

Riparian, Aquatic, and Groundwater-Dependent Ecosystems of Southern Oregon and Northern California: An Assessment of Ecological Integrity to Inform Forest Plan Revision. Volume 1: Introduction and Summary of Findings

D. Max Smith, Laurel F. Martinez, Cynthia King, Taylor L. Pearson, Katelyn P. Driscoll



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Abstract

This six-volume assessment provides information on the current conditions of riparian, aquatic, and groundwater-dependent ecosystems on the Rogue River-Siskiyou, Klamath, Six Rivers, Shasta-Trinity, and Mendocino National Forests of southern Oregon and northern California. We used peer-reviewed literature and national and regional-level data from the forests and their partners to evaluate the status of several key ecosystem characteristics. These characteristics are distribution, hydrologic regimes, water quality, connectivity, instream habitat quality, and riparian reserve condition for four different stream habitats (permanently flowing fish-bearing, permanently flowing nonfish-bearing, seasonally flowing fish-bearing, seasonally flowing nonfish-bearing); lakes, ponds, and reservoirs; and rare and unique riparian and aquatic habitats. We determined that roads, altered fire regimes, and climate change were major stressors to riparian, aquatic, and groundwater-dependent ecosystems on the national forests. The relative impacts of these stressors and the resistance and resilience of the focal ecosystems differed across the Five Forests cohort. Altered fire regimes and impacts from drought and climate change appear to be most pronounced in the southern reaches of the study area and projected hydrologic impacts of climate change are expected to be significant throughout the Cascades. Our results support the ecosystem assessment completed during the forest plan revision process and can help inform decision making related to restoration and maintenance of riparian, aquatic, and groundwater-dependent ecosystems across the Five Forests.

Keywords:

forest plan, key ecosystem characteristic, riparian vegetation, flow regime, channel morphology, floodplain, natural range of variation

Cover: Middle Fork Smith River in the Six Rivers National Forest, northwestern California. USDA Forest Service photo by Max Smith.

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Authors

D. Max Smith is a Research Associate with the Rocky Mountain Research Station at the Forestry Science Laboratory in Albuquerque, New Mexico. He completed a B.S. degree in wildlife biology at the University of Montana, Missoula, Montana, and an M.S. degree in zoology at the University of Oklahoma, Norman, Oklahoma.

Laurel F. Martinez is a Biological Science Technician with the Rocky Mountain Research Station at the Forestry Science Laboratory in Albuquerque, New Mexico. She completed a B.S. degree in environmental science with a minor in plant biology at the University of Vermont, Burlington, Vermont.

Cynthia King is a Biological Science Technician with the Rocky Mountain Research Station at the Forestry Science Laboratory in Albuquerque, New Mexico. She received a B.S. degree in environmental science with a minor in wildlife from New Mexico State University, Las Cruces, New Mexico and an M.S. in environmental management, with a graduate certificate in hydrology, from Portland State University, Portland, Oregon.

Taylor L. Pearson is a Biological Science Technician with the Rocky Mountain Research Station at the Forestry Science Laboratory in Albuquerque, New Mexico. She completed a B.S. degree in agriculture with a major in wildlife and minor in fisheries and aquatic sciences at Purdue University, West Lafayette, Indiana.

Katelyn P. Driscoll is a Research Ecologist with the Rocky Mountain Research Station at the Forestry Science Laboratory in Albuquerque, New Mexico. She completed a B.S. degree in biology with a minor in Spanish at Gonzaga University, Spokane, Washington and an M.S. degree in systems ecology at the University of Montana, Missoula, Montana.

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CHAPTER 1: INTRODUCTION

Background and Objectives

We completed an assessment of riparian, aquatic, and groundwater-dependent ecosystems (GDEs) in fulfillment of an agreement between the Forest Service, U.S. Department of Agriculture Regions 5 and 6 Northwest Forest Planning Team and the Rocky Mountain Research Station. Our aim was to provide support during the process of revising management plans for national forests under the 2012 Planning Rule (36 CFR Part 219; USDA FS n.d.a). We prepared this assessment to assist the Rogue River-Siskiyou, Klamath, Six Rivers, Shasta-Trinity, and Mendocino National Forests (hereafter referred to collectively as the Five Forests) in understanding ecological conditions under their respective current plans and identify needs-for-change to be addressed by the revised forest plan. Our methods meet planning rule requirements for a rapid assessment of ecological integrity—"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"—that uses only existing information (USDA FS n.d.a). As specified in the planning rule, we addressed structure, function, composition, and connectivity of terrestrial and aquatic ecosystems, along with drivers and stressors of key ecosystem characteristics. Study systems can cross administrative boundaries. For this reason, the planning rule uses an all-lands approach that requires consideration of how management actions that occur within the National Forest System (NFS) impact resources beyond the boundary and how conditions outside the national forest influence resources on NFS land.

Scale of Assessment

This assessment of riparian, aquatic, and groundwater-dependent ecosystems was completed within eight geographic units on the Five Forests in southern Oregon and northern California (fig. 1). These units were defined using physiographic provinces. The Rogue River-Siskiyou, Klamath, and Shasta-Trinity National Forests were divided into two units classified by the Klamath Mountains and the Cascade Range. We evaluated and summarized key ecosystem characteristics for habitats described in the Aquatic Conservation Strategy of the Northwest Forest Plan—permanently flowing fish-bearing streams, permanently flowing nonfish-bearing streams, seasonally flowing fish-bearing streams, seasonally flowing nonfish-bearing streams, lakes, ponds, and reservoirs—and fens, springs, and vernal pools at the scale of the geographic unit.

Study Area

The study area is composed of diverse geologic formations and ecosystems. Most of the Five Forests land area is in the Klamath Mountains. These areas are physically and biologically variable. The Klamaths are composed of igneous, sedimentary, and metamorphic geologies that are highly dissected (Griffith et al. 2016; Thorson et al. 2003). The climate tends to be mild and subhumid, with lengthy summer droughts. The eastern section of the study area is composed of the Cascade Range and its eastern

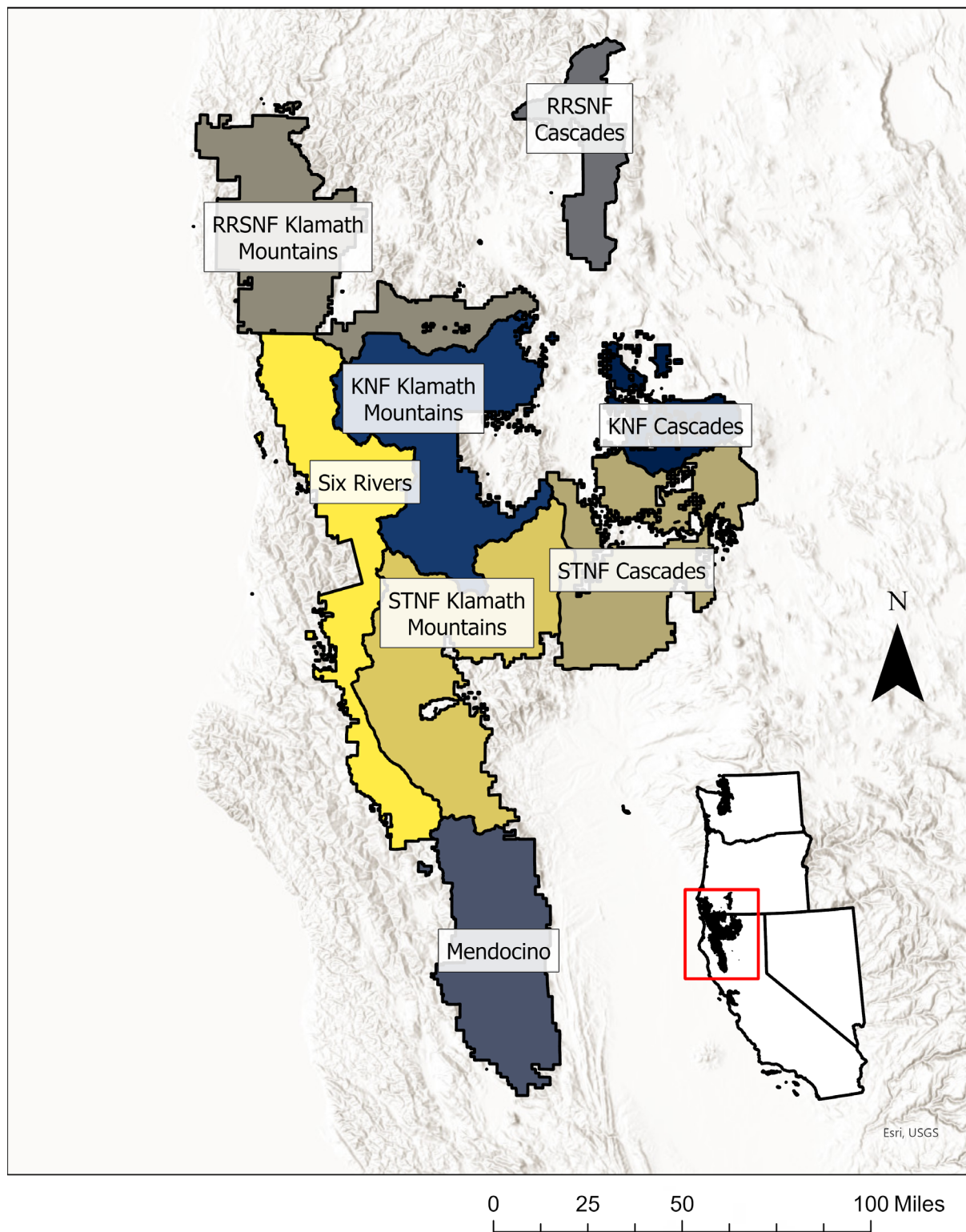


Figure 1—Study units used for analysis of the five national forests in this assessment. Lower map shows location within Oregon and California. KNF: Klamath National Forest; RRSNF: Rogue River-Siskiyou National Forest; STNF: Shasta-Trinity National Forest.

slopes and foothills (Griffith et al. 2016; Thorson et al. 2003). The Cascades include volcanic mountains that have been shaped by alpine glaciation. The climate of these areas tends to be moist and temperate, supporting a large productive conifer forest with meadows at high elevations. The eastern slopes and foothills are in the rainshadow of the Cascades (Griffith et al. 2016; Thorson et al. 2003). These areas receive less precipitation and experience greater temperature extremes. The vegetation of the eastern Cascade foothills includes ponderosa pine (*Pinus ponderosa*) and lodgepole pine (*Pinus contorta*). These plant communities tend to be susceptible to wildfire. The northernmost and westernmost sections of the study area are in the Coast Range, which is composed of highly productive rainforests (Thorson et al. 2003). Finally, the southernmost areas are characterized by the chaparral and oak woodlands of central California (Griffith et al. 2016). These landscapes consist of low mountains and foothills that have hot, dry summers and cool, moist winters.

Anthropogenic History

The lands currently managed by Five Forests personnel are within the traditional territories of many Indigenous groups (exhibit 1), with over 20 languages spoken in the region before the arrival of Euro-Americans (Gross et al. 2020). For centuries, the composition and structure of riparian and aquatic ecosystems in this area were shaped by the actions of Indigenous populations. Most notably, fire was used to maintain forest openings, for hunting, and for stimulating the production of acorns, berries, bulbs, and basket-making materials (Anderson 2006). Cultural burning provided resources for human use and maintained frequent-fire forest composition and structure within upland and riparian areas (Van de Water and North 2011). In many cases, these practices prevented stand-replacing, catastrophic fires from impacting these ecosystems and increased species diversity and productivity (Anderson 2006).

Indigenous groups also influenced streams, lakes, and wetlands by using them as travel corridors and areas for hunting, fishing, and gathering (Gross et al. 2020). By collecting and cultivating plants for purposes such as food and basket-making, these groups affected the structure and composition of riparian and wetland vegetation (Kiviat and Hamilton 2001). The upstream migrations of fall Chinook salmon (*Oncorhynchus tshawytscha*) and other anadromous fishes drew large numbers of people to streams such as the Klamath, Shasta, Smith, and Trinity Rivers. Fish were captured using nets, spears, and communal dams (Pierce 1998).

The first Euro-American groups entered the region for exploration and fur-trapping by the early 1800s (Gross et al. 2020). Beginning in the late 1700s, beavers (*Castor canadensis*) were trapped from streams in coastal watersheds and the Sacramento Basin for the international fur trade. Reductions in beaver populations were evident by the 1830s, but intensive trapping continued into the early 1900s (Lanman et al. 2013). This widespread removal of beaver from streams likely altered the geomorphology of

unconfined valley bottoms, changing the distribution of surface water and riparian vegetation in these areas (Wohl 2021).

Exhibit 1—Traditional territories and current Tribal lands within or in close proximity to each of the national forests' geographic units. Data from map viewers (Native Land Digital n.d.; USDA FS n.d.b).

National Forest	Traditional territories	Current Tribal lands
Rogue River-Siskiyou	Chit-dee-ni (Chetco), Confederated Tribes of Grande Ronde, Coquille, Cow Creek Umpqua, Modoc, Klamath, Shasta, Takelma, Tolowa Dee-ni', Tutuni	Coquille Reservation, Cow Creek Reservation (Cow Creek Umpqua)
Klamath	Confederated Tribes of Grande Ronde, Cow Creek Umpqua, Hupa, Karuk, Klamath, Konomihu, Modoc, New River Shasta, Pit River, Shasta, Takelma, Tolowa Dee-ni', Tsnungwe, Winnimem Wintu	Karuk Off-Reservation Trust Land, Quartz Valley Reservation (Klamath, Karuk, Shasta), Quartz Valley Off-Reservation Trust Land
Six Rivers	Chilula, Confederated Tribes of Grande Ronde, Hupa, Karuk, Lassik, Nomlaki, Nongati, Northern Yukian Takelma, Tolowa Dee-ni', Tsnungwe, Wailaki, Whilkut, Wiyot, Yurok	Hoopa Valley Reservation, Round Valley Off-Reservation Trust Land, Round Valley Reservation (Yuki, Concow Maidu, Little Lake and other Pomo, Nomlaki, Cahto, Wailaki, Pit River), Yurok Reservation
Shasta-Trinity	Achumawi, Chimarko (territory), Lassik, Modoc, New River Shasta, Nomlaki, Okwanuchu, Pit River, Shasta, Tsnungwe, Winnimem Wintu, Win th u-Po-m (Northern Wintu)	Big Bend Rancheria (Pit River), Montgomery Creek Rancheria (Pit River), Pit River Trust Land, Redding Rancheria (Pit River, Wintu, Yana), Roaring Creek Rancheria (Pit River)
Mendocino	Eastern Pomo, Nomlacki, Northeastern Pomo, Northern Pomo, Northern Yukian, Patwin, Shigom, Southeastern Pomo	Big Valley Rancheria (Pit River, Pomo), Cortina Indian Rancheria (Wintu), Coyote Valley Reservation (Pomo), Grindstone Indian Rancheria (Wintu and Wailaki), Guidville Off-Reservation Trust Land, Guidville Rancheria (Pomo), Hopland Rancheria (Pomo), Laytonville Rancheria (Cahto), Paskenta Rancheria (Nomlacki), Pinoleville Rancheria (Pomo), Redwood Valley Rancheria, Robinson Off-Reservation Trust Land, Robinson Rancheria, Round Valley Off-Reservation Trust Land, Round Valley Reservation (Cahto, Concow Maidu, Nomlaki, Pit River, Pomo, Wailaki, Yuki), Sherwood Valley Rancheria (Pomo), Sulfur Bank Rancheria (Pomo), Upper Lake Rancheria (Pomo)

Permanent Euro-American settlements were established after the discovery of gold in the 1840s, resulting in more widespread and long-term impacts on riparian and aquatic ecosystems. A variety of mining activities removed riparian vegetation and stream gravels from valley bottoms. At the same time, widespread logging was underway to support mining operations and the growth of towns (Gross et al. 2020). Upon arriving in California, Euro-American settlers prohibited cultural burning by Indigenous groups

because it was thought to interfere with agriculture, mining, and timber harvest. Fires ignited by lightning were also suppressed as part of forest management policies (Reeves et al. 2018). As a result, forest types dominated by California black oak (*Quercus kelloggii*) and tanoak (*Notholithocarpus densiflorus*), and by ponderosa pine, along with grassland and meadow communities, were replaced by forests dominated by fir (*Abies* spp.) that were prone to large and destructive fires and provided lower biodiversity and fewer cultural resources (Anderson 2006). These changes have been observed in riparian areas as well, and in some areas, riparian forests have higher fuel loads than adjacent uplands (Van de Water and North 2011).

After the forced removal of Indigenous populations from their traditional territories and the establishment of the U.S. Forest Service, management of the Five Forests was focused on timber production (Cerveny et al. 2018). Extensive road-building and logging continued through the 1900s, peaking between the 1960s and 1980s (Charnley et al. 2018; Cover et al. 2010). This widespread timber harvest reduced the deposition of down wood in streams, where it enhances salmonid habitat. Loss of forest cover also decreased stream shading and increased sediment deposition into streams throughout the Five Forests (Reeves et al. 1995). In some places, forests were logged up to the streambank and replanted with conifers, further altering the structure and composition of riparian ecosystems (Reeves et al. 2018).

Developments for water use have heavily impacted riparian and aquatic ecosystems. Large dams have made extensive areas of habitat inaccessible to anadromous fishes in the Klamath and Sacramento River Basins (Good et al. 2005). Transbasin diversions were constructed to move water from the Trinity River to the Sacramento Basin and from the Eel River to the Russian River Basin (Asarian and Walker 2016; Dettinger et al. 2015). Smaller diversions, both regulated and unregulated, have been constructed for *Cannabis* cultivation, impacting headwater streamflows (Bauer et al. 2015; Dillis et al. 2020). Long-term reductions in streamflows have been attributed to these and other water uses, and to changes in vegetation cover (Asarian and Walker 2016).

In the 1990s, a shift in forest management was guided by the Endangered Species Act of 1973 (ESA) and the Northwest Forest Plan (NWFP). The reduction in the extent of old-growth forests led to a decline in population and the eventual listing of the northern spotted owl (*Strix occidentalis caurina*) and marbled murrelet (*Brachyramphus marmoratus*) as threatened under the ESA in 1990 and 1992, respectively (Lesmeister et al. 2018; Raphael et al. 2018). Major declines in salmon and steelhead (*Oncorhynchus mykiss*) runs were caused by many factors including mining, overfishing, diversions, dams, erosion from roads, timber harvest, and catastrophic fires (Hamilton et al. 2016; Yoshiyama and Moyle 2010). As a result, several evolutionarily significant units of Pacific salmon and distinct population segments of steelhead have been Federally listed (Reeves et al. 2018). In 1994, the NWFP was adopted to manage old-growth forest ecosystems to comply with the ESA and protect habitat for northern spotted owl, marbled murrelet, anadromous fishes, and other species (USDA FS and USDOI BLM

1994). The NWFP established a system of land allocations that preserve mature and old-growth forests. Among the allocations are riparian reserve (RR) areas that were set aside to protect riparian and aquatic habitats and serve as dispersal corridors connecting the other reserves (USDA FS and USDOI BLM 1994). Recent analyses have found that the establishment of RRs has improved riparian and aquatic habitats through passive restoration, particularly in wet forests (Reeves et al. 2018). In RRs in dry forests, the effects of fire suppression are apparent, but these areas have received little active management despite a need to restore the roles of cultural burning and lightning-caused fires in ecological processes (Anderson 2006). Treatment is needed to reduce fuel loads and restore the desired composition and structure of RRs in dry forests of the NWFP area (Reeves et al. 2018). In some areas, restoration of cultural burning has shown promise for providing resources for Indigenous communities and restoring ecosystem function (Marks-Block et al. 2021).

There is growing recognition that forest ecosystems are affected by climate change, driven by greenhouse gas emissions. Observed and projected changes in the NWFP area include increases in air temperature and a reduction in snowpack (Reeves et al. 2018). Despite projected increases in winter precipitation, increases in air temperature and water demand will create drier overall conditions, resulting in modest decreases in streamflows, but significant declines in summer flows for rivers such as the Klamath (Dettinger et al. 2015). Indirect effects of climate warming include increases in the extent of disturbances such as insects, disease, and severe wildfires (Reeves et al. 2018). Impacts of these changes on riparian and aquatic ecosystems will be shaped by interactions with other anthropogenic influences such as dams, diversions, and fire suppression (Asarian and Walker 2016).

CHAPTER 2: ECOSYSTEM CHARACTERISTICS

In this chapter, we describe the spatial extent of analyses conducted for this assessment. We then give a broad description of the riparian and aquatic ecosystems that occur across the Five Forests. We also describe rare and unique ecosystems that may be present in the national forests.

Spatial Extent

We used the administrative boundaries of the Five Forests to delineate the area of study units, the miles of stream ecosystems in these units, and the area of associated riparian reserves (RRs). These measurements are the basis for the analyses presented throughout this assessment. Within the administrative boundaries are NFS lands and inholdings of non-NFS lands (figs. 2–6).

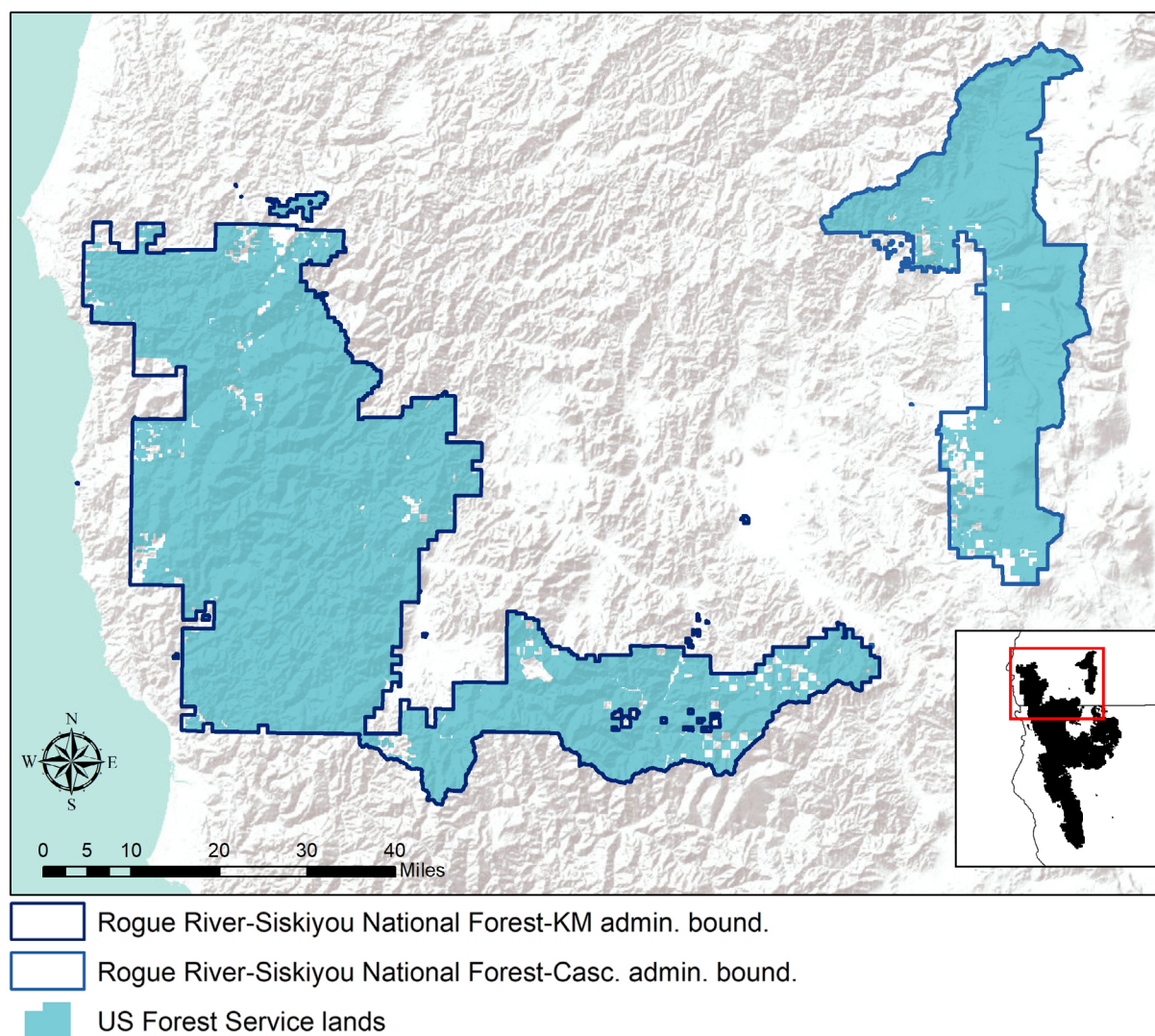
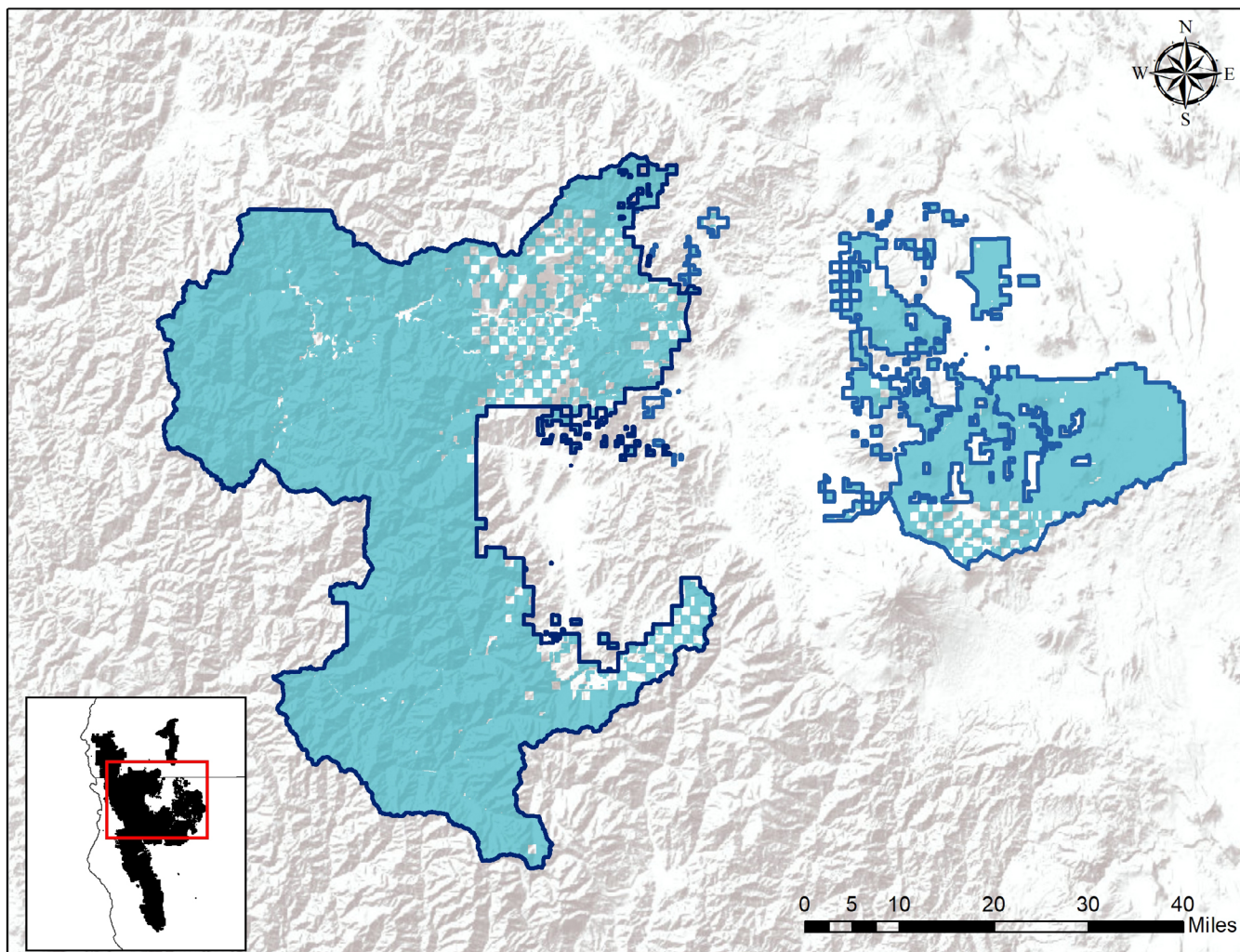


Figure 2—Extent of National Forest System land within the administrative boundaries of the Rogue River-Siskiyou National Forest (RRSNF). The forest is divided into the Klamath Mountains (KM) and Cascades (Casc.) study units. Inset shows location within Oregon and California. USFS: USDA Forest Service



- Klamath National Forest-KM admin. bound.
- Klamath National Forest-Casc. admin. bound.
- KNF US Forest Service lands

Figure 3—Extent of National Forest System lands within the administrative boundaries of the Klamath National Forest (KNF). The forest is divided into the Klamath Mountains (KM) and Cascades (Casc.) study units. Inset shows location within Oregon and California. USFS: USDA Forest Service.

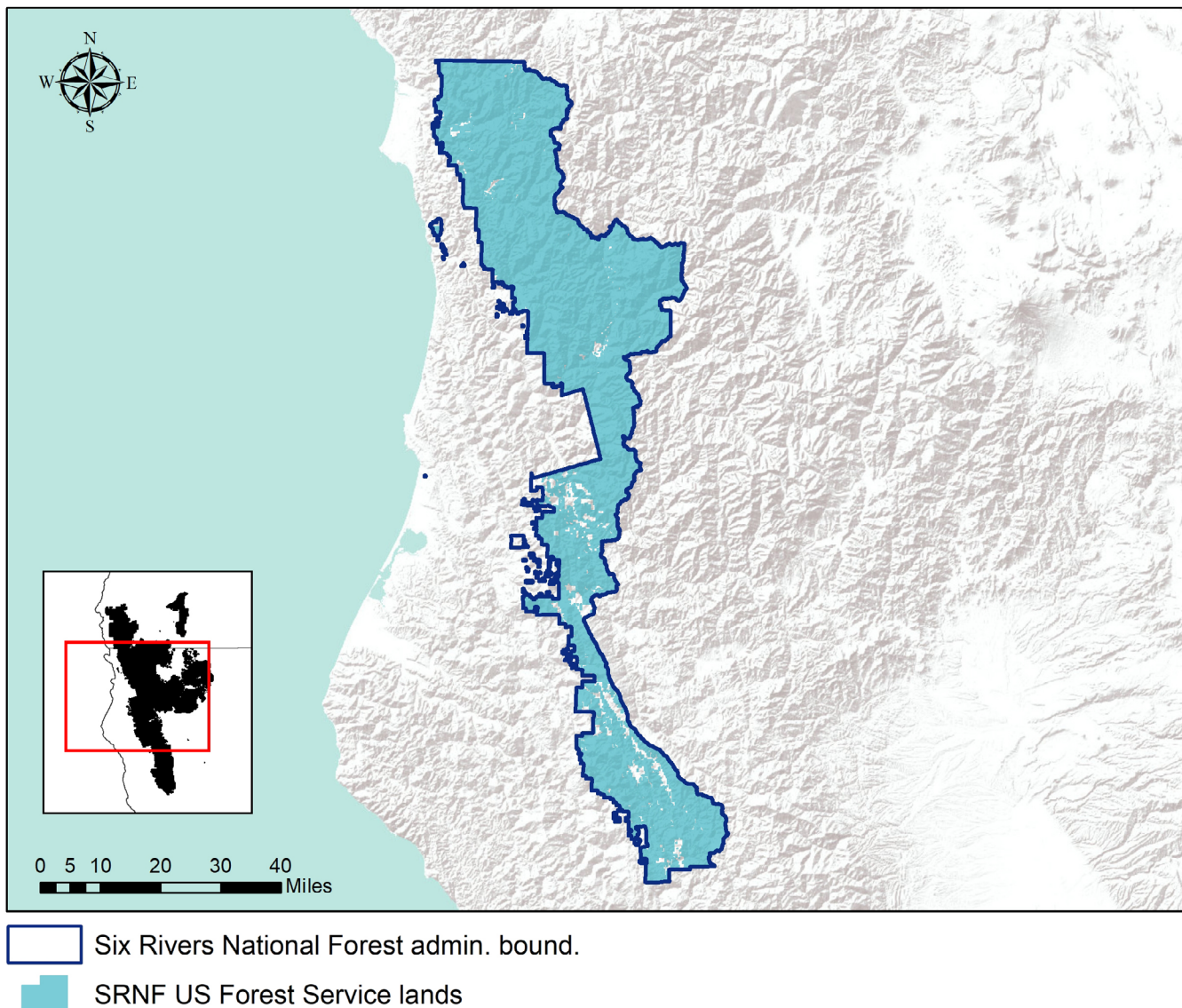


Figure 4—Extent of National Forest System lands within the administrative boundaries of the Six Rivers National Forest (SRNF). Inset shows location within California. USFS: USDA Forest Service.

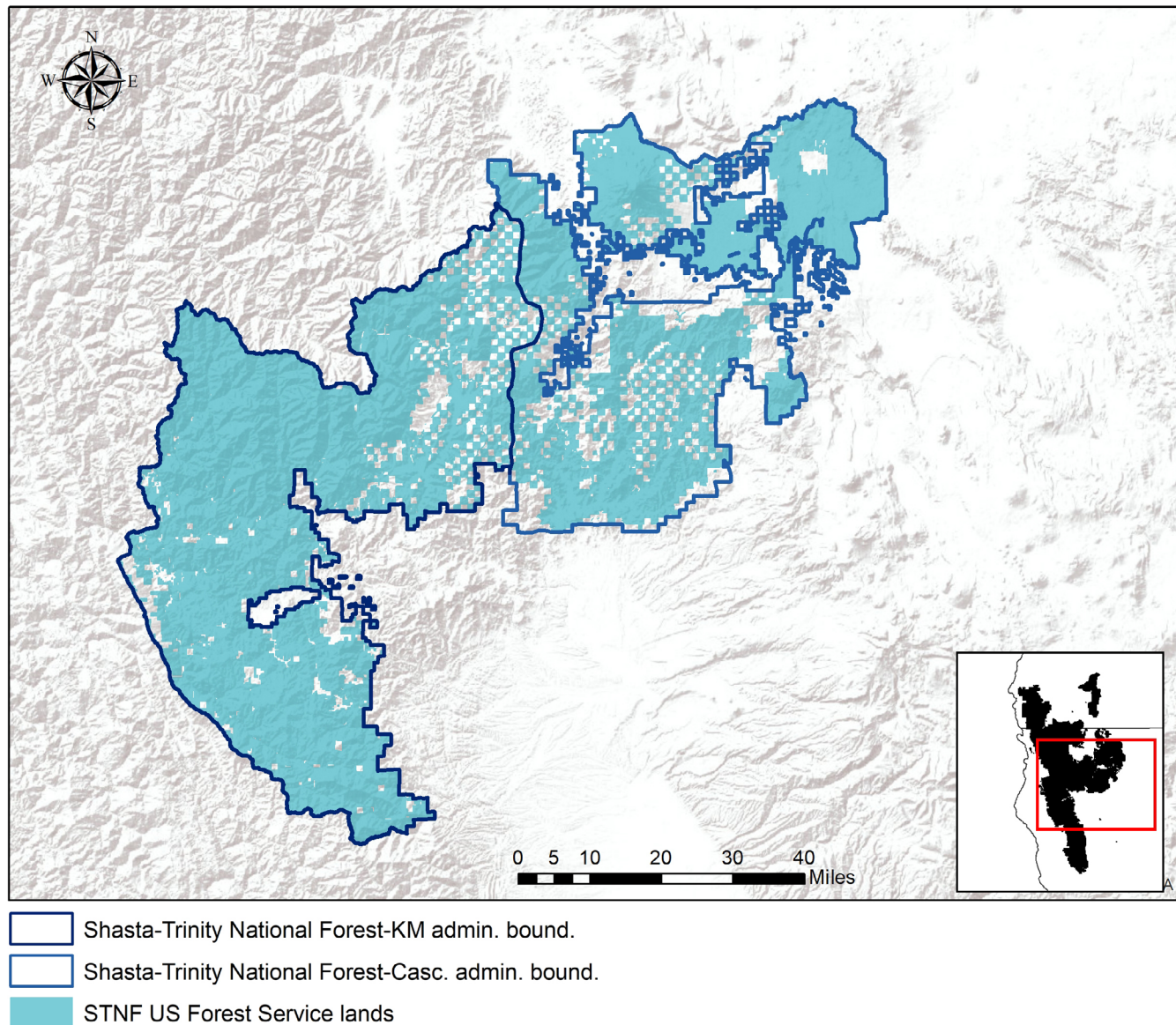


Figure 5—Extent of National Forest System lands within the administrative boundaries of the Shasta-Trinity National Forest (STNF). The forest is divided into the Klamath Mountains (KM) and Cascades (Casc.) study units. Inset shows location within California. USFS: USDA Forest Service.

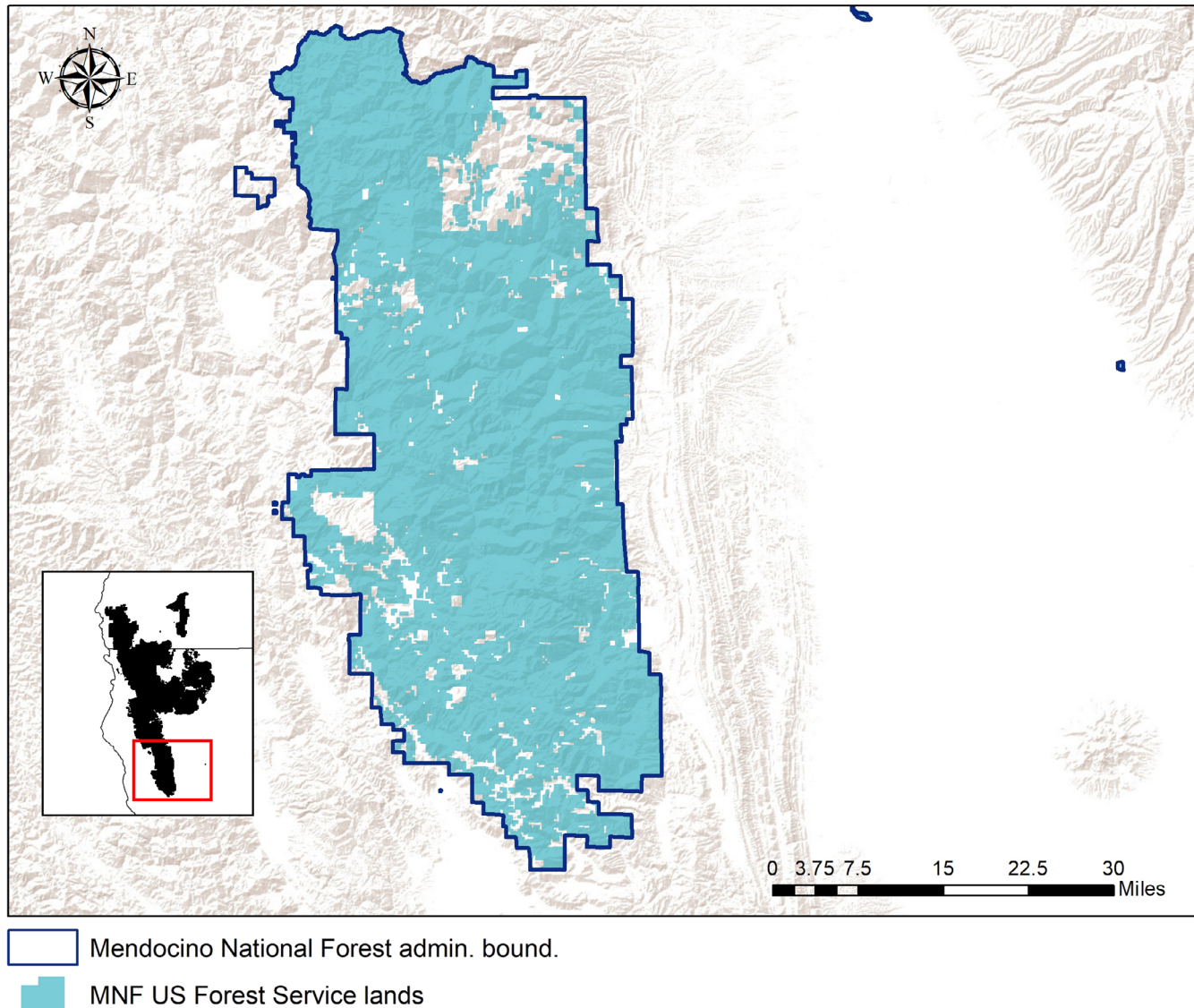


Figure 6—Extent of National Forest System lands within the administrative boundaries of the Mendocino National Forest (MNF). Inset shows location within California. USFS: USDA Forest Service.

Stream Ecosystems of the Five Forests

We delineated ecosystems using RRs, which were created with streamside buffers extending the length of two site-potential trees or 300 feet, whichever is greater, for fish-bearing streams. For permanently flowing nonfish-bearing streams, buffer widths equal the height of one site-potential tree, or 150 feet, whichever is greater. Buffer widths for seasonally flowing or intermittent streams equal the height of one site-potential tree, or 100 feet, whichever is greater (USDA FS and USDOI BLM 1994). Riparian reserves were established to protect the health of aquatic ecosystems, provide benefits to terrestrial species, maintain and restore riparian structure and function, and provide for greater connectivity of late-successional forest habitat (USDA FS and USDOI BLM 1994). These reserves represent terrestrial habitats coupled to streams, providing resources for aquatic and riparian-dependent species (Reeves et al. 2018).

Within RRs are zones of riparian vegetation. These zones are transitions between aquatic and terrestrial ecosystems and, through the exchange of matter and energy, function as important connections between these areas (Capon et al. 2013; National Research Council 2002). Riparian zones are distinguished by plant communities influenced by surface flows and groundwater. They represent large or small percentages of RRs (see the section “Riparian Reserves Condition”), depending on site conditions such as physical setting and management history (Gross et al. 2020). The composition and structure of vegetation types in riparian zones are influenced by site conditions, watershed position, and climate (Everest and Reeves 2007; Pabst and Spies 1999).

Stream settings within the Klamath Mountains are topographically complex, are forested, and occur at relatively low elevations (Asarian and Walker 2016; Isaak et al. 2022). Most watersheds are rain dominated, with peak flows resulting from runoff during the winter. Major river systems include the Eel River, Klamath River, Rogue River, Sacramento River headwaters, Smith River, and Trinity River. In contrast, fish-bearing streams in the Cascades units are low gradient and influenced by considerable groundwater inputs. In some Cascades watersheds, surface flows and groundwater originate as snow in high elevations such as Mount Shasta and the slopes below Crater Lake (Jeffres et al. 2009). Peak flows occur during the winter or spring, depending on the primary source of runoff. Major river systems include the McCloud River, Shasta River, upper Klamath River, upper Rogue River, and Sacramento River headwaters.

In the next sections of this assessment, we describe conditions for the following stream habitats: permanently flowing fish-bearing streams, permanently flowing nonfish-bearing streams, seasonally flowing fish-bearing streams, and seasonally flowing nonfish-bearing streams. Each habitat is assessed separately for the Klamath Mountains and Cascades units.

Aquatic Habitats

Resident and anadromous fishes on the Five Forests occur in a range of permanently flowing stream habitats that include low-gradient lowland streams with numerous side channels, higher velocity mainstems with rocks and deep pools, and shallow mountain tributaries (Moyle et al. 1995). Among the important habitat features are gravel spawning beds, instream wood, vegetated banks, cold water temperatures, and connected floodplains (Brown et al. 1994; Burnett et al. 2007; Jeffres et al. 2008). In some areas, instream habitats have been degraded by dredge mining, timber drives, and road construction (Gross et al. 2020; Isaak et al. 2022). As a result, streambeds were scoured to bedrock, instream wood was removed, riparian vegetation was lost, water temperatures increased, and streams were disconnected from their floodplains (Loose et al. 2019).

The Five Forests also contain seasonally flowing streams that provide habitat for fish and other aquatic species. During the summer dry season, these reaches may dry completely or be reduced to isolated pools. During the fall and winter rainy seasons, surface flows resume, and stream channels are used as spawning and rearing habitats by salmonids and other fishes (Moyle 2014; Wigington et al. 2006). Seasonally flowing streams are especially important where nearby permanently flowing stream habitats have been degraded (Ebersole et al. 2006). The use of seasonally flowing tributaries during the winter months has been shown to enhance the growth and overwinter survival of juvenile salmon (Ebersole et al. 2006; Jeffres et al. 2008). Where pools are deep or hydrologically connected, salmonids may remain in seasonally flowing streams throughout the summer (Moyle 2014; Obedzinski et al. 2018). If such pools are unavailable, salmonids leave for permanently flowing streams and return with the fall and winter rains (Wigington et al. 2006).

Within the Klamath Mountains area, fish-bearing streams have been designated as critical habitat for populations of coho salmon (*Oncorhynchus kisutch*), Chinook salmon, steelhead, and Pacific eulachon (*Thaleichthys pacificus*) (Reeves et al. 2018). Critical habitat streams make up a small portion of the stream networks in these units (figs. 7–12).

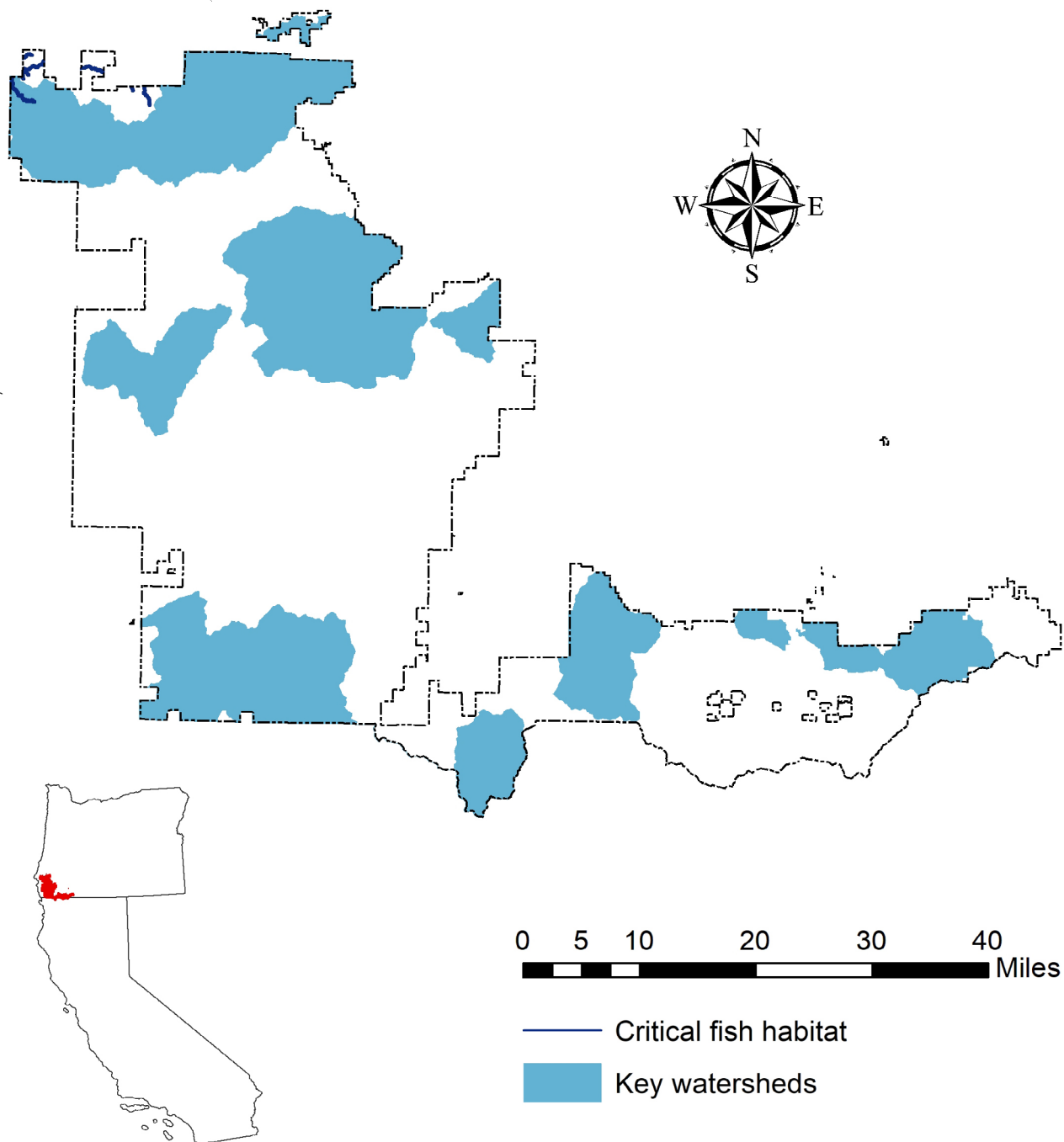


Figure 7—Distribution of key watersheds and critical fish habitat in the Rogue River-Siskiyou National Forest—Klamath Mountains unit. Critical habitat for the Southern Oregon and Northern California Coasts evolutionarily significant unit of coho salmon is present in this unit but is not shown on the map because the data are not publicly available. Lower map shows location within Oregon and California.

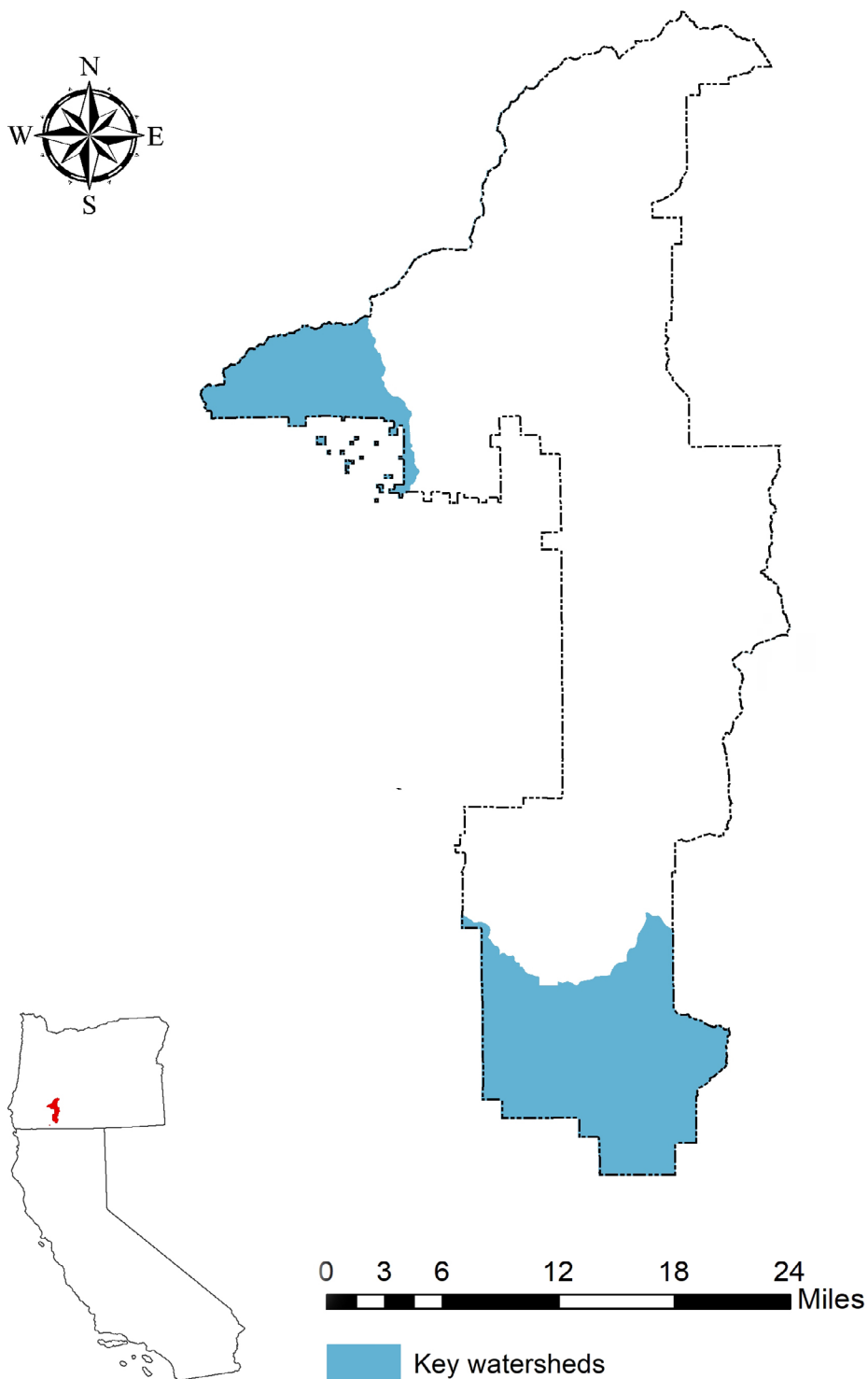


Figure 8—Distribution of key watersheds in the Rogue River-Siskiyou National Forest—Cascades unit. There is no critical habitat designated for fishes in this unit. Critical habitat for the Southern Oregon and Northern California Coasts evolutionarily significant unit of coho salmon may be present in this unit but is not shown on the map because the data are not publicly available. Lower map shows location within Oregon.

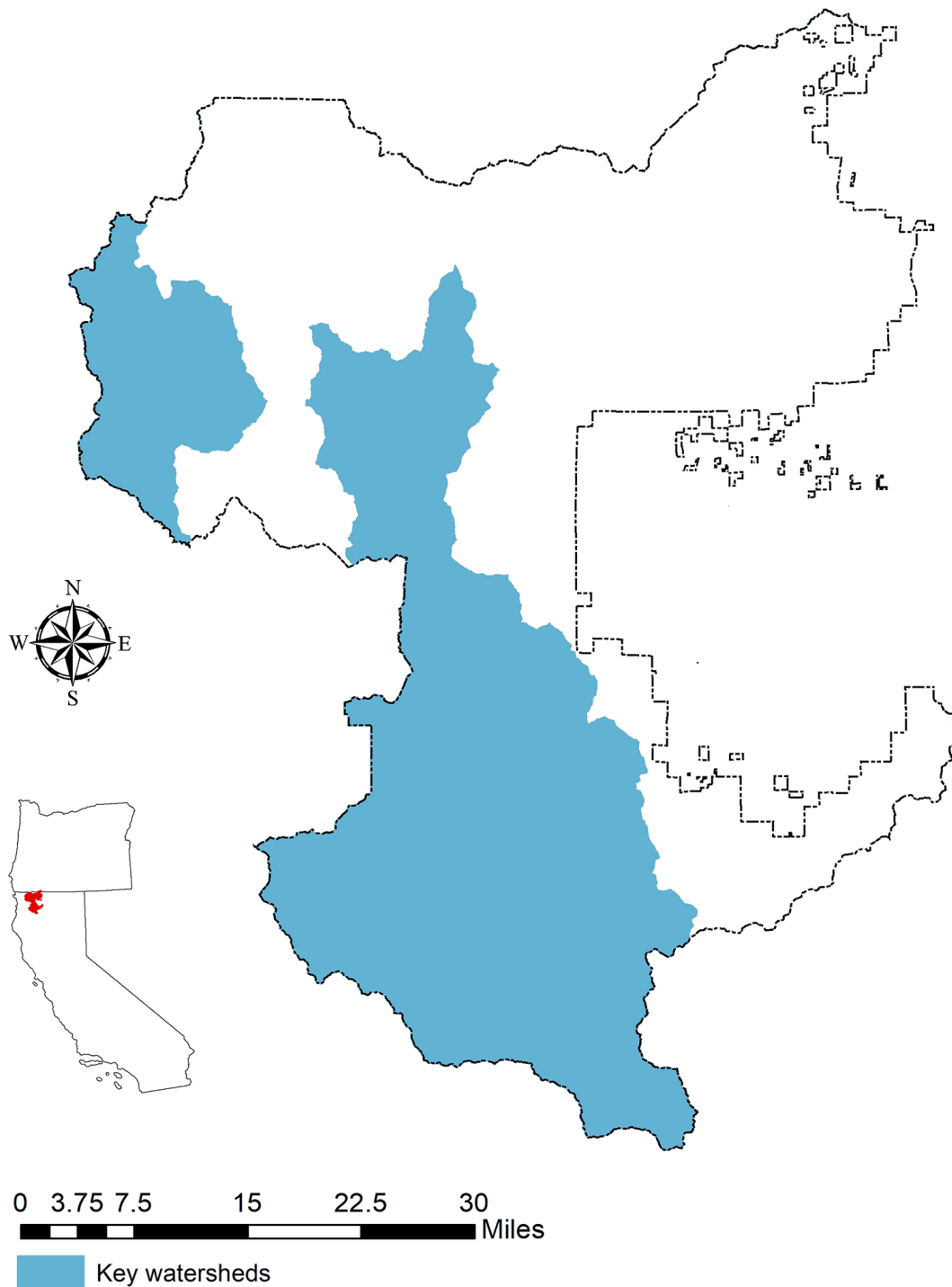


Figure 9—Distribution of key watersheds in the Klamath National Forest—Klamath Mountains unit. There is no critical habitat designated for fishes in this unit. Critical habitat for the Southern Oregon and Northern California Coasts evolutionarily significant unit of coho salmon is present in this unit but is not shown on the map because the data are not publicly available. There are no key watersheds or critical habitat streams in the Klamath National Forest—Cascades unit. Lower map shows location within Oregon and California.

