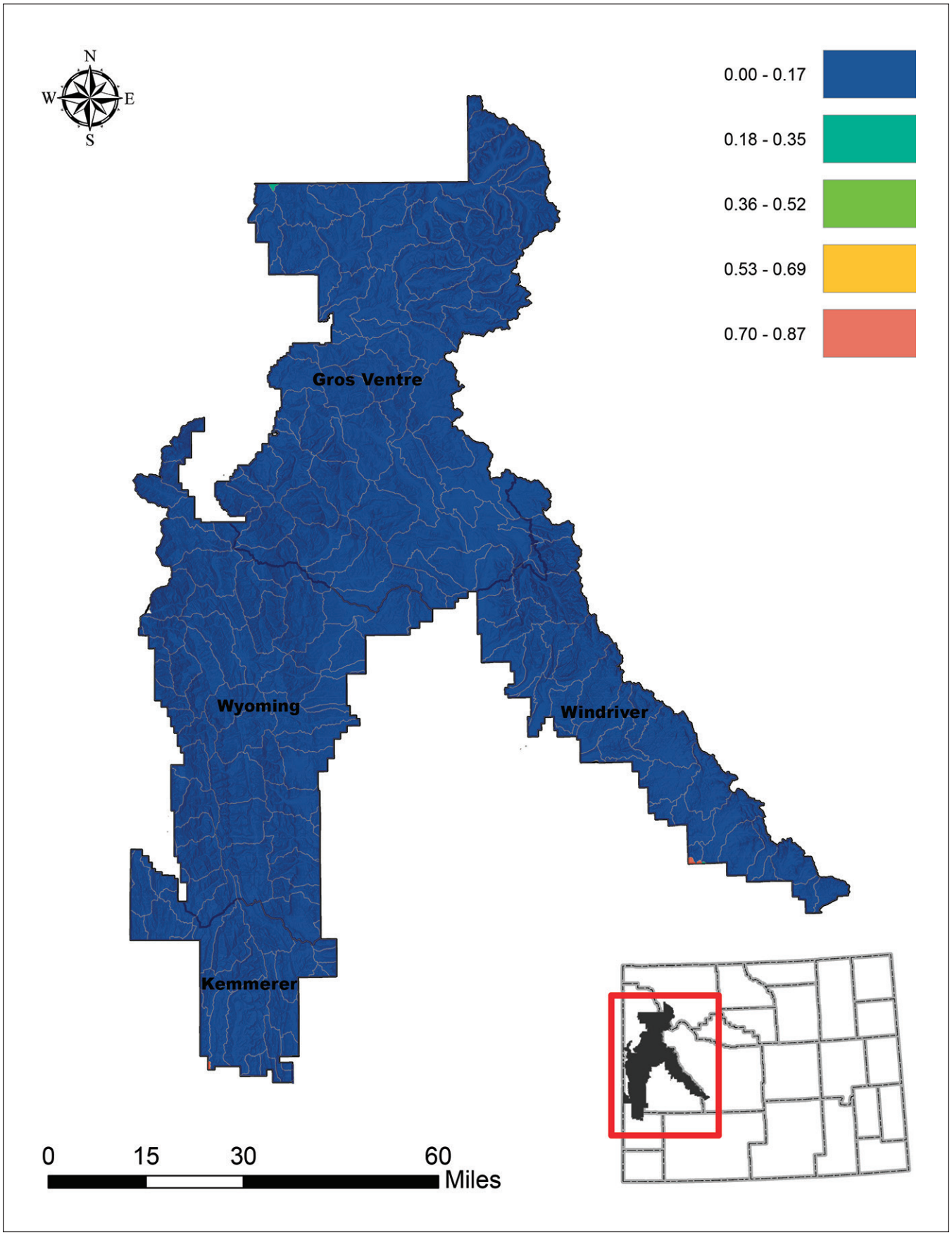


Figure J19—Trail miles per floodplain acre within each watershed.

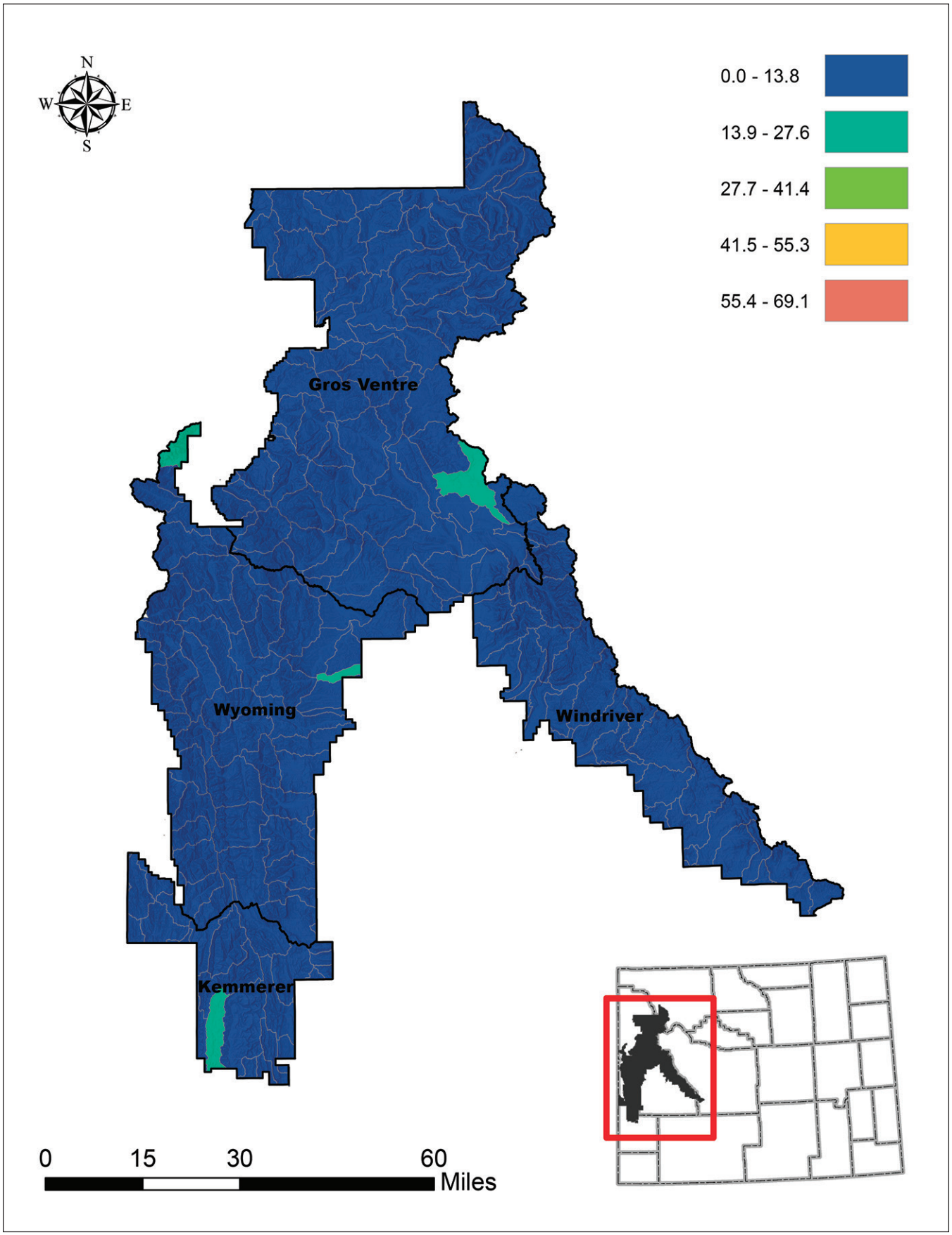


Figure J20—Percent of watershed within a timber harvest unit.

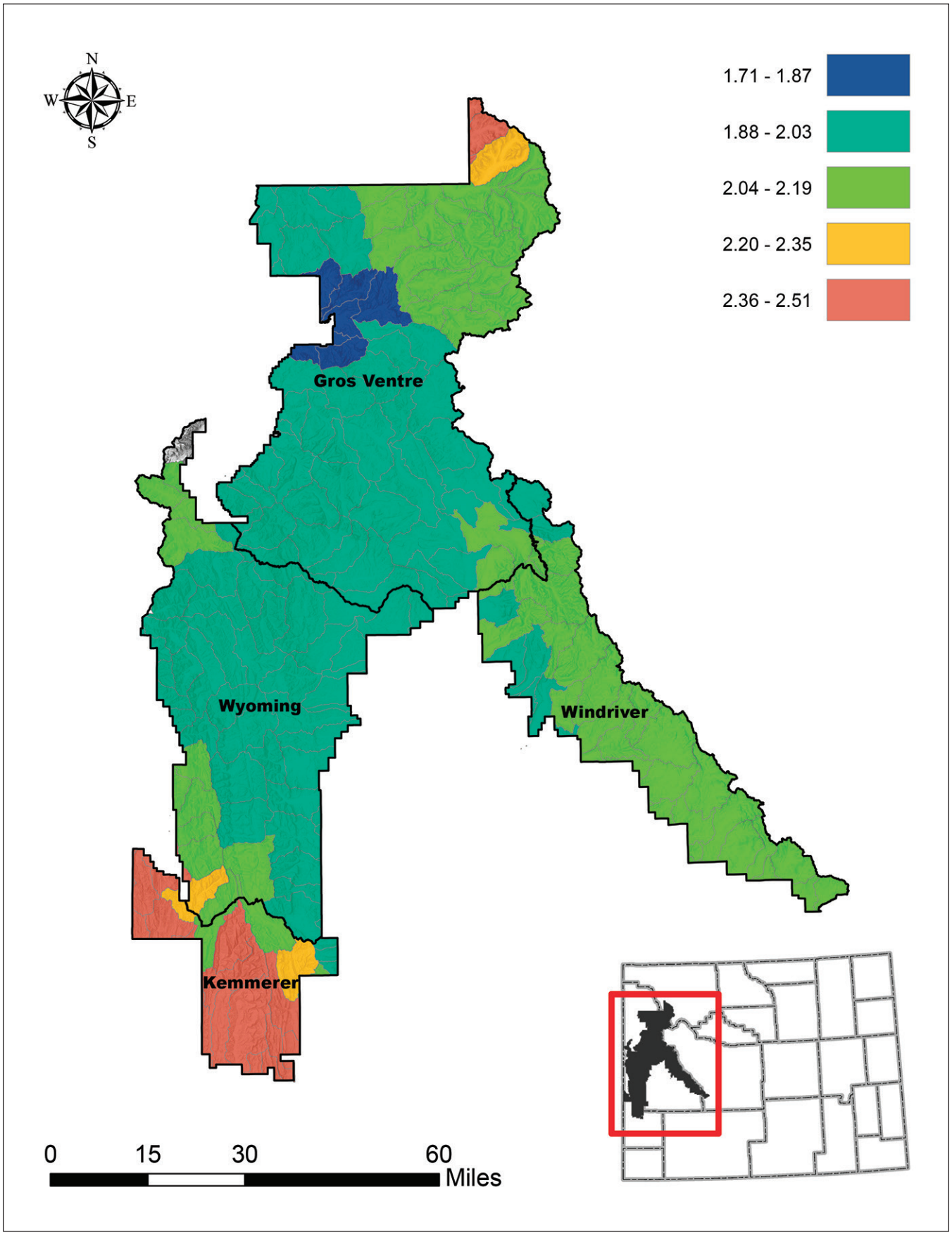


Figure J21—Average increase in winter temperature (°F) between 2010 and 2014 compared to the previous century. Determined using TCA data.

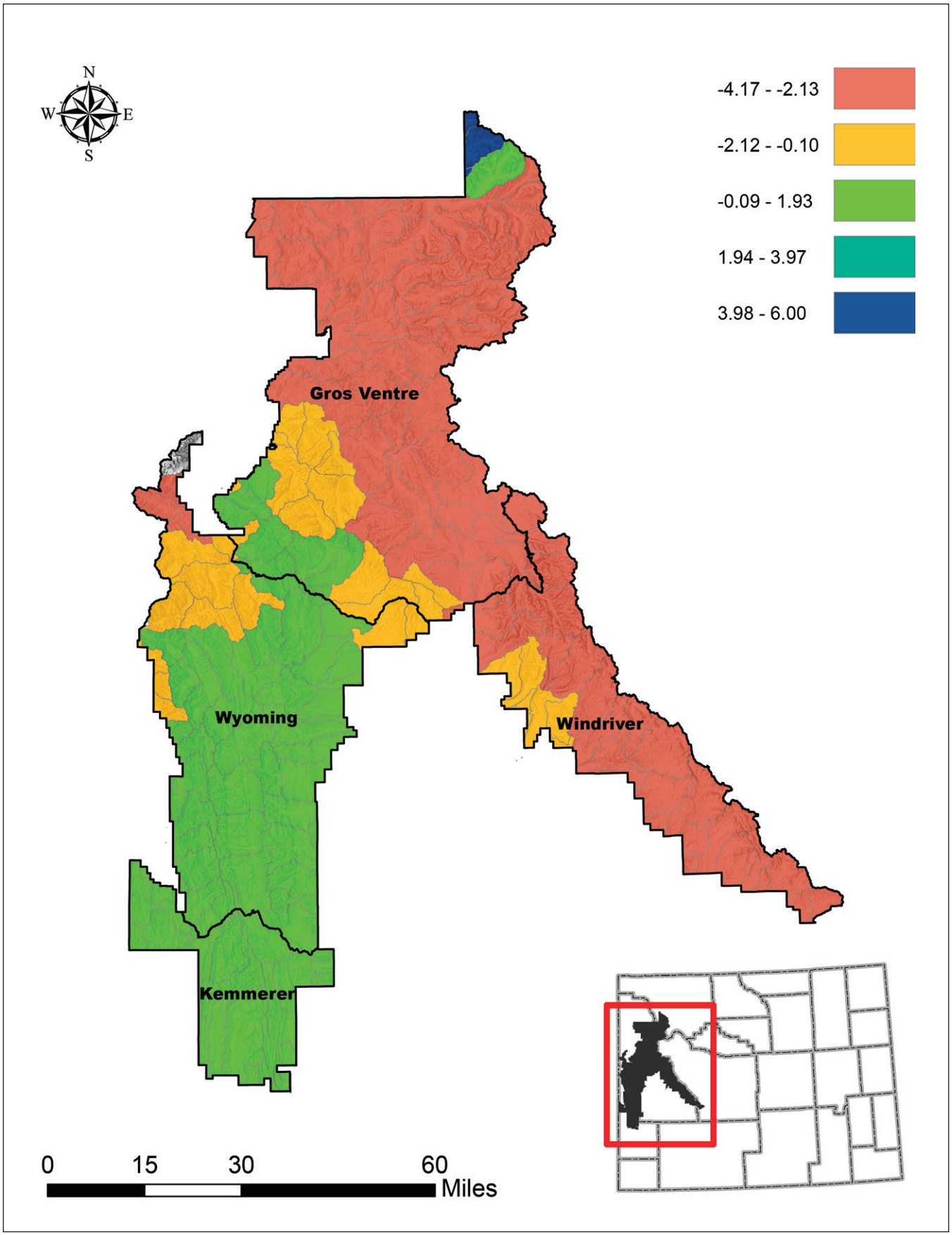


Figure J22—Average percent deviation in winter precipitation between 2010 and 2014 compared to the previous century. Determined using TCA data.

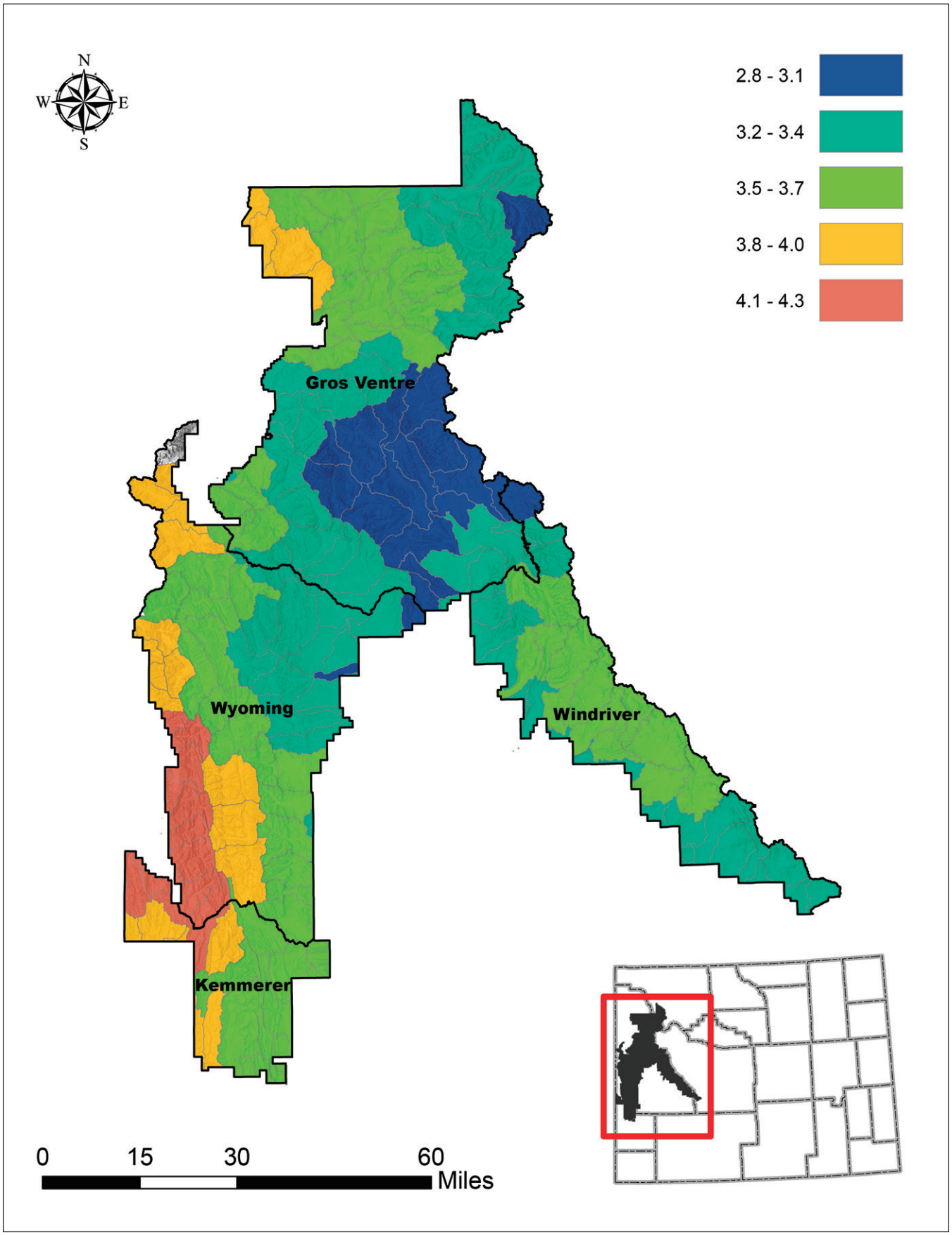


Figure J23—Average nitrogen deposition (kg/ha/yr) within each watershed. Determined using TCA data.

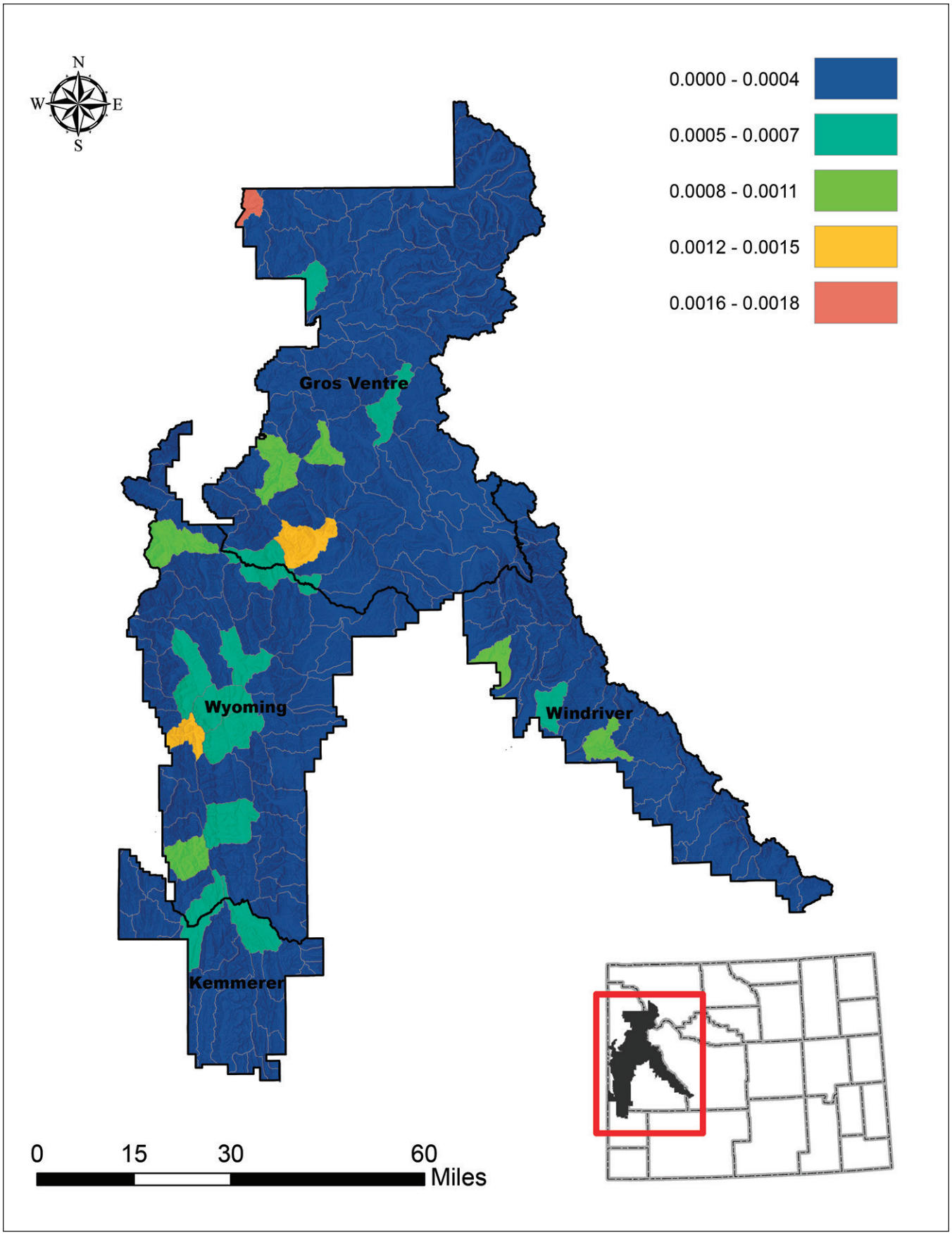


Figure J24—Recreation sites per floodplain acre within each watershed.

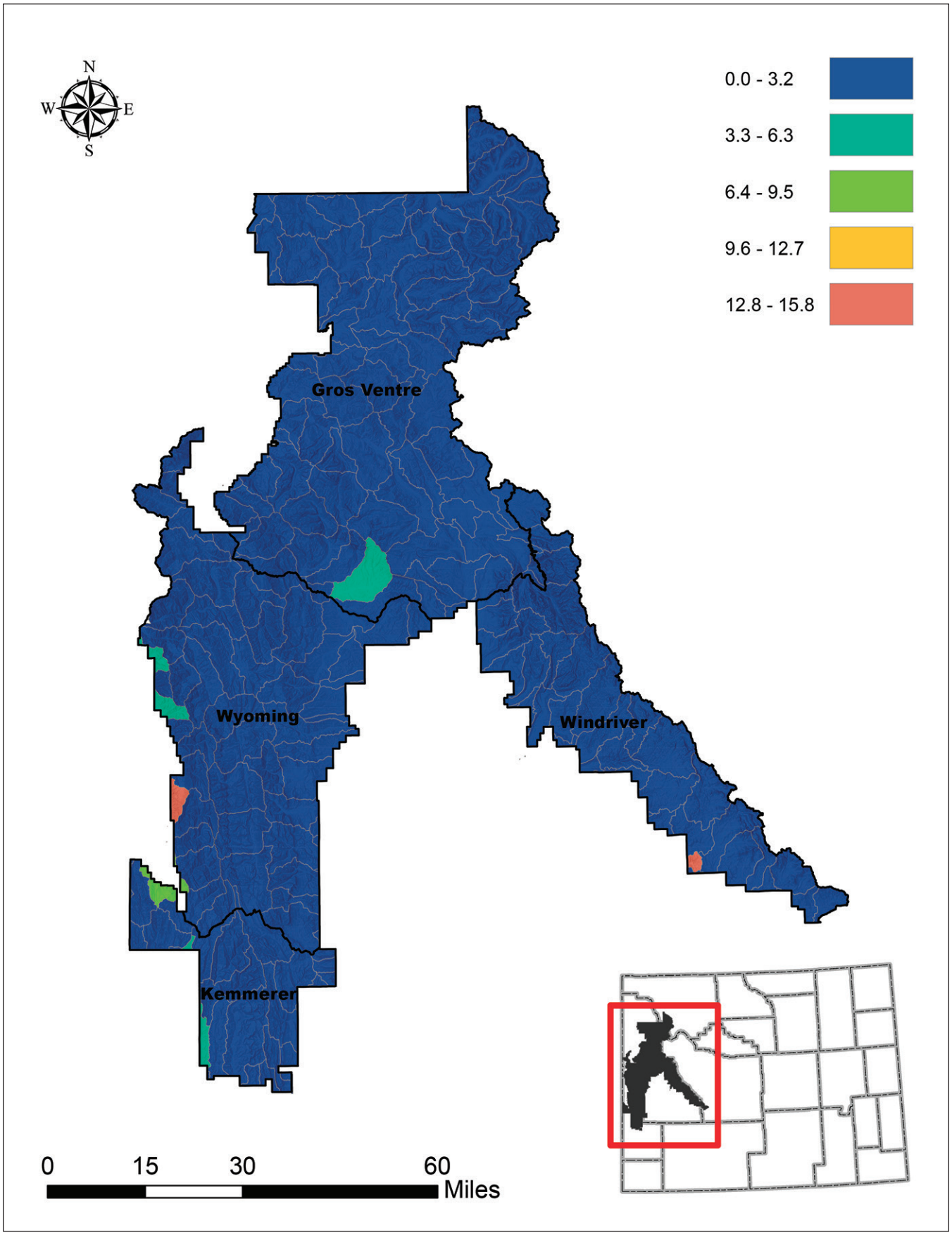


Figure J25—Percent of floodplain converted from riparian vegetation to agricultural cover. Determined using R-CAT data.