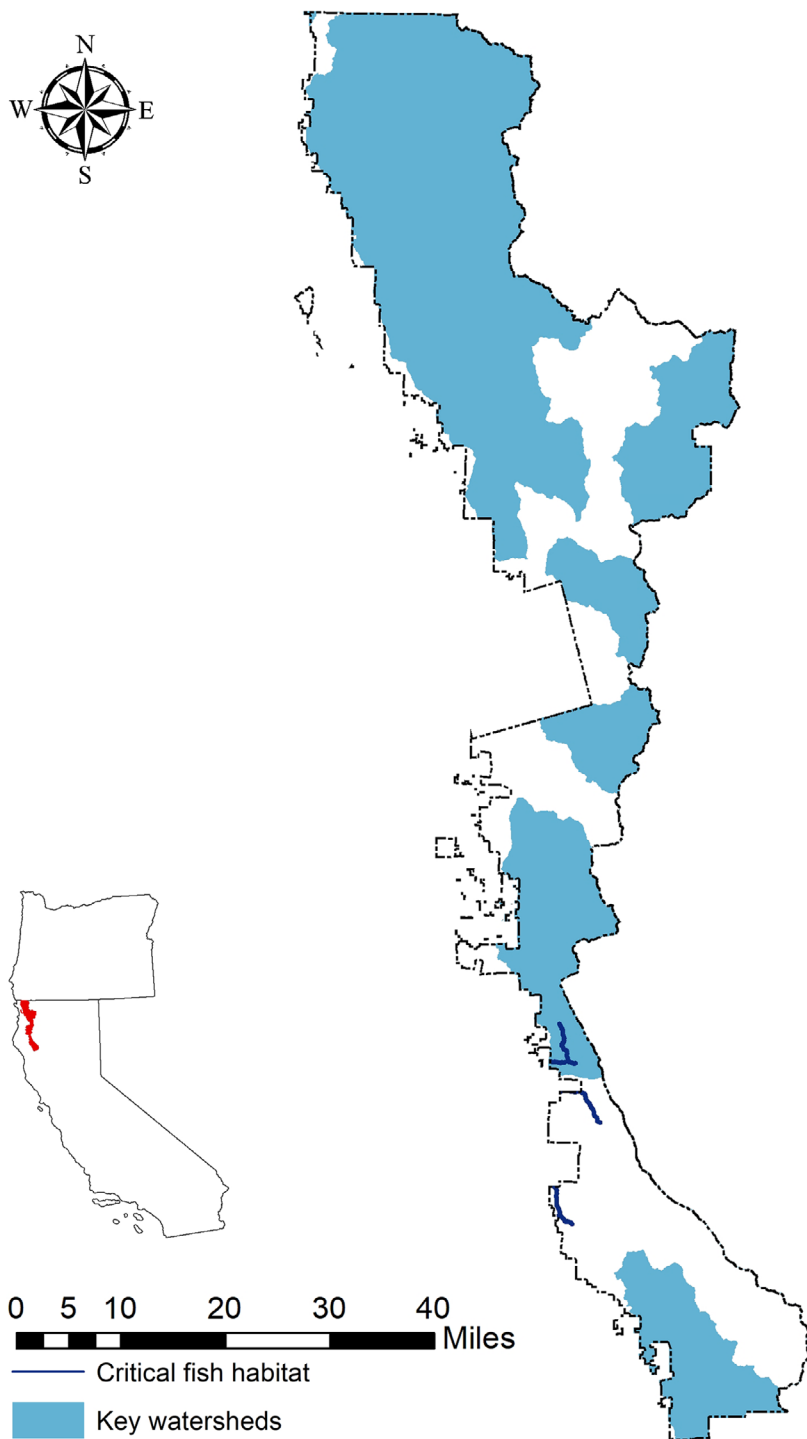


Figure 10—Distribution of key watersheds and critical fish habitat on the Six Rivers National Forest. Critical habitat for the Southern Oregon and Northern California Coasts evolutionarily significant unit of coho salmon is present in this unit but is not shown on the map because the data are not publicly available. Lower map shows location within California.

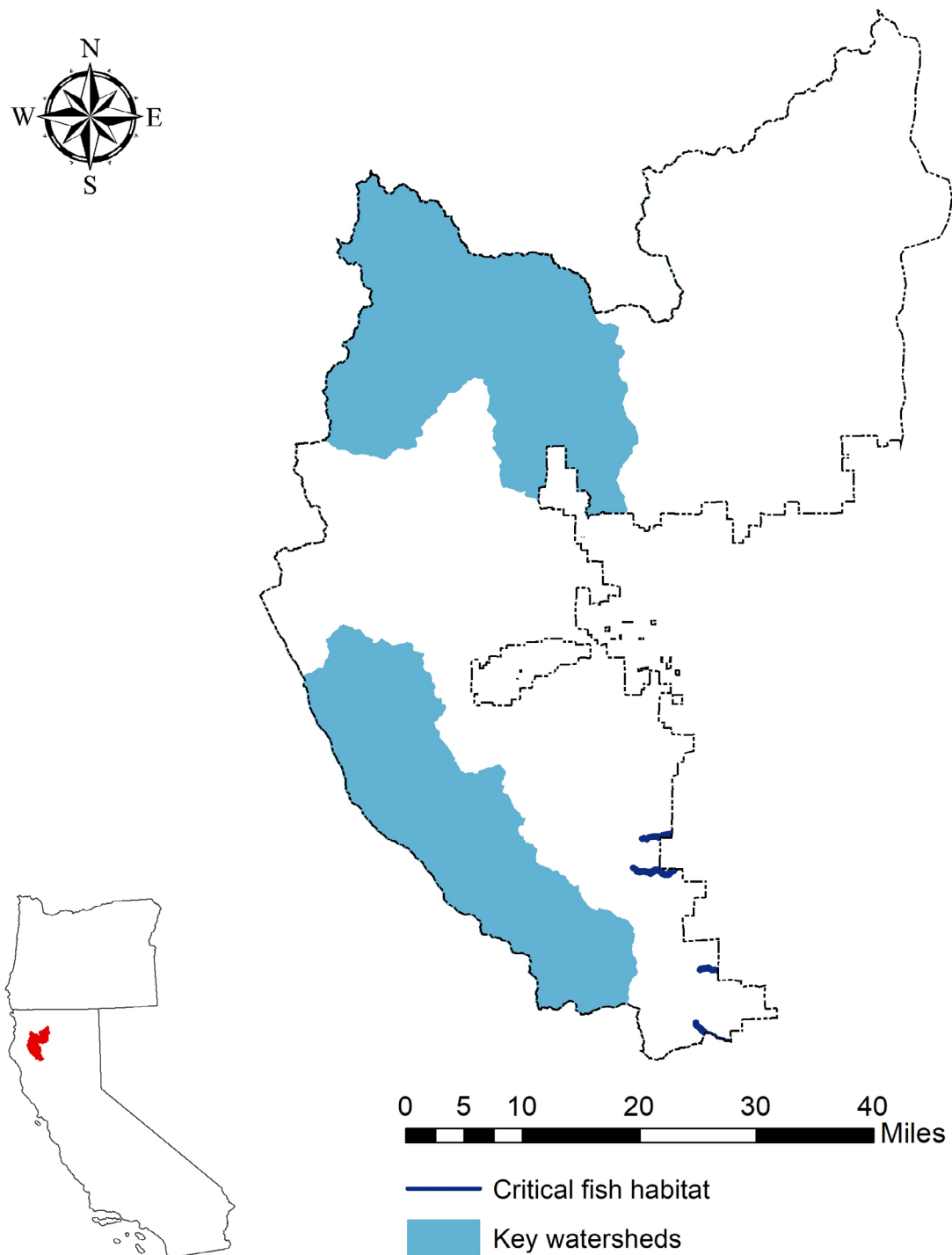


Figure 11—Distribution of key watersheds and critical fish habitat in the Shasta-Trinity National Forest—Klamath Mountains unit. Critical habitat for the Southern Oregon and Northern California Coasts evolutionarily significant unit of coho salmon may be present in this unit but is not shown on the map because the data are not publicly available. There are no key watersheds or critical habitat streams in the Shasta-Trinity National Forest—Cascades unit. Lower map shows location within California.

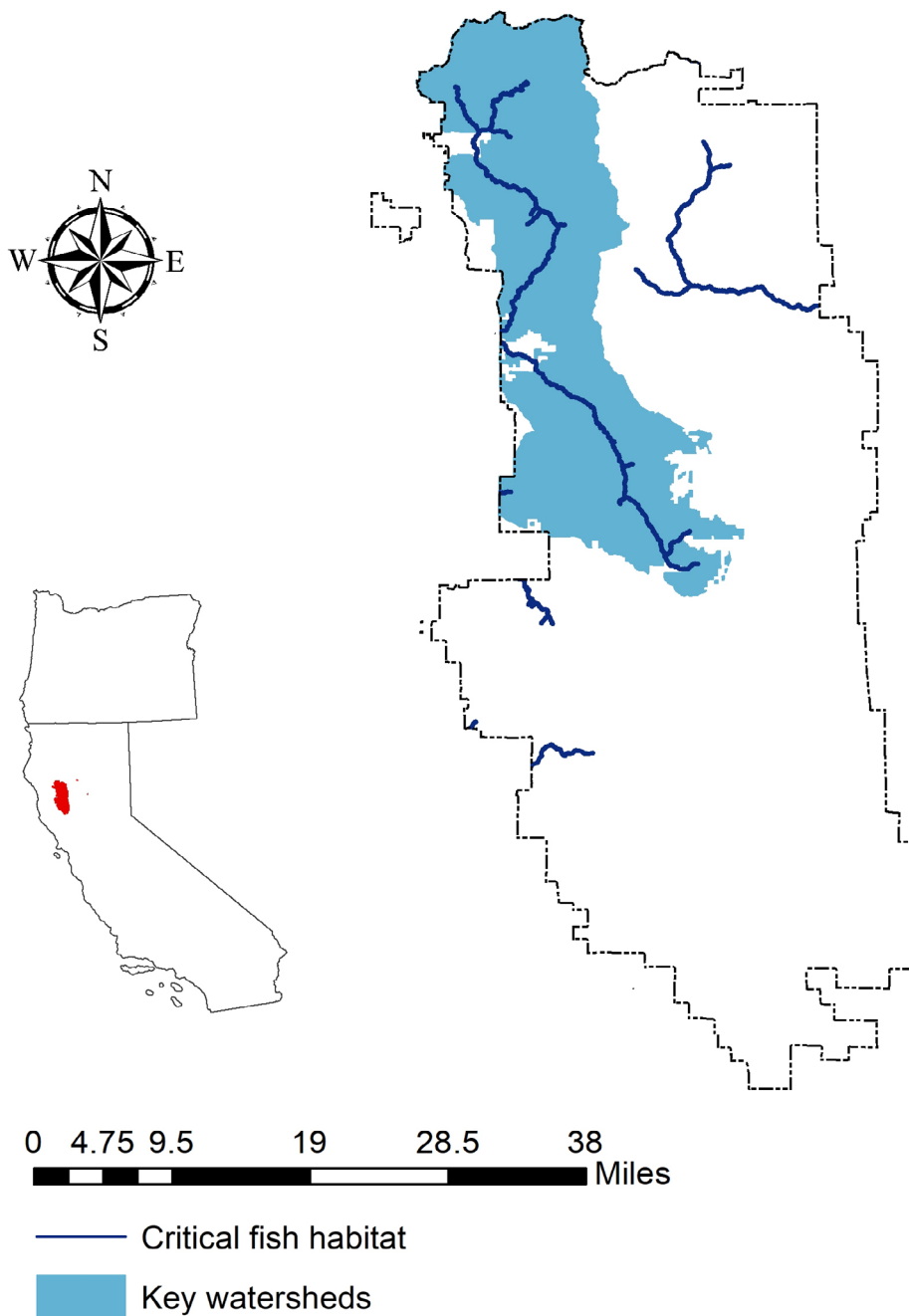


Figure 12—Distribution of key watersheds and critical fish habitat on the Mendocino National Forest. Critical habitat for the Southern Oregon and Northern California Coasts evolutionarily significant unit of coho salmon may be present in this unit but is not shown on the map because the data are not publicly available. Lower map shows location within California.

Burnett et al. (2007) developed a method for estimating the intrinsic potential of streams to provide salmonid habitat. Their method identifies stream reaches with physical attributes suitable for spawning and rearing Chinook salmon, coho salmon,

and steelhead. Streams with high intrinsic potential (HIP; intrinsic potential index values ≥ 0.75) are present in each study unit.

In addition to threatened and endangered species, stream ecosystems support populations of species listed as sensitive by the Forest Service's Region 5 and as special status or sensitive by the Forest Service's Region 6. Aquatic species include coastal cutthroat trout (*Oncorhynchus clarki* ssp. *clarki*), Klamath River lamprey (*Lampetra similis*), and Pacific lamprey (*Lampetra tridentata*) (Moyle et al. 1995). Sensitive amphibians and reptiles include foothill yellow-legged frog (*Rana boylei*) and northwestern pond turtle (*Actinemys marmorata*) (Sims et al. 2019a, b, c, d).

Perennial and intermittent headwater streams support unique assemblages of vertebrates that are dominated by amphibians, including coastal tailed frog (*Ascaphus truei*) and torrent salamanders (*Rhyacotriton* spp.) (Olson and Weaver 2007). Despite the importance of headwater streams as wildlife habitats and sources of wood, sediment, and nutrients for downstream reaches, there is little information available about the processes and conditions of these streams relative to fish-bearing streams (Welsh 2011).

Riparian Habitats

Results from LANDFIRE and gradient nearest neighbor (GNN) rasters (Ohmann et al. 2014) indicate that high-order streams with low gradients and alluvial floodplains support a variety of forest types and shrublands. In the RRs of the Klamath Mountains units, forests on terraces and lower hillslopes are typically dominated by Douglas-fir (*Pseudotsuga menziesii*) and tanoak (fig. 13).

Red alder (*Alnus rubra*) is often the dominant deciduous tree in valley bottoms. A number of deciduous tree species, including bigleaf maple (*Acer macrophyllum*), black cottonwood (*Populus balsamifera* ssp. *trichocarpa*), Fremont cottonwood (*Populus fremontii*), white alder (*Alnus rhombifolia*), and a variety of oaks, may dominate the canopy as well. Shrublands dominated by willows (*Salix* spp.) occur in forest gaps (fig. 14).

Additional tree species, including California laurel (*Umbellularia californica*) and Pacific madrone (*Arbutus menziesii*), occur at the interfaces of floodplains and hillslopes. In the Cascades units, extensive stands of willows and other shrubs dominate the streambanks of low-gradient reaches (fig. 15). Dominant conifers also include ponderosa pine and grand fir (*Abies grandis*).



Figure 13—Douglas-fir and tanoak, the dominant overstory species in this riparian reserve along the Elk River on the Rogue River-Siskiyou National Forest. USDA Forest Service photo by Max Smith.



Figure 14—Dense growth of willow shrubs in the active floodplain within a riparian reserve along the Chetco River on the Rogue River-Siskiyou National Forest. Bigleaf maple, California laurel, tanoak, Douglas-fir, and other trees grow on the adjacent hillslopes. USDA Forest Service photo by Max Smith.



Figure 15—Herbaceous plants, willows, and other deciduous shrubs along the banks of the McCloud River in the Shasta-Trinity National Forest—Cascades unit. USDA Forest Service photo by Carlita Hallett and Felicia Schneider.

Extensive, well-developed alluvial floodplains also contain wet meadow, emergent marsh, and mudflat communities. These communities are temporarily or semi-permanently flooded by peak streamflows, groundwater discharge, and beaver dams. The herbaceous-dominated vegetation of emergent wetland communities includes sedges (*Carex* spp.), bulrushes (*Scirpus* spp.), rushes (*Juncus* spp.), and cattails (*Typha* spp.). Wet meadow communities contain sedges, tufted hairgrass (*Deschampsia cespitosa*), small camas (*Camassia quamash*), and other herbaceous plants. Mudflat communities include a variety of low-stature, herbaceous annuals. Wet meadows are groundwater-dependent ecosystems that have formed on mineral soils that accumulate in unconfined valley bottoms behind moraines, side valley fans, and other constrictions (Weixelman et al. 2011). Meadow complexes can contain expansive mosaics of riparian and wetland vegetation supported by surface flows and springs (Trowbridge et al. 2011).

Low-order streams in steep mountainous areas are bordered by narrow riparian zones. In RRs, conifer-dominated forests include Douglas-fir, as well as lodgepole pine, incense cedar (*Calocedrus decurrens*), and several species of fir. Deciduous trees include black cottonwood, quaking aspen (*Populus tremuloides*), and alders. Herbaceous communities are often dominated by ferns (*Athyrium filix-femina*, *Equisetum arvense*) and sedges.

Riparian reserves overlap areas designated as critical habitat for marbled murrelet and northern spotted owl. Neither species is a riparian obligate, but RRs can contain suitable nesting sites (Lesmeister et al. 2018; Raphael et al. 2018), and spotted owls frequently forage in riparian areas (Wiens et al. 2014). Critical habitat for spotted owl is present in

each of the Five Forests (figs. 16–23). In contrast, critical habitat for marbled murrelet is present only in the Rogue River-Siskiyou and Six Rivers National Forests (figs. 24–25).

Sensitive birds and mammals that may occur in coniferous riparian forests include northern goshawk (*Accipiter gentilis*), harlequin duck (*Histrionicus histrionicus*), fisher (*Pekania pennanti*), and Pacific marten (*Martes caurina*) (Marcot et al. 2018). A variety of neotropical migrant birds, such as willow flycatcher (*Empidonax traillii*) and yellow-billed cuckoo (*Coccyzus americanus*), are associated with riparian hardwoods and may nest along lowland streams (Hilberg et al. 2019). See the appendixes in volumes 2 through 6 for other wildlife species that may rely on streams or RRs in each forest of the cohort. In addition to providing habitat for threatened, endangered, and sensitive species, riparian habitats support some of the highest levels of wildlife diversity among terrestrial ecosystems in the Five Forests planning area (Kattelman and Embury 1996; Reeves et al. 2018).

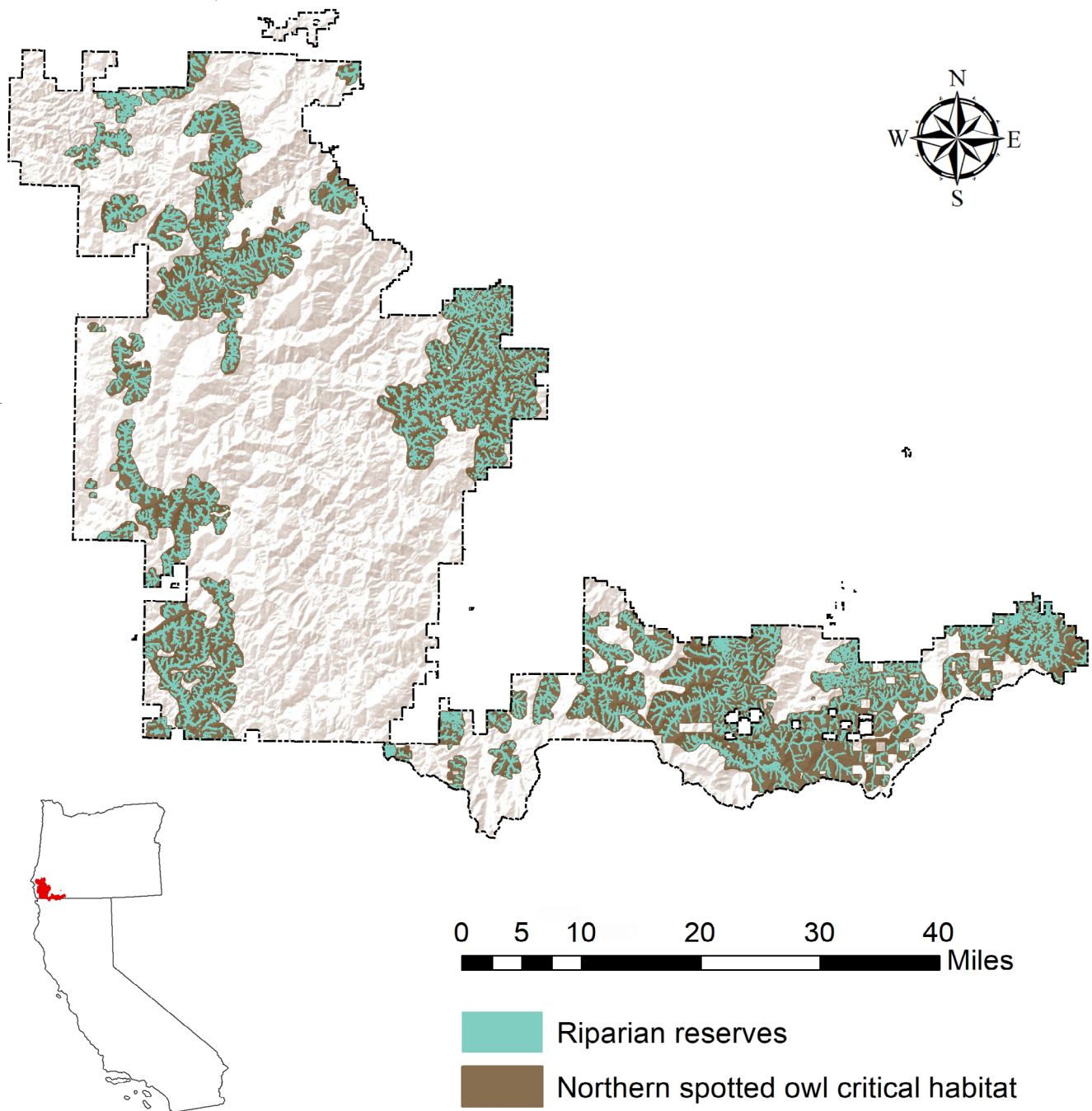


Figure 16—Overlay of riparian reserves and northern spotted owl critical habitat in the Rogue River-Siskiyou National Forest—Klamath Mountains unit. Lower map shows location of study area within Oregon and California.

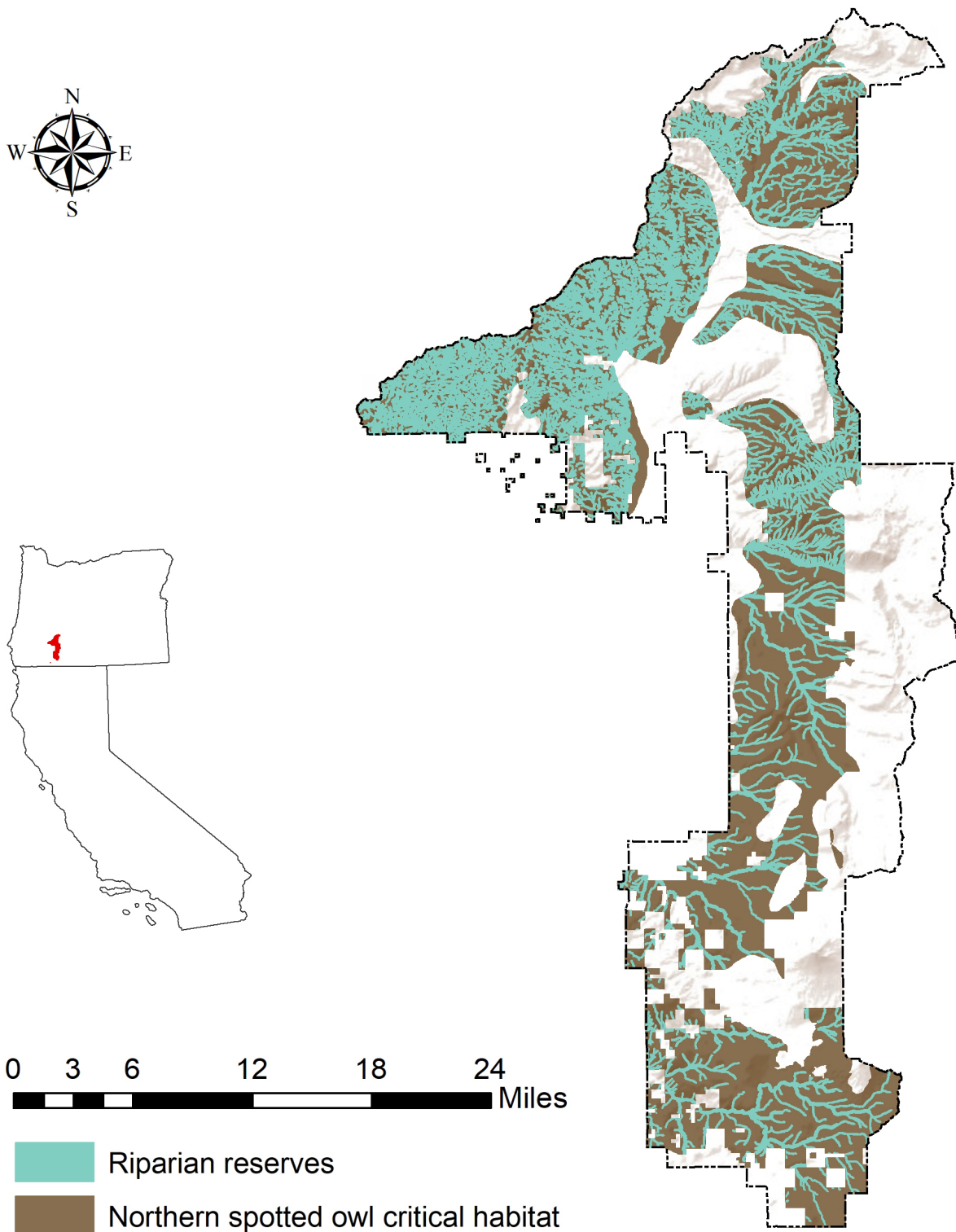


Figure 17—Overlay of riparian reserves and northern spotted owl critical habitat in the Rogue River-Siskiyou National Forest—Cascades unit. Lower map shows location of study area within Oregon.

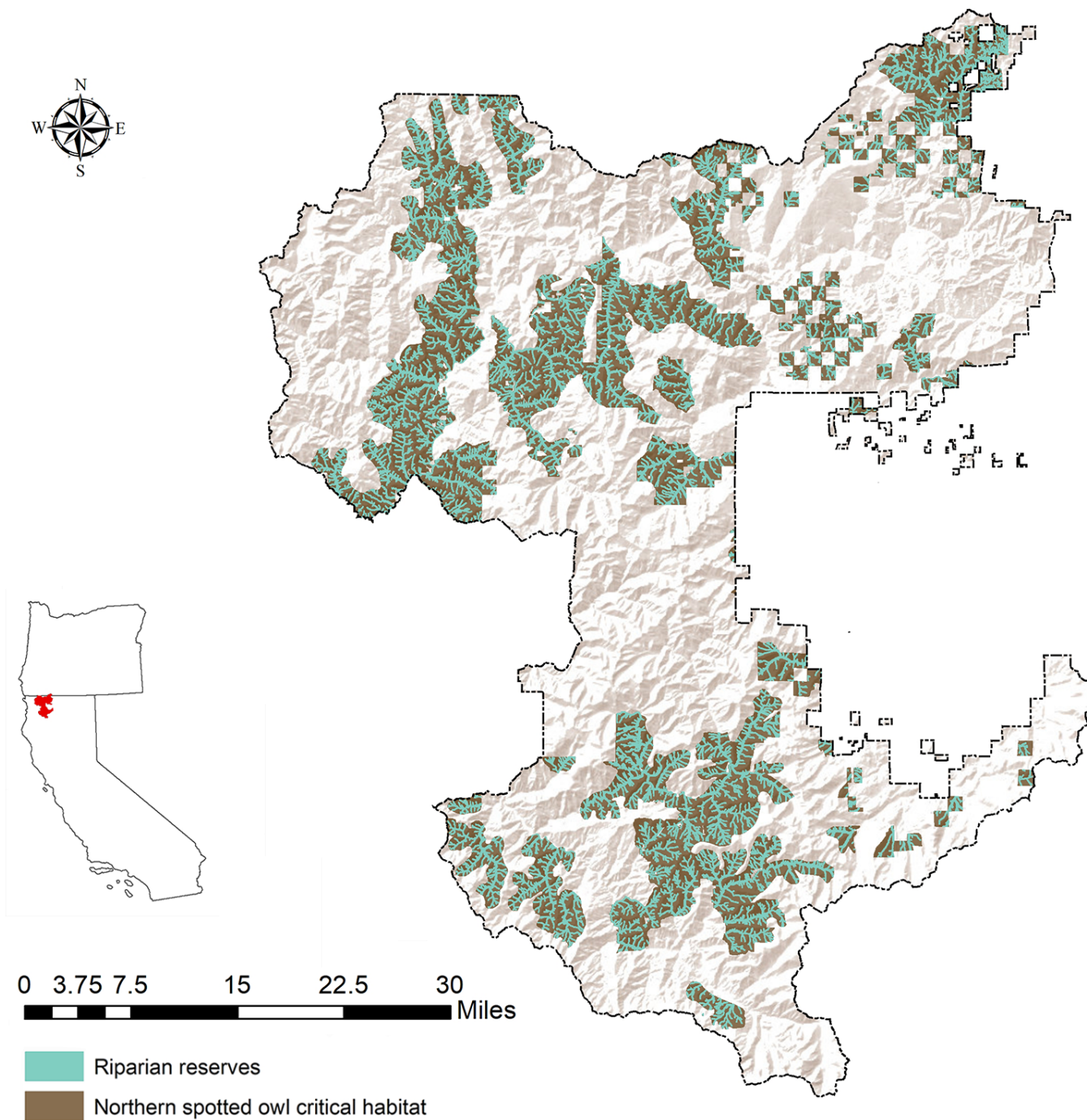


Figure 18—Overlay of riparian reserves and northern spotted owl critical habitat in the Klamath National Forest—Klamath Mountains unit. Lower map shows location of study area within Oregon and California.

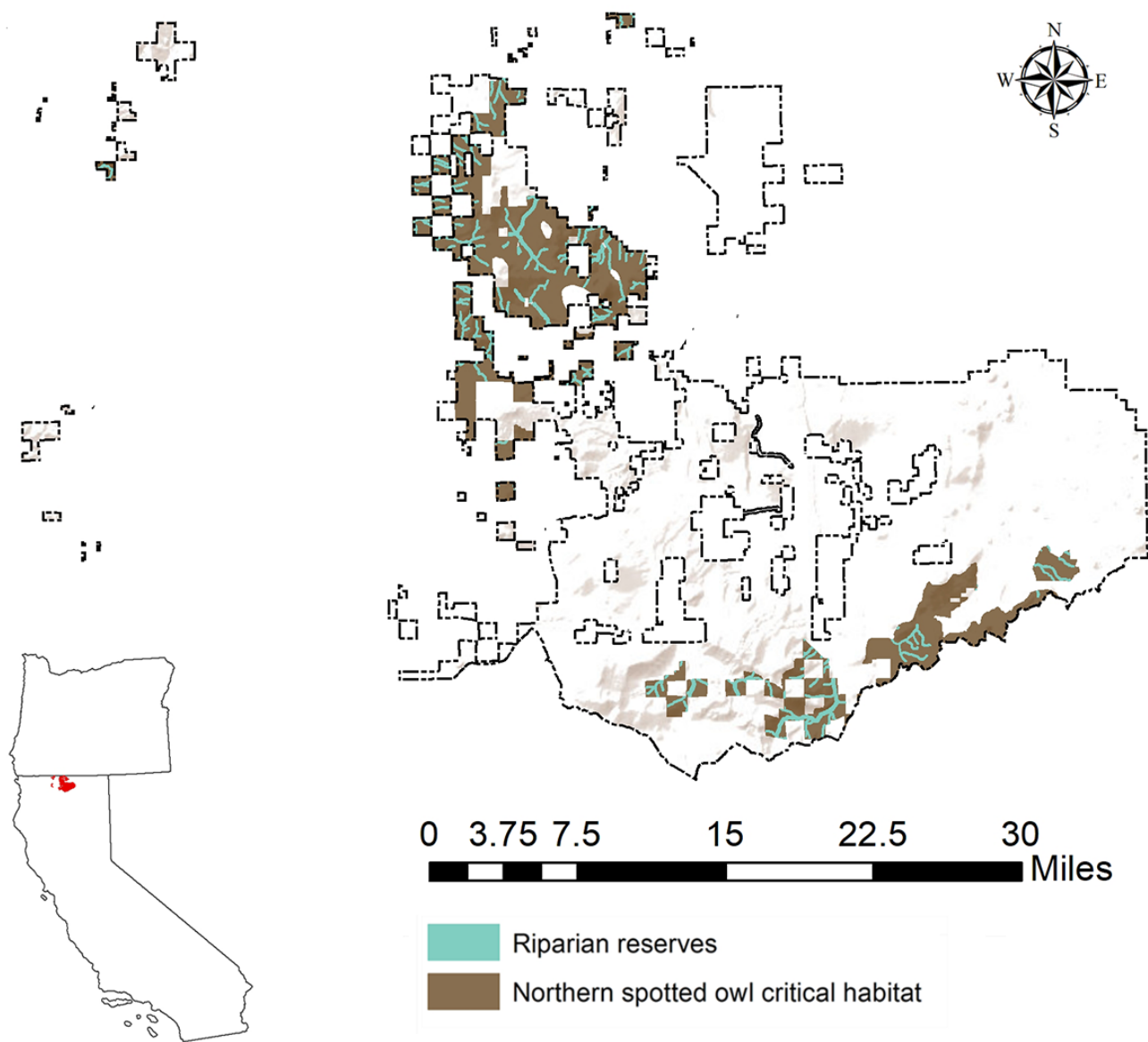


Figure 19—Overlay of riparian reserves and northern spotted owl critical habitat in the Klamath National Forest—Cascades unit. Lower map shows location of study area within California.

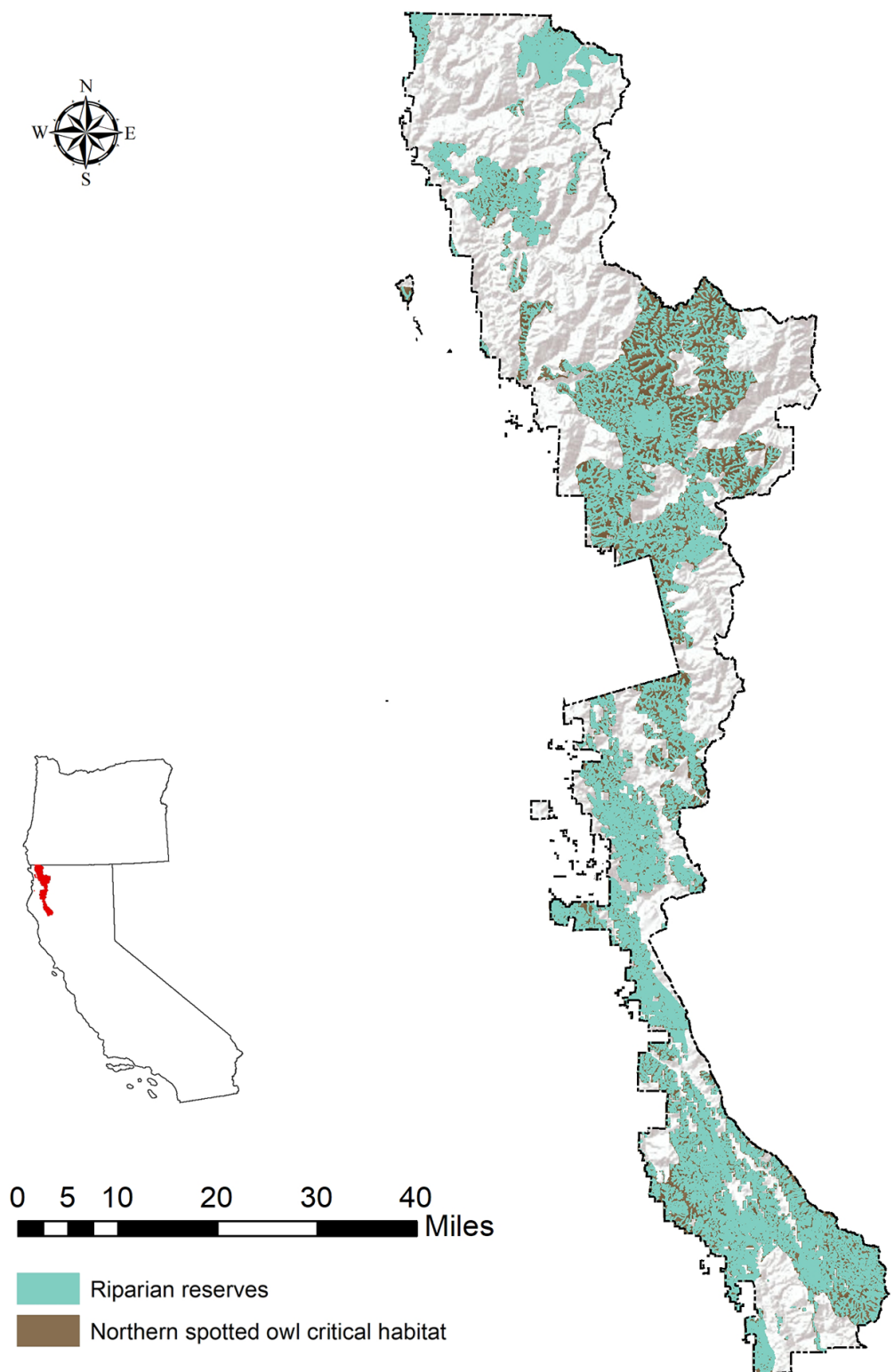


Figure 20—Overlay of riparian reserves and northern spotted owl critical habitat on the Six Rivers National Forest. Lower map shows location of study area within California.

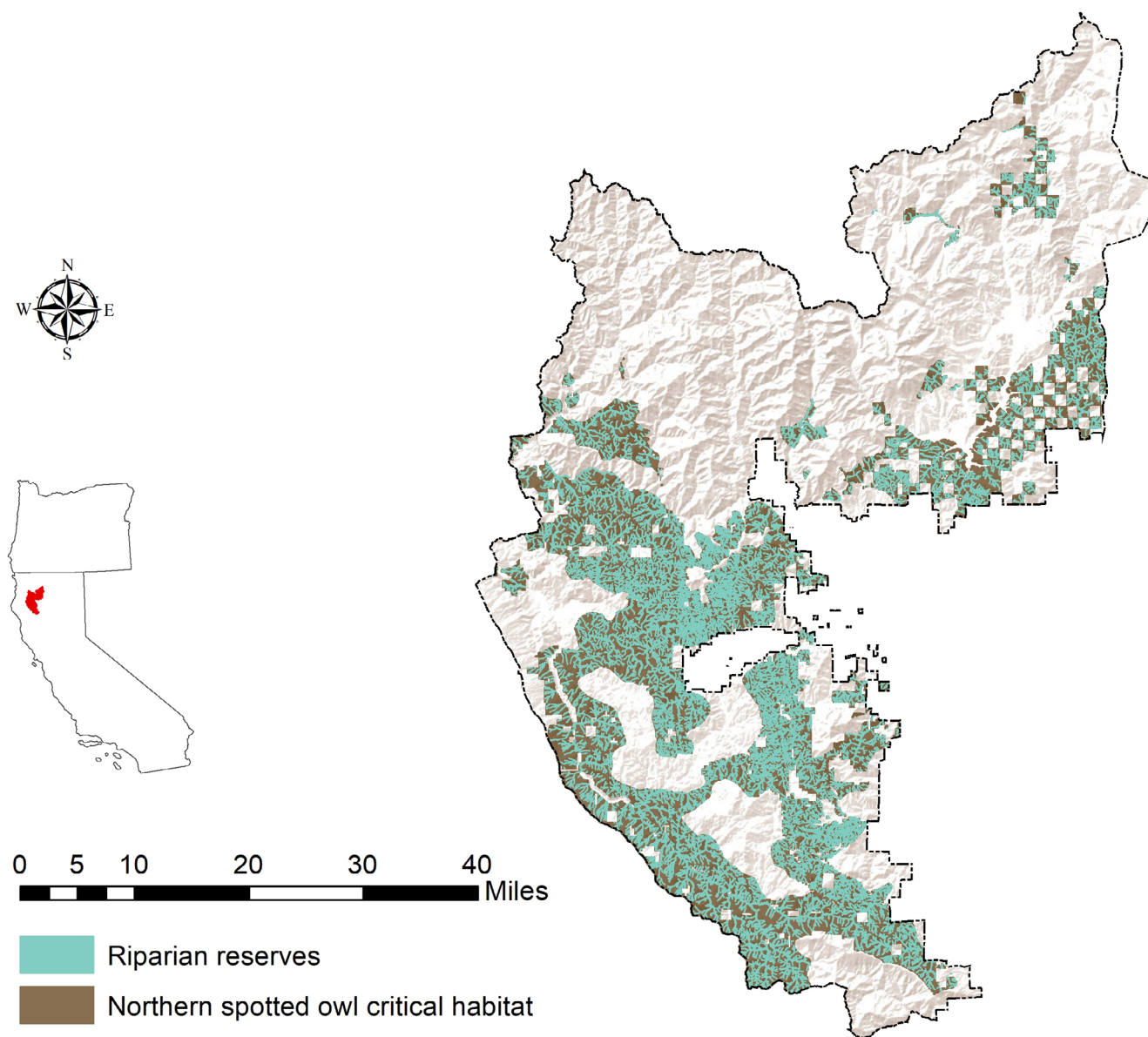


Figure 21—Overlay of riparian reserves and northern spotted owl critical habitat in the Shasta-Trinity National Forest—Klamath Mountains unit. Lower map shows location of study area within California.

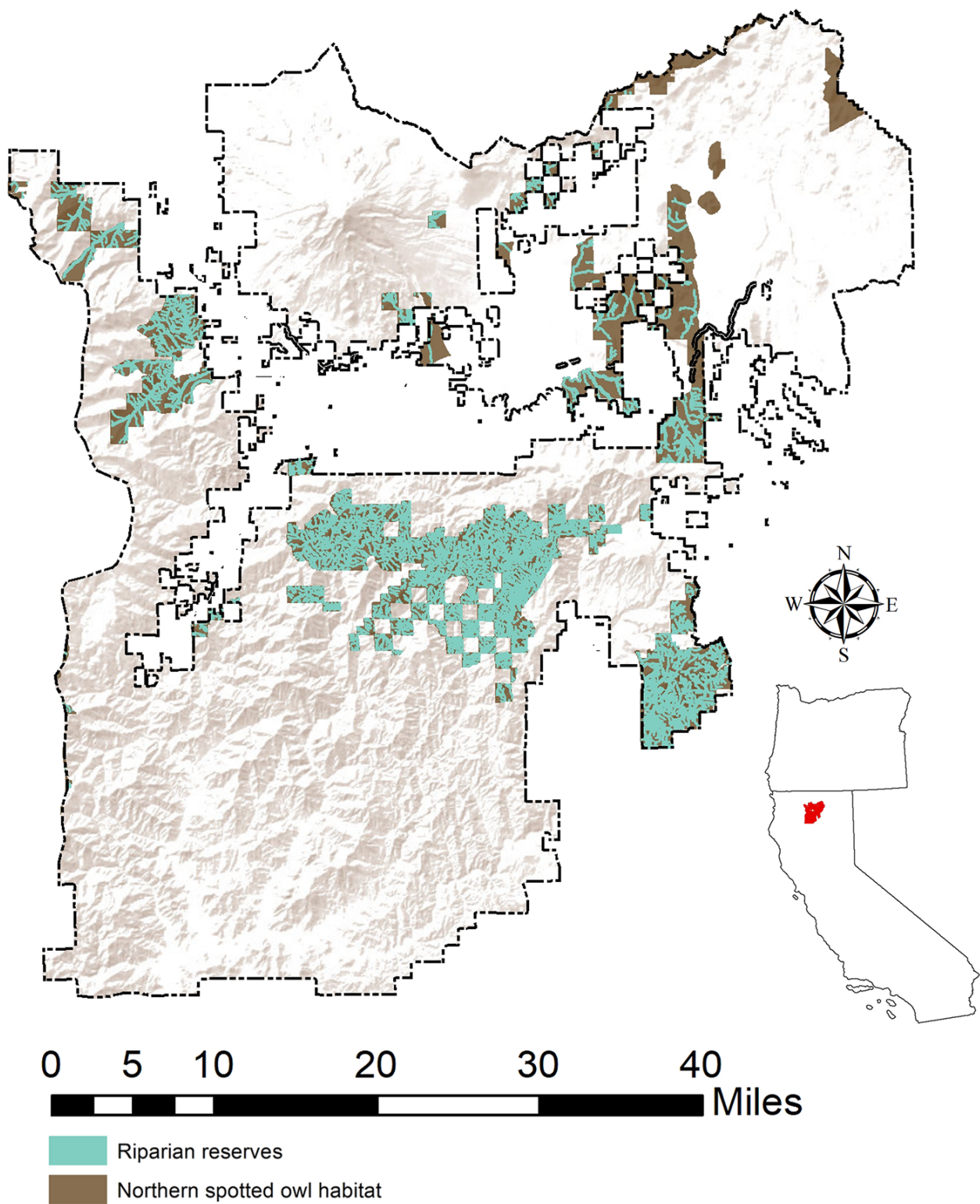


Figure 22—Overlay of riparian reserves and northern spotted owl critical habitat in the Shasta-Trinity National Forest—Cascades unit. Lower map shows location of study area within California.

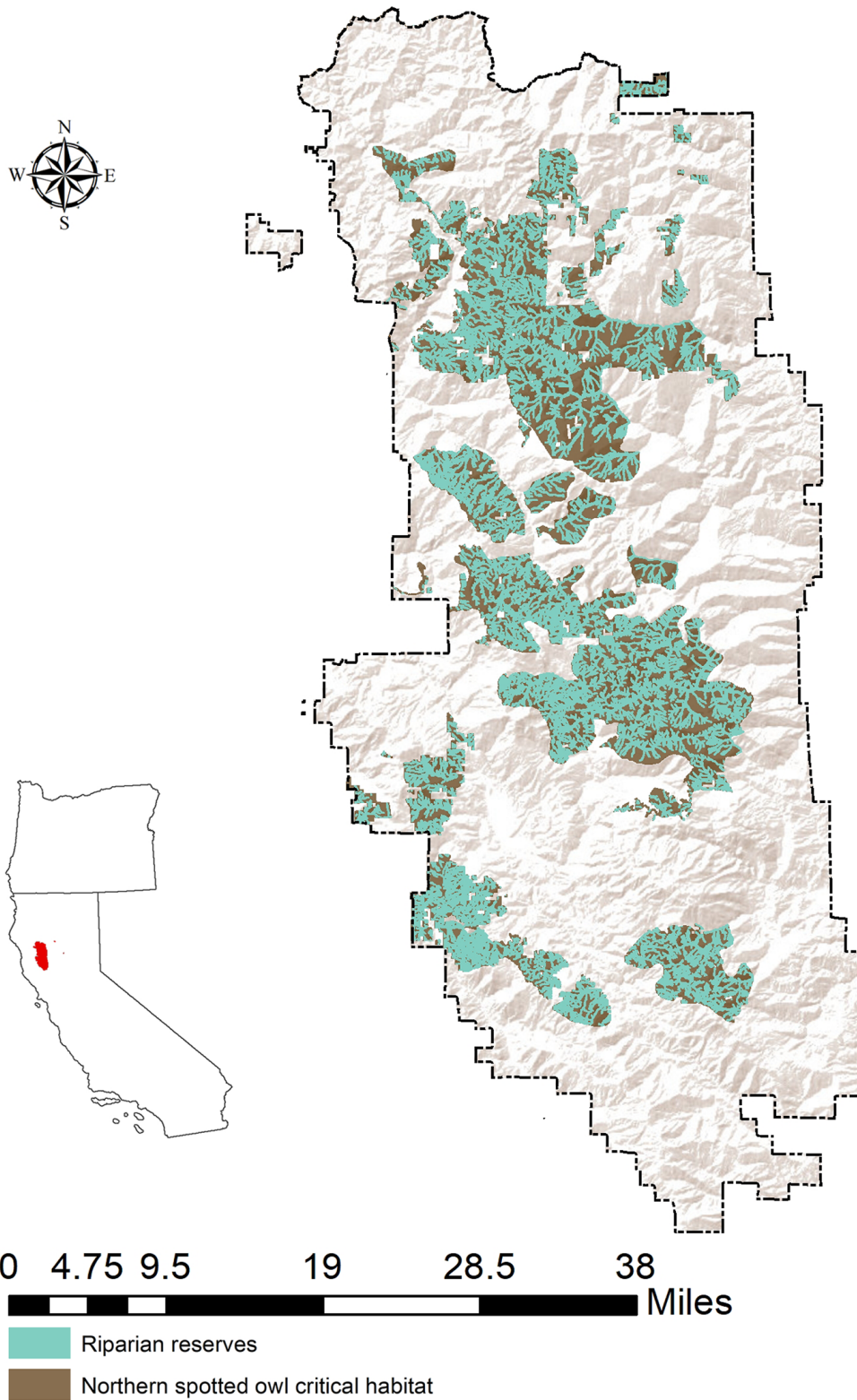


Figure 23—Overlay of riparian reserves and northern spotted owl critical habitat on the Mendocino National Forest. Lower map shows location of study area within California.

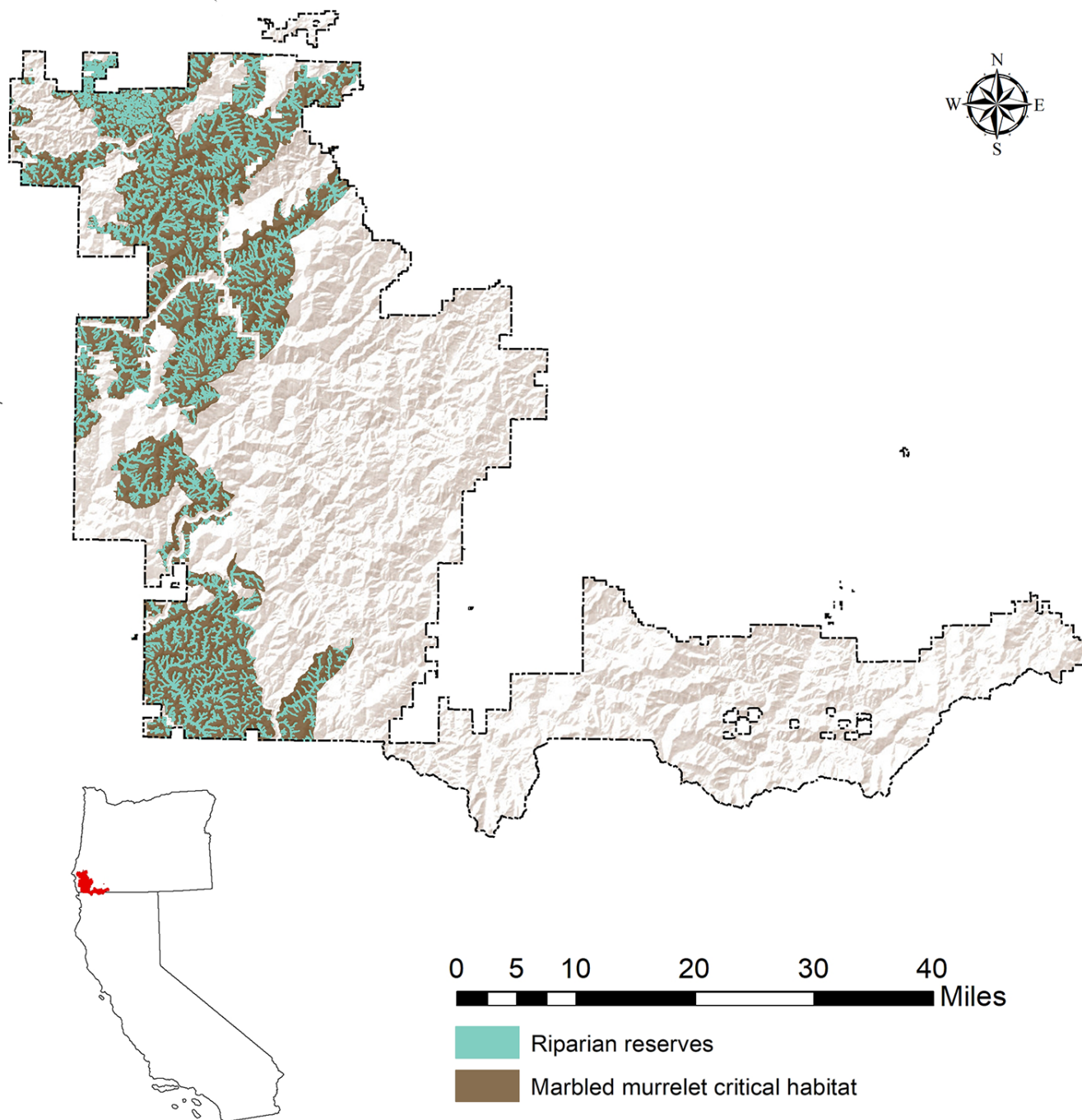


Figure 24—Overlay of riparian reserves and marbled murrelet critical habitat in the Rogue River-Siskiyou National Forest—Klamath Mountains unit. Lower map shows location of study area within Oregon and California.

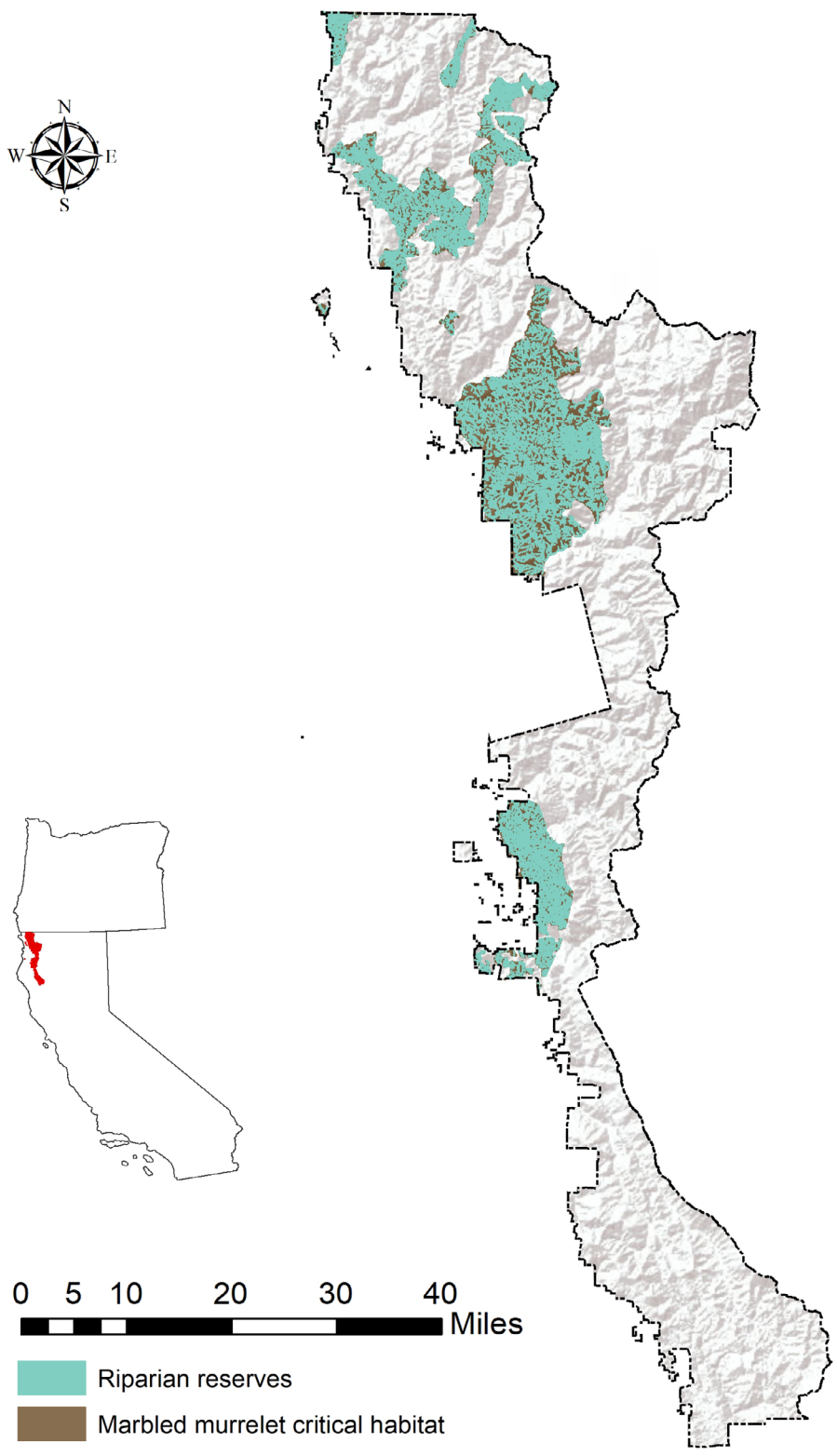


Figure 25—Overlay of riparian reserves and marbled murrelet critical habitat on the Six Rivers National Forest. Lower map shows location of study area within California.

Rare or Unique Vegetation Types, Successional Stages, Geologies, or Soils

Ultramafic rocks create chemical and physical conditions that favor unique and rare plants (Alexander 2011: 20). In the Klamath Mountains, RRs overlap areas of ultramafic rocks and serpentine soils that support these communities (Safford 2011). Port Orford Cedar (*Chamaecyparis lawsoniana*) is often the dominant tree in these sites. Willows, California buckthorn (*Frangula californica*), and other shrubs are present as well. The unique herbaceous community includes goldenrods (*Solidago* spp.), monkeyflowers (*Mimulus* spp.), and columbines (*Aquilegia* spp.).

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 (USDA FS 2016). Karst systems facilitate the movement and discharge of groundwater in many parts of the region, and they host unique floras and faunas (Humphreys 2006). Riparian reserves overlap areas of potential karst in the Rogue River-Siskiyou, Klamath, Shasta-Trinity, and Six Rivers National Forests. Carbonate rocks and their soils also influence plant species composition, creating habitats for endemic plants and animals (Loose et al. 2019; Van de Ven et al. 2007).

The volcanic bedrock of the Cascades units has produced unique spring-fed stream ecosystems. Volcanic landscapes of the southern Cascades are characterized by rapid infiltration of precipitation and snowmelt into porous bedrock, which created extensive groundwater systems that discharge at large springs (Jefferson et al. 2006; Padgett 2020). Spring-dominated stream channels contain thick mats of aquatic vegetation or islands of riparian vegetation growing on instream wood (Whiting and Moog 2001). These plant communities develop as a result of the dampened fluctuations in streamflow volume associated with groundwater discharge.

Ecosystem Services

Numerous services are provided by the stream ecosystems of the Five Forests. These include the provisioning of food, fresh water, medicinals, and other ecocultural resources; floodplain regulation of flood and erosion damage; water purification; disease regulation for fish; support for primary production; floodplain soil retention; nutrient cycling; and spiritual and cultural values (Fair et al. 2018; USDA FS 2021). Important ecocultural resources include anadromous fishes, mussels, otters, beaver, giant salamanders, torrent salamanders, aquatic garter snake, frogs, ferns, and willows (Loose et al. 2019). Additional services include recreation opportunities in wild and scenic river corridors and associated benefits to local communities. The harvest of nontimber forest products (moss, mushrooms, cones, and grasses) and the use of streams for forage and water by livestock help to support local economies as well (USDA FS 2021). When in good functioning condition, wet meadows provide a variety of ecosystem services, such as carbon sequestration and spring runoff storage (Hunt et al. 2018; Reed 2020). In addition, meadow communities dominated by herbaceous plants

and shrubs are critical habitats for several species of management concern (Fair et al. 2018).