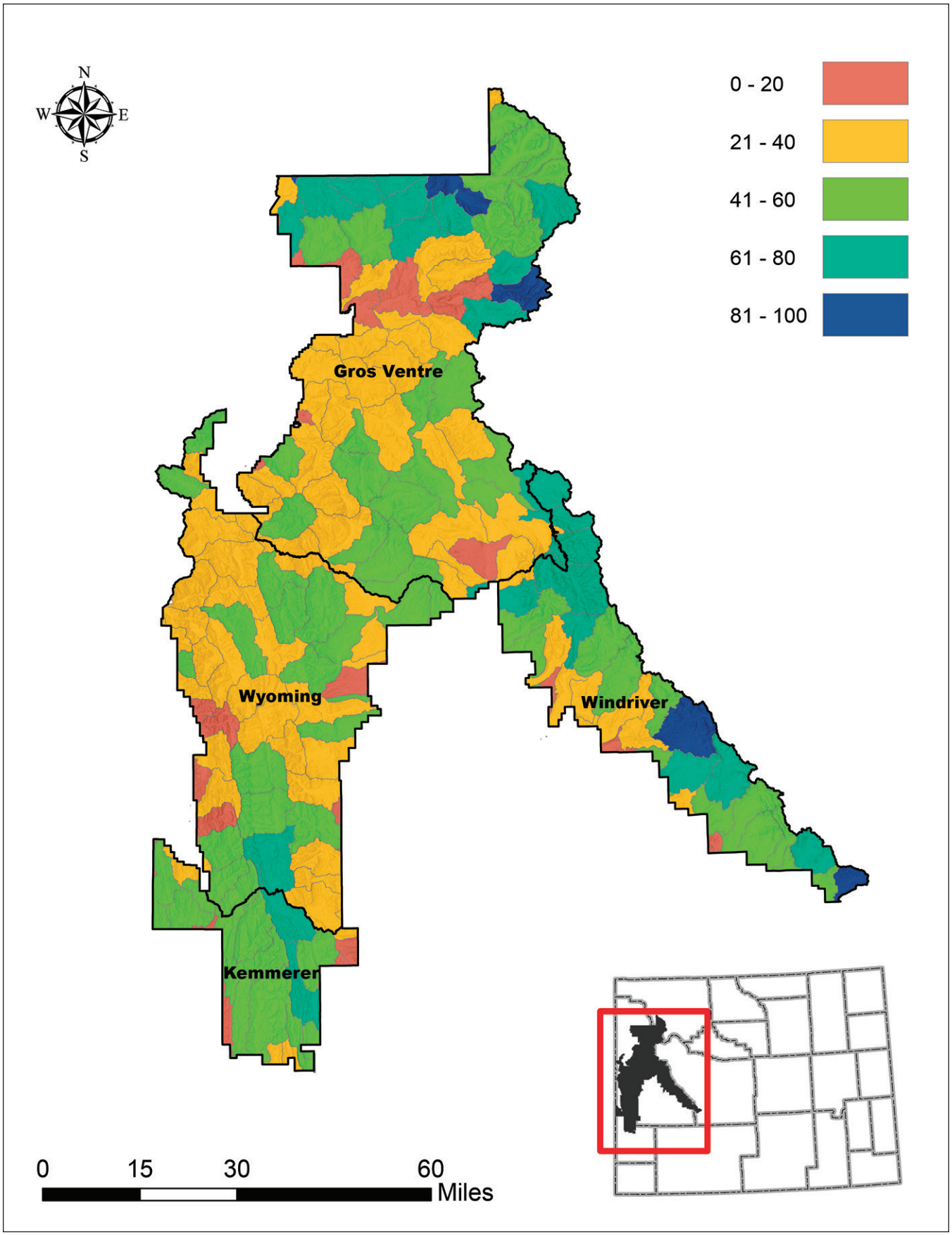


Figure J26—Percent of stream miles within watersheds classified as perennial by the NHD.

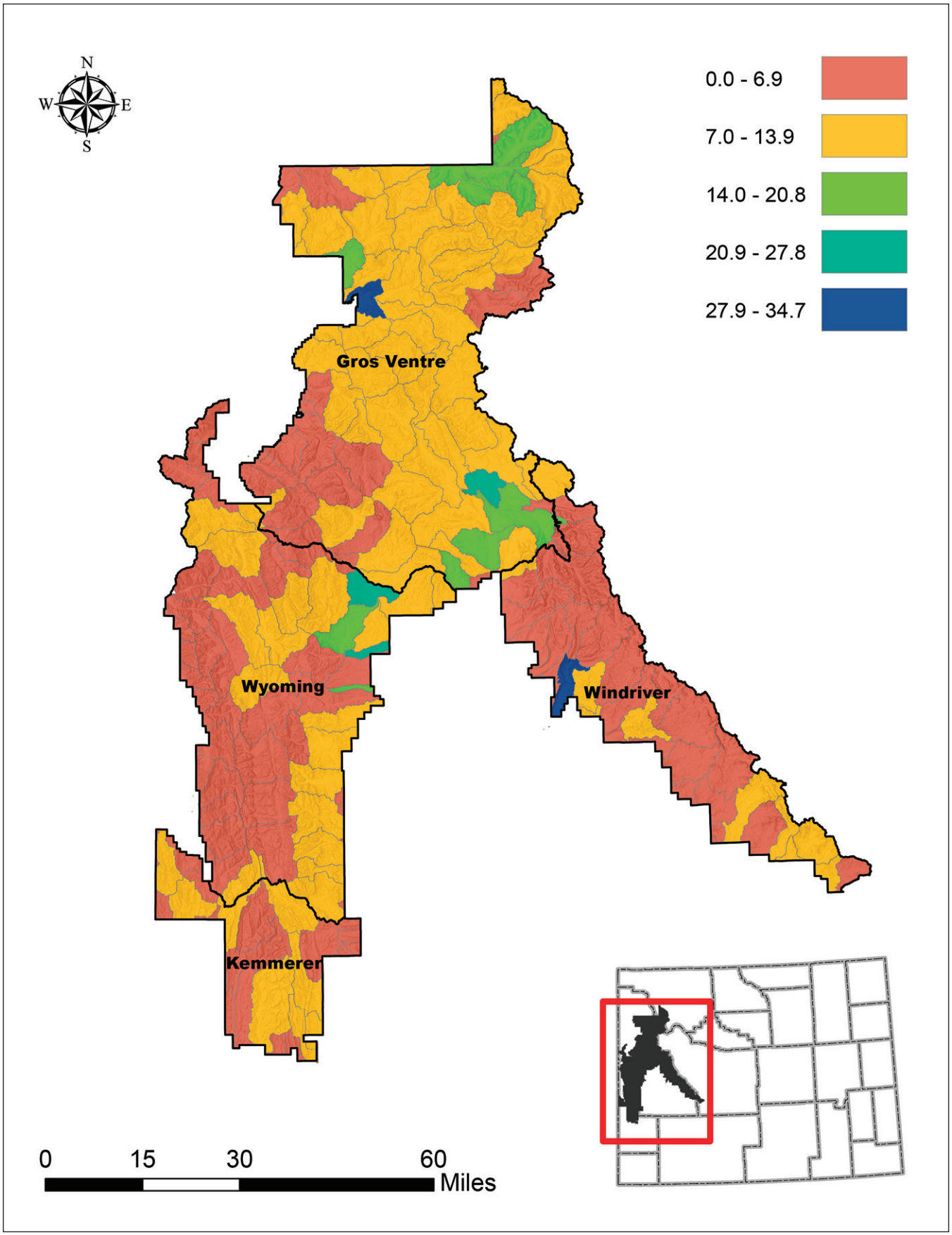


Figure J27—Percent of watershed within 50 year floodplain.

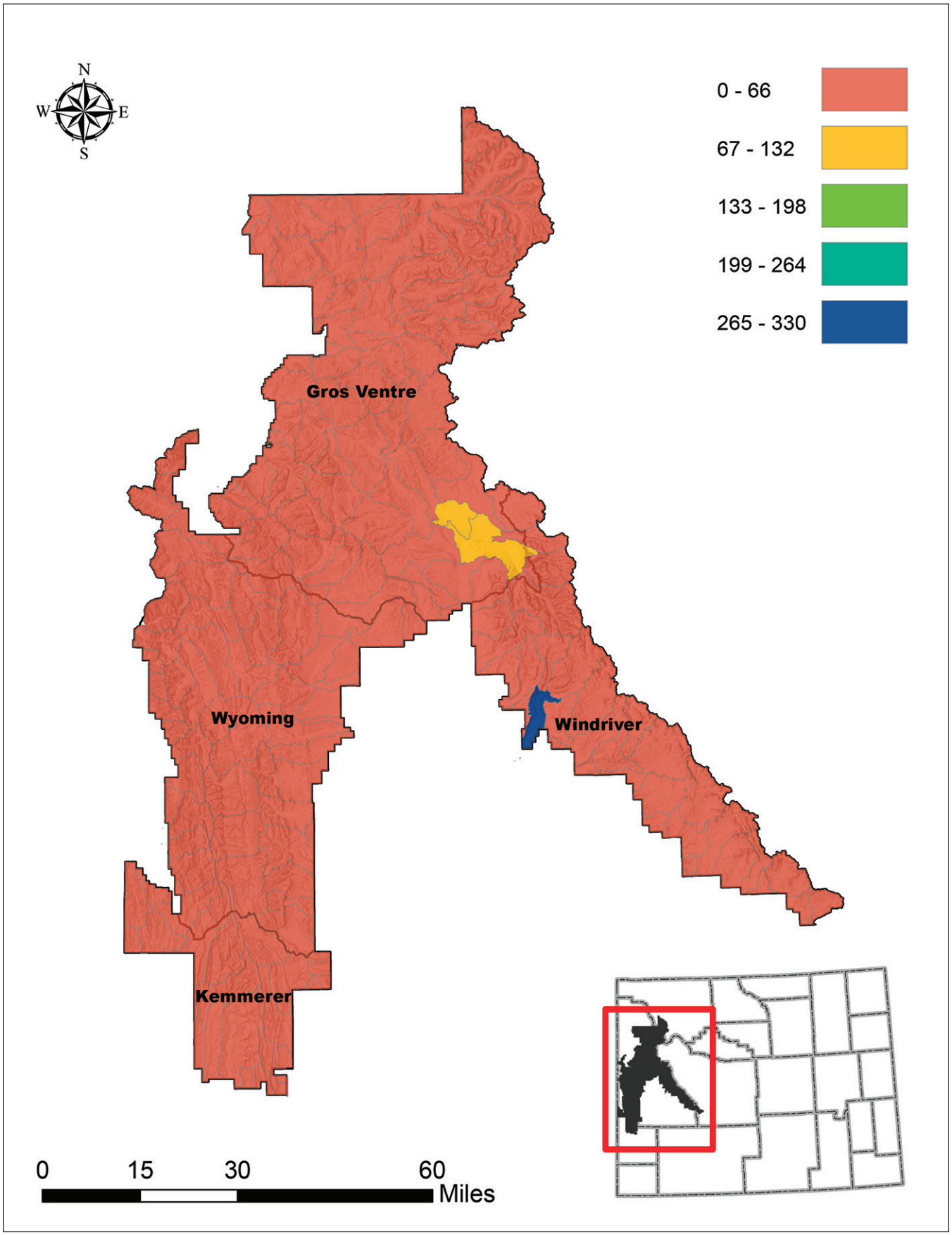


Figure J28—Ratio of floodplain acres per stream mile within each watershed.

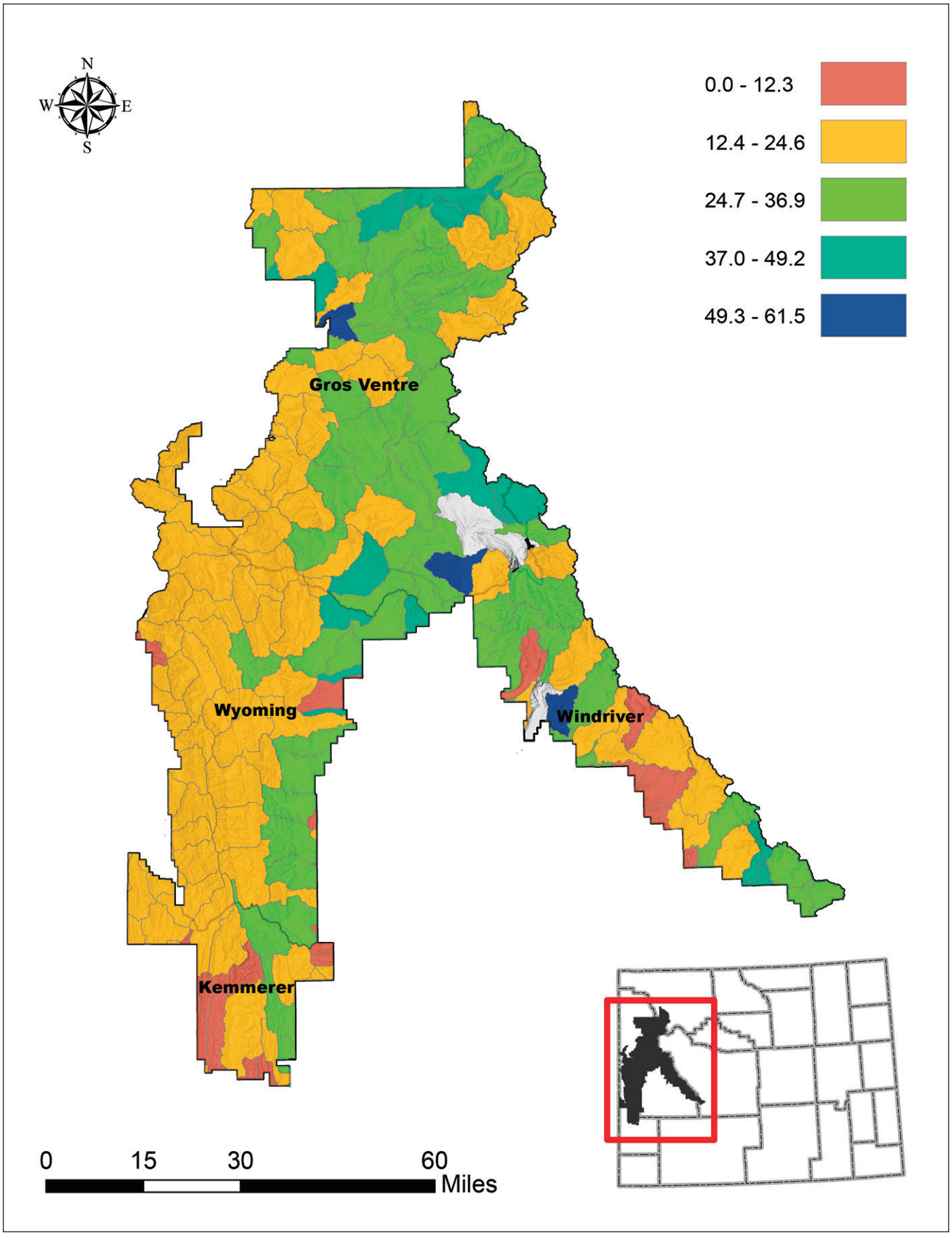


Figure J29—Ratio of floodplain acres per stream mile within each watershed with outliers removed.

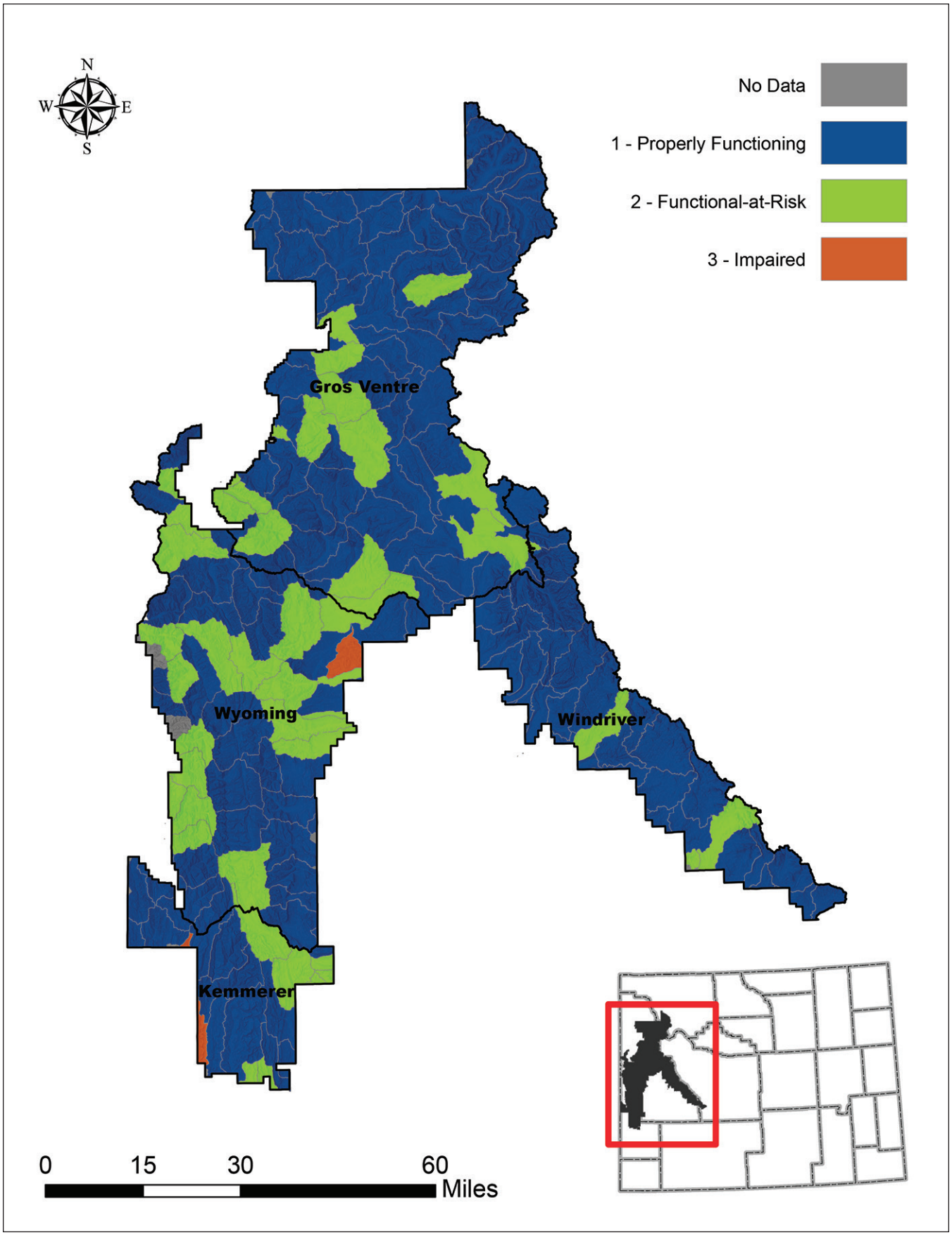


Figure J30—Conditions of channel shape and function including vertical stability, expected width-to-depth ratios, and floodplain connectivity as determined by the WCC.

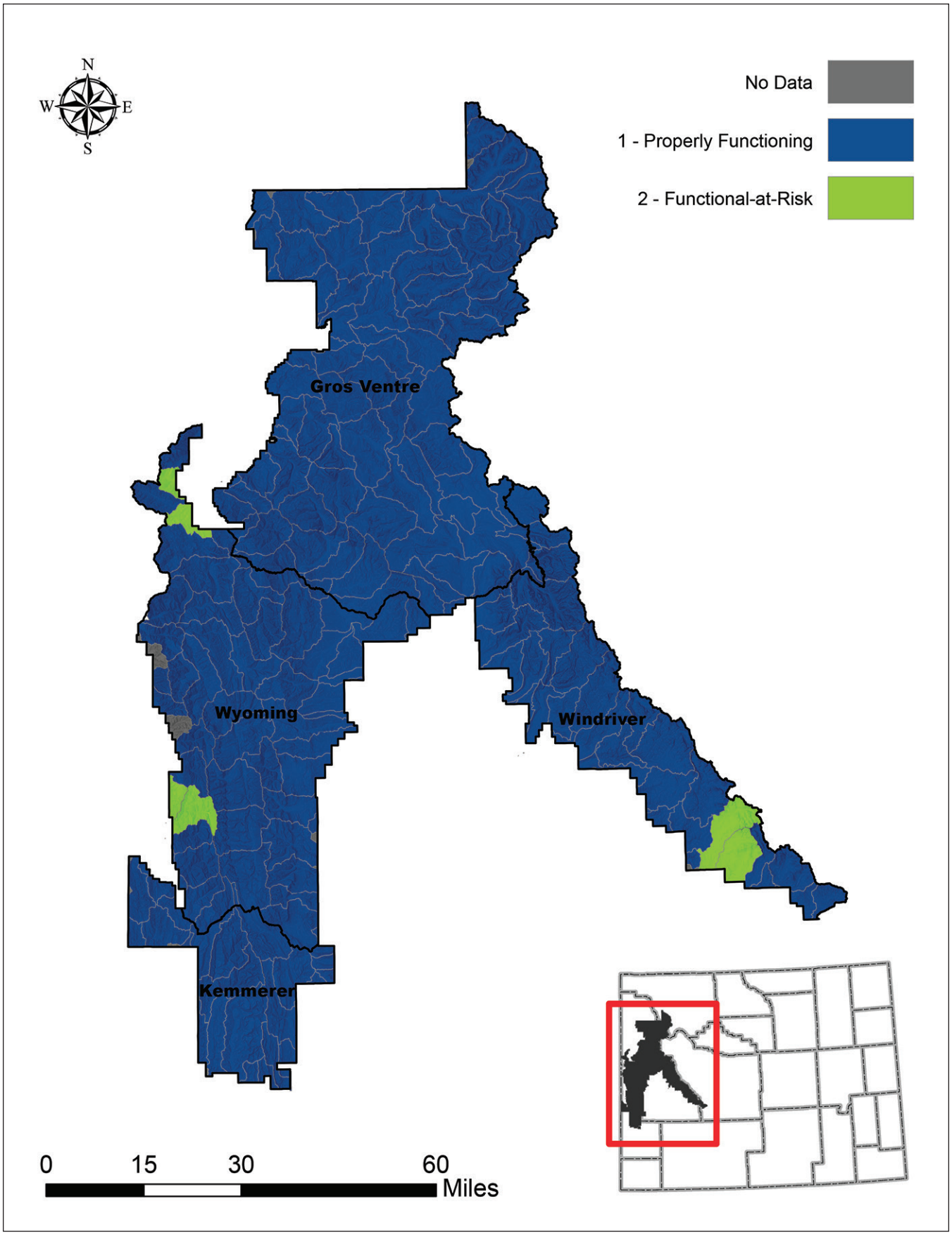


Figure J31—Presence and recruitment of large woody debris in aquatic and riparian systems that evolved with wood near the stream as determined by the WCC.

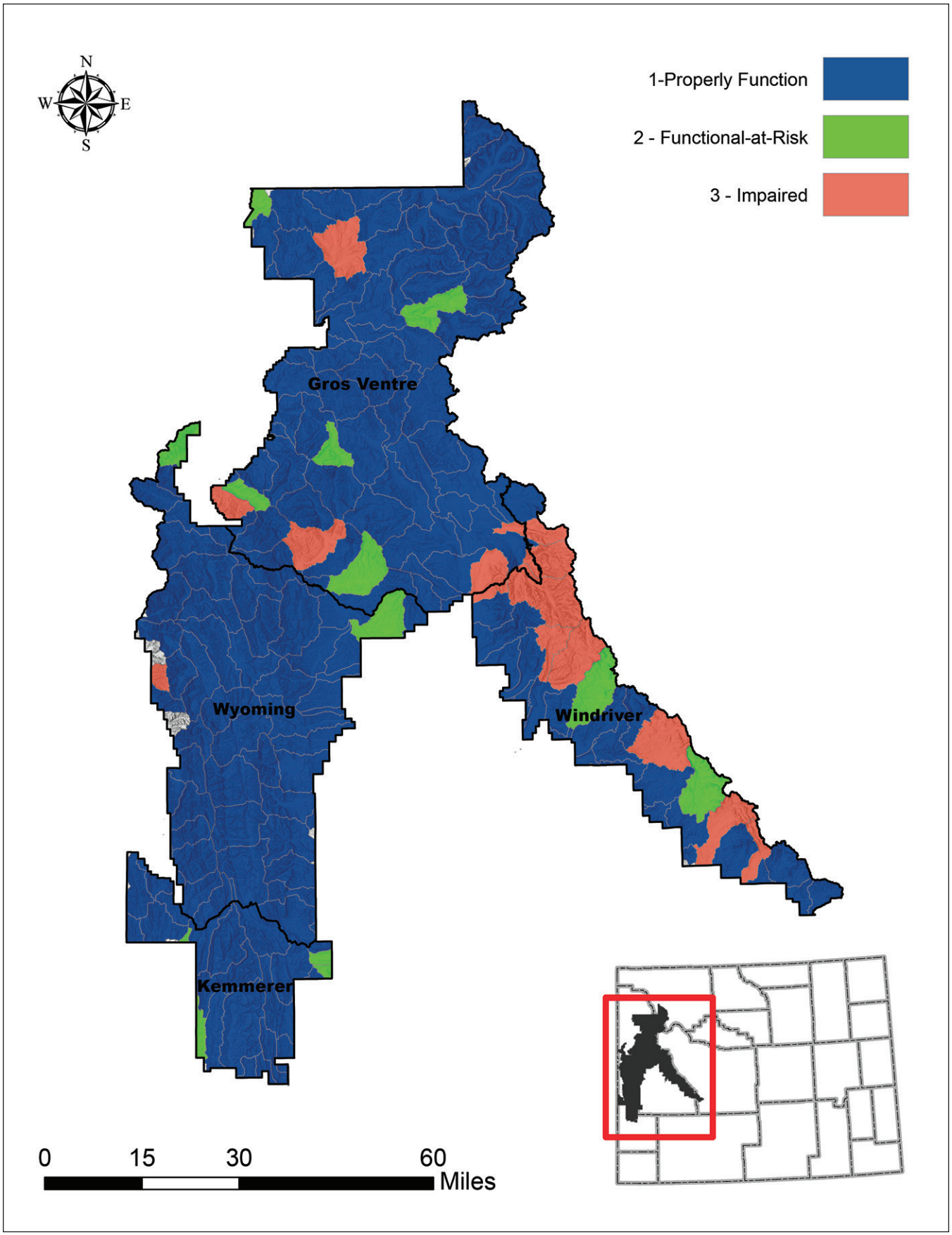


Figure J32—The WCC water quality indicator describing the level of impairment to beneficial uses of water bodies within each watershed.