Ecosystem Dynamics

The dynamics of streams and their riparian areas are driven in part by underlying geology, terrain, and land use. The legacy of bedrock formation and subsequent geologic events controls the dynamics of valley bottoms, streams, and groundwater in the forests' watersheds (Heath 1983; Waring 2011). Through the processes of erosion and deposition, streams create and modify geomorphic features such as floodplains, gravel bars, and terraces (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 the complex interplay of geomorphology, surface and groundwater movement, disturbances, wildlife, and anthropogenic use (Youngblood 1985).

Lakes, Ponds, and Reservoirs on the Five Forests

Lakes and ponds, both natural and constructed, occur across a wide range of elevations in the region. Settings include valley depressions, dammed stream channels, and glaciated alpine areas (Piovia-Scott et al. 2016; Sims et al. 2019a). Lakes and reservoirs are larger than ponds and have wider temperature profiles, supporting a more diverse aquatic community (Sims et al. 2019a). Ponds have been created by beaver dams, excavation of springs and vernal pools for stock use, and filling of natural depressions (EcoAnalysts 2008; Lanman et al. 2013). The largest lakes in the forests are reservoirs constructed behind major dams. These include Applegate Reservoir in the Rogue River-Siskiyou National Forest, Lake Pillsbury in the Mendocino National Forest, Ruth Lake in the Six Rivers National Forest, and Shasta Lake and Trinity Lake in the Shasta-Trinity National Forest. Riparian reserves have been designated around lakes, ponds, and reservoirs in each study unit.

Habitats

Lakes and ponds provide habitats for a variety of aquatic organisms, including imperiled taxa such as mussels, amphibians, and native fishes (Sims et al. 2019a). Lakes and ponds are important sites for amphibians, with species such as northern red-legged frog (*Rana aurora aurora*) and Cascade frog (*Rana cascadae*) using high elevation lakes and ponds for much of their lives. Other amphibians, including western chorus frogs (*Pseudacris triseriata*), toads, and salamanders, use lakes and ponds at lower elevations primarily during egg and tadpole stages (Piovia-Scott et al. 2016). Beaver ponds are important aquatic habitats for frogs, Chinook salmon, coho salmon, and other species (Lanman et al. 2013).

Lakes and ponds are sources of water for terrestrial organisms and support a variety of riparian ecosystems. Western pond turtles use lakes and ponds for foraging and overwintering sites (Reese and Welsh 1997; Rosenberg 2013). Riparian ecosystems

adjacent to ponds are used as pond turtle nesting sites (Reese and Welsh 1998). Willow-dominated riparian ecosystems, supported by beaver ponds, are habitats for a variety of birds, including willow flycatcher (Lanman et al. 2013).

Ecosystem Services

In addition to wildlife habitat, lakes and ponds provide water storage, flood control, nutrient cycling, recreation, and cultural benefits (Sims et al. 2019a). Much of the water originating in the forests is stored in reservoirs and natural ponds and lakes before being diverted for human use (USDA FS 1995b). Lakes and reservoirs are among the most popular recreation sites in the forests and include popular fishing sites for native and introduced resident species (USDA FS 1990, 1995a).

Ecosystem Dynamics

Aquatic ecosystems in lakes and ponds are primarily affected by water quality and water quantity. Water chemistry is influenced by precipitation, runoff, input of terrestrial organic matter, and atmospheric deposition (Piovia-Scott et al. 2016). Water temperature and sedimentation are mediated, in part, by shade and soil stability provided by riparian vegetation, along with hyporheic exchange (Sims et al. 2019a). Structure and composition of lacustrine riparian ecosystems are shaped by disturbances associated with wave action and water level fluctuations. The emergence of amphibians and aquatic insects from lakes and ponds also provides aquatically derived food and nutrients to adjacent riparian ecosystems (Piovia-Scott et al. 2016; Pope et al. 2009).

Rare and Unique Ecosystems of the Five Forests

Fens

Fens are wetlands that support unique plant communities, with species capable of growing in challenging soil conditions (Dwire and Mellmann-Brown 2017). Peatland fens occur where saturated conditions at or near the soil surface are primarily supported by groundwater. Over long periods of time, organic soils have accumulated at these sites because of the slow decay of peat-forming plants (Sikes et al. 2013). Wetlands with a peat layer of at least 15.7 inches and a water table within 7.9 inches of the surface are classified as peatland fens in assessment protocols for GDEs (Sikes et al. 2012; USDA FS 2012 a, b). Serpentine fens occur where there are soils derived from ultramafic rocks. These wetlands contain plants that grow either in peat soils in serpentine settings or where cold water flows over soils derived from ultramafic rocks (Frost et al. 2004; Sikes et al. 2013). Plant communities of peatland and serpentine fens are typically dominated by herbaceous vegetation, with some shrubs and conifer trees present as well. In the Cascades, Coast Range, and Klamath Mountains, peatland fens support a high diversity of herbaceous vascular plants and mosses (Sikes et al. 2013). Klamath Mountain serpentine fens contain many rare plant species, several of which are endemic to these sites (Frost et al. 2004; Sikes et al. 2013). Fens have been studied in several of the Five Forests but have not been mapped systematically. Geologic features

associated with fens have been mapped in each study and are described in the section “Distribution of Rare and Unique Habitats” in chapter 3.

Habitats

In the Five Forests planning area, fens dominated by herbaceous plants contain many species of forbs and graminoids. Herbaceous communities in these fens differ from those in other regions of the United States because they are often dominated by species in the Liliaceae family (Wolf and Cooper 2015). The Cyperaceae and Asteraceae families are also well represented. Mosses, including many species in the genera *Sphagnum* and *Drepanocladus*, are typically associated with peatland fens. Carnivorous plants, including California pitcher plant (*Darlingtonia californica*) and sundews (*Drosera* spp.), are frequent components of herbaceous communities in both peatland and serpentine fens (fig. 26).



Figure 26—The carnivorous pitcher plant *Darlingtonia californica*, is the dominant herbaceous species at this serpentine fen on the Six Rivers National Forest. Port Orford cedar, Jeffrey pine, and other trees grow in the drier areas. USDA Forest Service photo by Max Smith.

Shrub-dominated communities are present as well, with most species in the Ericaceae family. Port Orford cedar, western hemlock (*Tsuga heterophylla*), and other conifer trees may occur within fens, but grow to much larger sizes in drier areas (Frost et al. 2004). Woody communities tend to cover a small portion of fens and are located at the outer edges. The inner areas of fens are typically dominated by herbaceous vegetation and may contain pools of open water (Sikes et al. 2010).

The herbaceous and woody vegetation of fens provides food and cover for large mammals, including Roosevelt elk (*Cervus canadensis*), black bear (*Ursus americanus*), and black-tailed deer (*Odocoileus hemionus*) (Sims et al. 2019d). Streams and pools within fens are used by fishes, amphibians, and snakes (Sikes et al. 2012). A variety of birds rely on fens and surrounding wet meadows during the nesting season. Species include Wilson's snipe (*Gallinago delicata*), willow flycatcher, yellow warbler (*Setophaga petechia*), and Lincoln's sparrow (*Melospiza lincolnii*) (Loffland 2019).

Ecosystem Services

By storing large amounts of water and carbon, fens provide a number of ecosystem services. Water is stored and slowly released from organic soils and mineral subsurfaces of fens. These wetlands can therefore help to regulate the volume and quality of water entering perennial streams (Bedford and Godwin 2003). When fens are in good functioning condition, characterized by stable groundwater inflow, high levels of soil saturation, and abundance of peat-forming plants, substantial amounts of carbon are sequestered during the accumulation and slow decomposition of organic matter (Reed 2020; Schimelpfenig et al. 2014). Given the influence of fens on water and carbon cycling, protection and restoration of fens can be an important component of climate change mitigation.

Ecosystem Dynamics

Peatland fens occur in areas where the soil is saturated throughout the year or during most of the year (Chadde et al. 1998). These conditions occur in geological settings where a local aquifer, composed of permeable substrates such as glacial till or quaternary lava flows, sits atop an impermeable layer, creating a consistently high groundwater level (Aldous et al. 2015; Wolf and Cooper 2015). Low rates of decomposition in oxygen-deprived soils allow for the accumulation of peat layers (Sikes et al. 2013). Peatland fens are often embedded within meadow complexes that contain wet, mesic, and dry meadow communities (Weixelman et al. 2011).

The soils and groundwater in serpentine fens have chemical properties, such as high levels of magnesium and heavy metals, to which most plants are not adapted (Alexander 2011; Wolf and Cooper 2015). Many of the plant species that are adapted to grow in these conditions cannot compete with other plants in nonserpentine soils. Because of these characteristics, serpentine habitats, including fens, support many endemic plant taxa (Frost et al. 2004; Safford 2011). Wetlands classified as serpentine fens contain peat soils or serpentine mineral soils (Frost et al. 2004; Schuller et al. 2010; Sikes et al. 2010). Serpentine fens in mineral soil are often dominated by plants, such as *Darlingtonia californica*, that are also associated with peatland fens, which are also nutrient limited.

Springs

Springs are ecosystems entirely supported by groundwater (Dwire and Mellmann-Brown 2017). Springs are also ecotones where aquifers and terrestrial systems are

linked across aquatic, riparian, and wetland ecosystems where groundwater is discharged (Cantonati et al. 2020). Springs occur where groundwater discharges to the surface in pools, runout channels, peat mounds, or other avenues (Springer and Stevens 2008). Each of these “spheres of discharge” involves unique features that contribute to watershed function. Some springs conspicuously discharge water into pools or flowing channels. Other springs discharge directly into larger streams or diffusely within marshes, wet meadows, or fens (Stevens et al. 2021). Springs also occur where groundwater reaches the near-surface and is discharged through evapotranspiration by riparian and wetland vegetation. Springs have been mapped in each unit of the Five Forests by the Spring Stewardship Institute.

Habitats

Given the many forms in which springs occur, springs create a wide variety of ecosystems and habitats. The many spring-associated species in the planning area include California pitcher plant, Port Arena mountain beaver (*Aplodontia rufa*), springsnails (*Pyrgulopsis* spp.), and a variety of fishes adapted to specific thermal regimes, such as those associated with geothermal features (Hershler et al. 2014; Jeffres et al. 2009). Plant and animal communities at springs often have greater species richness and structural diversity than adjacent upland areas (Fleishman et al. 2005). Surface pools provide lentic habitat for plants, aquatic animals, and other biota. Runout channels are unique lotic habitats with relatively uniform water temperatures and low oxygen concentrations (Springer and Stevens 2008).

Ecosystem Services

Perennial springs are notable for the consistent volume, temperature, and chemical composition of water discharged to the surface (Minckley and Unmack 2000). In many areas, springs maintain perennial flows and cool water temperatures in streams (Jeffres et al. 2009). Spring-fed wetlands store substantial amounts of carbon. In the western United States, springs can play dual roles as current biodiversity hotspots and future climate refugia (Cartwright and Johnson 2018). Protection and restoration of these ecosystems can therefore contribute to climate change adaptation and mitigation (Reed 2020; Schimelpfenig et al. 2014). Springs can also be reliable sources of water for wildlife, livestock, and human use (Kreamer et al. 2014; Young 1994).

Ecosystem Dynamics

Snowmelt is the primary mechanism of groundwater recharge in high-elevation montane areas (Meixner et al. 2016). In some areas, however, mountain aquifers are also recharged during heavy rainfall events, a mechanism that may increase in importance as climate change increases the proportion of winter precipitation that falls as rain (Kløve et al. 2014). Springs are distributed widely but unevenly throughout northern California (Sims et al. 2019b). In the Klamath Mountains, deep fractures support perennial springs with unique flora (Halofsky et al. 2022). Perennial streams in the Cascades are fed by large springs emerging from volcanic bedrock (Jefferson et al. 2006).

Vernal Pools

Vernal pools form where impermeable soil or bedrock layers prevent the drainage of water that accumulates in depressions. Such depressions are flooded by precipitation during the winter and spring and are desiccated by evaporation by late summer or early fall (Keeley and Zedler 1998; Montrone et al. 2019). These wetlands support unique communities of plants and animals that are adapted to cycles of inundation and drought. Large vernal pools, also known as intermittent lakes, have been studied in the Shasta-Trinity National Forest (figs. 27, 28) but have not been systematically mapped (EcoAnalysts 2008). Geologic features associated with vernal pools have been mapped for each of the forests in volumes 2 through 5.

Habitats

The plants and animals known to be vernal pool specialists have life-history strategies that are customized to drying and wetting and the projectability of pool reappearance (Keeler-Wolf et al. 1998; Keeley and Zedler 1998). Specialist plant species are capable of germinating and growing underwater and completing their life cycle after ponds have dried (Padgett 2020). Vernal pool plant communities contain annual specialists, perennial specialists, wetland generalists tolerant of some level of desiccation, and upland generalists tolerant of some level of inundation (Bovee et al. 2018).

Where present in the Five Forests, vernal pools may provide habitat for threatened, endangered, and sensitive animals, including western pond turtle, vernal pool tadpole shrimp (*Lepidurus packardii*), and vernal pool fairy shrimp (*Branchinecta lynchi*) (Bury et al. 2008; EcoAnalysts 2008). In some areas, amphibians, including California tiger salamander (*Ambystoma californiense*) and western spadefoot (*Scaphiopus hammondi*), are dependent on vernal pools for breeding sites (Laabs et al. 2002). Vernal pools are also important habitats for birds and other migratory species that visit seasonally (Rogers 2014).

Ecosystem Services

The productive aquatic plant and invertebrate communities of vernal pools are important food sources for waterfowl, shorebirds, and other migratory animals (Silveira 1998). Vernal pools also provide forage and water to wild herbivores and livestock. Amphibians use vernal pools during various stages of their life cycles as well (Keeler-Wolf et al. 1998). Rare amphibians breed in vernal pools and their distribution is determined by the presence of these wetlands (Laabs et al. 2002). In the spring, a variety of showy plants bloom at the edges of vernal pools, providing aesthetic benefits to people and food for insect pollinators (Thorpe and Leong 1998).

Ecosystem Dynamics

Direct precipitation is the primary source of water in vernal pools, but surface runoff and groundwater can contribute as well (Keeler-Wolf et al. 1998). Birds and other migrant animals disperse propagules of plants and invertebrates from one vernal pool to another across the landscape (Rogers 2014). Livestock and wild ungulate



Figure 27—White Deer Lake, one of the largest vernal pools in the Shasta-Trinity National Forest—Cascades unit. The lake was inundated when this photo was taken in July 2017. USDA Forest Service photo by Steve Bachmann.

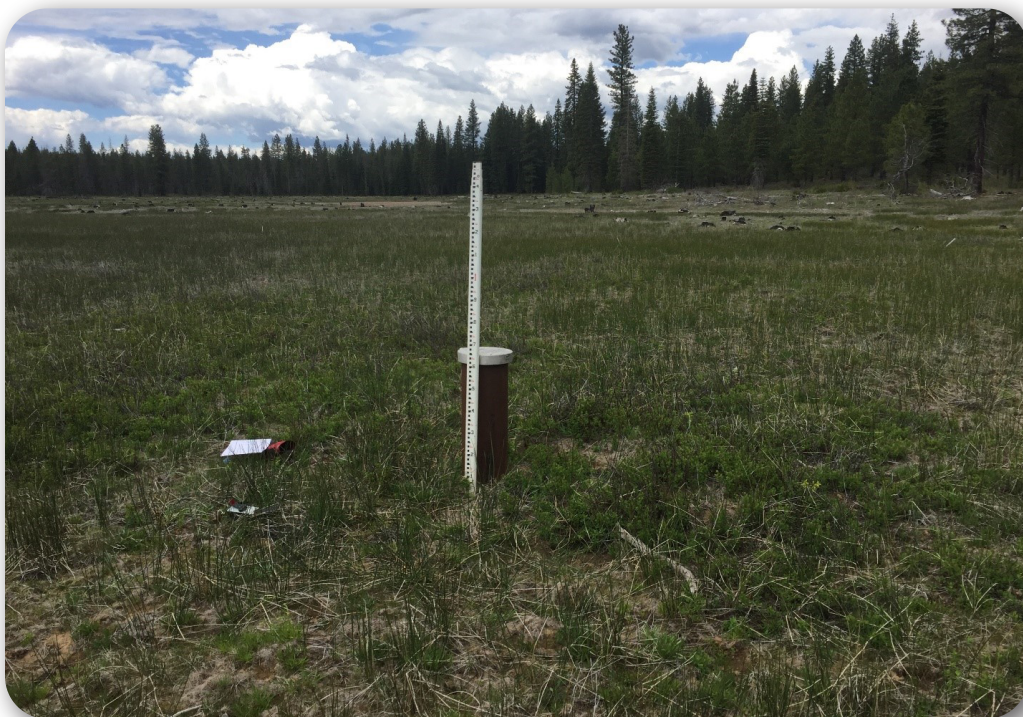


Figure 28—White Deer Lake when dry, May 2018. USDA Forest Service photo by Steve Bachmann.

grazing helps to maintain species-rich plant communities by preventing dominance of generalist plants (Bovee et al. 2018; Marty 2005).

CHAPTER 3: KEY ECOSYSTEM CHARACTERISTICS

Introduction

The 2012 Planning Rule directs national forests to consider key ecosystem characteristics (KECs) of riparian and aquatic ecosystems. In this assessment we evaluated six KECs: (1) distribution, (2) hydrologic regimes, (3) water quality, (4) connectivity, (5) instream habitat quality, and (6) condition of riparian and rare and unique habitats. We reviewed scientific literature and reports to identify drivers, stressors, and indicators of the current condition for each KEC. In this chapter we have summarized these findings and provided information on possible desired or reference conditions.

Distribution of Riparian and Aquatic Ecosystems

Drivers

The distribution of stream ecosystems is influenced by the climate and geological settings of the Five Forests' watersheds. Within the planning area, stream densities are greatest in the Klamath Mountains, which are composed of older, crystalline rocks. Groundwater storage is greater in the Cascades because of its younger, more porous volcanic bedrock (Luce et al. 2022). Permanently flowing streams contain reaches where surface flows persist throughout the year and remain connected with groundwater (Reeves et al. 2018). Seasonally flowing streams are more abundant and occur where surface flows occur in response to snowmelt and rainfall (Boughton et al. 2009). Seasonally flowing streams can include (1) intermittent segments, which, in their natural condition, have flows only during certain times of the year but contain interspersed, permanent surface water areas with aquatic flora and fauna adapted to periodically harsh conditions; or (2) ephemeral segments, where surface flows occur only in direct response to precipitation within the watershed, and stream channels are otherwise above the zone of groundwater saturation (Reeves et al. 2018).

Lakes and ponds historically occurred in natural depressions or in stream channels dammed by beavers, landslides, or log jams (Lanman et al. 2013; Sims et al. 2019a). Following Euro-American settlement, ponds and reservoirs were constructed throughout the Five Forests planning area for irrigation, water supply, fish and wildlife use, flood control, and hydroelectric power generation (Gross et al. 2020).

Stressors

Stressors affecting the distribution of stream ecosystems in the Five Forests include drought, dams, diversions, and floodplain conversion. Increases in drought severity lead to reductions in perennial stream length and increases in intermittent and ephemeral stream length (Boughton et al. 2009). Though drought is a naturally occurring stressor, its impacts, combined with current rates of surface temperature warming and increasing water demand, threaten the persistence of riparian and aquatic ecosystems (Dettinger et al. 2015). In some areas, dams and diversions have reduced the extent of perennial streams and increased the extent of intermittent streams. In other areas, dams and diversions have made formerly intermittent streams

perennial (Moyle 2014). Dams have also reduced the extent of habitat occupied by native fishes (Isaak et al. 2022). Development of roads, urban areas, and other infrastructure in floodplains reduces the extent of riparian ecosystems (Carothers and House 2020). Reduction in the area of riparian ecosystems has also resulted from the disconnection of streams from floodplains for agricultural conversion (Loose et al. 2019).

Stressors affecting the distribution of natural lakes and ponds include climate change, floodplain conversion, and removal of beaver. Decreases in precipitation, snowpack, and snowmelt can lead to the complete drying of ponds and small lakes during droughts (Sims et al. 2019a). Long-term shifts to a hotter and drier climate would therefore reduce the extent of these waterbodies in the study area. Following the disconnection of streams from floodplains by development such as roads, the extent of ponds formed by oxbows and side channels is reduced in alluvial valley bottoms. Beaver and beaver dam removals have reduced the extent of these ponds as well (Singleton et al. 2022).

Desired and Reference Conditions

The desired distribution of riparian and aquatic features will vary among watersheds, given differences in climate, topography, and geology. For this reason, a simple set of reference conditions does not exist for the Five Forests planning area. A properly functioning watershed contains physical attributes that maintain or improve biological integrity, with minimal undesirable human impacts (Potyondy and Geier 2011). Therefore, the distribution of riparian and aquatic features is intact if the extent of streams and other waterbodies is minimally affected by anthropogenic activities.

Data Sources and Evaluation

To describe the distribution of stream ecosystems, we created shapefiles for RRs using data generated for the Forest Service's bioregional assessment of northwest forests. These data include stream segments designated as fish-bearing rather than nonfish-bearing and permanently flowing rather than seasonally flowing. Riparian reserves were created and analyzed for all lands within the administrative boundary of each study unit. We evaluated levels of stressors that may influence the distribution of riparian and aquatic ecosystems associated with streams (table A.3 in Appendix A). We considered three indicators that suggest likely impacts from stressors to distribution: (1) the Terrestrial Condition Assessment (TCA) drought condition; (2) dams, diversions, and the Watershed Condition Framework (WCF) flow characteristics attribute; and (3) LANDFIRE data showing land-use change. See Appendix B for more details on data sources and Appendix D for definitions of WCF indicators and attributes. We defined an altered distribution of riparian and aquatic ecosystems as those with relatively high levels of multiple stressors within a unit.

Distribution of Rare and Unique Habitats

Drivers

Peatland fens develop in locations where there are low rates of mineral sediment deposition, and groundwater discharge rates are adequate to maintain perennial soil saturation. Over long periods of time, organic soils accumulate with the slow decay of peat-forming plants (Sikes et al. 2013). Mountain fens develop in a variety of settings, including hillslopes, cirques, and basins with unconsolidated glacial deposits (Aldous et al. 2015). Fens also occur near springs in wet meadows that have formed on alluvial deposits (Sikes et al. 2012; Weixelman et al. 2011). In volcanic landscapes, fens often occur at the contacts of bedrock layers where younger, permeable lava flows lie atop older, impermeable flows (Wolf and Cooper 2015). Serpentine fens develop where peatland fens form in areas of ultramafic rock and in areas where cold water from springs or streams flows over mineral soils derived from ultramafic rocks (Frost et al. 2004; Sikes et al. 2010).

Springs occur in a variety of geologic settings, but are often clustered at faults, escarpments, or valley walls, where groundwater is forced to the surface or aquifers are exposed (Cartwright and Johnson 2018; Junghans et al. 2016; Whiting and Stamm 1995). Large springs and spring-fed streams are abundant in landscapes with highly permeable bedrock. These aquifers include volcanic rocks that are highly fractured or porous, as well as carbonate karst, which is limestone or other carbonate bedrock containing caves, sinkholes, and passageways formed by chemical dissolution (Jefferson et al. 2006; Mills and Huntoon 1989). In the Oregon Cascades, springs are most abundant in low-permeability bedrock where groundwater flow paths are short, and water is quickly routed to the surface (Freed et al. 2019; Whiting and Moog 2001).

Vernal pools tend to form in relatively flat areas where depressions are underlain by impermeable substrates, which limit the drainage of water (Keeler-Wolf et al. 1998). A variety of geologic, fluvial, and biotic processes create depressions that may become vernal pools (Norwick 1991). In southern Oregon and northern California, vernal pool complexes have formed in alluvial terraces and on volcanic plateaus composed of andesitic and basaltic rocks (Borgias 2004; Gosejohan et al. 2017; Keeley and Zedler 1998; Metlen et al. 2016).

Stressors

Peatland fens are vulnerable to changes in groundwater discharge. Activities such as reservoir inundation, groundwater withdrawal, ditching, and drainage could result in the loss of peat soil and associated plant communities (Austin and Cooper 2016; Chimner 2011; Chimner et al. 2010). Alteration of surface flows by dams, diversions, or roads could eliminate serpentine fen communities associated with streams (Frost et al. 2004).

The primary threat to the distribution of springs is excessive groundwater pumping for irrigation, drinking water, and other uses. Unregulated pumping and other activities

that disrupt groundwater flow networks may result in the loss of entire plant and animal communities (Cantonati et al. 2020; Kreamer et al. 2015; Minckley and Unmack 2000). In the western United States, spring ecosystems have also been lost where discharge sites were modified for recreational use and livestock watering (Minckley and Unmack 2000). Springs are also sensitive to changes in precipitation, drought severity, and drought frequency (Sims et al. 2019b). As a result of decreases in precipitation and groundwater recharge associated with climate change, water may cease to flow from springs with low or intermittent discharge (Earman and Dettinger 2011).

In much of California and southern Oregon, vernal pools have been lost to agricultural conversion and urbanization (Keeler-Wolf et al. 1998). In national forests, vernal pool communities are also affected by the excavation and damming of pools to create stock ponds (Holland 2006). Natural stressors include gradual fill of pools with sediment or peat and eventual drainage following erosion of earthen dams (Norwick 1991). Lowland areas where vernal pools were once abundant have been heavily altered by agriculture and residential development; the consequences of such activity underscore the importance of mapping, monitoring, and protecting vernal pools on Federal lands (Parker 2002).

Desired and Reference Conditions

The desired distribution of rare and unique habitats will vary among watersheds, given differences in climate, topography, and geology. For this reason, a simple set of reference conditions does not exist for the Five Forests planning area. A properly functioning watershed contains physical attributes that maintain or improve biological integrity, with minimal undesirable human impacts (Potyondy and Geier 2011). Therefore, the distribution of rare and unique habitats is intact if the density and extent of these features are minimally affected by anthropogenic activities.

Data Sources and Evaluation

We used several spatial data sources to map the known distribution of rare and unique habitats or geologic features associated with these habitats. Fens have been assessed in several forests, but the locations of fens have not been systematically mapped across the planning area. We identified areas where fens may potentially exist by mapping glacial deposits, alluvial deposits, and ultramafic bedrock using the U.S. Geological Survey (USGS) State geologic map compilation (Horton et al. 2017). We mapped springs using locations that were compiled by the Spring Stewardship Institute. Most of these spring locations were obtained from the National Hydrography Dataset (USGS 2019). These data do not represent a complete inventory of springs but can be used as an indicator of relative density among geographic areas (Brown et al. 2011; Howard and Merrifield 2010). We also mapped geological drivers of spring distribution using the USGS State geological map compilation. Vernal pools have been assessed in the Shasta-Trinity National Forest but have not been mapped across the planning area. We identified areas where vernal pools may potentially exist by mapping alluvial deposits and volcanic plateaus. We used additional datasets to compare stressor levels among study units

(table A.3). Data were insufficient to determine whether the distribution of fens, springs, or vernal pools was altered or intact in the Five Forests.

Hydrologic Regimes

Drivers

Hydrologic regimes are influenced by climate, vegetation, beaver activity, topography, soils, and geology (Carlisle et al. 2009; Hornberger 2014). Precipitation patterns, specifically the seasonality, amount, and type (snow or rain), can influence timing of runoff and infiltration, magnitude and duration of high and low flows, and rate of change in water levels (Hornberger 2014; Poff et al. 1997). Temperature can influence rates of evapotranspiration that alter water table levels and the timing of runoff, particularly in snowmelt-dominated systems (Hornberger 2014). Vegetation can impact hydrologic processes by influencing runoff (i.e., via the physical impact of plant matter on the movement of water in the channel and across the floodplain) and through the influence of plant physiology on water uptake, storage, and evapotranspiration (Tabacchi et al. 2000). Beaver activity impacts hydrology by the construction of dams that slow runoff, store water, raise the level of local surface water and groundwater, increase recharge, and moderate both high and low flows by collecting runoff during peak flow and releasing it slowly during dry periods (Andersen and Shafroth 2010; Gibson and Olden 2014; Westbrook et al. 2006). Impacts from beavers are compounded in locations with a series of dams along a stream's longitudinal gradient (Gibson and Olden 2014; Westbrook et al. 2006). Topography can influence the rate of change in water levels and duration of flows (Carlisle et al. 2009). Aspect and gradient influence water retention on the landscape, and elevation drives whether precipitation falls as snow. Soil texture (e.g., sand vs. clay), structure (e.g., distribution of macropores and micropores), and pore size influence the movement of water and can allow for slower or more rapid movement of water through a watershed (Fitts 2013). Finally, hydrologic regimes are driven by geology, specifically infiltration and storage capacity of geologic formations and whether geologic linkages exist between basins (Fitts 2013; Hornberger 2014).

Stressors

Hydrologic regimes are stressed by forces or activities that impact connectivity between groundwater and surface water systems or alter the timing, frequency, duration, magnitude, or rate of change in high and low flows. These stressors can be natural or anthropogenic and include wildfire, vegetation mortality, drought, roads, diversions, dams, mining, timber harvest, fire suppression, grazing, beaver extirpation, and climate change.

Wildfire, vegetation mortality due to insects and disease, and drought are examples of natural hydrologic regime disturbances. Depending on severity, wildfires can have significant hydrologic impacts such as flash flooding or debris flows (Doerr et al. 2006; Ice et al. 2004). Widespread vegetation mortality can alter the timing of

water fluctuations and is linked to increased infiltration to groundwater systems during summer months (Bearup et al. 2014). Long-term trends in levels of surface and groundwater systems within the study area are associated with climate conditions, with less precipitation, lower water tables, and reduced streamflow occurring during drought (Abatzoglou et al. 2014; Bumbaco and Mote 2010). Though wildfire, vegetation mortality, and drought are natural stressors, their effects can be amplified by anthropogenic activities. Fire suppression has led to the accumulation of large fuel loads compared to historical conditions, driving an increase in the size and frequency of high severity fire (Donovan and Brown 2007; Schoennagel et al. 2004; Wimberly and Liu 2014). Last, changes in climate that include warmer temperatures and reduced or more variable precipitation could prolong drought or alter fire regimes in ways that impact hydrology throughout the Five Forests.

Dams, diversions, roads, timber harvest, beaver extirpation, and livestock grazing are anthropogenic stressors to hydrology. Timing, magnitude, and frequency of flows can be profoundly impacted by dams and diversions, which generally reduce peak and base flows and release water at different times for different durations than would occur under a natural flow regime (Graf 1999; Magilligan and Nislow 2005; Winter et al. 1998). Roads and trails add impervious surfaces to the landscape and alter hillslope contours in ways that can reduce infiltration and increase runoff (Forman and Alexander 1998a). Additionally, these types of transportation infrastructure can serve as unnatural sources of fine sediment that can obstruct natural flow paths between ground and surface water systems (Forman and Alexander 1998a). The impacts of timber harvest largely depend on management, but some approaches, such as clear cutting, are associated with increased surface runoff and sedimentation, which can disrupt natural hydrologic networks (Bosch and Hewlett 1982). Fur-trapping records and ethnographic evidence suggest beavers were historically widespread throughout the study area (Lanman et al. 2013; Lundquist et al. 2013). It appears beaver populations throughout southern Oregon and northern California significantly declined in the early 1800s, with the leader of the Hudson's Bay Company ordering a creation of a "fur desert" south of the Columbia River in the 1820s followed by the Hudson's Bay Company ceasing the dispatch of hunting parties to California by 1843 (Lundquist et al. 2013). This rapid loss of beaver activity on the landscape likely impacted natural hydrologic regimes and recharge to groundwater systems. Finally, grazing by livestock can reduce upland and riparian plant cover, increase runoff, and downcut streams, which can ultimately lead to lower water tables and drying of perennial water sources (Krueper 1993, 1996; Larsen et al. 1998).

Natural flow regimes can be highly impacted by changes in climate. Warmer temperatures and altered precipitation regimes often contribute to reduced snowpack, earlier snowmelt, and more precipitation in the form of rain. These changes can substantially alter the timing and magnitude of flows (Cayan 1996; Hamlet et al. 2005). Additionally, higher temperatures result in increased rates of evapotranspiration

and altered distributions of plants that draw from groundwater (Chen et al. 2011; Rind et al. 1990). Natural groundwater and surface water fluctuations are strained by changes in temperature and precipitation, with all other stressors acting cumulatively (Intermountain Adaptation Partners 2016).

Desired and Reference Conditions

The WCF defines natural hydrographs as those that represent the natural seasonal flows of a river without the moderating influence of management actions or human-created features such as dams and canals (Potyondy and Geier 2011). Among the desired conditions for hydrologic regimes throughout the study area are functional watersheds that contribute to long-term ecological integrity, including structure, function, and composition of aquatic, riparian, and groundwater-dependent ecosystems (Potyondy and Geier 2011). The dynamic movement of water and sediment that exists in equilibrium in free-flowing rivers is desirable with limited or no disruptions (Dunne and Leopold 1978; Potyondy and Geier 2011). Hydrologic regimes contribute to functional physical habitats with unaltered water temperatures, oxygen content, water chemistry, or substrate (Potyondy and Geier 2011). Finally, desired conditions for hydrologic regimes include support for species that are either socially valuable or sustain the health of associated ecosystems (Potyondy and Geier 2011).

Data describing hydrologic reference conditions are scarce throughout the Five Forests planning area; however, Gross et al. (2020) were able to infer natural range of variation (NRV) for some hydrologic characteristics based on relationships between streamflow and climate and known historical temperature and precipitation patterns. For example, extended periods of drought are associated with reduced flow in streams and rivers (Gross et al. 2020; Moreland 1993). Droughts occurred frequently within the Five Forests and those that occurred within the last 1,000 years are not significant compared to droughts of the previous 12,000 years (Brunelle and Anderson 2003; Gross et al. 2020). Gross et al. (2020) conclude that because contemporary droughts are within NRV, then it is likely that magnitude of low flows are also within NRV if not impacted by other stressors. Similarly, Gross et al. (2020) did not identify any data specifically identifying reference conditions for timing of peak or base flows within the planning area; however, the report was able to infer that peak flows in rain-dominated basins, which cover much of the study area, likely occurred during winter months (Asarian and Walker 2016; Gross et al. 2020). Peak streamflow in snow-dominated and groundwater-dominated watersheds likely occurred during late spring and summer (Gross et al. 2020). Gross et al. (2020) also did not locate data describing the occurrence of debris flows and large floods but were able to generalize likely reference conditions based on topography. Watersheds with high-gradient, low-concavity streams, specifically those in the Klamath Mountains, likely experienced frequent debris flows followed by large floods (Gross et al. 2020; May 2007). Finally, Gross et al. (2020) determined that there was no historical analogue for anthropogenic dams and that these features were historically absent from the landscape. Therefore, the presence of dams is inconsistent

with reference conditions and contributes to conditions outside of NRV (Gross et al. 2020).

The Aquatic and Riparian Effectiveness Monitoring Program (AREMP) evaluated changes in flow regimes associated with human disturbances to watershed condition, specifically identifying thresholds for peak flows. Recognizing the impact of upslope conditions on the quantity and timing of water entering stream systems, AREMP analysts used road density and vegetation condition to evaluate peak flows throughout the study area (Miller et al. 2017). They used values published in the literature along with their own analysis to determine that increases in peak flow of less than 5 percent were unlikely to substantially impact riparian and aquatic biota (Miller et al. 2017). Increases in peak flow of greater than 36 percent were indicative of very likely impaired hydrologic regimes (Miller et al. 2017). The AREMP analysis and these threshold values can be used to inform desired conditions for flow regimes within the study area.

Data Sources and Evaluation

We used several datasets to evaluate hydrologic conditions within the study area (Appendix B). To determine the potential impacts of stressors, we used shapefiles with the locations of dams, diversions, roads, timber harvest projects, changes in temperature and precipitation, long-term deviations in moisture, and livestock grazing allotments. We combined these datasets with information from the WCF and TCA, which address whether these stressors have impacted the structure and function of watersheds and ecosystems, respectively.

We summarized major components of hydrologic regimes for historical (1977–2006) and future (2030–2059) climate scenarios using the Western U.S. Stream Flow Metrics dataset (USDA FS 2019b; Wenger et al. 2010). For every reach within the National Hydrography Dataset, the flow metrics model estimates hydrologic parameters, such as center of flow mass, mean summer flow, mean August flow, mean annual flow, 1.5-year return interval flood (bankfull) flows, and maximum modeled flood flows. The center of flow mass identifies the day of the water year (October 1–September 30) by which half of the year’s flow occurs. We used these data to evaluate timing. Streams with center of flow mass less than 150 (February 27) were classified as “early.” These streams tend to have rainfall-dominated hydrology and high flows during winter (Wenger et al. 2010). Streams with center of flow mass greater than 200 (April 18) were classified as “late” and these systems typically are characterized by snowmelt hydrology and limited high flows during winter (Wenger et al. 2010). “Intermediate” streams have center of flow mass between 150 and 200, which is analogous to transient hydrographs (Wenger et al. 2010). We evaluated magnitude of high and low flows using the mean summer flow, mean August flow, 1.5-year flood return interval (bankfull) flow, and maximum modeled discharge. Finally, we characterized potential shifts in flow duration by using annual mean daily flow, calculated as the average daily flow for the water year.

We evaluated the likelihood that hydrologic regimes in the four different types of streams (permanently flowing fish-bearing streams, permanently flowing nonfish-bearing streams, seasonally flowing fish-bearing streams, seasonally flowing nonfish-bearing streams) were altered. For this analysis we determined whether the WCF or TCA (or both) indicated widespread impacts from stressors. The WCF was originally completed in 2011 for all watersheds that intersect NFS lands. It has periodically been updated, including an update of some attributes in 2021. The TCA evaluates effects of uncharacteristic stressors and disturbance on the ecological integrity of land-type associations on NFS lands. We considered seven indicators from the WCF and TCA that suggest likely impacts from many stressors to hydrology: (1) the WCF flow characteristics attribute, (2) the WCF Roads and Trails Condition Indicator, (3) the WCF rangeland vegetation condition attribute, (4) the WCF forest cover loss attribute, (5) the WCF Fire Regime Condition Class, (6) the TCA drought condition, and (7) the TCA climate exposure condition. We determined the hydrologic regimes of streams to be altered if:

- More than two indicators suggested impacts (WCF rating of impaired or TCA rating of poor or very poor) from stressors in more than one-third of watersheds containing the specific stream habitat,
- Or if drought/climate exposure had impacted ecological integrity in more than half of the unit and was exacerbated by additional stressors,
- Or if one stressor impacted (WCF rating of impaired or TCA rating of poor or very poor) more than half of watersheds containing the specific stream habitat.

To estimate the current hydrologic conditions in lake, pond, and reservoir habitat we considered five indicators: (1) whether changes in the runoff timing of streams that feed lakes and ponds is expected to occur within the unit, (2) whether the TCA indicates more than half of the unit has been impacted by drought and whether these impacts are likely to be exacerbated by additional stressors, (3) the percentage of watersheds containing lake and pond habitat that were classified by the WCF as impaired for flow characteristics, (4) the percentage of watersheds containing lake and pond habitat that were classified by the WCF as impaired for loss of forest cover, and (5) the percentage of watersheds classified by the WCF as impaired for Fire Regime Condition Class. We selected these indicators using Sims et al. (2019a), which identified changes in the timing of snowmelt and runoff, dams, altered fire regimes, and timber harvest as the primary stressors to lake and pond hydrology. We determined the hydrologic regimes of lakes and ponds to be altered if:

- More than two stressors were impacting (WCF rating of impaired or TCA rating of poor or very poor) more than one-third of watersheds containing lake and pond habitat,
- Or if drought had impacted ecological integrity in more than half of the unit and was exacerbated by additional stressors,

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- Or if one stressor impacted (WCF rating of impaired or TCA rating of poor or very poor) more than half of watersheds containing lake and pond habitat.

Last, we determined whether lake and pond hydrologic regimes are vulnerable based on projected changes in stream runoff timing within the unit.

There were limited data available within the study area related to the hydrologic regimes of fens, springs, seeps, and vernal pools. We summarized stressors to these habitats but were unable to determine the likelihood of altered hydrology.

Water Quality

Drivers

Biogeochemistry of aquatic systems is driven by climate, geology, precipitation chemistry, residence time of water within certain soil and rock types, mixing of cold and thermal water sources, and dissolution of organic and mineral substances from vegetation, soil, and rocks (Hem 1985). These factors contribute to concentrations of dissolved substances and water temperature. Climate, specifically humidity and precipitation, influences the amount of water present within a system and therefore drives concentrations of solutes and pollutants (Hem 1985). Additionally, the temperature, amount, distribution, and chemical composition of precipitation contribute to geologic weathering patterns that drive sediment loads and dissolved solid concentrations (Hem 1985). These precipitation characteristics are controlled by reactions that occur in the atmosphere and can vary widely across space and time (Hem 1985).

Water quality is also influenced by ecological and biochemical processes controlled by biota, including soil reactions and formation (Hem 1985). As precipitation infiltrates through soil, eventually becoming runoff or groundwater, the chemical composition is affected by biochemical processes that produce carbon dioxide, nitrogen fixation, concentration of solutes by evapotranspiration, dissolution of minerals, and selective removal of nutrients by plants and other organisms (Hem 1985). In addition to processes that occur within soil, water quality is impacted by aquatic biota that fix carbon, respire, and decompose organic matter (Hem 1985). The functions driven by aquatic biota contribute to diurnal fluctuations in stream metabolism, dissolved oxygen content, and pH (Hem 1985). Water quality can also be influenced by structural characteristics of riparian vegetation, which can lower temperatures by providing shade and reduce erosion by stabilizing banks and trapping sediment (Beschta 1997; Potyondy and Geier 2011; Simon and Collison 2002).

Watershed geology, including rock composition and geothermal activity, also influences water quality. The Klamath Mountains within the study area have a complex geologic history and are primarily composed of metasedimentary rock (Bennett et al. 2014). Granitic, metamorphic, ultramafic or mafic, and undifferentiated rocks, as well as alluvial sediments, are also present within the Klamath Mountains (Bennett et al. 2014).

These geologic formations tend to have relatively low permeability; however, the presence of several trace elements in groundwater systems suggests that dissolution of minerals and weathering of these formations naturally drive chemical composition of aquatic systems in the Klamath Mountains (Bennett et al. 2014). Most of the remaining study area is characterized by the Cascades, which are entirely composed of volcanic and sedimentary deposits (Fram and Shelton 2015). Organic matter contained in sedimentary rocks throughout the Cascades influences dissolved oxygen content and pH (Fram and Shelton 2015). Dissolution of mineral surfaces and weathering of geology within the Cascades have contributed to concentrations of nutrients and trace elements detected in groundwater and surface water systems throughout the Cascades units of the study area (Fram and Shelton 2015).

Stressors

Stressors to water quality include forces or activities that alter water temperature, suspended sediments, and the concentrations of nutrients, minerals, or pollutants (Bilotta and Brazier 2008; Dauer et al. 2000; Johnston 1991). Solute concentrations can be influenced by increasing input or changing the amount of water in the system. Large nutrient loads and warmer water temperatures can lead to algal blooms that contribute to eutrophication (Anderson et al. 2002; Smith et al. 1999). Increases in sediment inputs can reduce channel, lake, or pond depth (Einstein 1950), and deposition of fine sediments can obstruct interstitial spaces that connect surface water and groundwater systems (Richards and Bacon 1994; Wood and Armitage 1997). These shallower aquatic habitats and systems with diminished groundwater exchange tend to have higher water temperatures (Poole and Berman 2001). Water temperatures can also be altered by the loss of riparian vegetation that shades aquatic systems (Poole and Berman 2001). In addition to altering water temperature, large sediment inputs can transport pollutants, and fine sediments suspended in the water column limit light penetration, reduce primary production, and alter trophic relations (Wood and Armitage 1997).

Water quality can be impacted by natural and anthropogenic stressors. Wildfires are a natural water quality stressor that can temporarily increase nutrient and sediment inputs and can remove shade-providing riparian vegetation (Shakesby and Doerr 2006; Spencer et al. 2003). Interaction between high-severity wildfire and other stressors, particularly drought, can contribute to declines in water quality (Sims et al. 2019a). Droughts are linked to warmer water temperatures, higher salinity, increased algal levels, reduced turbidity, increased organic carbon, and increased fecal coliform levels in streams and rivers (Mosley 2015). Lakes and reservoirs tend to increase in salinity, algal levels, and organic carbon and decrease in dissolved oxygen and fecal coliform levels during drought (Mosley 2015).

Anthropogenic stressors to water quality are generated by burning fossil fuels, agriculture, diversions, roads, recreation, mining, and loss of riparian habitat. Both fossil fuel combustion and agriculture have increased nitrogen deposited across landscapes from the atmosphere (Carpenter et al. 1998). Likewise, runoff from fertilized

fields or grazed areas can increase nutrient inputs to aquatic systems (Carpenter et al. 1998). Diversions and pumping remove water and can increase dissolved mineral and solute concentrations. Similarly, dams and reservoirs can influence concentrations of solutes by storing and releasing water. Roads are unnatural sources of sediment and are associated with increases in heavy metals, salinity, turbidity, and dissolved oxygen (Forman and Alexander 1998a). Livestock grazing can degrade water quality by increasing sedimentation and water temperature through bank trampling and browsing shade-providing riparian vegetation (Armour et al. 1994; Fleischner 1994). Recreation areas, including trails and campsites, can also increase sediment inputs and affect water quality through refuse disposal (Crabill et al. 1999; Varness et al. 1978). Impacts from legacy mining can impact water quality by increasing loads of heavy metals (Bjerklie and LaPerriere 1985; Thomas et al. 2002). Although impacts from mining tend to be localized, some mines within the study area continue to have acid mine drainage issues that impact the ability of these systems to support aquatic biota (Steve Bachmann, USDA Forest Service, personal communication, March 18, 2021). These stressors can be mitigated by functional wetland and riparian zones, which are effective at trapping sediments and nutrients (Gilliam 1994); however, a global loss of riparian cover is linked to degraded water quality (Verhoeven et al. 2006).

The impacts on water quality of these natural and anthropogenic stressors can be exacerbated by climate change (Loose et al. 2019). The water quality of aquatic ecosystems in the study area is sensitive to warmer air and water temperatures, changes in precipitation amount and timing, reduced snowpack, altered hydrologic regimes, and increased frequency and duration of droughts and heat waves (Loose et al. 2019; Sims et al. 2019d). Warmer air temperatures can be linked to warmer water temperatures, which can influence the levels of algae and dissolved oxygen and rates of nutrient cycling, productivity, and chemical reactions (Loose et al. 2019; Poole and Berman 2001). Shifts in precipitation and flow regimes impact the transport and concentration of pollutants (Halofsky et al. 2020). Finally, the loss of snow, or shifts in precipitation that increase rain-on-snow events, is likely to lead to earlier drying of streams and altered sediment yields and water quality (Halofsky et al. 2020).

Desired and Reference Conditions

The WCF suggests water quality of aquatic systems should support beneficial uses, including drinking water supply, primary contact recreation, and aquatic life support (Potyondy and Geier 2011). Desired conditions for water quality throughout the study area include functional watersheds that have neither significant water quality problems such as excessive sediment, nutrients, or chemicals nor State-listed impaired or threatened waterbodies (Potyondy and Geier 2011; USDA FS 2019a); aquatic systems that are free of extensive contamination from active or abandoned mines or frequent incidents of public drinking water source contamination (Potyondy and Geier 2011); water temperatures that maintain food consumption, metabolic rates, cardiorespiratory performance, migratory behavior, resistance to disease and parasites, and competitive

relationships of aquatic species (Loose et al. 2019; Lynch et al. 2016; Whitney et al. 2016); and little or no evidence of acidification, toxicity, or eutrophication due to atmospheric deposition (Potyondy and Geier 2011). Finally, desired conditions for water quality include the maintenance of biological, physical, and chemical integrity of riparian, aquatic, and wetland ecosystems such that riparian and aquatic species can survive, grow, reproduce, and migrate within the study area (USDA FS 2019a).

Reference conditions for water quality can be inferred from the historical distribution and abundance of fish species, such as salmon (Gross et al. 2020). These species are sensitive to increases in water temperature and associated changes in biological, physical, and chemical properties (Gross et al. 2020; Loose et al. 2019). There are Native American accounts of abundant Chinook and coho salmon runs in the Shasta River watershed (Gross et al. 2020), suggesting spring and summer stream temperatures in this area historically ranged from approximately 46.4 to 60.1 °F (Stenhouse et al. 2012). Additionally, the presence of these species suggests that dissolved oxygen throughout the study area was greater than 2 to 5 ppm, which is considered the threshold that limits survival, growth, or swimming ability (Woelfle-Erskine et al. 2017). It is likely that reference conditions for turbidity are less than 70 NTU, a value at which coho salmon begin to exhibit significant sediment avoidance (Bisson and Bilby 1982). Last, water quality reference conditions exclude pollutants that enter streams through atmospheric deposition or runoff from agricultural or developed areas.

Recognizing the difficulty of defining true reference conditions within a landscape that has been subjected to at least some human impact, such as climate change, AREMP researchers selected a network of reference sites that are the least human-disturbed (Miller et al. 2017). These areas continue to experience natural disturbances but display minimal human impact (Miller et al. 2017). Sites were selected as reference if they fell below the 25th percentile for all human disturbance variables, including those known to influence water quality. Under these methods, watershed reference conditions for water quality are defined by road density less than 2.17 miles per square mile, agriculture occupying less than 0.05 percent of the watershed, development occupying less than 2.0 percent of the watershed, and mines representing less than 0.21 percent of the watershed (Miller et al. 2017).

Data Sources and Evaluation

We used several datasets to evaluate water quality within the study area (Appendix B). To determine the potential impacts of stressors, we used shapefiles with the locations of dams, diversions, mines, recreation sites, roads, timber harvest projects, changes in temperature and precipitation, long-term deviations in moisture, and livestock grazing allotments. We used LANDFIRE biophysical setting (LANDFIRE 2016a) and existing vegetation type (LANDFIRE 2016b) raster data to estimate land-use change throughout the study area. We combined these datasets with information from the WCF (Potyondy and Geier 2011) and TCA (Cleland et al. 2017), which address whether these stressors have impacted the structure and function of watersheds and ecosystems, respectively.

We used the Northwest Stream Temperature (NorWeST) model output for the western United States (Isaak et al. 2017) to summarize past and expected trends in stream temperatures. The NorWeST model uses spatial statistical network models and more than 220 million temperature recordings from more than 22,700 stream and river sites to estimate historical and future climate stream temperature scenarios in the western United States (Isaak et al. 2017). Model results are registered to the National Hydrography Dataset streamlines, and are available for perennial stream habitats that are likely to support aquatic species (Isaak et al. 2017). We used the NorWeST dataset to evaluate whether water temperatures have increased since 1993 and whether stream temperatures are expected to increase by mid- and late century.

We estimated accumulated and incremental loads of suspended sediment, nitrogen, and phosphorus contributed to streams from various sources using the U.S. Geological Survey's Spatially Referenced Regression On Watershed attributes (SPARROW) model (Wise 2019). The SPARROW model uses nonlinear regression equations describing transport of contaminants from point and nonpoint sources on land to streams and rivers to project the flux, concentration, and yield of different contaminants (Wise 2019). Sources modeled by SPARROW, such as upland geology, urban lands (including roads), forested lands, scrublands, and grasslands, are determined using the National Landcover Dataset (Homer et al. 2015). The model uses water quality monitoring points from numerous agencies to inform outputs (Wise 2019). The SPARROW modeling process begins by estimating contaminant loads of headwater reaches (Wise 2019). These incremental loads are accumulated as the model projects loads for downstream reaches, and this process continues until a calibration station is reached and the load is adjusted to match measured values (Wise 2019). Most catchments within the Five Forests considered in this assessment are characterized by low incremental or accumulated sediment and nutrient loads (figs. C.5–C.40 in Appendix C); however, some basins within the boundaries of the national forests receive accumulated loads of sediment and nutrients from upstream activities that are not occurring on the forests, such as agricultural operations (figs. C.9, C.10, C.15, C.16).

We evaluated the likelihood that (1) water quality of the four different types of streams (permanently flowing fish-bearing, permanently flowing nonfish-bearing, seasonally flowing fish-bearing, seasonally flowing nonfish-bearing) was altered and (2) lake, pond, and reservoir habitat was altered. For this analysis we determined whether the WCF or TCA indicates widespread impacts from stressors. We considered eight indicators that suggest likely impacts from stressors to water quality: (1) the percentage of stream miles or waterbodies placed on the 303(d) impaired waters list by California or Oregon, (2) the WCF water quality problems attribute, (3) the WCF soil contamination attribute, (4) the WCF riparian/wetland vegetation condition attribute, (5) the WCF Roads and Trails Condition Indicator, (6) the WCF mass wasting attribute, (7) the WCF loss of forest cover, and (8) the TCA pollution condition. We determined that water quality in streams was altered if:

-
- At least two indicators suggested impacts (WCF rating of impaired or TCA rating of poor or very poor) from stressors in more than one-third of watersheds containing the habitat,
 - Or if pollution had impacted ecological integrity in more than half of the unit,
 - Or if one stressor impacted (WCF rating of impaired or TCA rating of poor or very poor) more than half of watersheds containing the specific stream habitat,
 - Or if the majority of the habitat appeared on the 303(d) list for impaired waters.

There were limited data available within the study area related to the water quality of fens, springs, seeps, and vernal pools. We summarized stressors to these habitats but were unable to determine the likelihood of altered water quality.

Connectivity

Drivers

The ecological integrity of riparian and aquatic systems is influenced by the exchange of water, resources, and organisms between the aquatic environment, the aquifer, and the riparian ecosystem (Stanford and Ward 1993; Ward and Stanford 1995). This connectivity in and between riparian and aquatic ecosystems occurs in four dimensions (Stanford et al. 2005; Ward 1989). Longitudinal connectivity describes the dimension that extends from the headwaters of a stream to its mouth (Vannote et al. 1980; Ward 1989). Vertical connectivity extends from the groundwater zone to the canopy of riparian vegetation (Stanford and Ward 1993; Ward 1989). Lateral connectivity extends from the streambed to the outer extent of the floodplain (Junk et al. 1989; Ward 1989). Finally, variation in upstream–downstream, groundwater–surface water, and channel–floodplain connections occur across time (Stanford et al. 2005; Ward 1989).

Patterns in connectivity within and between riparian and aquatic ecosystems are influenced by landscape features such as hydrology, geology, topography, and soils (Fritz et al. 2018; Sheer and Steel 2006; Stanford and Ward 1992). Longitudinal and vertical water movement is constrained by porosity of the substrata and the extent of unconfined aquifers (Fritz et al. 2018; Stanford and Ward 1992). In general, impermeable geology results in less vertical connectivity and more surface flow (Fritz et al. 2018). For example, vertical connectivity may be high in locations where streamflow downwells to the alluvial water table at the upstream end of a floodplain, flows through interstitial spaces, and emerges to surface flow in a location where bedrock is exposed or canyon walls encroach (Stanford and Ward 1992). Alternatively, streams may exhibit a high degree of longitudinal connectivity in locations where geologic formations limit penetration. Lateral connectivity tends to be highly influenced by hydrology, specifically timing, frequency, magnitude and duration of high and low flows, and the rate of change between periods of flooding and baseflow (Junk et al. 1989; Stanford and Ward 1992). Topography, specifically steepness of terrain and valley confinement, can influence whether a system has high longitudinal, lateral, or vertical connectivity

(Fritz et al. 2018). Streams flowing through steep terrain tend to have high connectivity between upstream and downstream reaches, but less exchange between the riparian and aquatic zone or the surface water and groundwater (Fritz et al. 2018). Conversely, streams and rivers flowing through gradual topography may have more lateral and vertical interactions (Fritz et al. 2018). Additionally, confined valleys may experience inundation and lateral connection during small floods, while the outer extents of wide, unconfined valleys may interact only with the channel during high magnitude floods (Fritz et al. 2018).

Connectivity is also influenced by climate, which governs patterns in water supply through precipitation, drought, and temperature (Fritz et al. 2018; Stanford and Ward 1992). Aquatic ecosystems, including streams, rivers, lakes, ponds, and groundwater, expand and contract in response to climatic drivers (Fritz et al. 2018; Loose et al. 2019; Sims et al. 2019a, b, c, d), which in turn influence three-dimensional connectivity across time (Fritz et al. 2018). The seasonality, rate, distribution, and form of precipitation, as influenced by phenomena like the El Niño Southern Oscillation or Pacific Decadal Oscillation, drive patterns in flooding, infiltration, and runoff (Fritz et al. 2018). Air temperature and vapor pressure drive evapotranspiration rates, which influence streamflow, infiltration, and lake volume (Loose et al. 2019; Sims et al. 2019a, b, c, d). As aquatic ecosystems respond to temperature and precipitation, lateral, longitudinal, and vertical connections may be established and severed in a projectable pattern over time. Generally, a greater proportion of streams flow year-round in mesic regions and a greater proportion of streams are intermittent or ephemeral in arid and semiarid regions (Fritz et al. 2018).

In addition to landscape characteristics and climate, connectivity in riparian and aquatic ecosystems is influenced by the proximity, size, and density of these ecosystems, and by natural disturbance regimes (Fritz et al. 2018; Naiman et al. 1993; Wissmar and Beschta 1998). In general, riparian and aquatic ecosystems that are closer together are more likely to have stronger, more frequent, and longer interactions (Fritz et al. 2018). For example, ponds or springs located in the outer extents of a floodplain are generally less impacted by flooding than similar habitats that are located near the main channel and frequently connected to the main channel by high water levels (Driscoll and Hauer 2019). The size of riparian and aquatic ecosystems can also influence connectivity, with larger streams, lakes, and wetlands more likely to maintain long and frequent connections (Fritz et al. 2018). Likewise, the probability and strength of connections tend to increase with higher density of streams and wetlands (Fritz et al. 2018). Finally, high connectivity is maintained by natural disturbance (Wissmar and Beschta 1998). The movement of water, sediment, and down wood that occurs during flooding or in response to fire and landslides drives channel migration and inundation and contributes to long-term patterns in lateral, longitudinal, and vertical connectivity over time (Naiman et al. 1993).