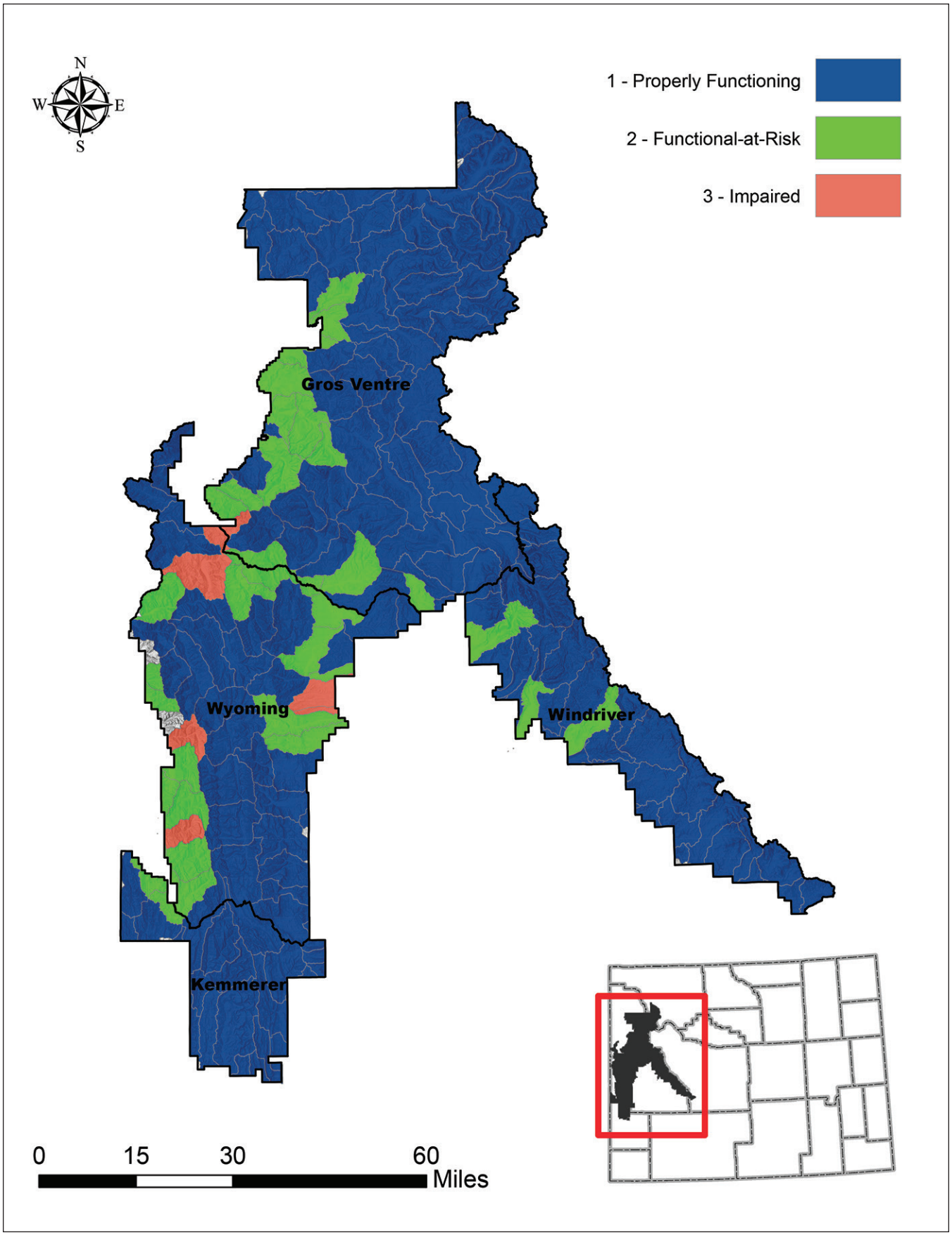


Figure J33—Departure of stream hydrographs from natural conditions as classified by the WCC.

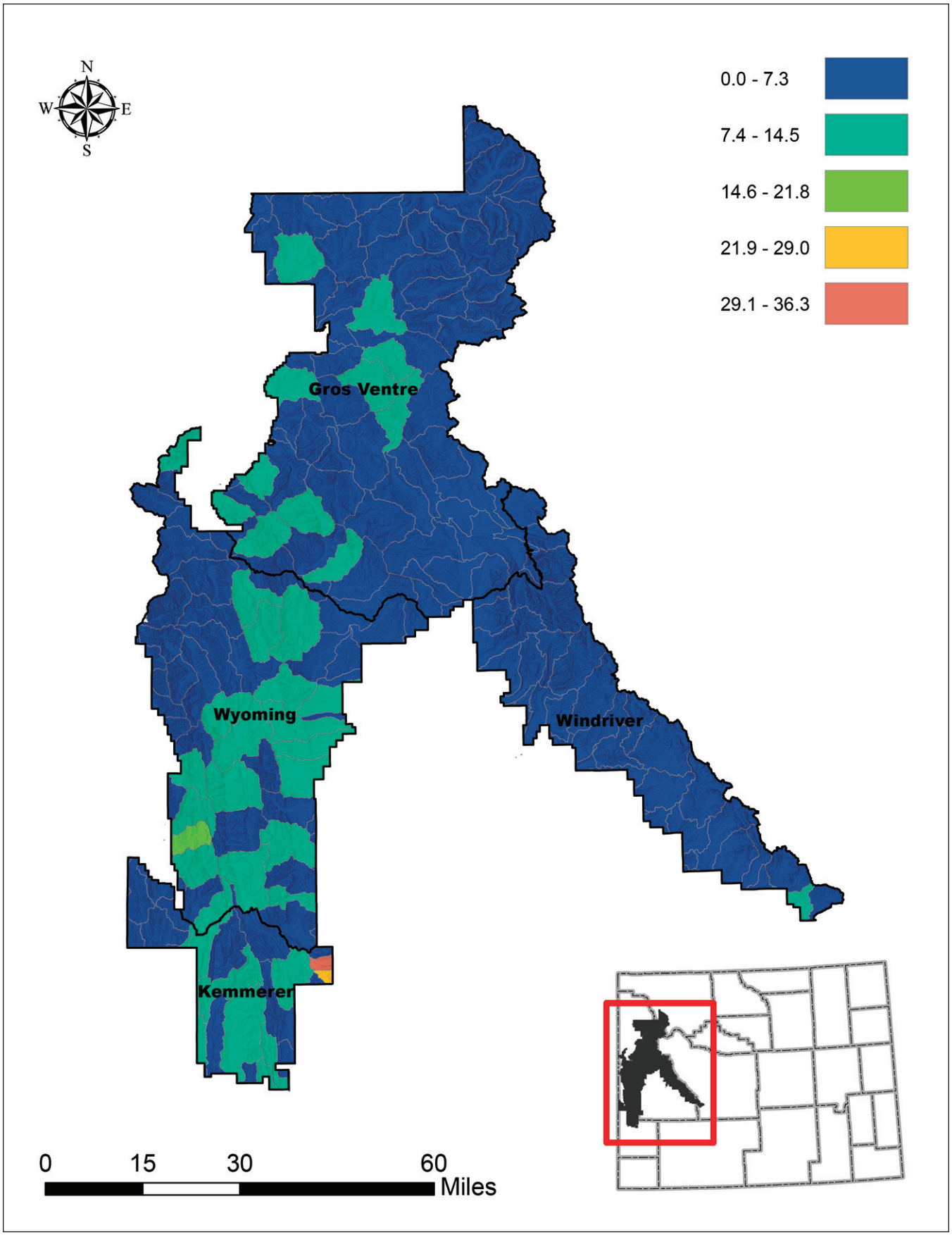


Figure J34—Percent of floodplains converted from riparian vegetation to encroaching conifers. Determined using LANDFIRE data.

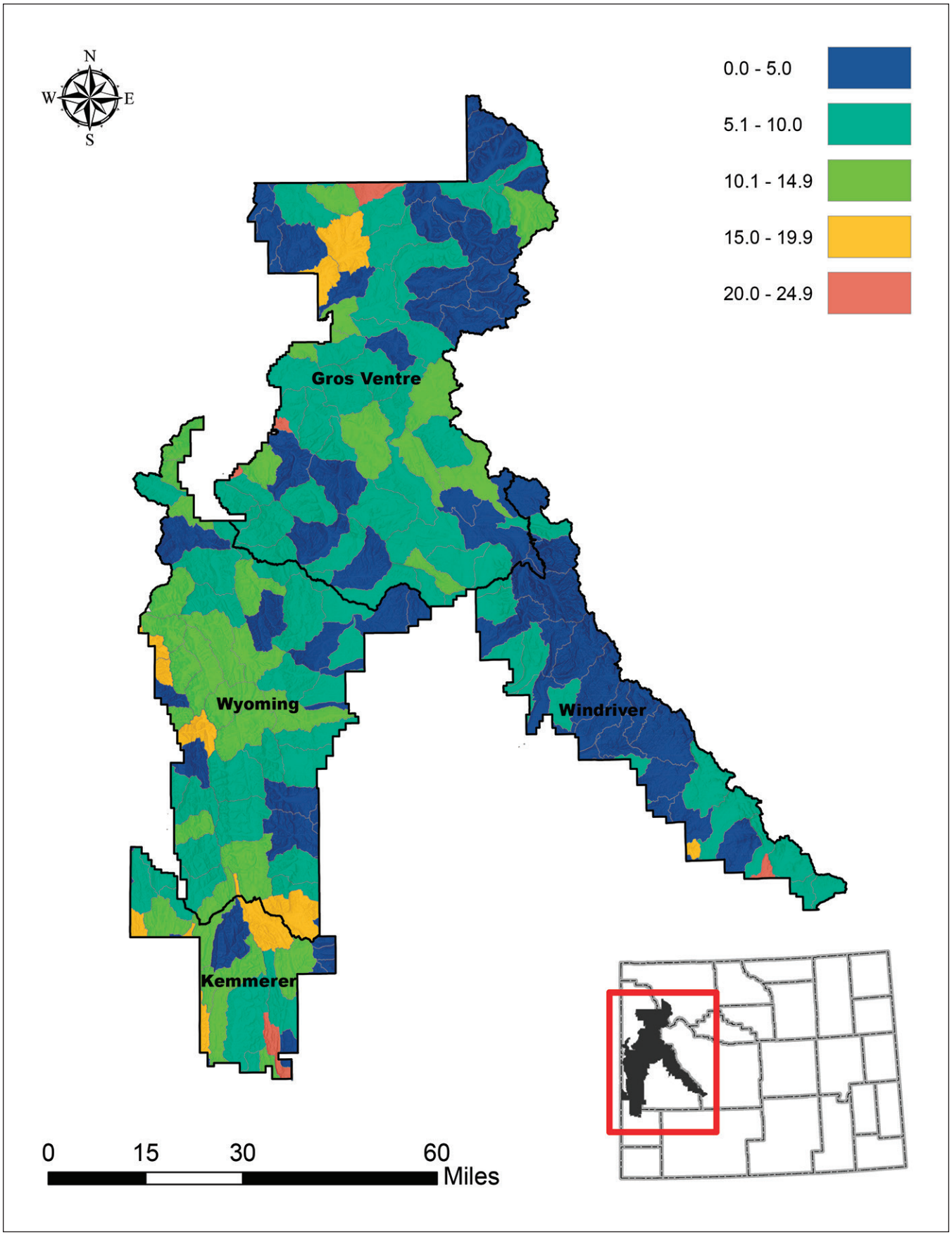


Figure J35—Percent of floodplains converted from riparian vegetation to encroaching upland species. Determined using LANDFIRE data.

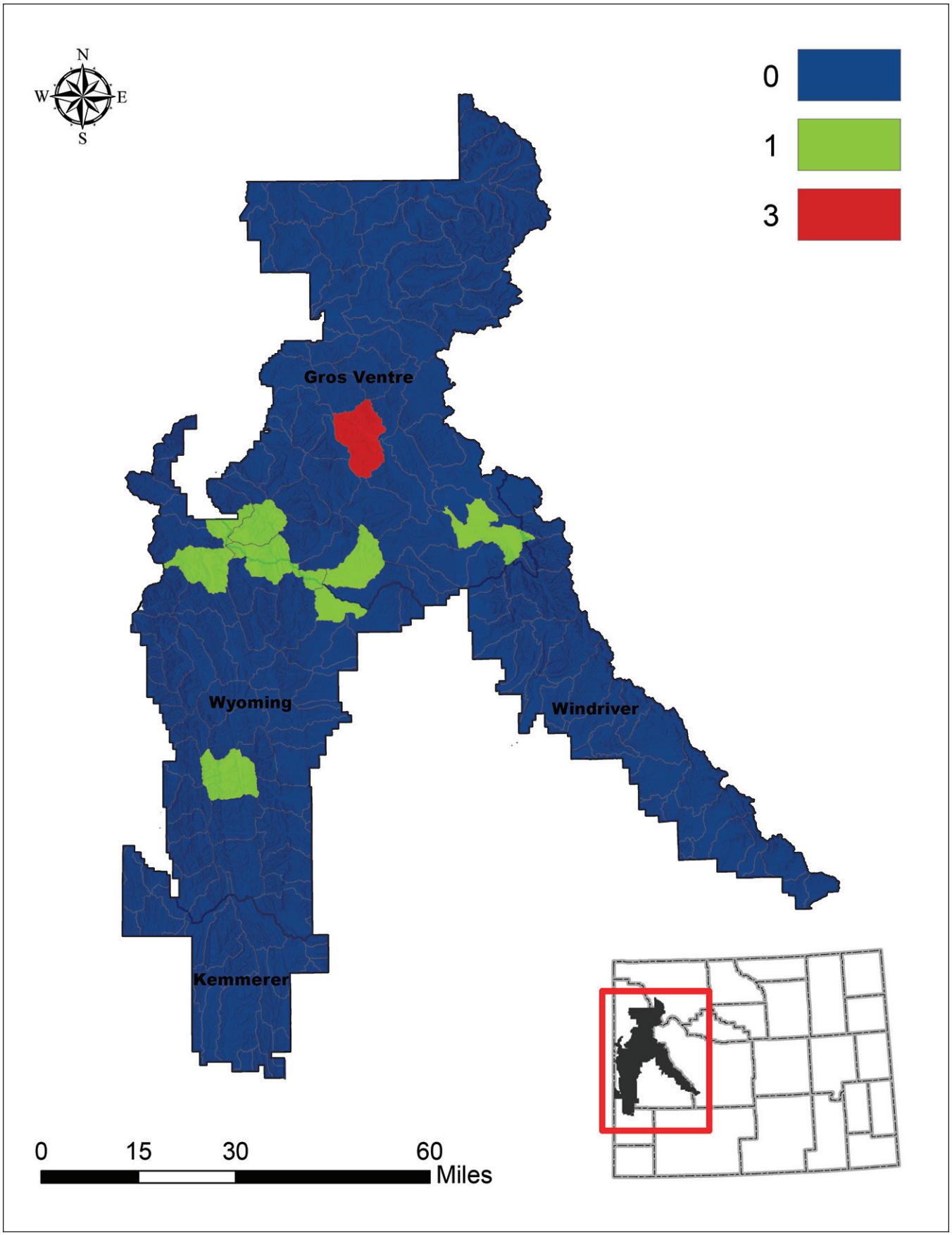


Figure J36—Number of wildlife, primarily elk, feed grounds within each watershed.

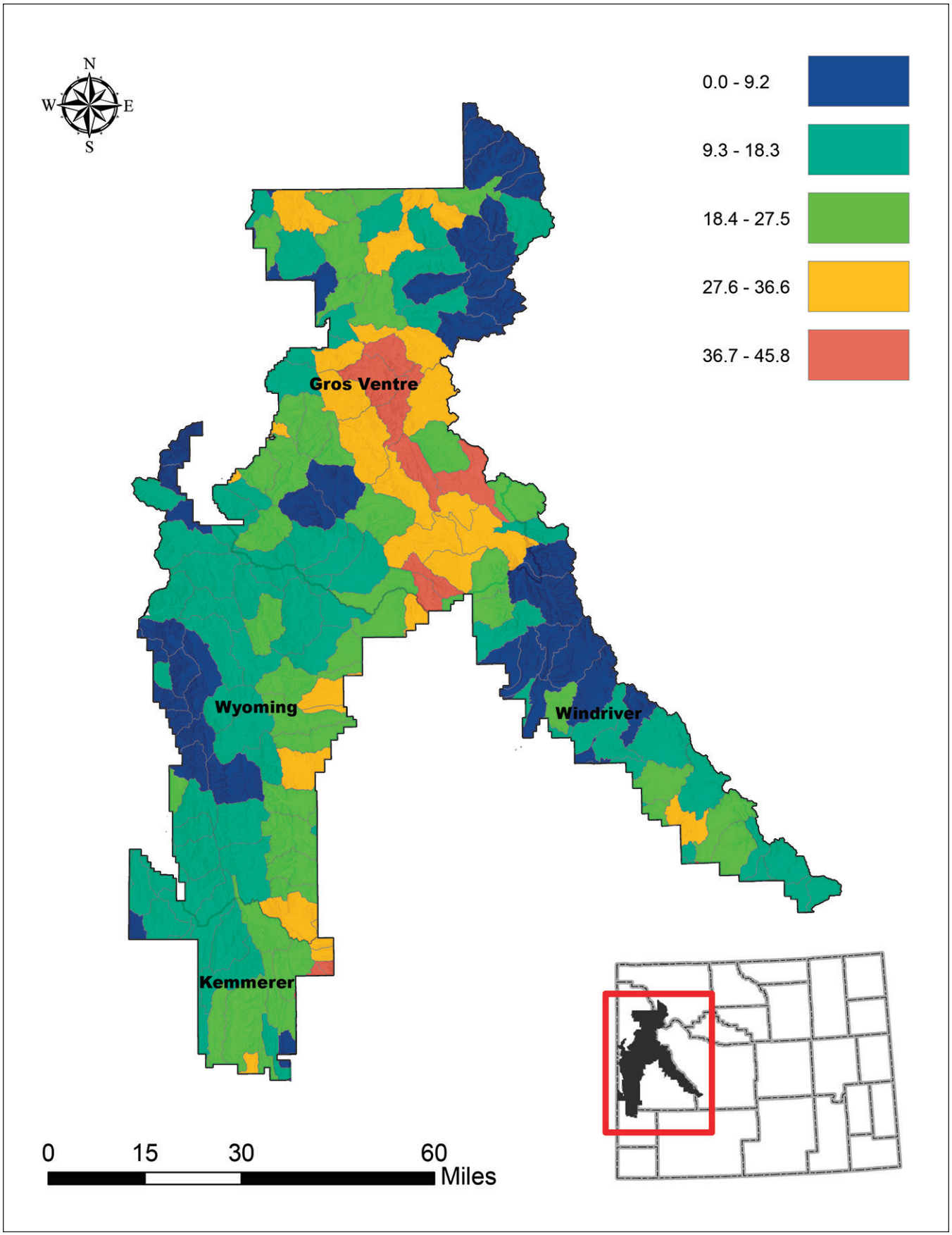


Figure J37—Percentage of the 50 year floodplain with high or very high wildfire hazard potential within each watershed.

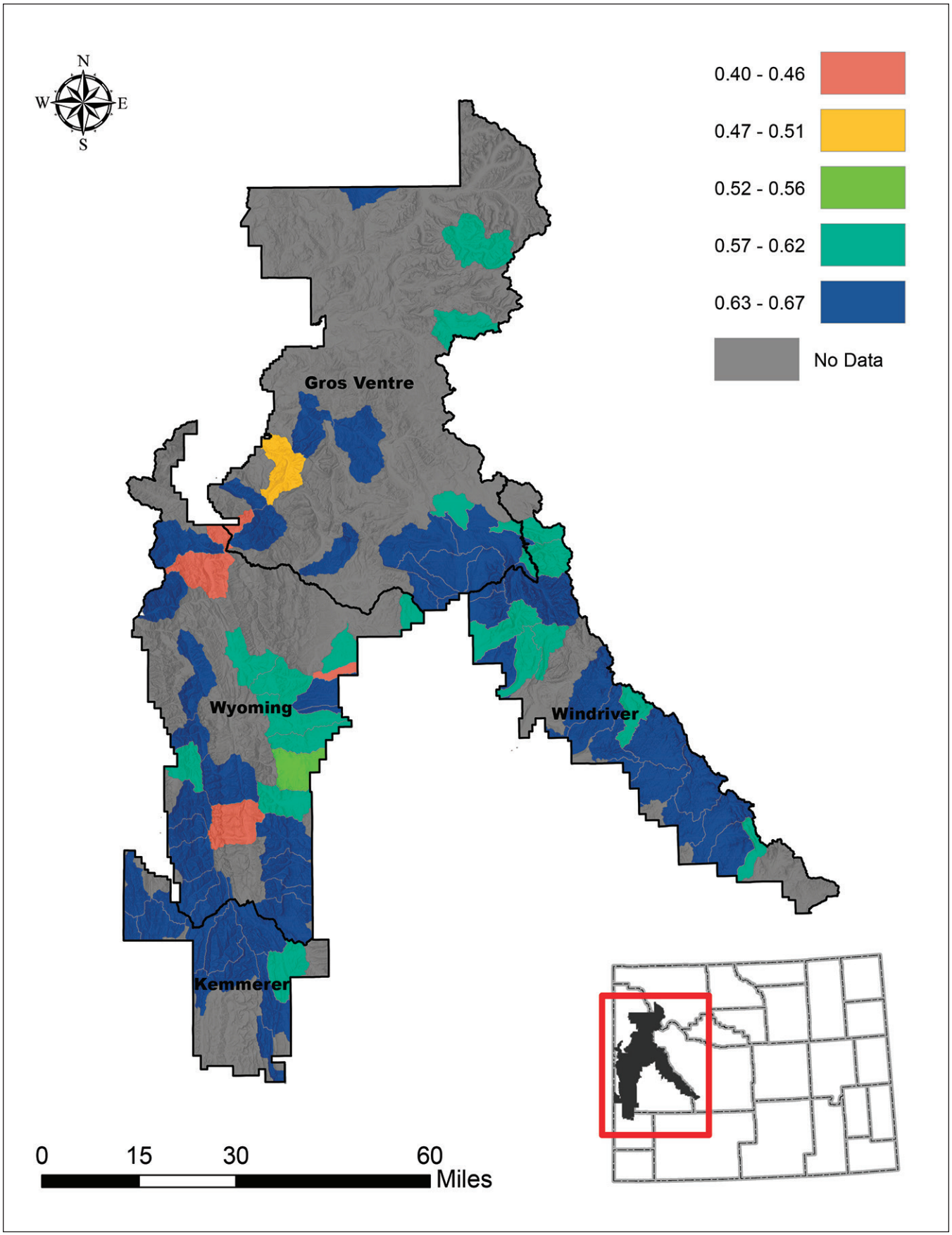


Figure J38—Aquatic habitat complexity, measured by Simpson's Dominance, incorporating percentages of each reach classified as pool, riffle, and run, for each watershed. Determined using WHAM data.

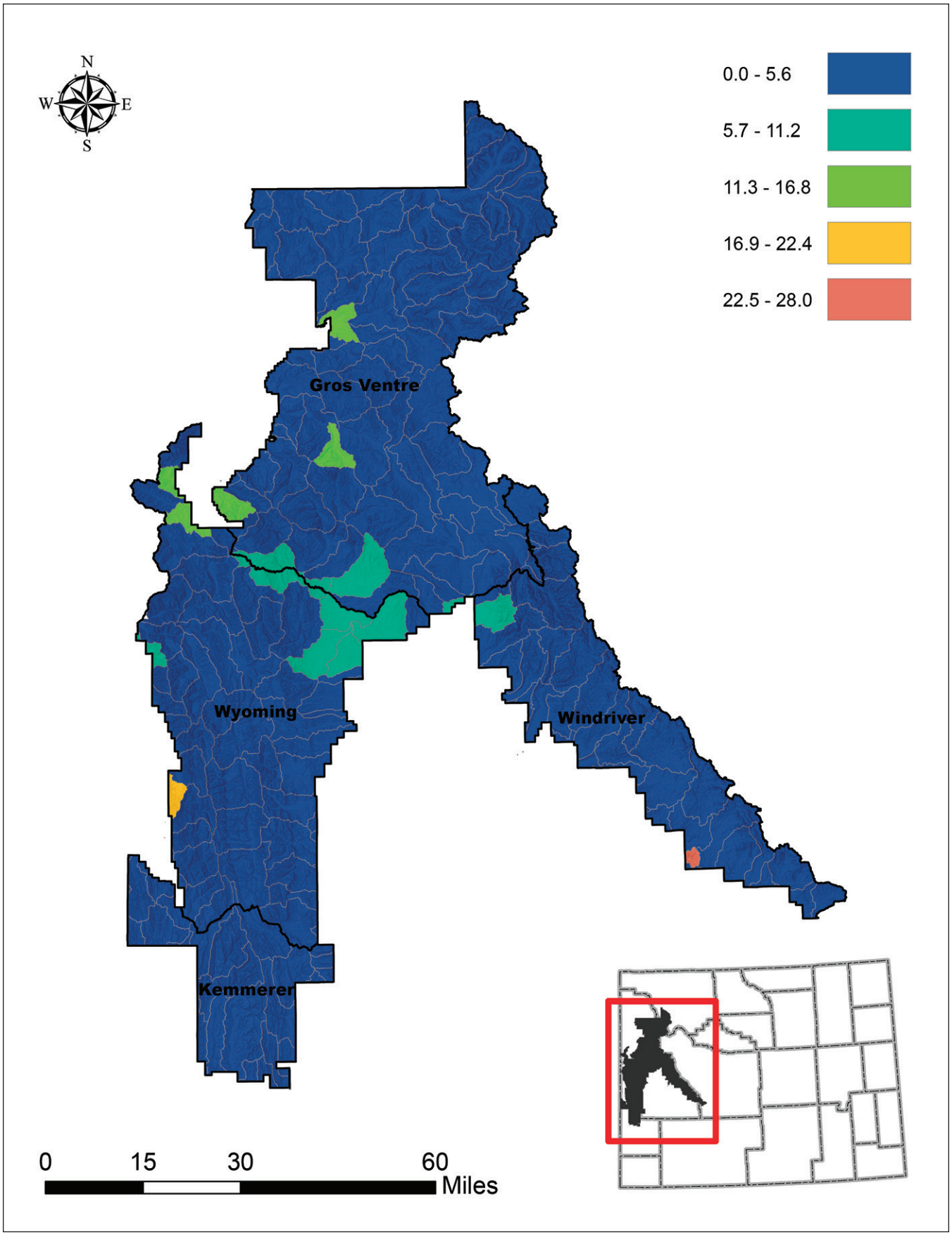


Figure J39—Percentage of valley bottoms converted from riparian vegetation to developed land within each watershed. Determined using R-CAT.

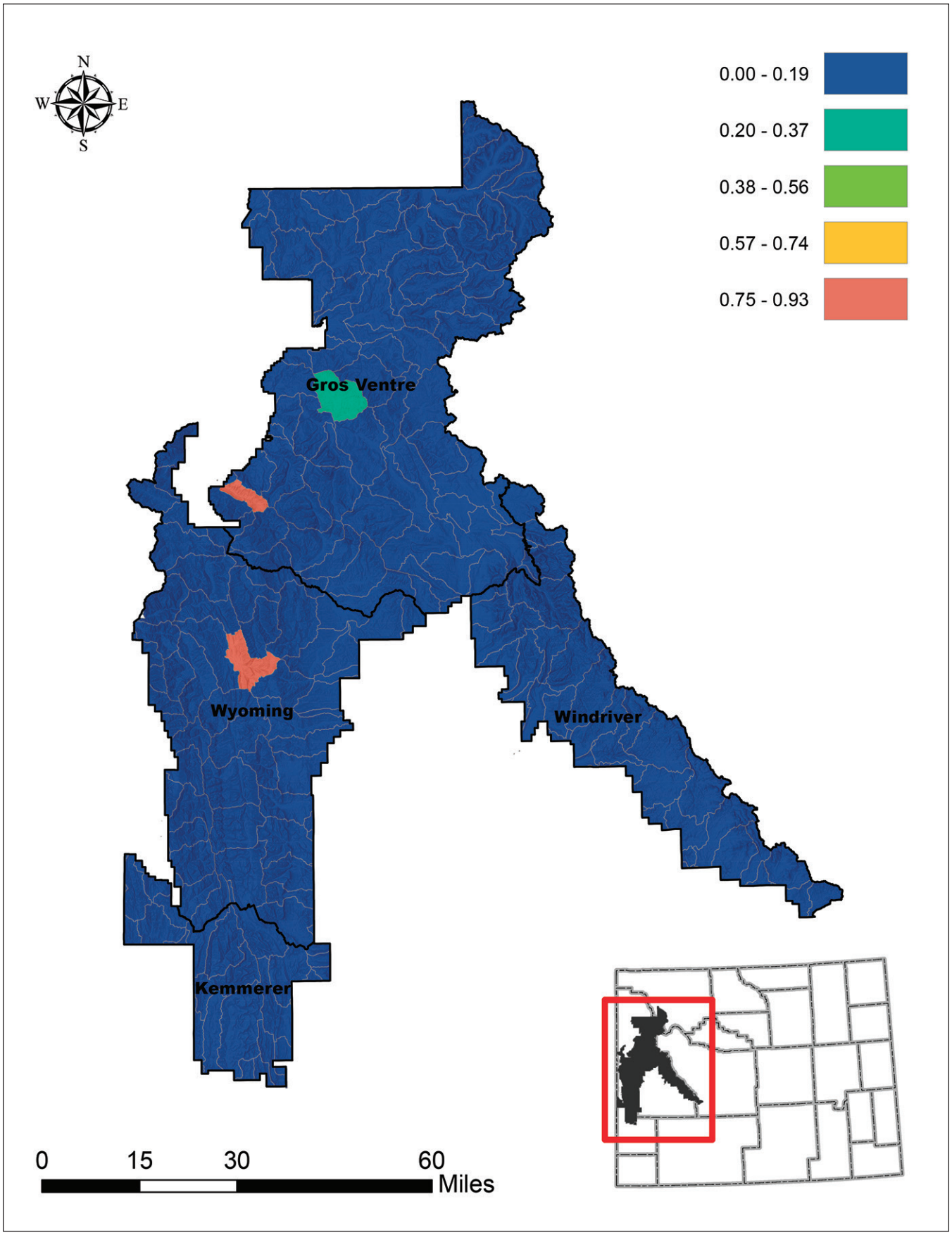


Figure J40—Percentage of valley bottoms converted from riparian vegetation to invasive species within each watershed. Determined using R-CAT.