Stressors

Connectivity within and between riparian and aquatic ecosystems undergo stress from factors or activities that disrupt natural lateral, longitudinal, or vertical interactions. These three-dimensional connections that vary over time can be impacted by actions that alter water or sediment inputs, change the natural flow regime, alter natural disturbance, remove these ecosystems from the landscape, or add barriers to the movement of water, organic matter, nutrients, or organisms. Structures such as dams and diversions disrupt water and sediment dynamics with significant negative impacts on connectivity. These structures tend to alter natural flow regimes or remove water from the system, generally resulting in smaller peak flows, modified sediment transport and stream power relationships, reduced overall discharge, and altered flow timing (Crook et al. 2015; Fritz et al. 2018; Wissmar and Beschta 1998). Water abstraction or releases of stored water during periods of low precipitation artificially sever or enhance longitudinal connectivity (Crook et al. 2015; Fritz et al. 2018). By trapping sediment and regulating streamflows, dams can have major impacts on channel migration, resulting in incised streams that are disconnected from their floodplain and riparian areas (Wissmar and Beschta 1998). Smaller peak flows generated by dams and diversions reduce overbank flooding and lateral connectivity, further severing interactions between the stream and its riparian area (Crook et al. 2015). In addition to altering flow regimes, dams and diversions fundamentally alter connectivity by adding physical and behavioral barriers to longitudinal movement (Crook et al. 2015). These barriers generally contribute to a loss of accessible critical habitat and can reduce the habitat suitability of a watershed for fish and wildlife (Crook et al. 2015; Sheer and Steel 2006).

Roads are a significant stressor that impacts riparian and aquatic connectivity in multiple ways. Roads add impervious surfaces to the landscape and alter hillslope contours in ways that can reduce infiltration and increase runoff (Forman and Alexander 1998b). These alterations to water inputs can artificially increase longitudinal connectivity. Additionally, roads can act as an unnatural source of fine sediment that can obstruct flow paths and disrupt vertical connectivity (Forman and Alexander 1998b). Increased sediment can also disrupt natural channel dynamics and stream migration and drive channel incision that isolates streams from floodplains. Roads located in floodplains that parallel the stream frequently limit lateral movement and disconnect portions of the valley bottom from the stream. Like dams and diversions, road crossings and culverts also have significant impacts on longitudinal connectivity by acting as barriers that limit migration or retain nutrients, materials, and organisms (Crook et al. 2015; Januchowski-Hartley et al. 2013; Sheer and Steel 2006). Finally, roads may interrupt landslides that deliver sediment and wood to channels (Scott Peets, USDA Forest Service, Portland, OR, personal communication, September 14, 2021).

Land-use change resulting in fragmentation or loss of habitat is another stressor to connectivity between and within riparian and aquatic ecosystems. Urban

development and conversion to agriculture are linked to increases in impervious cover, sedimentation, burial of natural channels, and construction of storm drains (Fritz et al. 2018). These changes can alter the timing, frequency, duration, and magnitude of high and low flows; ultimately, connectivity within the overall stream network is unnaturally enhanced or severed (Fritz et al. 2018). Conversion of lands that changes water or sediment inputs can reduce channel migration, increase incision, and disconnect floodplains from channels (Wissmar and Beschta 1998). Additionally, development or agriculture tends to increase the number of barriers that constrain the movement of biota, including road crossings, culverts, and light from streetlamps (Crook et al. 2015). These changes in land use often result in containment of rivers with artificial levees that limit lateral channel migration and connectivity (Fritz et al. 2018). As more lands are modified by industrial, agricultural, forestry, and urban development, riparian and aquatic habitat patches can be reduced in size or outright lost (Crook et al. 2015; Fritz et al. 2018). This result impacts the density of patches on the landscape and the distance between them; changes in these variables can inhibit the dispersal of organisms and reduce connectivity (Crook et al. 2015).

Lastly, climate change that alters the hydrology through altered temperature and precipitation regimes is a stressor to connectivity. It is likely that climate change will result in more variable flow regimes, with lower baseflows for longer periods of time and more frequent and larger flood events (Crook et al. 2015). Extended low-flow periods may reduce both longitudinal and lateral connectivity (Crook et al. 2015). Conversely, increases in flood frequency and magnitude may connect habitats and communities that have historically been isolated (Crook et al. 2015). Warmer air temperatures that increase rates of evapotranspiration are linked to reduced hydroperiods and water volume in habitats like wetlands, vernal pools, lakes, and ponds (Sims et al. 2019a, c, d). As these habitats dry earlier or are lost from the landscape, the density of riparian features declines, and the distance between habitats increases (Fritz et al. 2018). Additionally, streamflow, recharge and discharge from groundwater systems, and volume of lakes, reservoirs, ponds, and vernal pools can dramatically decline during periods of drought (Loose et al. 2019; Sims et al. 2019a, c, d). As drought conditions increase in frequency, extent, and severity (Loose et al. 2019; Sims et al. 2019a, b, c, d), three-dimensional connectivity is likely to decline (Crook et al. 2015).

Desired and Reference Conditions

Desired conditions throughout the study area include watersheds that support large continuous blocks of high-quality riparian and aquatic habitat (Potyondy and Geier 2011). Longitudinal, lateral, and vertical connectivity that reflects natural linkages over time should be exhibited within and between riparian and aquatic components (USDA FS 2019a). Three-dimensional interactions should be maintained with climate change in mind, with specific focus given to preserving or establishing connections between existing habitat patches and those that may be suitable in the future (Gray

et al. 2020). Flow regimes in perennial, intermittent, and ephemeral streams should provide upstream–downstream interactions consistent with the range of variation in a given watershed (USDA FS 2019a). Lateral connectivity between the channel and its floodplain should be maintained through limited stream incision and flooding that occurs within the natural range for timing, frequency, duration, and magnitude (Junk et al. 1989; Potyondy and Geier 2011). The exchange of water, resources, and organisms between groundwater and surface water systems should readily occur in locations where geologic formations allow it. Three-dimensional connectivity should maintain valuable ecosystem services, including biofiltration of water in riparian areas and wetlands, recreation opportunities, flood control, and wildlife habitat (Gray et al. 2020). Spatial and temporal connectivity should be provided within and between watersheds such that riparian and aquatic ecosystems enable species and communities to survive perturbations while maintaining genetic diversity through resistance, avoidance, and recolonization (Fremier et al. 2015; USDA FS 2019a). Additionally, the extensive linear network provided by riparian and aquatic systems should be maintained for species to move through otherwise inhospitable areas with some focus given to lowland systems that tend to be underrepresented among protected areas (Fremier et al. 2015). Connectivity is maximized when fragmentation by roads, culverts, diversions, and dams is limited because these structures can exclude species from their historical habitat and inhibit ecological processes that depend on the exchange of water, organic matter, or nutrients (USDA FS 2019a).

Tree canopies and down wood create microsites that are buffered from fluctuations in ambient temperature. Protection of these sites may aid the survival of riparian organisms, such as salamanders, during migration and dispersal (Kluber et al. 2009). Large down wood and remnant stands of mature forest are components of habitat “chains” that assist the movement of organisms from riparian ecosystems across ridgelines into adjacent watersheds (Olson and Burnett 2013). The maintenance of such headwater connections among watersheds is critical to facilitating migration and dispersal of riparian organisms (tables A.5 and A.6) throughout the planning area (Olson and Burnett 2009).

In reference systems, high degrees of three-dimensional connectivity are maintained by natural disturbances, such as flooding, fire, and landslides (Cordeira et al. 2019; Everest and Reeves 2007; Naiman et al. 1993; Stanford and Ward 1992; Wissmar and Beschta 1998). Floods that facilitate lateral connectivity occur in response to spring snowmelt and intense precipitation from large Pacific Ocean storms (Everest and Reeves 2007). As there is no historical analogue for dams (Gross et al. 2020), desired conditions are timing, magnitude, and frequency of flooding and lateral connection that is similar to the natural flow regime of reference systems where dams do not occur. Additionally, longitudinal connectivity in reference conditions is limited only by natural intermittency and ephemerality in some reaches. Upstream–downstream interactions remain intact with no unnatural barriers to migration or exchange of water and

resources (Vannote et al. 1980). Finally, vertical connectivity in reference conditions is maintained in locations with permeable geology and porous substrata (Stanford and Ward 1993; USDA FS 2019).

Recognizing the difficulty in defining a true reference condition in a landscape that has widely been subject to at least some human impact, AREMP analysts created a network of least human-disturbed sites to evaluate conditions. These reference sites were defined as sites that fell below the 25th percentile for all human disturbance variables, with the exception of distance to dam, where the 75th percentile was used (Miller et al. 2017). Many of these stressors are known to impact connectivity, and the thresholds identified by AREMP analysts can be used to inform reference and desired conditions. Some thresholds to define reference sites are as follows: Road density within watersheds is less than 2.2 miles per square mile; stream crossings density is less than 0.6 crossings per square mile; agriculture and development are less than 0.05 and 2.0 percent of the landscape, respectively; canals are less than 1.7 percent of flowlines mapped in the National Hydrography Dataset; and reference sites are more than 12.8 miles from dams (Miller et al. 2017).

Data Sources and Evaluation

We used several datasets to evaluate the connectivity of the stream network within the study area (Appendix B). To determine the potential impacts of stressors, we used shapefiles with the locations of dams, diversions, mines, roads, changes in temperature and precipitation, and long-term deviations in streamflow. We used LANDFIRE biophysical setting (LANDFIRE 2016a) and existing vegetation type (LANDFIRE 2016b) raster data to estimate land-use change throughout the study area. We combined these datasets with information from the WCF (Potyondy and Geier 2011) and the TCA (Cleland et al. 2017), which address whether stressors have impacted the structure and function of watersheds and terrestrial ecosystems, respectively.

We used AREMP fish passage data to summarize whether connectivity was significantly impacted by barriers. This dataset included a point layer of bridge and culvert locations classified by passability (barrier, partial barrier, passable, no data or unknown). AREMP specialists extract and transform culvert data from interagency data sources to meet one data standard as closely as possible. Locations and information regarding culvert specifications are determined through direct observation during survey sampling, informal observations by professional natural resource agency staff, or by professional opinion (or combination thereof) (Marcia Snyder, USDA Forest Service, Corvallis, OR, personal communication, February 24, 2021). The point layer was used to construct an associated functional stream network that classifies stream reaches based on downstream culvert and bridge passability (Marcia Snyder, USDA Forest Service, Corvallis, OR, personal communication, February 24, 2021).

We summarized projected changes in high and low flows based on the Western U.S. Stream Flow Metrics dataset (USDA FS 2019b; Wenger et al. 2010). See the section

“Hydrologic Regimes” for more information on this dataset. We also summarized results from the NorWeST model, which estimates mean August stream temperatures in permanently flowing streams within the study area (Isaak et al. 2017). See the section “Water Quality” for more information on this dataset. The AREMP evaluation of physical stream habitat condition within the Northwest Forest Plan area used stream temperature thresholds established by the National Marine Fisheries Service (59 °F as properly functioning condition for anadromous fishes) and the State of Oregon (60.8 °F as the standard for temperatures in salmonid habitat; Miller et al. 2017). Although these temperatures are based on thresholds for fish species, they also represent thresholds that can serve as barriers for other aquatic species, including several amphibians within the study area (Welsh and Hodgson 2008).

We estimated whether connectivity in the four stream types (permanently flowing fish-bearing, permanently flowing nonfish-bearing, seasonally flowing fish-bearing, and seasonally flowing nonfish-bearing) was altered. For this analysis, we determined whether AREMP or NorWeST datasets indicated widespread fragmentation due to fish passage barriers or stream temperature and whether the WCF indicates widespread impact from stressors. We considered eight indicators that evaluate potential impacts on connectivity: (1) the WCF flow characteristics attribute, (2) the WCF Water Quality Indicator, (3) the WCF proximity to water attribute, (4) the WCF Roads and Trails Condition Indicator, (5) the WCF channel shape and function attribute, (6) the WCF habitat fragmentation attribute, (7) the percentage of streams obstructed by a downstream barrier as measured by AREMP (applied only to permanently flowing streams), and (8) the percentage of streams with mean August stream temperatures exceeding 60.8 °F (applied only to permanently flowing streams). We determined the connectivity of streams to be altered if:

- More than two indicators suggested impacts (WCF rating of impaired or TCA rating of poor or very poor) from stressors in more than one-third of watersheds containing the stream habitat,
- Or if one stressor impacted (WCF rating of impaired or TCA rating of poor or very poor) more than half of the watersheds containing the stream habitat,
- Or if more than half of watersheds containing the stream habitat are classified as functional-at-risk or impaired for the WCF habitat fragmentation attribute,
- Or if more than half of watersheds containing the habitat are classified as impaired for the WCF channel shape and function attribute,
- Or if AREMP fish passage data indicate more than half of the stream type is obstructed by impassable downstream barriers (applied only to permanently flowing streams),

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- Or if NorWeST stream temperature modeling indicates that average August stream temperatures exceeded 60.8 °F in more than half of the stream type between 2002 and 2011.

Interwatershed Connectivity

To evaluate connectivity between watersheds and identify areas where RRs could be expanded to maintain or create connectivity across watershed divides, we considered distances between RRs in neighboring 12-digit hydrologic unit code (HUC12) watersheds. We completed this analysis by selecting all HUC12 watersheds that overlap at least one of the Five Forests. For each watershed, we calculated the total number of neighboring watersheds with which the focal watershed shared a boundary. We then used the RRs shapefile to map riparian areas within each HUC12 watershed within the study area. Data for RRs were available only within national forest boundaries, which limited our assessment of connectivity for watersheds that extend outside the Five Forests.

For each pair of neighboring HUC12 watersheds we calculated the shortest distance between RRs in each watershed. We used this measurement of distance to classify each pair of watersheds as either “connected,” “within 0.25 mile,” or “not connected.” Neighboring watersheds with 0 miles of distance between RRs were considered “connected.” A distance of 0 between neighboring watersheds occurred in locations where either one watershed flowed into its neighbor, creating a continuous riparian area that extended across the watershed boundary (fig. 29), or in locations where an RR in the headwaters crossed a watershed boundary, generating a riparian area on either side of a divide (fig. 29). We then identified neighboring watersheds with RRs that did not extend across the watershed boundary but were within 0.25 mile of one another (fig. 29). These watershed pairs classified as “within 0.25 mile” are potential sites for interwatershed connectivity. Finally, we identified “disconnected” neighboring watersheds with more than 0.25 mile between RRs (fig. 29). For each watershed, we calculated the number and percentage of neighbors with which the focal watershed was connected, within 0.25 mile, and not connected.

To further evaluate connectivity for terrestrial riparian organisms, we identified locations where the headwaters of three 8-digit hydrologic unit code (HUC8) watersheds meet within the national forests, as recommended by Olson and Burnett (2013). These watershed connections, known as triads, have the potential to facilitate the movement of riparian organisms throughout the planning area. Triads are among the priority linkage areas proposed to maintain or restore landscape connectivity in managed forests (Olson and Burnett 2009).

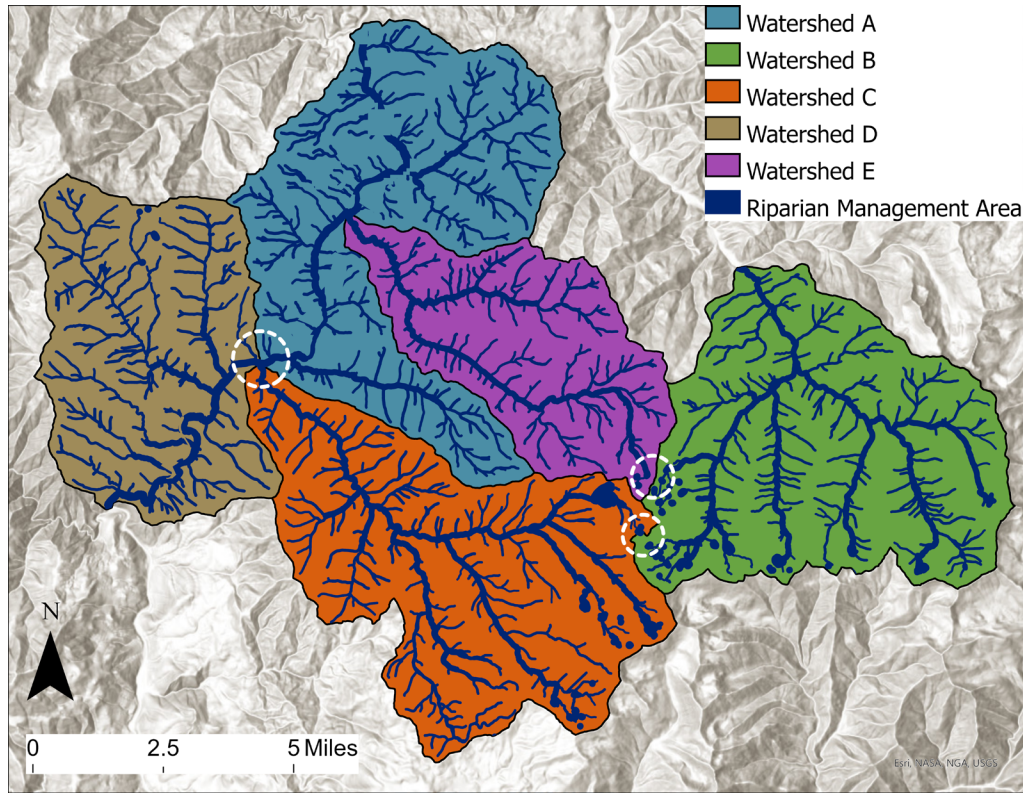


Figure 29—Watershed connectivity, with different examples of potential connectivity relationships between 12-digit hydrologic unit code (HUC12) watersheds highlighted by white circles. The orange, blue, and brown watersheds (Watersheds C, A, and D) are considered “connected” because one watershed flows into its neighbor, creating a continuous riparian reserve (RR) across a watershed boundary. The orange and green watersheds (Watersheds C and B) are considered “connected” because an RR within the red watershed extends over the divide into the green watershed. If the distance between RRs in the green and purple watersheds (Watersheds B and E) is less than 0.25 mile, these neighbors would be classified as “within 0.25 mile.” If the distance between RRs in the green and purple watersheds is greater than 0.25 mile, these neighbors would be classified as “not connected.”

For each of the Five Forests, we identified HUC8 watersheds that are connected by triads. We included triads in our analysis if they met the following criteria: (1) Three watersheds are joined at their headwaters, (2) the point where they are joined is within one of the Five Forests, (3) each watershed overlaps a portion of at least one of the Five Forests, and (4) the watersheds are not directly hydrologically connected. In other words, one does not drain into another, they do not drain into a shared stream at the same point, or their connections are disrupted by large dams and reservoirs.

We merged polygons of the three watersheds joined by each triad and analyzed spatial data associated with these areas. We estimated the percentage of triad area within the administrative boundary of national forests, key watersheds (KWs), and RRs. We also estimated tree canopy cover, down wood cover, large down wood cover, and tree density, both for the full watershed area and for land in watersheds that is within the administrative boundary of the Five Forests. We obtained vegetation data from GIS rasters of results from GNN mapping of vegetation in the Northwest Forest Plan area (Appendix B). Nearest neighbor imputation integrates forest inventory plots with

satellite imagery to map forest characteristics across large extents (Ohmann et al. 2014). The GNN datasets used here were developed with 30-m resolution Landsat imagery and data from the Forest Service's Forest Inventory and Analysis program by the Landscape Ecology, Modeling, Mapping and Analysis Group. Results from our analysis of triads can be used to assess management potential of watersheds that link riparian habitats across the planning area.

Instream Habitat

Drivers

Streams and their floodplains are highly dynamic landscapes that provide heterogeneous habitats across space and time (Stanford et al. 2005). Riparian and aquatic organisms require complex floodplains with high habitat heterogeneity to complete their life cycles (Stanford et al. 2005). The population health and diversity of fish and other aquatic species are typically related to habitat diversity (USDA FS 2019a). Complex floodplains with shifting habitat mosaics are the result of multiple drivers, including natural disturbance, operating at variable spatial and temporal scales (Stanford et al. 2005). Drivers of channel and floodplain habitat presence and quality include the fluvial geomorphologic processes influenced by geology, topography, climate, hydrology, riparian vegetation structure and composition, and beaver activity.

Channel shape, distribution of habitats, and substrate composition are important components of habitat that are partially controlled by geology and topography, which influence the delivery of sediment and water (Bjornn and Reiser 1991). Major geologic formations within the study area include volcanic rock that is relatively hard and resistant to weathering and softer erodible sedimentary rock (Kaufmann and Hughes 2006). Because surface erosion is limited in volcanic settings, sediment delivery in these areas is often influenced by steep topography that is subject to infrequent mass-failures; landslides and other mass-failures contribute large amounts of substrate and wood to channels (Bjornn and Reiser 1991). Less steep sedimentary settings, which generate more fine sediment and inputs, are generally sustained by slow-moving, deep-seated earth flows and rotational failures (Bjornn and Reiser 1991). Geology can also influence the location of gaining reaches, where groundwater upwells into the channel. Inputs of groundwater can maintain stream temperatures that support aquatic biota, and salmonids often select upwelling zones as the location for their redds (California Department of Fish and Game 2004). Last, geology can influence water quality, specifically suspended sediment loads and concentrations of solutes that can affect the suitability of habitat for native fish and other aquatic species (California Department of Fish and Game 2004).

Climate and its influence on hydrologic regimes interact with geology and topography to influence the presence, quantity, and quality of channel and floodplain habitats. The timing, frequency, duration, and magnitude of high and low flows drive processes such as channel avulsion and cut and fill alluviation, creating complex channels that

support diverse populations of aquatic organisms (Naiman et al. 1992; Stanford et al. 2005). Additionally, the amount of water at a given time drives flow velocity, flow depth, and the distribution of aquatic habitats across the floodplain (Driscoll and Hauer 2019; USDA FS 2019a). Where terrain and geology allow, these processes build and connect habitats such as pools, riffles, ponds, oxbow lakes, and side channels on which organisms rely (Stanford et al. 2005). Many low-order streams in the study area tend to be high-gradient bedrock channels with high colluvial inputs from landslides and debris flows (Naiman et al. 1992). These small streams typically contain boulders and down wood that influence the longitudinal profile (Naiman et al. 1992). Mid-order channels within the study area generally have moderate to steep gradients with substrates that range from gravel to boulders (Naiman et al. 1992). These streams are generally influenced by debris flows that deposit large amounts of wood and sediment, with alluvial fans driving high sinuosity in many medium-sized streams (Naiman et al. 1992). The form of mid-order channels is often single-thread channels that include alternating pool and riffle morphology, with some examples of boulder-cascades or step-pools in reaches dominated by large substrate (Naiman et al. 1992). High-order large rivers tend to have low gradients and wide valleys with meandering channels and alternating pool and riffle morphology (Naiman et al. 1992).

Riparian vegetation influences instream habitat quality in several ways. Streamside vegetation that overhangs the channel shades the water and cools temperatures (Bjornn and Reiser 1991). Overhanging vegetation also provides cover that fish use to avoid predation (Bjornn and Reiser 1991; USDA FS 2019b). Additionally, riparian vegetation and down wood are important sources of nutrients and organic matter that establish the trophic base of riparian and aquatic food webs (USDA FS 2019a). Streamside vegetation also supports instream habitat quality by trapping sediment, dissipating flow energy, and stabilizing banks (Bjornn and Reiser 1991; USDA FS 2019a). Finally, riparian areas are a source of large wood, the deposition of which is a critical component of channels that evolved with wood present (Potyondy and Geier 2011). Deposition of large down wood within channels can stabilize streambeds, trap fine sediment, and develop habitats that are spatially and hydraulically complex (Bjornn and Reiser 1991).

Natural disturbances, including floods, fires, wind, and landslides, interact with the drivers just outlined to maintain complex high-quality instream habitat (Bisson et al. 1997). Depending on the magnitude, flooding can move and sort substrate, change the pool-to-riffle ratio, fill side channels, and move and deposit large down wood (Bisson et al. 1997). Windthrow can increase delivery of sediment and large wood, reduce riparian vegetation cover, increase pool habitat, and retain organic matter within the channel (Bisson et al. 1997). Wildfires also increase the delivery of sediment and large wood, reduce canopy cover of riparian vegetation, increase inputs of organic matter and nutrients, increase pool habitat, increase summer stream temperatures, and reduce dissolved oxygen (Bisson et al. 1997). Insects and diseases that cause tree mortality can increase inputs of large wood, decrease vegetation cover, increase summer flows,

increase pool habitat and in-channel cover, and increase summer temperatures (Bisson et al. 1997). Debris flows, landslides, slumps, and earthflows can contribute sediment and wood, partially block channels, increase pool habitat, and destroy side channels (Bisson et al. 1997). Volcanism increases the delivery of fine sediment and organic matter, scores channels, destroys riparian vegetation, dams streams, increases nutrients, alters channel geomorphology, and can form barriers to migration (Bisson et al. 1997). Together, these natural disturbances are a critical driver of habitat formation and are essential for maintaining productive high-quality instream habitats (Bisson et al. 1997).

Beaver activity contributes to the condition of channels and instream habitat through damming, obstruction and redirection of flow, overbank flooding of riparian areas and side channels, entrainment of wood, and creation of depositional anaerobic conditions (Bisson et al. 1997). Beavers modify channels and floodplains by cutting wood and building dams that trap sediment, slow runoff, and build wide, low-gradient, alluvial valleys (Gurnell 1998). These meadows generate a step pattern along a stream's longitudinal profile (Gurnell 1998). Additionally, beaver dams increase variation in channel width, depth, and geomorphologic structure (Gurnell 1998). Beaver ponds are known to provide deep pools that are suitable salmonid habitat during summer low flows and winter periods, with specific documented benefits to salmonids in mountainous or semiarid landscapes (Collen and Gibson 2000). Beaver activity can also sustain and stabilize streamflow, moderating both high and low flows (Collen and Gibson 2000). Their activities also tend to increase inputs and storage of nutrients and organic matter, which contribute to the trophic base of riparian and aquatic food webs. These beaver impacts contribute to instream habitat quality by enhancing rearing and overwintering habitat, increasing water volumes during low flows, and providing refugia during floods (Bisson et al. 1997). Beaver ponds can increase summer temperatures and drive local reductions in dissolved oxygen (Bisson et al. 1997). These habitats, with their deep, low-velocity waters, can increase production of pond invertebrates and increase production downstream from the pond (Bisson et al. 1997).

Stressors

Stressors to instream habitat quality include activities or forces that alter the balance between water and sediment supplies, limit lateral movement of the channel across its floodplain, disrupt inputs of wood and nutrients, alter riparian vegetation cover and composition, or alter natural disturbance regimes. Environmental degradation and the resulting loss of habitat have contributed to the decline or extinction of many species, particularly anadromous salmon, in the Pacific Northwest (Bisson et al. 1997; Kaufmann and Hughes 2006).

The settlement of humans along streams and rivers over the past 150 years has altered instream habitat by changing inputs of sediment, wood, and nutrients, severing connections to the floodplain, altering flow regimes, and changing riparian plant cover and composition (Larsen et al. 2004; Naiman et al. 1992). Land-use change and

removal of native vegetation has increased erosion and inputs of sediment (Kaufmann and Hughes 2006). Within the study area, the impacts of land-use change and other anthropogenic stressors are more pronounced in streams that drain sedimentary lithology compared to those that drain volcanic basins (Kaufmann and Hughes 2006). Lower richness and abundance of salmonids, tailed frogs, and other cold-water and sediment-sensitive taxa are associated with greater road density and anthropogenic riparian disturbance within the study area (Kaufmann and Hughes 2006).

Dams and water diversion influence habitat quality by altering hydrologic regimes and the flow of water, sediment, nutrients, organic matter, and biota (Ligon et al. 1995). Dams and diversions are linked to declines in the magnitudes of both high and low flows, reduced overall discharge, and altered flow timing (Crook et al. 2015; Fritz et al. 2018; Wissmar and Beschta 1998). Smaller flood magnitudes alter cut and fill alluviation and avulsion processes that shape heterogeneous channels with diverse high-quality habitat (Ligon et al. 1995). Additionally, reduced peak flow magnitudes can sever connections to floodplain habitats, such as side channels used by aquatic biota to complete their life cycle; active floodplain area and floodplain complexity of regulated streams are reduced by 79 and 37 percent, respectively (Graf 1999). Dams and diversions can also alter thermal regimes, specifically by changing the timing of warmer and colder flows (Angilletta et al. 2008). The overall impact from dams and diversions on flow regimes, including stream temperature, can decouple the timing of hydrologic conditions from those under which native species evolved. These changes can impact the behavior, physiology, and life history of native fish and other aquatic species (Angilletta et al. 2008; Bauer et al. 2015; Ligon et al. 1995). Finally, in addition to the hydrologic alterations caused by dams and diversions, these structures can function as barriers that obstruct both access to critical habitat and the movement of nutrients and organic matter that support food web structure (Crook et al. 2015; Januchowski-Hartley et al. 2013; Sheer and Steel 2006).

Like dams and diversions, forest roads can alter hydrologic processes within watersheds. High-density roads can reduce infiltration rates and increase runoff during precipitation events (Kastridis 2020). Additionally, roads can increase connectivity between ditches, channels, culverts, and gullies. This change in the density of the hydrologic network can result in changes to the timing of peak flow and the shape of hydrographs within watersheds (Kastridis 2020). These road-driven changes in hydrology have similar influences on instream habitat quality as those described in the preceding paragraph.

Some actions, such as mining, timber harvest, road construction, land-use change, and livestock grazing alter the rate, timing, and volume of sediment inputs and transport within stream channels (Forman and Alexander 1998; Hicks et al. 1991; Kauffman and Krueger 1984; Platts et al. 1989; Yee and Roelofs 1980). Unnatural sediment loads can alter channel morphology and substrate composition in ways that negatively impact fish, benthic invertebrates, and other aquatic biota (Platts et al. 1989). Increasing fine

sediments can reduce spawning success, affect rearing capacity, and reduce food abundance (Hicks et al. 1991). For example, fry survival and fitness are reduced when spawning gravels become laden with fine sediment that reduces the permeability of substrates, deprives oxygen, or entombs fry (Cederholm and Salo 1979). Additionally, fish behavior can be altered by substantial suspended sediment loads, as salmonids avoid significant turbidity (Bisson et al. 1997).

Activities that alter the composition or structure of riparian vegetation or disrupt the delivery of large down wood can have detrimental impacts on instream habitat quality. These activities can include livestock grazing, timber harvest, fire suppression, land-use change, or biological invasion (Hicks et al. 1991). Livestock grazing can contribute to the loss of riparian vegetation cover, as well as to the incision of channels, which reduces the size of adjacent riparian zones (Hicks et al. 1991; Kauffman and Krueger 1984). Timber harvest, fire suppression, and land-use change have contributed to reducing the frequency of pieces of large down wood within channels (Hicks et al. 1991). Invasive vegetation alters the composition and structure of riparian zones, with potential impacts on instream habitat. Overall, these activities can reduce the presence of shade-providing streamside vegetation, and the loss of large down wood negatively impacts the populations of aquatic biota, specifically salmonids (Hicks et al. 1991). Finally, loss or altered riparian zones and large down wood inputs can influence the trophic base of aquatic food webs that support aquatic species (Hicks et al. 1991).

Finally, climate change can have significant impacts on instream habitat quality. Spawning, incubation, and rearing of salmon, along with life-history stages of other biota, are disrupted by warmer stream temperatures (Battin et al. 2007; Regier and Meisner 1990). Additionally, the altered precipitation patterns, earlier snowmelt, and higher winter peak flows can scour streambeds and destroy salmon eggs (Battin et al. 2007; Regier and Meisner 1990). Lower summer flows expected under climate change reduce habitat availability and contribute to warmer stream temperatures (Battin et al. 2007; Regier and Meisner 1990). Overall, as climate change continues to alter stream temperature, precipitation, and habitat regimes, instream habitat quality will be altered with likely consequences for aquatic biota.

Desired and Reference Conditions

Desired conditions throughout the study area include watersheds that support large continuous blocks of high-quality riparian and aquatic habitat. High-quality habitats include dynamic floodplain ecosystems with natural disturbance regimes that maintain heterogeneous habitat patches which support diverse and robust populations of riparian and aquatic biota. Sediment is expected to be delivered to channels at rates natural for the geology of the watershed, and its input should sustain the development of channel habitats with variable substrates. Channels should include natural structures, such as log jams and beaver dams, that trap sediment and generally be free of unnatural structures that trap or starve downstream reaches of sediment. Large amounts of sediment may be delivered to channels following natural disturbances such

as landslides or wildfires, but sediment delivery from human-caused stressors such as roads or land-use change is limited.

High-quality habitats are maintained by natural hydrologic regimes. In high-quality habitats, the timing, magnitude, duration, and frequency of high and low flows provide riparian and aquatic biota with sufficient volume to allow for the survival and reproductive success of native fishes, herpetofauna, and other organisms (USDA FS 2019a). Flows are sufficient to sustain the natural patterns of sediment, heat, nutrient, and wood routing. Additionally, water temperatures remain within ranges that allow for the survival of freshwater species, including cold-water native fish (USDA FS 2019b). Flooding occurs within natural ranges of variation for magnitude and timing. These high flows move and sort substrates and spawning gravels, contribute to changes in the abundance of pool and riffle habitat, fill side channels, and form log jams (Bisson et al. 1997). The overall hydrology creates shallow, higher velocity areas that alternate with deeper, low-velocity areas (USDA FS 2019a).

Riparian vegetation in high-quality habitats cools water and provides cover for aquatic species by overhanging the channel. Native riparian vegetation and occasional upland trees may enter the stream system and become part of the large down wood load that contributes to complex channels (USDA FS 2019a). Additionally, riparian vegetation maintains the trophic base of aquatic food webs by dropping litter and debris into streams. Streamside vegetation is sufficiently abundant and diverse to stabilize soil, trap sediment, and dissipate flow energy (USDA FS 2019a).

Robust beaver populations that reflect natural abundance are also characteristics of high-quality riparian habitat. Beavers are expected to inhabit relatively wide streams with low gradient, and soils with poor drainage, as well as sufficient herbaceous and woody vegetation for food (Howard and Larson 1985). The loss of beaver dams is a primary factor limiting the production of coho salmon and other species in coastal and inland streams (Charnley et al. 2020; Pollock et al. 2004). In Oregon and California, beaver dams created important rearing habitats for coho salmon and aquatic habitat for additional species in low-gradient, unconfined valley bottoms and coastal plains (Leidholt-Bruner et al. 1992; Parish 2016). Several types of beaver activities in the study area enhance rearing and overwintering habitat, sustain water volume during low-flow periods, and provide refugia during floods. Beaver provide these ecosystem services through activities that dam, obstruct, and redirect channel flow, flood streambanks and side channels, introduce wood into the channel, and create large depositional areas (Bisson et al. 1997).

Under reference conditions, the full range of riparian and aquatic conditions generated by natural disturbance regimes are maintained at the landscape scale (Bisson et al. 1997). Productivity and biodiversity of stream ecosystems are maintained through functional interactions between the stream, its floodplain, and its watershed during flooding, fire, and wind disturbances (Bisson et al. 1997). Desired conditions can be

identified by characterizing the impacts of natural disturbances on the distribution of habitats within reference watersheds (Bisson et al. 1997).

Virtually no large river basins remain in a completely pristine state within the study area to be used as reference conditions (Bisson et al. 1997). Recognizing the difficulty in defining true reference conditions within a study area landscape that has widely been exposed to at least some human impact, AREMP researchers identified least human-disturbed areas within their monitoring network. These sites had to fall below the 25th percentile for all human disturbance variables including road density, stream crossings, agriculture, developed open space, mines, gravel mines, canals, and distance to dams (Miller et al. 2017). Least-disturbed reference sites were located in watersheds with less than 2.2 miles of road per square mile, fewer than 0.6 stream crossings per square mile, less than 0.05 percent agriculture, less than 2 percent developed open space, less than 0.21 percent mines, less than 0.01 gravel mines per square mile, less than 1.7 percent canals, and more than 12.78 miles to the nearest dam (Miller et al. 2017). Large pieces of instream wood, particularly from conifer trees, create important habitat features such as pools and log jams in stream channels (Pollock and Beechie 2014). Pieces of wood with diameters ranging from 11.8 inches to 59.1 inches are key to forming log jams in northern California streams (Benda and Bigelow 2014).

Data Sources and Evaluation

We used several datasets to evaluate instream habitat within the study area (Appendix B). To determine the potential impacts of stressors, we used shapefiles with the locations of dams, diversions, mines, roads, timber harvest projects, changes in temperature and precipitation, and livestock grazing allotments. We used LANDFIRE biophysical setting (LANDFIRE 2016a) and existing vegetation type (LANDFIRE 2016b) raster data to estimate land-use change throughout the study area. We combined these datasets with information from the WCF (Potyondy and Geier 2011) and TCA (Cleland et al. 2017) to address whether these stressors have impacted the structure and function of watersheds and ecosystems, respectively.

We assessed the management status of salmonid stream habitat by estimating the extent of critical habitat and the level of watershed protections across each forest. Critical habitat is defined by the National Oceanic and Atmospheric Administration as “specific areas within the geographical area occupied by the species at the time of listing that contain physical or biological features essential to the conservation of the species and that may require special management considerations or protection; and specific areas outside of the geographical area occupied by the species if the agency determines that the area itself is essential for conservation” (NOAA 2016). We calculated the total length of streams designated as critical habitat in each study unit. We also used data compiled for the Northwest Forest Plan Bioregional Assessment (USDA Forest Service 2020) to calculate the area in key watersheds and other management designations (USDA Forest Service and USDOI Bureau of Land Management 1994).

We estimated the amount of stream habitat with high intrinsic potential (HIP) for salmon and steelhead in each unit. We mapped the length of HIP streams separately for Chinook salmon, coho salmon, and steelhead. Intrinsic potential indices were calculated using measurements of mean annual streamflow, valley constraint, and channel gradient (Burnett et al. 2007; Busch et al. 2013). We used the NetMap software package (TerrainWorks, Mount Shasta, CA and Seattle, WA) to extract index values for HUC8 watersheds overlapping each study unit. Following Burnett et al. (2007), we used index values of 0.75 or greater to indicate stream reaches with HIP. We then calculated the total miles of HIP streams in each watershed, within each unit, and within land management designations.

To describe the potential for wood recruitment in RRs, we obtained GIS rasters of results from GNN mapping of vegetation in the Northwest Forest Plan area (Appendix B). Nearest neighbor imputation integrates forest inventory plots with satellite imagery to map forest characteristics across large extents (Ohmann et al. 2014). The GNN datasets used here were developed with 30-m Landsat imagery and Forest Inventory and Analysis data by the Landscape Ecology, Modeling, Mapping and Analysis Group. In addition to the GNN dataset, we incorporated the WCF large woody debris attribute, which provides information on whether wood is present and recruited at natural rates into stream systems that evolved with wood near the channel (Potyondy and Geier 2011). Finally, we included data on the size class and number of wood jams present at AREMP sites.

We used AREMP fish passage data to summarize whether instream habitat was significantly impacted by barriers. This dataset included a point layer of bridge and culvert locations classified by passability (barrier, partial barrier, passable, no data/unknown). AREMP specialists extract and transform culvert data from interagency data sources to meet one data standard as closely as possible. Locations and information regarding culvert specifications are determined through direct observation during survey sampling, informal observations by professional natural resource agency staff, or by professional opinion (or combination thereof) (Marcia Snyder, USDA Forest Service, Corvallis, OR, personal communication, February 24, 2021). The point layer was used to construct an associated functional stream network that classifies stream reaches based on culvert and bridge passability (Marcia Snyder, USDA Forest Service, Corvallis, OR, personal communication, February 24, 2021).

To describe hydrologic conditions, we described the projected changes in the timing and magnitude of streamflows modeled by the Western U.S. Stream Flow Metrics dataset (USDA FS 2019b; Wenger et al. 2010) and the NorWeST model (Isaak et al. 2017). See the sections “Hydrologic Regimes” and “Water Quality” for more information on these datasets.

We evaluated whether instream habitat in permanently and seasonally flowing fish-bearing streams was likely to be altered. For this analysis we determined whether the

WCF or TCA indicates widespread impacts from stressors. The TCA evaluates the effects of uncharacteristic stressors and disturbance on the ecological integrity of land-type associations on National Forest System (NFS) lands (Cleland et al. 2017). We considered nine indicators from the TCA and WCF that suggest likely impacts from many stressors to instream habitat: (1) WCF roads and trails condition, (2) WCF rangeland vegetation condition, (3) WCF loss of forest cover, (4) WCF large woody debris, (5) WCF channel shape and function, (6) WCF flow characteristics, (7) WCF water quality, (8) TCA departure from natural fire regime, and (9) the percentage of stream length blocked by culverts or bridges categorized by AREMP. We determined that instream habitat was altered if:

- At least two indicators suggested impacts (WCF rating of impaired) from stressors in more than one-third of watersheds containing the habitat,
- Or if departure of fire regimes was indicated by the TCA in more than half of the unit,
- Or if one stressor impacted (WCF rating of impaired) more than half of watersheds containing the stream habitat,
- Or if the majority of the stream habitat was blocked by culvert or bridge barriers.

Riparian Reserves Condition

Drivers

The composition and structure of RRs are influenced by a variety of physical, biotic, and anthropogenic factors. The topographic, geologic, and climatic diversity of the region is reflected in the diversity of plant cover found within RRs (Reilly et al. 2018). The primary drivers of forest vegetation are climate, topography, soils, succession, and disturbances (Spies et al. 2018). In addition to these processes, riparian vegetation is influenced by fluvial and groundwater dynamics that operate across multiple scales (Gross et al. 2020; Pabst and Spies 1999). Both conifer and hardwood trees are important sources of productivity and habitat quality in riparian and aquatic ecosystems (Reeves et al. 2018).

Potential vegetation types and successional pathways in RRs are constrained by the biophysical setting. The distribution of successional stages in a landscape is determined by interactions between these settings and disturbance regimes. Along unmodified streams, riparian communities on streambanks and floodplains are largely maintained by dynamic flow regimes. High flows deposit sediment and rework stream channels in unconfined valley bottoms, creating floodplains, benches, and terraces. These features are colonized by early-successional tree species, such as cottonwoods, willows, and alders (Gregory et al. 1991). The growth and survival of cottonwoods and willows are dependent on stable groundwater connections (Bilyeu et al. 2008). These connections are maintained by processes and structures that include flooding, groundwater

discharge, beaver dams, and instream wood (Montgomery et al. 2003; Pollock et al. 2014; Stromberg 2001). Large conifers such as Douglas-fir that are intolerant of shallow water tables establish in the drier areas of the riparian zone (Pabst and Spies 1999). Communities dominated by herbaceous vegetation establish in riparian meadows where shallow groundwater levels are maintained by springs or surface flows and geomorphic conditions allow the accumulation of fine sediments (Weixelman et al. 1997). Fluvial processes of flooding and sediment deposition are limited along low-order streams and in narrow, bedrock-confined valley bottoms. As a result, these sites have narrower bands of riparian vegetation, which often resembles the vegetation of upland forests (Pollock et al. 2012). Wildfire influences riparian ecosystems by favoring disturbance-adapted trees and shrubs over shade-tolerant, late successional species (Halofsky and Hibbs 2009; Messier et al. 2012).

In the Northwest Forest Plan area, fire is the primary disturbance driving upland vegetation in RRs. Before Euro-American settlement, the four dominant fire regimes were frequent, low-severity fires in dry forests; frequent, mixed-severity fires in seasonally dry forests; moderately frequent, mixed-severity fires in wet forests; and infrequent, high-severity fires in wet forests and cold forests (Hessburg et al. 2019). Fires occurred as a result of lightning strikes and the cultural burning practices of Indigenous groups. Higher severity, stand-replacing fires would reset successional pathways in wetter forests, whereas frequent, lower severity fires maintained a mosaic of vegetation conditions in drier forests (Spies et al. 2018).

In the Five Forests planning area, historical fire return intervals varied across elevations, climate zones, and microhabitats. The majority of forested area (89 percent) in the Five Forests is classified as dry or seasonally dry types that were maintained by frequent, low- and mixed-severity fire (Hessburg et al. 2019; Spies et al. 2018). Small areas of wet forest types at higher elevations or near coastal areas experienced mixed- to high-severity fires within longer return intervals (Skinner and Taylor 2006; Skinner et al. 2006). Frequent, low-severity regimes (≤ 35 -year fire return interval, < 20 percent of trees killed) maintained open forests with islands of dense vegetation. Frequent, mixed-severity fires resulted in medium to large patches of high-severity burns and extensive areas of low- to moderate-severity burns. In the topographically complex Klamath Mountains, fire size and severity were strongly influenced by physical features such as aspect and slope position (Skinner et al. 2006). Topography had less of an influence on fires in the gentler terrain of the southern Cascades, where features such as unvegetated lava flows influenced fire spread by acting as fuel breaks (Skinner and Taylor 2006).

Landslides and debris flows have long-term effects on floodplain and stream channel function. Deposition of large wood and sediment in and near streams by landslides adds habitat complexity to riparian and aquatic ecosystems in forested mountain terrain (Reeves et al. 1995). Debris flows can scour sediment and wood from headwater streams and transfer these resources to higher-order streams (Cover et al. 2010). By removing

vegetation and depositing bare substrate, debris flows and landslides can also promote the establishment of early-successional riparian vegetation such as alders, cottonwoods, and willows.

A number of processes drive the abundance of snags and down wood, which are important components of fish and wildlife habitats (Kluber et al. 2009; Pollock and Beechie 2014). In Douglas-fir stands, most mortality occurs during the transition from a young (<80 years) to a mature (80–200 years) forest. It is during this period that snags are created and large wood is provided to aquatic riparian ecosystems (Pollock et al. 2012).

Beavers influence the composition and structure of RRs through a variety of mechanisms. Beaver dams raise groundwater levels in valley bottoms, limiting conifer encroachment in low-gradient riparian zones and protecting riparian vegetation from wildfire (Chadde and Kay 1991; Fairfax and Whittle 2020). By felling large trees, beavers reduce canopy cover and increase down wood, adding complexity to the understory of riparian forests (Gibson and Olden 2014). Beaver dams and canals increase the extent of surface water, groundwater, and riparian vegetation in valley bottoms (Grudzinski et al. 2020; Williams et al. 2015). The cycle of flooding and draining of water behind beaver dams encourages the establishment of herbaceous wetland plant communities, which are important habitats for amphibians, small mammals, and other species (Arkle and Pilliod 2015; Frey 2018; Westbrook et al. 2011).

Stressors

The forced removal of Indigenous populations from their land, the loss of cultural burning practices, and over 100 years of active wildfire suppression have resulted in changes to the structure and composition of forests adapted to frequent fire regimes (Spies et al. 2018). Dry and seasonally dry forests have undergone increases in tree density and decreases in mean stem size (Hagmann et al. 2021). Dominance has shifted toward shade-tolerant species that preclude the reestablishment of pines, oaks, and other fire-adapted plants. These changes, coupled with climate warming, have shifted the fire regime to one of greater severity and larger size (Hessburg et al. 2021). Fire suppression has also shifted the composition and structure of riparian ecosystems, with recruitment of fire-sensitive, shade-tolerant conifers increasing forest density and replacing larger, less shade-tolerant trees such as oaks and Douglas-fir (Messier et al. 2012). In forest types with infrequent, high-severity fire regimes, the effects of fire suppression are more evident at the landscape level. With fewer fires, there is a reduction in the heterogeneity of successional stages and cohorts (Spies et al. 2019).

A variety of invasive plant species have established in riparian zones of southwestern Oregon and northwestern California. Abundant invasive plants include Himalayan blackberry (*Rubus armeniacus*) knotweed (*Fallopia* spp.), and saltcedar (*Tamarisk ramosissima*). Many woody and herbaceous species were imported to North America as ornamental plants or were planted for soil stabilization. Following disruption of natural

disturbance processes, these plants became established in floodplains, where they can negatively affect native species (Reeves et al. 2018; Richardson et al. 2007). Invasive plants often provide poor habitat for wildlife and disrupt the natural dynamics of streams and floodplains (Gross et al. 2020; Smith and Finch 2014).

Insect and disease effects include tree mortality caused by bark beetles, defoliators, and root pathogens. These disturbances affect vegetation dynamics, but at extents that are increasingly smaller than those affected by fire disturbance (Pabst and Spies 1999). Bark beetles are native to the study area and cause extensive mortality during outbreaks, which occur during periods of warmer winters. Nonnative root pathogens include *Phytophthora ramorum*, which causes sudden oak death, reducing basal area and density of tanoaks by up to 50 percent in forest stands; and *Phytophthora lateralis*, which has reduced cover of Port Orford cedar in riparian zones throughout most of the tree's native range (Hansen et al. 2000; Waring and O'Hara 2008). The spread of *Phytophthora lateralis* has slowed in recent years, so the elimination of Port Orford cedar is not expected (Jules et al. 2015). Sudden oak death has been aggressively controlled, but *Phytophthora ramorum* is unlikely to be eradicated from the Five Forests planning area (Hansen 2008).

Dams, diversions, and roads can disrupt surface flows that shape a stream's geomorphology and connect the channel to its floodplain. Additionally, these structures disrupt the natural processes of scour and deposition (Kondolf 1997; Trombulak and Frissell 2000). By altering the volume and timing of surface flows or removing them altogether, dams and diversions reduce the extent of riparian vegetation in affected areas (Asarian and Walker 2016; DeWine and Cooper 2007). Roads and other forms of development restrict the movement of stream channels, thereby limiting the horizontal structure of riparian vegetation to a subsection of the historical floodplain (Forman and Alexander 1998; Jones et al. 2000). Roads also fragment riparian and aquatic habitats, disrupting dispersal corridors (Reeves et al. 2018).

Old-growth and mature forest stands have been greatly reduced by logging, making the persistence of these forest types more vulnerable to natural disturbances (Spies et al. 2018; Taylor and Skinner 2003). In many areas, postharvest replanting resulted in spacing and composition of forests that differ from those that would have naturally established post-fire. The loss of large, fire-resistant trees to logging has affected forest ecosystem integrity in seasonally dry forests (Hessburg et al. 2019). In some areas, forests were logged up to streams and replaced with conifer plantations, reducing hardwood cover. In other places, conifers have not reestablished post-logging and now hardwood cover is greater than in the past (Reeves et al. 2018). Other harvest methods, such as green tree retention and postfire salvage logging, reduce the abundance of live trees, snags, and potential for down wood (Spies et al. 2018).

The Northwest Forest Plan placed 80 percent of remaining old-growth stands into late successional reserves because forest harvest practices were not compatible with

the management of ecological integrity and endangered species (USDA FS and USDO BLM 1994). Riparian reserves protected additional areas of forest. Seasonally dry forests, however, require some forms of management to promote ecological integrity in response to decades of fire suppression and succession to forests dominated by shade-tolerant species (Hessburg et al. 2021). In these forests, shade-tolerant conifers have also encroached onto riparian ecosystems, reducing the cover of hardwoods and other riparian-associated types (Reeves et al. 2018). In dry or seasonally dry forests, management to restore or mimic natural fire regimes is now considered a higher priority than maintaining or creating large expanses of dense, multilayered habitat for northern spotted owl (Spies et al. 2018). Changes to RR management may therefore be necessary to maintain or restore ecological integrity (Messier et al. 2012).

Livestock and wildlife herbivory influence the composition, vertical structure, and coverage of riparian vegetation. Impacts of cattle grazing include decreased cover of native plants and increased cover of introduced plants (Platts and Nelson 1989). Grazing has also been shown to influence the composition of wetland vegetation in California meadows, especially when coupled with a drying climate (Oles et al. 2017). Streams and valley bottoms are vulnerable to the effects of other land uses including agriculture, development, and recreation. These stressors directly reduce the cover of vegetation and indirectly alter communities through the introduction of invasive species and alteration of geomorphic processes (Gross et al. 2020; Richardson et al. 2007).

Where beavers were present before Euro-American settlement, their removal has resulted in stream incision, lowering of water tables, and disconnection of streams from floodplains (Pollock et al. 2014; Wohl 2021). These changes prompt the loss of willow and herbaceous plant communities and encourage the encroachment of conifers and upland plants into valley bottoms (Marshall et al. 2013).

The warming and drying climate is interacting with fire suppression to increase the frequency, size, and severity of wildfires, thus favoring hardwoods and shade-intolerant conifers and limiting the production of large snags and down wood (Spies et al. 2018). In drier sites, this fire regime can cause a conversion from forests to shrublands (Hessburg et al. 2019). Increases in temperature shift precipitation from snow to rain, reduce snowpack depth, and cause earlier snowmelt (Reeves et al. 2018). Associated increases in winter flows and decreases in peak flows may result in changes to channel form and dynamics. Reductions in summer flows may narrow the extent of riparian zones, alter riparian plant composition, and reduce cover of stream-shading vegetation (Halofsky et al. 2022).

Desired and Reference Conditions

Desired conditions of RRs promote ecological functions for riparian and aquatic habitats, as well as upland-aquatic linkages. These functions include wood deposition, stream shading, nutrient input, protection of microclimates, movement corridors,

habitat for sensitive species, and buffers against stressors in uplands (Pollock et al. 2012).

In dry and seasonally dry forests, which make up most of the Five Forests planning area, desired forest conditions include the presence of large fire-resistant trees, large snags, successional heterogeneity, stands with an open understory, and patches of nonforest vegetation (Hessburg et al. 2021; Spies et al. 2018). These features are associated with a high density of woodrats (*Neotoma* spp.) which are the primary prey of northern spotted owl in the southern portion of their range (Lesmeister et al. 2018). Instead of specific densities of live trees and snags, a landscape mosaic of forest types and nonforest areas is recommended to meet the needs of multiple species and respond to various types of disturbance (Hessburg et al. 2019; Pollock and Beechie 2014).

Large trees, snags, and down wood are important features of aquatic and terrestrial habitats within RRs. Large, live trees (minimum 13.8 inches diameter, mean diameter greater than 19.7 inches, and maximum diameter exceeding 39.4 inches) are used as nest sites by marbled murrelet and spotted owl (Lesmeister et al. 2018; Raphael et al. 2018). In dry forests, trees with a mean diameter of 23.6 inches or greater are considered components of highly suitable habitat (Lesmeister et al. 2018). The ideal minimum diameter of instream wood varies from 5.9 to 29.5 inches, depending on stream size (Pollock and Beechie 2014). Snags and down wood in any size class are valuable to wildlife, but snags or down wood greater than 19.7 inches in diameter will benefit the greatest number of species (Pollock and Beechie 2014). Larger sizes of down wood are also more effective at buffering fluctuations in temperature that may affect ectotherms such as salamanders (Kluber et al. 2009).

Given the effects of valley width, surface flows, groundwater dynamics, watershed position, and other physical variables on riparian ecosystem dynamics, the percent cover of riparian ecosystems in RRs will vary considerably among locations (Pabst and Spies 1999). Species composition also has high spatial and temporal variation (Reeves et al. 2018). Pabst and Spies (1999) found that hardwoods and shrubs, but not conifers, typically dominate in unconfined valley bottoms of unmanaged forests in the Klamath Mountains of Oregon. Conifers instead dominate adjacent terraces and lower hillslopes, where they can still contribute to riparian and aquatic ecosystem function. Red alder dominates valley bottom forests under reference conditions but can establish in upland areas following disturbances such as landslides and timber harvest. Data from additional stands in the Klamath Mountains and Cascades are needed, however, to determine how these results can be extrapolated to the majority of the Five Forests planning area.

Data Sources and Evaluation

To describe the composition and structure of vegetation in RRs, we obtained GIS rasters of results from Gradient Nearest Neighbor (GNN) mapping of vegetation in the Northwest Forest Plan area (Appendix B). Nearest neighbor imputation integrates forest

inventory plots with satellite imagery to map forest characteristics across large extents (Ohmann et al. 2014). The GNN datasets used here were developed with 30-m Landsat imagery and Forest Inventory and Analysis data by the Landscape Ecology, Modeling, Mapping and Analysis Group. In addition, we used the LANDFIRE 2016 REMAP Existing Vegetation Type raster to measure the amount of area within RRs classified as existing and potential riparian vegetation (Rollins 2009). Spatial data representing timber harvest, wildfire, and forest loss were obtained from the USDA Forest Service National Dataset and the Global Forest Change project (GFC) (Appendix B).

Because the majority of vegetation in RRs is upland forest, we also evaluated current conditions using results from assessments of departure from potential natural vegetation (dominant vegetation in the absence of disturbance) in upland forest zones, conducted for the Five Forests. We used these, in combination with the datasets listed earlier, to determine whether the composition and structure of RRs have departed from that expected under historical disturbance regimes, with implications for current conditions. We determined that the RR condition was altered if multiple indicators revealed impacts of stressors on composition and structure.

Condition of Rare and Unique Habitats

Drivers

The composition and structure of vegetation in fens are largely influenced by topography and groundwater chemistry (Chimner et al. 2010; Lemly and Cooper 2011; Wolf and Cooper 2015). Rich fens, fed by high-pH water from carbonate bedrock, have high species richness. Poor fens have a low pH from iron-rich bedrock and serpentine fens occur in areas with high levels of magnesium and heavy metals; these fens have lower species richness but support plant species that are rare or endemic to the region (Frost et al. 2004; Sikes et al. 2010). Historically, frequent low- to moderate-severity fire controlled the encroachment of conifers and other woody plants into fens (Frost et al. 2004). Fire can alter the composition of wetland vegetation in fens, but impacts are typically minor in the wet areas dominated by sedges and other herbaceous plants (Christy et al. 2014; Jules et al. 2011).

The composition of plant and animal communities associated with springs is largely determined by site-specific geomorphology (Stevens et al. 2021). The discharge of groundwater to the surface via pools, stream channels, and phreatophytic vegetation creates a variety of microhabitats for aquatic, wetland, and riparian species. Temperature, chemical composition, and permanence of groundwater influence the composition of plants and animals at springs (Sada and Pohlmann 2006; Sada et al. 2001).