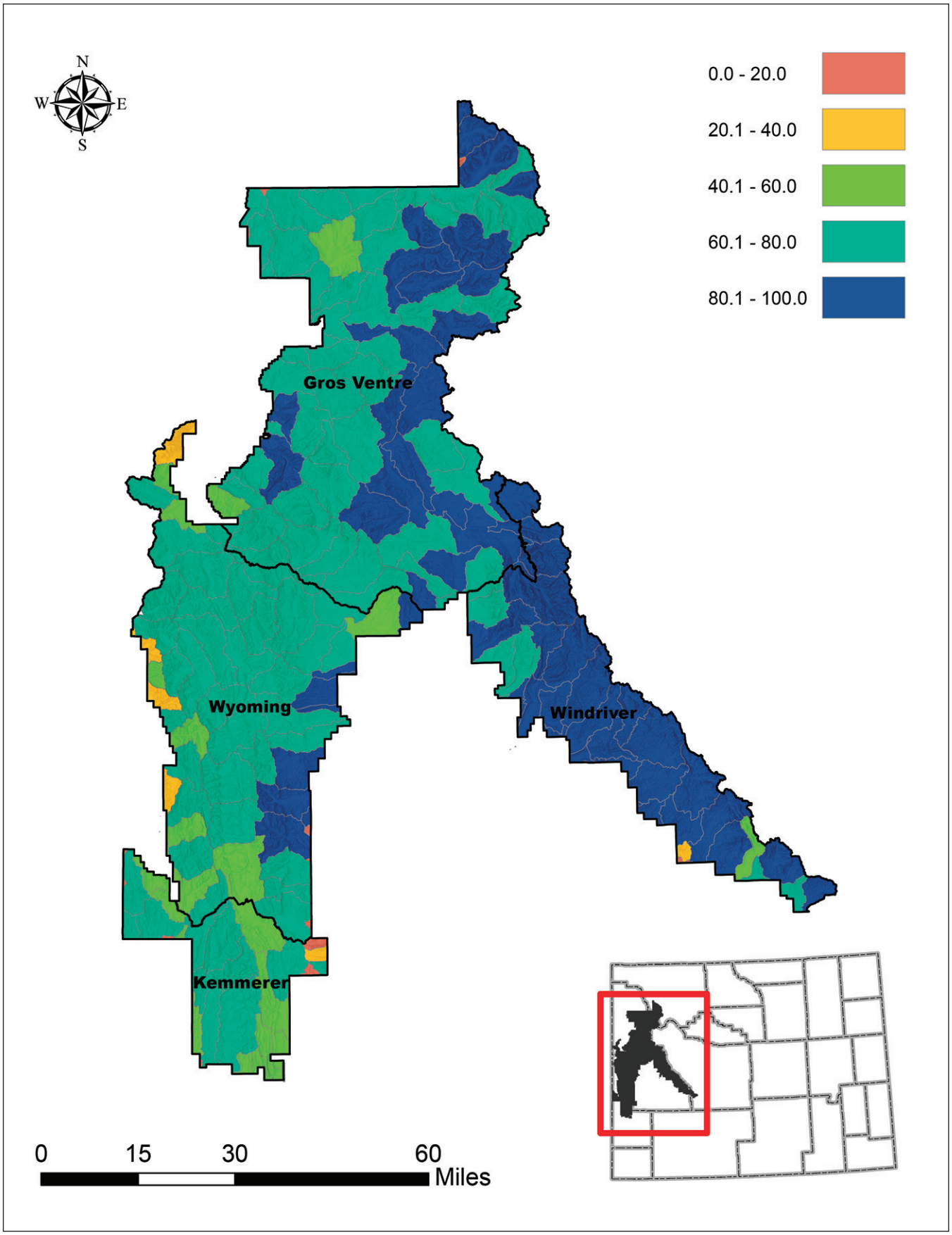


Figure J41—Percentage of valley bottoms that have remained riparian vegetation with no conversion to alternative cover within each watershed. Determined using R-CAT.

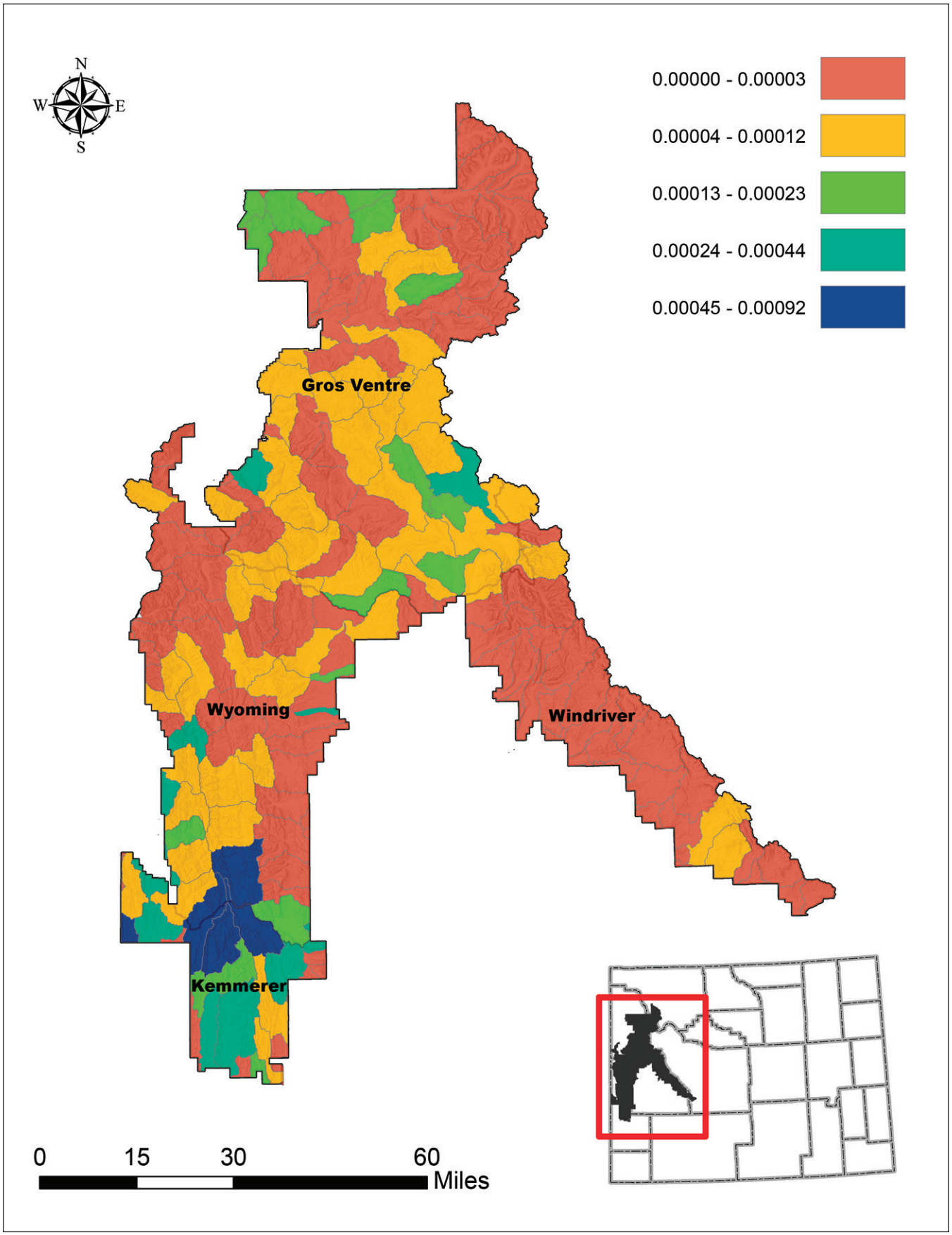


Figure J42—Spring density (# springs per acre) within each watershed.

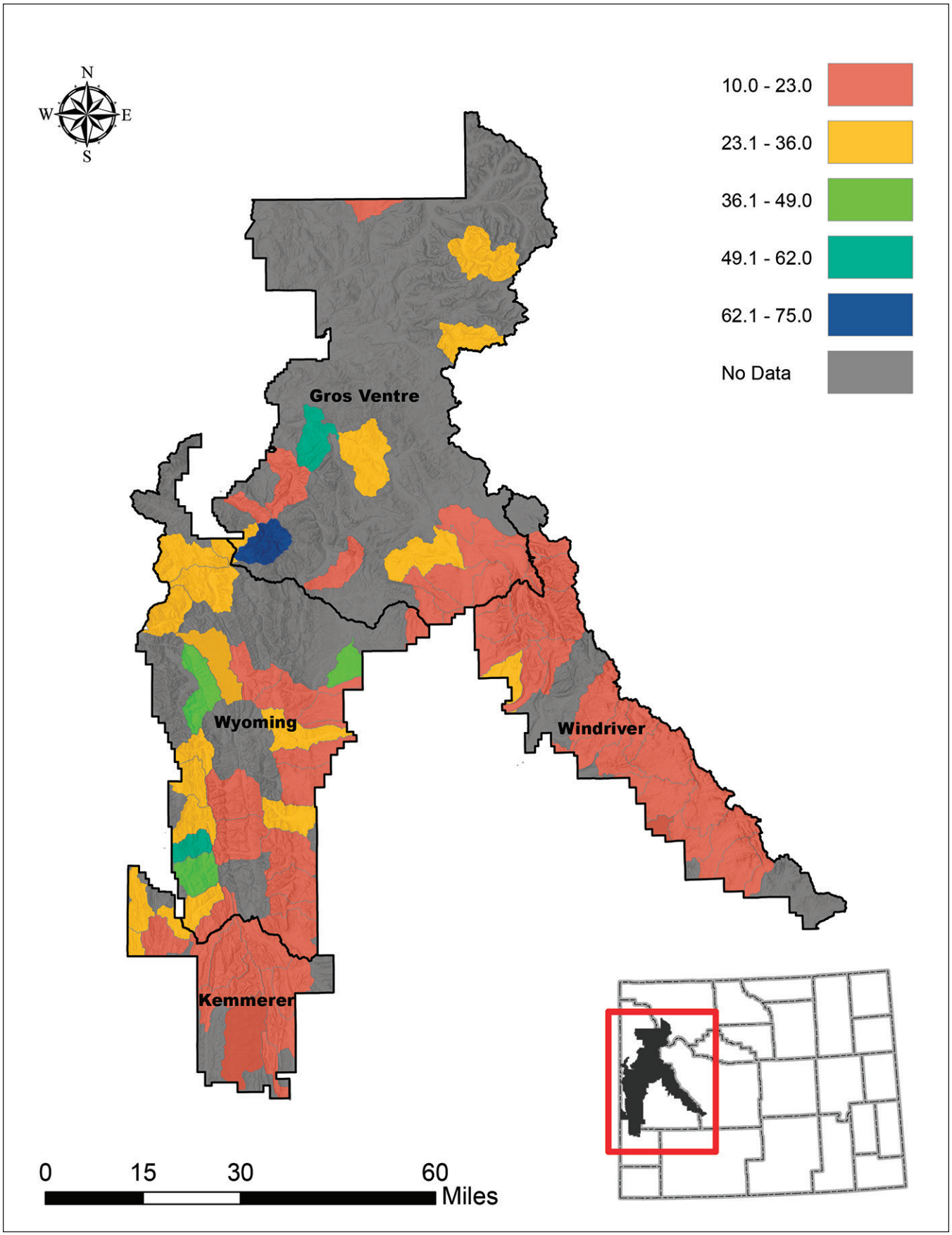


Figure J43—Percentage of stream reaches with less than 10% of bank erosion on both right and left banks within each watershed. Determined using WHAM data.

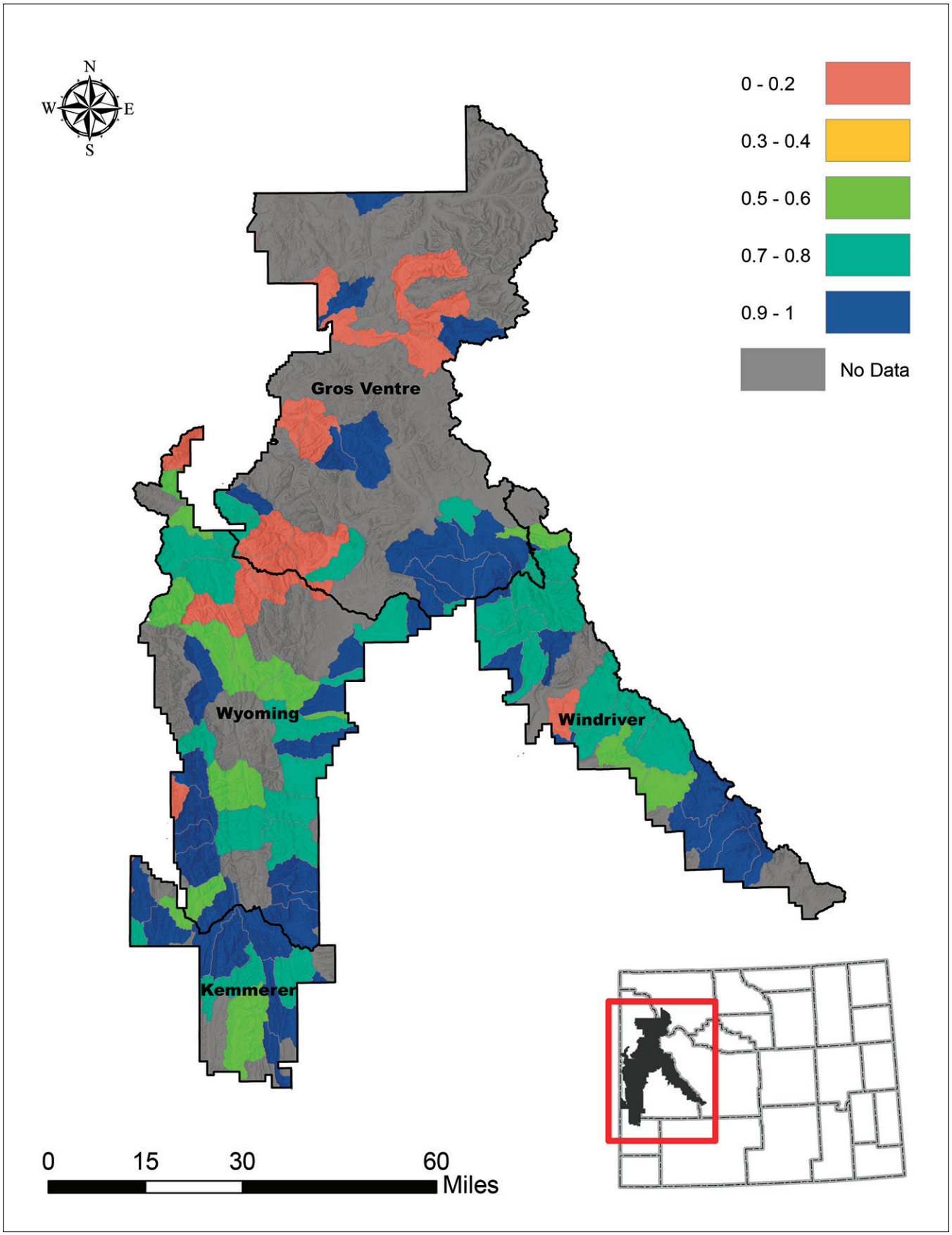


Figure J44—Percentage of sties with functional riparian area that had a high water table and the ability to trap sediment within each watershed. Determined using WHAM data.

Appendix K. Scientific and Common Names of Plants Described in This Assessment

Scientific name	Common name
Abies lasiocarpa	Subalpine fir
Acer grandidentatum	Bigtooth maple
Acer negundo	Boxelder
Achillea millefolium	Common yarrow
Aconitum columbianum	Columbian monkshood
Actaea rubra	Red baneberry
Alnus incana	Gray alder
Alnus viridis	Green alder
Alopecurus aequalis	Shortawn foxtail
Amelanchier alnifolia	Saskatoon serviceberry
Angelica arguta	Lyall's angelica
Antennaria corymbosa	Flat-top pussytoes
Arctium lappa	Greater burdock
Agrostis humilis	Alpine bentgrass
Agrostis scabra	Rough bentgrass
Agrostis stolonifera	Creeping bentgrass
Arnica latifolia	Broadleaf arnica
Arnica mollis	Hairy arnica
Artemisia cana	Silver sagebrush
Artemisia tridentata	Big sagebrush
Astragalus alpinus	Alpine milkvetch
Athyrium filix-femina	Common ladyfern
Aulacomnium palustre	Aulacomnium moss
Betula glandulosa	Resin birch
Betula occidentalis	Water birch
Bromus ciliatus	Fringed brome
Bromus inermis	Smooth brome
Bryum pseudotriquetrum	Common green bryum moss
Calamagrostis canadensis	Bluejoint
Calamagrostis stricta	Slimstem reedgrass
Calliergon stramineum	Calliergon moss
Calliergon trifarium	Calliergon moss
Calliergonella cuspidata	Calliergonella moss
Callitriche spp.	Water-starwort
Caltha leptosepala	White marsh marigold
Cardamine cordifolia	Heartleaf bittercress
Carex aquatilis	Water sedge
Carex atherodes	Wheat sedge
Carex bigelowii	Bigelow's sedge
Carex buxbaumii	Buxbaum's sedge
Carex canescens	Silvery sedge
Carex disperma	Softleaf sedge
Carex geyeri	Geyer's sedge
Carex illota	Sheep sedge
Carex lachenalii	Twotipped sedge
Carex microptera	Smallwing sedge
Carex nebrascensis	Nebraska sedge
Carex nigricans	Black alpine sedge
Carex norvegica	Norway sedge
Carex paysonis	Payson's sedge
Carex pellita	Woolly sedge
Carex petasata	Liddon sedge
Carex praticola	Meadow sedge
Carex praeceptorum	Early sedge
Carex praegracilis	Clustered field sedge
Carex saxatilis	Rock sedge
Carex scirpoidea	Northern singlespike sedge
Carex scopulorum	Mountain sedge
Carex simulata	Analogue sedge
Carex utriculata	Northwest Territory sedge
Carex vesicaria	Blister sedge
Castilleja miniata	Giant red Indian paintbrush
Centaurea stoebe	Spotted knapweed
Chamerion angustifolium	Fireweed
Cinna latifolia	Drooping woodreed
Cirsium arvense	Canada thistle
Comarum palustre	Purple marshlocks
Cornus sericea	Redosier dogwood
Crataegus douglasii	Black hawthorn
Danthonia intermedia	Timber oatgrass
Dasiphora fruticosa	Shrubby cinquefoil
Deschampsia cespitosa	Tufted hairgrass
Delphinium occidentale	Larkspur spp.
Dodecatheon jeffreyi	Sierra shootingstar
Drepanocladus aduncus	Drepanocladus moss
Drepanocladus exannulatus	Drepanocladus moss

(continued on next page)

Scientific name	Common name
Elaeagnus commutata	Silverberry
Eleocharis acicularis	Needle spikerush
Eleocharis palustris	Common spikerush
Eleocharis quinqueflora	Fewflower spikerush
Eleocharis rostellata	Beaked spikerush
Elymus cinereus	Basin wildrye
Elymus glaucus	Blue wildrye
Elymus trachycaulus	Slender wheatgrass
Epilobium ciliatum	Fringed willowherb
Equisetum arvense	Field horsetail
Equisetum fluviatile	Water horsetail
Equisetum hyemale	Scouringrush horsetail
Erigeron peregrinus	Subalpine fleabane
Erigeron ursinus	Bear River fleabane
Eurybia integrifolia	Thickstem aster
Festuca brachyphylla	Alpine fescue
Festuca idahoensis	Idaho fescue
Fragaria virginiana	Virginia strawberry
Gaultheria humifusa	Alpine spicywintergreen
Galium boreale	Northern bedstraw
Galium trifidum	Threepetal bedstraw
Galium triflorum	Fragrant bedstraw
Gentiana calycosa	Rainier pleated gentian
Geranium richardsonii	Richardson's geranium
Geranium viscosissimum	Sticky purple geranium
Geum macrophyllum	Largeleaf avens
Glyceria borealis	Small floating mannagrass
Glyceria striata	Fowl mannagrass
Glycyrrhiza lepidota	American licorice
Heracleum maximum	Common cowparsnip
Hippuris vulgaris	Common mare's-tail
Hordeum brachyantherum	Meadow barley
Hydrophyllum fendleri	Fendler's waterleaf
Hymenoxys hoopesii	Owl's-claws
Juncus arcticus	Mountain rush
Juncus drummondii	Drummond's rush
Juncus mertensianus	Mertens' rush
Juniperus spp.	Juniper
Kalmia microphylla	Alpine laurel
Kalmia polifolia	Bog laurel
Ledum glandulosum	Western Labrador tea
Ligusticum tenuifolium	Idaho licorice-root
Lonicera involucrata	Twinberry honeysuckle
Lupinus spp.	Lupine
Mahonia repens	Creeping barberry
Maianthemum stellatum	Starry false lily of the valley
Meesia triquetra	Meesia moss
Melilotus officinalis	Sweetclover
Mentha arvensis	Wild mint
Menyanthes trifoliata	Buckbean
Menziesia ferruginea	Rusty menziesia
Mertensia ciliata	Tall fringed bluebells
Osmorhiza occidentalis	Western sweetroot
Packera paupercula	Balsam groundsel
Packera streptanthifolia	Rocky Mountain groundsel
Pedicularis groenlandica	Elephanthead lousewort
Phalaris arundinacea	Reed canarygrass
Phleum alpinum	Alpine timothy
Phleum pratense	Timothy
Phyllodoce empetriformis	Pink mountainheath
Picea engelmannii	Engelmann spruce
Picea pungens	Blue spruce
Pinus contorta	Lodgepole pine
Pinus albicaulis	Whitebark pine
Poa pratensis	Kentucky bluegrass
Poa palustris	Fowl bluegrass
Polemonium occidentale	Western polemonium
Polygonum amphibium	Water knotweed
Polygonum bistortoides	American bistort
Polytrichum strictum	Polytrichum moss
Populus angustifolia	Narrowleaf cottonwood
Populus balsamifera	Balsam poplar
Populus tremuloides	Quaking aspen
Potamogeton alpinus	Alpine pondweed
Potamogeton perfoliatus	Claspingleaf pondweed
Potentilla diversifolia	Varileaf cinquefoil
Potentilla gracilis	Slender cinquefoil
Prunus virginiana	Chokecherry
Pseudotsuga menziesii	Douglas-fir
Pyrola spp.	Wintergreen
Ranunculus aquatilis	White water crowfoot
Rhamnus alnifolia	Alderleaf buckthorn
Rhodiola rhodantha	Redpod stonecrop
Rhus trilobata	Skunkbush sumac
Ribes hudsonianum	Northern black currant
Rosa woodsii	Woods' rose
Rubus idaeus	American red raspberry
Rubus parviflorus	Thimbleberry

(continued on next page)

Scientific name	Common name
Rudbeckia occidentalis	Western coneflower
Salix barclayi	Barclay's willow
Salix bebbiana	Bebb willow
Salix boothii	Booth's willow
Salix drummondiana	Drummond's willow
Salix eastwoodiae	Mountain willow
Salix exigua	Narrowleaf willow
Salix geyeriana	Geyer willow
Salix glauca	Grayleaf willow
Salix lucida	Pacific willow
Salix lutea	Yellow willow
Salix melanopsis	Dusky willow
Salix nivalis	Snow willow
Salix planifolia	Diamondleaf willow
Salix wolfii	Wolf's willow
Saxifraga odontoloma	Brook saxifrage
Schedonorus pratensis	Meadow fescue
Schoenoplectus acutus	Hardstem bulrush
Sedum spp.	Stonecrop
Senecio serra	Tall ragwort
Senecio sphaerocephalus	Ballhead ragwort
Senecio triangularis	Arrowleaf ragwort
Solidago canadensis	Canada goldenrod
Sonchus arvensis	Field sowthistle
Sphagnum subsecundum	Sphagnum
Sphagnum platyphyllum	Sphagnum
Sphagnum teres	Sphagnum
Spiraea betulifolia	White spirea
Streptopus amplexifolius	Claspleaf twistedstalk
Symphoricarpos occidentalis	Western snowberry
Symphyotrichum foliaceum	Alpine leafybract aster
Symphyotrichum spathulatum	Western mountain aster
Tanacetum vulgare	Common tansy
Taraxacum officinale	Common dandelion
Tomenthypnum nitens	Tomentypnum moss
Thalictrum fendleri	Fendler's meadow-rue
Thalictrum occidentale	Western meadow-rue
Trichophorum cespitosum	Tufted bulrush
Trifolium hybridum	Alsike clover
Trifolium repens	White clover
Trisetum spicatum	Spike trisetum
Trollius laxus	American globeflower
Typha angustifolia	Narrowleaf cattail
Typha latifolia	Broadleaf cattail
Urtica dioica	Stinging nettle
Utricularia macrorhiza	Common bladderwort
Utricularia vulgaris	Common bladderwort
Vaccinium membranaceum	Thinleaf huckleberry
Vaccinium scoparium	Grouse whortleberry
Vaccinium uliginosum	Bog blueberry
Valeriana occidentalis	Western valerian
Veratrum californicum	California false hellebore
Veronica americana	American speedwell
Veronica wormskjoldii	American alpine speedwell
Viola epipsila	Dwarf marsh violet

Appendix L. Acronyms

ATV	All-terrain vehicle
BLM	Bureau of Land Management
BTNF	Bridger-Teton National Forest
CTQ	Community Tolerance Quotient
GDE	Groundwater-Dependent Ecosystems
HGVC	Hydrogeomorphic Valley Classification
KEC	Key Ecosystem Characteristic
MIM	Multiple Indicator Monitoring
MTBS	Monitoring Trends in Burn Severity
NHD	National Hydrography Dataset
NRV	Natural Range of Variation
NWI	National Wetlands Inventory
PEMB	Palustrine Emergent Wetlands
PFC	Proper Functioning Condition
R-CAT	Riparian Condition Assessment Tool
RIVPACS	Wyoming River Invertebrate Prediction and Classification System
RVCT	Riparian Vegetation Conversion Type
TCA	Terrestrial Condition Assessment
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WCC	Watershed Condition Classification
WGFD	Wyoming Game and Fish Department
WDEQ	Wyoming Department of Environmental Quality
WHAM	Wyoming Habitat Assessment Methodology
WSII	Wyoming Stream Integrity Index

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