Temperature, precipitation, and pool dimensions are major drivers of vernal pool plant and animal community composition because they influence the length of inundation periods (Keeler-Wolf et al. 1998). Pools must remain inundated long enough for animals such as California tiger salamander, western spadefoot, and vernal pool tadpole

shrimp, to complete the aquatic phases of their life cycles (King et al. 1996; Laabs et al. 2002). The cycle of flooding and drying is also instrumental in maintaining the unique composition of vernal pool plant communities. Long inundation periods prevent invasion from upland plants, whereas dry periods prevent dominance by perennial wetland plants (Gosejohan et al. 2017). Organisms can move among vernal pools using several mechanisms, including overland travel and dispersal by migratory animals such as birds (Laabs et al. 2002; Rogers 2014). Landscape conservation is therefore necessary to maintain connectivity for vernal pool obligates (Keeler-Wolf et al. 1998). Disturbances, such as herbivory and wildfire, structure plant communities as well. For example, moderate levels of livestock grazing can prevent the exclusion of annual specialists by generalist and invasive species, thereby maintaining the species richness of wetland plant communities (Borgias 2004; Bovee et al. 2018; Marty 2005).

Stressors

Anthropogenic modifications to watersheds, such as drainage ditches, diversions, groundwater pumping, mines, road construction, and timber harvest, have altered groundwater and surface water flow paths to fens, lowering their water tables and increasing sediment deposition (Frost et al. 2004; Patterson and Cooper 2007; Wolf and Cooper 2015). This results in encroachment by upland, non-fen plant species, and oxidation of peat soils. Disturbances to vegetation and peat soils result from livestock use, and off-road vehicles and other forms of recreation (Sikes et al. 2010). Fire suppression has exacerbated the encroachment of conifers and other woody plants into fens and may have increased fuel loads in and near fens (Jules et al. 2011). These changes may cause drying of peat soils and impacts on rare and endemic plant species due to increased levels of evapotranspiration and wildfire severity. The composition of fen plant communities is also sensitive to climatic factors that alter recharge to and discharge from groundwater systems, including changes in snowpack and precipitation amount, and drought severity and frequency (Sims et al. 2019d).

Springs are among the ecosystems most threatened by anthropogenic activities in the western United States (Stevens and Meretsky 2008). Spring developments for irrigation, livestock, and wildlife include the installation of headboxes, diversion of flows to troughs and other structures, and excavation of ponds (Sada et al. 2001). Groundwater pumping may disrupt flow networks connecting precipitation, aquifers, and springs, with consequences for vegetation at emergence sites and spring-fed streams (Kreamer et al. 2015). These activities have adverse effects on plant and animal assemblages, but spring-dependent species can persist if spring developments are planned correctly (Gurrieri 2020; Unmack and Minckley 2008). Like riparian ecosystems, springs, even in an undisturbed state, are vulnerable to colonization by invasive plant species (Perla and Stevens 2008). In addition to grazing and trampling vegetation, livestock contribute to the spread and dominance of invasive plants (Gurrieri 2020; Nielson et al. 2019). Livestock-related stressors are most widespread in arid rangelands (Freed et al. 2019). Springs are also sensitive to climatic factors that alter recharge to and discharge from

groundwater systems, including changes in snowpack and precipitation amount, and drought severity and frequency (Sims et al. 2019c).

Livestock grazing affects the structure and composition of vernal pool communities through various mechanisms. A study on the Modoc Plateau (northeastern California) found that annual specialists are favored by livestock grazing, at the expense of perennial specialists (Bovee et al. 2018). Excessive levels of grazing or early season grazing, however, may reduce the cover of all generalists and specialists (Merriam et al. 2016). Where invasive grasses may compete with native species, the removal of disturbance, such as livestock grazing, has been linked to increased cover of invasive vegetation and litter, decreased cover of native species, and a decrease in the length of the inundation period, which affects habitat for aquatic invertebrates (Borgias 2004; King et al. 1996; Marty 2005; Pyke and Marty 2005). Additional stressors include off-road vehicle use and other recreation impacts, and damming, excavation, and other hydrologic changes (Holland 2006; Keeler-Wolf et al. 1998; Metlen et al. 2016). The composition of aquatic fauna is affected by predation by invasive species, such as American bullfrog (*Lithobates catesbeianus*), and pollution from livestock and roads (EcoAnalysts 2008; Laabs et al. 2002). Invasive plants affect vernal pool communities in the Central Valley of California and the Rogue Valley of Oregon, but probably do not have as large an impact in vernal pools on the Five Forests (Borgias 2004; Padgett 2020). Given the strong influence of precipitation and evaporation on the hydrology of vernal pools, these ecosystems are highly sensitive to changes in precipitation and temperature. Climate change affects vernal pool communities, but impacts will vary among locations. Where winter precipitation increases, inundation length is likely to increase, which could create additional habitat for vernal pool specialists, such as fairy shrimp, but could also increase habitat for species that prey on them, such as aquatic insects (Pyke 2005). Where increases in air temperatures exceed increases in precipitation, inundation periods are likely to decrease, with consequences for vernal pool specialists such as annual plants (Montrone et al. 2019).

Desired and Reference Conditions

The following are desired conditions for fens and springs in western national forests, as compiled by Gurrieri (2020). Normal patterns of groundwater recharge, flow, and discharge occur. Groundwater is not contaminated. Ecological structure, diversity, and function are intact. A diversity of spring types (pool-forming, mound-forming) are conserved in the landscape. Aquifers are not being affected by groundwater withdrawal or loss of recharge. Soils are intact and functional. Erosion and deposition are within NRV. Springbrooks function naturally and are not entrenched, eroded, dewatered, or otherwise altered. Anticipated composition of vegetation is present. Hydric species are not replaced by upland species. Processes are in place to support peat production. Livestock herbivory and trampling are not adversely affecting springs and fens.

Properly functioning vernal pools experience a hydrologic regime characterized by winter and spring inundation followed by a period of drying in the summer and

fall. During the dry period, intermediate levels of disturbances such as grazing and fire occur to maintain a species-rich plant community (Borgias 2004). Under desired conditions, water depth, inundation period, and disturbance will maintain a plant community composed of annual specialists, perennial specialists, perennial generalists, and a minimal amount of invasive species (Bovee et al. 2018; Gosejohan et al. 2017). The aquatic invertebrate community will be dominated by species with life cycles dependent on seasonal inundation and drying of pools, such as tadpole shrimp and fairy shrimp (EcoAnalysts 2008; King et al. 1996).

Data Sources and Evaluation

We used the data sources described in the section “Riparian Reserves Condition” to compare stressors among the Five Forests. To describe the current condition of unique and rare habitats, we summarized results from studies within and near the Five Forests planning area. Data were insufficient to determine whether the condition of fens, springs, or vernal pools was altered in the Five Forests.

CHAPTER 4: CONCLUSIONS

Limitations of This Assessment

This report describes our initial assessment of riparian, aquatic, and groundwater-dependent ecosystems in the Five Forests planning area. Our analyses were limited to datasets covering the full extent of the planning area and our results highlight management issues at the scale of the eight study units. Additional syntheses of site-specific data are needed to assess variation within forests and identify issues of local importance.

General Management Issues Affecting the Five Forests Planning Area

Projected climate change impacts include increases in high-severity wildfire, increases in stream intermittency, increases in flood magnitude, increases in stream temperature, and decreases in summer baseflows. Given our observations of the high percentage of RR area burned in the Mendocino National Forest (MNF) and the increases in stream temperatures throughout the Five Forests, these impacts are likely to be already occurring.

The most widespread stressor with the greatest potential impacts on riparian and aquatic ecosystems is departure from historical fire regimes (fig. 30). The legacy of forest management has created an urgent situation for active management, such as mechanical thinning, managed fire, and restoration of cultural burning, especially in the Cascades units and lower elevations of the Klamath Mountains units. As current conditions interact with climate change, it will be increasingly important to take these steps to protect endangered species habitat, unique ecosystems, and wildlife corridors.

Populations of anadromous fishes have been most heavily impacted by factors outside of forest management, such as dams, hatcheries, and ocean conditions. Populations are further imperiled from impacts of global climate change. Forest management actions that may aid recovery include removal of dispersal barriers, protection of riparian vegetation from fire and other types of forest loss, reestablishment of beaver, and protection of groundwater-dependent ecosystems.

Summary of Assessment Results

Ecosystem Distribution

Permanently flowing fish-bearing streams are evenly distributed throughout the Klamath Mountains units but are much more limited in extent on the volcanic plateaus of the Cascades units. Seasonally flowing fish-bearing streams are rare in each of the forests. Seasonally flowing nonfish-bearing streams cover the greatest area of each forest, with the exception of the Rogue River-Siskiyou National Forest (RRSNF). The apparent difference between this forest and the others may reflect issues in the National Hydrography Dataset, which is currently being updated for the region.

The Klamath Mountains units contain ultramafic rocks and abundant springs, which create conditions for the development of serpentine fens and their unique plant



Figure 30—Dense stands of conifers in the understory along the McCloud River in the Shasta-Trinity National Forest—Cascades unit. The high density of understory conifers indicates departure from the historical frequent fire regime in these riparian reserves. USDA Forest Service photo by Carlita Hallett and Felicia Schneider.

communities. Conditions for development of peatland fens and vernal pools are greatest in the Cascades units, where there are alluvial deposits, glacial deposits, and volcanic plateaus. Springs occur throughout all of the forests but tend to occur at higher densities in the Cascades units. Springs with high discharge volume may be associated with carbonate karst in the Klamath Mountains and with volcanic bedrock in the Cascades. Little information is available regarding the presence or distribution of vernal pools in the forests, apart from a study in the Shasta-Trinity National Forest. Because of overlap with both the Klamath Mountains and Cascades physiographic provinces, the Shasta-Trinity National Forest (STNF)—Cascades unit stands out as the area with the richest assortment of unique and rare habitats in the planning area. Within this unit, surveyors have documented serpentine fen plant communities, vernal pool tadpole shrimp, and important limestone habitats.

Connectivity

Indicators of aquatic connectivity varied among units of the Five Forests. The RRSNF—Cascades unit and the MNF had the lowest measures of connectivity. In these units, climate change, drought, and habitat fragmentation appear to have impacted connectivity by raising water temperatures and blocking passage of fish and other organisms. Bridges, culverts, and dams are present throughout the Five Forests

planning area, but these barriers are likely to have relatively minor impacts on connectivity within the study area.

Riparian connectivity between watersheds across the Five Forests appears to generally be high. Interwatershed connectivity was greatest for Klamath Mountains units in the southern portion of the study area. Most watersheds on the MNF and SRNF, and those in the STNF—Klamath Mountains unit, are connected to more than 20 percent of their neighbors (fig. 31). Watersheds in the RRSNF, the Klamath National Forest (KNF), and the STNF—Cascades unit tend to be less connected to neighbors, with the amount of disconnected neighboring watersheds particularly high in the KNF—Cascades unit. The KNF—Cascades unit is the only unit considered in this assessment with most neighboring watersheds disconnected from one another (fig. 31). The remaining units have numerous neighboring watersheds that are connected with 0 miles between RRs. The KNF—Klamath Mountains unit, RRSNF—Klamath Mountains unit, STNF—Cascades unit, STNF—Klamath Mountains unit, and the SRNF also have many neighboring watersheds with RRs within 0.25 mile of one another (fig. 32). These units have high potential for increasing connectivity between RRs. The MNF and the RRSNF—Cascades unit have relatively fewer watersheds with RRs that occur within 0.25 mile of one another (fig. 32).

A variety of amphibians and other organisms rely on riparian habitat linkages for dispersal throughout the planning area. Riparian reserves and triads, where headwaters of three HUC8 watersheds meet, are an important component of watershed connectivity in each of the Five Forests. As a result, forest management in one watershed is likely to have implications extending to other watersheds and river basins. Management of forest lands within watersheds joined by triads is influenced by the presence of key watersheds and other protected land designations, and by the condition of RRs. Several watersheds in the KNF—Cascades unit, the MNF, and the STNF—Cascades unit do not overlap key watersheds. Expansion of KWs to cover a greater percentage of areas linked by triads could help to prevent increases in stressors to connectivity, such as road density. Additional protection of these watersheds could support climate change adaptation for amphibians and other sensitive species.

Condition of Riparian Reserves

In addition to buffering stream ecosystems from upland disturbance, RRs are habitat for a variety of wildlife, including many sensitive species. Spatial data suggest that, in the Klamath Mountains, riparian vegetation covers a smaller percentage of RRs than expected under historical conditions. A greater percentage is covered by riparian vegetation in the Cascades, where stream gradients are gentler and valley bottoms are wider. Though upland forest types were classified within RRs, riparian vegetation types, such as willow-dominated shrublands, are more difficult to map and classify because they occupy a narrow extent and are prone to frequent changes in composition and distribution.

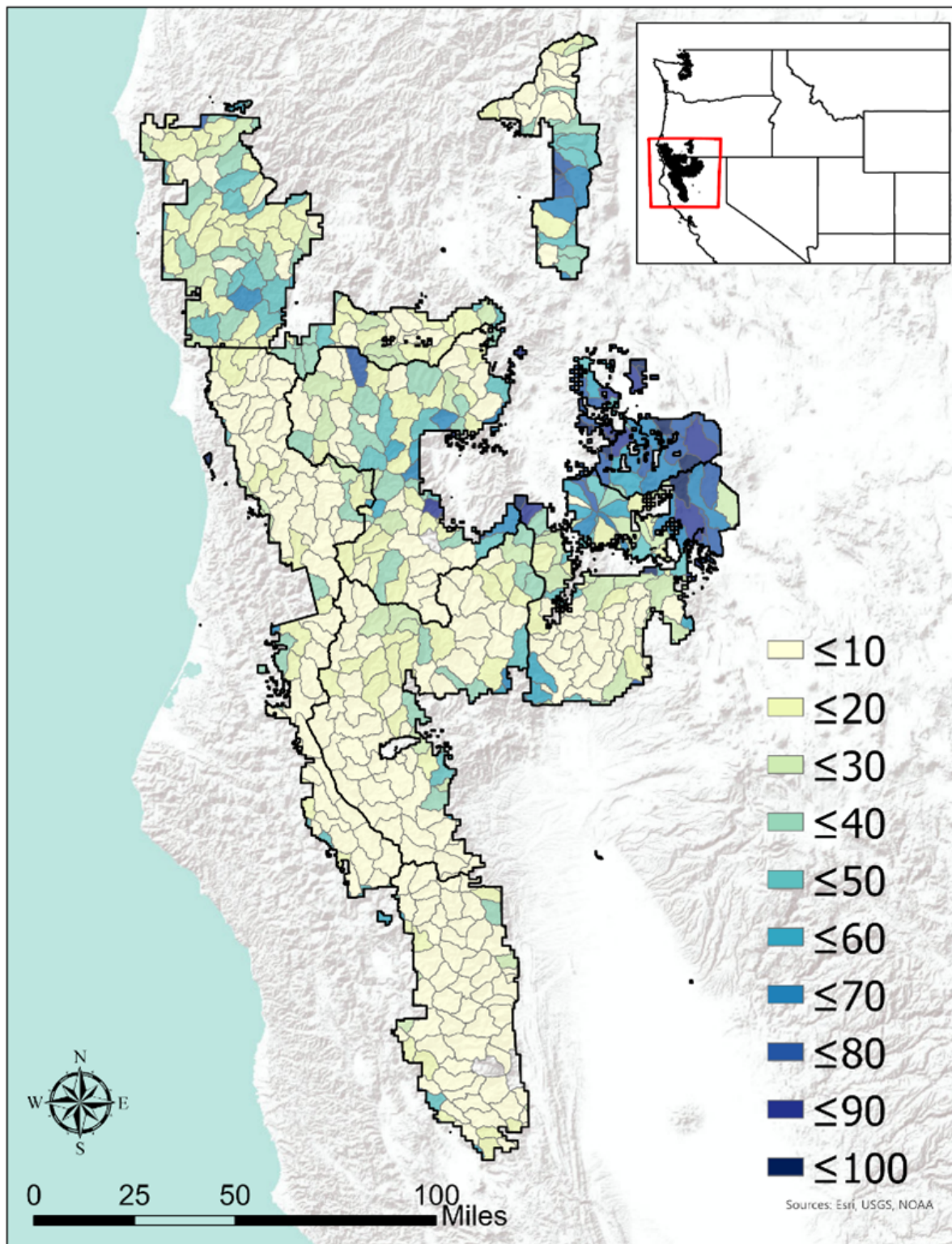


Figure 31—Percentage of neighboring watersheds with which each watershed is not connected within the Five Forests cohort. Light yellow watersheds are more connected to their neighboring watersheds. Dark blue watersheds are more disconnected from their neighboring watersheds. Inset shows location of study area within Oregon and California.

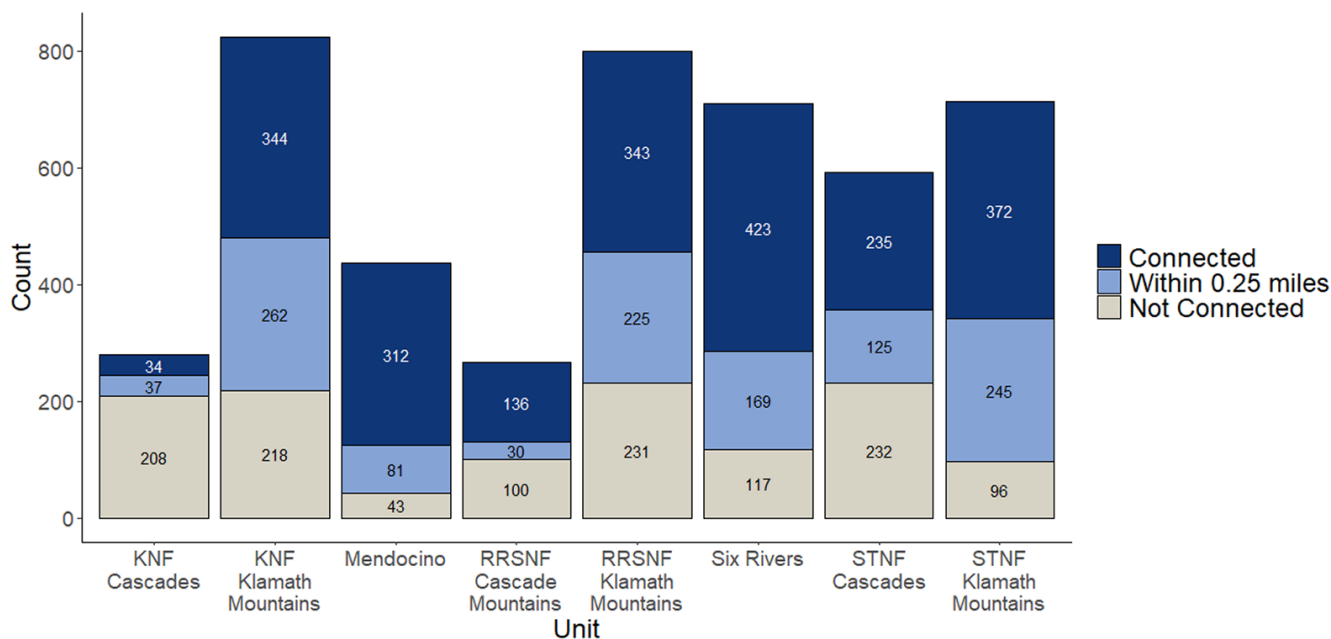


Figure 32—The total number of paired watersheds with potentially connected riparian reserves (RRs) within each unit of the Five Forests and the number of paired watersheds classified as connected (distance of 0 miles between RRs in neighboring watersheds), within 0.25 mile, or not connected (distance greater than 0.25 mile between RRs in neighboring watersheds). KNF: Klamath National Forest; RRSNF: Rogue River-Siskiyou National Forest; STNF: Shasta-Trinity National Forest.

In most study units, we found evidence that live trees, snags, and down wood exist in a range of size classes that benefit numerous species. Several stressors to composition and structure of RRs, such as roads and invasive species, occur throughout the planning area. Hydrological changes, resulting from stressors such as altered disturbance regimes, climate change, dams, diversions, and loss of forest cover, have likely impacted RRs in the RRSNF—Klamath Mountains unit, KNF—Cascades unit, STNF—Klamath Mountains unit, STNF—Cascades unit, and MNF.

Most of the area in RRs is covered by dry and seasonally dry forest types that were historically maintained by frequent, low-intensity or mixed-intensity fire regimes. These fire regimes created a landscape with patches of various successional states, including mature and old-growth forest, and nonforest areas. These historical likely conditions promoted ecosystem resilience and created habitat for a variety of wildlife including northern spotted owl. The dry and seasonally dry forest types that are currently found in RRs have departed from NRV because of fire exclusion and climate change, and the resulting increase in large, high-severity fires. As in other forests of the western United States, increases in severity resulted from fire exclusion and increases in size have likely been driven by the increasingly hot and dry conditions associated with climate change.

Exposure to climate change effects generally increases from north to south in the Five Forests cohort. The MNF has the greatest exposure to climate change and, accordingly

has by far the greatest percentage of forest loss within RRs (18–40 percent across stream habitats). Overall, RRs in the Klamath Mountains units had greater percentages affected by fire and subsequent forest loss. Nonetheless, RRs in the Cascades units have also departed from historical conditions, as evidenced by departure from historical fire regimes. In addition, few stand treatments have occurred within RRs, making riparian and aquatic habitats vulnerable to high-severity fire, which will increase in extent as a result of climate warming. Forest loss tended to be greatest in RRs associated with seasonally flowing streams. Riparian reserves associated with permanently flowing fish-bearing streams typically had the lowest percentages of forest loss. Wildlife associated with headwater streams and seasonally flowing streams may therefore be most vulnerable to increases in severity and extent of wildfire. Because our structure and composition data were obtained from models run prior to 2018, additional research and monitoring are necessary to identify effects of recent wildfires and forest loss on current RR conditions.

Condition of Aquatic Habitats

Critical habitat has been designated for Federally listed salmonids in each of the Five Forests. The vast majority of stream miles designated as critical habitat are associated with perennial streams. Critical habitat for Chinook salmon and steelhead in the RRSNF, SRNF, and MNF are located in key watersheds, which receive protection from future road development and include additional land-use regulations. We were unable to determine the full percentage of coho salmon critical habitat in key watersheds because data were unavailable. Percentage of areas with protections in the Cascades units (which also includes late successional reserves, administratively withdrawn areas, and congressional reserves) is generally lower than in the Klamath Mountains units. In general, there is a greater amount of stream habitat with HIP for steelhead than for Chinook or coho salmon. The watersheds with the greatest HIP for Chinook and coho salmon are currently blocked to fish passage by Shasta Dam. Additional barriers are present in each forest, but the greatest number of barriers occur on the KNF, RRSNF, and STNF.

Results from sampling sites and vegetation models suggest that large wood is contributing to instream habitat and is likely to continue to do so in the future. Instream wood was observed in four size classes at permanently flowing stream sampling sites in each study unit sampled by AREMP. Wood jams were observed in permanently flowing streams on the KNF, RRSNF, and SRNF. The greatest amounts of large instream wood were found in the RRSNF—Cascades unit. Based on GNN results, the Cascades units have the highest densities of large conifer trees and snags, indicating the greatest potential for deposition of this important habitat component into streams.

It appears that streams across the Five Forests have been impacted by multiple interacting stressors, resulting in moderate to substantial alterations to ecological integrity (exhibit 2). With the exception of the STNF, the distribution of stream habitats is likely to be within the natural range of variation within the cohort. Hydrologic

regimes are likely to be intact in the RRSNF—Cascades unit, the KNF—Klamath Mountains unit, and the SRNF, but are otherwise altered throughout the Five Forests. Water quality has been impacted in streams throughout the cohort, but streams in the Cascades appear to be resistant to stressors and maintain high water quality. With the exception of the RRSNF—Cascades unit and the MNF, stream connectivity is likely to be maintained throughout much of the Five Forests. Instream habitat quality of fish-bearing streams has likely been impacted by multiple interacting stressors in much of the cohort and RR conditions are also altered across the Five Forests.

Lakes, ponds, and reservoirs throughout much of the Five Forests are likely to exhibit high ecological integrity; the exceptions are those in the RRSNF—Klamath Mountains unit, STNF—Cascades unit, and the MNF, where these lentic habitats have likely experienced moderate alterations to ecological integrity (exhibit 2). The distribution of lakes, ponds, and reservoirs has been altered across the RRSNF and STNF. Hydrologic regimes in lakes, ponds, and reservoirs have likely been altered in the KNF—Cascades unit, STNF—Cascades unit, and RRSNF—Klamath Mountains unit, and throughout the MNF. In general, these habitats exhibit high water quality throughout much of the study area, with the exception of the MNF.

Condition of Rare and Unique Habitats

Fens, springs, and vernal pools are sensitive to changes in their watersheds, as well as to site-specific effects of stressors. Roads, fire suppression, surface water diversions, and groundwater use have likely influenced the dynamics of these habitats in the forests, but site visits are needed to evaluate their impacts. Direct impacts of livestock, invasive species, and recreation should be evaluated as well. These habitats are moderate to highly vulnerable to climate change, but the mechanisms differ, with fens and springs most vulnerable to changes in groundwater dynamics and vernal pools most vulnerable to changes in precipitation and temperature. Variation among geologic and geographic settings must therefore be considered in projecting future changes in condition.

Exhibit 2—Estimated ecological integrity status for aquatic habitats across the Five Forests based on the estimated condition of multiple key ecosystem characteristics (KECs)^a.

Study unit	Habitat ^b	Distribution	Hydrologic regimes	Water quality	Connectivity	Instream habitat quality	Riparian reserves condition	Ecological integrity
Rogue River-Siskiyou National Forest—Klamath Mountains	PFFB	Intact	Altered	Altered	Intact	Altered	Altered	Substantially altered
	PENFB	Intact	Altered	Intact	Intact	—	Altered	Moderately altered
	SFFB	Intact	Altered	Altered	Intact	Altered	Altered	Substantially altered
	SFNFB	Intact	Altered	Intact	Intact	—	Altered	Moderately altered
	Lakes, ponds, reservoirs	Altered	Altered	Intact	—	—	—	Moderately altered
Rogue River-Siskiyou National Forest—Cascades	PFFB	Intact	Intact	Intact	Altered	Altered	Altered	Moderately altered
	PENFB	Intact	Intact	Intact	Altered	—	Altered	Moderately altered
	SFFB	Intact	Intact	Intact	Altered	Altered	Altered	Moderately altered
	SFNFB	Intact	Intact	Intact	Altered	—	Altered	Moderately altered
	Lakes, ponds, reservoirs	Altered	Intact	Intact	—	—	—	High ecological integrity
Klamath National Forest—Klamath Mountains	PFFB	Intact	Intact	Altered	Intact	Intact	Altered	Moderately altered
	PENFB	Intact	Intact	Altered	Intact	—	Altered	Moderately altered
	SFFB	Intact	Intact	Altered	Intact	Intact	Altered	Moderately altered
	SFNFB	Intact	Intact	Altered	Intact	—	Altered	Moderately altered
	Lakes, ponds, reservoirs	Intact	Intact	Intact	—	—	—	High ecological integrity
Klamath National Forest—Cascades	PFFB	Intact	Altered	Intact	Intact	Altered	Altered	Moderately altered
	PENFB	Intact	Altered	Altered	Intact	—	Altered	Moderately altered
	SFFB	Intact	Altered	Intact	Intact	Altered	Altered	Moderately altered
	SFNFB	Intact	Altered	Intact	Intact	—	Altered	Moderately altered
	Lakes, ponds, reservoirs	Intact	Altered	Intact	—	—	—	High ecological integrity

Study unit	Habitat ^b	Distribution	Hydrologic regimes	Water quality	Connectivity	Instream habitat quality	Riparian reserves condition	Ecological integrity
Six Rivers National Forest	PFFB	Intact	Intact	Altered	Intact	Altered	Altered	Moderately altered
	PNFNB	Intact	Intact	Altered	Intact	—	Altered	Moderately altered
	SFFB	Intact	Intact	Altered	Intact	Altered	Altered	Moderately altered
	SNFNB	Intact	Intact	Intact	Intact	—	Altered	High ecological integrity
Lakes, ponds, reservoirs		Intact	Intact	Intact	—	—	—	High ecological integrity
Shasta-Trinity National Forest—Klamath Mountains	PFFB	Altered	Altered	Altered	Intact	Altered	Altered	Substantially altered
	PNFNB	Altered	Altered	Altered	Intact	—	Altered	Substantially altered
	SFFB	Altered	Altered	Altered	Intact	Altered	Altered	Substantially altered
	SNFNB	Altered	Altered	Altered	Intact	—	Altered	Substantially altered
Lakes, ponds, reservoirs		Altered	Intact	Intact	—	—	—	High ecological integrity
Shasta-Trinity National Forest—Cascades	PFFB	Altered	Altered	Intact	Intact	Altered	Altered	Substantially altered
	PNFNB	Altered	Altered	Intact	Intact	—	Altered	Moderately altered
	SFFB	Altered	Altered	Intact	Intact	Altered	Altered	Substantially altered
	SNFNB	Altered	Altered	Intact	Intact	—	Altered	Moderately altered
Lakes, ponds, reservoirs		Altered	Altered	Intact	—	—	—	Moderately altered
Mendocino National Forest	PFFB	Intact	Altered	Altered	Altered	Altered	Altered	Substantially altered
	PNFNB	Intact	Altered	Intact	Altered	—	Altered	Moderately altered
	SFFB	Intact	Altered	Altered	Altered	Altered	Altered	Substantially altered
	SNFNB	Intact	Altered	Intact	Altered	—	Altered	Moderately altered
Lakes, ponds, reservoirs		Intact	Altered	Altered	—	—	—	Moderately altered

— Indicates the KEC was not assessed for that habitat type.

^a We determined ecological integrity was likely moderately altered if two or three KECs indicated alteration. We determined ecological integrity was likely substantially altered if four or more KECs indicated alteration.

^b Abbreviations for streams are PFFB: permanently flowing fish-bearing; PNFNB: permanently flowing nonfish-bearing; SFFB: seasonally flowing fish-bearing; SNFNB: seasonally flowing nonfish-bearing.

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APPENDIX A. STUDY UNIT DATA FOR THE FIVE FORESTS COHORT

The following data tables for the Five Forests, with brief descriptions, are contained in this appendix.

Table A.1—Percentages of level IV ecoregions represented within the eight study units.

Table A.2—Miles of streams and area of riparian reserves calculated for four stream types in each study unit.

Table A.3—Levels of stressors within each study unit. Data pertain to all lands within the administrative boundaries of the national forests and include fire regime departure, recent wildfire activity, and percentage of unit in poor or very poor condition for climate change exposure.

Table A.4—Land-use allocations, such as percentage of area in key watersheds and riparian reserves, within the study units.

Table A.5—Endangered, threatened, and sensitive riparian species that may rely on interwatershed linkages for dispersal across the Five Forests.

Table A.6—Amphibian species observed at Aquatic and Riparian Effectiveness Monitoring Program monitoring sites that may rely on interwatershed linkages for dispersal across the Five Forests.

Table A.7—Rare and unique habitats and associated geologic features within the study units.

Table A.1—Percentages of level IV ecoregions represented within the eight study units of the Five Forests.

Study unit	Rogue River-Siskiyou National Forest—Klamath Mountains	Rogue River-Siskiyou National Forest—Cascades	Klamath National Forest—Klamath Mountains	Klamath National Forest—Cascades	Six Rivers National Forest	Shasta-Trinity National Forest—Klamath Mountains	Shasta-Trinity National Forest—Cascades	Mendocino National Forest
Total area (acres)	1,388,923	458,962	1,335,355	436,680	1,557,864	1,155,682	1,272,969	1,072,435
Klamath Subalpine	—	—	4	—	—	4	1	—
Foothill Ridges and Valleys	—	—	—	—	—	1	<1	<1
Northern Franciscan Redwood Forest	1	—	—	—	<1	—	—	—
North Valley Alluvium	—	—	—	—	—	—	—	<1
Coastal Uplands	<1	—	—	—	—	—	—	—
Coastal Lowlands	—	—	—	—	<1	—	—	—
Montane Highlands	—	10	—	—	—	—	—	—
Sacramento/Feather Riverine Alluvium	—	—	—	—	—	—	—	<1
Mid-Coastal Sedimentary	4	—	—	—	—	—	—	—
High Southern Cascades Montane Forest	—	19	—	28	—	—	8	—

Table A.1 continued

Study unit	Rogue River-Siskiyou National Forest—Klamath Mountains	Rogue River-Siskiyou National Forest—Cascades	Klamath National Forest—Klamath Mountains	Klamath National Forest—Cascades	Six Rivers National Forest	Shasta-Trinity National Forest—Klamath Mountains	Shasta-Trinity National Forest—Cascades	Mendocino National Forest
Total area (acres)	1,388,923	458,962	1,335,355	436,680	1,557,864	1,155,682	1,272,969	1,072,435
Marble/Salmon Mountains—Trinity Alps	—	—	26	—	8	12	—	—
Scott Mountains	—	—	3	—	—	12	9	—
Duzel Rock	—	—	<1	<1	—	—	<1	—
Serpentine Siskiyou	17	—	10	<1	17	—	—	—
Border High Siskiyou	11	—	7	—	—	—	—	—
Coastal Siskiyou	32	—	—	—	<1	—	—	—
Inland Siskiyou	21	<1	—	—	—	—	—	—
Low Southern Cascades Mixed Conifer Forest	—	66	—	36	—	—	27	—
California Cascades Eastside Conifer	—	—	—	6	—	—	4	—
Klamath River Ridges	—	—	16	1	—	—	—	—
Klamath/Goose Lake Basins	—	—	—	5	—	—	—	—

Level IV Ecoregions

Table A.1 continued

Study unit	Rogue River-Siskiyou National Forest—Klamath Mountains	Rogue River-Siskiyou National Forest—Cascades	Klamath National Forest—Klamath Mountains	Klamath National Forest—Cascades	Six Rivers National Forest	Shasta-Trinity National Forest—Klamath Mountains	Shasta-Trinity National Forest—Cascades	Mendocino National Forest
Total area (acres)	1,388,923	458,962	1,335,355	436,680	1,557,864	1,155,682	1,272,969	1,072,435
Southern Cascades Slope	—	1	—	1	—	—	—	—
Southern Cascades Foothills	—	—	—	—	—	—	<1	—
Southern Oregon Coastal Mountains	12	—	—	—	—	—	—	—
Modoc Lava Flows and Buttes	—	—	—	19	—	—	—	—
Old Cascades	—	—	—	<1	—	—	—	—
Rogue/Illinois/Scott Valleys	<1	—	<1	—	—	—	—	—
Western Klamath Low Elevation Forests	<1	—	21	—	42	13	—	—
Eastern Klamath Low Elevation Forests	—	—	7	—	—	42	41	—

Table A.1 continued

Study unit	Rogue River-Siskiyou National Forest—Klamath Mountains	Rogue River-Siskiyou National Forest—Cascades	Klamath National Forest—Klamath Mountains	Klamath National Forest—Cascades	Six Rivers National Forest	Shasta-Trinity National Forest—Klamath Mountains	Shasta-Trinity National Forest—Cascades	Mendocino National Forest
Total area (acres)	1,388,923	458,962	1,335,355	436,680	1,557,864	1,155,682	1,272,969	1,072,435
Western Klamath Montane Forests	<1	—	3	—	7	—	—	—
Eastern Klamath Montane Forests	—	—	2	—	—	8	6	—
Cascades Subalpine/Alpine	—	2	—	—	—	—	2	—
North Coast Range Eastern Slopes	—	—	—	—	—	—	—	22
Clear Lake Hills and Valleys	—	—	—	—	—	—	—	<1
Outer North Coast Ranges	—	—	—	—	19	—	—	13
High North Coast Ranges	—	—	—	—	6	9	—	65
Western Cascades Montane Highlands	—	10	—	—	—	—	—	—
Oak Savanna Foothills	<1	1	—	—	—	—	—	—

Level IV Ecoregions

Table A.1 continued

Study unit	Rogue River-Siskiyou National Forest—Klamath Mountains	Rogue River-Siskiyou National Forest—Cascades	Klamath National Forest—Klamath Mountains	Klamath National Forest—Cascades	Six Rivers National Forest	Shasta-Trinity National Forest—Klamath Mountains	Shasta-Trinity National Forest—Cascades	Mendocino National Forest
Total area (acres)	1,388,923	458,962	1,335,355	436,680	1,557,864	1,155,682	1,272,969	1,072,435
Shasta Valley	<1	—	—	2	—	—	1	—

— Indicates ecoregion is not present in the study unit.

Table A.2.—Total length of streams and area of riparian reserves calculated for four stream types in each study unit of the Five Forests. Data were summarized for all lands within the administrative boundaries of the national forests.

Length of streams and area of riparian reserves ^a	Rogue River-Siskiyou National Forest—Klamath Mountains unit	Rogue River-Siskiyou National Forest—Cascades unit	Klamath National Forest—Klamath Mountains unit	Klamath National Forest—Cascades unit	Six Rivers National Forest	Shasta-Trinity National Forest—Klamath Mountains unit	Shasta-Trinity National Forest—Cascades unit	Mendocino National Forest
Miles PFFB streams	1,339.0	434.7	1,091.8	41.1	1,511.7	1,434.3	542.4	714.8
Miles PFNFB streams	3,675.9	527.3	1,573.0	42.0	1,354.5	1,379.4	516.6	717.5
Miles SFFB streams	18.5	15.1	30.8	4.5	112.4	52.8	18.0	55.5
Miles SFNFB streams	1,235.4	1,310.9	3,289.2	335.6	9,012.0	5,220.1	3,540.7	7,898.0
Acres PFFB RRs	87,494.7	30,629.8	73,118.6	3,946.5	76,470.0	97,118.0	38,034.3	39,425.9
Acres PFNFB RRs	152,732.9	20,943.5	57,962.9	2,101.5	42,743.2	56,415.2	27,916.4	26,941.6
Acres SFFB RRs	1,242.6	1,254.0	2,130.5	355.4	5,128.3	3,869.6	1,340.7	3,273.4
Acres SFNFB RRs	52,051.7	60,266.8	126,103.4	14,088.4	336,468.4	202,067.4	198,556.0	274,074.1

^aPFFB: permanently flowing fish-bearing streams; PFNFB: permanently flowing nonfish-bearing streams; SFFB: seasonally flowing fish-bearing streams; SFNFB: seasonally flowing nonfish-bearing streams; RRs: riparian reserves.

Table A.3—Levels of stressors within the study units of the Five Forests. Data pertain to all lands within the administrative boundaries of the national forests.

Stressor	Rogue River-Siskiyou National Forest—Klamath Mountains	Rogue River-Siskiyou National Forest—Cascades	Klamath National Forest—Klamath Mountains	Klamath National Forest—Cascades	Six Rivers National Forest	Shasta Trinity National Forest—Klamath Mountains	Shasta Trinity National Forest—Cascades	Mendocino National Forest
Road density (miles per square mile)	1.3	3.2	1.92	1.92	1.28	2.56	1.92	1.92
Diversions (number per square mile)	0.7	0.5	0.3	0.1	0.3	0.4	0.1	0.2
Mines (number of historical and active in unit; total acres impacted)	901; 266	78; 87	1,274; 1,237	46; 56	619; 157	469; 1,542	272; 226	39; 0
Timber harvest (percentage of unit affected since 1930s)	8.4%	26.9%	12.1%	22.1%	9.2%	8.3%	9.1%	3.9%
Livestock use (percentage of unit in grazing allotments)	16.6%	72.9%	40.5%	75.5%	22.2%	37.9%	16.5%	52.9%
Springs in active allotments	69.3	65.0	54.8	77.2	36.9	21.4	13.6	30.3
Recreation impacts (trail miles per acre; recreation sites per acre)	0.0005; 0.0002	0.001; 0.0002	0.0005; 0.0004	0.0004; 0.0002	0.0002; 0.0006	0.0007; 0.0008	0.0004; 0.0005	0.0005; 0.0006
Fire regime departure (percentage of unit classified as impaired)	57%	37%	23%	72%	3%	3%	39%	32%

Table A.3 continued

Stressor	Rogue River-Siskiyou National Forest—Klamath Mountains	Rogue River-Siskiyou National Forest—Cascades	Klamath National Forest—Klamath Mountains	Klamath National Forest—Cascades	Six Rivers National Forest	Shasta Trinity National Forest—Klamath Mountains	Shasta Trinity National Forest—Cascades	Mendocino National Forest
Recent wildfires (percentage of unit burned by moderate- and high-severity wildfire, respectively, since 2018)	1%, 2%	0%, 0%	3%, 7%	6%, 15%	5%, 7%	8%, 10%	1%, 2%	13%, 21%
Drought (percentage of unit affected)	0	10.3%	7.1%	0	20.2%	64%	54%	99.7%
Climate change exposure (percentage of unit in poor or very poor condition for climate change exposure)	0	10%	7%	50%	25%	65%	67%	100%

Table A.4—Land-use allocations within the study units of the Five Forests.

Variable	Rogue River-Siskiyou National Forest—Klamath Mountains unit	Rogue River-Siskiyou National Forest—Cascades unit	Klamath National Forest—Klamath Mountains unit	Klamath National Forest—Cascades unit	Six Rivers National Forest	Shasta Trinity National Forest—Klamath Mountains unit	Shasta Trinity National Forest—Cascades unit	Mendocino National Forest
Percentage in key watersheds	38.0	21.4	43.7	0	64.9	32.1	0	21.2
Percentage in late successional reserves	43.6	36.6	22.9	10.7	26.9	20.2	17.2	16.8
Percentage in administratively withdrawn areas	2.4	3.6	2.2	0.02	3.0	1.9	8.0	10.2
Percentage in congressional reserves	19.2	17.0	24.7	0	28.8	29.2	4.1	22.0
Percentage in riparian reserves	21.1	24.6	19.4	5.6	36.2	23.1	23.0	32.0

Table A.5—Endangered, threatened, and sensitive riparian species that may rely on watershed linkages for dispersal across the Five Forests planning area. Species were compiled from lists of sensitive species and special status species produced by USDA Forest Service Regions 5 and 6.

Group	Species	Federal status	State status	Listed national forest(s)
Fungi	Angel's hair lichen (<i>Ramalina thrausta</i>)	No status	Special concern	Six Rivers
	Cabbage lung lichen (<i>Lobaria linita</i>)	No status	Special concern	Rogue River-Siskiyou
	Unnamed fungus (<i>Stagnicola perplexa</i>)	No status	Special concern	Rogue River-Siskiyou
	Veined water lichen (<i>Peltigera gowardii</i>)	No status	Special concern	Klamath, Mendocino, Shasta-Trinity, Six Rivers
Amphibians	Cascade frog (<i>Rana cascadae</i>)	No status	Candidate	Klamath, Shasta-Trinity
	Foothill yellow-legged frog (<i>Rana boylei</i>)	No status	Endangered/special concern	Klamath, Mendocino, Rogue River-Siskiyou, Shasta-Trinity, Six Rivers
	Northern red-legged frog (<i>Rana aurora aurora</i>)	No status	Special concern	Shasta-Trinity, Six Rivers
	Shasta salamander (<i>Hydromantes shastae</i>)	No status	Threatened	Shasta-Trinity
	Siskiyou Mountain salamander (<i>Plethodon stormi</i>)	No status	Threatened	Rogue River-Siskiyou, Shasta-Trinity
	Southern torrent salamander (<i>Rhyacotriton variegatus</i>)	No status	Special concern	Klamath, Mendocino, Shasta-Trinity
	Speckled black salamander (<i>Aneides flavipunctatus</i>)	No status	Special concern	Rogue River-Siskiyou

Table A.5 continued.

Group	Species	Federal status	State status	Listed national forest(s)
Invertebrates	Big Bar hesperian (<i>Vespericola pressleyi</i>)	No status	Special concern	Shasta-Trinity
	Coastal greenish blue butterfly (<i>Plebejus saepiolus littoralis</i>)	No status	Special concern	Rogue River-Siskiyou
	Crater Lake tightcoil (<i>Pristiloma crateris</i>)	No status	Special concern	Rogue River-Siskiyou
	Dalles hesperian (<i>Vespericola depressus</i>)	No status	Special concern	Rogue River-Siskiyou
	Franklin's bumble bee (<i>Bombus franklini</i>)	No status	Special concern	Rogue River-Siskiyou
	Gray-blue butterfly (<i>Agriades podarce klamathensis</i>)	No status	Special concern	Rogue River-Siskiyou
	Green sideband (<i>Monadenia fidelis flava</i>)	No status	Special concern	Rogue River-Siskiyou
	Oregon shoulderband (<i>Helminthoglypta hertleini</i>)	No status	Special concern	Rogue River-Siskiyou
	Shasta chaparral snail (<i>Trilobopsis roperi</i>)	No status	Special concern	Shasta-Trinity
	Shasta hesperian (<i>Vespericola shasta</i>)	No status	Special concern	Six Rivers
	Shasta sideband snail (<i>Monadenia troglodytes troglodytes</i>)	No status	Special concern	Shasta-Trinity
	Siskiyou hesperian (<i>Vespericola sierranus</i>)	No status	Special concern	Rogue River-Siskiyou
	Siskiyou short-horned grasshopper (<i>Chloealtis aspasma</i>)	No status	Special concern	Rogue River-Siskiyou
	Tehama chaparral snail (<i>Trilobopsis tehamana</i>)	No status	Special concern	Shasta-Trinity
	Western bumble bee (<i>Bombus occidentalis</i>)	No status	Candidate	Klamath, Rogue River-Siskiyou, Shasta-Trinity
	Wintu sideband snail (<i>Monadenia troglodytes wintu</i>)	No status	Special concern	Klamath

Table A.5 continued.

Group	Species	Federal status	State status	Listed national forest(s)
Mammals	Fisher (<i>Pekania pennanti</i>)	Proposed: threatened	Special concern	Klamath, Rogue River-Siskiyou, Shasta-Trinity, Six Rivers
	Pacific marten (<i>Martes caurina</i>)	Proposed: threatened	Special concern	Klamath, Mendocino, Rogue River-Siskiyou, Shasta-Trinity, Six Rivers
Reptiles	Western pond turtle (<i>Emys marmorata</i>)	No status	Special concern	Klamath, Mendocino, Rogue River-Siskiyou, Shasta-Trinity, Six Rivers

Table A.6—Amphibian species observed at Aquatic and Riparian Effectiveness Monitoring Program (AREMP) monitoring sites that may rely on interwatershed linkages for dispersal across the Five Forests planning area.

Species	Observation areas in national forests
Black salamander (<i>Aneides flavipunctatus</i>)	Shasta-Trinity
Cascades frog (<i>Rana cascadae</i>)	Rogue River-Siskiyou
Del Norte salamander (<i>Plethodon elongatus</i>)	Six Rivers
Dunn's salamander (<i>Plethodon dunni</i>)	Rogue River-Siskiyou
Ensatina (<i>Ensatina eschscholtzii</i>)	Rogue River-Siskiyou, Shasta-Trinity
Foothill yellow-legged frog (<i>Rana boylei</i>)	Rogue River-Siskiyou, Shasta-Trinity, Six Rivers
Pacific chorus frog (<i>Pseudacris regilla</i>)	Rogue River-Siskiyou, Shasta-Trinity, Six Rivers
Pacific giant salamander (<i>Dicamptodon tenebrosus</i>)	Klamath, Mendocino, Rogue River-Siskiyou, Shasta-Trinity, Six Rivers
Red-legged frog (<i>Rana aurora</i>)	Rogue River-Siskiyou
Rough-skinned newt (<i>Taricha granulosa</i>)	Rogue River-Siskiyou, Shasta-Trinity
Tailed frog (<i>Ascaphus truei</i>)	Klamath, Rogue River-Siskiyou, Shasta-Trinity
Western toad (<i>Bufo boreas</i>)	Six Rivers

Table A.7—Rare and unique habitats and associated geologic features within the study units of the Five Forests.

Habitat or geologic feature	Rogue River-Siskiyou National Forest—Klamath Mountains unit	Rogue River-Siskiyou National Forest—Cascades unit	Klamath National Forest—Klamath Mountains unit	Klamath National Forest—Cascades unit	Six Rivers National Forest	Shasta-Trinity National Forest—Klamath Mountains unit	Shasta-Trinity National Forest—Cascades unit	Mendocino National Forest
Fens per square mile	No data	No data	No data	No data	No data	No data	No data	No data
Springs per square mile	0.2	0.3	0.3	0.3	0.1	0.2	0.2	0.0004
Vernal pools per square mile	No data	No data	No data	No data	No data	No data	No data	No data
Fault miles per square mile	0.6	0.01	0.2	0.1	0.2	0.2	0.1	0.0006
Acres alluvial deposits (percentage of unit)	6,678 (0.5)	1,861 (0.4)	47.5 (0.004)	31,091 (8.4)	1,649 (0.1)	140.9 (0.01)	75,331 (6.5)	4,937 (0.5)
Acres glacial deposits (percentage of unit)	18.3 (0.001)	44,066 (9.6)	9,881 (0.7)	7,060 (1.9)	1,164 (0.1)	22,905 (1.5)	32,302 (2.8)	0
Acres carbonate karst (percentage of unit)	95,523 (6.9)	0	330,529 (24.8)	0	110,799 (8.7)	533,492 (34.2)	155,224 (13.4)	0
Acres volcanic rocks (percentage of unit)	126,436.4 (9.1)	405,462.0 (88.3)	416.1 (0.03)	326,083.5 (88.4)	41,914.4 (3.3)	5,456.9 (0.4)	409,624.7 (35.4)	58,219.8 (5.4)
Acres volcanic karst (percentage of unit)	0	156,801 (34.2)	0	306,559 (83.1)	0	0	300,570 (26.0)	0
Acres ultramafic rocks (percentage of unit)	276,317 (19.9)	0	184,712 (13.8)	947 (0.3)	217,732 (17.1)	201,169 (12.9)	101,541 (8.8)	44,566 (4.2)

APPENDIX B. FIVE FORESTS COHORT DATA SOURCES

Exhibit B.1—Datasets used to assess key ecosystem characteristics of riparian and aquatic ecosystems across the Five Forests cohort.

Data source	Description	Citation
Watershed Condition Framework (WCF)—Forest Cover Loss	Addresses the potential for altered hydrologic and sediment regimes because of the loss of forest cover on forest lands.	Potyondy and Geier 2011
WCF—Fire Regime Condition Class	Addresses the potential for altered hydrologic and sediment regimes because of departures from historical ranges of variability in vegetation, fuel composition, fire frequency, fire severity, and fire pattern.	
WCF—Insects and Disease	Addresses forest mortality impacts to hydrologic and soil function due to major invasive and native forest pest, insect, and disease outbreaks.	
WCF—Road and Trail Condition	Addresses changes in the hydrologic and sediment regimes due to the density, location, distribution, and maintenance of the road and trail network.	
WCF—Water Quantity Condition	Addresses changes in the natural flow regime with respect to the magnitude, duration, or timing of natural streamflow hydrographs.	
WCF—Rangeland Vegetation Condition	Addresses effects on soil and water resulting from the vegetative health of rangelands.	
Terrestrial Condition Assessment (TCA)—Drought	Evaluates whether the long-term moisture deficit within a unit is sufficiently large to provide evidence that drought has impacted ecological integrity.	Cleland et al. 2017
TCA—Climate Change	Evaluates whether deviations in recent mean seasonal temperature and precipitation compared to long-term averages are sufficiently large to provide evidence that climate change has impacted ecological integrity within the unit.	
California Dams	Identifies all dams currently under the jurisdiction of the California Department of Water Resources, Division of Safety of Dams.	
California Points of Diversion	Identifies locations where water is being drawn from a surface water source such as a stream or river. Each water right registered with the California State Water Resources Control Board's Division of Water Rights includes a point of diversion. Does not include groundwater extraction points.	
Oregon Dams	Depicts the approximate location of dams in the State of Oregon that the State has statutory authority over.	
Oregon Diversions	Maps Points of Diversion at approved locations where water may be diverted. Points represent the water right(s), not the device.	
USDA Forest Service National Dataset—Roads	Maps road infrastructure on National Forest System lands.	
USDA Forest Service National Dataset—Timber Harvest	Depicts the area planned and accomplished acres treated as part of the Forest Service Timber Harvest program of work. Activities are self-reported by Forest Service units.	

Exhibit B.1 continued.

Data source	Description	Citation
USDA Forest Service National Dataset—Grazing Allotments	Designates boundaries to establish the extent of livestock distribution and management within a grazing allotment.	
USDA Forest Service National Dataset—Burned Area Perimeters	Estimates area within wildfire-burned area perimeters, based on fire severity data.	
Western U.S. Stream Flow Metrics	Maps a set of summary flow metrics that describe key attributes of the flow regime for each stream segment in the 1:100,000 scale National Hydrography Dataset for streams in the western United States under historical conditions and climate change scenarios. Estimates are based on daily simulations of the Variable Infiltration Capacity macroscale hydrologic model.	USDA FS 2019; Wenger et al. 2010
U.S. Geological Survey (USGS) Protected Areas Database of the United States (PADUS)	Maps boundaries of land ownership designations, including National Forest System lands	Ohmann et al. 2013
U.S. Geological Survey (USGS)—Geological Features	Depicts bedrock types, faults, and unconsolidated deposits, as mapped by State geological agencies.	Horton 2007
Spring Stewardship Institute (SSI)	Depicts locations of known springs, as mapped by the Springs Stewardship Institute.	Ledbetter et al. 2014
Landscape Ecology, Modeling, Mapping and Analysis Group (LEMMA)	Estimates canopy cover, tree and snag density, down wood cover, basal area, stand age, and composition in riparian reserves (RRs) by using gradient nearest neighbor (GNN) mapping, representing conditions in 2017.	
Aquatic and Riparian Ecosystem Monitoring Program (AREMP)—Invasive Species	Records invasive species detected during riparian monitoring site visits from 2011 to 2019.	
Global Forest Change Project (GFC)	Estimates annual forest loss from 2001 to 2020, relative to forest cover in 2000.	Hansen et al. 2013
LANDFIRE—Conversion to Agriculture and Urbanization	Maps percentage area of unit within administrative boundaries classified as agriculture or developed land. This includes Forest Service lands and other lands.	
LANDFIRE—Existing Riparian Cover	Maps percentage of RR classified as existing riparian vegetation.	Nelson et al. 2016
LANDFIRE—Potential Riparian Cover	Maps percentage of RR classified as riparian under pre-European settlement conditions.	
LANDFIRE—Fire Regime Group	Maps percentage of RR within each fire regime group, based on historical wildfire frequency and intensity.	

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APPENDIX C. FIVE FORESTS COHORT MAPS

The following maps of the Five Forests, with brief descriptions, are contained in this appendix.

Figure C.1—Composite burn index fire severity ratings for fires, 2012–2021.

Figure C.2—Z-scores indicating moisture surplus or moisture deficit, 2019.

Figure C.3—Nitrogen deposition.

Figure C.4—Soil acid critical load exceedance.

Figure C.5—Accumulated suspended sediment contributed to streams from stream channel sources.

Figure C.6—Incremental suspended sediment contributed to stream from stream channel sources.

Figure C.7—Accumulated suspended sediment contributed to streams by forested lands.

Figure C.8—Accumulated suspended sediment (tons) contributed to streams by forested lands.

Figure C.9—Accumulated suspended sediment contributed to streams by agricultural lands.

Figure C.10—Incremental suspended sediment contributed to streams by agricultural lands.

Figure C.11—Accumulated suspended sediment contributed to streams by urban lands.

Figure C.12—Incremental suspended sediment contributed to streams by urban lands.

Figure C.13—Accumulated total nitrogen contributed to streams by scrublands and grasslands.

Figure C.14—Incremental total nitrogen contributed to streams by scrublands and grasslands.

Figure C.15—Accumulated total nitrogen contributed to streams from atmospheric deposition.

Figure C.16—Incremental total nitrogen contributed to streams from atmospheric deposition.

Figure C.17—Accumulated total nitrogen contributed to streams by urban lands.

Figure C.18—Incremental total nitrogen contributed to streams by urban lands.

Figure C.19—Accumulated total nitrogen contributed to streams from spring discharge.

Figure C.20—Incremental total nitrogen contributed to streams from spring discharge.

Figure C.21—Accumulated total nitrogen contributed to streams from red alder trees.

Figure C.22—Incremental total nitrogen contributed to streams from red alder trees.

Figure C.23—Accumulated total nitrogen contributed to streams from fertilizer and manure applied to croplands.

Figure C.24—Incremental total nitrogen contributed to streams from fertilizer and manure applied to croplands.

Figure C.25—Accumulated total nitrogen contributed to streams from wastewater treatment discharge.

Figure C.26—Incremental total nitrogen contributed to streams from wastewater treatment discharge.

Figure C.27—Accumulated total phosphorus contributed to streams by urban lands.

Figure C.28—Incremental total phosphorus contributed to streams by urban lands.

Figure C.29—Accumulated total phosphorus contributed to streams from wastewater treatment discharge.

Figure C.30—Incremental total phosphorus contributed to streams from wastewater treatment discharge.

Figure C.31—Accumulated total phosphorus contributed to streams from fertilizer and manure applied to croplands.

Figure C.32—Incremental total phosphorus contributed to streams from fertilizer and manure applied to croplands.

Figure C.33—Accumulated total phosphorus contributed to streams from grazing cattle manure applied to rangelands.

Figure C.34—Incremental total phosphorus contributed to streams from grazing cattle manure applied to rangelands.

Figure C.35—Accumulated total phosphorus contributed to streams from weathering of upland geology.

Figure C.36—Incremental total phosphorus contributed to streams from weathering of upland geology.

Figure C.37—Accumulated total phosphorus contributed to streams from stream channel sources.

Figure C.38—Incremental total phosphorus contributed to streams from the channel.

Figure C.39—Accumulated total phosphorus contributed to streams from spring discharge.

Figure C.40—Incremental total phosphorus contributed to streams from spring discharge.

Figure C.41—Watersheds classified by the Watershed Condition Framework.

Figure C.42—State-listed 303(d) impaired streams.

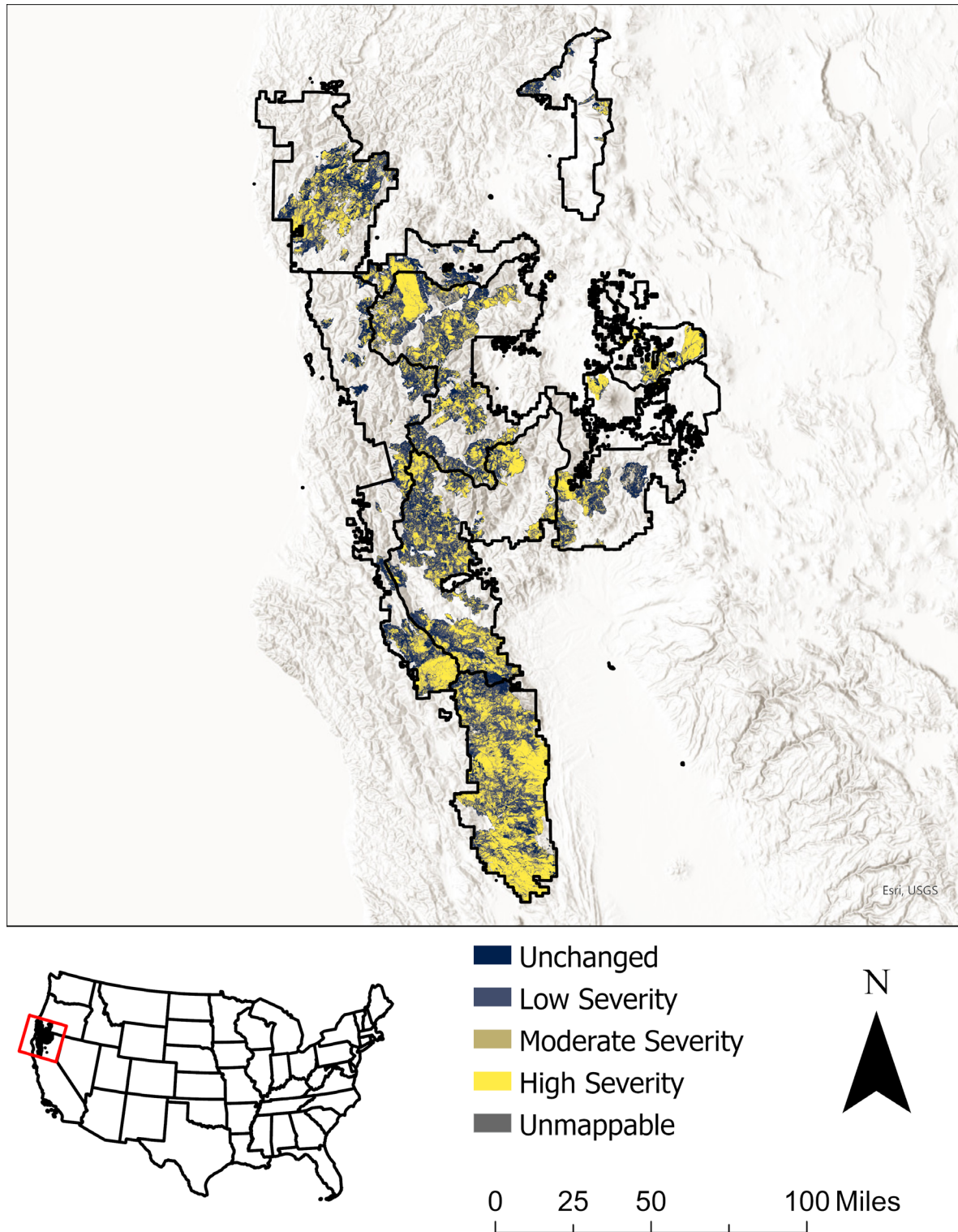


Figure C.1—Composite burn index fire severity ratings for all fires that have occurred within the Five Forests planning area from 2012 through 2021. In areas that have burned more than once, the more recent fire severity is displayed. Data from the Rapid Assessment of Vegetation Condition after Wildfire (RAVG; USDA FS 2022). Lower map shows location of study area in Oregon and California.

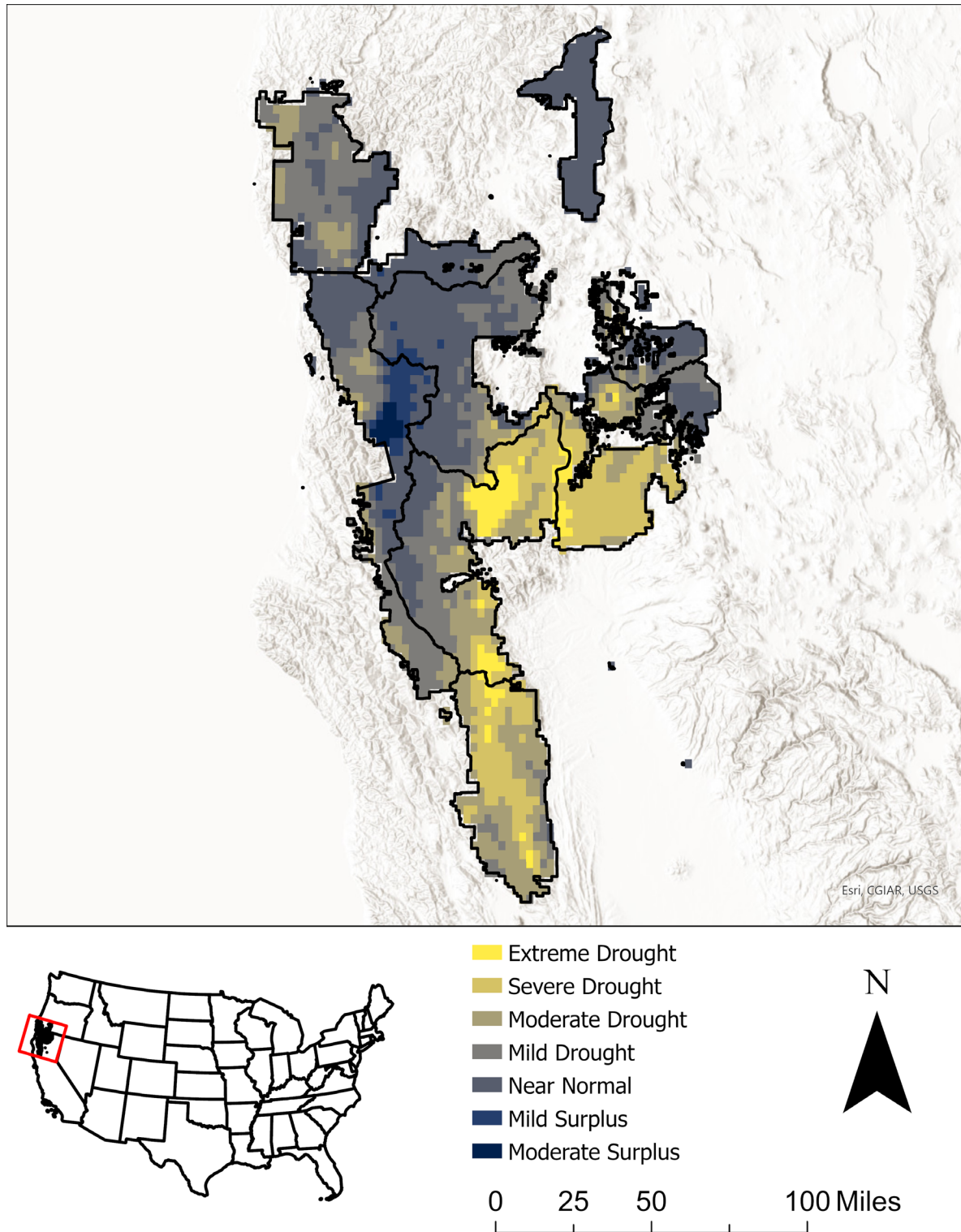


Figure C.2—Z-scores mapped by the 2019 USDA Forest Service Terrestrial Condition Assessment (Cleland et al. 2017) throughout the Five Forests planning area. Positive values are associated with moisture surplus and negative values are associated with moisture deficit. Deviations are calculated as the current conditions of recent 3 years compared to the historical record. Lower map shows location of study area in Oregon and California.

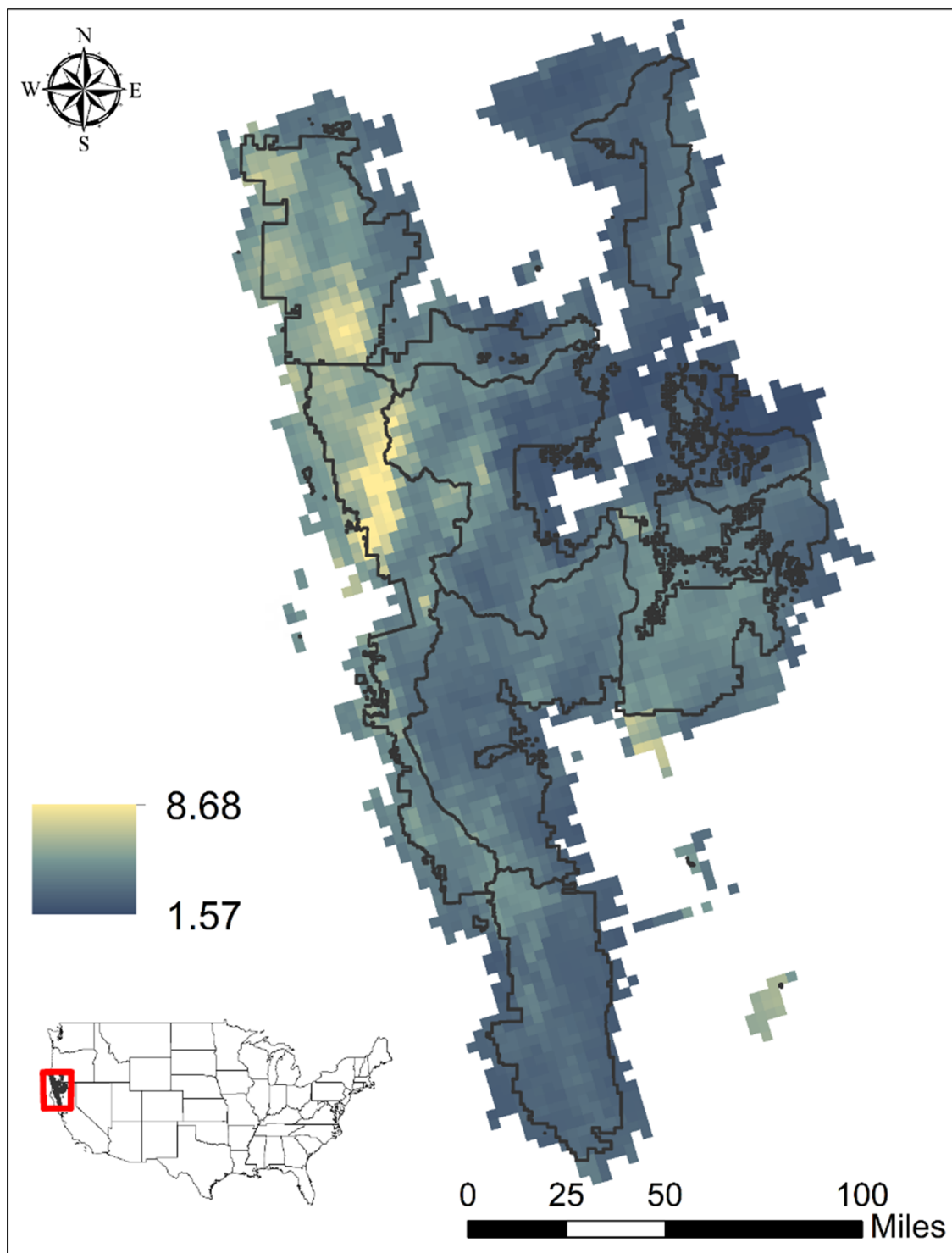


Figure C.3—Nitrogen deposition (tons per acre per year) across the Five Forests planning area. Data from the Terrestrial Condition Assessment (Cleland et al. 2017) at a resolution of 120 m. Lower map shows location of study area in Oregon and California.

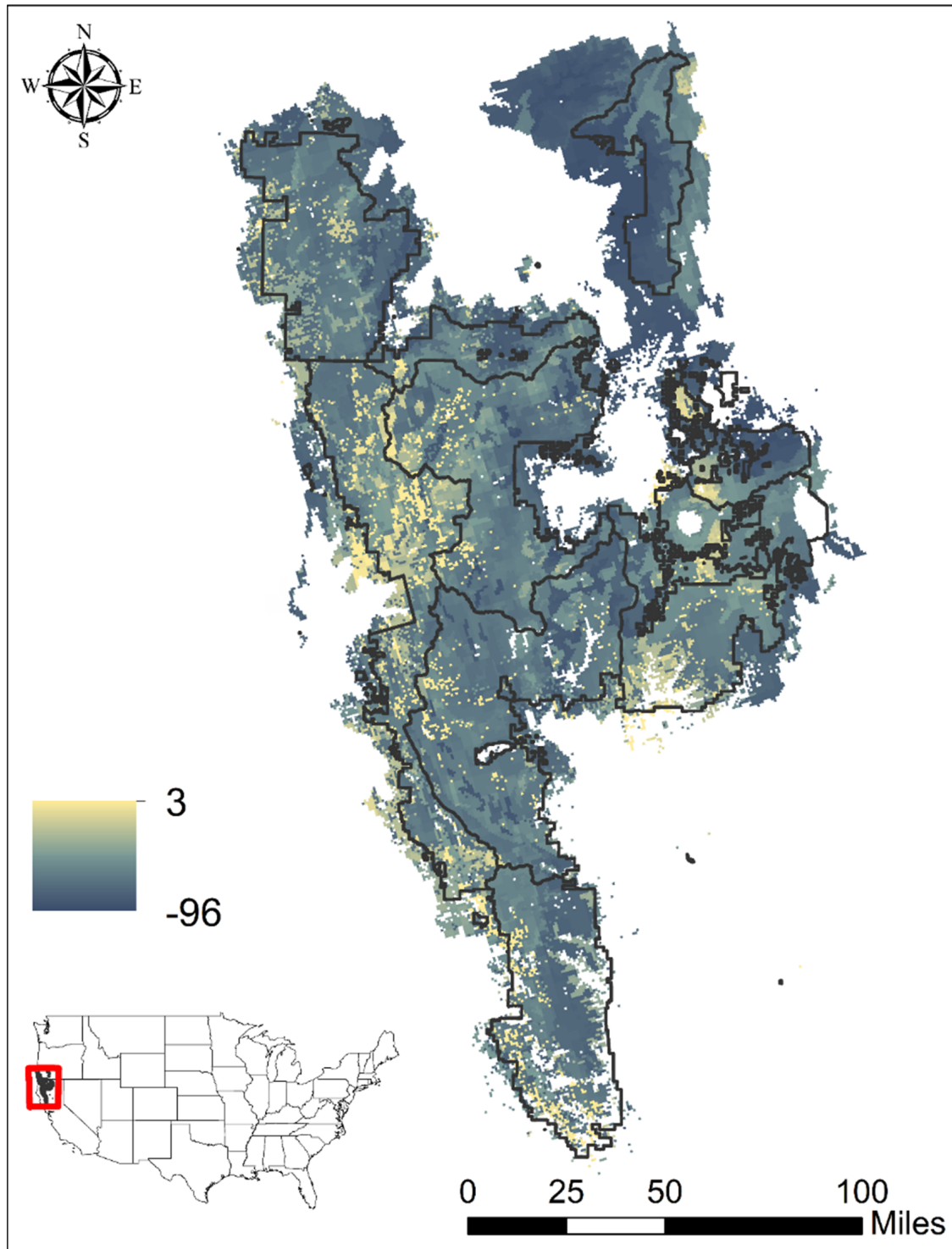


Figure C.4—Soil acid critical load exceedance within the Five Forests planning area. Positive values indicate the extent to which the current loading exceeds the critical load. Negative values indicate that the current loading is below the critical load. Data from the Terrestrial Condition Assessment (Cleland et al. 2017). Lower map shows location of study area in Oregon and California.

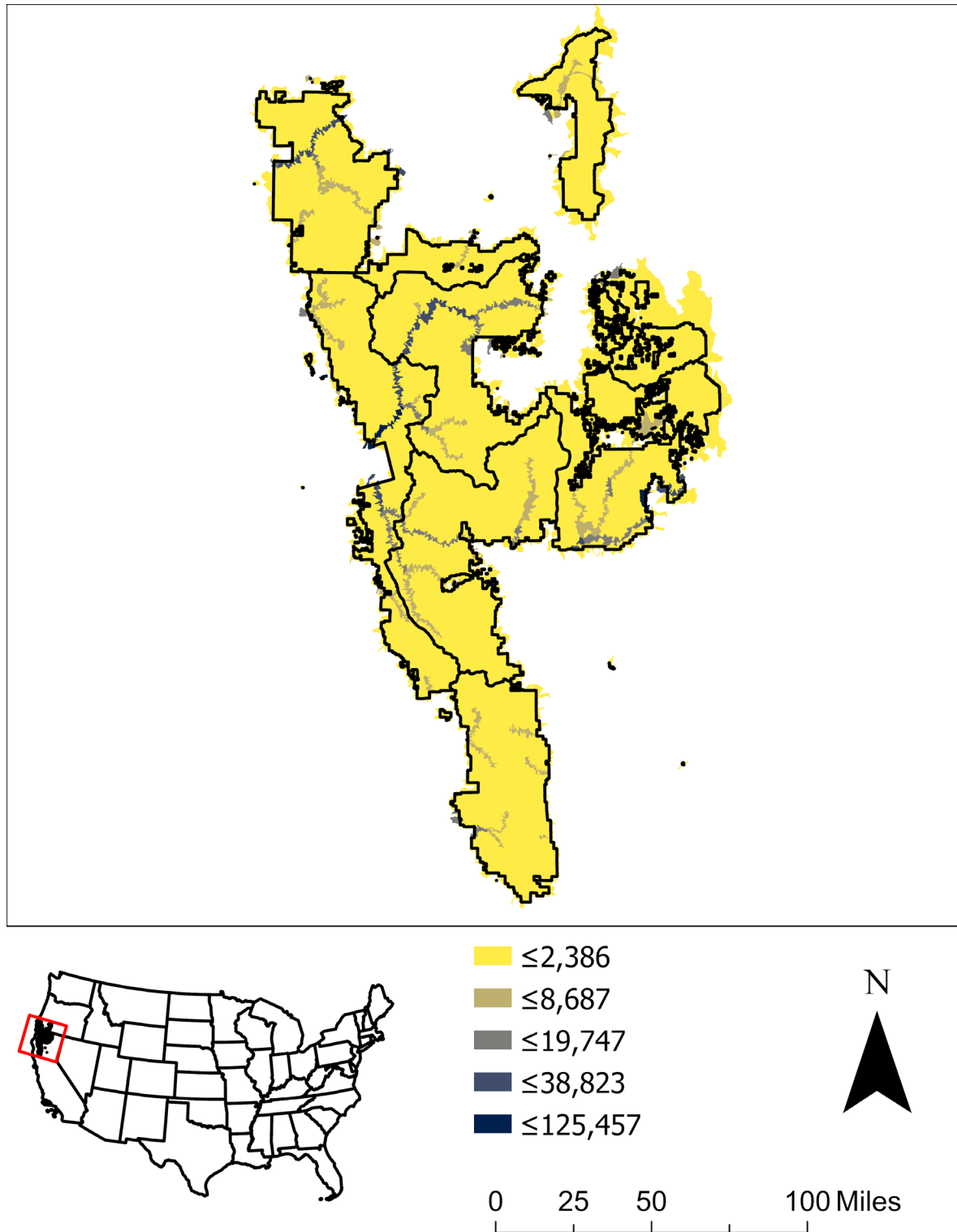


Figure C.5—Map of accumulated suspended sediment (tons) contributed to streams within the Five Forests planning area from stream channel sources. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

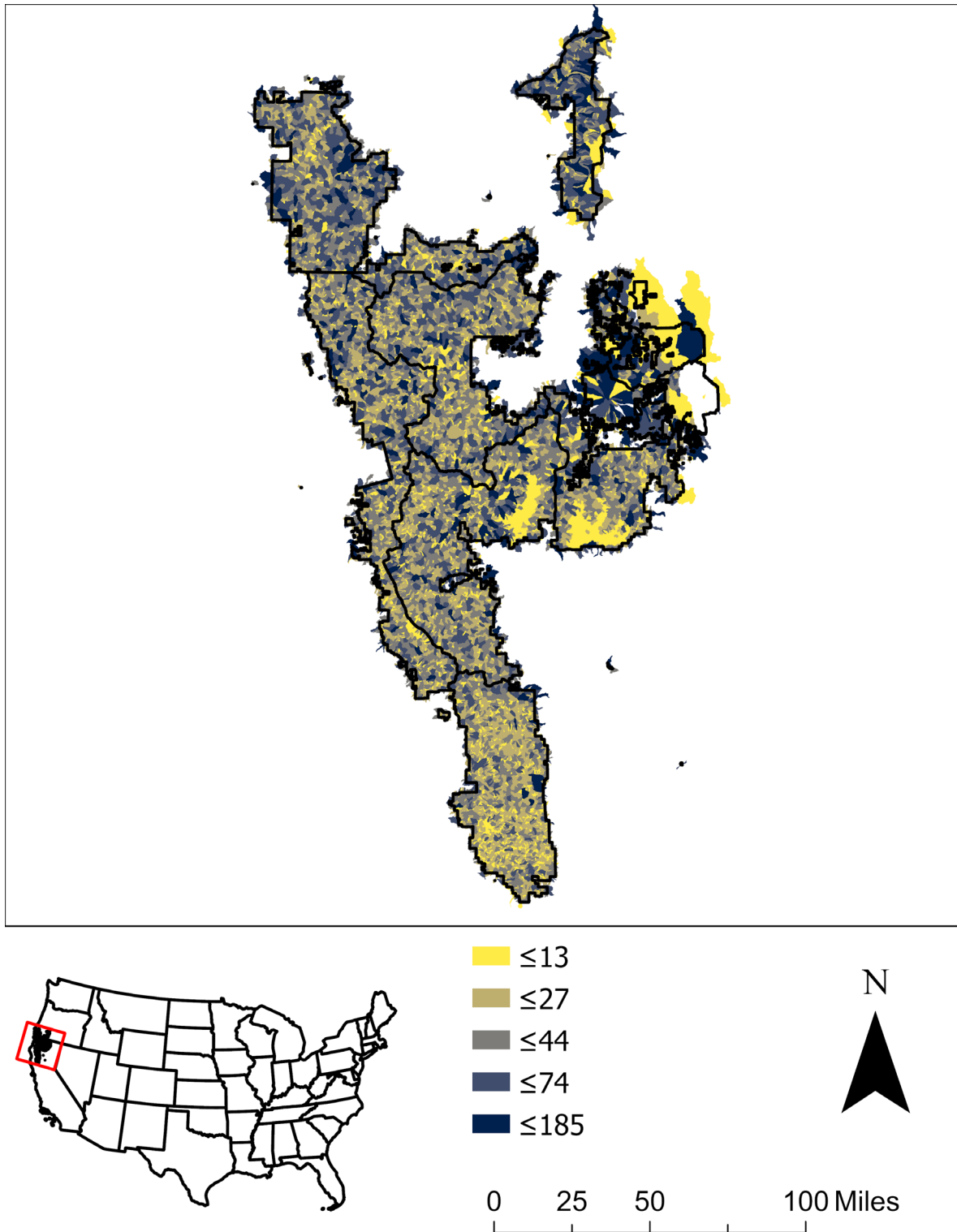


Figure C.6—Map of incremental suspended sediment (tons) contributed to streams within the Five Forests planning area from stream channel sources. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

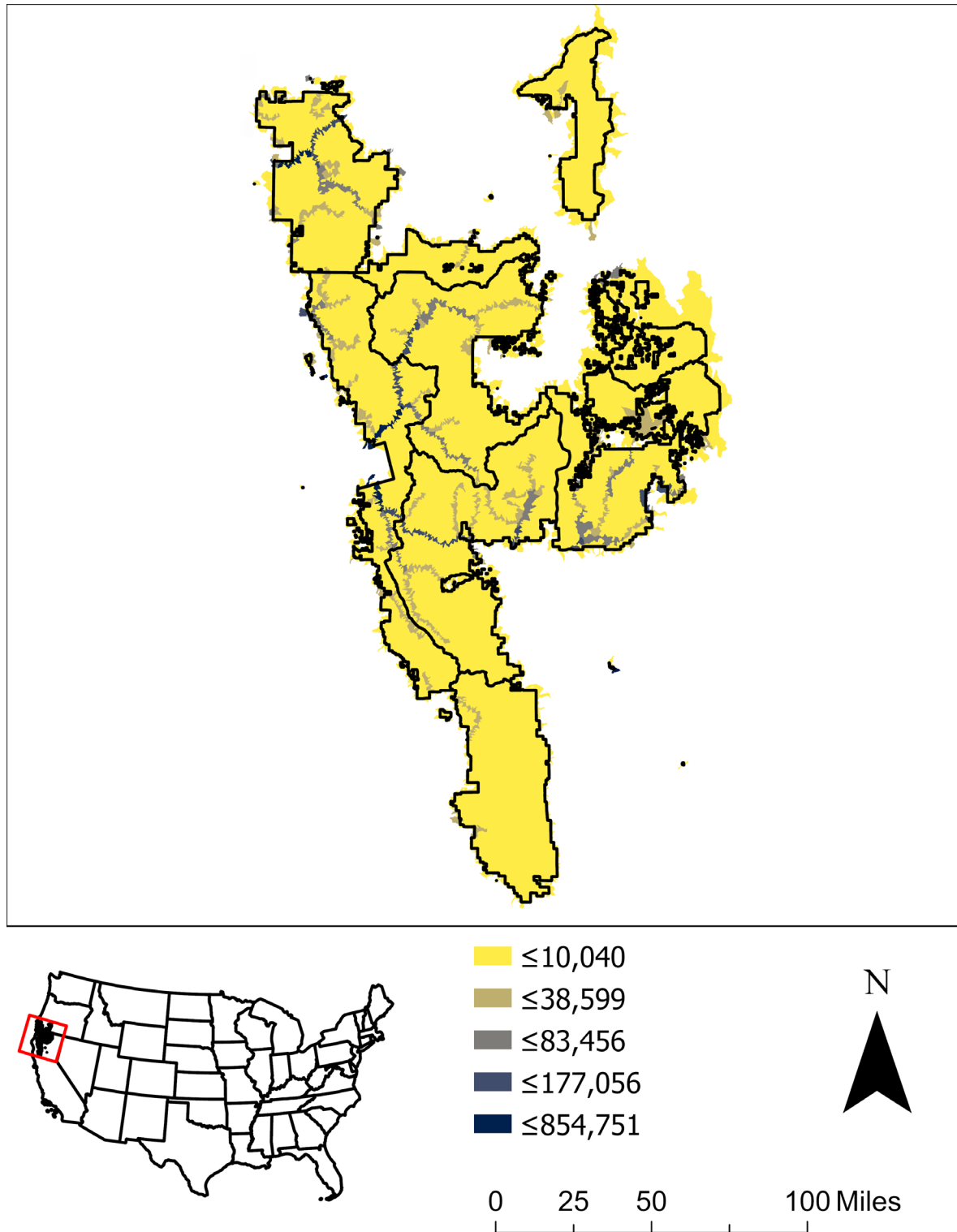


Figure C.7—Map of accumulated suspended sediment (tons) contributed to streams within the Five Forests planning area by forested lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

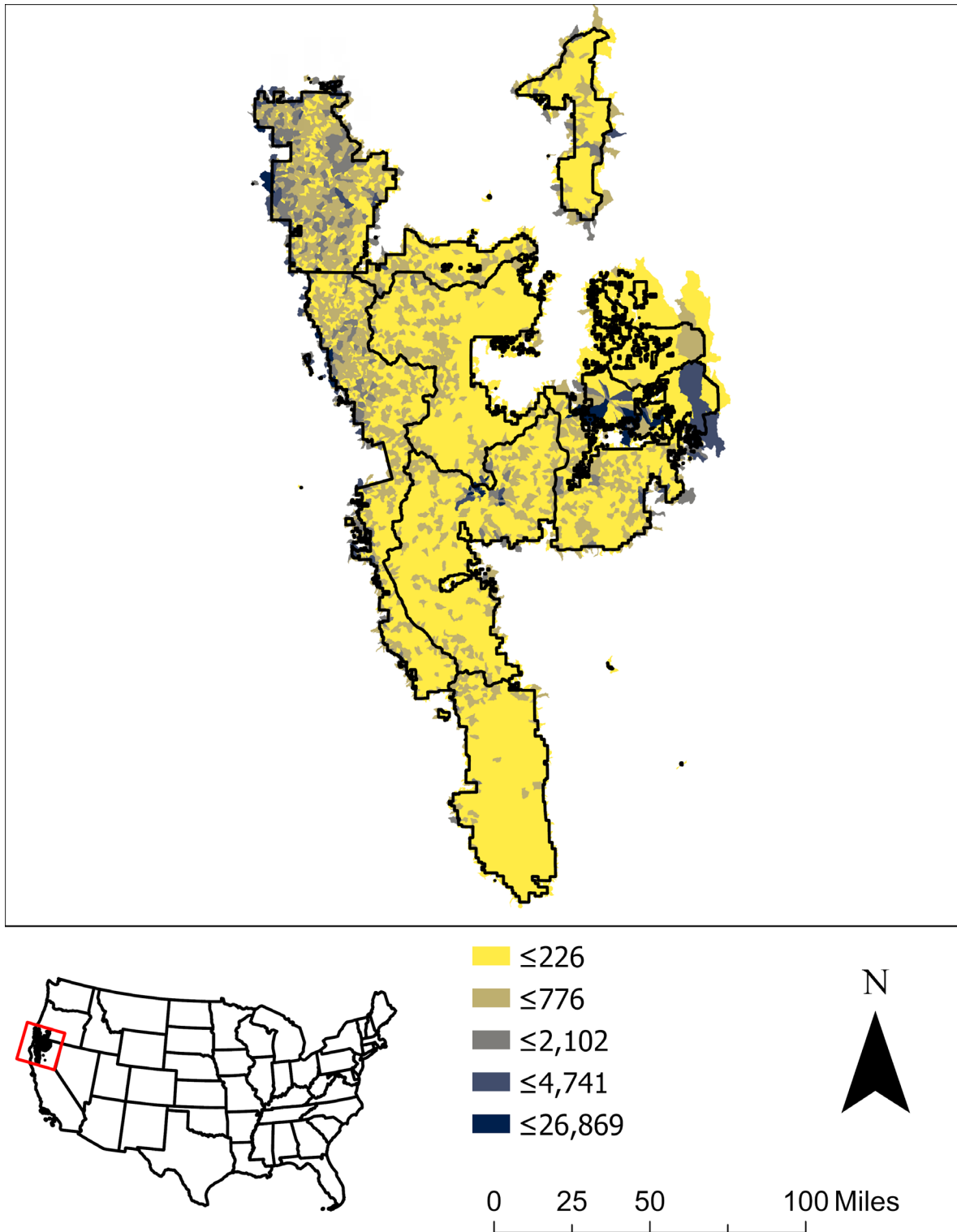


Figure C.8—Map of incremental suspended sediment (tons) contributed to streams within the Five Forests planning area by forested lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

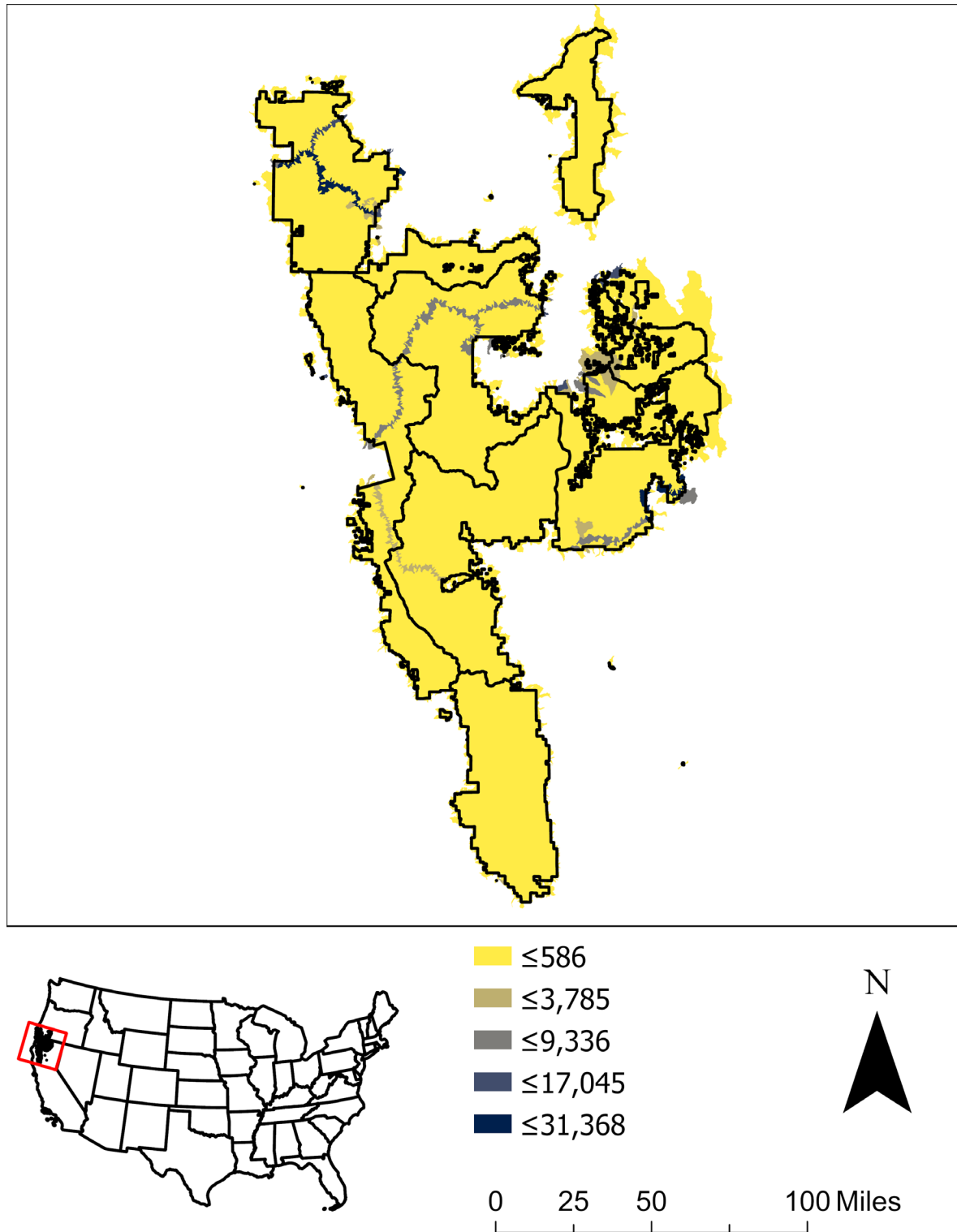


Figure C.9—Map of accumulated suspended sediment (tons) contributed to streams within the Five Forests planning area by agricultural lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

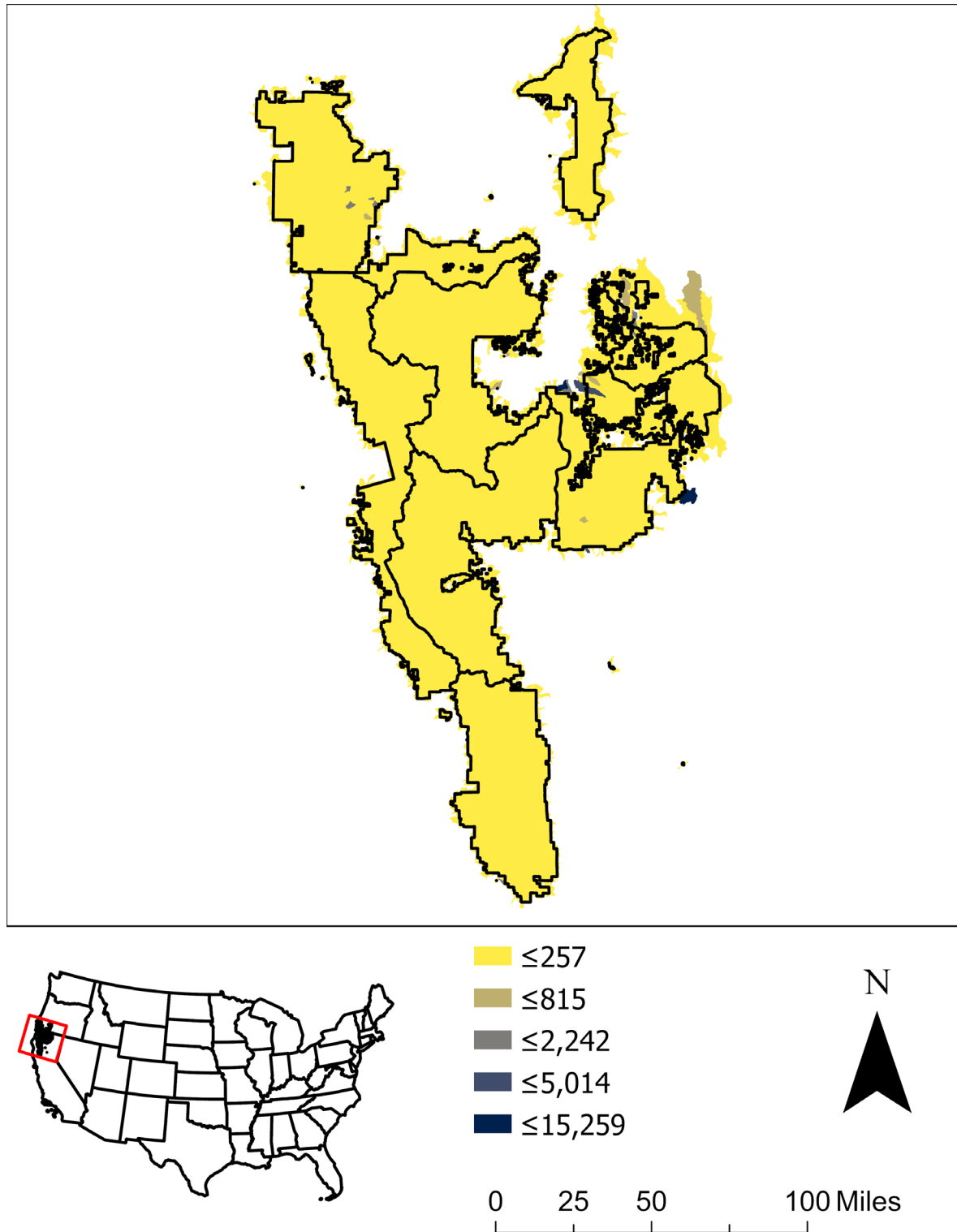


Figure C.10—Map of incremental suspended sediment (tons) contributed to streams within the Five Forests planning area by agricultural lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

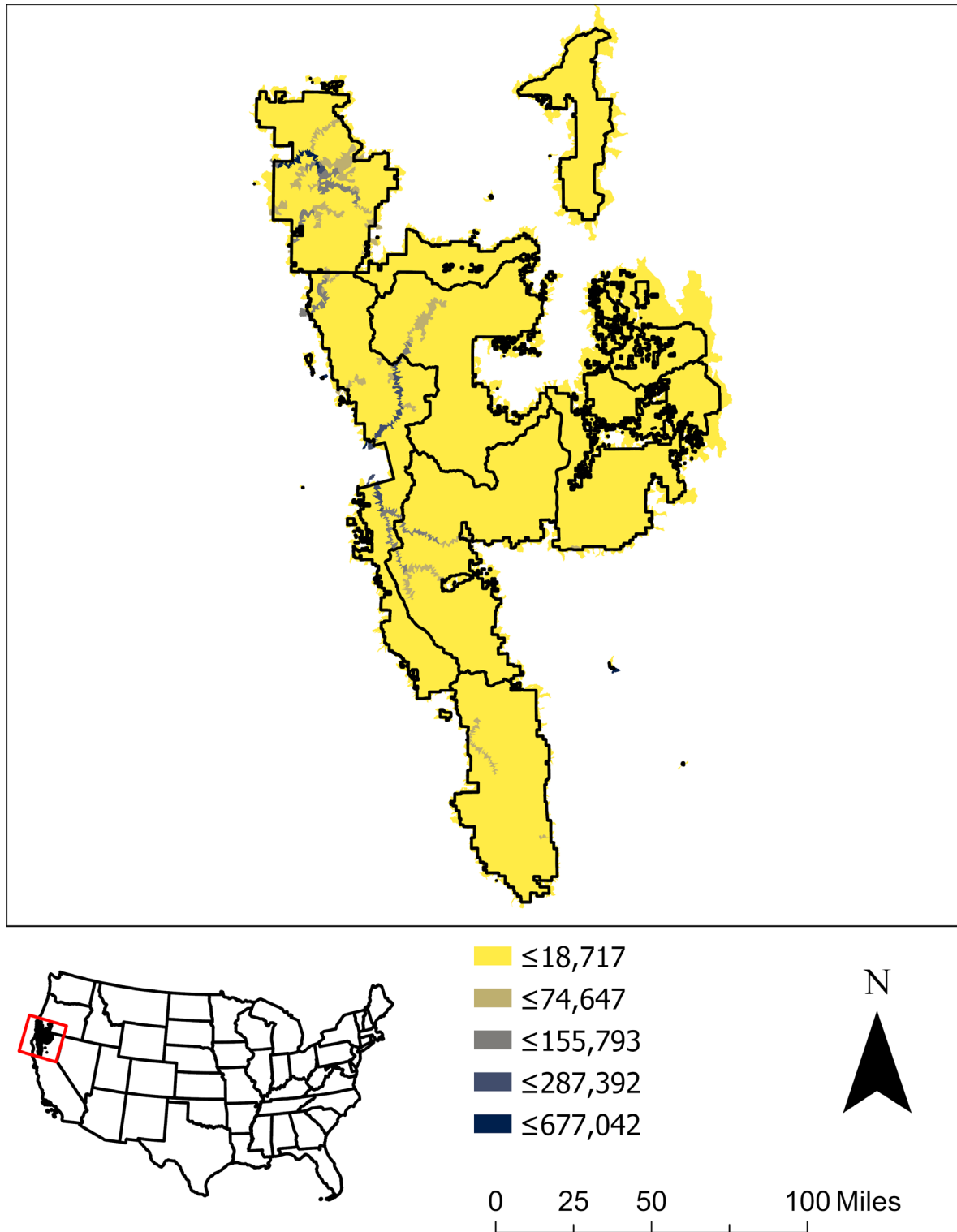


Figure C.11—Map of accumulated suspended sediment (tons) contributed to streams within the Five Forests planning area by urban lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

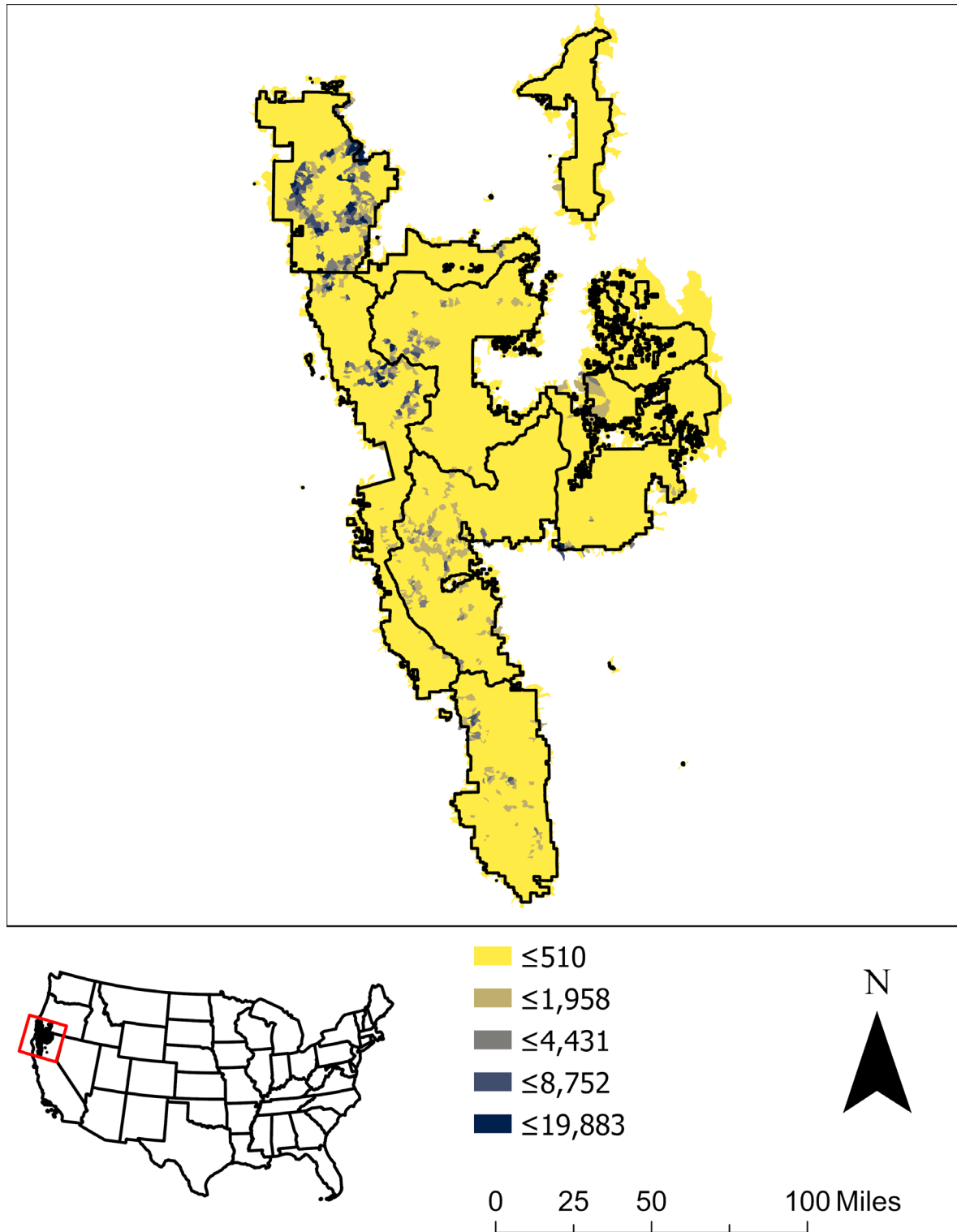


Figure C.12—Map of incremental suspended sediment (tons) contributed to streams within the Five Forests planning area by urban lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

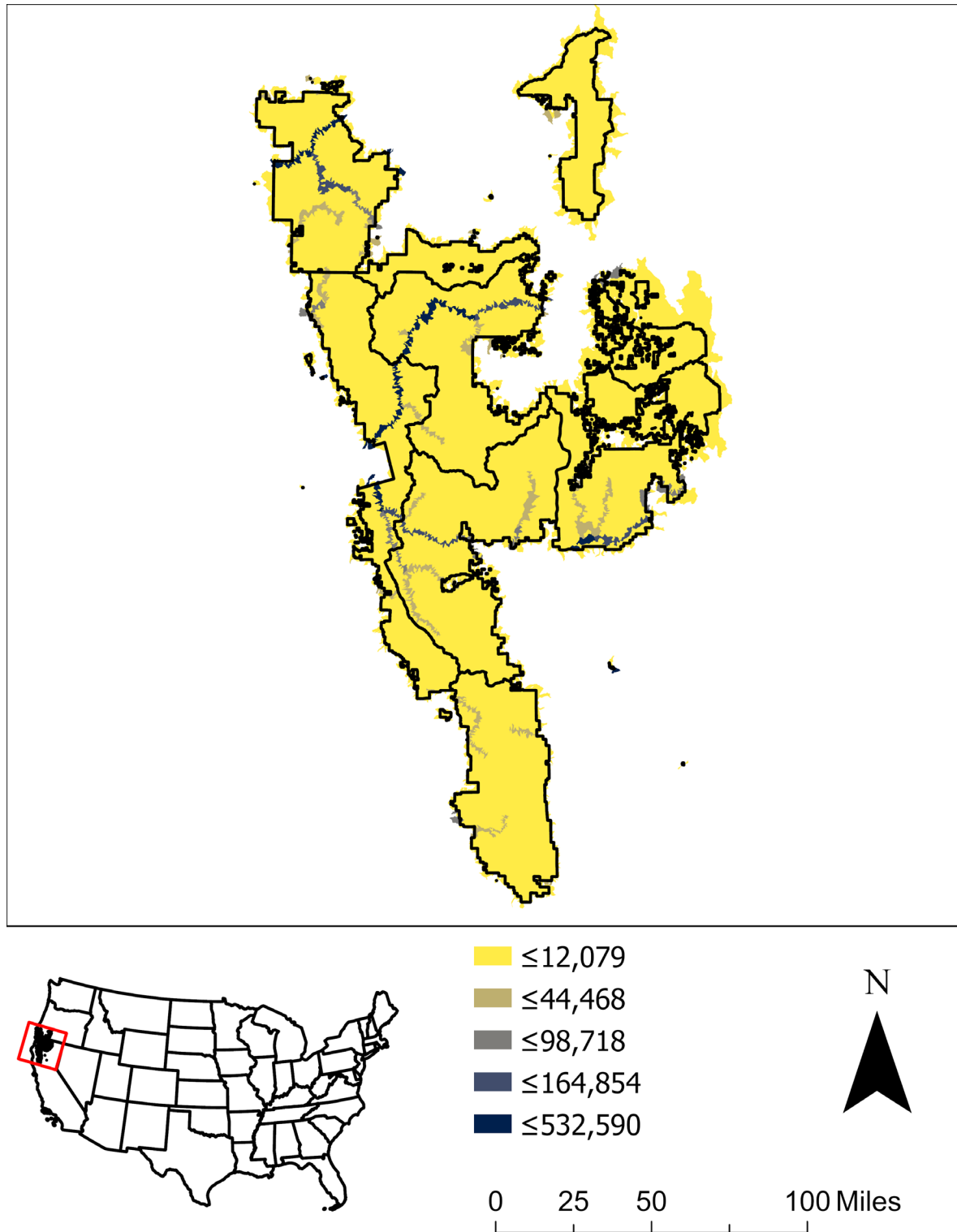


Figure C.13—Map of accumulated total nitrogen (tons) contributed to streams within the Five Forests planning area by scrublands and grasslands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

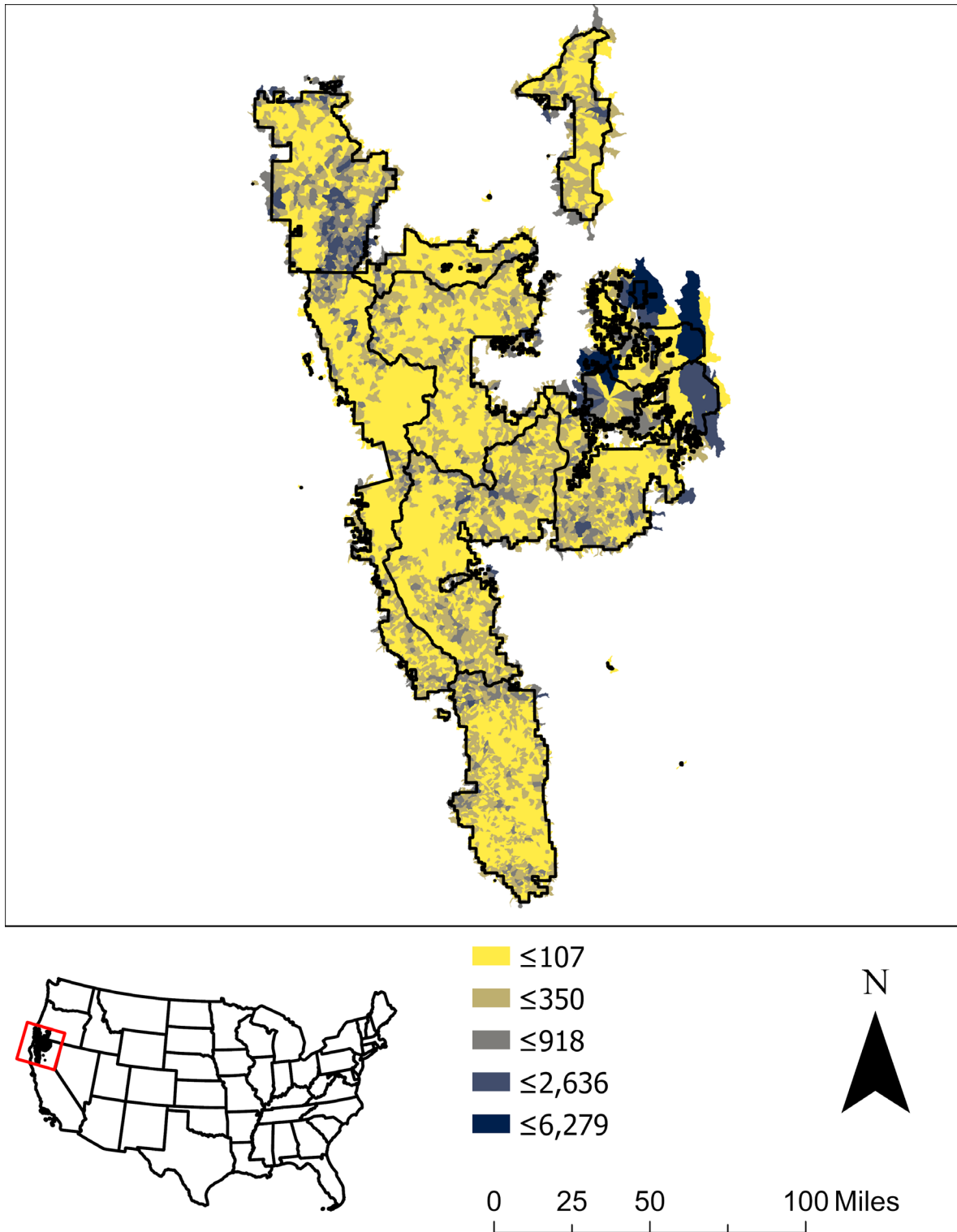


Figure C.14—Map of incremental total nitrogen (tons) contributed to streams within the Five Forests planning area by scrublands and grasslands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

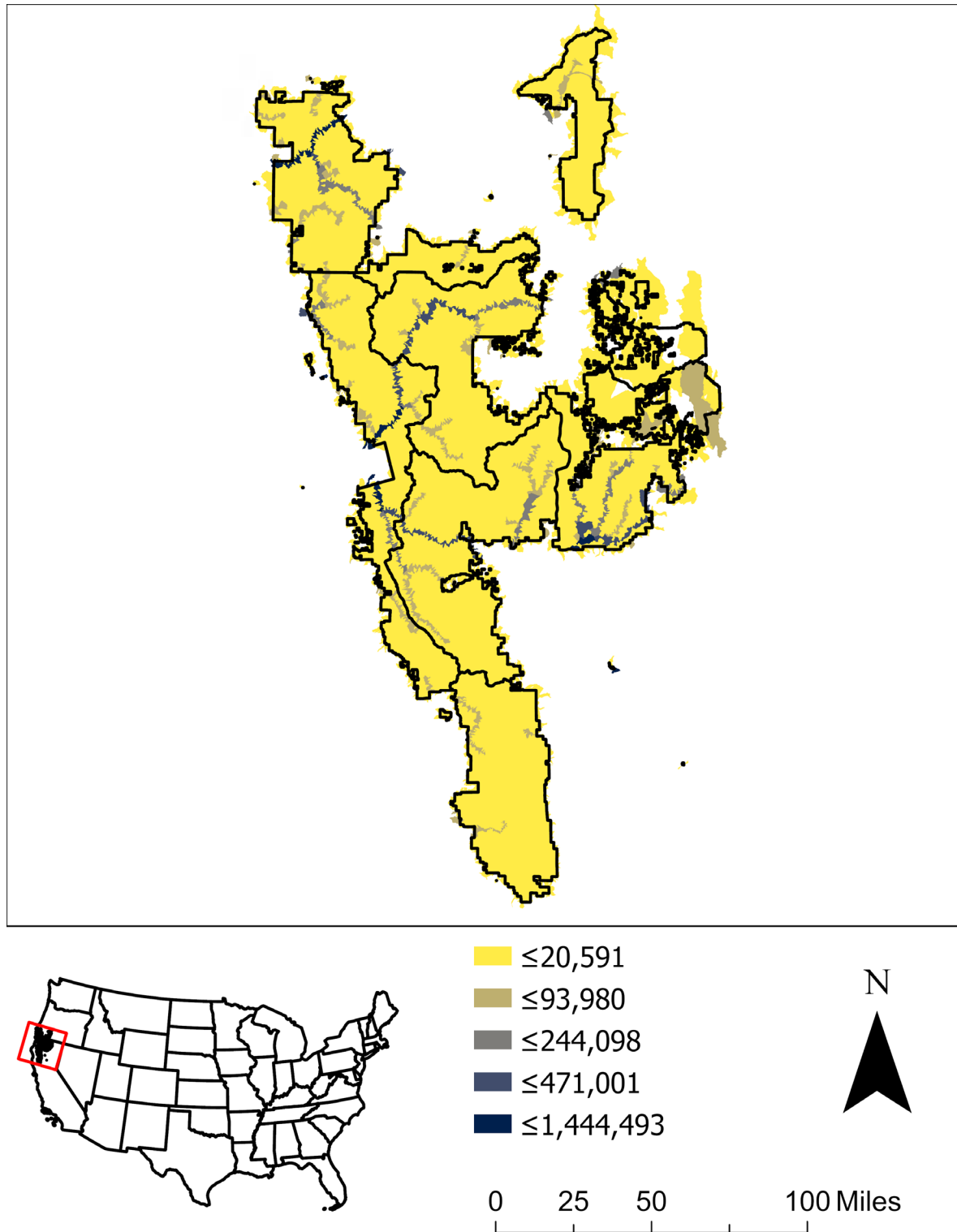


Figure C.15—Map of accumulated total nitrogen (tons) contributed to streams within the Five Forests planning area from atmospheric deposition. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

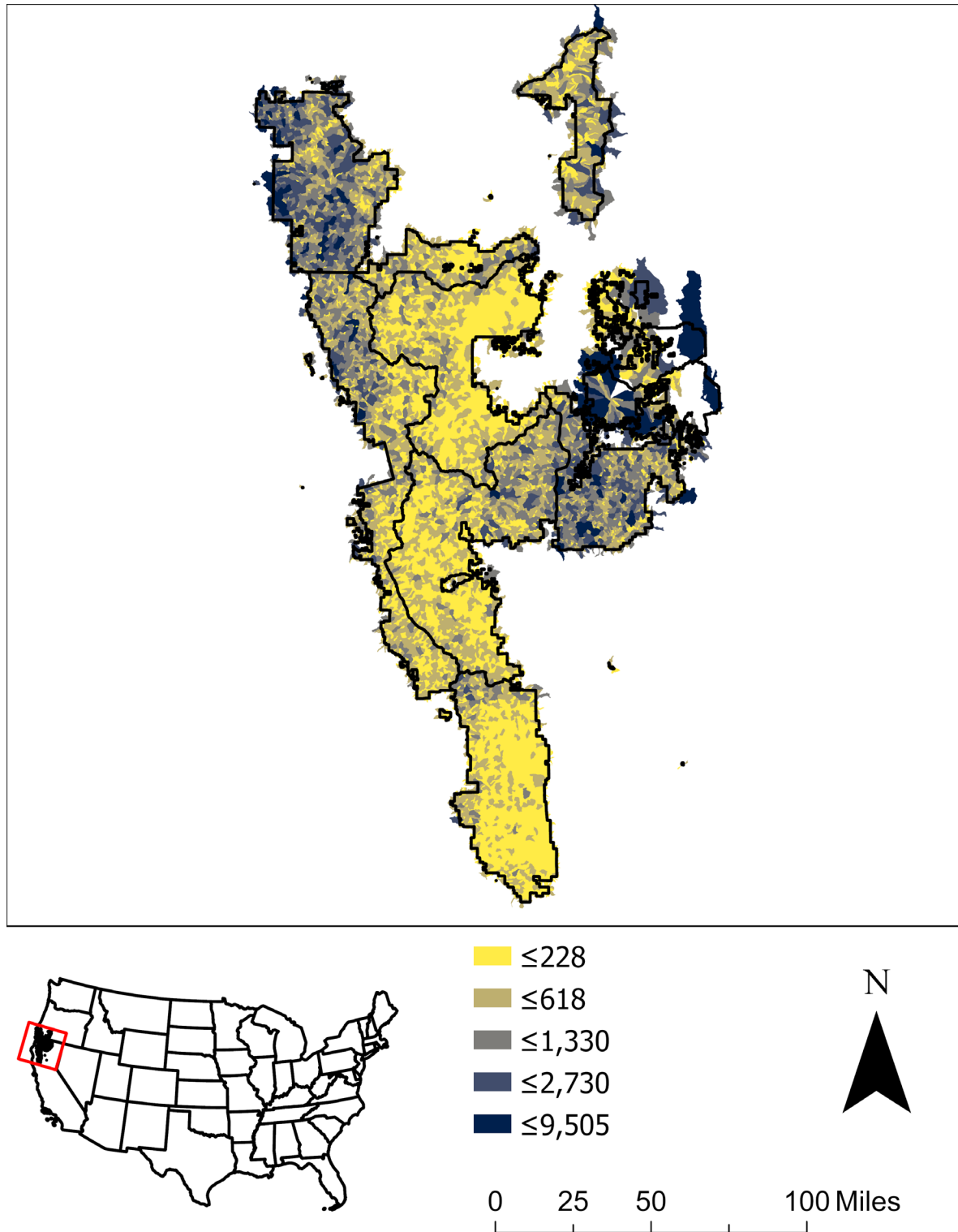


Figure C.16—Map of incremental total nitrogen (tons) contributed to streams within the Five Forests planning area from atmospheric deposition. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

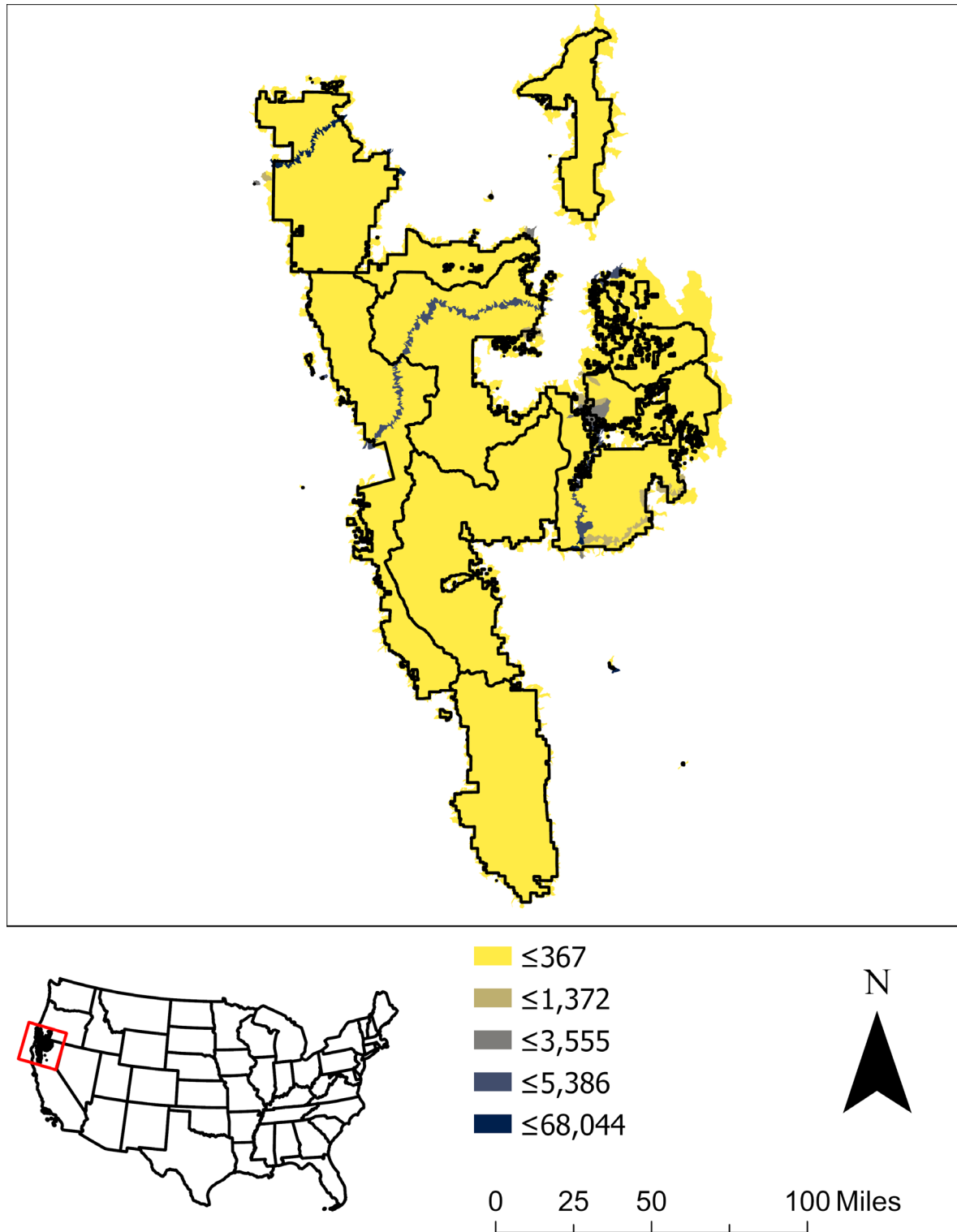


Figure C.17—Map of accumulated total nitrogen (tons) contributed to streams within the Five Forests planning area by urban lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

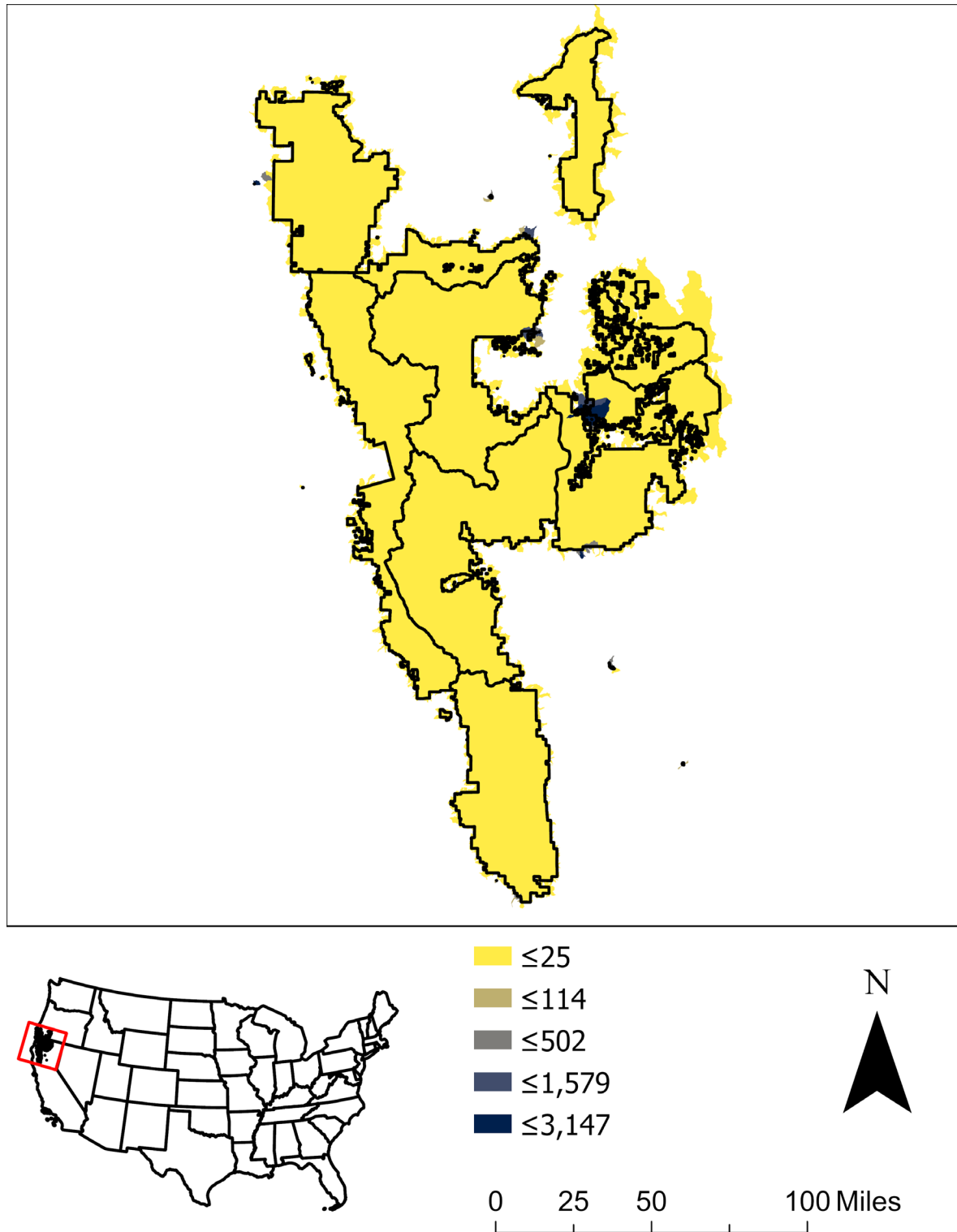


Figure C.18—Map of incremental total nitrogen (tons) contributed to streams within the Five Forests planning area by urban lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

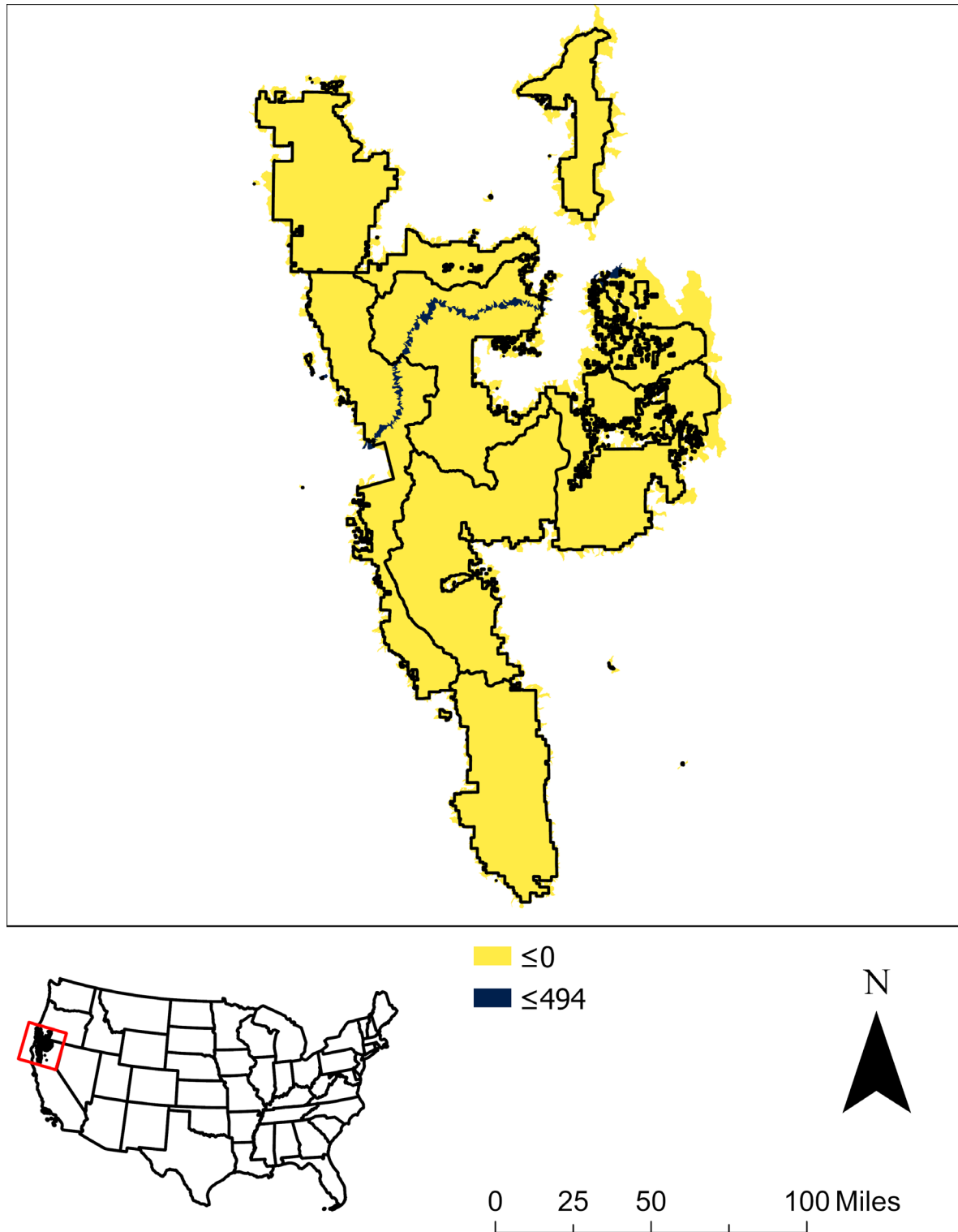


Figure C.19—Map of accumulated total nitrogen (tons) contributed to streams within the Five Forests planning area from spring discharge. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

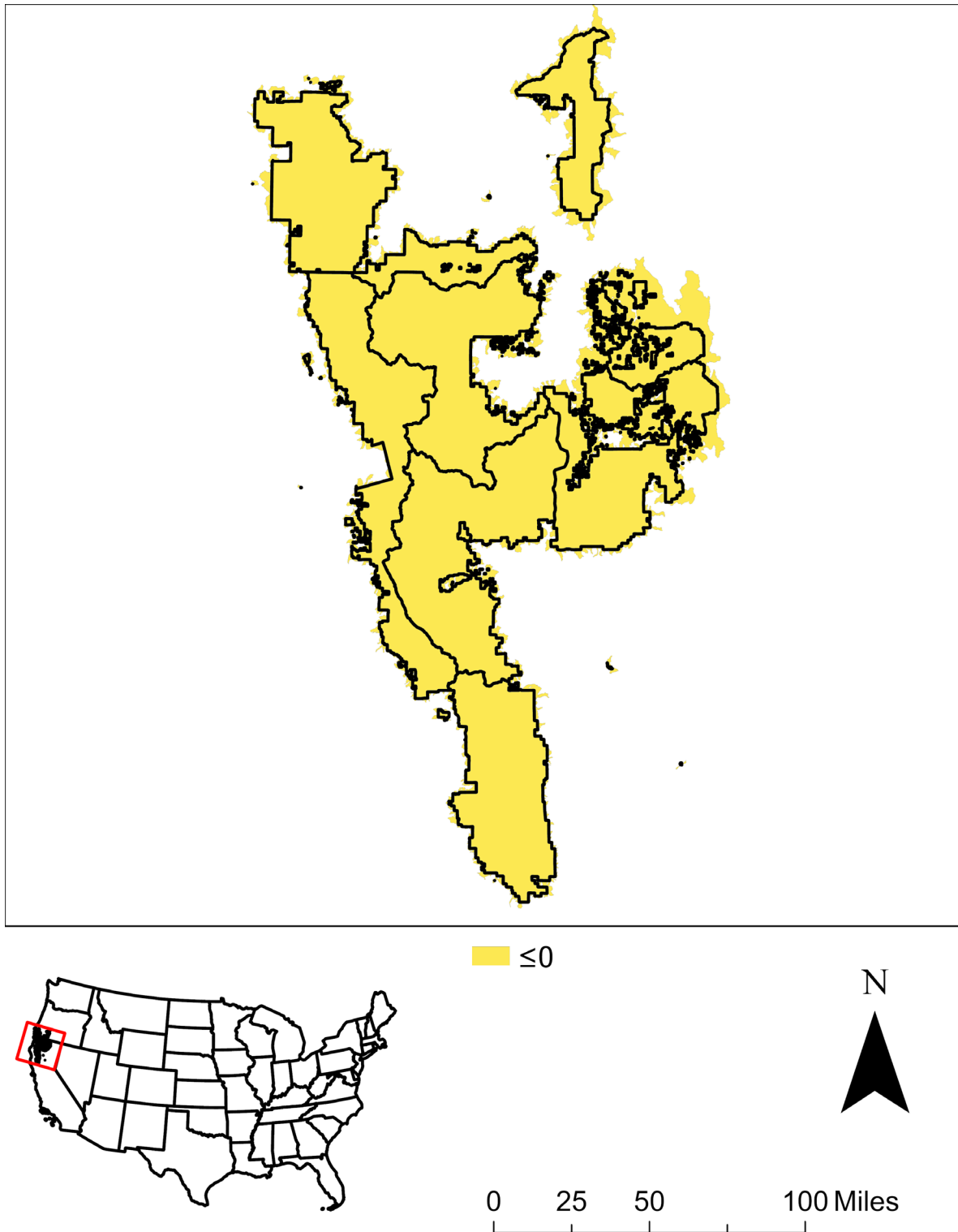


Figure C.20—Map of incremental total nitrogen (tons) contributed to streams within the Five Forests planning area from spring discharge. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

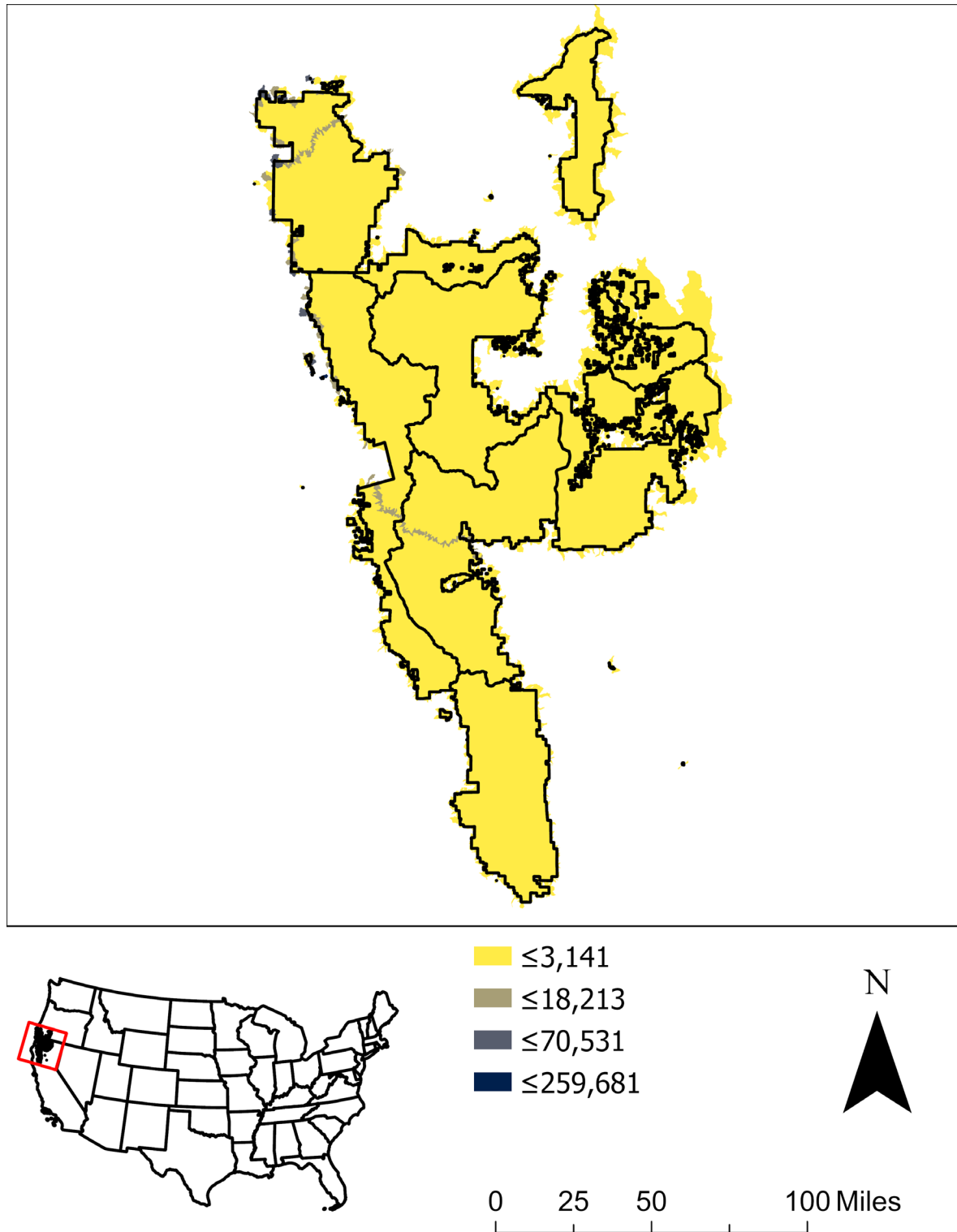


Figure C.21—Map of accumulated total nitrogen (tons) contributed to streams within the Five Forests planning area from red alder trees. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

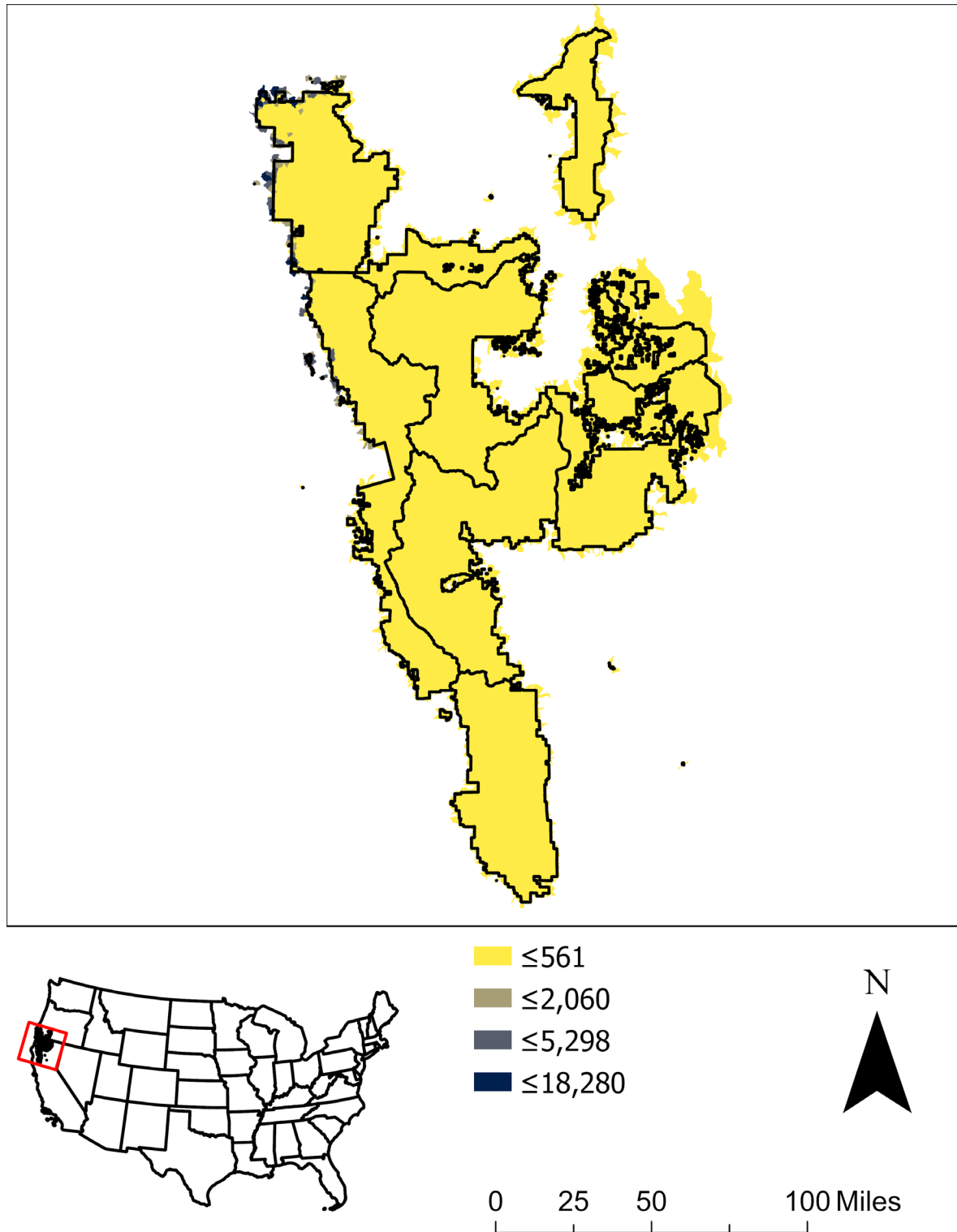


Figure C.22—Map of incremental total nitrogen (tons) contributed to streams within the Five Forests planning area from red alder trees. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

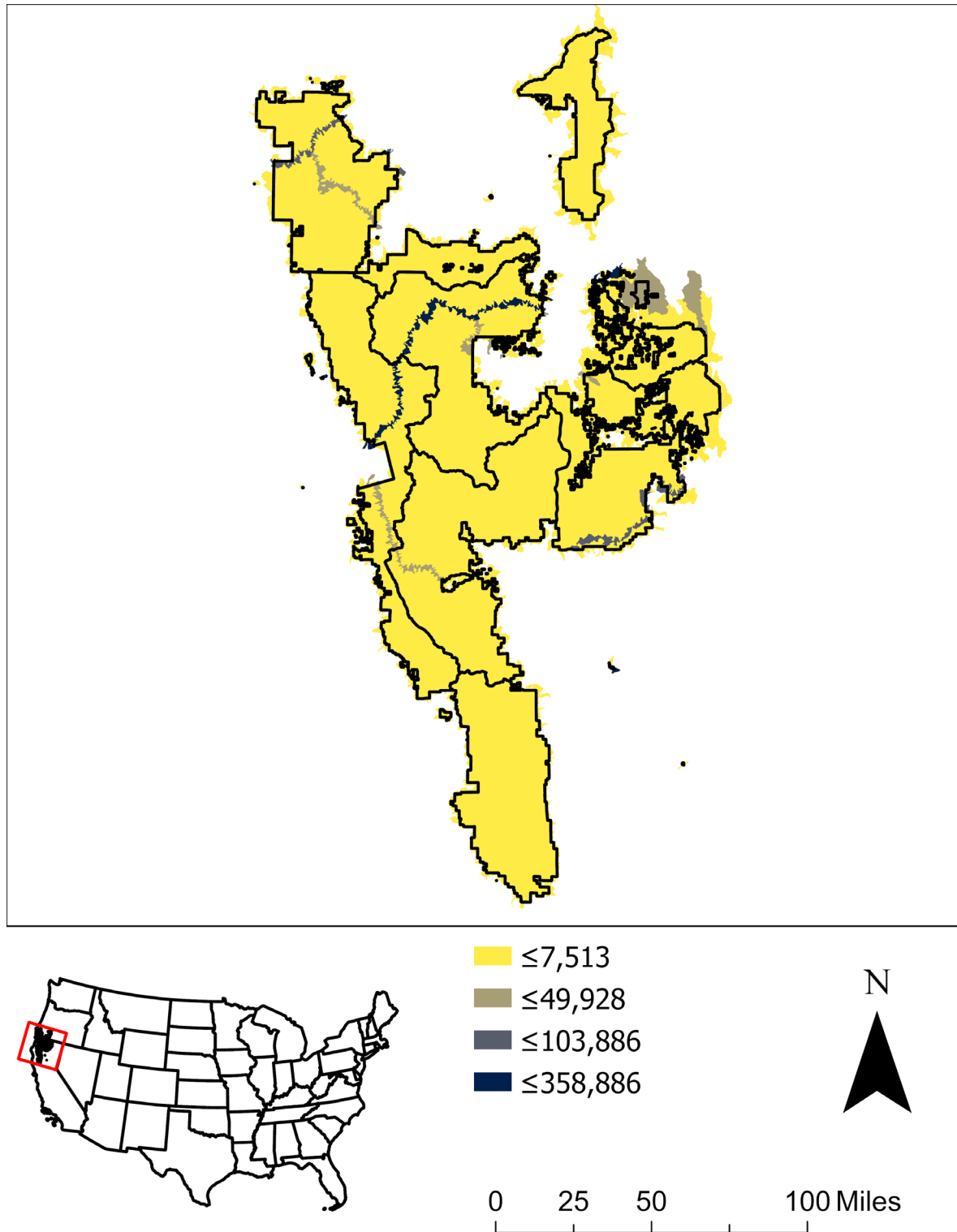


Figure C.23—Map of accumulated total nitrogen (tons) contributed to streams within the Five Forests planning area from fertilizer and manure applied to croplands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

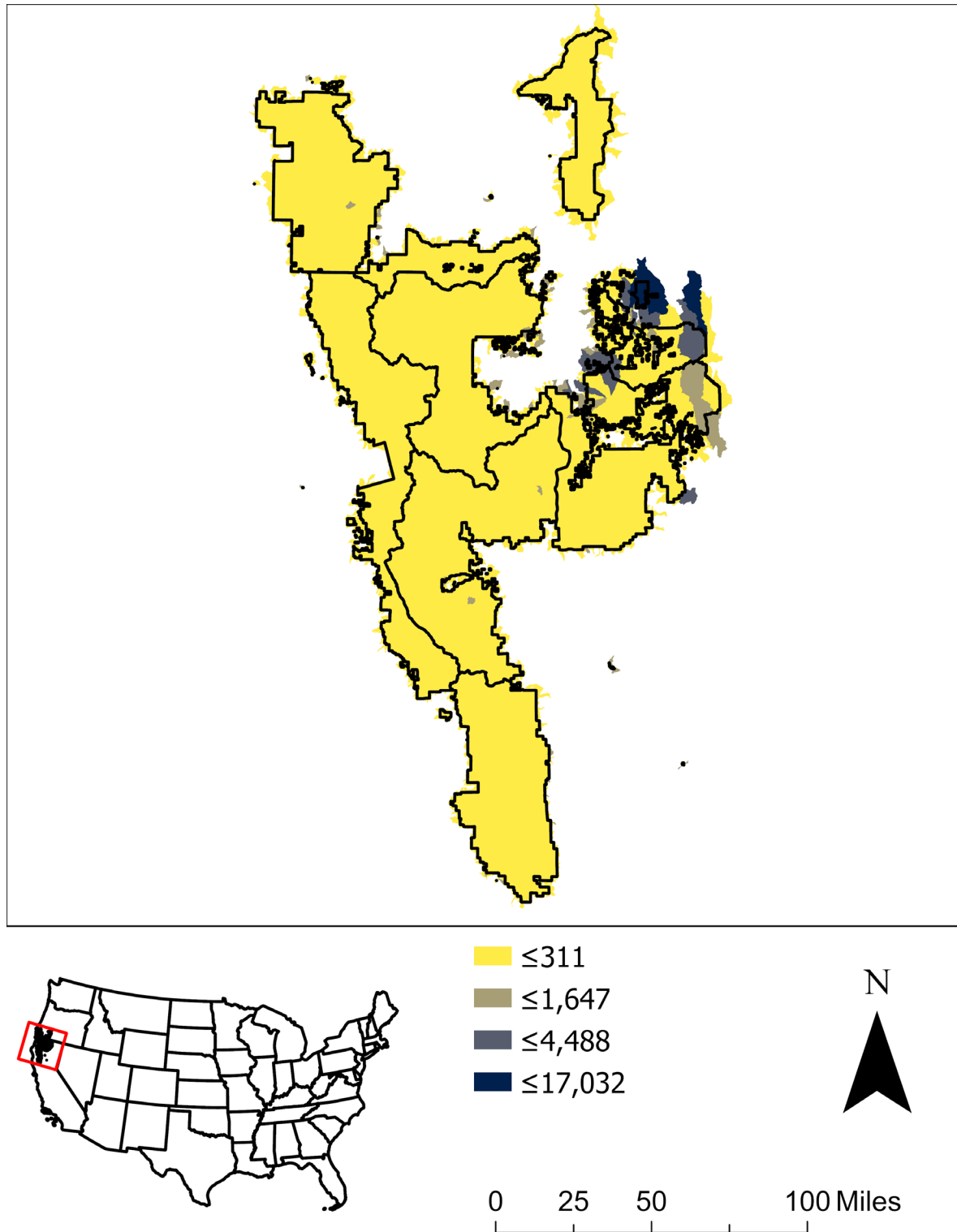


Figure C.24—Map of incremental total nitrogen (tons) contributed to streams within the Five Forests planning area from fertilizer and manure applied to croplands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

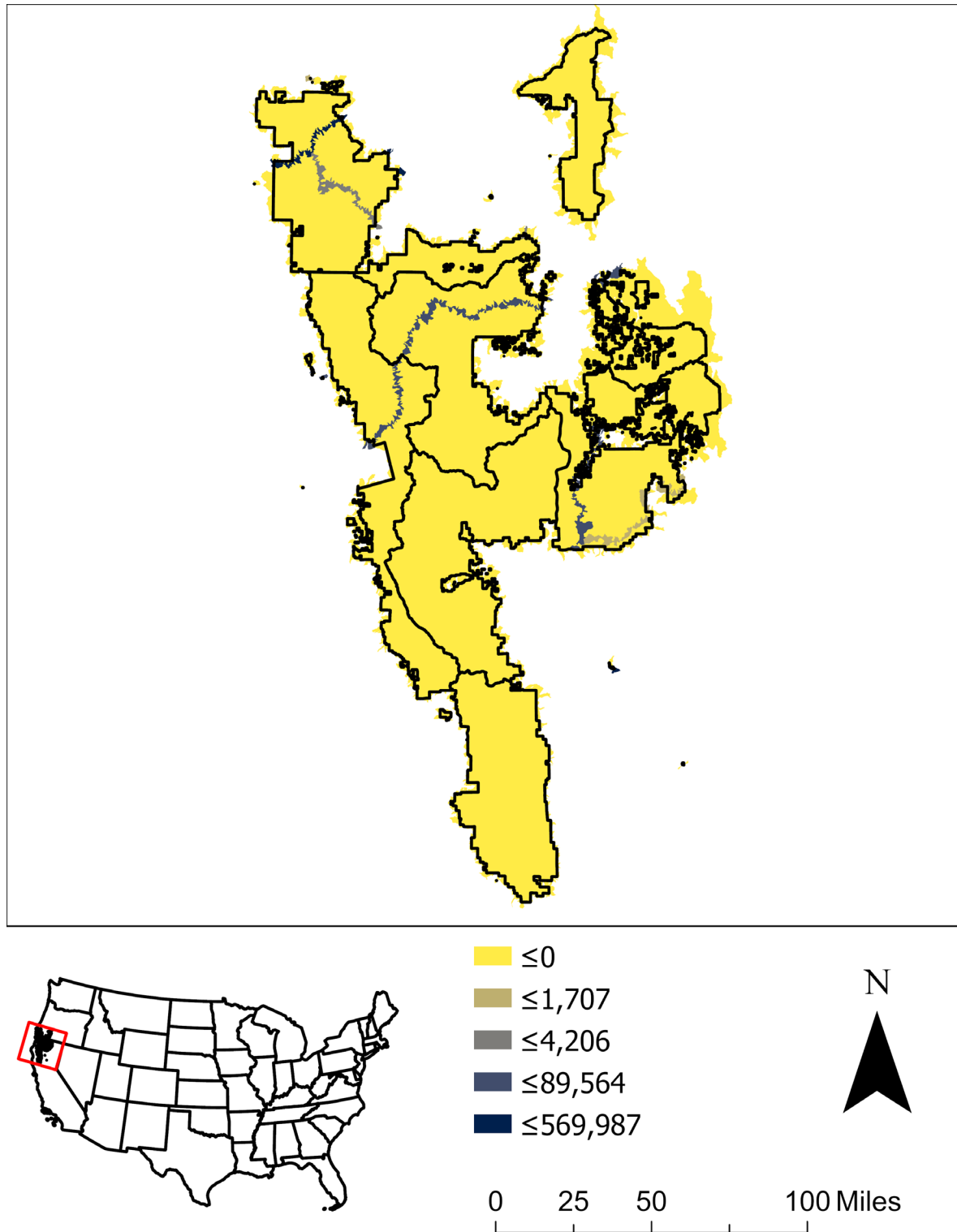


Figure C.25—Map of accumulated total nitrogen (tons) contributed to streams within the Five Forests planning area from wastewater treatment discharge. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

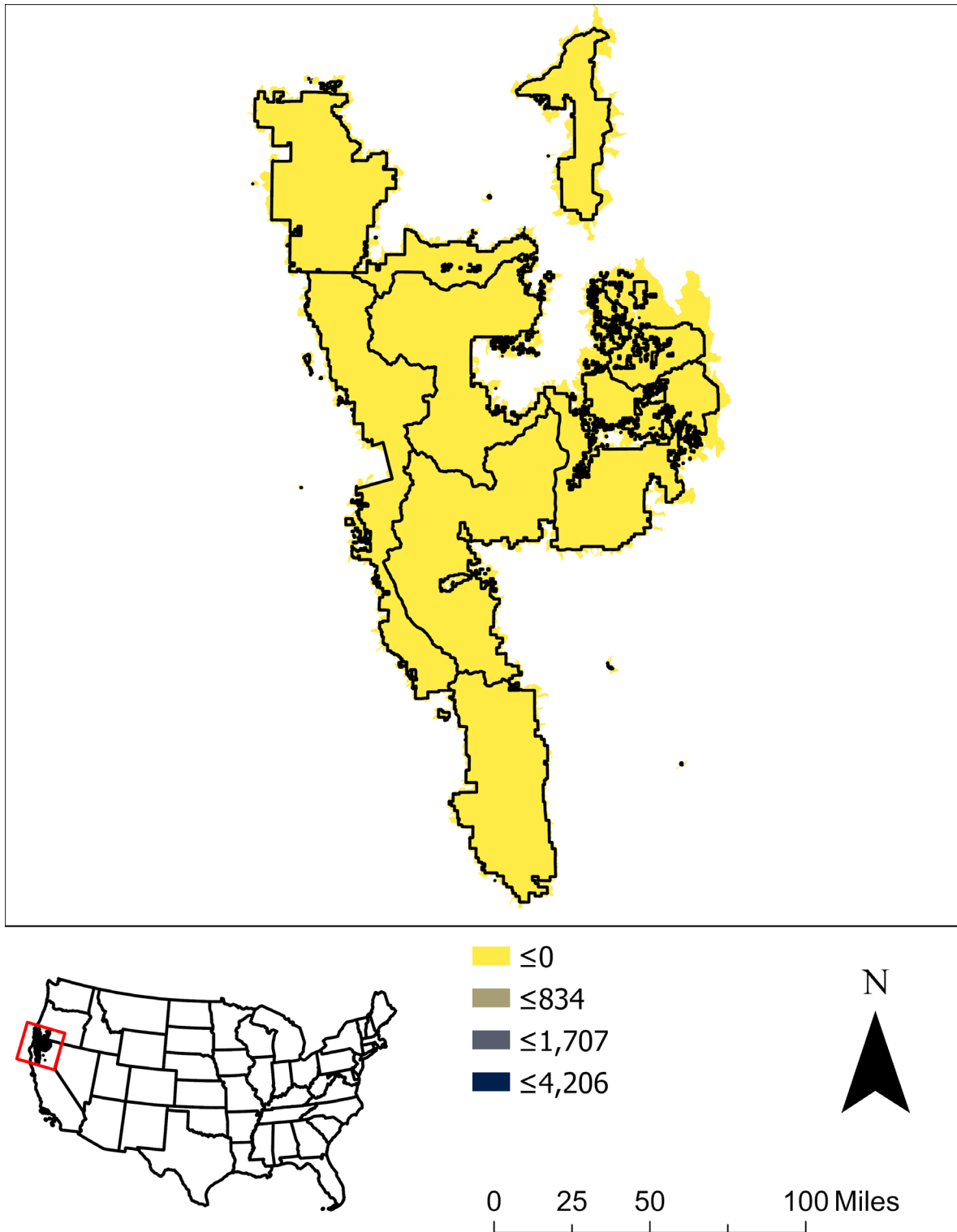


Figure C.26—Map of incremental total nitrogen (tons) contributed to streams within the Five Forests planning area from wastewater treatment discharge. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

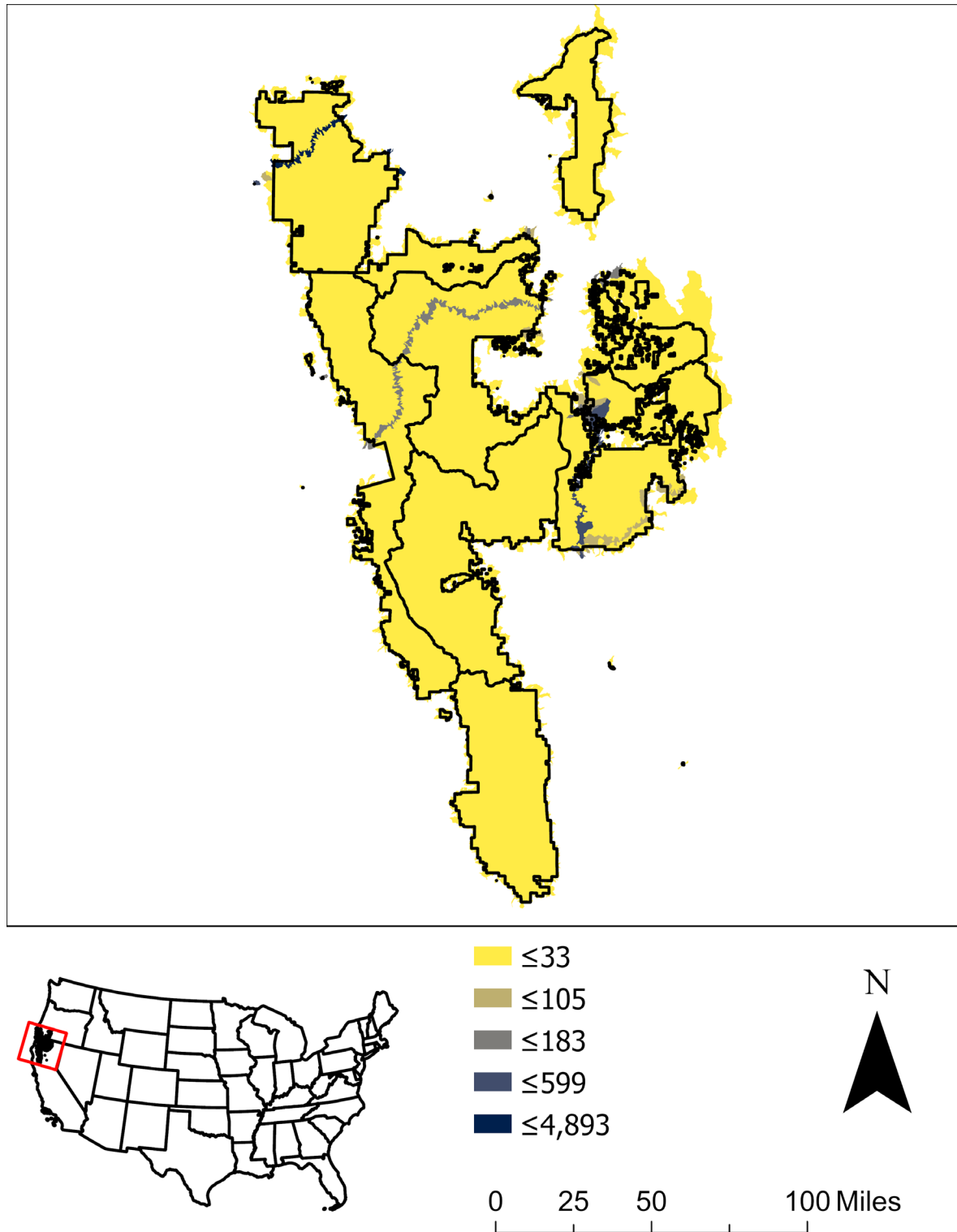


Figure C.27—Map of accumulated total phosphorus (tons) contributed to streams within the Five Forests planning area by urban lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

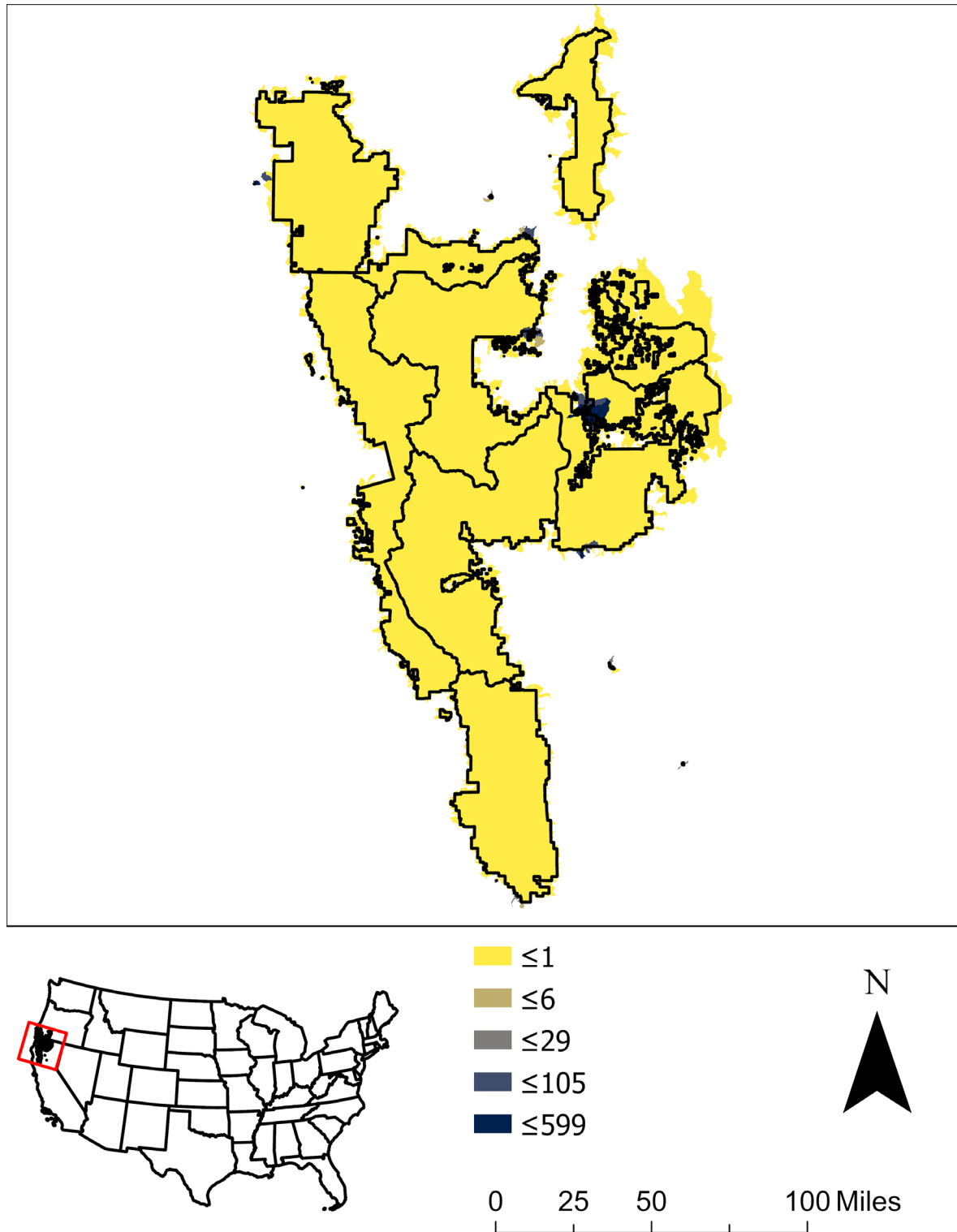


Figure C.28—Map of incremental total phosphorus (tons) contributed to streams within the Five Forests planning area by urban lands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

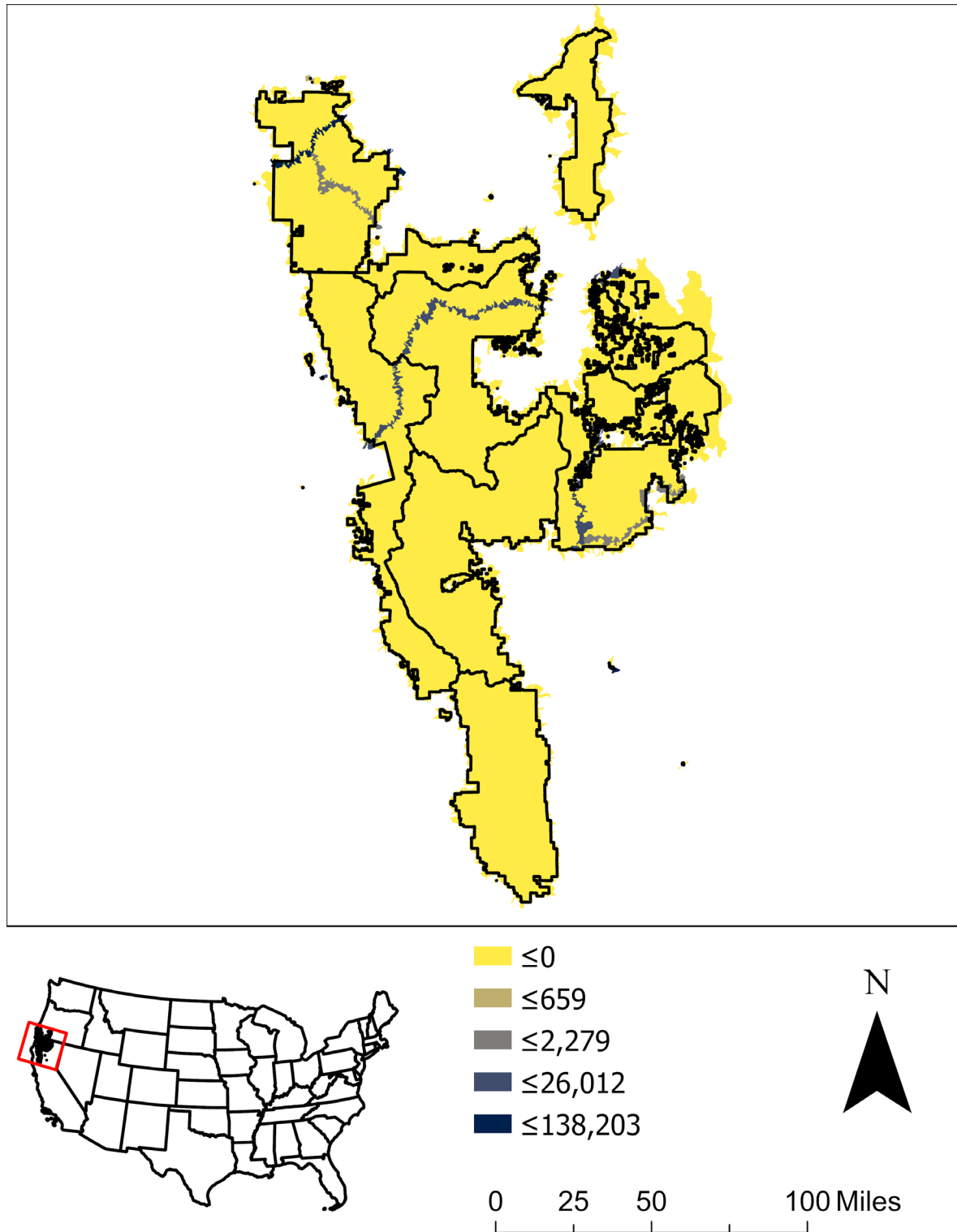


Figure C.29—Map of accumulated total phosphorus (tons) contributed to streams within the Five Forests planning area from wastewater treatment discharge. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

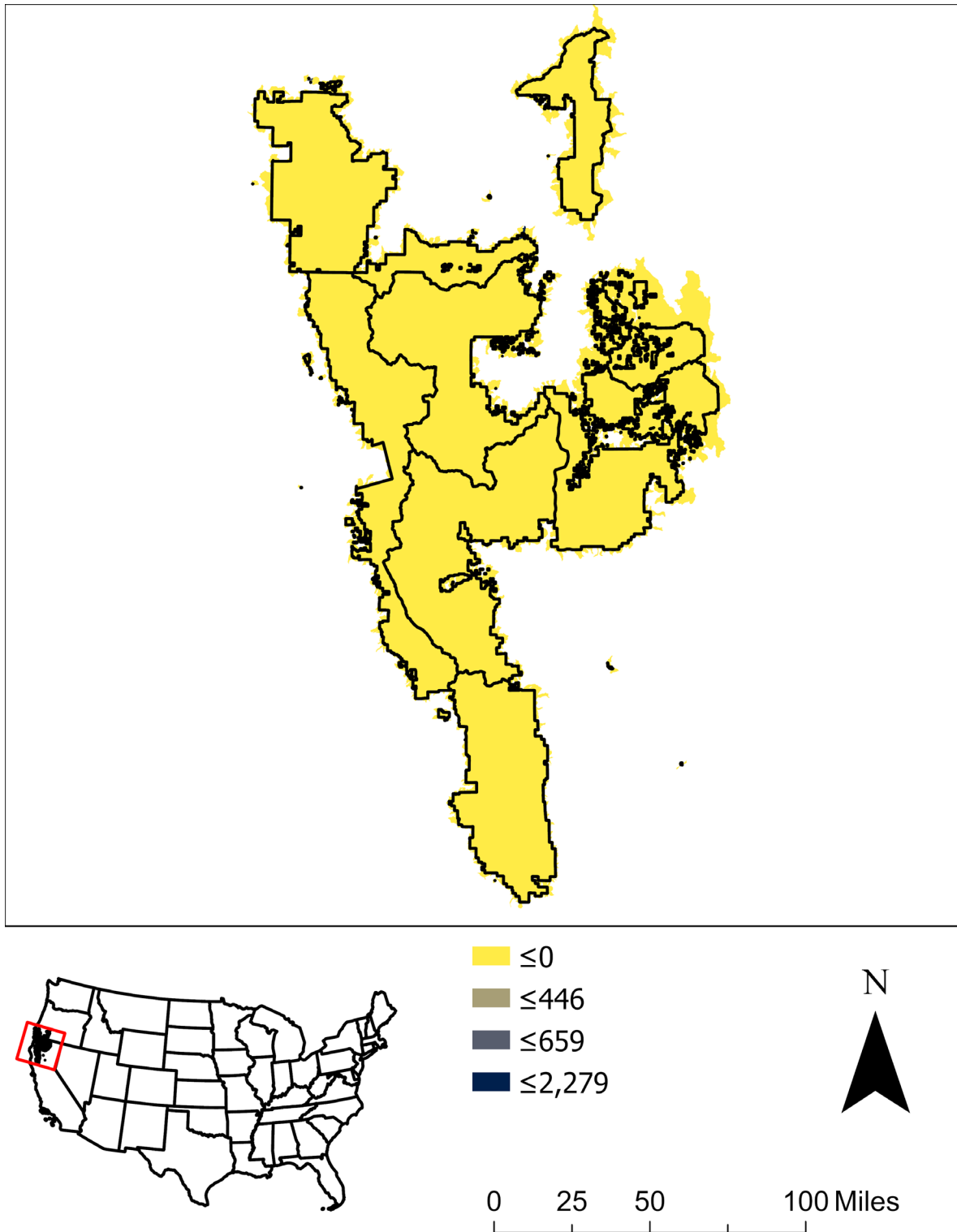


Figure C.30—Map of incremental total phosphorus (tons) contributed to streams within the Five Forests planning area from wastewater treatment discharge. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

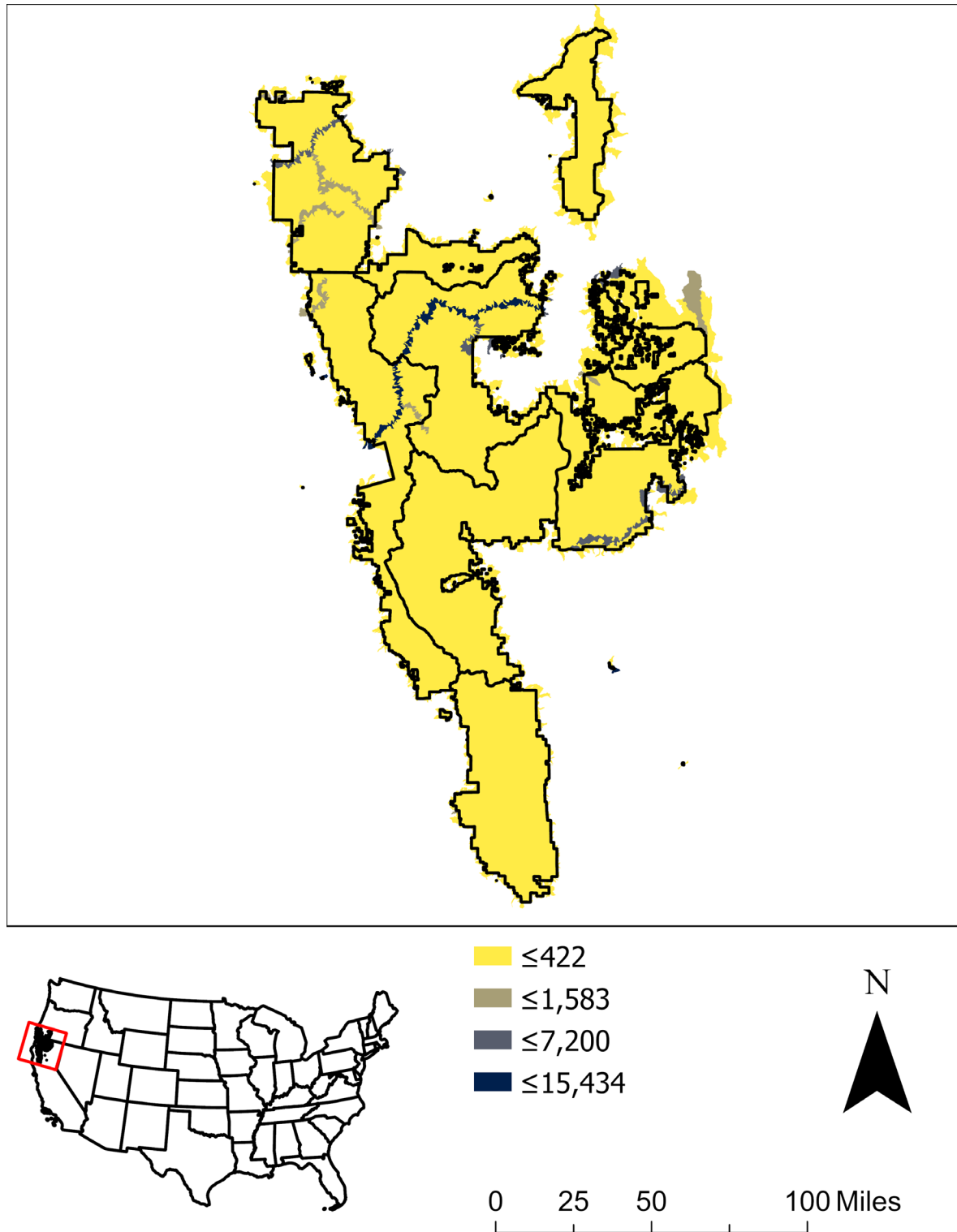


Figure C.31—Map of accumulated total phosphorus (tons) contributed to streams within the Five Forests planning area from fertilizer and manure applied to croplands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

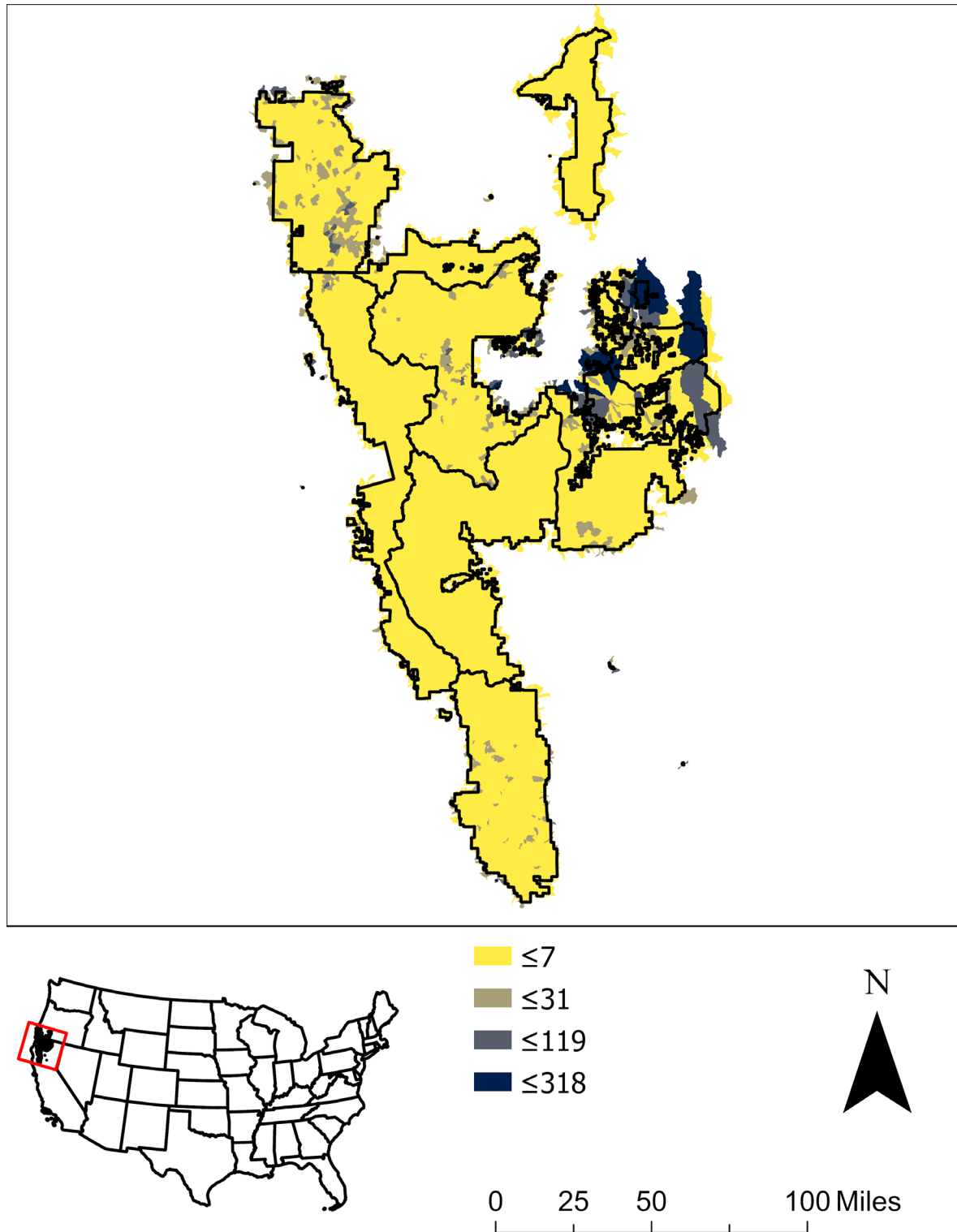


Figure C.32—Map of incremental total phosphorus (tons) contributed to streams within the Five Forests planning area from fertilizer and manure applied to croplands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

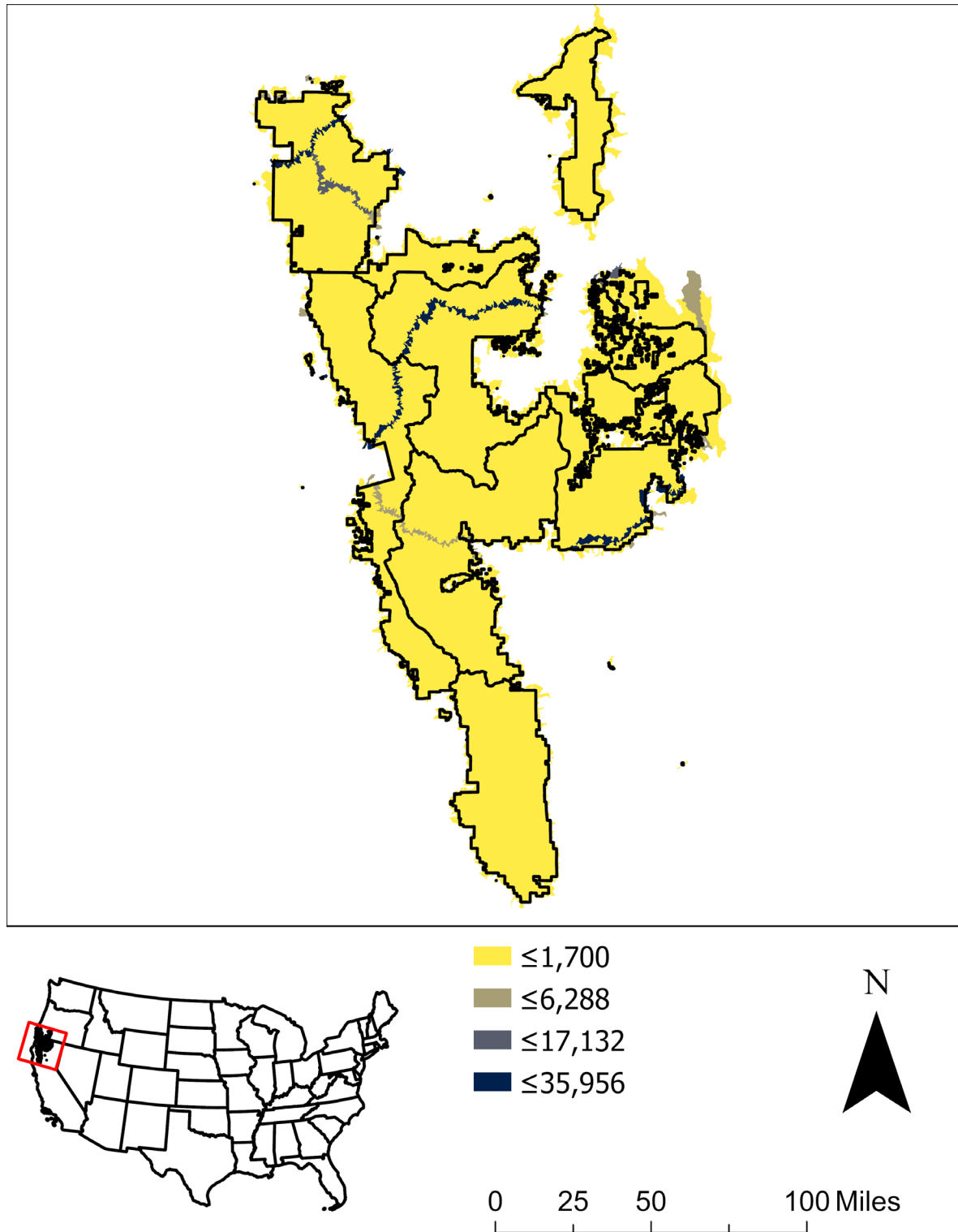


Figure C.33—Map of accumulated total phosphorus (tons) contributed to streams within the Five Forests planning area from grazing cattle manure applied to rangelands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

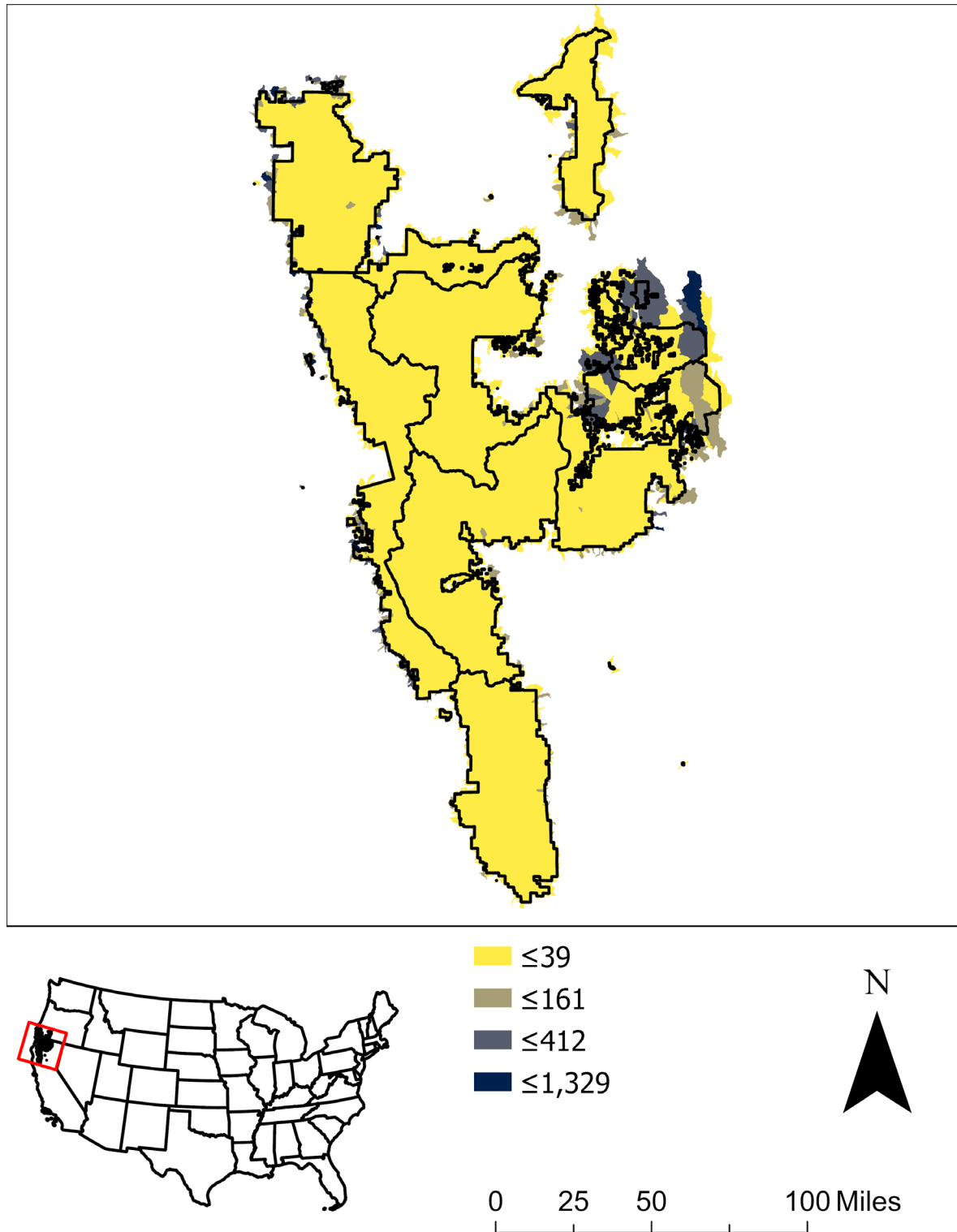


Figure C.34—Map of incremental total phosphorus (tons) contributed to streams within the Five Forests planning area from grazing cattle manure applied to rangelands. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

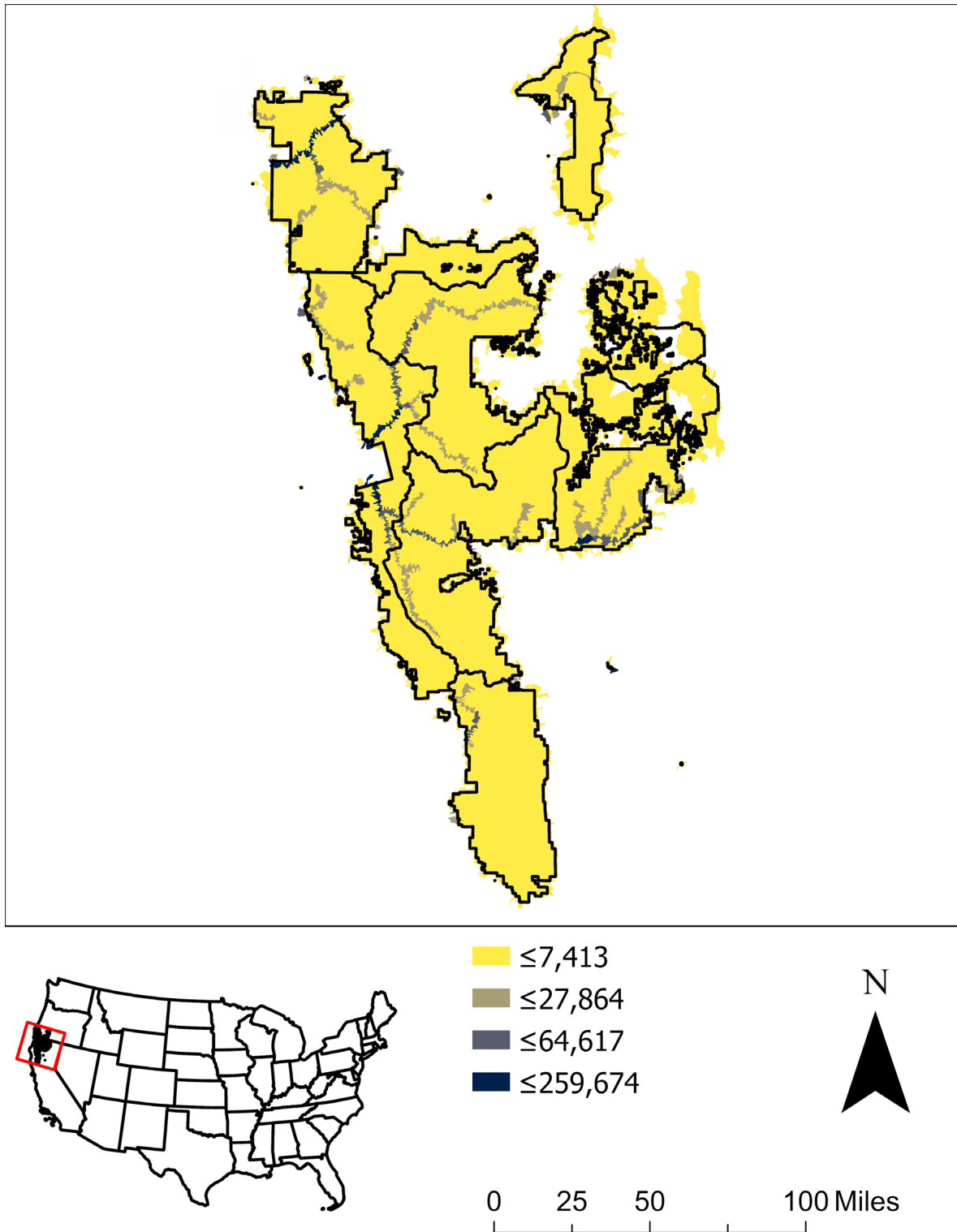


Figure C.35—Map of accumulated total phosphorus (tons) contributed to streams within the Five Forests planning area from the weathering of upland geology. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

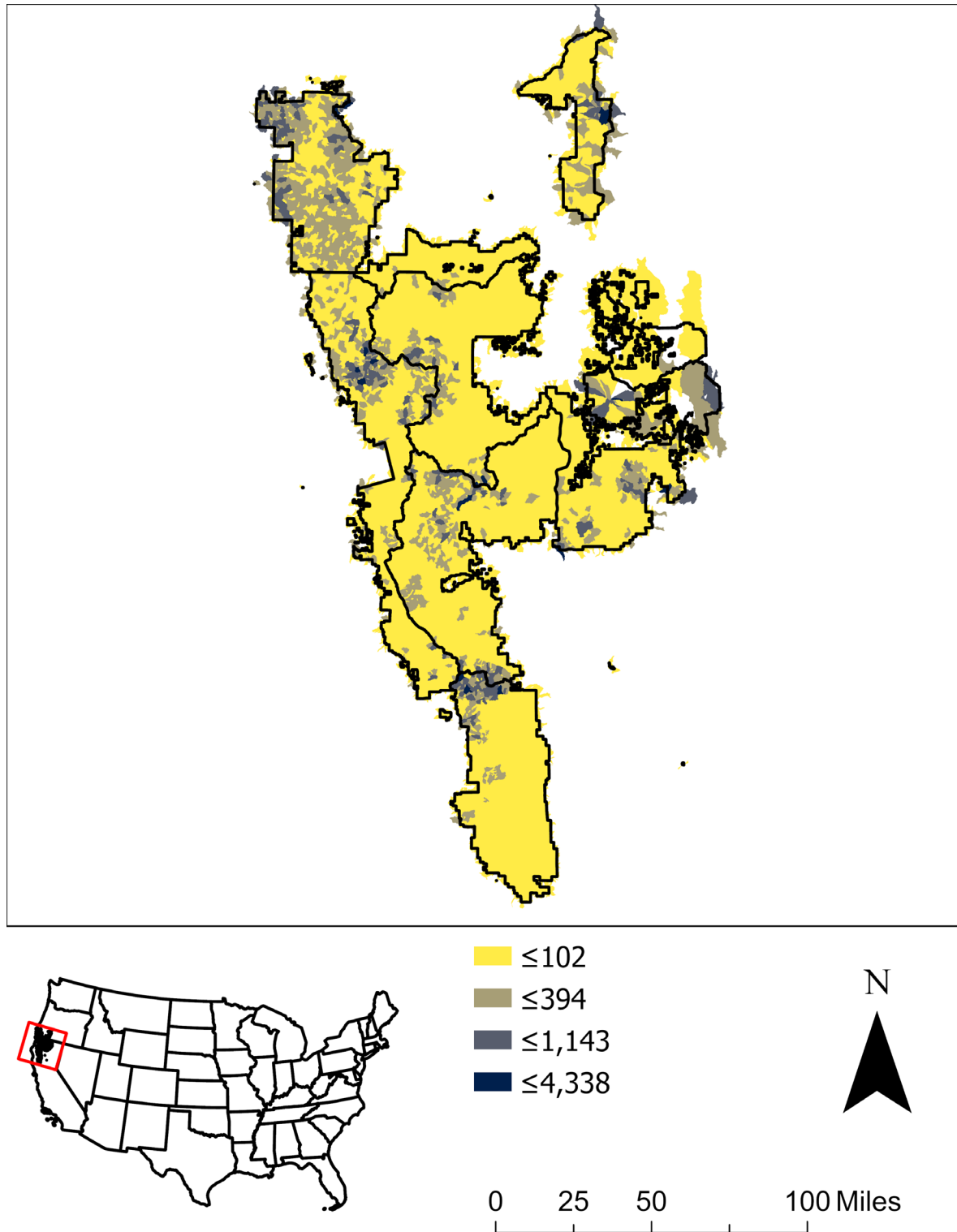


Figure C.36—Map of incremental total phosphorus (tons) contributed to streams within the Five Forests planning area from the weathering of upland geology. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

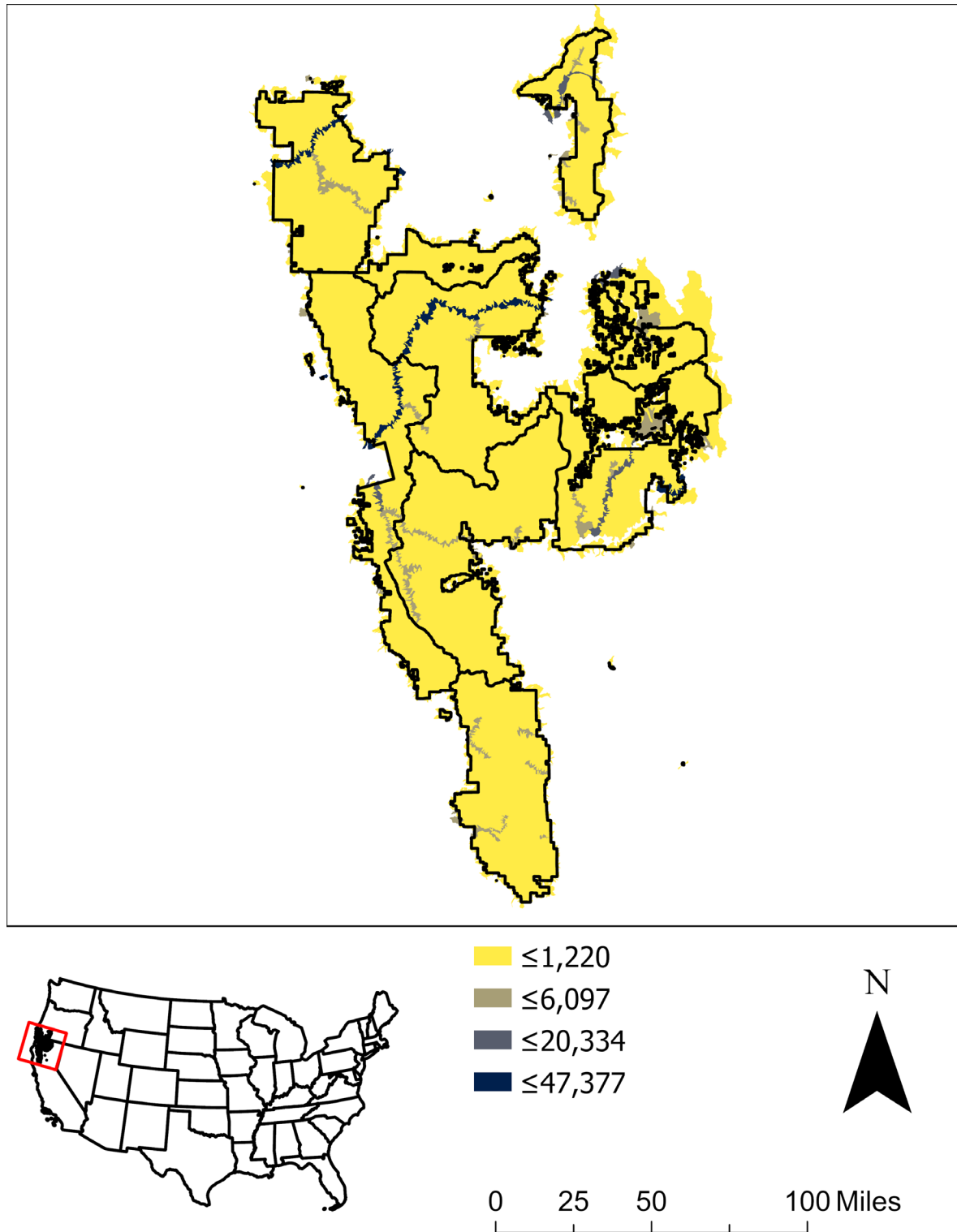


Figure C.37—Map of accumulated total phosphorus (tons) contributed to streams within the Five Forests planning area from stream channel sources. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

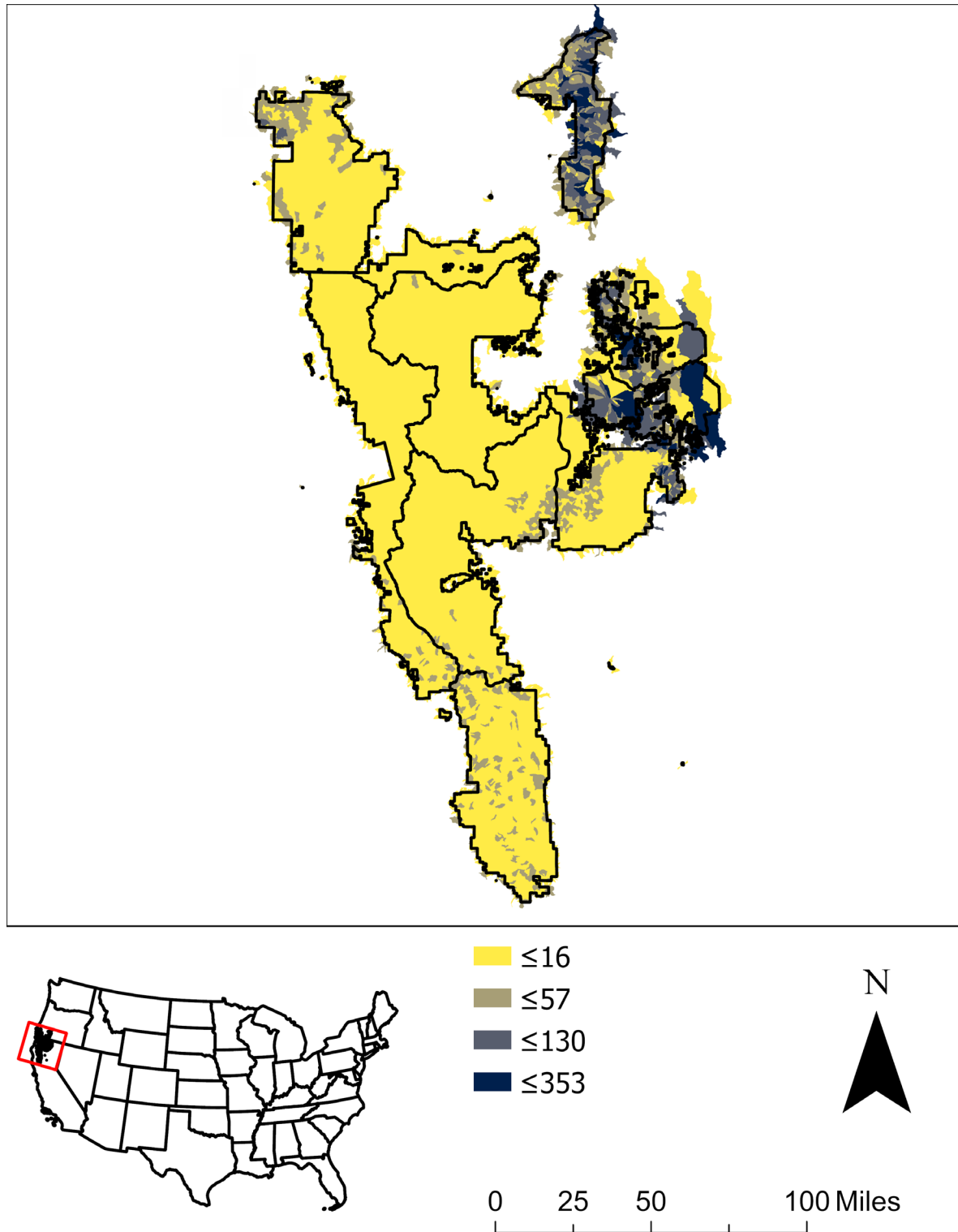


Figure C.38—Map of incremental total phosphorus (tons) contributed to streams within the Five Forests planning area from stream channel sources. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

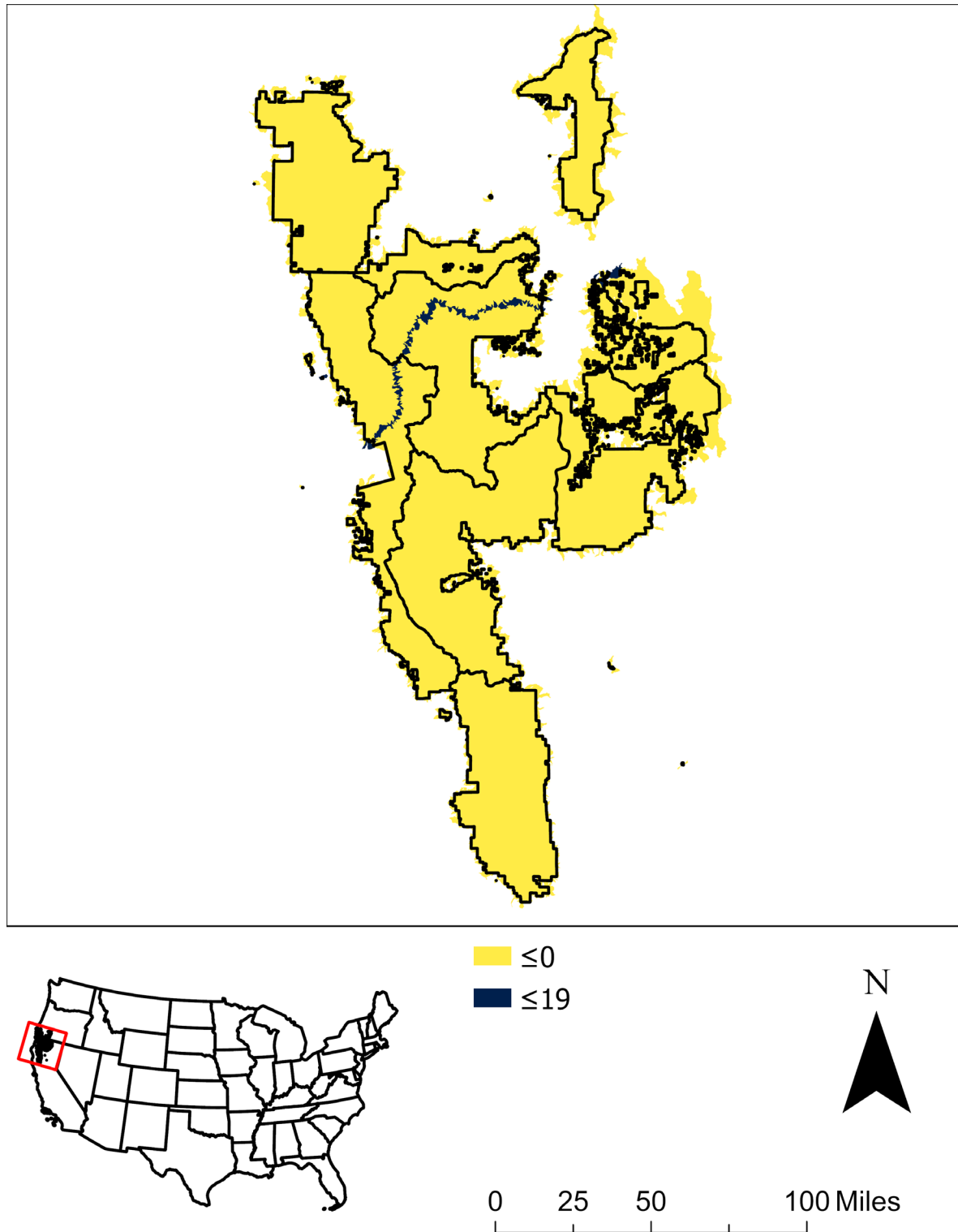


Figure C.39—Map of accumulated total phosphorus (tons) contributed to streams within the Five Forests planning area from spring discharge. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

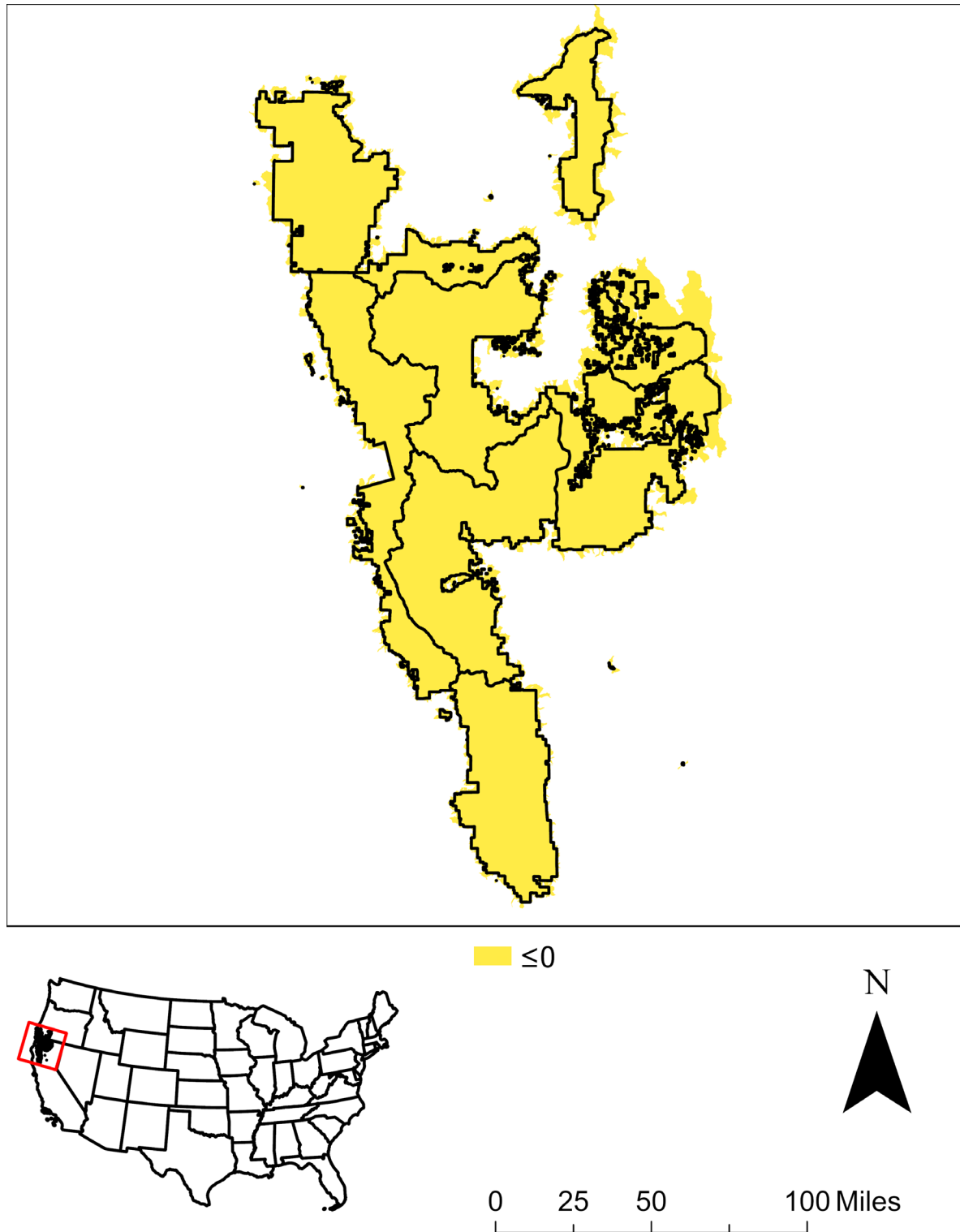


Figure C.40—Map of incremental total phosphorus (tons) contributed to streams within the Five Forests planning area from spring discharge. Data from the U.S. Geological Survey's SPARROW model (Wise 2019). Lower map shows location of study area in Oregon and California.

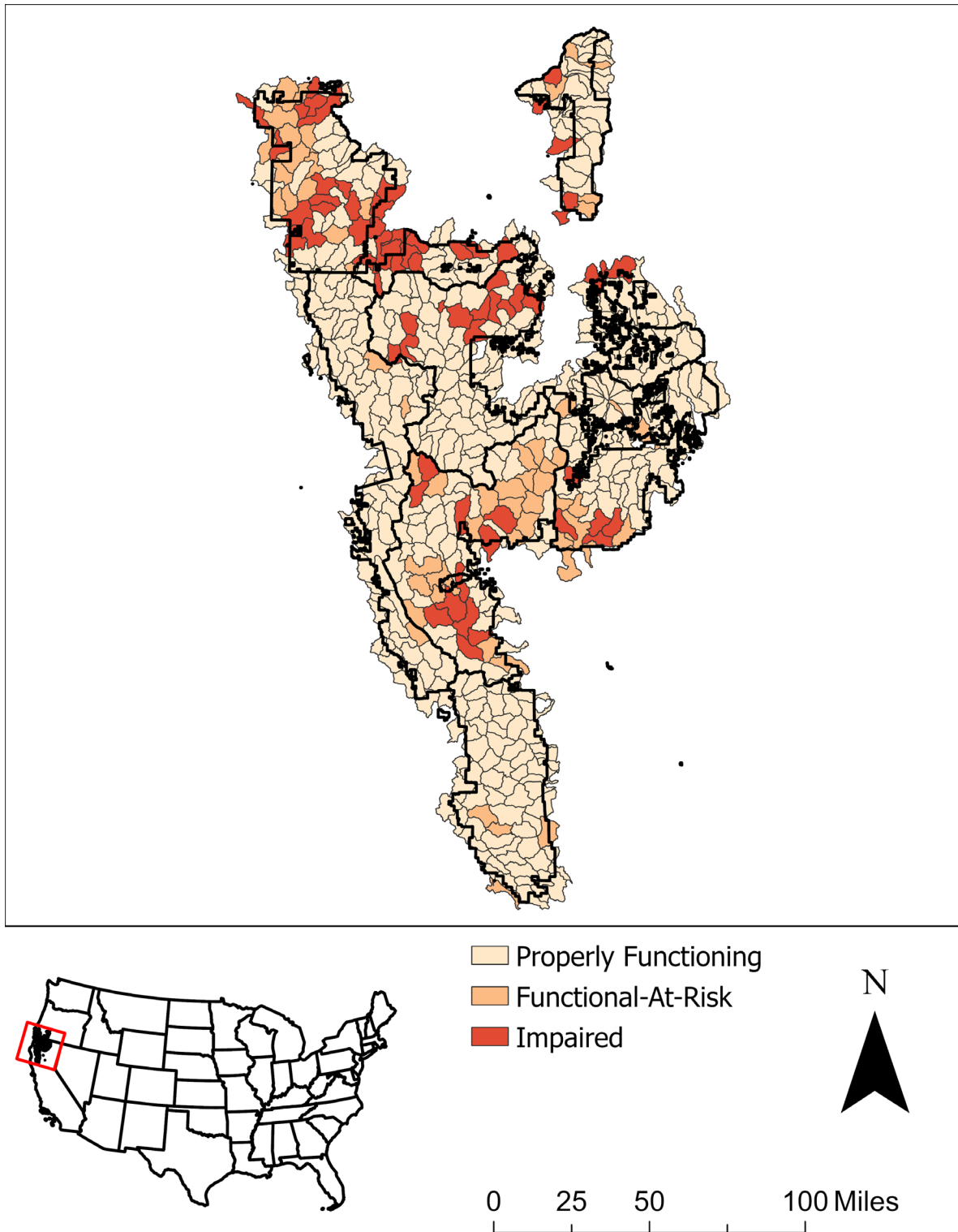
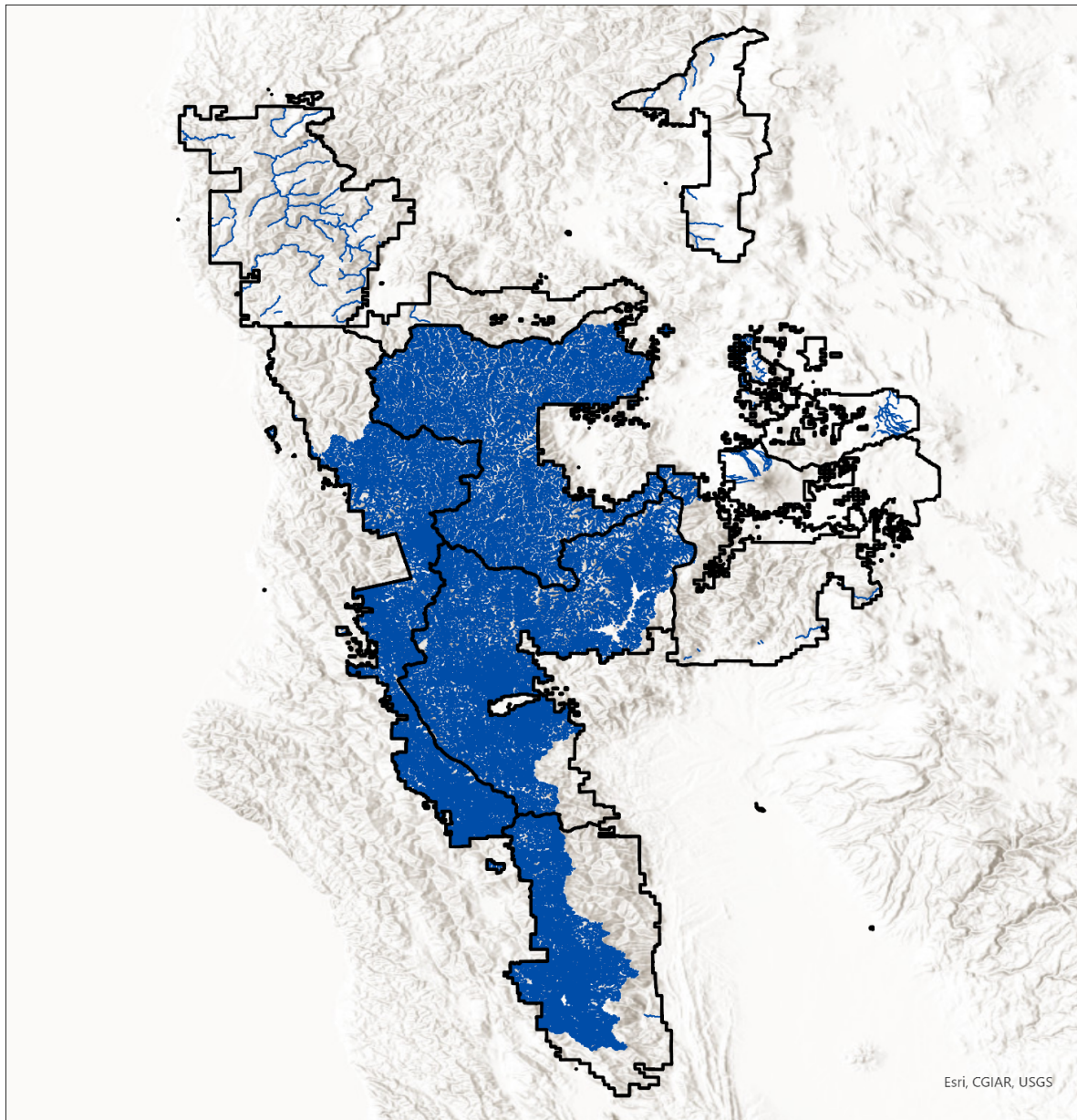


Figure C.41—Map of watersheds classified by the Watershed Condition Framework as properly functioning, functional-at-risk, and impaired for the Water Quality Problems attribute.



— 303(d) streams



0 25 50 100 Miles

Figure C.42—Map of State-listed 303(d) impaired streams within the Five Forests planning area. The State water quality board for northern California listed nearly all streams within its footprint as impaired. Lower map shows location of study area in Oregon and California.

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Cleland, D.; Reynolds, K.; Vaughan, R.; Schrader, B.; Li, H.; Laing, L. 2017. Terrestrial condition assessment for national forests of the USDA Forest Service in the continental US. *Sustainability*. 9(11): 2144. <https://doi.org/10.3390/su9112144>

USDA Forest Service [USDA FS]. 2022. RAVG homepage. Page last modified: September 17, 2022. Washington, DC: U.S. Department of Agriculture, Forest Service, Geospatial Technology and Applications Center. <https://burnseverity.cr.usgs.gov/ravg/> [Accessed September 26, 2022].

Wise, D.R. 2019. Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the Pacific region of the United States. Scientific Investigations Report 2019–5112. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey.

APPENDIX D. WATERSHED CONDITION FRAMEWORK ATTRIBUTE AND INDICATOR DEFINITIONS

Exhibit D.1—Definitions of properly functioning, functional-at-risk, and impaired Watershed Condition Framework (WCF) attributes and indicators used in this assessment (Potyondy and Geier 2011).

Attribute or indicator	Properly functioning	Functional-at-risk	Impaired
Channel shape and function attribute	Channel width-to-depth ratios exhibit the range of conditions expected in the absence of human influence. Less than 5 percent of the stream channels show signs of widening. Channels are vertically stable, with isolated locations of aggradation or degradation, which would be expected in near-natural conditions. The distribution of channels with floodplain connectivity is close to that found in reference watersheds of similar size and geology.	Channel width-to-depth and vertical stability are maintained except where riparian vegetation has been disturbed. Between 5 and 25 percent of the stream channel have increased in width-to-depth ratios. Channel degradation or aggradation (or both) is evident but limited to relatively small sections of the channel network. There is evidence of downcutting to the extent that some stream channels are no longer connected to their floodplain.	More than 25 percent of channels have width-to-depth ratios greater than expected under near-natural conditions. The size and extent of gullied sections of channels are extensive, are currently increasing, or have increased recently. Many streambanks show signs of active erosion above that which is expected naturally. Channel degradation or aggradation (or both) is evident and widespread because of unstable streambeds and banks. Many (more than 50 percent) of the stream channels are disconnected from their floodplain or are braided channels because of increased sediment loads.
Exotic and/or aquatic invasive species attribute	Exotic or aquatic invasive species (or both) may be present, but they have not greatly altered condition of native species (less than 25 percent of the historical aquatic-life-bearing habitats have exotic or aquatic invasive species present, spread of exotic or aquatic invasive species has been minimal over the past decade).	Exotic or aquatic invasive species (or both) are generally present and have lowered the health and sustainability of native species (between 25 and 50 percent of the historical native aquatic-life-bearing habitat have exotic or aquatic invasive species present, or there has been an expansion of exotic or aquatic invasive species over the past decade).	Exotic or aquatic invasive species (or both) are present and have greatly lowered the condition of native aquatic species (more than 50 percent of the historical native-fish-bearing streams have exotic or aquatic invasive species present, or there has been an expansion of nonnative exotic or aquatic invasive species over the past decade).

Attribute or indicator	Properly functioning	Functional-at-risk	Impaired
Fire Regime Condition Class attribute	A predominant percentage of the watershed is within the natural (historical) range of variability ("reference fire regime") of vegetation characteristics; fuel composition; fire frequency, severity, and pattern; and other associated disturbances. The vegetative species and cover types are well adapted to the fire regime and offer good protection to soil and water resources.	A predominant percentage of the watershed has moderate departure from the reference fire regime of vegetation characteristics; fuel composition; fire frequency, severity, and pattern; and other associated disturbances. The vegetative species and cover types are somewhat affected by the abnormal fire regime, and this results in less protection to soil and water resources when fire occurs.	A predominant percentage of the watershed has a high departure from the reference fire regime of vegetation characteristics; fuel composition; fire frequency, severity, and pattern; and other associated disturbances. The vegetative species and cover types are affected by the fire regime, and this results in periods of fuel accumulation with infrequent intense fires with high severity that are more likely to lead to vegetation mortality, loss of soil organic matter, and poor protection to soil and water resources.
Flow characteristics attribute	The watershed lacks significant human-made reservoirs, dams, or diversion facilities. The watershed has primarily free-flowing rivers and streams, unmodified lakes, and no or limited groundwater withdrawals. Stream hydrographs have no or minor alterations from natural (unaltered by anthropogenic actions) conditions.	The watershed contains dams and diversion facilities that are operated to partially mimic natural hydrographs. A departure from a natural hydrograph occurs during periods other than extreme flows (lows or highs). Peak and base flows are maintained, but changes to the timing, rate of change, or duration of mid-range discharges (or combination thereof) occur.	Dams and diversion facilities are operated so that they fail to mimic natural hydrographs. The magnitude, duration, or timing of annual extreme flows (low or high) significantly depart from the natural hydrograph. The timing and the rate of change in flows often do not correlate with expected seasonal changes.
Habitat fragmentation attribute	Habitat fragmentation is not a serious concern (more than 95 percent of historical aquatic habitats are still connected).	Aquatic habitat fragmentation is increasing because of temperature, blockages of aquatic organism passage, or dewatering (25 to 95 percent of the historical aquatic habitats are still connected).	Aquatic habitat fragmentation because of temperature, blockages, or dewatering is a serious concern (less than 25 percent of the historical aquatic habitat is still connected).
Insects and disease attribute	Less than 20 percent of the forested land in the watershed is at imminent risk of abnormally high levels of tree mortality because of insects and disease.	Between 20 and 40 percent of the forested land in the watershed is at imminent risk of abnormally high levels of tree mortality because of insects and disease.	More than 40 percent of the forested land in the watershed is at imminent risk of abnormally high levels of tree mortality because of insects and disease.

Exhibit D.1 continued.

Attribute or indicator	Properly functioning	Functional-at-risk	Impaired
Large woody debris attribute	In aquatic and riparian systems that evolved with wood near the streams, large woody debris is present and continues to be recruited into the system at near-natural rates.	In aquatic and riparian systems that evolved with wood, large woody debris is present but is recruited into the system at less than natural rates because of riparian management activities.	In a system that should contain large wood as an ecosystem component, wood is lacking, resulting in poor riparian or aquatic habitat conditions including bank destabilization, inadequate pool formation, and microclimate maintenance.
Loss of forest cover attribute	Less than 5 percent of National Forest System (NFS) land in the watershed contains cut-over, denuded, or deforested land where appropriate forest cover should be reestablished or restored to achieve the desired conditions or other applicable forest plan direction for NFS lands.	Between 5 and 15 percent of NFS land in the watershed contains cut-over, denuded, or deforested forest land where appropriate forest cover should be reestablished or restored to achieve the desired conditions or other applicable forest plan direction for NFS lands.	More than 15 percent of NFS land in the watershed contains cut-over, denuded, or deforested forest land where appropriate forest cover should be reestablished or restored to achieve the desired conditions or other applicable forest plan direction for NFS lands.
Mass wasting attribute	Very few roads are on unstable landforms or rock types subject to mass wasting with little evidence of active movement or evidence of road damage. There is no danger of large quantities of debris being delivered to the stream channel because of mass wasting.	A few roads are on unstable landforms or rock types subject to mass wasting with moderate evidence of active movement or road damage. There is some danger of large quantities of debris being delivered to the stream channel, although this is not a primary concern in this watershed.	Most roads are on unstable landforms or rocky types subject to mass wasting with extensive evidence of active movement or road damage. Mass wasting that could deliver large quantities of debris to the stream channel is a primary concern in this watershed.
Open road density attribute	Default road/trail density: less than 1 mile per square mile, or a locally determined threshold for good conditions supported by forest plans or analysis and data.	Default road/trail density: From 1 to 2.4 miles per square mile, or a locally determined threshold for fair conditions supported by forest plans or analysis and data.	Default road/trail density: more than 2.4 miles per square mile, or a locally determined threshold for poor conditions supported by forest plans or analysis and data.
Proximity to water attribute	No more than 10 percent of road or trail length is located within 300 feet of streams and waterbodies or hydrologically connected to them.	Between 10 and 25 percent of road or trail length is located within 300 feet of streams and waterbodies or hydrologically connected to them.	More than 25 percent of road or trail length is located within 300 feet of streams and waterbodies or hydrologically connected to them.

Attribute or indicator	Properly functioning	Functional-at-risk	Impaired
Rangeland vegetation condition attribute	Vegetation contributes to soil condition, nutrient cycling, and hydrologic regimes at near-natural levels. Rangelands that are functioning properly have the capacity to limit redistribution and loss of soil resources (including nutrients and organic matter) by wind and water and have the capacity to capture, store, and safely release water from rainfall, runoff, and snowmelt and to recover following disturbance.	Rangelands that have a reversible loss in productive capability and increased vulnerability to irreversible degradation.	Rangelands on which degradation has resulted in the loss of ecological processes that function properly and the capacity to provide values and commodities to a degree that external inputs are required to restore the health of the land.
Riparian/Wetland vegetation condition attribute	Native vegetation is functioning properly throughout the stream corridor or along wetlands and waterbodies. Riparian or wetland areas that are functioning properly exist when adequate vegetation, landform, or large woody debris is present to dissipate stream energy associated with high waterflow, thereby reducing erosion, and improving water quality; filter sediment, capture bedload, and aid in floodplain development; improve floodwater retention and groundwater recharge; develop root masses that stabilize streambanks against cutting action; develop diverse ponding and channel characteristics to provide the habitat and the water depth, duration, and temperature necessary for fish production, waterfowl breeding, and other uses; and support greater biodiversity.	Disturbance partially compromised the properly functioning condition of native vegetation attributes in stream corridor areas or along wetlands and waterbodies. Riparian/wetland areas that are in functional condition, but one or more existing soil, water, or vegetation attributes makes them susceptible to degradation.	A large percent of native vegetation attributes along stream corridors, wetlands, and waterbodies is not functioning properly. Riparian/wetland areas that clearly are not providing adequate vegetation, landform, or large woody debris to dissipate stream energy associated with high flows, and thus are not reducing erosion, improving water quality, etc.

Exhibit D.1 continued.

Attribute or indicator	Properly functioning	Functional-at-risk	Impaired
Road and trail maintenance attribute	Best management practices (BMPs) for the maintenance of designed drainage features are applied to more than 75 percent of the roads, trails, and water crossings in the watershed. The National Core BMPs (USDA FS 2012) for stream crossings advise that all crossings, including culverts, bridges, arched pipes, low-water crossings, vented fords, and permeable fills, should be designed and installed to provide for flow of water, bedload, and large woody debris; provide for desired aquatic organism passage; and minimize disturbance to the surface and shallow groundwater resources.	BMPs for the maintenance of designed drainage features are applied to 50 to 75 percent of the roads, trails, and water crossings in the watershed.	BMPs for the maintenance of designed drainage features are applied to less than 50 percent of the roads, trails, and water crossings in the watershed.
Roads and Trails Condition Indicator	The density and distribution of roads and linear features within the watershed indicate that the hydrologic regime is substantially intact and unaltered.	The density and distribution of roads and linear features within the watershed indicate there is a moderate probability that the hydrologic regime is substantially altered.	The density and distribution of roads and linear features within the watershed indicate there is a higher probability that the hydrologic regime (timing, magnitude, duration, and spatial distribution of runoff flows) is substantially altered.
Soil contamination attribute	No substantial areas of soil contamination in the watershed exist. When atmospheric deposition is a source of contamination, sulfur or nitrogen deposition (or both) is more than 10 percent below the terrestrial critical load.	Limited areas of soil contamination may be present, but they do not have a substantial effect on the overall soil quality. When atmospheric deposition is a source of contamination, sulfur or nitrogen deposition (or both) is 0 to 10 percent below the terrestrial critical load.	Extensive areas of soil contamination may be present. When atmospheric deposition is a source of contamination, sulfur or nitrogen deposition (or both) is above the terrestrial critical load.
Water Quality Indicator	Minimal to no impairment to beneficial uses of the waterbodies in the watershed.	Minor impairment to beneficial uses of the waterbodies in the watershed.	Significant impairment to beneficial uses of the waterbodies in the watershed.

Exhibit D.1 continued.

Attribute or indicator	Properly functioning	Functional-at-risk	Impaired
Water quality problems attribute	The watershed has minor or no water quality problems. For example, no documented evidence of excessive sediment, nutrients, chemical pollution, or other water quality issues above natural or background levels; no consumption advisories or contamination from abandoned or active mines; little or no evidence of acidification, toxicity, or eutrophication because of atmospheric deposition.	The watershed has moderate water quality problems. For example, consumption advisories in localized areas; minor contamination from active or abandoned mines; localized incidence of accelerated sediment, nutrients, or chemicals, or infrequent, documented incidents of contamination of public drinking water sources. Moderate evidence of acidification, eutrophication, or toxicity because of atmospheric deposition.	The watershed has extensive water quality problems. For example, consumption advisories over extended areas; excessive sediment, nutrients, or chemicals; extensive contamination from active or abandoned mines; or frequent incidents of contamination of public drinking water sources. Strong evidence of acidification, eutrophication, or toxicity because of atmospheric deposition.

REFERENCES

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USDA Forest Service [USDA FS]. 2012. National Best Management Practices for water quality management on National Forest Systems lands. Vol. 1: National Core BMP Technical Guide. FS-990a. Washington, DC: U.S. Department of Agriculture, Forest Service.

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